HOW DO INTERFACE CONDITIONS IN MOTOR VEHICLES AND THE MODES OF USING CHILD RESTRAINT SYSTEMS (CRS) AFFECT THE INJURY SEVERITY OF CHILDREN IN CRASHES?

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I. ABSTRACT

The interface conditions or variables between motor vehicles and child restraint systems (CRS) may adversely affect the performance of CRS and consequently the severity of injuries of children. The amount of interior space may determine the likelihood of head impact. The accessibility in a 2-door vs. a 4-door car may increase misuse. The larger size of a child within the same CRS may be a reason for body contact with subsequent injuries etc. Furthermore crash or CRS-specific conditions like the occurrence of pre-impact braking, seating location of the child, upright or reclined position of the CRS may influence the outcome in a crash.

On the basis of in-depth studies of real-life crashes done by the Accident Research Unit of the Medical University Hannover / Germany and the assessment of accident reports obtained by Britax Römer, Ulm / Germany the effects of variable interface conditions and use modes are investigated.

Keywords: Child Restraint Systems, Accident Analysis, Injury Severity

II. PURPOSE OF INVESTIGATION

Child restraint systems (CRS) are approved and certified according to the requirements of safety standards, i.e. ECE44 or US MVSS 213 (ECE44, 1980 / FMVSS 213, 1981). If the requirements are fulfilled, the CRS may be granted a universal approval. It is inevitable that the requirements and test conditions of such standards influence the design of CRS. The test conditions, however, may strongly differ from the conditions in motor vehicles.

This dilemma raises a number of questions. The purpose of our paper was searching answers to the following questions:

- In what different ways are CRS used in the vast variety of motor vehicle conditions?
- How do these variables affect the performance of CRS for children of different age/mass?
- What are the effects of different crash or pre-crash conditions?

Injury related information is commonly found by accident analysis. The same source is also useful for non-injury related issues, i.e. how are children transported and restrained in cars.

III. METHOD OF INVESTIGATION

The method chosen for this investigation is based on 2 different sets of accident data with different representative properties and statistical significance:

- A representative study of the performance of all CRS including – where appropriate – the (less -desirable) use of adult belts. This information was taken from on-the-scene data of 241 accidents involving children of all age/mass groups collected by ARU-MUH (Accident Research Unit at Medical University Hannover/Germany) named "MUH-data" within this paper.
  The MUH-data is homogeneous and covers all types of CRS - regardless of mass groups - all types of accidents and all accident cases. It allows for a calculation of statistical significance, results of which are stated below the relevant tables.

- A focussed assessment of a specific CRS based upon accident reports of 766 collisions involving group I children (as per ECE44 terminology) restrained in a forward facing harness-type CRS. The well-documented accident reports were collected and assessed by Britax Römer, Ulm/Germany and are named as BR-data.
  The BR-data is non-representative since the assessed cases are restricted to a single type of CRS and mainly to frontal/oblique collisions. Its assessment is of descriptive nature. For above reason the authors have omitted calculations on statistical significance.

The authors were interested to investigate whether and where the 2 different sets of data bases would lead to identical or equivalent results.

Both the MUH and the Britax Römer accidents were restricted to the period from 1990-2000 in order to exclude the effects of CRS of old technology.

The data documented by ARU/MUH were collected in the greater district of Hannover within a statistical random spot check sampling procedure (Otte, 1994). Every year approximately 1000 accidents with injured persons are collected by a research team of engineers and medical staff as part of the work of the German Federal Highway Institute BAST. Each kind of traffic accident is included in this approach. A representative portion consists of children in cars using a CRS.
The data of deformation, traces on the scene and detail information about injuries are stored in a databank. A comprehensive reconstruction with determination of collision speed as well as delta-V is done for every case.

The source of the BR-data is totally different: parents with children after being involved in an accident are encouraged to contact CRS manufacturers in order to have their CRS inspected and – if necessary and possible – repaired. Upon this contact they are commonly asked to fill in a detailed accident report, which includes data such as

- type of motor car
- type of CRS and adult restraint
- description and location of injuries
- seating positions
- description and sketch of collision
- age / height and mass of children
- occurrence of pre-impact braking.

Above data can be used for detailed assessment. Particularly the information on injuries is a useful tool for in-depth studies. On the forms the parents are urged to use the professional terms to be taken from official medical reports, which allow analyses according to the MAIS method (AAAM, 1998).

COMPARISON OF INJURY SEVERITY BETWEEN RESTRAINED CHILDREN AND BELTED ADULTS

Within the BR-data information on the estimated crash speed and on the car deformation is insufficient and too subjective to be used for calculating or estimating the crash severity, which, however, may be “substituted” on the basis of the following aspects and conclusions.

There is a correlation between the crash severity and the injury severity for any restrained occupant involved in the same accident, i.e. a 3-point belted driver or a child secured in a CRS. Therefore a correlation must also exist between the injury severity of the belted driver and of the restrained child. For both variables we have the required data specified under injuries in the accident form. Fortunately the data on injuries, as outlined above, is precise.
This method has been reported about in the literature as pair or double-pair comparison (Evans, 1987 / Tingvall, 1987).

Table 1 shows whether the child is less, equally or more severely injured than the driver or front passenger in frontal/oblique accidents.

Table 2 shows the identical comparison for forward facing group II/III children on booster seats combined with 3-point lap/shoulder belts.

And finally table 3 compares rear facing group 0/0+ infants with adults.

The results of tables 1-3 are related to the CRS as shown in fig. 1-3 and should not generally be applied to all CRS of such or similar restraint designs.

Fig. 1
Forward facing group I CRS

Fig. 2
Group II/III booster cushion

Fig. 3
Rear facing group 0 infant seat

The terminology in Fig. 1 – 3 refers to ECE44 and is to be understood as follows:
Group 0/0+ CRS are designed for infants up to 10 respectively 13 kg body mass.
Group 1 toddler seats cover a mass group of 9 to 18 kg.
Group II/III CRS – dominated in the market by booster cushions – range from 15 to 36 kg.

The differences between the 3 basic types of CRS are remarkably small. If at all, the two forward facing restraint methods seem to score slightly better than the rear facing infant restraint. It must be considered that the majority of injuries are at AIS 1 level and that in by far most cases the children stayed uninjured in all 3 types of restraints investigated.

Restrained Children injured	**than belted drivers n = 598**	**than belted front passengers n = 244**
less severely	50,8%	50,8%
equally	46,7%	46,3%
more severely	2,5%	2,9%

Table 1: Effectiveness of a forward facing group I CRS in frontal and oblique crashes (BR-data).

Restrained Children injured	**than belted drivers n = 61**	**than belted front passengers n = 38**
less severely	49,1%	47,4%
equally	50,9%	50,0%
more severely	0%	2,6%

Table 2: Effectiveness of a forward facing group II/III booster seat in frontal and oblique crashes (BR-data).

Restrained Children injured	**than belted drivers n = 112**	**than belted front passengers n = 10**
less severely	45,5%	40,0%
equally	50,9%	60,0%
more severely	3,6%	0%

Table 3: Effectiveness of a rearward facing group 0 infant seat in frontal and oblique crashes (BR-data).

DISTRIBUTION OF INJURIES

The data given in table 4 is based upon the MUH investigation and shows the distribution of injuries over all body regions of children using CRS in frontal, struck and non-struck side impacts. Regardless of the type of collision head injuries dominate, particularly in side impact collisions.

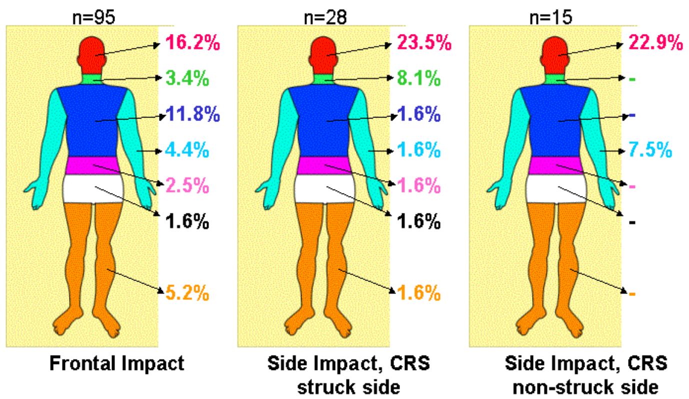


Table 4: Frequencies of Injured Body Regions of Children using CRS (MUH data)

Table 5 shows the distribution of injuries restricted to group I children in the forward facing CRS shown in fig. 1.

Head	28,2%	Pelvis	0,8%
Face	19,7%	Arms	1,7%
Neck	18,0%	Legs	3,4%
Thorax	18,0%	External injuries	9,4%
Abdomen	0,8%		

Table 5: Distribution of injuries in a forward facing group I seat in frontal / oblique crashes, n = 117 (BR-data)

In both data bases head / face injuries are dominant for frontal and struck side impacts and are probably caused by contact with car interior parts.

The low percentage of abdominal injuries indicates that the risk of submarining is minimal.
The external skin injuries are mainly lacerations and abrasions, which may be the result of flying glass. Nevertheless, these injuries were rated to MAIS and included as injuries in this study.

SEATING POSITION OF CHILDREN IN CARS

Table 6 shows the MUH material regarding the position of children in 2- and 4-door cars and is based upon 166 accidents. The outboard rear seat behind the front passenger is most preferred, though less than in the following distribution related to a specific group I seat. The use of the front passenger seat is low, in spite of the fact that the MUH material includes a number of rear facing infant seats, which are commonly restrained on this seat. This effect seems to be offset by older children on boosters commonly sitting in the outboard rear position.

2 doors n = 43 4 doors n = 123

Table 6: Position of Child Restraint System (n= 166 / MUH-data, p = 0,657)

Out of 766 cars involved 92% had 4 doors as per table 7 (MUH data 73,9%). Parents with children seem to prefer to own a 4-door car due to its advantages for installing a CRS and restraining a child in it.

The toddler type CRS as per fig. 1 is suitable and approved for use with 2 point lap belts and 3 point lap/shoulder belts. It can therefore be used on all three rear seat positions as well as on the front passenger seat.

According to table 7 the most preferred seating position (63,1%) is the outboard rear seat behind the front passenger with 2- and 4-door cars combined. The seat behind the driver comes next with 21,3%, whereas the center rear seat at 6,4% and the front passenger seat at 9,2% substantially lower. It appears that – whenever possible – parents will place a group I child behind the front passenger seat, perhaps due to better access from the sidewalk and to allow for more space between front and rear seat at times when the front passenger seat is not occupied.

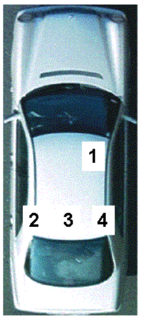
For 2-door cars the situation is somewhat different. For this particular forward facing CRS the outboard seat behind the passenger drops by more than 1/3 to 40,8%. The opposite outboard rear seat at 24,2% rises slightly, and also the center rear seat at 10,2% gains preference.
The front passenger seat itself rises to 24,8% due to its better and safer accessibility in a 2-door car and the fact that some 2-door cars have unsuitable rear seats for the transport of children (or even no rear seats).

Type of Car	**behind the front passenger**	**behind the driver**	**center rear**	**front passenger seat**
4-door car n = 702	66,3%	20,9%	5,9%	6,9%
2-door car n = 64	40,8%	24,2%	10,2%	24,8%
2- and 4-door car combined n = 766	63,1%	21,3%	6,4%	9,2%

Table 7: Seating position of group I children in a forward facing group I CRS (BR-data)

SEATING POSITION VERSUS INJURY SEVERITY

Tables 8 and 9 illuminate the injury severity variable as related to the seating position of the child. The differences between both for MAIS 0 figures can be explained by the general crash performance of all CRS in all types of collisions on the one hand and the performance of a specific CRS in frontal / oblique collisions only on the other hand. The comparatively low MAIS 0 figure on the front seat in table 8 may be partly caused by a low sample size.



	Seat Position			
	1	2	3	4
MAIS 0	44.1%	59.6%	73.9%	69.1%
MAIS 1	55.9%	38.2%	26.1%	29.3%
MAIS 2	-	1.4%	-	0.6%
MAIS 3+	-	0.8%	-	1.0%

Table 8: Maximum Injury Severity of Children using CRS (n = 166 / MUH-data, p = 0,223)

The injury severity of children seated in the forward facing CRS in frontal or oblique crashes and related to the four potential seating positions is shown in table 9. It can be noted that the front passenger seat, which offers more space for head excursion, shows a high percentage of uninjured children. Another positive feature of the front passenger seat was discussed earlier. It offers better accessibility for correctly installing the seat and restraining the child. Both effects may be the reason for the small advantage shown in the table. It is unfortunate that, due to the front passenger airbag issue, the use of this seating position is decreasing and will continue to do so until the airbag problem is solved.

The center rear position equipped with a 2-point lap belt scores about the same as the highly preferred outboard seat behind the front passenger. The possible performance advantage of the two lower symmetrical lap belt anchor points seems to offset the additional safety margin the outboard seat offers with its shoulder belt, but with asymmetrical lower anchor points, as described in the literature (Weber, K.).

	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4-6
Behind the front passenger, n = 363	79,1%	19,3%	0,8%	0,8%	
Behind the driver n = 110	84,5%	12,7%	1,8%	0,9%	
Center rear n = 38	78,9%	21,1%			
Front passenger seat, n = 73	83,6%	15,0%	1,4%		

Table 9: Distribution of injury severity related to seating position in a forward facing group I CRS in frontal / oblique crashes (BR-data)

INJURY SEVERITY RELATED TO DELTA-V

The MUH-data taken from the accident scene allows for a quantitative assessment of the injury severity versus Delta-v.
In frontal collisions the injury severity gradually increases with increasing Delta-v as per table 10. Severe injuries of MAIS 2-4 occurred at > 40 km/h only.

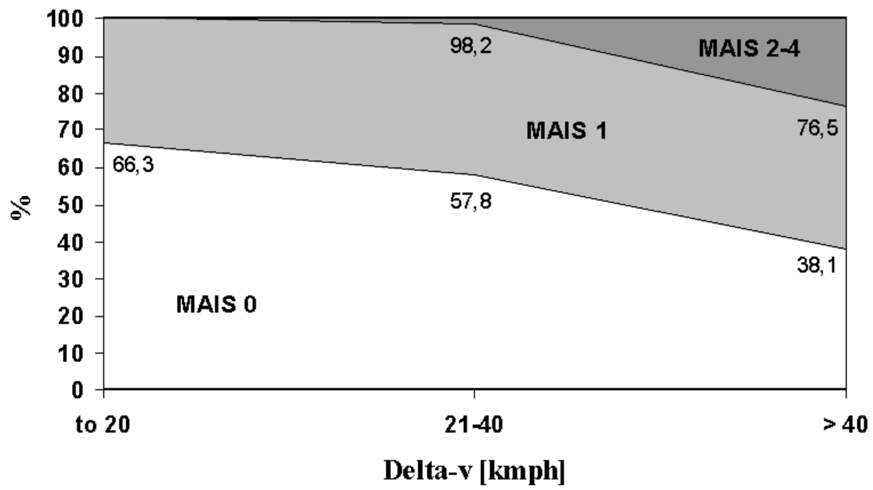


Table 10: Children using CRS in frontal collisions (n = 95 / MUH-data, p<0,001)

The assessment of children seated at the struck side in side collisions is shown in table 11 and does not differ very much from frontal collisions. MAIS 2-4 show a lower percentage. This type of collision has, however, the most severe injuries at MAIS 5/6.

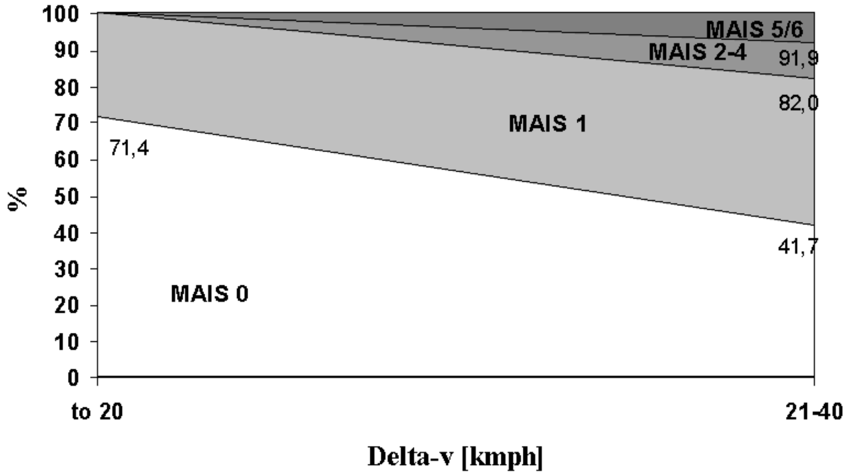


Table 11: Children using CRS in side collisions, seat at struck side (n = 28 / MUH-data, p<0,001)

INJURY SEVERITY BETWEEN SMALL, MID-SIZE AND LARGE CARS

The distinction chosen between small, mid-size and large cars was done in a rather crude way. Small cars are of the mini-type one (i.e. VW Polo/Lupo, Opel Corsa) and large cars represent the luxury car segment. Both segments were restricted to the more peripheral car size on both ends in order to maximize perceived differences in performance.

With head / face injuries dominating as shown in table 5 it was anticipated that small cars would score worse and large ones better than mid-size cars due to the free space available for head excursion.

However, table 12 shows a partly different outcome. Ignoring a small difference in favour of the small cars – which may be partly affected by a comparatively small sample size – there seems to be no advantage of any size segment. At least the head excursion space alone is not a decisive influencing factor. Also the incompatibility factor in car-to-car crashes does not show up in our results. Other factors such as design features of the CRS, the inherent design-induced effect of misuse, the thickness of the car seat cushion etc. seem to override potential or expected differences in the injury severity due to different car sizes.

Size of car	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4-6
small n = 81	84,0%	13,6%	2,4%		
mid-size n = 454	79,3%	18,9%	0,9%	0,9%	
large n = 53	81,1%	17,0%	1,9%		

Table 12: Distribution of injury severity in small, mid-size and large cars in a forward facing group I CRS in frontal / oblique crashes (BR-data)

THE EFFECT OF IMPULSE ANGLE IN FRONTAL COLLISIONS

The impulse vector in table 13 was established in a range of 90 to 230 degrees in a defined measurement system where 180 degrees replicates an impact in longitudinal axis. The highest injury severity can be seen in longitudinal loads.

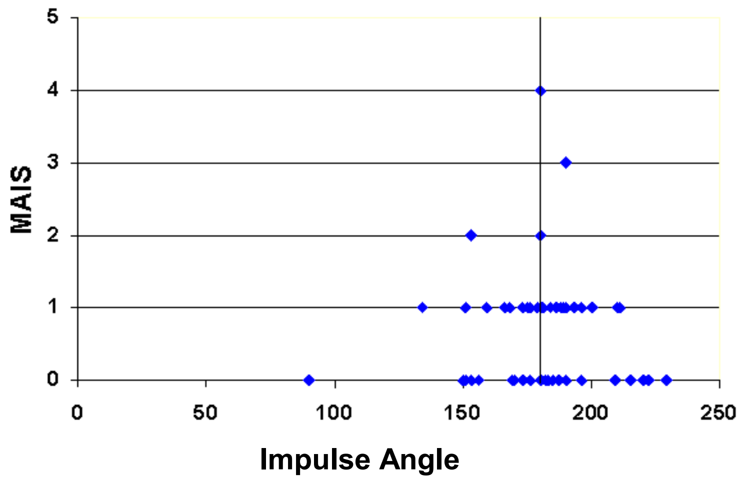


Table 13: Impulse Angles of Cars with CRS in Frontal Collisions (n= 86 / MUH-data, p = 0,434)

THE EFFECT OF IMPULSE ANGLE IN SIDE COLLISIONS

In lateral impacts the impulse vector is oriented mainly in oblique directions and very seldom under 90 degrees, as shown in table 14. This is the effect of the collision of moving vehicles following mostly in an impact angle tolerance field of 100 to 150 degrees, respectively an impact load direction from the front to the rear rather than at a 90° rectangular impulse angle.

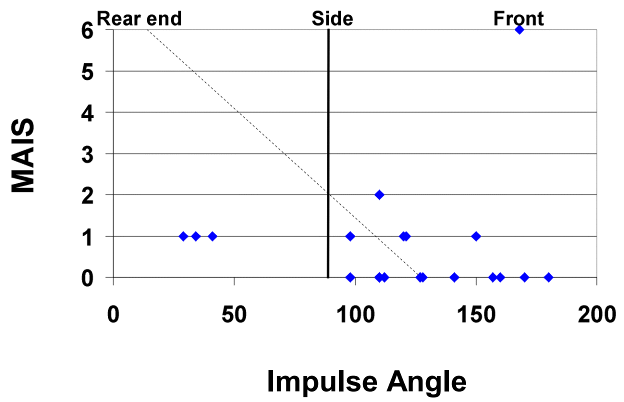


Table 14: Impulse Angles of Cars with CRS in struck side collisions (n = 23 / MUH-data, p = 0,498)

The dotted line is meant to be an indication of the mean value of the impact angle related to injury severity.

The number of cases is rare in this kind of impact situation, but it can be expected that the highest injury severity will happen in rectangular conditions.

THE EFFECT OF SEAT SHELL INCLINATION

Forward facing group I seats commonly allow the child to be changed from a rather upright torso position into an inclined "sleeping" position. This possibility is perceived by the parents as an important comfort feature. The degree of inclination is usually variable in steps.

Table 15 shows to what degree parents make use of the recline feature depending on the mass of their child.

In total only in 23% of all cases the seat shell was inclined. As expected, the inclined position is preferred for the small child, but as children grow the parents switch the CRS to the upright position and leave them in this position. The use rate of this comfort feature is considerably lower than might be expected. It mainly is employed at the time a group I seat is purchased.

Weight	upright n = 733	reclined n = 221
(< 8,5 kg)	35%	65%
(8,5 -10 kg)	60%	40%
(10 - 12,5 kg)	81%	19%
(12,5 - 15 kg)	85%	15%
(> 15 kg)	93%	7%
TOTAL	77%	23%

Table 15: Comparison of weight of child versus upright / reclined position for a group I forward facing CRS (BR-data)

Regarding the injury severity in terms of MAIS 0 the reclined position scores slightly better than the upright one. This result is often confirmed by dynamic tests with the head excursion of dummies in the inclined position slightly less than upright. However, the results of table 16 may not be typical for all group I seats. In CRS which allow for a large inclination angle the risk of submarining is likely to exist with consequent deleterious effects on the injury severity.

	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4-6
upright n = 427	78,9%	19,7%	0,5%	0,9%	
reclined n = 151	85,4%	12,6%	2,0%		

Table 16: Distribution of injury severity related to the upright and reclined position in a forward facing group I CRS in frontal / oblique crashes (BR-data)

HEIGHT OF MASS OF CHILDREN VERSUS INJURY SEVERITY

A group I seat as per ECE44 is approved for children from a mass of 9 kg to 18 kg, which averages to a height of 70 cm to about 100 cm. It was interesting to investigate whether a child below the lower limit with its weaker body structure or towards or beyond the upper limit with its higher head excursion would risk a higher injury severity.
Generally these expectations are confirmed by the results shown in tables 17 and 18.

The segment < 70 cm or < 8,5 kg indicates the use of this CRS at a time when the child should still be in a group 0/0+ seat. In terms of MAIS 0 there is a decrease for this too small child, which confirms the need not to restrain children forward facing when they should still be rear facing.

The decrease of MAIS 0 for taller or heavier children is remarkable. In addition to body size and weight this decrease may also be caused by belt slack, since these children often buckle up themselves without the assistance and care of their parents.

Height	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4-6
< 70 cm n = 14	71,4%	28,6%			
70 – 77 cm n = 124	86,3%	13,7%			
78 – 90 cm n = 248	82,7%	15,7%	0,8%	0,8%	
91 – 97 cm n = 83	80,7%	16,9%	1,2%	1,2%	
> 97 cm n = 91	58,2%	35,2%	5,5%	1,1%	

Table 17: Distribution of injury severity related to the height of children in forward facing group I CRS in frontal / oblique crashes (BR-data)

Mass	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4-6
< 8,5 kg n = 18	77,8%	22,2%			
8,5 – 10 kg n = 130	86,2%	13,1%	0,7%		
10 – 12,5 kg n = 220	82,3%	15,5%	1,3%	0,9%	
12,5 – 15 kg n = 118	78,9%	20,3%		0,8%	
> 15 kg n = 78	62,8%	34,6%	1,3%	1,3%	

Table 18: Distribution of injury severity related to the mass of children in forward facing group I CRS in frontal / oblique crashes (BR-data)

CHILDREN RESTRAINED IN CRS VERSUS SEAT BELTS

The German legislation (effective as from April 1993) requires the use of ECE44 approved CRS. However, the use of adult seat belts only, that is, without a CRS during the period 1990-2000 was found to be wide spread, as shown in tables 19 and 20. When children were restrained, CRS were used mainly at the lower age, 90% up to 6 years, compared to the use of the 3-point belt only with around 75% in the age group 5 to 12 years. The MUH study confirms that adult belts only are even used with infants and represent a total misuse rate of 59% related to children up to 11 years of age.

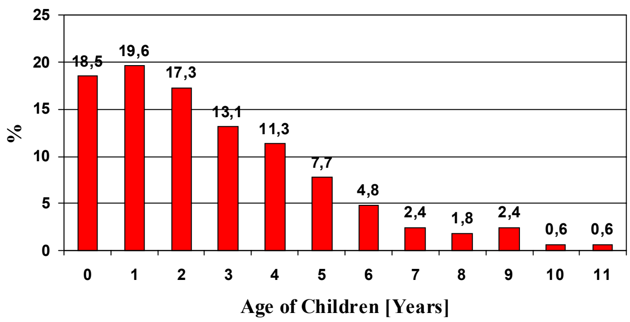


Table 19: Age of Children using CRS (n = 168 / MUH-data, p<0,001)

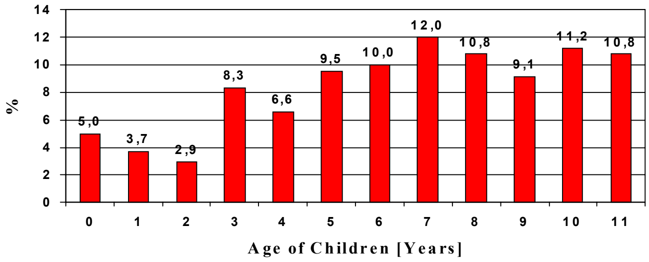


Table 20: Age of Children using Seat Belts (n = 241 / MUH-data, p<0,001)

OCCURRENCE OF PRE-IMPACT BRAKING

The MUH sample with 86 cases shows that 60,5% of all cars were braking prior to impact in frontal collisions. The equivalent figure in the Britax Römer study is even higher, at 79,2%.

In contrast to frontal / oblique accidents, however, pre-impact braking does not occur in most of side-impact accidents. The MUH-study results show no pre impact braking in 67,3% of side impacts and the Britax Römer shows no pre-impact braking in 58% of side impacts, as shown in table 21.

These results indicate that in the majority of side impact accidents children in group I seats will stay with the protective zone of the seat shell prior to impact. The information may be useful for the ongoing task of adding side impact testing to ECE 44.

The sample showed little difference between struck and non-struck side (related to the driver).

Pre-impact braking	**frontal / oblique crashes**		**side-impact crashes**	
	MUH **n = 86**	**Britax** **n = 554**	**MUH** **n = 23**	**Britax** **n = 119**
without	39,5%	20,8%	67,3%	58,0%
with	60,5%	79,2%	32,7%	42,0%

Table 21: The occurrence of pre-impact braking in frontal / oblique and side-impact crashes (MUH- and BR-data)

PRE-IMPACT BRAKING VERSUS INJURY SEVERITY IN FRONTAL / OBLIQUE ACCIDENTS

The positive effect or pre-impact braking in frontal or oblique accidents has been reported earlier (Czernakowski / Otte, 1993). As shown in table 22, the MAIS 0 ratio rises with the occurrence of pre-impact braking. This advantage, however, seems to level off with increasing crash severity respectively injury severity.

Pre-impact braking	**MAIS 0**	**MAIS 1**	**MAIS 2**	**MAIS 3**	**MAIS 4 – 6**
without; n = 115	71,3%	27,0%		1,7%	
with; n = 439	82,0%	16,6%	0,9%	0,5%	

Table 22: Distribution of injury severity related to the degree of pre-impact braking in forward facing group I CRS in frontal / oblique crashes (BR-data)

IV. CONCLUSIONS

The analysis and assessment of accidents are a useful tool to investigate the effects on injury severity of different modes using CRS in the variety of motor vehicles. The investigation could indicate that adverse interface conditions between both may lead to a higher injury severity level, and that these conditions cannot adequately be covered by standard test methods.

A number of perceived negative interface conditions, however, did not result in a higher measurable injury severity, most likely due to other dominating effects.

Both the MUH- and BR-data seem to prove a high general effectiveness of CRS with a low number of severely injured restrained children.

The high rate of pre-impact braking in frontal collisions and a remarkably lower one in side collisions should be of interest for CRS manufacturers.

Though the impulse angle in side collisions is widely spread, an oblique impulse from the front is the dominant mode of impact

The study demonstrates that small infants should not be restrained in forward facing toddler seats too early. Taller group I children are more likely to be injured than smaller ones.

The results found may be considered for upgrading child safety standards and designing CRS.

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