Safety benefits of the new ECE regulation for the homologation of CRS – an estimation by the CASPER consortium

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Abstract

The GRSP informal group on child restraint systems (CRS) is finalising phase 1 of a new regulation for the homologation of CRS. This draft regulation is already the subject of several discussions concerning the safety benefits and the advantages and disadvantages that certain specific points may bring. However, these discussions are sometimes not based on scientific facts and do not consider the whole package but only single items.

Based on the experience of the CASPER partners in the fields of human behaviour, accident analysis, test procedures and biomechanics in the area of child safety a consideration of the safety benefits of the proposal for phase 1 and recommendations for phase 2 will be given.

1 Introduction

Analysis of the EC CARE database for the European situation in 2008 (EU27 - except Cyprus, Bulgaria, Lithuania) finds that 340 children were killed (0–11y) as passenger car occupants and 2790 severely injured. During the last decade the number of children killed on the roads has decreased in the same way as for adults,

but this tendency is not uniform across all European countries. Recently, the United Nations General Assembly proclaimed “the period from 2011 to 2020 as the Decade of Action for Road Safety” and the European Commission proposed “to continue with the target of halving the overall number of road deaths in the European Union by 2020 starting from 2010”. This target can only be reached if all countries are making common efforts to improve the situation and share the knowledge in this field together. UNECE started in 2008 an Informal Group of GRSP in order to develop a new regulation for the homologation of CRS that should replace in the medium to long term the current ECE Reg. 44. Composed of experts from different parts of the world, it was set up in order to regroup and integrate as much as possible the knowledge and points of view of the different actors in the child safety chain. The main objective of this informal group is to consider the development of a new regulation for “Restraining devices for child occupants of power-driven vehicles” for consideration by GRSP. This will be done using a step by step approach. During phase 1 the development of the definitions, the performance criteria and the test methods for ISOFIX Integral - “Universal” CRS - status has to be proposed. Once accepted by GRSP a phase 2 concerning ISOFIX CRS non integral, in which the child is restrained by the adult safety belt, should be set up. Then if necessary a phase 3 would be considered the other types of CRS.
The starting points for the activity of this group are the following observations:

- CRS are often not used correctly
- Incompatibility between car and CRS exists
- No lateral impact protection capabilities are required in current regulation

The work has been based on the most recent results that have been provided by pre-reglementary working groups such as EEVC WG12 and WG18 and research projects in the child safety areas. During phase 1 two projects are still in activity and regular reports of work advancement are made by project leaders, in order that findings are integrated in the proposal when available;
These two projects are:

- EPOCh (**E**nabling **P**rotection for **O**lder **Ch**ildren) that has the objectives to produce a 10/12 year old prototype dummy, to extend the NPACS testing and rating protocols for older children and to make proposals for Q10/12 dummy use in UN-ECE Regulation.
- CASPER (**C**hild **A**dvanced **S**afety **P**roject for **E**uropean **R**oads) that aims to improve the rate of correctly restrained children by the analysis of the reasons and consequences of the conditions of transportation of children both on scientific and sociological aspects and to improve the efficiency of child protection devices. To reach these goals, a consortium of 15 partners from 7 countries, all recognized in the area of child safety has been set up. This project has integrated the results of previous research works from the CREST and CHILD projects. This project is partially funded by the European Commission and is register under the reference *FP7-SST-2007-RTD-1 - GA no.: 218564.* Its work organization covers a large number of subjects around child safety such as field data, (accident, misuse surveys, parents point of view), test data of different configurations, activities on dummies and associated equipment, and a large effort in the modelling of dummies and of child human body. Each time it has been required, the group has been collaborating with the GRSP informal ad-hoc group on CRS. Its main inputs were field data, dummy experience and test procedure works.

Based on objective research results of the CASPER project and its predecessor projects CHILD and CREST, the current situation regarding child safety in cars is described in this paper from the point of view of the CASPER consortium. These results are the input for an estimation of safety benefits of the new proposal and recommendations for the next phase of the activity.

2 Field Observation

2.1 Accident data

For this section French and German data have been used. The first sample is about a French fatality study, the CASIMIR project (more details available below) and for Germany GIDAS and National data have been used.

Figure 1 shows the distribution of killed children as car occupant in Germany by age. It is obvious that children with an age of 1 year old are of greatest risk. It is expected that this peak results from too early change from rear facing to forward facing CRS. However, the national data used for this analysis is too general to prove this theory.

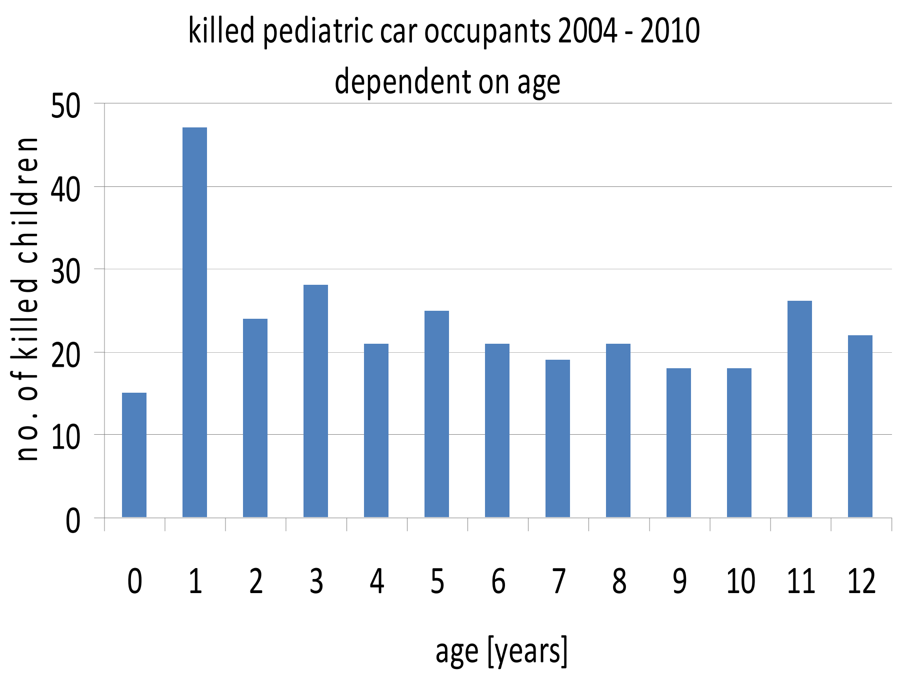


Figure 1: Killed children as car occupants dependent on age in Germany

2.1.1 CASIMIR (Child Accident Study Investigation Mortal Incidents on the Road)

This study conducts an exhaustive analysis of road accidents where children have been killed as car passengers. It based on an analysis of all police reports on such accidents occurring during a two-year period (Oct 2001 – Sept 2003) in France. Its aim is to determine the main typology of accidents leading to child car occupant fatality. A larger description of the study and of the results of the analysis is given in a paper dedicated to the fatality studies in the Protection of Children in Cars conference 2011 by Kirk et al. [Kirk, 2011].

Data on 206 fatally injured children aged less than 12 years old are available. Among them, 57% used a restraint system and 31% were not restrained. The information was unknown for the remaining 12%. Field studies conducted in France on the same period find that more than two thirds of children were not correctly restrained while traveling in cars, which reduces considerably their level of protection [D09 annex5

CHILD project]. The distribution of the type of impact for the 206 children is shown in Table 1.

Table 1: Repartition of children according to the type of impact

Impact type	Frontal	Side	Roll over	Rear	Multiple	Others
Nb children	70	58	38	8	7	25
(%)	(34%)	(28%)	(18%)	(4%)	(3%)	(12%)

In the CASPER project, one of the tasks was to evaluate the existing test procedures in different impact configurations. Frontal impacts remain the primary accident configuration in terms of killed children with approximately one third of the total, followed by side impacts that represent 28% of the total and roll-overs / tip-over with a total of 18%, which is not negligible. The focus has therefore been on these three types of impacts. For rear impacts and the category “others” which is mainly composed of unusual situations, such as falls into rivers, fire, rock falls, etc., the sample is too small to be able to analyze it in detail. In addition, the fact that only 4% of children are killed in rear impacts shows that it is not a priority to enhance the protection of children on this type of impact, existing specification in the current regulation seems sufficient on that point.

The estimation of the quality of use of CRS is always difficult when it’s only based on the analysis of police reports. Nevertheless, it has been possible to determine that on the 206 children killed as car occupants, 99 children were using an appropriate CRS, among which 66 have shown no evidence of misuse. This makes a maximum rate of 32% of children correctly restrained, knowing that this figure is over-estimated. The distribution is shown on Figure 2.

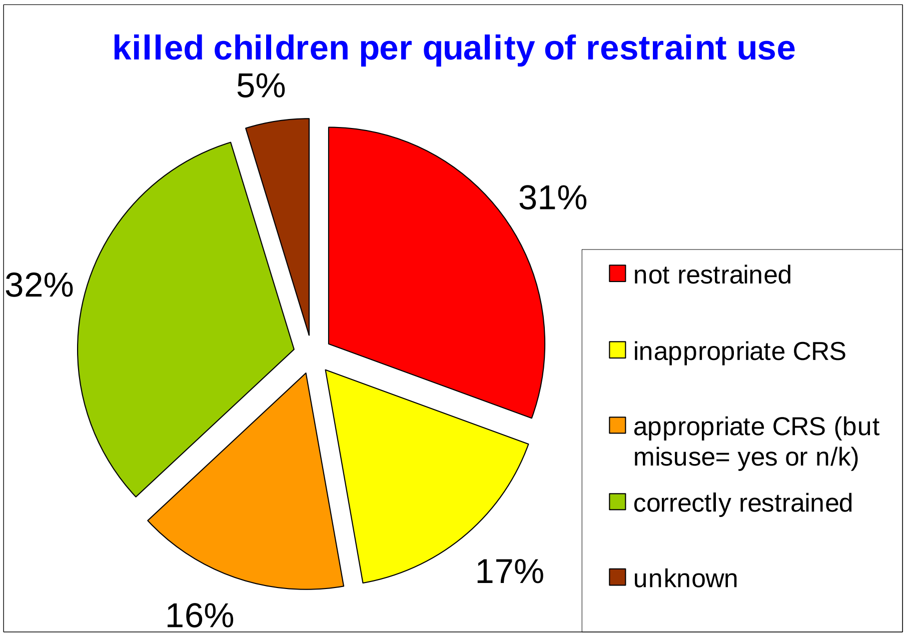


Figure 2: Distribution of restraint use for killed children (n=206)

Note: “inappropriate” considers the CRS selection only while misuse addresses the incorrect use of a CRS

<u>Frontal impact:</u> Analysis of the characteristics of the crashes according to the type of impact shows that 34% of the children were killed in frontal impact although two thirds of them used a specific restraint. To quantify the crash severity in frontal impact experts decided to use the EES (Equivalent Energy Speed) which is a translation of the energy absorbed by the car during the crash. An estimated method is used based on comparing structural deformations of the case car to with the ones sustained during crash-tests.

Looking at the main reasons of fatality of children in frontal impacts, the first cause (32%) is the fact that they are unrestrained. Then comes that 23% use an inappropriate and/or a misused restraint system, keeping in mind these are the cases with such evidence available in the police report. This makes a total of 55% of the killed children in frontal impact that were not properly restrained and that was estimated to be the cause of death. For the other 25% of children killed in a frontal impact as car occupant, the crash severity was far above the design criteria of cars and CRS (EES>=75 kph) and following that somehow not survivable and was considered as the main reason of death.

<u>Additional analysis for frontal impacts:</u>
In order to be able to have a better view on restraint conditions for children killed in frontal impacts, a second phase of the CASIMIR project has been initiated in the task 3.2 of the CASPER project. It consists of a similar approach for all fatal accidents that occurred between 2005 and 2010. During this period, some of the fatal cases have been investigated in depth by experts in accidentology with, when possible, a close look to the restraint systems of all occupants and an analysis of the structural deformations of vehicles. Only the cases of frontal impacts fully documented in this way are reported in the present paper.

The sample is composed of 28 children involved in a frontal impact. They are all restrained and 26 of them are using appropriate restraint systems regarding the French law. For 21 children the frontal impact occurs against another passenger vehicle, for 5 against a tree or a pole and for the 2 remaining, they sustained their impact against a very high weight vehicle.

Concerning the EES, it is estimated equal or over 65 kph in 17 cases (including 11 >=75kph) and in 11 cases it is estimated under 65kph. On these last 11; misuse situations have been observed in 6 cases and it is unknown for 2 cases. On the 3 remaining cases, no evidence of misuse has been observed. It has to be said that such severe crashes are not numerous but their investigation brings interesting data for projects such as CASPER, for which extreme loading conditions are often useful to determine injury criteria. This analysis confirms the statement made in the first phase of CASIMIR for frontal impact: improving the use and the quality of use of restraint systems is the first priority in frontal impact.

<u>Side impact:</u> Returning to the CASIMIR results, 28% of the fatalities occurred in lateral impact. In contrast to frontal impact, misuse or inappropriate CRS was in most cases not the reason for the fatality and improvements of CRS dynamic behaviour would result in a larger benefit than for frontal impact. To better assess effectiveness of protection devices, children killed in side impact were put into 2 categories: the ones with intrusion at their initial seating position 72% (n=42), and the ones with no intrusion, even if seated on the struck side 28% (n=16).

For children in the area of intrusion, 34 were restrained. For 21, the intrusion value is higher than 450 mm, which makes the accident difficult to survive especially with protection devices designed before 2003 (end of the period of the study). 8 children were not restrained and were killed by projection inside the vehicle or by ejection from the car. 6 others sustained an impact with a rigid part of the car interior and 3 were ejected because of an incorrect use of their restraint systems.

For the 16 children with no intrusion, the main fatality reasons are impact in vehicle and non use or misuse of restraint systems.

Roll-overs: the rate of use of restraint system of children killed in roll-over and tip-over is low compared to the other crash configurations with only 24%. For 68% of the sample, ejection is the reason of fatality. For an additional 10% of restrained children, the reason of death has been attributed to the lack of correct use of an appropriate restraint system. One can say that most of these fatalities might have been avoided with the correct use of a restraint system. The priority to reduce the number of the children killed in roll-overs is clear: to get them properly restrained.

Of course, in this kind of study, the analysis is limited by the lack of homogeneity in the quality of police reports (lack of photos, quality of data related to children,…). That's why some complementary works have been initiated, focussed on frontal and side impacts with in depth investigations conducted. The evaluation of the quality of restraint is always something difficult as the absence of evidence of misuse does not mean that the restraint system is correctly used. Unfortunately very few medical data were available for the study as autopsy is not usual in France for children killed in cars, so clear indications on the body segments and injury mechanisms are not available, except that head impacts often occur. This study is only representative of the French, but very few data with so many details are available elsewhere for the moment.

2.1.2 Representative real world data (GIDAS)

This part of the paper is based on the GIDAS (German In Depth Accident Study) database. The areas of data collection are Hannover and Dresden and their relative surrounding areas. In the sample a minimum severity level is guaranteed: to have the accident data collection team activated, it is necessary that at least one person gets injured in the accident. The team then go on the scene and collect the data for all vehicles and all occupants involved, and also collect data on the infrastructure. Collected accidents are representative of the German situation and their annual numbers correspond approximately to 1% of the total German accidents.

The sample of the current study is composed of the accidents involving children less than 12 years of age as car passengers between 1999 and 2008. Only accidents against cars, objects and lorries were considered. Figure 3 shows the distribution of injury severity for children involved in accidents according to the type of impacts. Of 894 children, 417 are involved in a frontal impact, 249 are involved in a side impact (145 on the far side, 104 on the near side) and 228 in a rear impact. The number of children injured at the MAIS 3+ level is low and indicates that the protection level is globally high in Germany, where nearly all children are restrained when travelling in cars.

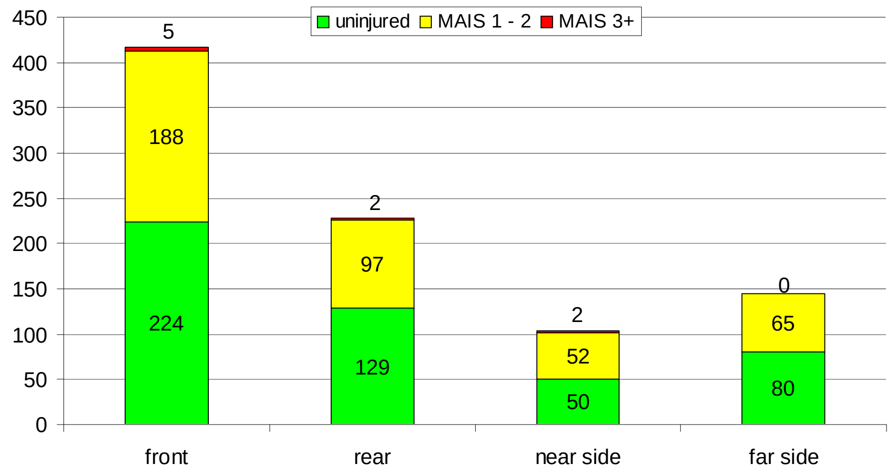


Figure 3: Injury level per impact direction

In order to go further in the knowledge of the level of protection of children, the crash severity is an important parameter. For frontal impact, it has been possible to determine for all cases of the sample a deltaV, that is the corresponding change of speed of the vehicle during the accident. The distribution of deltaV and the corresponding injury level for children involved in frontal impacts is shown in Figure 4. Looking at injury severity, it appears that the safety level guaranteed by the current regulation seems satisfying for most of the accidents in frontal impacts and that its frontal test severity represents more than 80% of the frontal impact accidents. The case by case analysis of the 5 MAIS3+ cases showed that the cause of injuries are accidents with a severity that is out of the scope of car design or misuse of restraint systems has occurred.

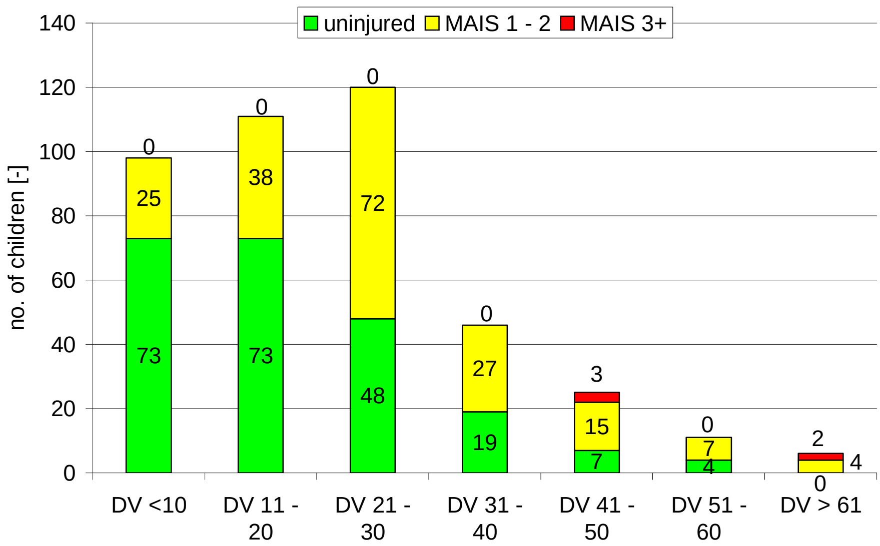


Figure 4: Injury level per delta-v in frontal impacts

2.2 Use of CRS

For the CASPER project a field study was conducted at different places in Europe. The aim of this part of the project is on the one hand to get an update of misuse behaviour and to see its development during the last years and on the other hand this study allows a comparison of child safety behaviour in different regions.

The interviews took place in Naples, Berlin, Hannover and Lyon and surrounding areas and were divided into two parts. The first one was the observation of the securing situation of the child in the car and its assessment; the second part was a short interview with the car driver. The observation should start at a very early point at best when the car is still rolling, so that the real securing situation could be seen. In general children start to unlock the buckle as soon as the car stops, which makes it difficult to assess misuse. For this first analysis of the study only the data from Berlin with 104 cases and Lyon also with 104 cases could be used. The other data is not yet available but the complete results will be published soon.

A look to the distribution of the age (Figure 5) of the children in this study shows that there are only a few observations in the group from 10 to 12 years and also not so many in the group up to one year of age, which is normally the group of rearward facing CRS. The age distribution was similar in both the Berlin and Lyon data, with some differences in the lower age group. The data collection strategy (near a city park with recreational facilities in Lyon and at a lot of different places in Berlin) may have affected this distribution.

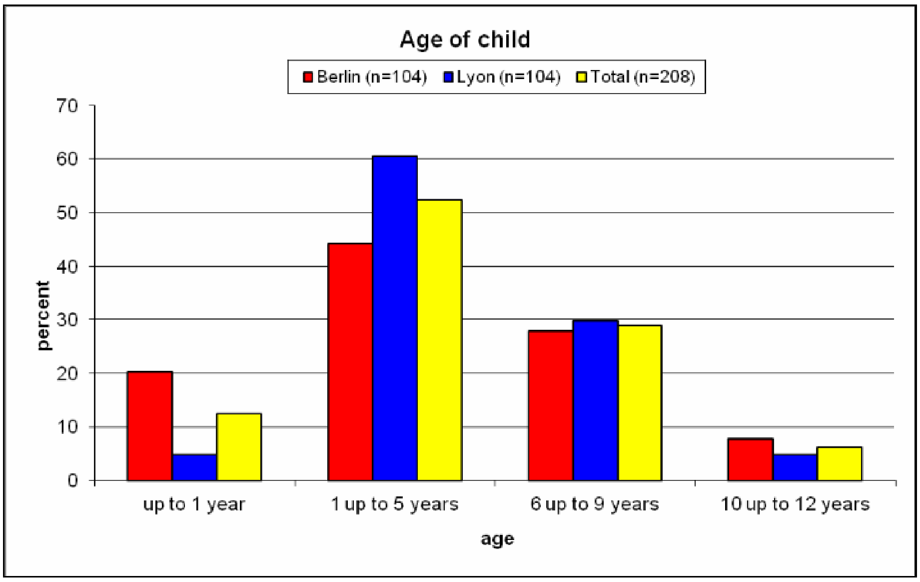


Figure 5: Distribution of age

The seating position (Figure 6) confirms the results of former field studies with most of the children seated at the outer seats in the second row with a little preference of the right position. There are only very few cases of children at the front passenger seat or at a seat in a third row.

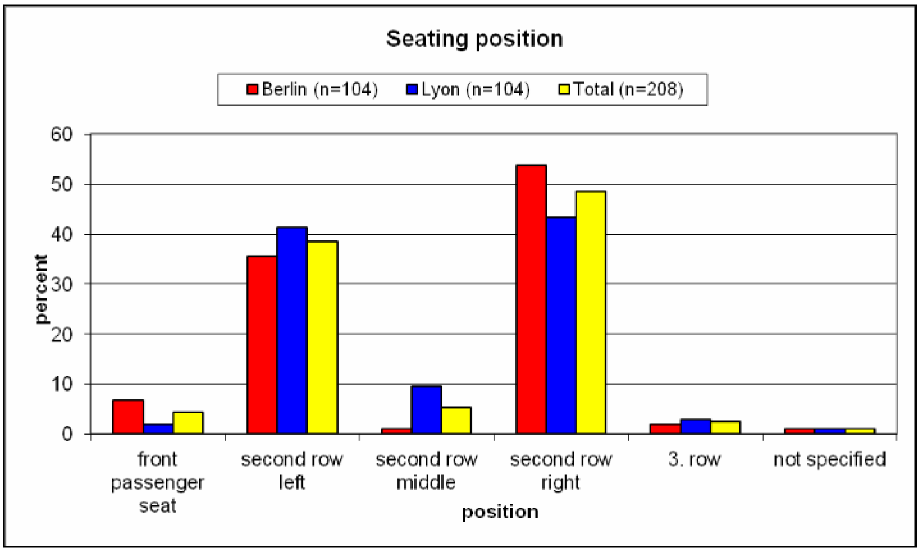


Figure 6: Seating position of the child in the car

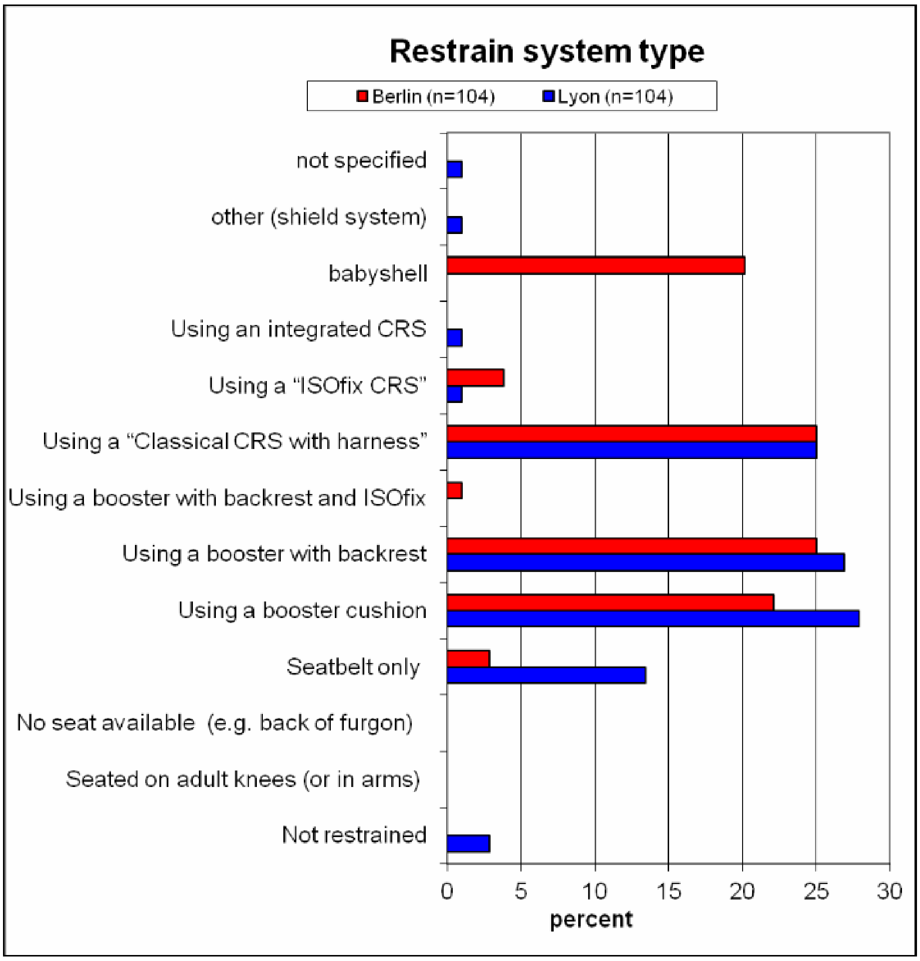


Figure 7: Restraint system type

The distribution of the CRS which was in use shows differences between Berlin and Lyon data (Figure 7). While there was no child secured in a babyshell in the Lyon sample, 20% of all viewed children in the Berlin sample were secured in a babyshell. Opposite to that, 14% of children in Lyon were secured with the seatbelt only, only 3% in Berlin, and additionally there were 3% unrestrained children in France while this was not seen in the Berlin study.

The generation of CRS shows that seats homologated according to ECE-R 44.02 are nearly not in use anymore, there was only one old CRS, in Lyon (Figure 8).

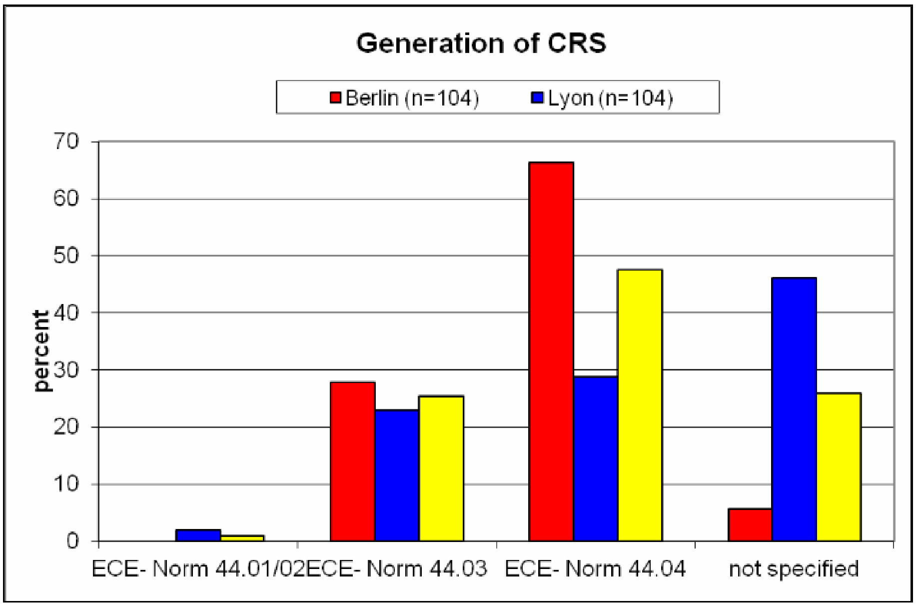


Figure 8: Generation of CRS

The use of ISOFIX CRS seems quite seldom, even if this system has been available for several years. There were six ISOFIX seats in Berlin in use and just one in Lyon. Most of the seats are still fixed by the 3-point retractor belt in the car or are class 2/3 seats which have no own fixation in the car (Figure 9).

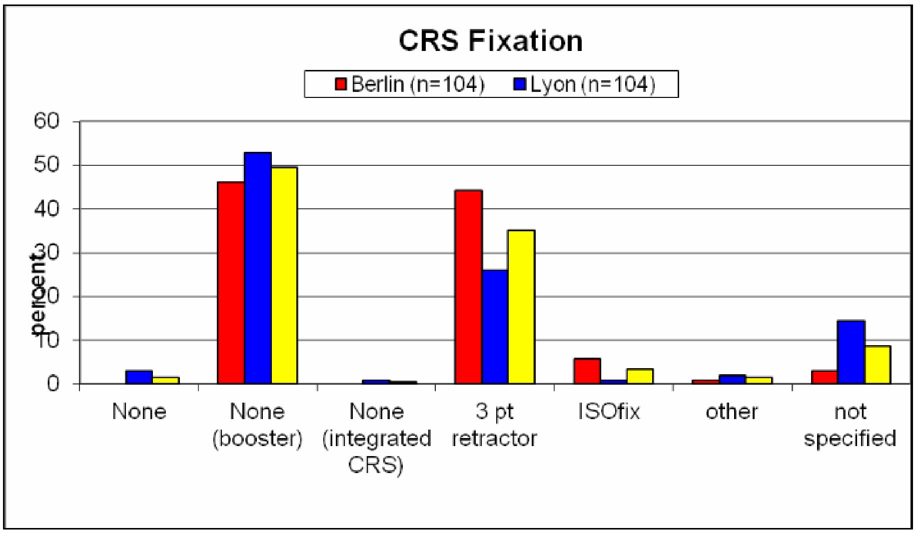


Figure 9: Fixation of the CRS in the car

In the beginning all interviewed people were asked whether they think the installation of the CRS and the securing of the child was good (Figure 10). And here again was confirmed what could be seen in a lot of studies [Fastenmeier, 2006] before. People want to secure their children correctly and they are convinced that they do it correctly.

While in Berlin 90% of all people think that they have secured the child correctly it was less than 60% in Lyon. However the groups 'not specified' (people did not answer the question) and 'partly' were larger in the Lyon sample.

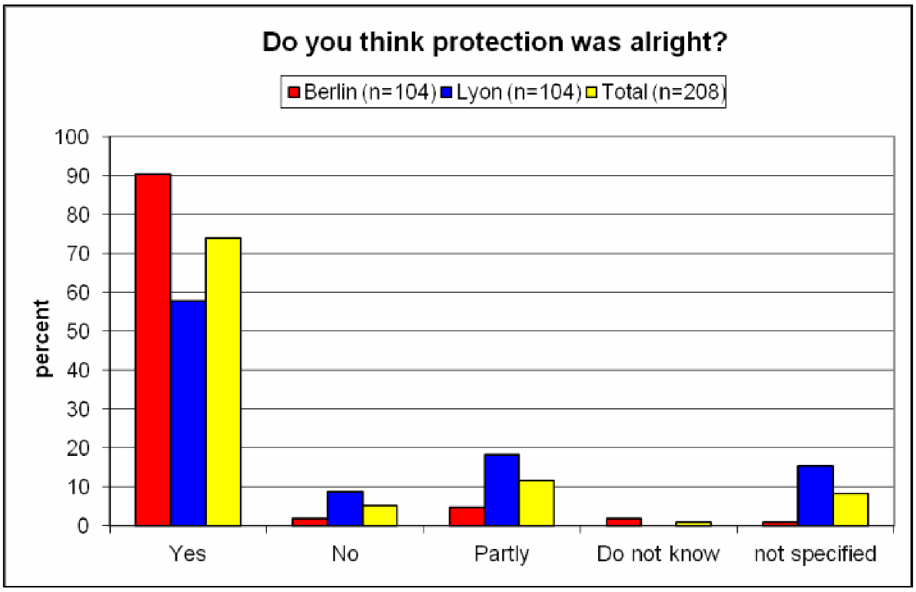


Figure 10: Question to the driver: Do you think the installation was alright?

In opposition to the perception of those interviewed, represented in Figure 10, Figure 11 shows that misuse conditions were found in about two thirds of the cases. In other words: only about one third of the children were secured correctly. Compared to older misuse studies it has to be realised that the rate of misuse stays constant in the last 15 years. There are more problems with the securing of the child in the CRS than with the installation of the CRS in the car.

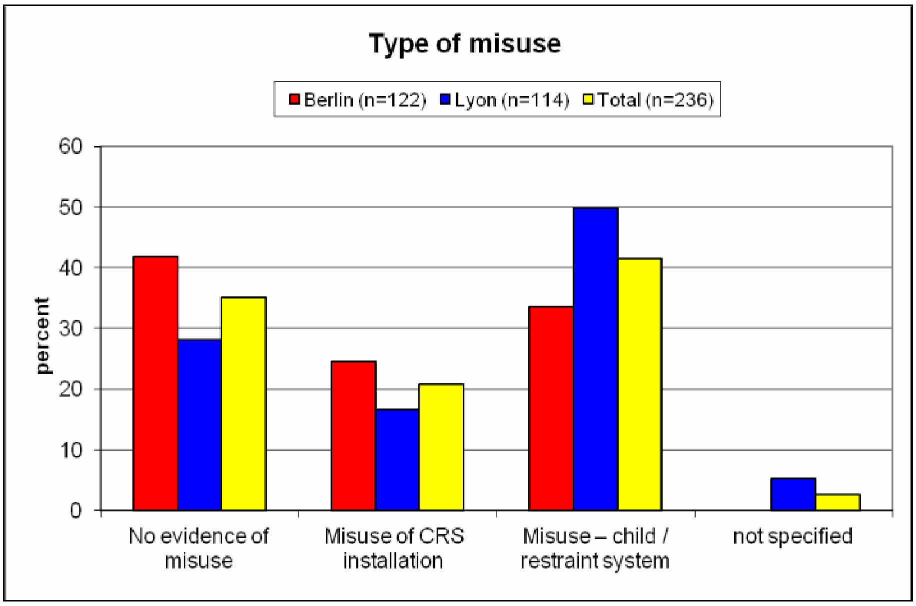


Figure 11: Types of misuse

Looking at the types of misuse related to the installation of the CRS in the car (Figure 12), the most common problems are car belt path, lack of shoulder belt guide use in a class 2/3 seat with a backrest, insufficiently tightened car belt and bulk seat fixation. All of these misuse conditions are very critical and could lead to serious injuries if an accident occurred. This is confirmed in Figure 13 where all Berlin misuse and nearly all Lyon misuse conditions are assessed as medium or severe.

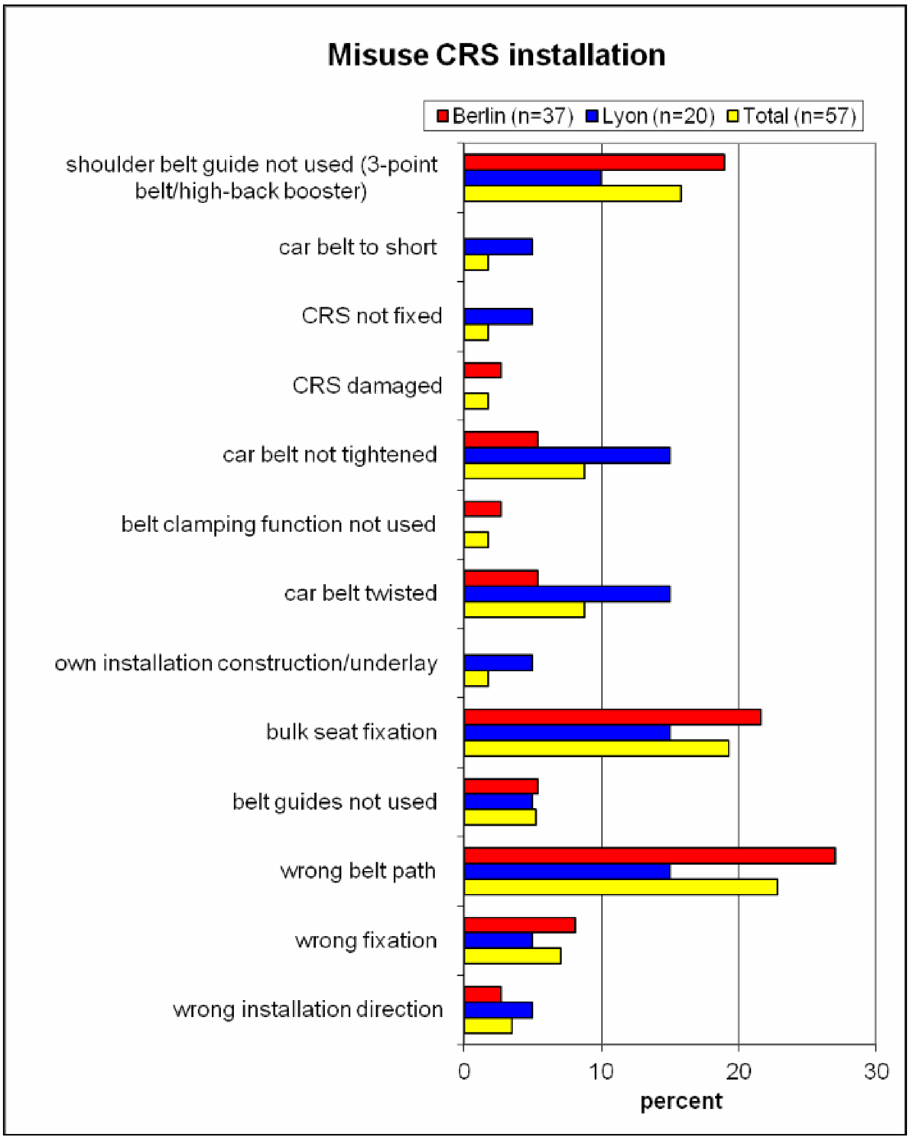


Figure 12: Misuse in connection with the installation of CRS in the car

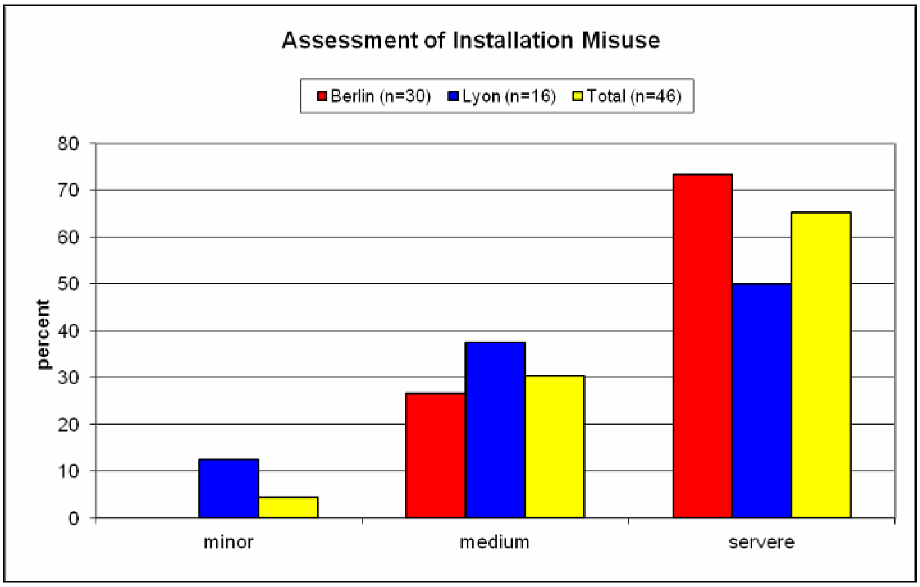


Figure 13: Assessment of the misuse in connection with the installation of CRS in the car

The most common misuse in connection with the securing of the child in the CRS is belt slack in the harness and the lack of lower belt guides use in class 2/3 seats

(Figure 14). The second most common misuse type could lead to direct abdominal loading and severe abdominal injuries in case of an accident. Other problems like a twisted car or CRS belt do not reduce the efficacy of the CRS by the same severity. It is unclear at this time if the difference in belt slack results between the Berlin and Lyon samples is related to a different usage or to a different perception by the investigators of what belt slack means.

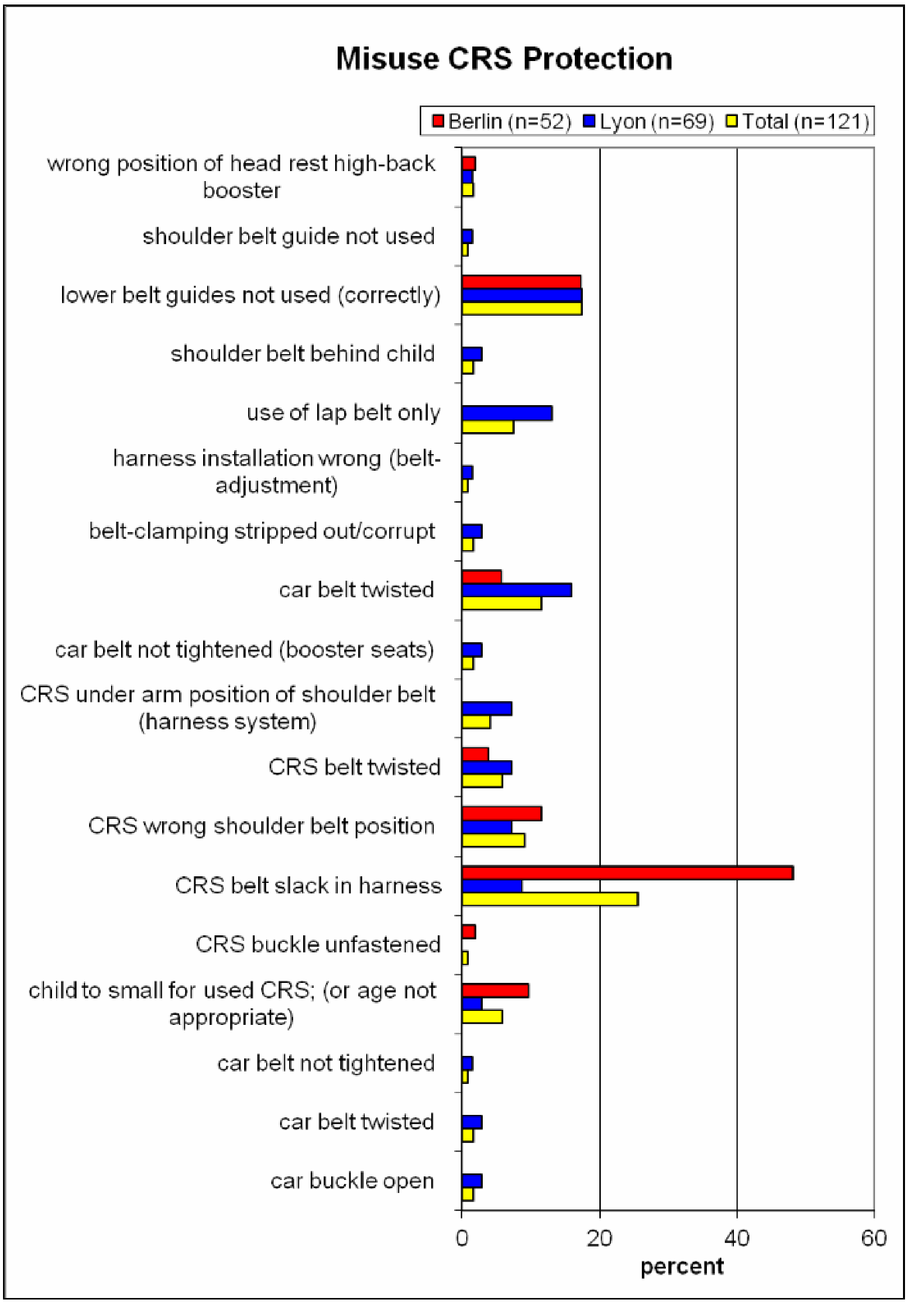


Figure 14: Misuse in connection with the securing of children in CRS

Looking to the assessment of misuse in connection with the securing of children in the CRS some misuses were rated as minor, but in total nearly 90% were rated as medium or severe misuses (Figure 15).

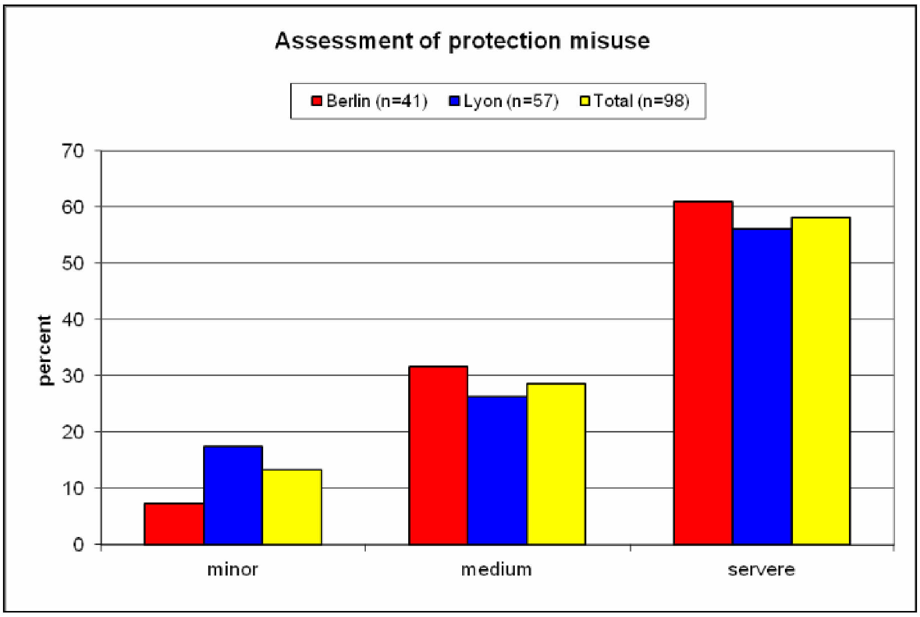


Figure 15: Assessment of the securing of children in CRS

In conclusion, the similarities between the results from the two samples outweigh the differences: misuse rates and severities were high in both studies, suggesting that an important effort is still needed to solve this issue. Most misuses related to the CRS installation could be addressed by the use of ISOFIX CRS but the ISOFIX usage rate was extremely small in the sample. However, ISOFIX fixation would not prevent misuses related to the securing of the child in the CRS, which is the most common type of misuse.

2.3 Sociological observations

In the CASPER project, one of the tasks is to provide a sociological overview to understand the safety practices concerning the child environment during car transportation. The main objective is to define the issues relating to child safety and to show the social factors which can affect the car transportation of children aged between 0 and 10 years in everyday life. Therefore a sociological research protocol was designed to investigate the way CRS are used and to understand parental attitudes, habits and behaviours but also to evaluate their safety knowledge and representation relating to children transportation in cars.

In order to collect data, a self-administrated questionnaire was sent to parents of children aged between 0 and 10 years and focus groups were conducted.

Furthermore, so as to evaluate the cultural disparities, the questionnaire was distributed to parents in France, Spain and Italy; n=252, n=176 and n=113 completed questionnaires were collected, respectively. In France focus groups were conducted and 25 parents participated to these groups. There were three conditions that the participants had to fulfil in order to complete the survey or to participate to the focus group: have a valid driving licence, own a car and have a child (children) aged between 0 to 10 years old.

The following results are based on the French study, since the data from the questionnaires and from the focus groups are currently available only for France.

2.3.1 The Sample

In France n=159 women (68.5%) and n=73 men (31.5%) responded to the questionnaires. Due to the fact that many participants had at least two children, the sample of children is larger than the sample of parents: it included n=221 boys (56%) and n=174 girls (44%) aged between 0 and 10 years old.

Concerning the Focus groups, n=12 women (48%) and n=13 (52%) men participated to these groups.

2.3.2 Children and the CRS

France adopted the European directive, but limiting the use of CRS to children under 1.35m. However the French traffic rules require to the driver travelling with children under 10 years to use a specific CRS.

As outlined earlier, the objective of this study is to examine the children safety situation in cars thanks to a comprehension of the driver's behaviour. Consequently, the main aim is to determine if children aged between 0 and 10 years of age were restrained appropriately (according to the participants' answers in the questionnaires and focus groups).

Weight distribution according to the age of children

In the questionnaires filled in by parents the total number of children aged between 0 and 10 years is 395, but the parents provided the weight for only 321 children.

The figure below shows the weight distribution according to children's age. There are some important disparities of weight according to the age. Between 0 and 9 months of age, new borns weigh up to 13 kg (40 % weigh between 9 and 13 kg and can legally travel in a forward-facing system). The disparities are also important amongst the ten year old children. In this study, their weights vary from 19 to 36 kg. In other words, a difference of 15 kg exists in the same age range.

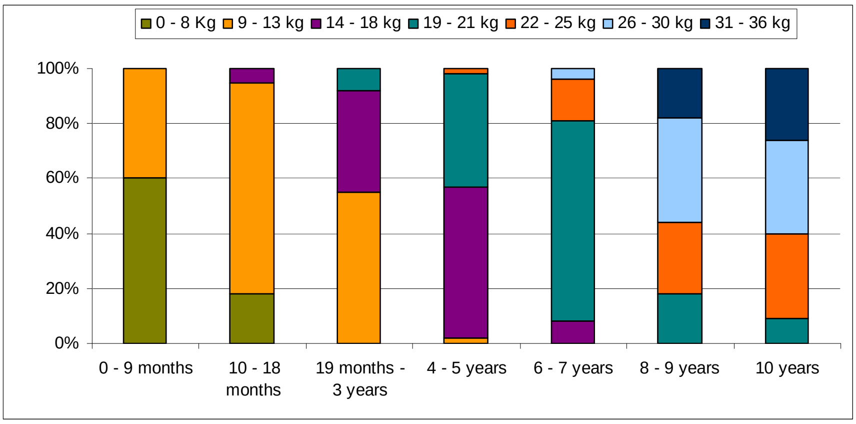


Figure 16: Weight distribution according to the age of children (%)

The use of CRS according to the weight

In the questionnaires, the participants are asked to provide the information on the restraint systems used for their children. Based on the weights and the restraint systems provided by them in the questionnaires (n=318 children), 27% of children were not appropriately restrained (inappropriate CRS selection). The following table shows the inappropriate selection of CRS according to the weight (in red).

According to the questionnaires, the first inappropriate selection of CRS concerns babies weighing between 0 and 8kg: 55% are in a rearward-facing position, as recommended by the legislation, but 45% of them are in a forward-facing position. The use of rearward-facing CRS sharply decreased with child's weight. Indeed, amongst 9 to 13 kg infants, 15% only are in a rearward-facing CRS. In the Focus groups, parents stated the difficulty to know when changing the baby from rearward-facing to forward-facing. They admitted that they do not know the legislation and the recommendation on this point.

Table 2: The inappropriate selection of CRS according to the weight (%)

	Carrycot 	Rearward facing infant carrier 	Forward facing system 	Child seat with shield 	Harness booster seat 	Booster seat with backrest 	Booster cushion 	3-point seatbelt 	2-point seatbelt 
0-8kg	0	55	45	0	0	0	0	0	0
9-13kg	0	15	56	2	20	2	5	0	0
14-18kg	0	0	8	2	18	39	30	3	0
19-21kg	0	0	1	1	7	49	30	12	0
22-25kg	0	0	0	0	0	0	100	0	0
26-30kg	0	0	0	0	0	19	57	24	0
31-36kg	0	0	0	0	0	8	42	44	6
> 37kg	0	0	0	0	0	5	50	45	0

The second inappropriate selection is related to booster cushions. 30% of children weighing between 14 and 18kg, 30% of children weighing between 19 and 21kg and 5% of children weighing between 9 and 13kg are restrained with booster cushion.
Thus n=45 out of n=318 children weighing between 9 and 21 kg are using booster cushion as restraint system. That is to say on a safety point of view a total of 14% of children could use a more appropriate restraint system a than booster cushion according to their weight.

The third inappropriate selection concerns the use of seatbelt only. We can notice that n=40 out of n=318 children weighing between 14 and 36 kg are using the seatbelt as the restraint system. Consequently, 12.5% of children are using the car belt as an inappropriate system according to their weight, although it is recognised that height considerations have an influence for these children as well.

2.3.3 Transportation

Concerning the transportation of children in cars, the first important point is about the change of car at the birth of one of the children. In the questionnaires, 41% of the participants reported that they changed the car with the arrival of one of their children, which is a high proportion. According to their views, the main reason to change the car is the lack of space in their old car (78% of answers). "Safety" is the second reason, but represents only 7.5%.
Although parents are aware of the aim and the important benefits provided by child restraint systems (to the question 'why they use a CRS', 66% of the participants gave the reason "Safety"), they do not associate the car to the topic "children safety". This observation could explain why they still do not know about or have ISOFIX Systems. According to the survey only 2% of the parents had ISOFIX and 60% of them did not know about ISOFIX. In the focus groups, only 8% of the participants responded that they knew about ISOFIX.

The second point is about the problems that the parents met when installing the CRS in the car or securing the child in the CRS.
Regarding mistakes that parents can make when installing the CRS, the response "No mistake" represented 46% of parents' answers in the questionnaire. A sizeable part of parents also did not know what mistake they could make in putting the restraint systems in the car (25%). In spite of these results, some parents admitted to making mistakes. Indeed, 28% of parents responded to making mistakes when they install the child restraint system. The main reason observed is the difficult way to route the seat belt through the correct path of the CRS. This problem was mentioned in the focus groups as the main disadvantage concerning CRS use. The systems which need to be fixed using the seat belt had the highest level of difficulty of use.
Regarding the installation of the children in the CRS, 34% of parents filled in the questionnaires that they make mistakes. The main mistake reported is the "Harness is not snug". 30% of them reported that they did not make any mistakes and 27% of them responded that they do not know if their children are well restrained.

To summarize the results of the questionnaires and the Focus groups according to the use of CRS, we can notice:

- Inappropriate CRS selection:
  - No use of rearward – facing system;
  - Inappropriate selection of booster cushion and seatbelt according to the weight on a safety point of view, even if some of them are legally in their rights.
- High proportion of parents changing the car in order to have more space at the arrival of a child.
- Parents have nearly no knowledge on ISOFIX.
- Parents face difficulties to install the CRS in the car and to restrain the child in the CRS.

3 Car-to-CRS interface

This part of the paper is based on car measurement data obtained while running CRS fitting tests in cars that were meant to be relevant for child seat manufacturers. Most of the cars provided ISOFIX anchorages and were selected from different model years. However, the majority can be bought as new cars.

The interface is partially regulated by ECE Reg. 14 and Reg. 16 for cars and ECE Reg. 44 for the CRS.

For the description of the car-to-CRS interface it is reasonable to distinguish between belted CRS, ISOFIX CRS and CRS that utilise both belt and ISOFIX at the same time. However, parts of the interface are of importance for all types of CRS. Following the focus of the new regulation, in the following information only the interface for ISOFIX CRS is summarised.

The geometry of car seats is crucial for CRS compatibility. Especially the angle between seat cushion and backrest is important for forward facing CRS with fixed backrest angle. In addition the cushion angle is important too. The latter one defines for example the backrest angle for rearfacing CRS which influences ergonomic issues of babyshells on the one hand and dummy readings according to ECE R44 and Euro NCAP on the other hand.

The angle of the seat cushion ranges from 1° to 29° with a mean value of 14°, see Figure 17. The differences between front passenger seats, rear outer seats and rear centre seats are minor with respect to the interval +/- σ.

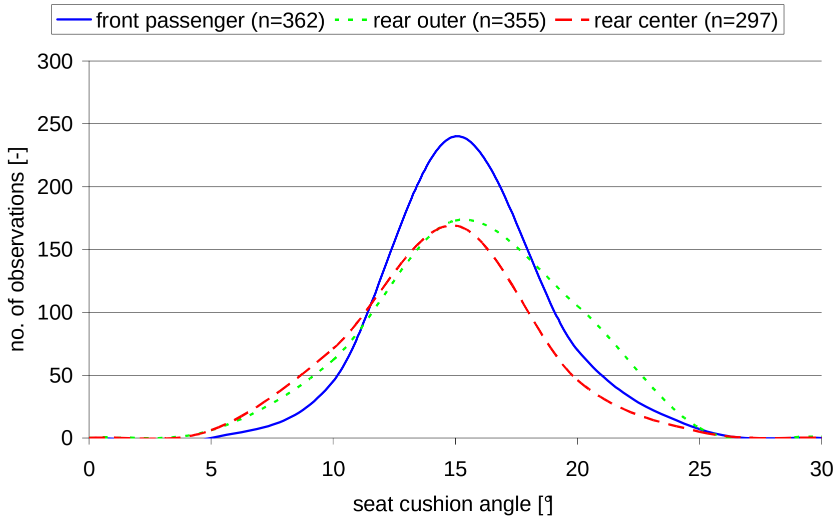


Figure 17: Seat cushion angle (angle between CR point and front edge of seat cushion) observed in today cars

As the backrest angle is normally adjustable for the front passenger seat, only rear seats were taken into account for analysing the angle between seat cushion and backrest. The angle between seat cushion and backrest varies between 83° (outer seat) and 115° (centre seat) with a mean value of 9 9° for the outer seats and 101° for the centre seats, see Figure 18.

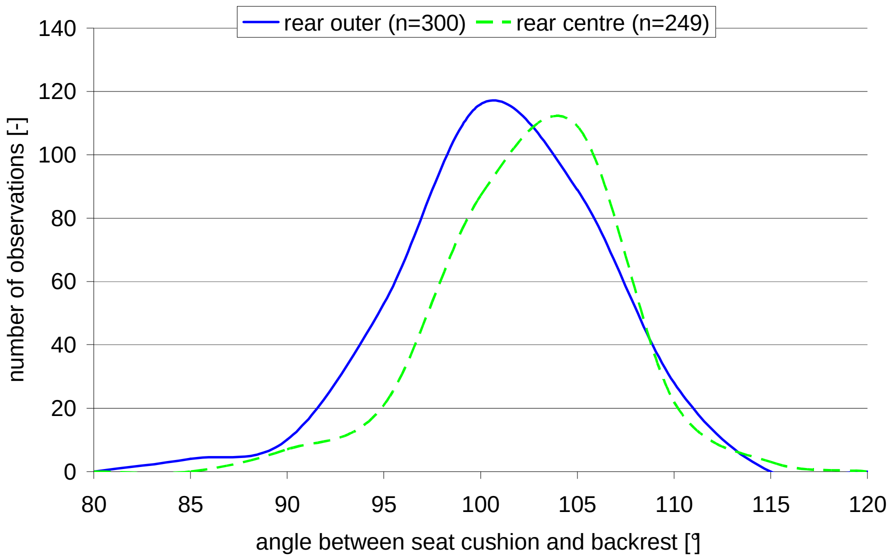


Figure 18: Angle between seat cushion and backrest in the second seating row.

3.1 ISOFIX CRS

According to the current ECE reg. 14 all cars, except those with only one seating row, convertibles and cars offering integrated CRS, need to be equipped with at least two seating positions with ISOFIX of which at least 2 needs to be equipped with TopTether. The first cars offering ISOFIX anchorages were on the market since the end of the 1990ies.

Following the selection criterion for the analysed cars, most of them offer at least one seating position with ISOFIX. Most of the ISOFIX positions are located in the rear outer seats, see Figure 19. In the rear outer position 72% of the analysed cars offer ISOFIX and TopTether, however, amongst these there are approx. 10 cars that do not allow universal ISOFIX CRS but only specific ISOFIX CRS with TopTether.

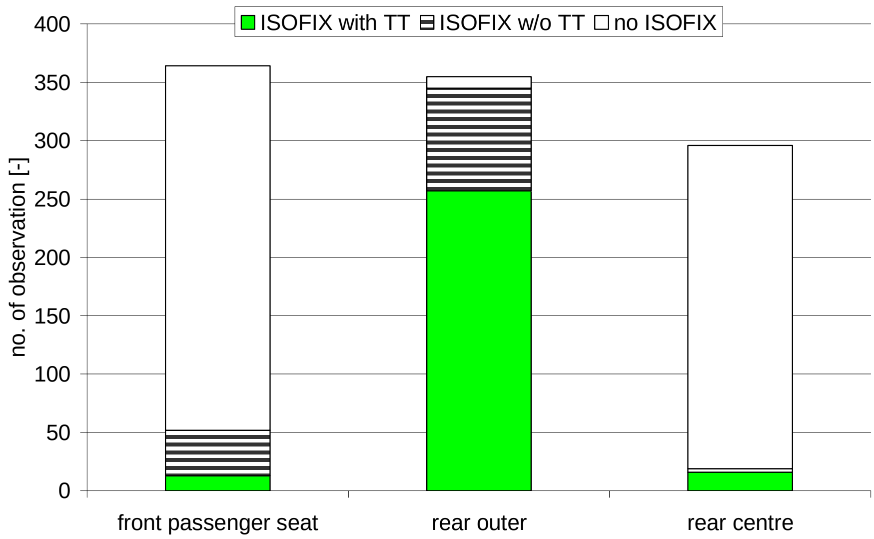


Figure 19: Availability of ISOFIX anchorages

For CRS with support leg, the distance between ISOFIX anchorages and the front end of the seat cushion and the necessary support leg length is also important. The seat cushion length varies between 350 mm and 590 mm in the rear outer positions, see Figure 20, and from 460 mm to 570 mm in the front passenger seat position. The mean values are 506 mm and 520 mm for the rear outer seats and the front passenger seat, respectively.

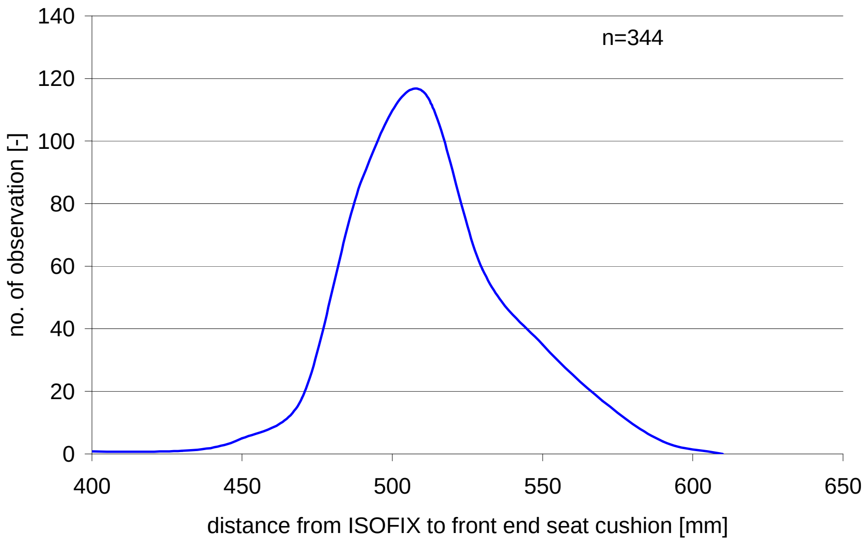


Figure 20: Assessed distance between ISOFIX anchorages and front end of the seat cushion

The distance of the floor as shown below is assessed perpendicular to a line between ISOFIX anchorages and front end of the seat cushion in a distance of 585 mm from ISOFIX anchorages. The distance varies in the front passenger seat from

260 mm to 425 mm and in the rear outer positions from 285 to 510 mm, see Figure 21.

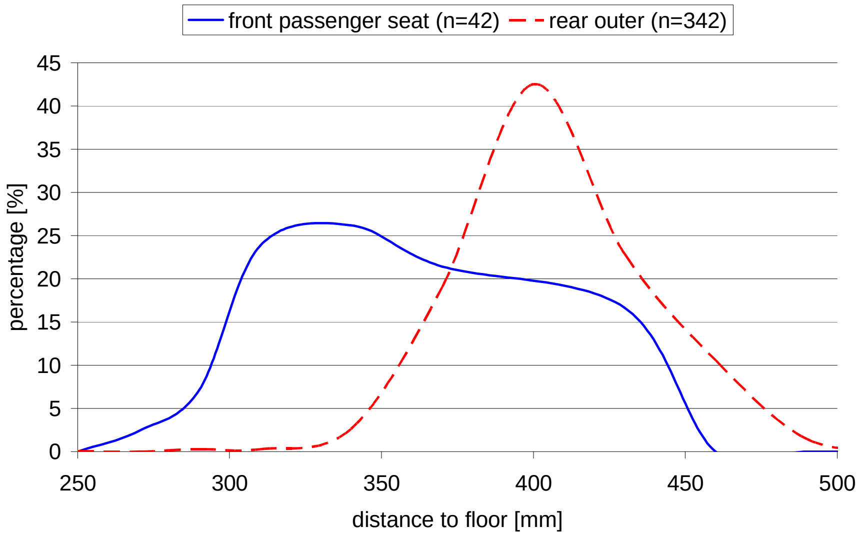


Figure 21: Assessed distance to floor

According to current ECE reg. 16, the car manufacturer needs to check the available space for rear facing ISOFIX CRS, lateral facing CRS and forward facing group I CRS with so called child restraint fixtures (CRF). In the manual the manufacturer shall provide the information regarding which of the fixtures are suitable in universal ISOFIX configuration (forward facing group I CRS with TopTether, size classes F2, F2X, F3 or B, B1, A respectively) and semi universal ISOFIX configuration, respectively. In case of suitability of semi-universal ISOFIX size classes, the manufacturer shall provide a list of corresponding recommended CRS of this group. The ISOFIX size class F2X (B1) is the one which is allowed in most of the cases. A quite high number of cars offering ISOFIX positions are not homologated according to the current ECE reg. 16 and the size classes are not specified, see Figure 22.

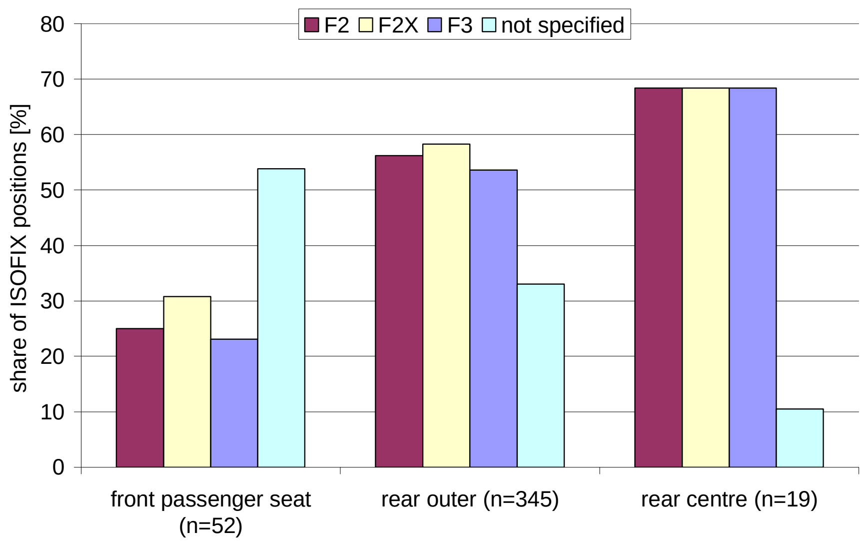


Figure 22: Suitability of universal ISOFIX size classes

In the semi-universal configuration the F2X size class is less often allowed than for universal ISOFIX CRS. In the rear outer positions the rear facing size classes are allowed in approx. 40% to 45% of the cars, see Figure 23. When ignoring those cars that do not allow any semi universal size class and without specification of the size, class R1 is accepted in 80% of the cars, R2 in 77% and R3 in 73% of the assessed cars in the rear seat. In the front seat, the numbers are 62% R1, 57% R2 and 43% R3, less than in the rear seat.

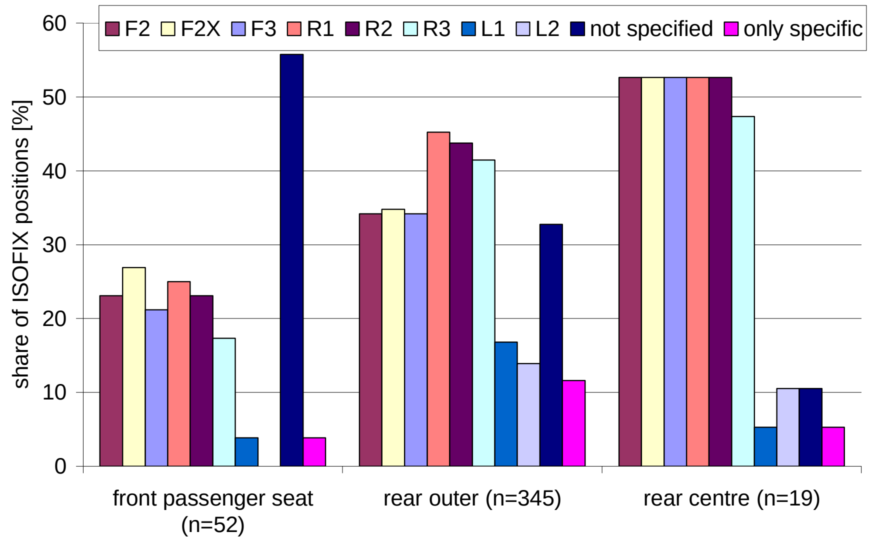


Figure 23: Suitability of universal ISOFIX size classes

In summary the largest FF size class (F3) is accepted in the rear seat in approx. 80% in the rear seat and 46% in the front seat. The largest RF size class (R3) is accepted in 40% in the front seats and 73% in the rear seats.

3.2 Booster type CRS with ISOFIX

For booster type CRS with ISOFIX two issues are known. The first one is that belt and ISOFIX anchorages in some cases cannot be used at the same time be used at the same time. The second one is interference with the car structure. The latter one cannot be addressed within this paper but activities of several groups are ongoing to define CRFs for this configuration.

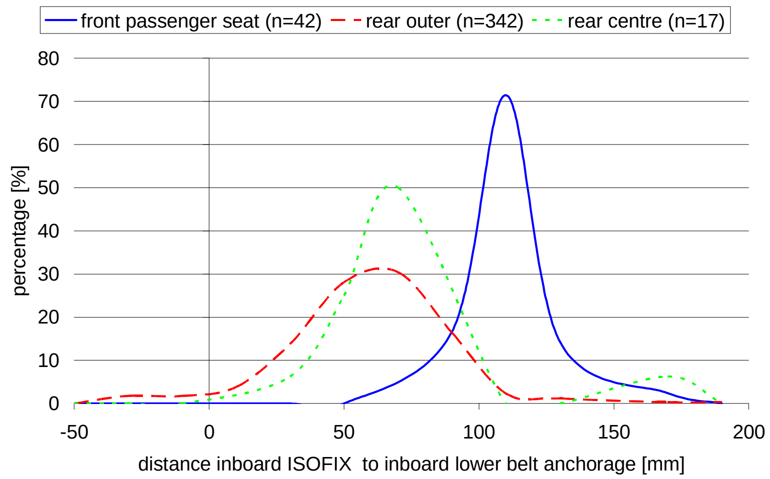


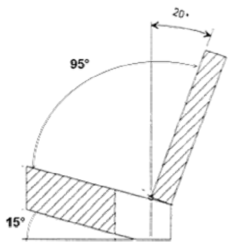
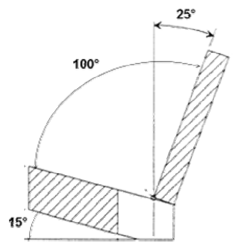
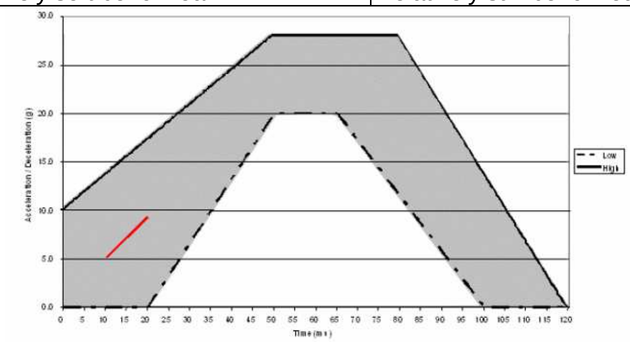
Figure 24: Assessed distance between inboard ISOFIX anchorage and inboard lower belt anchorage

In the front passenger seat the distance between the outboard ISOFIX anchorage and the buckle is at least 50 mm. In the rear seat the distance varies from -40 mm (ISOFIX anchorage is between the lower belt anchorages) to 190 mm. Actual problems were observed up to a distance between ISOFIX anchorages and buckle of 20 mm.

4 New regulation for homologation of CRS

Based on the initiative of France, GRSP started in 2008 an Informal Group on CRS in order to develop a new regulation that should replace ECE Reg. 44. This group has completed its phase I addressing ISOFIX integral CRS for universal use (comparable with current group 0, 0+ and I). Phase II focussing on booster CRS with ISOFIX has just started.

Table 3: Most important differences between ECE Reg. 44 and ECE Reg. 1XX

Item	ECE R44	ECE R1XX
CRS homologation types	Universal, semi-universal, restricted, vehicle specific	Universal (called i-size), vehicle specific
CRS classes	Fixed weight classes	CRS manufacturer defines the suitability of the product based on the child's stature
Requirements for CRS orientation	CRS classes 0 and 0+ may not be used FF	Children up to 15 months old may not be FF
Anti rotation device ISOFIX	TopTether universal for group I FF, TopTether for other CRS and support leg semi-universal	TopTether and support leg universal with special criteria for the support leg w.r.t. position in car X and Z orientation
Test bench	 relatively soft bench foam	 relatively stiff bench foam
Test procedure frontal impact	 generel test layout similar, differences exist w.r.t. test bench, dummies etc.	
Dummy criteria frontal impact	Head displacement < 550 mm (500 mm for ISOFIX, 600 mm RF), a3ms chest < 55 g; a3ms chest Z < 35 g	Head displacement < 500 mm (700 mm RF); HPC < 600 or 800; a3ms head < 75 g or 80 g; a3ms chest < 55 g
Test procedure rear impact	For RF CRS	For RF CRS test conditions comparable to R44 except test bench, dummies etc.
Test procedure roll over	Quasi static roll over along X and Y axis	Quasi static roll over along X and Y axis, comparable with ECE R44
Test procedure lateral impact	No test	Test procedure with flat door and linear intrusion
Child dummies	P dummies (P0, P3/4, P1.5, P3, P6, P10)	Q dummies (Q0, Q1, Q1.5, Q3, Q6, Q10 in preparation)
Geometric requirements for space for the child (internal dimensions)	P dummies	Geometrical checks taking into account 5th percentile and 95th percentile of seating height, shoulder height, shoulder width, pelvis width
Geometric requirements external dimensions	For ISOFIX CRS different CRF (F1, F2, F2X, R1, R2, R3, L1, L2)	Universal maximum F2x (B1) or R2 (D)
Chest clip	Not allowed	Not forbidden

The most important differences between ECE Reg. 44 and the new regulation (in the following also called Reg. 1XX) are summarised in Table 3.

The draft proposal of the new regulation does not only address items for CRS but requires also modifications for the car homologation according to ECE Reg. 14 and Reg. 16.

5 Estimation of safety benefits

5.1 Mandatory ISOFIX use for integral harness CRS

The new regulation requires installation of CRS by ISOFIX only for CRS of the integral harness group. The mandatory use of ISOFIX addresses part of the identified misuse (CRS installation misuse). Following that it is expected that the new regulation will improve the quality of restraining children in cars and thus improving safety.

5.2 CRS orientation

The area of main focus for CRS orientation is the change from rearward facing CRS to forward facing and specifically when this occurs.

Parent/Carer habits Anecdotally parents and carers often appear eager to move their children into forward facing CRS as soon as possible, citing the lower 9kg limit of the 9kg to 18kg Group (I) as a target rather than the upper 13kg limit of the Group 0+ seat they are already using. Supporting this, the results from the questionnaires (section 2.3.2) show that 45% of the children in the weight band of 0-8kg, in the response group, are already forward facing. Then in the 9-13kg group only 15% are rearward facing. Regarding road accidents, at least 30% of the restrained children in their first year in the CHILD road accident database (D12A: Overview of the CHILD Accident Database and Analysis, 2006, EC CHILD Project) are forward facing. This dataset is not representative of the overall crash population due to serious injury sampling (although slight injuries in high crash severity are included) but it is another indication that early transfer to forward facing does occur before age 1, or rather it is likely to be early with reference to the upper 13kg limit of group 0+.

Anatomical aspects Away from legislation and field data results it is important to examine just why it is a sound concept for young children to be travelling rearward facing, in particular when involved in frontal collisions. The head of a new born is 10-15% of its body weight, whereas for an adult it is 2-3%, so proportionally much heavier [Case, 2003]. The fontanelles of the skull are soft in young children (closing over from approximately 18 months to 2 years of age due to ossification) and the sutures take further time to close into adulthood. For a baby, the neck vertebrae are separate portions of bone joined by cartilage. During the first years of the child's life this cartilage turns into bone, with development continuing to puberty. The muscles and ligaments also develop during this time whilst the vertebrae develop a saddle shape rather than the flat shape of early childhood. Extra flexibility in the child's spine leads to an increased possibility of damage to the spinal cord [Volvo, 2004]. The process of bone development in the cervical spine is not uniform all along the cervical vertebras, important to consider in the development of CRS in order to limit the loads that are applied on the neck until the vertebras are solid enough to prevent the cervical spine from being damaged [Yoganandan, 2011].

This leads to a proportionally large head, with a skull that is still developing in strength, supported by a soft, flexible neck that is still developing in strength. It is therefore advantageous to support both the head and torso to reduce load on the neck, using a rearward facing shell system. This arrange also provides greater protection against head contact for a still developing and also thinner (than an adult) skull, whilst general spreading crash forces over as large an area as possible. Compared to forward facing with a harness in a frontal collision, this distribution of loading also benefits the protection of the undeveloped pelvis and the abdominal organs.

Safety risks from early change An early change increases the possibility of the anatomical aspects above leading to injury, particularly in frontal impacts, whilst the physically smaller body of the child can increase the possibility of the shoulders escaping the harness straps. It is therefore important to encourage parents to keep children rearward facing as long as practically possible.

Recommended age for change In the proposed new regulation, with the use of a '0-15 M' label indicating only rearward facing and not forward facing installation and "IMPORTANT - DO NOT USE FORWARD FACING BEFORE THE CHILD'S AGE EXCEEDS 15 months (Refer to instructions)" for forward facing CRS the message to parents and carers is clear that the criteria for change is 15 months.

In R44, whilst Group 0+ is 0-13kg, the Group 1 lower limit of 9kg indicates a lower criterion for change. According to UK-WHO growth charts (www.rcpch.ac.uk/child-health/research-projects/uk-who-growth-charts/uk-who-growth-charts) at the 50th centile, 9kg equates to 12 months for girls and just under 10 months for boys. At 15 months, between 50% and 75% (nearer the 25th centile) of girls are already 9kg and approximately 91% of boys (these are the nearest centile lines on the charts). If parents are currently changing at 9kg the new regulation would give a greater length of time rearward facing for the majority, compared to R44. Conversely, at the 50th centile, 13kg equates to just under 32 months for girls and just under 29 months for boys. At 15 months, between 98 to 99.6% of girls are below 13kg, the same for boys. If parents are currently observing the upper 13kg limit of Group 0+ the new regulation would promote change too early, compared to R44 limits. Although, in reality, the child's head starting to extend above the restraint is currently often the real upper limit rather than 13kg.

Overall, 15 months equates to around 9.5kg at the 50th centile for girls and around 10.3kg for boys. In terms of child weight it could therefore be said that the new regulation is not moving the situation forward a large amount but using age instead of weight does offer practical advantages, that could be large. Parents and carers know the child's age, whilst weight is sometimes not known as the child moves away from being medically seen so often, or can easily be measured incorrectly at home. Also, although proof would still be required, enforcement should be easier by age rather than weight. In the same way, peer pressure may also play more of a part as age of a child will be more transparent to friends and family than weight.

Using the UK-WHO data, the 98th centile line for 15 month old girls falls at 83cm length, between 98th and 91st for boys. The new regulation states that the rearward facing CRS must accommodate at least a child with a stature of 83 cm, so it appears that at 15 months fit should not be a problem for the majority of children, according to this height dataset. A child's height is usually slightly less than their length.

Accident database An analysis of the CREST and CHILD road accident database was performed at the beginning of the CASPER project in order to make a recommendation of the age to switch children from rearward to forward facing, based on in depth investigations of restrained children. This database is not statistically representative of the real word but only of more severe accidents with restrained children in cars. It contains then a higher proportion of injured children because its first aim is to characterize injury mechanism and to produce a sufficient number of cases that physical reconstructions in crash test laboratories can lead to the construction of injury criteria that can be used to prevent such injuries on correctly restrained children.

In case of a head contact, the loads applied onto the cervical spine are different to non contact, with different injury mechanisms. In the database sample, it has been necessary to determine case by case the presence or not of a head contact. In some cases it is indicated by the accident investigator or because of the presence of a contact injury to the face or to the head, but in some other cases, nothing indicates if the child had a contact with a part of his body or with the car interior. Considering these last cases, only one accident with severe neck injury has been observed for a child older than 15 months of age (for an 18 month-old child). A lower limit of 15 months to install children forward-facing seems to properly cover the majority of the cases that are known for the moment. In addition, the new regulation does not forbid designing systems that can be used rearward facing for a longer time than 15 months.

5.3 Support leg as universal anti-rotation device

Currently (within ECE R44) CRS with support legs are considered as semi-universal child restraint systems. Following that the CRS manufacturer needs to check the fitting of the CRS in cars and provide a list of suitable cars.

Car fitting testing experience shows that support leg specific problems mainly occur in the rear centre seat, where the support leg is often too long and seldom because the support leg is to long in other seats or because the support leg is too short. Also seldom observations show interference problems with structures below the seat cushion. Another issue are storage boxes below the support leg.

With the new regulation and corresponding modifications of ECE regulations 14 and 16 good experience with support legs will be standardised and following that in principle further improved, defining criteria for the support leg geometry and the car floor resistance and geometry, and improved compatibility between CRS and car. However, the proposed dimensions for the support leg in X and Z direction seem not to be the best compromise. While important interference between support leg and seat cushion was never observed with CRS that have a too short distance between ISOFIX connectors and support leg (with respect to the proposal of the new regulation), interference with the front seat were reported. By defining a support leg position in X direction taking into account the largest distance observed in cars there is a considerable risk that increased problems of interference with the front seats will occur.

Past experience concerning CRS use showed that the TopTether is often not used in the field. In addition a large number of cars that are equipped with ISOFIX do not offer TopTether anchorages. This result also supports attempts to make support leg CRS universal.

5.4 Test bench

The seat cushion angle and angle between seat cushion and back rest comply better with average car design than the ECE R44 test bench.

However, testing experience shows that it is possible to secure child dummies without CRS at the test bench without any indication of abdominal loading in the dummy. This behaviour is likely to be caused by the seat cushion angle, which causes additional pelvis restraint leading to reduced submarining risk. The dummy response may however also play a role.

For taking into account the worst case for booster type CRS (Phase 2) it makes sense to consider a more horizontal seat cushion design in order to emphasis abdominal protection for this type of CRS.

5.5 Dummies

Before the start of the CREST project P-dummies were used to homologate CRSs. These dummies were developed in the 1970s to act as loading devices with appropriate dimensions and mass distribution but with limited measurement capability. At the beginning of the CREST program in 1996, these tools were not satisfactory for research purposes and were limited to reach some of the objectives, such as the replication of injury mechanisms and the definition of child tolerance limits. One of the first tasks in this first European collaborative project was to collect anthropometric data and to modify the P dummies, to make them closer to what seemed at this time the correct body segments to be protected. So dummies up to 3 years were equipped with neck load sensors and the foam of the thighs was modified to make them softer for dummies of 3, 6 and 10 years old. These three dummies also received a plate made of metal that was installed to measure the forces that are applied on the abdomen of the dummies during tests. Some reconstruction tests were performed but the global kinematics of the modified P dummies was still not sufficiently satisfactory. That is why CREST started developing the new Q-dummies. They were developed to have more human like behaviour in CRS impact tests with regards to anthropometry, kinematics and biomechanics and facilitate injury risk assessment in critical body parts. The new dummies should also offer the possibility to use them as a multi-directional tool. The Q3 was developed first and it has been used in many tests (reconstruction and sled tests). When the prototype of the Q3 has been validated, the CREST partners agreed on the development of the Q6 and of a Q1, in order not to focus only on one age. Once the 3 dummies were developed, CREST partners were overall satisfied with them as the new dummies showed a significant improvement in comparison with the existing P-dummies. However, some concerns were expressed about the belt interaction of the Q dummies, both at the pelvis and the shoulder level. After taking into account these concerns and producing a new design for the pelvis area, it was concluded that the Q-dummies now show a more realistic submarining behaviour. At the end of CREST several issues were not addressed and left for further studies: The number of data points for neck or chest injury criteria and limits was not sufficient, nothing was available on these dummies to assess abdominal tolerances, and the submarining behaviour was still questioned. In addition, very few accident cases had been reconstructed at that time in lateral impacts, so no injury criteria for side impact was available for any of the body segments. Another European collaborative project was then born: CHILD (Child

Injury Led Design). Its objectives were similar to the ones of CREST but with an overall larger scope. Concerning the Q dummies, a lot of work was conducted in this new program. A Q0 was developed and different kind of sensors to predict injury criteria were created and tested but remained at the stage of prototypes usable as research tools. Additional accident reconstructions were performed both in frontal and side impact and some injury criteria were proposed for the head. Indications for other body segments were given but still with works to be conducted to achieve the construction of injury risk curves.

Q dummies were originally designed to be omni-directional (for frontal impact, lateral impact and rear impact). While improving the Q dummy reliability, focus was put on frontal impact. Following that the biofidelity performance in frontal impact is better than in the other impact directions.

Regarding the anthropometry of the Q dummies a database (CANDAT) containing external dimensions of children of different regions of the world was used. The dummy dimensions were selected to provide appropriate upper and lower limits of the ECE R44 CRS weight groups based on the CANDAT database. While the P dummy family consists of P0, P3/4, P1.5 (which was developed after starting of ECE R44 in order to cope with the new ECE R44 weight group 0+), P3, P6 and P10 the commercially available Q dummy family consists of Q0, Q1 (in contrast to P3/4), Q1.5, Q3 and Q6. That means that a substitute of the P10 is currently missing. However, within the EPOCh project, running in parallel to the CASPER project, a Q10 was developed which is expected to be commercially available soon.

According to ECE Regulation 44 only chest accelerometers are used with P dummies. However, they also can assess head acceleration and neck loads. However, after the testing programme Euro NCAP decided while introducing the child safety protocol to use head and chest acceleration in Z direction as an indicator for neck injury risks after observing repeatability and reproducibility problems with the neck load cells in P dummies. Q dummies can be equipped with more sensors. Table 4 shows a comparison of the possible instrumentation of P and Q dummies.

Table 4: Possible instrumentation per Q / P – dummy [Wismans, 2008]

Instrumentation		**Dummies**					
Sensor	Region	Q0	P0	Q1 / Q1½	P1½	Q3 / Q6	P3 / P6
3-axis accelerometers	Head	✔		✔	✔	✔	✔
	Thorax	✔		✔	✔	✔	✔
	Pelvis	✔		✔	✔	✔	
6-axis load cell	Upper neck	✔		✔	✔	✔	✔
	Lower neck				✔	✔	
	Lumbar spine			✔	✔	✔	
3-axis angular rate sensor	Head			✔		✔	
Displacement sensor	Chest			✔	✔	✔	

The Q-dummy series have been primarily designed for frontal UNECE R44 and future side impact testing. EEVC stated that the new Q-dummy family showed significant improvement in comparison with the P-dummy family in frontal impact tests. The Q-dummies (excluding the Q10 which is being developed by EPOCh) are well adapted to the recent child anthropometry data and their performance complies with the most up to date biofidelity requirements. However, it must be mentioned that the thoracic response is still stiffer than the biofidelity requirement [Wismans, 2008] and that some biofidelity requirements still seem lacking (e.g. lumbar spine stiffness). The dummies also showed good repeatability, reproducibility and durability in severe repeated sled tests [Wismans, 2008].

EEVC recommended that the P-dummies are replaced by the Q-dummies in tests, following the UNECE R44 procedure. They also recommended improving the criteria by adding 4 new injury criteria: HIC, Upper Neck tension (Fz), Upper Neck bending moment (My) and Chest deflection. For the Injury Assessment Reference Values (IARVs) it is recommended to apply set base on AIS3+ 50% injury risk. When applying only ECE R44 criteria, Q dummies provide equivalent results that P dummies [Wismans, 2008].

In total the Q dummies fit better to child anthropometry than P dummies, are more biofidelic than P dummies and offer better instrumentation. Using the Q-dummies in the new regulation is estimated to be a substantial benefit for child safety.

One weak point of Q dummies is the missing capability to detect abdominal injury risks. While a very simple approach was used in P dummies to indicate submarining risk by deformed clay between abdominal insert and lumbar spine, no commercial solution for the assessment of abdominal injury risks in Q dummies is available now. It needs to be stated that the P dummy solution using the clay is far from being perfect. However, within CREST, CHILD and CASPER projects the assessment of abdominal injury risks was investigated. While in the CHILD project, two promising sensor prototypes were developed the CASPER team decided to concentrate on the so called APTS (abdominal pressure twin sensor) that assesses the abdominal pressure. During the course of the project it was possible to address the remaining problems and to develop a prototype that is ready for regular use. Validation of the sensor is still ongoing but it is anticipated that it will be finalised within the next 6 months, so in time to be considered in phase 2. Proposals to use lumbar spine loads or chest compression as indicators for abdominal injury risks seem not to acceptable [Johannsen, 2006].

Another problem is the dummy design in the pelvis area that makes submarining nearly impossible, thus masking abdominal injury risk assessment even with sensors. During the CASPER project and partially with cooperation with the EPOCh project possibilities to address this problem were developed and analysed. Finally a reinforcement of the dummy suit was considered to be the best compromise. This solution was tested at different labs and considered to be effective. However, it is unclear if this solution will be sufficient to obtain an appropriate submarining response for the dummy in all relevant circumstances.

5.6 Frontal impact pulse

During the EC research projects CREST, CHILD and CASPER, frontal accident reconstructions were performed in order to reproduce the injury mechanisms observed in real cases and to get measurement on dummies that can be linked with the injuries observed on children. The pulses from reconstructions are visible on Figure 25. A corridor for frontal impact was proposed in the CREST project and it was kept in CHILD for research purposes [Visvikis, 2006]. It corresponds to the level for which it is necessary to go to find injured restrained children (with and without misuse) in the CRS approved according to the current regulation. The pulse of this corridor corresponds to the most severe frontal accidents that have been observed and does not correspond to an average of the pulses of a large majority of accidents. It cannot therefore be used for regulation purpose because it is better that CRS are designed to protect occupants across a wider range of severities than those observed in just a severe accident population. Otherwise CRS could be designed to a point that they become potentially large, heavy and more expensive, and possibly too stiff at the lower crash severities. The pulse proposed in CREST and CHILD is useful for research works to perform parametric tests on CRS or once a CRS is designed to see how far it can protect children from getting injured.

The following Figure 25 shows a comparison of the R44/proposed frontal impact corridor with the body acceleration measured in CHILD and CASPER accident reconstruction tests with new cars (i.e. cars that meet ECE reg. 94 requirements). This comparison indicates that the pulse in the new regulation is lower than in the reconstructions. While the increase and decline of the new regulation pulse seems to fit well with the assessed pulses the maximum acceleration level is lower in the sled tests (regulation pulse). However, it needs to be considered that the reinforcement of anchorages and the test bench, as undertaken for sled testing, increases the severity for a given pulse. In addition it is important to consider that the accidents that are reconstructed are of high severity level and are not representative. It is useful though to make this comparison as it gives an indication of where the new regulation pulse lies compared to the generally severe pulses of the reconstructed accidents.

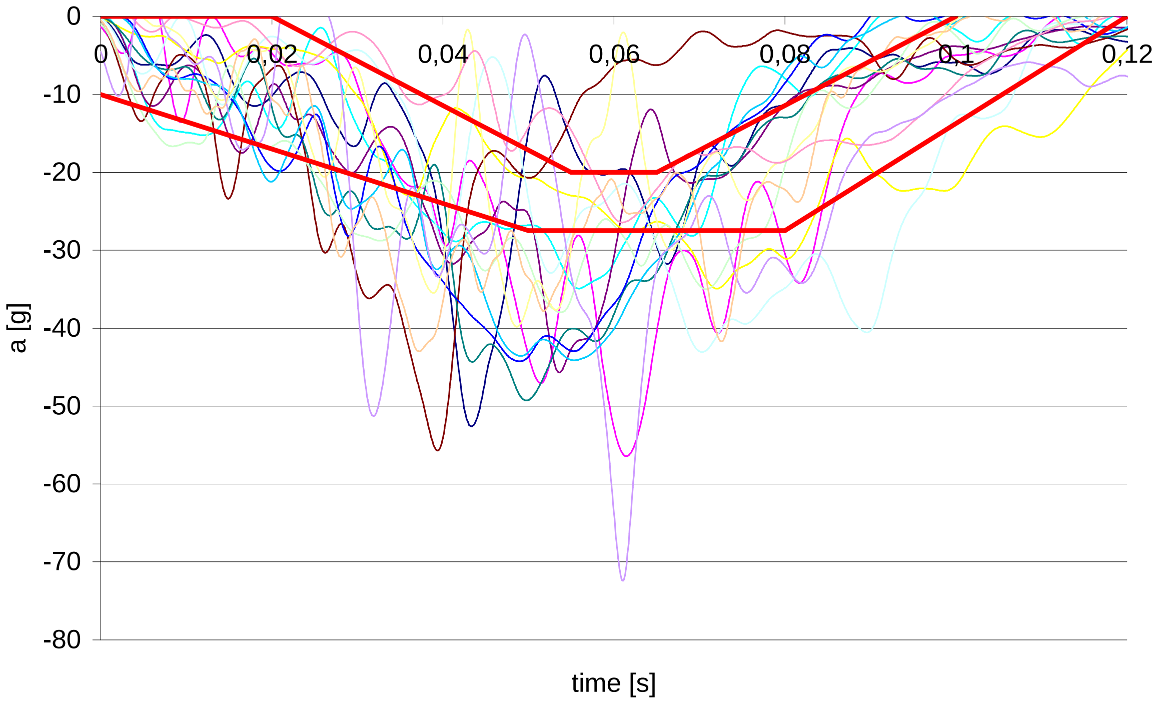


Figure 25: Comparison of body acceleration assessed in CASPER and CHILD accident reconstruction with cars being compliant with ECE Reg 94 and ECE reg. 44 frontal impact corridor

It should be born in mind that some of the severe accidents reconstructed also contain some understood misuse that has contributed to injury severity. Also, results from the GIDAS and CASIMIR accident data (Chapter 2) show high levels of non use and misuse in frontal impact analysis. Following the discussion in Chapter 2.1, children are generally safe in cars (frontal impacts) except for very severe accidents and incorrect restraint conditions

It is considered that taking these issues into account the proposed pulse should give satisfying results in terms of protection from CRS across an appropriate range of crash severities, for well restrained occupants.

5.7 Lateral impact test procedure

Worldwide, although lateral impact injury risks are considerably high, compulsory requirements for the lateral impact performance of CRS only exist in Australia and New Zealand.

The test procedure is based on key parameters to be considered for lateral impact tests for CRS as defined by ISO WG1 (Child Safety). These are reproduction of lateral acceleration and lateral intrusion amongst others. In addition, ISO PAS 13396 [ISO 2009] recommended the head as the first priority body region to be protected and emphasised that for head protection testing of body kinematics and CRS energy management capabilities are important.

The dedicated designed GRSP lateral impact test procedure is capable of improving lateral impact protection in CRS, even those which are designed to meet consumer testing lateral impact requirements. The main challenge is to maintain the head of the largest dummy of individual CRS within the protective zone of the CRS (head containment) and to reduce dummy readings for the smallest dummy. By demanding both performance criteria (head containment and head loading limits) with a range of child dummy sizes, most of the CRS tested by CASPER partners will not meet the requirements.

Tests in different laboratories show good repeatability and reproducibility using acceleration and deceleration sled systems.

Despite the development of side impact dummy versions of Q3 and Q6 (Q3s and Q6s), GRSP decided to use standard Q dummies also in lateral impact conditions. The CASPER team has no experience with the side impact versions of the dummies. Following that no recommendation can be given.

In summary, lateral impact protection capabilities of CRS need to be improved according to the accident data in section 2.1. The proposed test procedure reproduces the main contributing factors for child injuries in lateral impact such as intrusion loading and acceleration loading as well as the assessment of the whole body kinematics and the energy absorption capabilities of a CRS. It is estimated that introducing the proposed side impact test procedure will result in significant benefit for child safety.

For phase 2 of the new regulation it is important to discuss whether or not side impact protection of the CRS is important for all CRS sizes or if a sufficient protection of the car can be expected for children exceeding a specific size. However, no recommendation is possible based on currently available CASPER data.

5.8 Dummy criteria

For children using CRS with integral harness head and neck are the body regions with the largest risk for severe injuries. For children using booster type CRS, abdominal injuries are becoming as important as head injuries while neck injuries are rarely observed. Chest injuries are more important for children using booster type CRS than for children in CRS with integral harness system but they are of less importance than head injuries even in the booster type CRS (D12A: Overview of the CHILD Accident Database and Analysis, 2006, EC CHILD Project). For the youngest children when excessive compression of the chest occurs it leads to internal organ injury while after 6 to 10 years of age ribs fractures become more frequent and can be sometimes linked with internal organs injuries.

The new regulation currently addresses head injuries by head a_{3ms} limits for frontal and lateral impacts, HIC for frontal impact with hard head contact, head excursion for frontal impact and head containment for frontal and lateral impact. Furthermore the resultant chest acceleration limit as included in ECE R44.

The neck limits as proposed by EEVC [Wismans, 2008] are derived from scaling from adult dummies and do not comply with the test experience gained with Q dummies. Following that currently no neck criteria are used in the new regulation. This important shortcoming is addressed by the CASPER project that aims at defining injury risk functions for the neck focussing on children up to 3 years old.

Equivalent to missing neck limits for integral harness, CRS abdominal performance criteria for booster type CRS are missing too. Again CASPER has been studying more closely the injury pattern for this body region and is now focussing on delivery of injury risk functions for the abdomen suitable for the sensor already mentioned above.

5.9 Geometrical requirements child fit

According to the results from sociological questionnaires and the focus groups, parents change the CRS for their children to the next bigger size group if they have the impression that the CRS is too small for the child or the child complains that the CRS is too tight. By defining minimum requirements for the internal dimensions of CRS taking into account the 95%ile it is expected that parents will feel more comfortable to use CRS longer. Accidents studies showed that early change of CRS type reduces the safety level for children (e.g., [Jakobsson, 2004]).

5.10 Geometrical requirements car fit

Current ECE regulation 16 requires car manufacturer to provide ISOFIX seating positions suitable for at least F2X ISOFIX CRS. However, often F2X is allowed only for universal ISOFIX CRS.

The new proposal for the amendment of ECE R16 to comply with the new regulation requires to offer space for R2 and F2X envelopes. As today a quite large number of cars do not accept R2 ISOFIX CRS this amendment is considered as a big step towards improved compatibility between cars and CRS.

It is important to note that no envelope for booster type CRS with ISOFIX exists, that is crucial for phase 2. ISO WG1 is currently working on new envelopes to address this issue.

6 Recommendations for Phase II

The recommendations are summarised below, addressing firstly issues to be considered for integral harness systems and secondly for booster type CRS.

6.1 Integral harness systems

The geometric support leg requirements proposed in the current draft ECE R1XX are likely to cause problems with the front seats in small cars. A review taking the front seats into account is recommended.

Neck injury criteria and corresponding load limits are crucial for the protection of the smallest children. It is likely that the CASPER project will deliver useful injury risk functions by the end of the project.

While chest injury criteria are mainly needed for older children, i.e., those using booster type CRS, chest injury risk should not be neglected for children using integral harness systems. However, it is unclear whether or not the CASPER project is able to provide data.

6.2 Booster type CRS

For children using booster type CRS appropriate protection of the abdomen is crucial. In order to address this protection, the following issues need to be considered:

- Review of the test bench geometry
- Dummy modification to enable submarining
- Abdominal sensors
- Abdominal injury risk functions

The current seat cushion angle does correspond to an average geometry but it seems to be more important to consider a worst case geometry, as seen in MPVs, for example. A flatter seat cushion would require better protection from submarining compared to the current test bench.

Furthermore Q dummy design also effectively prevents the dummy from submarining. Based on current knowledge the reinforcement of the suit as proposed by the CASPER and EPOCh projects seems to be adequate to address this item.

The abdominal APTS sensor as proposed by the CASPER project is expected to be a reliable tool for the assessment of abdominal injury risks as soon as test bench design and dummy design allow replication of submarining. Abdominal injury risk functions are also expected as a CASPER deliverable.

As already mentioned in Section 6.1, appropriate chest injury criteria and load limits are also important for improving child safety especially for children using booster type CRS. However, it is unclear whether or not the CASPER project is able to provide data.

Furthermore it is important to develop ISOFIX envelopes for booster type CRS as currently done by ISO.

Finally it seems to be important to analyse whether or not CRS need to protect children of all sizes for lateral impact or if sufficient side impact protection can be expected from the car as soon as children exceeding a certain stature. For adult safety it is expected that cars can protect at least from 5th percentile female upwards. Children with a stature of 150 cm when sitting on a booster are exceeding the size of a 5th percentile.

For both types of CRS, any relevant new data or information that arrives regarding the frontal impact pulse should be reviewed and considered, to keep the regulation as relevant as possible.

7 Conclusion

This new regulation is going to improve the compatibility between CRS and cars, to use test configurations that are more realistic in terms of geometry, and to cover a larger range of impacts. The tools used to assess the CRS performance and the associated tolerance limits, will ensure a better level of protection to children. This new regulation is based on field studies, accident data and the latest results of European research projects. The increase of correct use of restraint systems by children will improve the situation in frontal impact, rear impact and roll-overs. The introduction of a dynamic side impact test in the regulation will allow the coverage of most of the accident situations in which children can be still severely injured. The promotion of ISOFIX systems will lead to better installation of CRS in cars, in addition parents are asking for systems that are simpler to install. Systems developed according to this new regulation will have to clearly indicate how to use the CRS and provide them better information on the right time to switch for the next system (clear range of use).

Information campaigns are needed in order that parents do not misunderstand the reason and the benefits of this new regulation. In addition, a new European regulation is a good opportunity to promote a European safety culture that would decrease the number of incorrectly restrained children due to regional and cultural habits.

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UK Loughborough cases, collected during the EC CREST/CHILD projects, include accident data from the United Kingdom Co-operative Crash Injury Study, collected up to 2006. CCIS was managed by TRL Ltd on behalf of the Department for Transport (Transport Technology and Standards Division) who funded the project with Autoliv, Ford Motor Company, Nissan Motor Europe and Toyota Motor Europe. The data were collected by teams from the Birmingham Automotive Safety Centre of the

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Data on the CRS-to-car interface was provided by CSC Car Safety Consulting UG in Berlin based on car assessment of current cars and old cars, mainly offering ISOFIX.

9 References

Case M.E.S.: Chapter 9, "Central Nervous System" in Nelson, J.E.: "Principles and Practice of Neuropathology", second edition 2003

CASPER project website www.casper-project.eu

D09: CHILD project Deliverable – Deliverable 09 Annex 5: Incorrect Use of Child Restrants in France (Alonzo & al.)

D12A: Overview of the CHILD Accident Database and Analysis, 2006, EC CHILD Project

Fastenmeier, W.; Lehning, U.: „Fehlerhafte Nutzung von Kinderschutzsystemen in Pkw"; (in German); Berichte der Bundesanstalt für Straßenwesen, Heft M178 Bremerhaven: Wirtschaftsverlag NW, 2006

ISO: "Publicly Available Specification ISO/PAS 13396 – Road Vehicles – Sled Test Method to Enable the Evaluation of Side Impact Protection of Child Restraint Systems – Essential Parameters, 2009

Jakobsson, L.; Isaksson-Hellman, I: "Volvo Research: Safety for the Growing Child", Conference Protection of Children in Cars, Cologne, 2004

Johannsen, H.: „The Assessment of Abdominal Injury Risks by Dummy Tests", Fortschritt-Bericht VDI, Reihe 12, Nr. 631, Düsseldorf 2006

Johannsen, H.; Bendjellal, F.; Renaudin, F.; Claeson, P.: "UPDATE ON LATERAL IMPACT TEST PROCEDURE FOR CHILD RESTRAINT SYSTEMS", Paper Number 11-0291, ESV Conference, June 2011
(http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000291.pdf)

Kirk, A.; Lesire, P.; Schick, S.: "Child car passenger fatalities – European figures and in-depth study – EC CASPER project"; 9th International Conference Protection of Cildren in Cars, Munich 2011

Volvo: "A Safety Manual – Children in Cars", http://www.carseat.se/images/volvo.pdf, 2004

Visvikis, D. 'WP3 – Proposed Front Impact Test Pulse', EC CHILD Project Dissemination Workshop, 30-31 May 2006
www.casper-project.eu/child%20web%20site/PDFs/35%20%20Proposed%20Front%20Impact%20Test%20Pulse.pdf

Wismans, J.; Waagmeester, K.; Le Claire, M.; Hynd, D.; de Jager, Kate; Palisson, A.; van Ratingen, M.; Trosseille, X: "Q-Dummies Report – Advanced Child Dummies and Injury Criteria for Frontal Impact", EEVC Report 514, 2008

Yoganandan, N.; Pintar, F.A.; Lew, S.M.; Rao, R.D.; Rangarajan, N.: "Quantitative Analyses of Pediatric Cervical Spine Ossification Patterns Using Computed Tomography", AAAM 2011