SAFETY BENEFITS OF THE NEW ECE REGULATION FOR THE HOMOLOGATION OF CRS - AN ESTIMATION BY THE EC CASPER PROJECT CONSORTIUM

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ABSTRACT

The GRSP informal group on child restraint systems (CRS) finalised phase 1 of a new regulation for the homologation of CRS . This regulation is 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 phase 1 of the new regulation and recommendations for phase 2 will be given.

INTRODUCTION

The United Nations Economic Commission for Europe (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 is 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 was proposed. After general acceptance 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 consider 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 were still in activity and regular reports of work advancement were made by project leaders, in order that findings were integrated in the proposal;

These two projects were:

- EPOCh (**E**nabling **P**rotection for **O**lder **Ch**ildren) with the objective 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) 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 registered under the reference *FP7-SST-2007-RTD-1 - GA no.: 218564.* Its activities cover 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 modeling 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.

FIELD OBSERVATION

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 (German In-Depth Accident Study) and National data have been used. Figure 1 shows the distribution of killed children as car occupant in Germany and Sweden (Swedish data was provided by Volvo Cars) by age. It is obvious that children with an age of 1 year old are of greatest risk in Germany while this peak is not visible in Sweden. It is expected that this peak results from too early change from rear facing to forward facing CRS in Germany. This change is happening in Sweden much later, i.e. with an age of 2 to 4 years. However, the national data used for this analysis is too general to prove this theory.

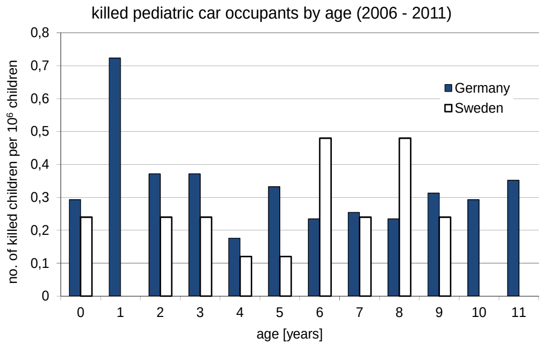


Figure 1. Killed children as car occupants dependent on age in Germany and Sweden.

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 is 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.

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 ECE R44 seems sufficient on that point.

Table 1.
Distribution of fatally injured 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%

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 of 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.

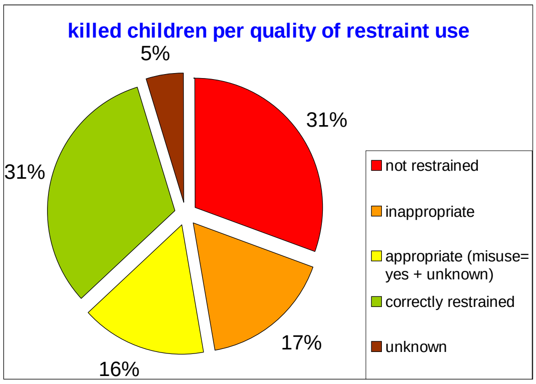


Figure 2. Distribution of restraint use for killed children (n=206).
Note: "inappropriate" considers the CRS selection only while misuse addresses the incorrect use of a CRS.

Frontal impact: 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 km/h) and following that somehow not survivable and was considered as the main reason of death.

Additional analysis for frontal impacts:

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 km/h in 17 cases (including 11 >=75km/h) and in 11 cases it is estimated under 65km/h. Of these last 11; misuse situations have been observed in 6 cases and it is unknown for 2 cases. Of 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.

Side impact: 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 behavior 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 tipover 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,etc.). That is 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 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 situation, but very few data with so many details are available elsewhere for the moment.

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 goes on the scene and collects the data for all vehicles and all occupants involved, and also collects 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.

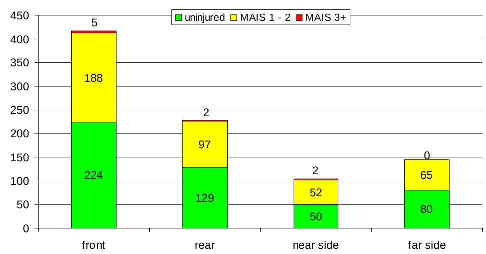


Figure 3. Injury level per impact direction.

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 delta-V, that is the corresponding change of speed of the vehicle during the accident. The distribution of delta-V 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 (e.g., small overlap accident with a lorry that intrudes from the front up to the rear seat) or misuse of restraint systems has occurred.

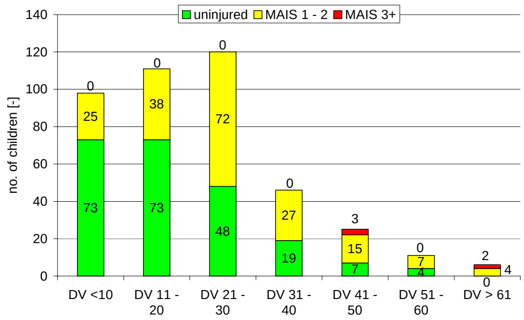


Figure 4. Injury level per delta-v in frontal impacts.

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 was 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. Detailed results were reported in CASPER deliverable D3.1.2 (PU), "Report on misuse and relative tests " – 2012, and published [Müller 2012], the main findings are summarized below.

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.

Only about one third of the children were secured correctly. Compared to older misuse studies it has to be realized 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 but looking at the types of misuse related to the installation of the CRS in the car, the most common problems are car belt path, and the lack of shoulder belt guide use in a class 2/3. All of these misuse conditions are very critical and could lead to serious injuries if an accident occurred.

An important effort is still needed to solve the issue of misuse of CRS. Problems 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.

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, and also to evaluate their safety knowledge and representation relating to children transportation in cars. Methodology and results obtained in the CASPER project have been presented in workshops [Krishnakumar 2010] and they are reported in detail [Guillaume 2012, Langlois 2011].

The first point is that there is a big disparity in the weight of children according to their age. This leads to situations that are not optimum in terms of protection of children: for example, between 0 and 9 months of age, 40 % of the children weight between 9 and 13 kg and can legally travel in a forward-facing system. The disparities are also important amongst the 10 year old children (variation from 19 to 36 kg). Globally about 27% of the children were not using the appropriate restraint system according to their weight. The choice of the restraint systems is recognized by parents as one of the problems, it is illustrated even in the smallest category of CRS with 45% of the children weighing less than 9 kg already transported forward facing, which represents a high risk for them of sustaining cervical spine injuries in case of a crash. Globally, parents tend to change the restraint systems as soon as their children have reached the lower limit of weight of the next size category: 30% of children weighing between 14 and 18kg are using a booster system while a harness type that is still approved for this weight category would be more appropriate to protect them. Finally, a large number of parents declare that their children are only using the adult seatbelt. It can be noticed that 12.5% of children are using the car belt as an inappropriate system according to their weight, although it is recognized that height considerations have an influence for these children as well.

Parents are lost and need to be guided: Even if nearly half of them think that they never mistake the way they use restraint systems, about a quarter have the feeling that they are doing something wrong but they are not able to say what. Parents from the last quarter know that they are making misuse especially with the seatbelt route to restraint the CRS, but only 2% of the parents in the sample had ISOFIX and 60% of them did not know about ISOFIX. In the focus groups, only 8% of the participants responded that they knew what ISOFIX is.

CAR-TO-CRS INTERFACE

The study on the car-to-CRS interface within this paper is limited to the bench geometry as this is key for the paper. More details on the subject can be found in the CASPER deliverable D4.6 "Assessment of solutions to improve the restraint conditions of children in vehicles" – Longton & al, 2012.

The geometry of car seats is crucial for CRS compatibility. The angle between seat cushion and backrest is especially 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 rear-facing 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.

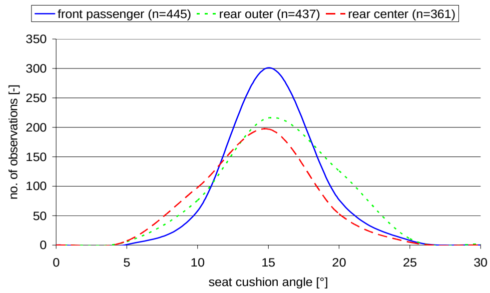


Figure 5. Seat cushion angle (angle between CR point and front edge of seat cushion) observed in today's cars.

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 99° for the outer seats and 101° for the centre seats, see Figure 18.

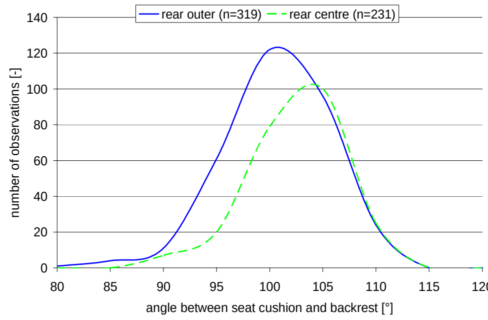


Figure 6. Angle between seat cushion and backrest in the second seating row.

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.

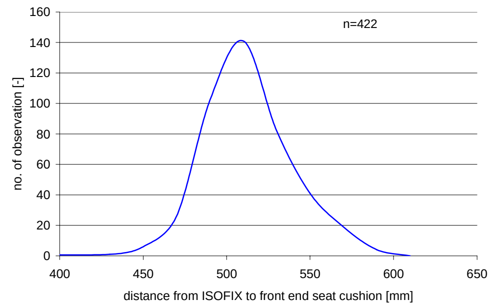


Figure 7. Assessed distance between ISOFIX anchorages and front end of the seat cushion.

The distance to 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.

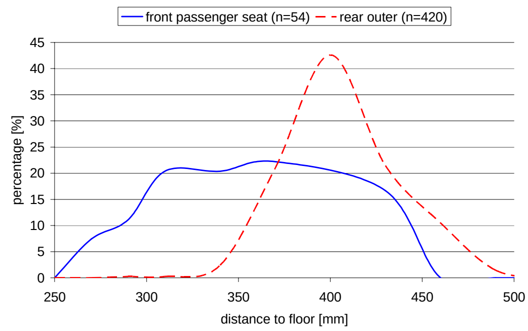


Figure 8. Assessed distance to floor.

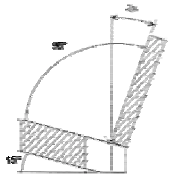
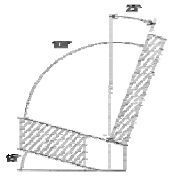
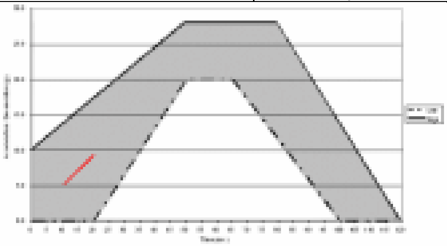
NEW REGULATION FOR HOMOLOGATION OF CRS

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 groups 0, 0+ and I).

Phase II is focussing on booster CRS with ISOFIX. The most important differences between ECE Reg. 44 and the new regulation are summarised in Table 2.

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

Table 2. Most important differences between ECE Reg. 44 and New ECE Reg.

Item	ECE Reg. 44	New ECE Reg.
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 comporable 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, comporable 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 considering 5th and 95th percentile of seating hight, shoulder hight, 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

ESTIMATION OF SAFETY BENEFITS

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.

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 survey show that 45% of the children in the weight band of "less than 9kg", 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 traveling 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 arrangement also provides greater protection against head contact for a still developing and also thinner (than an adult) skull, whilst generally 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 "less than 13kg", the Group 1 lower limit of 9kg indicates a lower criterion for change. According to UK-World Health Organisation growth charts (http://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 percentile) 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 a higher proportion of injured children because its first aim is to characterize injury mechanisms and to produce a sufficient number of cases that physical reconstructions in crash test laboratories can lead to the construction of injury criteria.

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.

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 too 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. None of the CRS that are currently on the market fulfill the requirements for support leg length and position in X direction.

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.

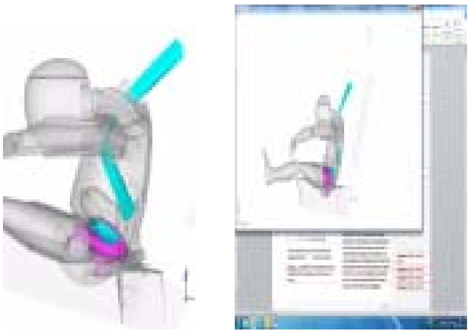
Test bench

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 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 is proposed to consider a more horizontal seat cushion design (5°) in order to emphasis abdominal protection for this type of CRS.

Figure 9 shows a Q6 model restraint with 3-point-belt only on the standard test bench for the new regulation and the proposed worst case test bench for booster type CRS. While the lap belt remains at the iliac crest in the standard test bench, it penetrates into the abdomen on the proposed test bench.



Q6 with adult belt only standard test bench | Q6 with adult belt only worst case test bench

Figure 9. Comparison of belt interaction between standard test bench and proposed worst case test bench.

In order to facilitate pragmatic operation of the test bench, it is proposed to modify only the seat cushion. Figure 10 shows a Q6 model using a simple booster at the proposed test bench with the belt staying at the abdomen.

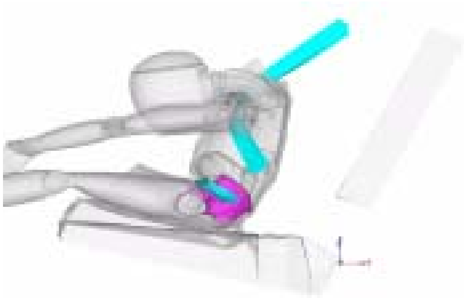


Figure 10. Q6 model with simple booster at worst case test bench.

Dummies

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 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.

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 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].

Table 3.
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			✔	✔	✔	

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 to 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 the 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 be 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.

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.

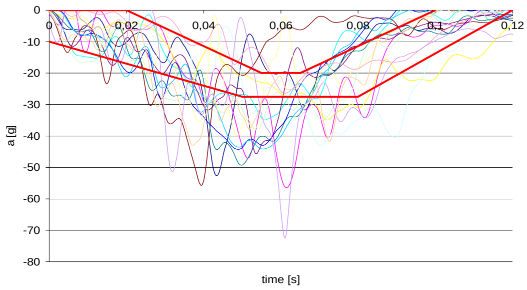


Figure 11. Comparison of body acceleration assessed in CASPER and CHILD accident reconstruction with cars being compliant with ECE Reg 94 and ECE reg. 44 frontal impact corridor.

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 show high levels of non use and misuse in frontal impact analysis. Following the discussion in chapter on accident data, 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.

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 reported previously. 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.

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, neck injuries are rarely observed. Chest injuries represent a more important proportion of severe injuries 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 has reviewed the existing injury criteria that can be applied for the first phase. CASPER has been contributing to this by the provision of updated injury criteria for Q dummies. [Johannsen 2012]. Currently the new regulation addresses head injuries by head a3ms 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. For the moment, the resultant chest acceleration limit as included in ECE R44 is kept and once a criteria for the chest compression will be made available, it will be considered by the group to ensure that systems approved do not present any risk of over loading the thoracic area.

The neck limits are an important point to ensure a good level of protection of children. This important shortcoming that has been addressed by the CASPER project aims at defining injury risk functions for the neck, focussing on children up to 3 years old. Using data from reconstruction tests, neck data points were plotted separately for Q1/Q1.5 and Q3/Q6 dummies since younger children are at particular risk for neck injury in frontal loading. The injury risk curve was constructed after a scaling to have all values for 1 year old. It can be observed that no severe injury appeared below 1 kN and that all children sustained a severe injury above 1.3 kN. Neck My data points for cases without head impact do not allow the development of an injury risk curve for this age group. For Q3 and Q6 dummies, only the cases without head impact were kept. None of the parameters (Fz, My) allowed for the construction of a relevant injury risk curve. A combination of Fz and My was investigated, but did not lead to a more relevant parameter. Therefore, no injury limit has been proposed by the CASPER project for Q3 and Q6, knowing that children in corresponding age show very few cases of severe injuries on the cervical spine area.

Until recently, no CRS abdominal performance criteria for booster type CRS was available. CASPER has been studying more closely the injury pattern for this body region and proposals of injury risk functions for the abdomen were made [Beillas, 2012]. Prior to be able to apply them, it is necessary that the abdominal sensors are produced at an industrial level, which means that they have been going through the repeatability and reproducibility tests, and that a calibration procedure of the dummy equipped with these sensors is provided by the dummy manufacturer. The protection of the chest and the abdomen has to be considered for all forward facing systems (from Q1,5 to Q10).

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]).

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.

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.

Integral harness systems

The geometric support leg requirements proposed in the current draft new ECE Reg. 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 recommended to use the CASPER proposal for Q1 and Q1.5. In addition it is recommended to fix limits for Q3, Q6 and Q10 based on the state-of-the-art performance of CRS.

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, especially taking into account shield systems [Johannsen, 2013]. However, CASPER was unable to provide a corresponding injury risk curve. It is believed that this is caused by issues in a large number of reconstruction tests.

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 including it's corresponding load limits 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.

As already mentioned above, appropriate chest injury criteria and load limits are also important for improving child safety especially for children using booster type CRS.

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 exceed 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 female.

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.

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 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 for 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 University of Birmingham, the Vehicle Safety Research Centre at Loughborough University, and the Vehicle & Operator Services Agency of the Department for Transport. The views expressed in this work are those of the authors and not necessarily those of the UK CCIS sponsors.

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.

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