CASPER - Focus on some specific technical points through field studies and test data

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Introduction:

During the 3 years of the EU research project CASPER (FP7 GA n°218564), partners have combined their expertise in the different fields of child safety in cars to reach the main objectives of the project: improvement of the rate of correctly restrained children and improvement of the performance of child restraint systems (CRS) through the definition of better tools and criteria for the evaluation of their protection level.

Through numerous collaborations and participation to working groups, the CASPER consortium has been one of the actors in the European area of child safety. A large amount of data has been collected, analyzed and disseminated according to the needs of the different groups, and some have already been included in the proposal for the text of the new regulation.

This paper intends to make an transversal analysis of some specific items through the data available in the different tasks of the project, such as child safety and airbags (frontal, side, curtains), situation of ISOFIX systems, protection of the abdomen and analyse of specific systems such as shield systems or seatbelt adjusters. A larger focus will be made on items that have not yet been presented during the dissemination workshops of the CASPER project or for which complementary information has been made available.

Child safety and airbags (frontal, side, curtains)

Field data:

During the different field surveys (CRS checking), the presence of a frontal airbag and its status are recorded by the investigator. Nevertheless, the presence of other airbags (side and curtains) is not considered in most of the studies. In addition their status normally cannot be controlled by the user: when the presence of a CRS is detected or when a manual switch deactivates the frontal airbag, in most of the cars the side airbag deployment is not inhibited, and the curtain remains active because it is also used for the rear seating position. Only a study of frontal airbags is made for this part of the analysis. For the sample coming from the latest surveys for which CASPER partners have access to the data, Table 1 shows the fitting rate of cars equipped with a frontal airbag at the front passenger seat (FPS), the number of children seated at this position, the number of children that are in front of an active airbag, and their distribution between these installed rearward facing and the others installed forward facing.

	Total sample size	Rate equipment frontal AB	Nb children at FPS	Nb children at FPS with F AB	NB children active F AB	
Name					FWD FC	RWD FC
CASPER (2012)	316 (44)	68%	25 (8%)	12	8	0
VSFB (2008)	115	100%	115 (100%)	115	0	20
IBSR (2011)	1472	82%	90 (6%)	70	5	6

Table 1 – frontal airbag at FPS

A specific point regarding the occupation of the FPS by children in France should be noted. It is only allowed if a child is installed in a rearward facing system if no active frontal airbag is present, or after 10 years old when children do not have to use an additional restraint system. Some exceptions are possible, especially in the case of too many children to accommodate them all at the second row, in commercial vehicles not fitted with a rear bench, and if the configuration of the vehicle temporarily does not allow the installation of a restraint system in the back seat (to transport large objects for example). This can explain that some figures are different in French samples than in the ones coming from other European countries.

The CASPER misuse surveys have been conducted in 2010 and 2011 in three different locations: Berlin (D), Lyon (F) and Naples (I). The total number of children in the survey is 316. Complete analysis has been conducted and reported in a public deliverable of the CASPER project [1]. The average rate of children at FPS is 8% but shows a large regional difference between Lyon (3%) and Naples (13%). The rate of cars fitted with frontal passenger airbag is 68%, the number of children in front of an active airbag is only 8. For 5 children installed at the FPS, the frontal airbag was disconnected, one of them was in rear infant carrier.

The data VFSB (2008) were collected for the project “Misuse in combination with the airbag deactivation” funded by BASt [2]. Here only cases were investigated, where a child in a rearward facing CRS was seated on the passenger seat. In 20 of these 115 cases the passenger airbag was active, which is clearly a serious misuse. Most of the misuse cases were recorded for cars that did not allow airbag deactivation or that require actions by a garage.
For this research project also data from GIDAS were analysed. All frontal accidents between 1999 and 2008 involving children up to 12 years in the car were investigated. In total 337 children were involved, 279 in rear seats and 58 in front passenger seat. Of the 58 children in the front passenger seat 9 cases with airbag deployment occurred, 34 cases without front passenger airbag and 15 cases without airbag deployment (here it is unknown if they were deactivated or not activated due to low accident severity or if a failure occurred). The results showed that the risk for severe injuries with airbag deployment is slightly higher than without. However airbag deployment requires a minimum accident severity level that is why it is likely that cases with and without airbag deployment cannot be compared. Based on the GIDAS analysis approx. 17% of children travelling in cars are using the front passenger seat, according to the misuse study conducted in Munich in 2006 [3] approx. 7% of children in CRS are using the front passenger seat.

It is always difficult to study the situation at the FPS because the size of the sample is very often too small. Even if the global sample size is large there are few numbers of children installed at this seating position, except the youngest ones transported rearward facing. During the CEDRE project that has been conducted between 2008 and 2009, a large part of the data was collected at the exit of maternity. On the global sample of 165 children, 114 are babies in their first journeys or having a medical visit at the hospital. Results of the CEDRE project were presented in different occasions [4]. Even if not fully representative of the situation of everyday trips, it has allowed the measurement of the number of times for which the frontal airbag has been disconnected and the links with parents knowledge with child safety [5]. On the 112 vehicles leaving the maternity parking lot, 72% of them were equipped with a frontal airbag at the FPS. The number of babies at the FPS was 35 (21%); 7 were travelling with an active airbag and 20 with an airbag that had been previously disconnected by the driver. For 8 others, the car was not equipped with a frontal airbag. Interviewing the drivers of cars equipped with a frontal airbag at the FPS, it has been observed that 15% of them had no idea of a risk.

The latest available data in the CASPER project has been obtained through collaboration with IBSR (Belgium Road Safety Institute) that was conducted in September 2011. Data on 1472 children in 932 vehicles has been collected on use and misuse situations. Results have been published and reported in conferences [6, 7]. 764 vehicles were equipped with a frontal passenger airbag, in 23 of them the airbag was not deactivated and in 145 cars it was impossible to assess the airbag status because of missing data. This means at the minimum 82% of the vehicles were equipped. 90 children were occupying the FPS among which 19 were rearward facing. In 9 cases the frontal airbag was disconnected, in 2 other cases it was still active and in 7 cases the data is not known. This underlines one of the difficulties encountered by inspectors that first need to know where disconnection systems are located on the different models of vehicles and to have the permission to check it. This is especially true when controlled by the onboard computer or when the switch is located on the external side of the dashboard (Figure 1) it is necessary to open the passenger door to check the airbag status. Similarly when it is in the glove box area it is nearly impossible to check it if the rear infant carrier remains in place.

Figure 1: Key switch located on the extremity of the dashboard (right side)

Accident data:

The CASPER project contains a specific task dedicated to the road accident data collection activity. The resulting database is also containing data from its predecessors (CREST and CHILD). Analysis of the content is possible within the constraints of the case selection criteria used. The real world accident cases are collected to ensure that information on child kinematics, injury causation, injury criteria and CRS performance (including misuse where understood) is available to the project in order to further activities in injury criteria, dummy/model development and the understanding of misuse. This has an implication for how the analysis should be interpreted as the database is not representative of the overall child car passenger crash population. However, the database gives an indication of which body regions are being injured in different CRS types or for different children's seating position and gives insights into restraint conditions that lead to injury. The CASPER accident database uses the AAAM Abbreviated Injury Scale (AIS98) [8] for the recording of injuries of all occupants. Injury severity is then reported further in the document as AIS score and the maximal level of severity of all injuries sustained by an occupant being the M.AIS. Due to a selection process applied during the technical meetings of the CASPER project [9], the cases are generally more severe in terms of both injury and crash severity than would be seen in the overall child car passenger crash population in frontal and lateral impacts. Overall there are 1301 restrained children in the combined database, 954 in frontal impacts, 341 in lateral impacts and 6 in rear impacts.

Frontal airbags:

In the CASPER sample of restrained children, 181 were seated at the FPS. 128 were involved in a frontal impact, 52 in a lateral impact and 1 in a rear impact. 89 were using an additional restraint system and 92 were using the seatbelt only. The fitting of frontal airbags in the involved cars is as follows: 127 vehicles were not equipped with frontal airbags, 41 have a frontal airbag deployed, including 6 involved in a side impact but combined with a frontal component, 6 frontal airbags not deployed because the crash was a side impact and for 5 others frontal airbags were de-activated (4 by manual switch, 1 with CPOD), so they did not inflate.

The distribution by age of the children seated at the FPS is given in Figure 2. In the sample, this position is mainly used by babies of less than 1 year of age or by children older than 9 years. This is because: Firstly parents are transporting babies on the FPS installed rearward facing in many countries across Europe and secondly, a large part of the sample is coming from France where transporting children at the FPS is not allowed at all ages as explained in the previous chapter. Between these two limits the number of restrained children in the database installed at FPS is more or less stable. For the same reasons, the number of children with frontal airbag deployed is also more important in the same age groups.

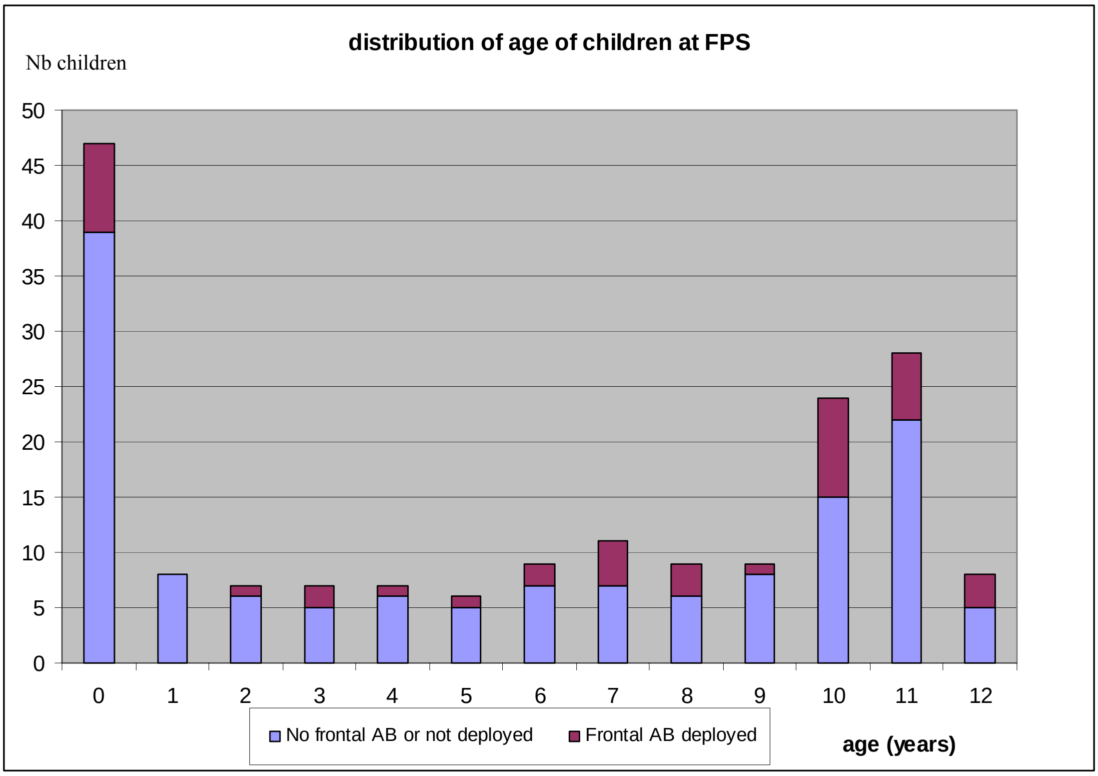


Figure 2: distribution by age of the children seated at the FPS

Rearward facing installations:

In the sample, all children of less than 1 year of age installed at the FPS involved in an accident during which the frontal airbag deployed, were injured at a high injury severity level. These 8 children were all installed in a rearward facing system. One of them is M.AIS3 (serious), 5 are M.AIS4 (severe), 1 is M.AIS5 (critical) and the last one is M.AIS6 (maximum). The number of injuries sustained by these 8 children is 20, with only one minor injury to the face, all the others being to the head segment. The distribution and severity of these injuries per body segment are given in Table 2.

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6
Face	1	0	0	0	0	0
Head	0	3	7	6	2	1
Neck and cervical spine	0	0	0	0	0	0
Other body segments	0	0	0	0	0	0

Table 2: number of injuries – at FPS - rearward facing with frontal airbag deployment

Concerning the description of the injuries, 6 children have combination of skull fracture and brain injuries, 1 sustained isolated brain injury and 1 had a skull fracture without any recorded brain damage The source of these injuries on the head segment have been attributed to the deploying airbag, some of them being observed in low severity accidents (at the limit of deployment of frontal airbags) where no intrusion at the level of the dashboard is recorded.

Forward facing installations:
27 frontal airbag deployments occurred in frontal impacts (where the predominate impact causing injury has been recorded as frontal) with children installed forward facing at the FPS - 20 adult seat belts, 2 forward facing harness CRS and 5 Booster seat/cushion. The distribution of their M.AIS is given in Table 3.

	M.AIS 1	M.AIS 2	M.AIS 3	M.AIS 4	M.AIS 5	M.AIS 6
With additional CRS	4	2	0	1	0	0
Seatbelt only	5	12	2	1	0	0

Table 3: Distribution of M.AIS values – at FPS - forward facing with frontal airbag deployment

It has to be noticed that there is no fatal case in the sample of children installed forward facing in front of a deploying airbag. 2 of them are M.AIS4. A closer look at these two cases shows that the AIS4 injuries are obtained at the level of the thorax and that no face or head injuries have been recorded for these children.

The one child with MAIS 4 injuries was sitting in an additional CRS. He was 4 year old and was installed in a group 1 harness system. The AIS 4 pulmonary contusion (bilateral) is attributed to the deploying airbag but is it noted that also harness contact could have made a contribution to the injury. The EES of the head on impact with another car was 70 km/h and the delta-v was 79 km/h (maximum deformation of 920 mm) with intrusion to the passenger compartment starting. This is a substantial impact and without the airbag deployment, head excursion to the dashboard may have occurred with associated head injuries being possible. Further detail in the case shows that the CRS was badly damaged during the impact with failure of the structure visible on Figure 3. The CRS being of the category of low quality systems, the crash severity would have been sufficient to have broken it during such an accident. The airbag is mounted on the vertical part of the dashboard and deploys in the direction of the occupant, it has contacted the CRS shell early in the crash but therefore it may have paid a part in the protection of the child from worse injury. It has to be noted that the FPS was not in the most rearward position, but in the middle one. The driver from this vehicle died 4 days after the accident, while the child, even if severely injured, survived.

Figure 3: Views of seating position and general state of CRS after the accident

The other child with MAIS 4 injuries was restrained only by the seatbelt (11 years old, therefore appropriate in France). The EES has been estimated at 67 kph, the belt load limitation at the FPS was 6 kN. Two chest injuries have been recorded: A pulmonary contusion and a pneumo-thorax but also abdominal wounds. This injury pattern indicates that the seatbelt is the main cause of injuries. The driver of this vehicle has been killed on the spot, the child survived this accident.
The distribution per body segment of the 96 injuries sustained by the 27 children is shown on Figure 4. There are "only" 8 that have a severity over AIS3.

Looking at all severities, it clearly appears that the head and face that are normally the most often injured body segments for children installed forward facing [9], do not show the higher score on Figure 4. The limbs (lower and upper) represent the biggest proportions, followed then by the face, the abdomen and the chest. Very few head and neck injuries are recorded for this category of children.

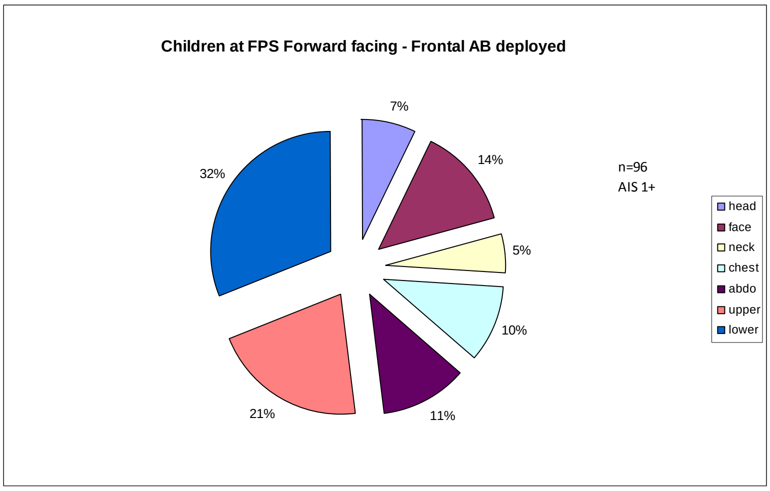


Figure 4: repartition of injuries - children in front of deployed frontal airbags

There are 27 AIS2+ injuries, which only allows an indication of tendencies: the limbs still represent about half of the number while they normally represent from 16 to 30% according to the type of restraint system considered, the head represent approximately 20% which is similar as the rate of boosters and seatbelts but far lower than the 50% of the forward facing harness systems, the chest scored less than 15% and the abdomen about 10% which is lower than the rates usually observed. It has to be noticed that in this category, no neck injury has been recorded.

Side airbags - seat or door mounted

There are 8 instances of a deployed side airbag in a position with a restrained child (6 with adult seat belts and 2 in rear facing CRS). One child is in the rear. Of these, 3 occurred in frontal impacts and 5 in lateral impacts (the predominate injury causing impact being recorded). Of the 5 children involved in a lateral impact, 2 were involved in very severe crashes where no protection from any safety device could be expected: One car was struck between a truck and a tree laterally and in the other case the car hit a tree on its left side at high speed, creating an important intrusion directly at the FPS position (right hand drive vehicle). An illustration of these cases is given on Figure 5.

Figure 5: illustration of extreme cases – no safety benefit expected from side airbags

On the remaining 3 cases, 1 child was restrained in a rearward facing system, the side airbag inflating at his feet not changing the level of protection.

The next case is a side impact on the engine block and front door of the car. The child was 8 years old and only wearing the adult seatbelt. Views of the accident vehicle are given on Figure 6. The three front positions were occupied by restrained occupants. The child on the struck side sustained no direct intrusion at the level of head, chest and pelvis but the seat cushion is deformed on its front part by the intruding door. The child only sustained external contusions except at the level of the lower limbs with an articular laceration of the right knee cap observed. The upper part of the body has been correctly protected and the inflating airbags (frontal and side deployed) have not created any injuries.

Figure 6: illustration of case n°1 with side airbag deployment

The last case is the one that would illustrate the most benefit of the side airbag as it is a right side impact with a child seated on the FPS only restrained by the seatbelt and with intrusion on the passenger compartment. The child of 10 years old was in a vehicle equipped with a head-chest side airbag. In this case both frontal and side airbags deployed. The B pillar level intrusion measure was 450 mm. Once deployed, the side airbag covered the B pillar area, preventing the child sustaining serious injuries on their trunk and to the head. Illustrations of this case are shown on Figure 7. The child sustained mainly external contusions all over the body and sustained two fractures: the first one at the level of the neck of right femur, because of the intruding door and another one at the level of the pubic rami on the left side, the child being stuck between the intruding B pillar and the central console.

Figure 7: illustration of case n°2 with side airbag deployment

Head level (tube or curtain)

There are more instances (23) of a deployed head level side airbag in a position with a restrained child than a seat or door mounted airbag, as these head level systems often cover the front and rear passenger compartments. Of these, 13 occurred in frontal impacts and 10 in side impacts (the predominate injury causing impact being recorded). Eleven children are restrained with adult seat belts, 1 in rear facing CRS, 6 in forward facing harness CRS and 5 using a booster seat/cushion. In the accident database, injury causation is documented, none of the head injuries were attributed to side airbag deployment by the accident investigators.
The distribution of the M.AIS of the 10 children involved in a side impact with the head airbag deployed is given in Table 4. Half of them sustained cranial or brain trauma, often in combination with other severe injuries on other body segments. Of course due to the specificity of the database and of its high global level of injuries, it is difficult to make a statement with so few data but it would be interesting with more data to investigate the efficiency of head airbag for children compared to adults and also to investigate the protection offered during testing.

	M.AIS 1	M.AIS 2	M.AIS 3	M.AIS 4	M.AIS 5	Killed (no medical report)
With additional CRS	2	2	1		2	
Seatbelt only	2					1

Table 4: Distribution of M.AIS values – forward facing with head airbag deployment

Testing experiences of child dummies and airbags

The CASPER project has been continuing the work initiated in the previous EC research projects CREST and CHILD on the definition of injury tolerance for children. For this, the method used was to reconstruct some accidents with dummies restrained in the same CRS models and re-creating the loading conditions of real accidents. Since 1996, a total number of 139 accident reconstructions have been performed, which represent a large database with dummy readings. In addition, other tests were carried out mainly in the misuse test programs, airbag interaction being one of the studied topics. It is proposed to examine the cases for which airbags have been deployed to study the interaction of restrained child dummies and airbags.

Frontal airbags:

Four accident reconstructions have been performed with interaction between a frontal airbag and a rearfacing infant carrier. One is shown as example in Figure 8. All corresponding children sustained serious or fatal injuries and the dummy readings reflect that. The main difficulty to properly reproduce the test configurations was that size/weight of child dummies are limited to the ones of the Q0 and of the Q1, which leads to very different relative positions of the CRS and head of the child. When the height of the child was too different than the one of the dummy, the priority was given to correctly position the head of the dummy, sometimes by taking a smaller dummy and putting a positioning cushion under it, raising it in the CRS. When it was necessary to make a Q1 lighter, the lower part of the legs were removed to put the head at the right position As it is assumed that brain and skull injuries should occur during the loading phase of the airbag deployment, these changes in the dummy statures and postures would not have a large effect at least in this first phase.

Figure 8: illustration of accident case and its reconstruction with frontal airbag deployment

Another additional source of data is from the misuse testing program conducted and reported during the CHILD project [10]. This document has been updated during the CASPER project but no new input on the subject of airbag interaction has been obtained in CASPER. Different frontal airbags and CRS types were tested in car body in white with the R44 pulse, Table 5 summarises the tested configurations. These tests were compared with reference tests conducted in the same situations without deployment of the frontal airbag.

	Low mounted	Mid mounted	Top mounted
Rear Infant Carrier G0+	1		1
Rearward facing G1		1	
Forward facing G1 – harness	1		1
High back booster G2	1		

Table 5: List of configurations tested for CRS / airbag deployment interaction

Rear infant carriers: The situation really depends on the geometry of the airbag. In the case of a low mounted airbag, the interaction is very strong and leads to critical values on the dummy readings at the level of the head. Films show that the interaction with the deploying airbag occurs while the CRS shell is moving forward, and results in a strong backwards push. In this configuration, a clear negative influence was seen. In the case of the top mounted device, the airbag deployed following the windscreen line, so the back of the CRS is not in direct contact with the airbag. The airbag when fully deployed is covering the major part of the front passenger seat, including the CRS and the child dummy (Figure 9 – left). Little influence can be seen on the dummy measurements, nevertheless as it is not of any help in the protection of the child inside the CRS, it is not recommended to leave the airbag switched on while a rearward facing child restraint system is installed on the front passenger seat. According to airbag deployment data from the literature, high dummy readings can also be observed when mid mounted and top mounted airbags are used [3].

Rearward facing G1 harness CRS: The fixation of the CRS base to the car by ISOFIX connection and the CRS being rigidly clicked onto its base, the system is quite rigid and does not allow any displacement of the CRS when the airbag is deployed. During its deployment, the airbag is stuck against the CRS that does not move sufficiently backward to allow its full deployment and lead to the explosion of the airbag. As result of this hard contact of the airbag against the shell, head acceleration curves show differences (higher peaks). HIC value and chest acceleration are twice as high in misuse (airbag deployment) configuration, neck forces are also show higher values than in the reference test.

Forward facing G1 harness CRS: The combination of the seatbelt pretensioner and the airbag activation leads to a good coupling between the child dummy in its harness and the deploying airbag (Figure 9 - centre). The contact seems soft on films and curves. No peak is visible on dummy accelerations at the level of the head or at the chest. Head 3ms acceleration value is really lower than in reference tests and the value for HIC36ms is divided by 2. The measure obtained for My at the neck is higher when the airbag deployed, and it is necessary to check if there is a risk of injury at this level. Chest and pelvis measurements show a little delay and maximum values occur later

High back booster G2: Seatbelt pretension and airbag deployment leads to a soft contact between the dummy and the airbag and to a good coupling between the child dummy and its restraint system (Figure 9 - right). No peak is visible on dummy readings. As for forward facing group I seat the effect is positive on the dummy results for the head and chest and for the neck with the exception of the force in the X direction which shows a higher value than in the reference test.

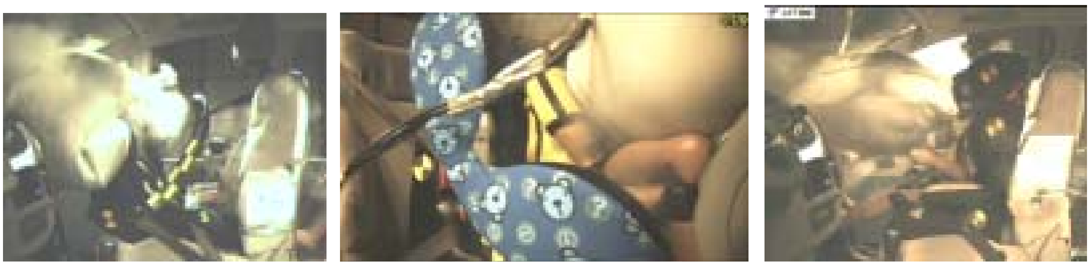


Figure 9: deployment of low-mounted airbag on different types of CRS

For forward facing tested configurations the deployment of the frontal airbag seems to be positive for the global safety of the child occupant. It would be necessary to run other tests with other combinations of airbags and CRS before having a clearer view.

Side airbags *(seat or door mounted and head level):*

Much of the procedure technical works in the CASPER project have been concentrated on the validation of the side impact test procedure because the protection of children in side impact has been defined as one the main priorities. Partners have conducted sled tests both on acceleration and deceleration systems and 6 tests with complete cars have been performed [11]. The objective of this test program is to study the response of Q dummies in side impact in a car environment and to compare the load levels with the ones obtained on a regulation bench in the side impact test procedure proposed by the informal group of GRSP on CRS. For that it is necessary to have a reproducible intrusion of the door on the struck car with a value comparable with the one proposed in the side impact test procedure (approximately 250 mm). Test configuration is shown on Figure 10. A moving sled of 1500 kg is thrown into the side of the car with a speed of 50 kph. To be able to compare with tests conducted in the informal CRS ad-hoc group, it was decided to use G0+ and G1 (according to ECE R44_04 definitions) CRS that correspond to the size of CRS that are included in the first phase of the GRSP informal group test procedure for side impact protection. For the G0+ CRS the dummy used is Q1½ and for the G1 it is a Q3. The instrumentation of both dummies was the standard one: linear acceleration of head, chest and pelvis, and loads (6 axes) at the level of the neck for the Q1½ and in some of the tests on the Q3.

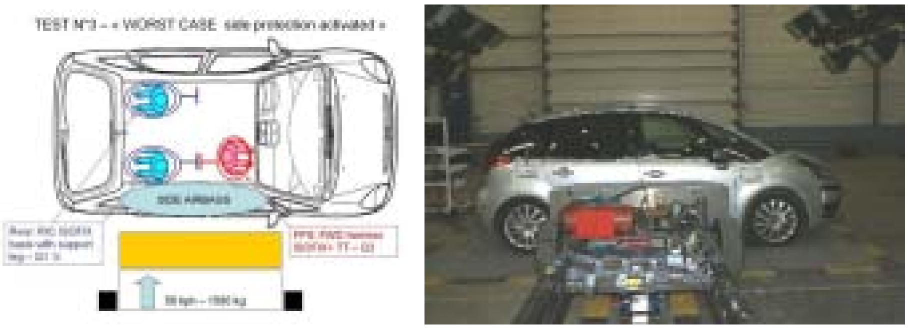


Figure 10: Test configuration for the effect of side airbags in testing

Two seating positions of dummies are tested in the series. On the first one, the maximum intrusion is located at the level of the head of the dummy - so called worst case: the rear infant carrier is then installed at the rear right position and the forward facing harness system at the FPS. The second is called the non-worst case because the maximum intrusion is located in the area of the feet of the dummies, which means that the rearward infant carrier is on the FPS and the forward facing system at the rear right position. In one of them, the side airbag protection has been activated with dummies in the worst case positions. The reference car is equipped at the front passenger seat with a side airbag in the vehicle seat designed for the protection of the thorax of an adult and a curtain airbag to protect the area of the head. The rear right passenger position is equipped with a curtain airbag only. Final positions of dummies in the car are given on Figure 11.Results have been compared with a reference test conducted in the same conditions without activation of safety devices.

Figure 11 Final positions of dummies with inflated side airbags

- For the Q1½ , results with and without side protection devices show very little differences. High speed films show that the curtain is not contacting the shell of the CRS or the dummy during the loading phase. The late contact between the deploying curtain and the CRS handle explains the fact that dummy readings are slightly lower in terms of maximum values, timing remaining similar for head and chest and with a little delay introduced for the pelvis.
- For the Q3 installed in a forward facing harness at the FPS, the situation is different. The analysis of the film shows that the side airbag located in the seat inflates and creates a soft interface between the door panel and the CRS. The effect of the side airbag is also visible on the dummy readings. For the head, loads go down to a level similar to one observed in the non-worst case test with an earlier coupling of the dummy (Figure 12). For the chest the time change is also visible and the maximum acceleration is even lower than in the non-worst case. For the pelvis the effect is a lower maximum value and a shift in the timing with a later coupling of the pelvis.
Results obtained with the side device deployments are only given as an indication as only one CRS and one car have been tested.

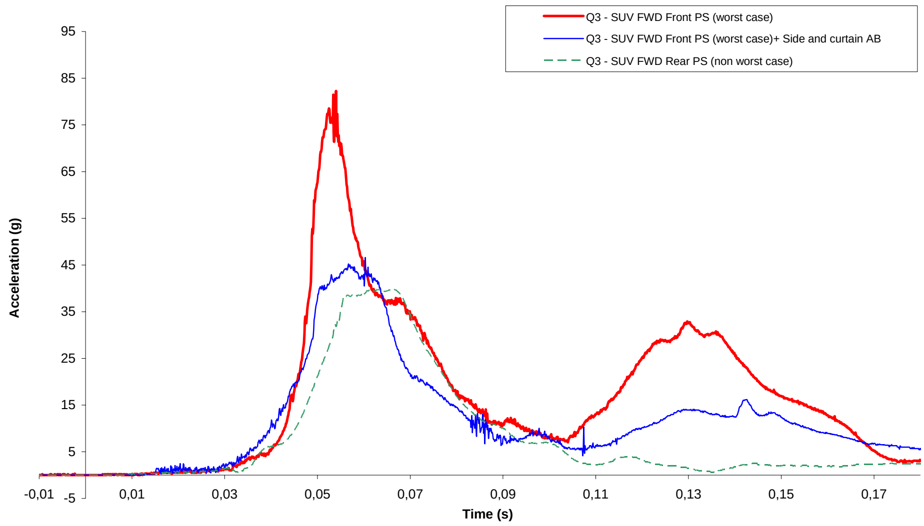


Figure 12: Head acceleration resultant of Q3on the struck side

ISOFIX experience with new systems

Field data:

In most of the field surveys, very few cases with ISOFIX systems are available. The only one that has a sufficient number of children using ISOFIX CRS is the Belgium study. A full paper is proposed in Munich conference 2012 that is focusing on the differences of use and users between classical CRS attachments and ISOFIX [12].

According to the National roadside survey on CRS conducted by the Belgian Road Safety Institute (BRSI) in 2011, at least 50% of the sample of 1,461 observed children were not correctly restrained (in an appropriate CRS without misuse) and 10% were not restrained at all. For each child, the conditions of restraint were observed in detail and the driver was interviewed. The survey was conducted on randomly selected sites across the country and represented various types of journeys: schools, maternity hospitals, supermarkets, recreational areas and sports centres. The sample of children using an additional CRS consists of 799 children (under 135cm) and it includes 76 ISOFIX CRS. Figure 13 shows the rate per region of children restrained by ISOFIX CRS : 7.5% in Brussels, 3.8% in Flanders and 2.6% in Wallonia.

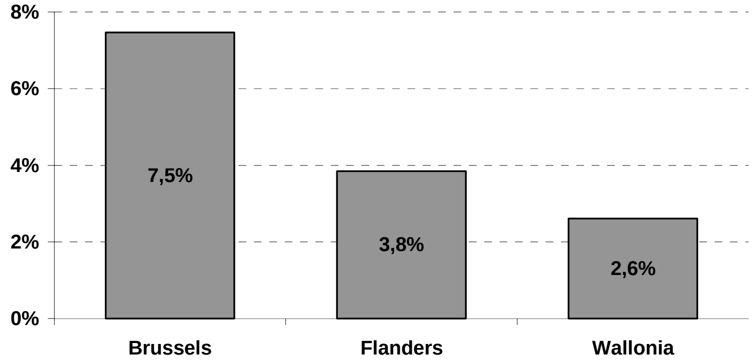


Figure 13: Percentage of restrained children with ISOFIX CRS according to the region.

Various factors influenced the use of CRS. The most significant ones were the use of a seatbelt by the driver, awareness of road hazards by the driver, whether advice was provided in the shop where CRS was bought and the length and frequency of the trip. For the 76 Isofix CRS; the repartition by type was 51% forward facing devices, 41% boosters with backrest and 7% rearfacing infant carriers. Figure 14 illustrates that ISOFIX systems differ by regions. Booster seats using ISOFIX connectors are the most popular system in the Brussels area, with a rate close to the one of the harness systems. For Flanders and Wallonia, forward facing harness systems are the most used systems with more than 60% of ISOFIX systems. In Flanders it is followed by booster seats with approximately 30%. Wallonia is the region where the rate of rearfacing infant carrier is the highest with 22%.

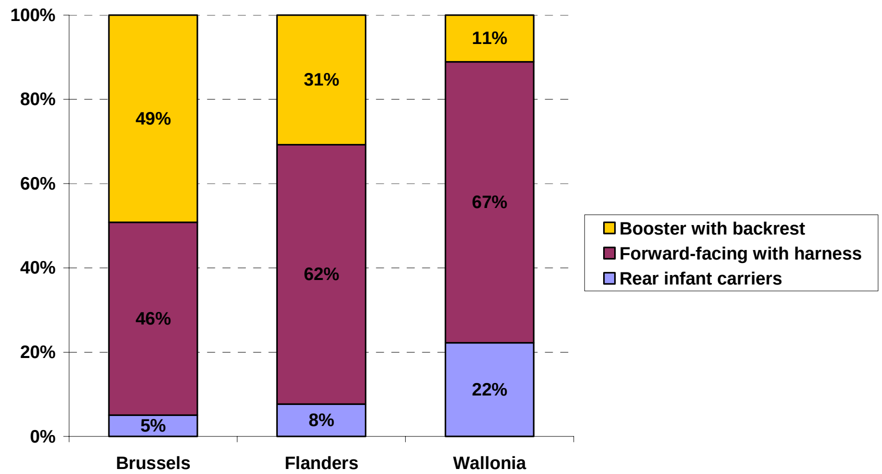


Figure 14: Distribution of ISOFIX systems per region

The ISOFIX system significantly reduces the rate of incorrectly restrained children (25% for ISOFIX versus 38% for non-ISOFIX), and in particular misuses regarding the installation of the CRS (5% versus 10%). These results slightly differ by CRS categories: for forward harness systems the misuse rate is 8% versus 23%, and the ISOFIX booster seats misuse rate is 19% while it reaches 32% for non ISOFIX booster devices. This last statement is surprising as the main advantage of ISOFIX systems should have been an easier installation than seat belted CRS, and no installation is required for booster systems. Looking at the detail, the misuse that is the most reduced between ISOFIX or seatbelt booster is the fact that the child has the seatbelt under the arm. This has nothing to do with ISOFIX itself. Two hypotheses on that point: the first one is that ISOFIX boosters are fitted with backrest in which a good seatbelt guidance is provided, so the child has no comfort issues with the diagonal belt in the neck area, and/or the parents that have bought such systems pay more attention to the quality of use of the systems.
Drivers using the ISOFIX system have a significantly different sociological profile. They are more often the parents of children transported, they are younger, they have a higher educational level, they live more frequently in big urban areas and they drive more often a car less than 3 years old (all differences being statistically significant). They are also less permissive regarding who installs the child in the CRS. All together these results show the use of ISOFIX systems is currently associated with specific sociological characteristics and that it is unclear if the conclusions on ISOFIX would be applicable to the complete population.

Accident data:

The number of child occupants with ISOFIX restraining in the CASPER accident database is low (7 cases), with 3 of these children in the same vehicle. All cases with children using ISOFIX are in the CASPER dataset (rather than the earlier datasets). Surprisingly, given that they are a relatively recent addition to the CRS market, 6 of the 7 children are restrained in ISOFIX booster seats, and only one in a forward facing harness system.
In the few accident cases with ISOFIX systems studied, no misuse has been observed but due to the small size of sample this is not significant. The level of severity of injuries sustained by the children in ISOFIX connected system is not representative as for these first cases investigators have looked on more severe cases to fulfil the objective of providing injuries cases for accident reconstruction. It would be dangerous to compare the protection offered by ISOFIX systems with other systems. As to show an example, 3 of the 7 children having ISOFIX were showing injury patterns that made the cases interesting for the definition of injury tolerance in side impacts. It is important to note that most children with ISOFIX in the sample were involved in lateral impacts where only minor influence from ISOFIX is expected.

Reconstructions or test data (frontal / side impact):

In the reconstruction test program, three cases (involving 5 children) of the CASPER accident database were side impacts with ISOFIX systems. They included a case with forward facing harness G1, and two others with high back boosters. The three systems were located at the struck side in the area of intrusion. They sustained damages during the accidents and the children were all severely injured. For the harness system the damage of the CRS was not reproduced in the reconstruction. Damages to the two boosters were similar in the accident and in the reconstruction tests.

Other test experiences:

In the different tasks of the CASPER project some tests were conducted for different objectives but their results contribute to enhance the knowledge on specific items.

- ***Frontal impact tests:***

Regarding ISOFIX, in the misuse test program, some tests were performed with ISOFIX systems. Reference tests being done, it is possible to compare the effect of misuse of the ISOFIX fixation in frontal impact. Results have been reported and are part of a presentation dedicated to the subject in the Munich Conference 2012 [13]. One of the test configurations is not to link a booster fitted with ISOFIX connectors to the rigid anchorage of the car. Tests have been conducted in a car body in white with a Q6 dummy equipped with standard instrumentation, a pair of abdominal pressure sensors and an ECE R44 pulse. Results of dummy reading values are summarized in Table 6.

	HEAD Accel (g)		NECK Loads (N-N/m)			CHEST Accel (g)		ABDOMEN Pressure (bar)		PELVIS Accel. (g)	
	Res.	3ms	FX	FZ	MY	Res.	3ms	Left	Right	Res.	3ms
ISOFIX	**65.6**	**64,1**	**-300**	**2200**	**-16.5**	**65**	**59,4**	**0,31**	**0,21**	**55**	**54,2**
NO ISOFIX	70.7	68,8	-300	2200	-20.5	64.2	59,2	/	/	57.6	55,2

Table 6: Comparison of dummy readings maximum values –use vs non use of ISOFIX anchorages- Q6

Globally it can be stated that no major differences in the maximum values have been seen between the test in which the booster is connected to rigid anchorages of the car and the test in which connectors are not used. On the chest, it can be noted that the loading phase is stiffer when the ISOFIX was not connected than when it was. CRS and dummy behaviour are similar in both tests. It has to be stated also that the booster used for this test series is equipped with energy absorption devices at the level of the ISOFIX connections. To have a clearer view, it could be interesting to have other results of the CRS tested with and without use of ISOFIX connection. No other test of that kind has been performed within the CASPER project, so it is important to state that these results are only valid in this configuration with this specific CRS.

- ***Side impact tests:***

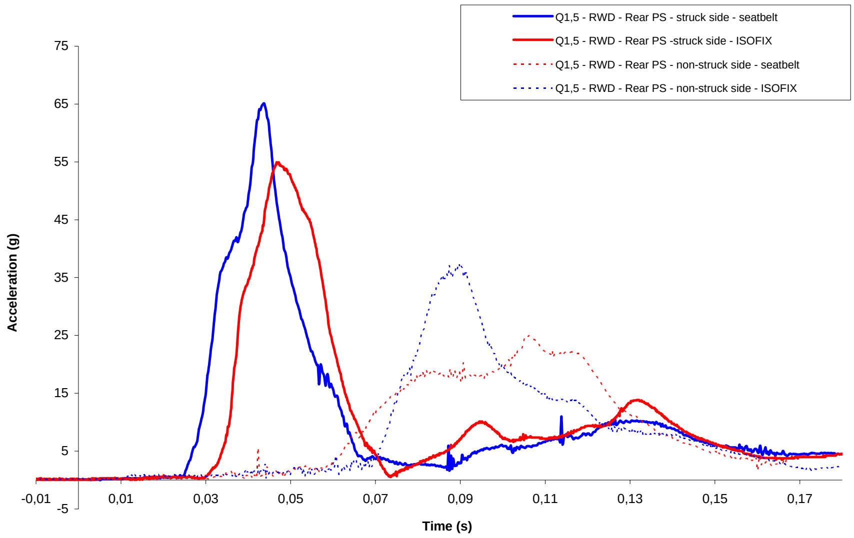
In the same test series as the one used for the side airbag investigation, and described in the related chapter, some tests have been conducted with ISOFIX connected CRS and the same model of CRS in the configurations of seatbelt attachment.

Rear Infant Carrier:

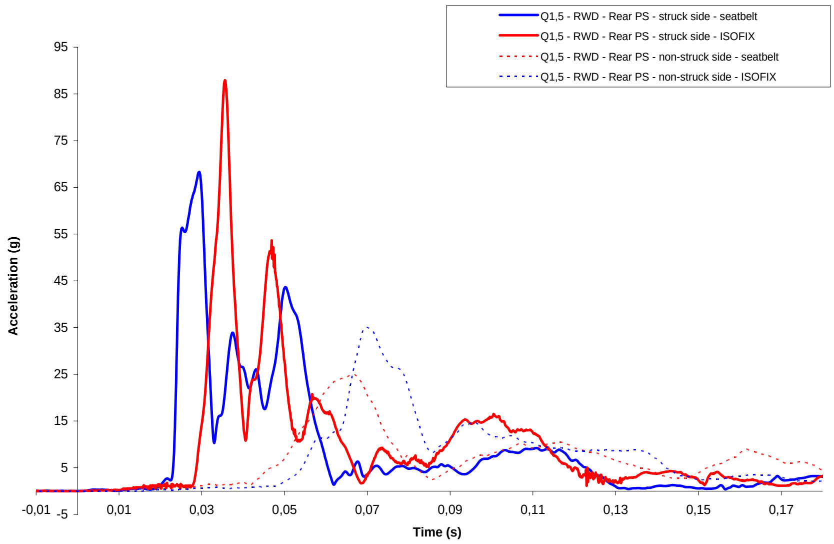
For the CRSs of G0+ installed in the rear lateral positions of the vehicle, the CRS shell is the same but in one case it is fixed on the ISOFIX base and in the next one directly positioned on the rear bench of the car (with seatbelt). Therefore its relative position in the vehicle interior is changed in all directions. This is illustrated on Figure 15. This also has an influence on the total weight of the system tested. What is not measured here and that is independent from dummy results is the change that is induced in terms of ease of installation of the system in the vehicle.

Figure 15: View of the RWD FC CRS G0+ with and without the ISOFIX base

Knowing this, the analysis has been conducted using both on-board videos and dummy readings for each situation (struck and non-struck side). What is visible on videos is that the excursion of the CRS with the dummy inside is higher when the restraint is done using the seatbelt only and leading to a contact with the CRS located of the non-struck side. This is an important factor to consider in the general protection of occupants. The analysis of Figure 16 shows that the head acceleration is higher when the RWD FC CRS is fixed with the seatbelt for Q1½ either on the struck side or on the non-struck side. Previous experience showed that the higher the head is positioned the lower the head acceleration is. Following that it remains unclear whether or not the improvements resulting from the use of the base are associated to ISOFIX connection. For the chest and the pelvis accelerations, dummy readings show lower values with the seatbelt than with ISOFIX base. The timing is also different with the dummy restrained by the seatbelt showing earlier loadings. This seems surprising in a first step as the ISOFIX connectors are rigid and should couple the CRS with the vehicle structure earlier than a seatbelt but the difference in timing is in this case due to a different positioning in Y and Z of the CRS in the vehicle as the base has not been used and that the intrusion occurs firstly in the lower part of the door. For the child dummy located on the non-struck side, as expected, the coupling appears earlier when the CRS is fixed by the rigid ISOFIX anchorages. For the dummies on the struck side, the neck loads in the Y direction are slightly higher with the ISOFIX connection than with the seatbelt only, but the situation is reversed for the forces applied in the Z direction. The neck moment around the X axis shows similar maximum values. On the non-struck side, forces for Y axis are higher for the ISOFIX fixation but remains at a low level. Similar observation is made for the forces in the Z direction, but with a bigger difference and a level that could be significant in terms of injury risk. The level reached on the neck for the moment around X axis is significantly higher in the case of the ISOFIX fixation but remains more than two times lower than the one observed on the struck side. The curve for the dummy restrained in the ISOFIX system on the non-struck side shows a higher value during the rebound than in the loading phase and then reaches a level close to the one of the struck side.



Q1½ head



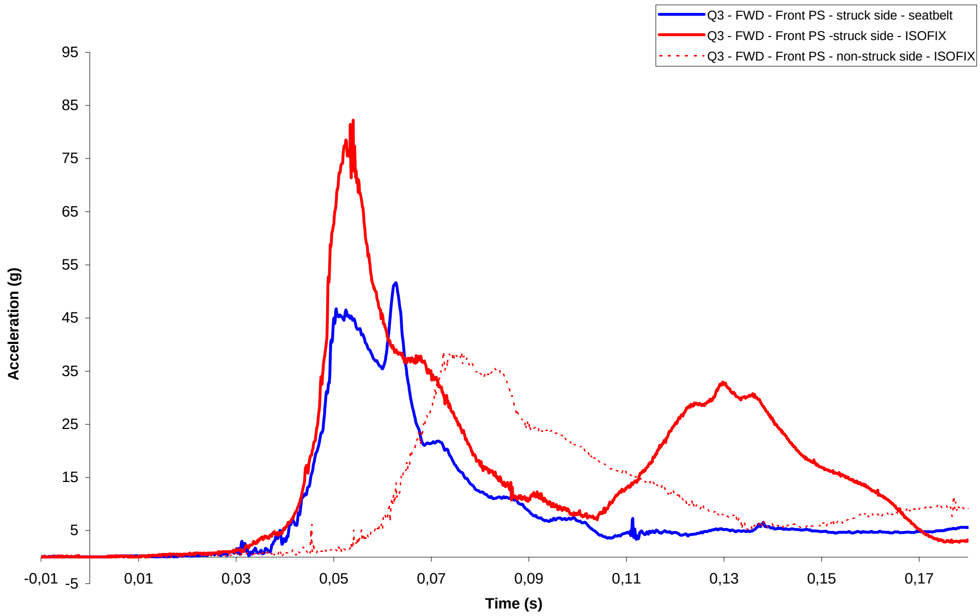
Q1½ chest

Figure 16: Comparison of Q1 ½ readings

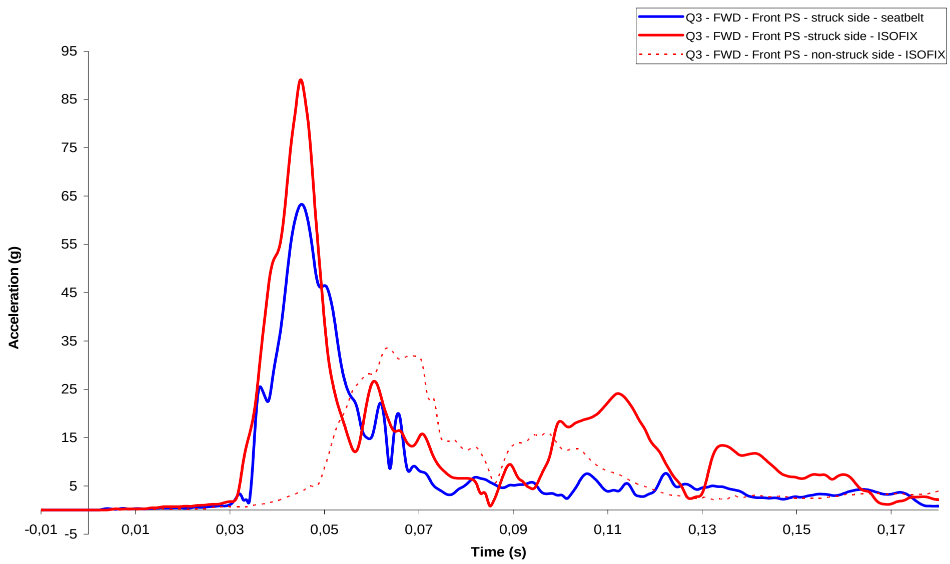
Forward facing G1 - harness:

For this comparison it is important to note that for the Q3 dummy located on the FPS, the CRS used for both tests is exactly the same once used with the ISOFIX connectors and the second time restrained by the vehicle seatbelt.

For the Q3, installed forward facing, only the comparison for the struck side is possible as no test has been conducted with a forward facing system restrained by the seatbelt on the non-struck side. In addition, no neck value is available. Results of the acceleration resultants are shown on Figure 17. For all body segments, the loading timing is similar with seatbelt and ISOFIX due to the proximity of the door panel of the CRS shell in both cases. Values measured on the dummy when ISOFIX connectors are used always higher than with the seatbelt. On the head, chest and pelvis the difference in peak values comparing the restraint solutions are high during the loading phase. The rebound movement seems to be important in the ISOFIX system.



Q3 head



Q3 chest

Figure 17: Comparison of Q3 readings

Limitations and conclusions

The data of the car tests that are used for comparison between ISOFIX and seatbelt fixation, are in a limited number. Results have then to be considered with caution and more results of similar tests could be added. At the moment, test conditions are limited to one car configuration, one set of CRS and one test per configuration. This work could also be extended to other CRS types (e.g. shield systems, boosters)

Other topics – with separate dedicated publications/ presentations

The following topics are major outcomes of the CASPER project so it is important to summarise them in this document and to bring complementary information available at the end of the CASPER project: misuse, shield systems, protection of the abdomen, seatbelt adjusters, …

Misuse

The performance of a Child Restraint System (CRS) is strictly influenced by the quality of its use. During the CASPER Project, CRS misuse has been observed in the field and tested dynamically, in order to evaluate the effect on the protection of children. The publication of this work is part of the 2012 Munich conference [13]. Additional data from other deliverables from CASPER on accidentology [9] and on possible solutions [14, 15] also contains items related to misuse. A summary of these documents is reported in the following sections.

Field data:

Field data from different sources can be considered, results are always that more than half of the children are not correctly restrained when travelling in cars. The tendency is not varying with the time. A deliverable of the CASPER project [1] is reporting the works that have been done on misuse by the CASPER partners during the period of the project. They have been using a common method and data collection form, so the analysis of samples can be done separately and combined. Data have been collected in 3 different locations (Berlin, Naples and Lyon). It considers the field data that have been collected and their analysis, and a study on the evaluation by data collectors of the severity of misuse. As some data were collected in a similar ways than in the previous CHILD project, a comparison of the situation is also proposed for the French data sample.

Main outcomes of field data (checking CRS):

- Misuse of child seats is still a widespread and serious problem. This is true for all three study regions even if there were also significant regional differences, for example, a very high rate of non-use cases in Naples compared to other places.
- The main problem with the use of CRS is the correct belt path of the vehicle belt and the general installation of the child seat in the vehicle. Both problems could be lessened by the use of ISOFIX.
- Field studies have shown that less than 4% of the CRS were fixed with ISOFIX in the vehicle. The CRS market penetration of this system is extremely low considering that the vehicle fleet equipment of ISOFIX anchorages is around 50% [7] and steadily increasing.
- External factors, such as the available time and the trip purpose, have influence on the securing quality.
- Parents want to secure their children correctly, but there is still a great need for the simplification of the usability of child seats.

- Comparison of the CHILD and CASPER surveys: no significant difference found in terms of appropriate use; the average rate of misuse found was about 65% in 2011 (71% in 2003) which confirms that many children are incorrectly secured in cars; the main difference concerns forward facing systems: the installation of the children in this CRS category was better in 2011 than in 2003 with a decrease of some serious misuse, such as incorrect harness use. Regarding booster seats, the most frequent misuse issues were the same in 2011 and 2003 with the lower belt guides often not used and the belt under the arm.
- Unbuckled seatbelt cases were still found in the 2011 surveys, which leads to critical situations in terms of protection.
- Most of these misuses could probably be reduced by giving better information on the effect of misuse and the correct use to parents.
- Difficulties in running comparable field studies in different locations. It seems necessary to define clear parameters for the assessment of misuse severity. All subjective influences should be excluded as much as possible. In addition investigators need to be very well prepared in order to detect possible misuse modes under time pressure conditions. The results have shown that the assessment of misuse differs from one person to another [16].

Accident data :

The CASPER accident database contains the possibility to store relevant data about misuse presence and misuse types [9]. The consideration of misuse remains a challenge and the knowledge continues to grow with the collection of further accident cases, experiences from field surveys and sled testing. In particular it can be difficult to identify low level misuse (for example, small amounts of slack), especially in low severity impacts, and to separate injury outcome from normal crash circumstance and injury outcome from misuse in high severity crashes.

The overall rate of misuse identified (16%) in frontal impacts is lower than figures found in misuse field studies (surveys and checking days). It is likely that at best the database is considering severe misuse, rather than being able to highlight lighter misuse. In the sample most misuse is seen for rear facing infant carriers. This is due to the clear misuse of the CRS being in the place of a deployed frontal airbag, leading to serious injury. For forward facing CRS with harness, misuse situations are well defined and can be found from evidence during investigation, for example, poor seat belt routing (in situ or from marks on CRS) or incorrect harness strap height. For booster systems using the adult seat belt, the details of the restraint condition between the CRS and car and between the seat belt and child are lost at the time of post-accident analysis and identifying misuse from CRS marks and injuries can be challenging. In addition, when using the seatbelt only, only seatbelt marks can indicate (and not in all cases) how the seatbelt was used, and to see if seatbelt friction marks correspond to a correct use of the system, it would be necessary to know the exact height and weight of every child. Nevertheless, special attention has been made by the CASPER investigation teams in order to bring as much reliable data on the item of misuse as possible.

For analysis just two categories are used ‘Misuse identified’ and ‘No misuse identified’. Therefore the definition of ‘No misuse identified’ should be read as ‘No misuse identified with the evidence available’.

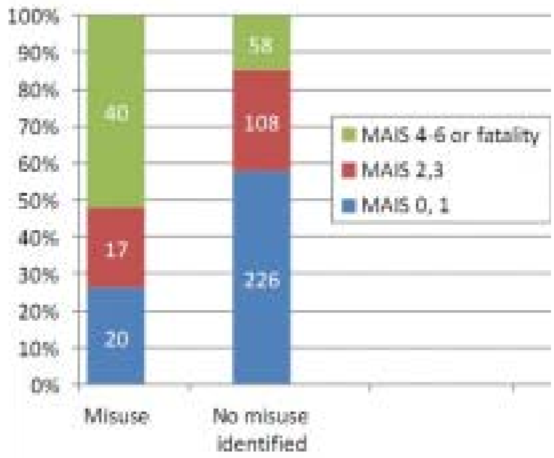


Figure 18: Misuse– Overall injury levels

Figure 18 shows banded injury severity by misuse. A relationship between misuse and injury level is apparent with higher MAIS ≥ 2 injury levels for restrained children in the sample where it has been possible to identify misuse, compared to those restrained children with misuse not identified. There is no control for crash parameters (the cases with misuse may be of overall higher crash severity). Also, cases with misuse in the field but no injury can be difficult to identify because of the absence of hematoma, abrasion and other sign of contact injury between belt and body.

Frontal impact:

To quantify the crash severity in frontal impact, EES (Equivalent Energy Speed) has been used. EES is a translation of the energy absorbed by the car during the crash (based on structural deformation) into an impact speed against a rigid object to obtain equivalent deformations in a crash test.

The distribution of crash severity (EES) (when available) shows as it would be expected that there is a general trend for a shift towards higher EES for higher overall injury level. Of the MAIS ≥ 3 children or those with fatal injuries, approximately half are in a vehicle for which the EES is over 60 km/h and approximately 25% over 70 km/h, exceeding the design criteria of cars and CRS (ECE R44 frontal impact test conditions). Figure19 shows the distribution of crash severity (EES) (when available) for restrained child with known MAIS ≥ 3 injury level or fatalities. Selection for misuse is introduced but no selection for intrusion, direction of force is undertaken.

Including severe injury and misuse in this analysis does introduce complexities, in particular the identification of misuse. For 19 of the fatalities injury details are not known. Injury patterns are one of the main ways of identifying misuse so it is more likely that misuse will not be positively identified for such fatalities. It is expected here that larger differences in EES are observed for lower severities than higher, if the hypothesis is that misuse is causing serious injury or fatalities at otherwise low crash severities. The effect of misuse is likely to be more masked at higher severity as the natural effects of higher severity - higher loads on the body and intrusion - play a larger role.

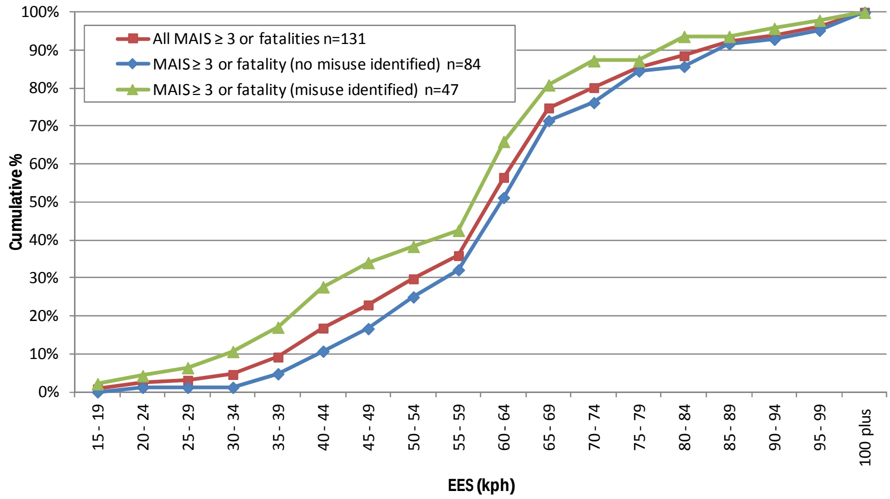


Figure 19: Distribution of EES in frontal impacts – MAIS ≥ 3 and fatalities

Figure19 indicates that at lower crash severities misuse is a factor when MAIS ≥ 3 and fatalities occur, with separation of the misuse and no misuse identified category lines on the figure.

Test data:

Based on recent field data collected in the frame of the project and through partnerships, a new test program has been defined. The testing program was based on the following realistic situations: wrong installation, inappropriate use and child posture. These two last configurations were not considered as misuse in the past but the aim was to test situations close to the ones observed in real life and have a better opinion of the real level of protection of children in cars. The new defined test program is complementary to the one of test results already available (CHILD project). Detailed results are reported in detail in a CASPER deliverable dedicated to misuse of restraint systems [1]. A total of 41 dynamic tests were performed (19 tests are about misuse, 11 dynamic tests about inappropriate use of the CRS, and 11 dynamic tests about dummy posture, sometimes mixed with a common misuse.

It has to be remembered that results are only applicable to the tested configurations (CRS, dummy, type and severity of impact), but global tendencies can be outlined:

- **Dummy behavior**: dummies are not able to measure the full range of injury risks (e.g. effect of having the seatbelt twisted for children using a booster seat, excessive slack in harness that should result in shoulder escaping from harness, ….)
- **Dummy instrumentation**: in a lot of cases, differentiating events using standard dummy readings is not an easy task. Videos are helpful to see differences in global kinematics. Abdominal sensors are also good predictors to evaluate loading in this region. For the moment this sensors are not part of the standard equipment of Q series dummies but only at an advanced stage of prototypes. Dummies are neither equipped to predict limb injuries.
- **Inappropriate use:** The use of the inappropriate CRS for children too young can lead to the ejection of the upper part or of the complete body from the CRS, and potentially to serious injuries. This statement is mainly based on videos combined with the knowledge that children and child dummies behave differently in these conditions due to a difference of rigidity at the level of the shoulders and thoracic spine. When used with a larger dummy than the CRS

was designed for, a CRS can show additional injury risks because of a higher head excursion (risk of head impact with vehicle interior). Additionally there can be a risk of integrity issues due to overloading leading to the risk of projection or ejection of the child and the CRS together. However, this is dependent on CRS characteristics: only high quality products were tested in this series and no global failure was observed. Tests conducted with a Q6 without CRS led to a dramatic increase of the abdominal pressure with a high risk of submarining compared to the same test performed with a CRS. It should be noted that such risk is not typically observed when testing the dummy on the bench without CRS. This highlights the importance of the seat bench and anchor geometry for evaluation procedures.

- **Postural effect**: when the child dummies are positioned in a more relaxed (and more realistic) positions, the risk of sustaining serious injuries is higher for the head and for the abdomen: some head impacts and some seatbelt penetrations into the abdomen have been observed on videos and where associated with high dummy readings. In some postures, only the video is able to indicate that the dummy behave differently than in the reference tests.
- **Wrong CRS installation:** Results vary according to the tested misuse from no visible effect to the separation of the basis and the shell with ejection of the dummy from the sled.
- **Wrong seatbelt route on boosters:** is a critical misuse that leads to not restraining the upper part of the child dummy or to high forces applied onto the lower rib cage and abdominal regions.

Investigations of possible solutions:

A complete deliverable on analysis of solutions and of actions of communications has been written in the CASPER project [15].

Field data have stated that:

- parents need to be made aware that children have to be restrained for every trip
- parents do not always know what is the appropriate CRS for their children,
- most of them are not aware that misuse is an issue, so they do not control the installation of their children as it would be necessary
- parents that have the feeling that their installation of CRS is not correct but do not know what is wrong would need indicators of correct adjustments
- children are sometimes refusing to use a CRS or even to be restrained
- level of knowledge of the public on items such as ISOFIX is not sufficient

Test results have shown that:

- it is very important to communicate to children that the correct use of the seatbelt is crucial for their safety and that it has to be combined with the use of a booster seat until their size is close to the one of adults.
- the choice of an appropriate CRS, its correct installation in the vehicle and the seatbelt route for children on boosters are essential requirements to guarantee the highest protection level for children.
- some systems are easier to use than others, equipped with indicators telling if installation and adjustments of different parts are correct (such as ISOFIX).

Protection of the abdomen

Some publications and presentations on the subject of the protection of the abdomen using accident data were already published during the life of the CASPER project [17], during the Final dissemination workshop of the project [18,19] and in other publications [20-22].

Field data:

Factors such as misuse of seatbelt (e.g. seatbelt under the arm, incorrect belt path around armrests), relaxed postures of children, absence of boosters use for many children older than 7 years of age can all contribute to direct abdominal loading (belt already on the abdomen before impact) and / or submarining behavior (the child pelvis moves under the lap belt which penetrates into the abdominal region) in case of impact.

Accident data:

It's important to consider first that the sample of the CASPER accident database is not representative of the real world situation but focussed on severe frontal and side impacts [9]. The following analysis is extracted from a publication done during the CASPER project [15]. In the global sample, about 20% of the restrained children sustained injuries (all severities) on the abdominal segment. About half of these children sustained AIS2+ injuries. The distribution of injury severity is provided in Table 7.

AIS1	201	44%	
AIS2	110	24%	**241** (53%)
AIS3	76	17%	
AIS4	45	10%	
AIS5	10	2%	
AIS6	0	0%	
AIS9	15	3%	
	457	100%	

Table 7: distribution of abdominal injuries by severity in the CASPER database

About half of the injuries were AIS2+. These AIS2+ injuries occurred mostly in frontal impact (n=207), followed by side impact (n=33) and rear impact (n=1). Overall, the percentage of children that sustained an injury to the abdomen increased with age, reaching a peak around 8 years old. Abdominal injuries were rare for ages lower than 3. The rate of children with AIS2+ to the abdomen was only 4% for children in harness, but it was 14% or more in case of use of booster systems or adult seatbelt only. When analysing in detail the injury patterns for the main restraint types, abdominal injuries were the second most commonly injured region after the head for AIS2+ for booster or seatbelt configurations, and it was the most commonly injured region for AIS3+ for seatbelt only. There were also injuries observed in the limited number of shield CRS (as reported in a separate paper in the current conference). When combined, abdominal and thoracic injuries were more common than head injuries for booster or seatbelt configuration but were still a small fraction of the head injuries (about 1/3) for the harness systems. Finally, there were differences in injury patterns with CRS usage in frontal impact: the hollow organs of the lower abdomen were more commonly injured when no CRS was used, while the organs of the upper abdomen seemed more common when a CRS was used.

Dummy capability to predict abdominal injuries:

The Q dummies are used in research projects and will likely be introduced in Euro NCAP procedures and EC regulation when these are updated. While they are believed to be an improvement over the current P family of dummies, the risk of injury to the abdomen cannot be assessed directly using these dummies as their abdomen is not instrumented. The implementation of instrumentation to assess the abdominal injury risk is necessary for the evaluation of the safety of children in cars. Research has been conducted on this issue in the past EC funded projects CREST and CHILD and in the CASPER project. Several solutions were considered for abdominal instrumentation and the Abdominal Pressure Twin Sensors (APTS) that were previously available for Q3 and Q6 dummies were selected for further evaluation and developments. Among other requirements, abdominal instrumentation should be able to detect the presence and intensity of abdominal loading in a variety of loading conditions that could be relevant for abdominal injuries and across age ranges not covered by adult dummies. Conversely, it should have a limited sensitivity to loading modes that are not expected to create serious injuries (e.g. belt loading the pelvis below the antero-superior iliac spine). Its presence should not affect adversely the biofidelity of the dummy.

Figure 20: APTS in Q6 abdomen (right)

The Abdominal Pressure Twin Sensors (APTS) for Q dummies are composed of soft polyurethane bladders filled with fluid and equipped with pressure sensors. Implanted within the abdominal insert of child dummies (Figure 20), they can be used to detect abdominal loading due to the belt during frontal collisions. APPTS have been mostly used with Q3 and Q6 dummies, but are now also available for Q10 [20]. APTS were used and evaluated in abdominal compression tests using belts and impactors, torso flexion test, several series of sled tests including with degraded restraint conditions [21] and accident reconstructions. The results suggest that the pressure sensitivity to torso flexion is limited. The APTS ability to detect abdominal loading in sled tests was also confirmed, with peak pressures typically below 1 bar when the belt loaded only the pelvis and the thorax (appropriate restraint) and values above that level when the abdomen was loaded directly (inappropriate restraint).

Test data:

Accident reconstructions

Accident reconstructions performed as part of CASPER and previous EC funded projects were reanalyzed. Selected data from 19 dummies (12 Q6 and 7 Q3) were used to plot injury risk curves [23]. Maximum pressure, maximum pressure rate and their product were all found to be injury predictors. Maximum pressure levels for a 50% risk of AIS3+ were consistent with the levels separating appropriate and inappropriate restraint in the sled tests (e.g. 50% risk of AIS3+ at 1.09 bar for pressure filtered CFC180). Further work is needed to refine the scaling techniques between ages and dummies, and to confirm the risk curves. Among others, limitations possibly affecting the risk curves include the small number of accident cases for each dummy, inherent limitations of the accident reconstruction approach (including case sampling). A more complete list of assumptions and limitations that should be taken into account prior the use of the curves is provided in [23].

Testing programs

In addition to the accident reconstruction for which abdominal loading data were required, the need of having a device to detect the risk of abdominal injuries to children has been underlined during the test programs duration of the CHILD and CASPER projects. Many tests were conducted and reported such as misuse test programs [13] and procedure works sled test programs. The APTS have shown their ability to detect situations for which the restraint conditions were not safe on the abdominal segment. They also have indicated unsafe situations in series of tests for which looking only at conventional dummy readings would have made no difference or would have orientate in the wrong direction in terms of child protection.

Latest developments and further needs:

Overall, based on the current results, it is believed that the APTS may be used in the future as a pragmatic tool for the assessment of the abdominal loading in Q6 and Q3 dummies. Their expansion to other dummies and loading scenarios is also considered. Their evaluation in the Q10 is ongoing and they were already used with the Thor adult dummy [22]. Their implantation in Q1.5 is ongoing and a first version should be available in the first half of 2013. Preliminary work performed for the evaluation of shield CRS [24] and side impact loading should also continue.

Discussions are on-going between the GRSP Informal Group on CRS with dummy manufacturer to have a tool able to predict abdominal injuries in the Q dummies for the new regulation for CRS certification.

Shield systems

Shield systems were used up to the 90's and were almost completely replaced by other CRS types afterwards. Today they are subject of a revival, probably because they are well rated by consumer organizations and easier/cheaper to produce than classical harness systems (no separate buckle, no harness anchor and adjustment in the back, etc) An increasing demand has led to new products coming on the market that are approved according to ECE R44/04.

During the second half of the CASPER project, while preparing the study on the risk of abdominal injuries, questions were raised about the safety performance of shield systems. Even if not in large number in the CASPER database, it would be interesting to analyze the data available for shield systems. These are both Group 1 and 2 systems and much of the accident data were studied during the CREST project (1996-2000). Experts wondered if the risks of injuries on the different body segments such as neck, chest and abdomen were different than for harness or booster systems as loading modes are totally different. It was considered important to spend some additional time on this item at the very end of the project, in order to bring the following points to the discussion: what is the level of protection of shield systems, are the tools used for the approval and consumer tests able to predict injury patterns specific to this kind of restraint systems?
A publication and presentation in the 2012 edition of the Munich conference [24] is based on accident, test and reconstruction data available at the moment to feed the scientific community with up to date results and initiate a debate

Further publication of results on this items are planned with new data results included when available (this will be done out of the CASPER project).

Conclusions

In the Casper project, multiple approaches were used to study the issue of safety of children in cars. Approaches presented in the current paper include field studies to account for actual use (partially in collaboration with CEDRE and IBSR), accident analyses and their reconstructions, and dummy testing. The combination of the results helps defining a better picture of the current level of protection, and gives indications of what could be done to further improve it:
Frontal airbags seems to be beneficial for children installed forward facing in terms of safety, but further evidence is necessary to confirm this statement that is for the moment based on tests with the system that seems to be the most aggressive (low-mounted systems). The situation is different for children installed rearward facing: dummy test results confirm the phenomenon observed in road accident studies: the risk of head injuries is increased when the rearward facing system is loaded by the deployment of a frontal airbag, especially in the low-mounted airbags configuration.
Side airbags reduces the dummy readings in the test performed with a forward facing G1. No other type of CRS has been tested in this configuration, but no benefit is expected for rearward infant carrier. Accident data, even if in few number are confirming this beneficial trend of seat mounted airbags for children using the adult seatbelt. Here again, more tests are needed with different configurations of airbags and CRS. The benefit of curtain airbags has not been highlighted neither by tests performed (only with a rearward infant carrier) nor by accident data.

Fields studies have shown that the issue of misuse is still real, and accident data indicates that children for whom a misuse situation has been identified are clearly more are risk than others: severe injuries occurred in lower energy crashes for children with misuse than for the group in which no misuse was identified. Test data with dummies are confirming this trend and a large number of misuse configurations have been evaluated.

The protection of the abdomen of restrained children remains a challenge for the coming years. Accident data have indicated the need of protection of this body segment, different size of child dummies have been modified and equipped with pressure sensors in order to be able to predict abdominal injury risk. The next step is to bring this research tool into an industrial version and consider it for inclusion in the regulation process for CRS approval.

Research is still on-going on the shield systems in order to clearly identify if these systems are really offering a good protection level. With the arrival of a new dummy generation equipped with chest deflection and abdominal sensors, new tests have been performed and accident data have been checked. It seems necessary to consider that these systems are loading differently the body of the child and that the criteria applied in the regulation for CRS approval is may be not adapted to prevent from injury mechanisms induced by this type of loadings.

Perspectives

Using the same kind of approach, two other topics could be interesting to analyze because many question are raised in working groups on them:

- **To evaluate the influence of the appropriateness of the restraint systems**.
It is known from field data that parents have tendency to switch their children from one restraint system to the one of the next category too early. It would be interesting to check in which proportion and what are the main reasons for that. It is also interesting to check if this inappropriate use leads to an increase of misuse situations (because of comfort issues for example).Then an analysis of accident data would be helpful to identify if this situation leads to a higher risk of being injured, and if yes, what are the consequences. Different categories of inappropriate use could be then considered children using forward facing systems when rearward facing ones would be preferable, the ones restrained by the seatbelt on boosters when harness systems use is still appropriate, and finally and also the most numerous ones, the children only restrained by the seatbelt while a booster cushion is still required. Test data could be used to see how this effect is translated by child dummies, and recommendations for phase 2 and phase 3 of the new text of regulation under construction by the GRSP informal group could be proposed.

- **To differentiate the protection between highback and backless boosters**
Field data would be used to see what the rate of use of the different systems is and how they are used, what are their advantages and disadvantages (user point of view, ease of use, protection capability, seatbelt positioning…). Up to now no differentiation was done in the CASPER accident database between both systems. This point could be updated and complementary analysis could be performed to check if a difference is visible in terms of injury patterns. Tests data with both systems have been run in the different tasks of the European projects and working group. They could be synthesized for this occasion. Results of this works could be then included in the on-going discussions of the GRSP informal group on CRS that needs to define the limits for which boosters need to be provided with a backrest to ensure a good level of protection of children.

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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.*

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