CHILD PROTECTION IN CARS – ADVANCES & KEY CHALLENGES

Farid Bendjellal
Britax Childcare Group

This paper deals with some of the key advances that occurred in the regulatory domain, the design and the testing of child restraint systems. Design of rear seats in vehicles is discussed in relation to enhancing child protection in both frontal and side impacts. Vehicle structural stiffness is also discussed in terms of increasing forces to occupant that need mitigation. Key challenges in terms of side impact test procedures and enhancement of the regulation are dealt with.

Keywords : Child Restraint Systems, ISO, Seats, Interiors, Misuse

CHILD SEATS ENVIRONMENT

A child restraint is a resultant of a number of constraints which can be divided into 6 main domains : regulatory, consumer testing and evaluations, real world exposure, CRS manufacturer experience, market demands and vehicle design, as illustrated in Figure 1. A child restraint system (CRS) is a special automotive safety device as it belongs to 2 worlds : the childcare domain and the automotive domain, both domains having their own specifications and demands. That means that a variety of requirements have to be met before the seat enters the market, leading to a broad and integrated approach. Broad approach because of the technical knowledge that is involved and integrated approach because it is essential to ensure a minimum level of compatibility between the CRS and the vehicle.

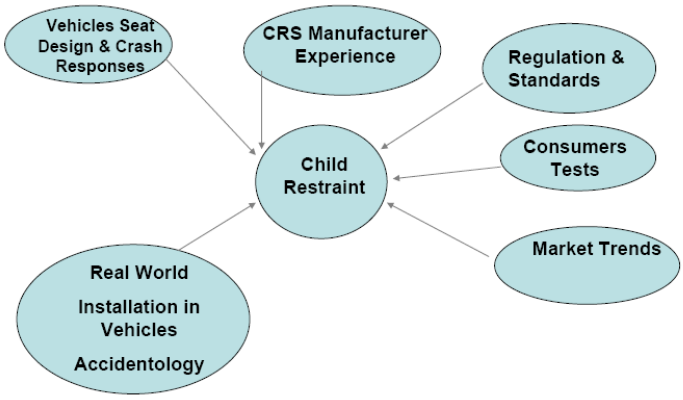

Figure 1 - Nature of constraints considered in developing child seats

A BRIEF HISTORY OF CHILD SEATS

From the late 30's to the 50's convenience seats have been used for children in cars. The seats were simple tubular devices hooked over seat backs, with canvas and fabric as shown in Figure 2. The development of adult seat belts, from aircraft belts, during the mid to late 50's led to the need for "proper" child restraints being identified and addressed in the early to mid 60's. The first standard on child restraint was established in the UK in 1964. The standard, BS 3254, included a 20 g pulse at 48 km/h sled test and requirements for a 4-point attachment system. During the 70's child restraint standards were introduced in Australia and USA in 1971, Germany in 1973, Sweden in 1974, The Netherlands and France in 1975. UN ECE R44-00 was introduced in Europe in 1981 with provisions for restraining children from 9kg to 36kg. Requirements included a dynamic test and performance

criteria. The same year FMVSS 213 was upgraded with a dynamic test. Later on UN ECE R44 was upgraded with 01 and 02 series of amendments in 1982 and 1986. 1990 is one of the major milestones in the history of child seats with the start of ISOFIX project in ISO. In 1995 UN ECER44-03 was introduced with major advancements such as strong crotch straps, testing of belt lock off devices, test bench updated to include inertia reels. In 1999 , the USA introduced the LATCH system, Lower Anchors and Tethers for Children, which consists of an upper anchor (top tether) and two lower anchor points. In 2004 UN ECE R44-03 was updated with ISOFIX specifications, as well as UN ECE R16 (Safety Belts) and UN ECE R14 (Safety Belt Anchorages). In February 2006 ISOFIX system became mandatory for all new vehicle models sold in EU. Along side the regulatory activity consumer tests were implemented in various countries. In EU Stiftung Warentest has conducted since 1973 a comparative evaluation of CRSs. Usability and crash performance are the key areas investigated (Görlitz, 2005). At present, a unified assessment system is being developed in EU within the NPACS organisation. Its aim is to implement more demanding crash performance criteria including a side impact test procedure with a moving door, as well as usability criteria. More details on NPACS can be found in reference (Lowne, 2005).

Figure 2 - An example of early child seat

CHILD SEAT DESIGN

A child restraint might be defined in different ways. In general it is a system comprising a structure- a shell for instance- to which a harness is attached. The harness, whose function is to secure the child to the CRS, includes straps, a buckle and adjustment devices. The structure of the seat is covered with a fabric that includes foam and energy absorbing means. The whole system is designed to be restrained to the vehicle with the vehicle seat belt or with ISOFIX, as shown in Figure 3. As the child grows its anthropometry changes, hence the need to have different sizes for the restraint. Using the UN ECE R44 terminology, child restraint fall into 5 mass groups:

- Group 0 and 0+, respectively for a mass less than 10kg and 13 kg
- Group 1, for children of mass from 9 kg to 18 kg
- Group 2, for children of mass from 15 kg to 25 kg
- Group 3, for children of mass from 22 kg to 36 kg

Another classification which is important is an integral or non integral restraint. According to UN ECE R44 04 “An integral restraint is a system where the retention of the child within the restraint is independent of any means directly connected to the vehicle; a non integral restraint is a system where the retention of the child is dependent upon any means directly connected to the vehicle”.

Figure 3 - A CRS : Structure and components (2001 design)

Infant carriers fall into Group 0 and 0+ categories and are recommended for use with infants in rear-facing mode until at least 1 year. Forward facing seat with harness will fall into Group 1 category. Booster seats belong to Groups 2 and 3. There are however seats which cover more than one group, i.e. rear facing seats for Group 0 and 1, or for Groups 0, 1, and 2, or combination seats which are approved for use in rear facing mode as Group 0+ and for use in forward facing mode as Group 1. For convenience there are forward facing seats which are designed to cover Group 1, 2 and 3 categories. Other countries such as Australia and USA are using different categorisation. Figure 4 shows the current child seats categorisation in the USA, Australia and EU as a function of the age and mass of the child. The common point to these regulations is the infant carrier category which is consistent in mass and age.

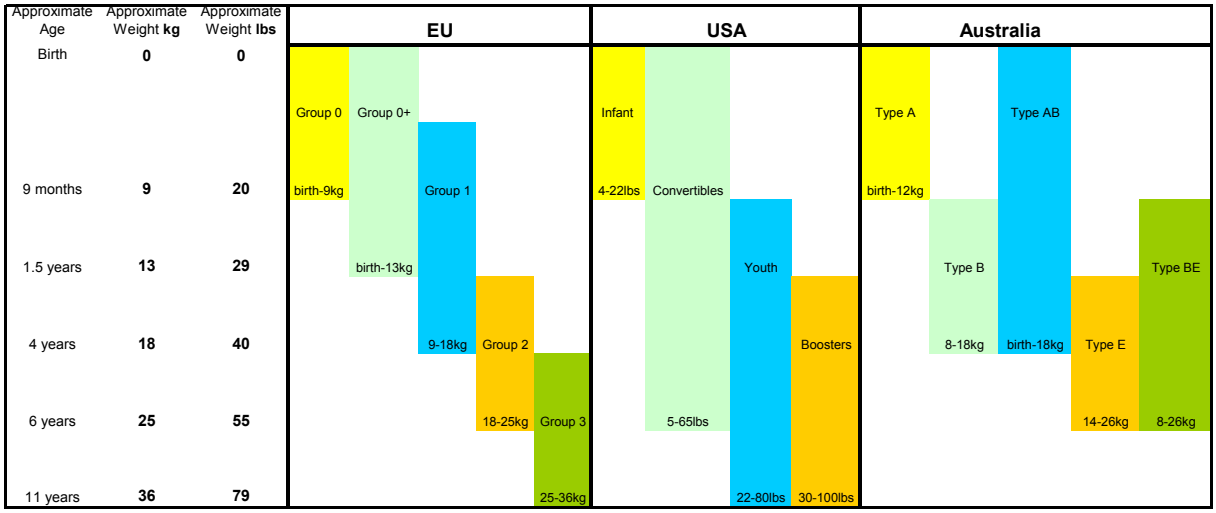

Figure 4 - Child seat categorisation in 3 jurisdictions

THE SPECIFICS OF THE CHILD RESTRAINT

One of the specifics of child safety in cars is that in case of an accident the occupant excursion is a sum of 2 displacements, the CRS displacement relative to the vehicle and the occupant displacement relative to the restraint. Therefore the child restraint performance in crash is critically dependant on the efficiency of both the coupling of CRS to the vehicle and the child to the CRS.. That leads to a very important subject in child safety area, known as the misuse.

EFFECT OF CRS MISUSE

The use of child seats in vehicles is subject to misuse. There are numerous studies that illustrate the nature and frequency of misuse. From studies conducted in the USA and Europe, it appears that the most typical misuse situations are:

- Loose vehicle belt
- Loose harness belt (in the CRS)
- Improper harness position in relation to child age
- Direction of CRS
- Improper belt or harness position in relation to the occupant (child being disengaged from the harness)

A number of campaigns were conducted by Britax with different institutions in the UK, i.e. Good Morning TV, Trading Standards, Road Safety Officers and parenting magazines. The objective was to measure the misuse situation and provide advice to users. In the misuse studies parents are invited to specific sites for a "free" safety check of the installation of the child seat. Experts investigate the case, record the information and where necessary the installation of the CRS is corrected and simple recommendations given to users. The recent misuse survey conducted with GMTV in 2006 (Bennett, 2006) showed that moderate to serious misuse was found in 63% of cases and correct use was determined in 37%. It is interesting to note that all Isofix type seats were found to be correctly installed. Compared to a previous study carried out in 2004 the correct use of CRS installation has improved by only 1% and serious misuse was reduced by 1%.
A recent study conducted in Germany by the MVU for BAST (Fastenmeier, 2006) indicates that misuse rate found in the 2006 survey is at 65%, i.e. a level that was also repoted in previous investigations done by Bast in 1995 and GDV in 2000.
This data confirm the need to develop solutions which will help address the problem in broader terms, including technical innovations and more importantly constant and focussed consumer education.

To explore the effect of some misuse modes sled tests using UN ECE R44 environment were conducted at Britax EU test facility. The test set up included a Group 1 seat and a P3 dummy. Four tests were conducted and for each test a specific set up was used for either the adult belt tension, or the harness tension or for both. HIC, the chest resultant acceleration pass/fail criterion and head excursion were used to measure the effect of the induced misuse modes. As can be expected the head excursion and HIC are higher with the condition where both the harness and the belt are loose. That means a higher risk for the occupant contacting the vehicle interior components. This basic data shows the need to ensure a proper use of CRSs in the real world.

	Head Excursion mm	Chest Resultant 55 G 3ms	HIC
ECE R44 Set Up including a spacer bewteen the dummy and the seat	488	pass	438
Loose Adult Belt & Tight Harness	498	pass	453
Loose Adult Belt & Loose Harness	550	fail	501

Table 1 - Experimental simulation of misuse modes with UN ECE R44 set up as a reference

ISOFIX

As mentioned earlier in the paper, ISOFIX (ISO 1999, 2005 & 2006) is a system that was developed by International Standard Organisation Working Group on Child restraints with the aim to reduce the misuse rate observed with conventional systems. It is probably one of the most innovative restraint approaches developed so far in the domain of child restraints. It consists of two anchor points (6mm rigid bars) that are located near the intersection of the seat back and the seat cushion. The system is completed by an upper anchor point for the top tether. The child restraint is equipped with rigid components (connectors) capable of latching to the vehicle anchor points, as shown in Figure 5a. An ISOFIX restraint comprising an ISOFIX base and a rear facing infant carrier is presented in Figure 5b.

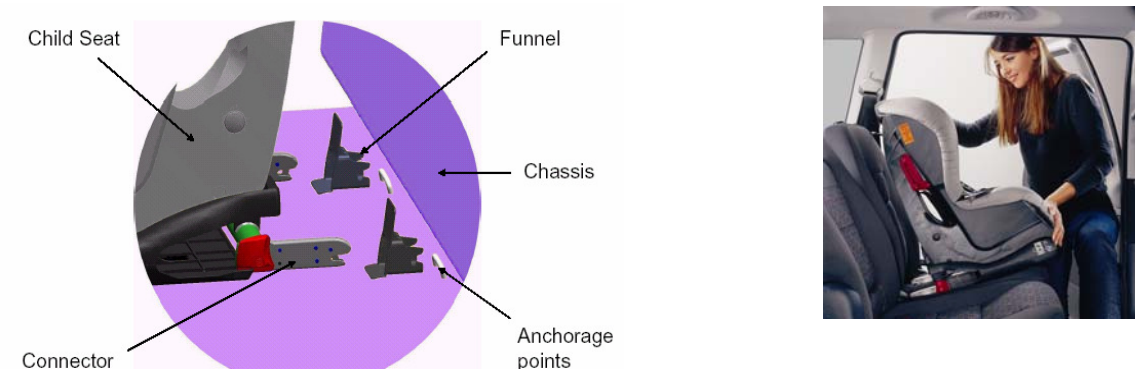

Figure 5a - Isofix system and an example of a Group 1 forward facing seat

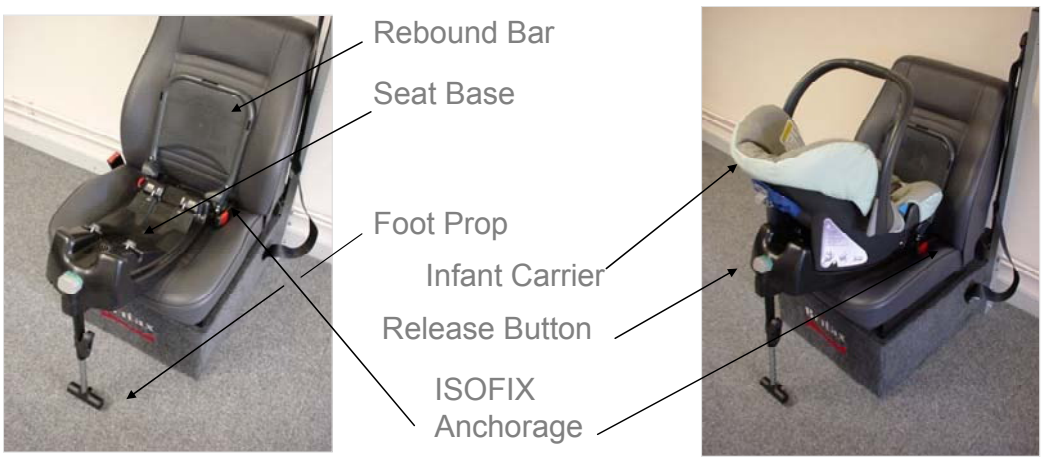

Figure 5b - A rear facing seat with its base (left), complete system seat and base (right)

To illustrate Isofix effect on the performance of a CRS two seats were tested in a UN ECE R44 environment. These were a forward facing seat with belt attachment and an ISOFIX seat equipped with a top tether. The belted seat allowed having an initial head position which was 16 mm from Cr point, i.e. further back that the head position in the ISOFIX seat which was 78 mm from Cr point. Despite the "deficit" in the initial head position, the total head excursion is much lower with the ISOFIX system and that is due to the much more reduced seat displacement with the ISOFIX, as illustrated in Figure 6.

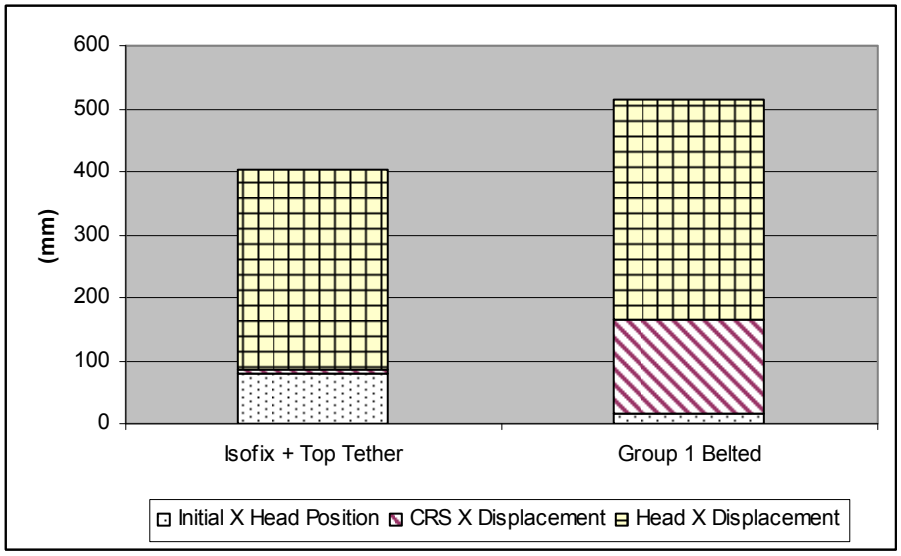

Figure 6 - CRS X horizontal displacement and P3 dummy's head X horizontal displacement. Comparison of a forward facing facing belted system and a seat equipped with ISOFIX and Top Tether in a UN ECE R44 environment.

MISUSE AND TECHNICAL INNOVATIONS

The loose harness mode is one of the most frequent misuse modes encountered in the studies mentioned previously in the paper. One of the main reasons for that situation is that the user has no indication when correct adjustment is achieved. The Safe Strap system was developed by Britax with the aim to provide such indication. The system is mounted on one of the straps of the CRS harness and comprises 2 members which are pivotally coupled. The upper member as shown in Figure 7 is equipped with visual pictograms illustrating the status of the harness tension. When the tension is incorrect the member is in a raised position thereby indicating that the tension is not correct. Pulling the adjuster strap of the CRS will reduce the slack and increase the tension in the harness; the upper member is then deflected to a flat position within the profile of the chest pad.

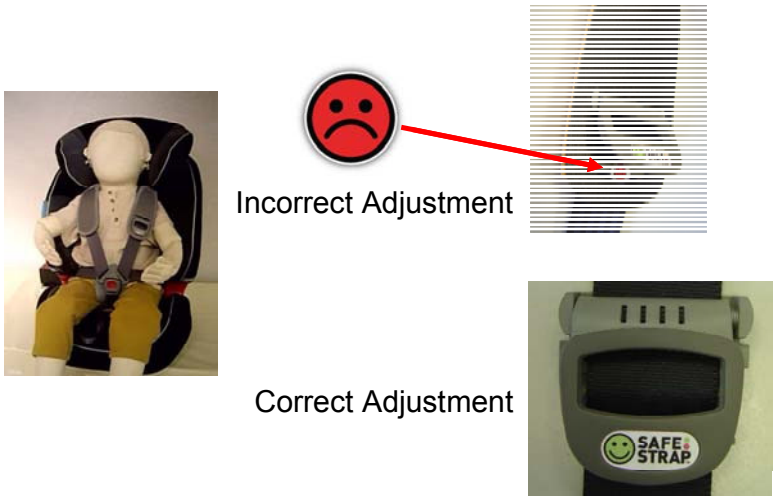

Figure 7 - Safe Strap System : Upper right hand side figure shows the upper member in its raised position (incorrect harness tension), lower right hand side figure illustrates a correct tension.

VEHICLE DEVELOPMENTS

In terms of regulatory framework child restraints and vehicles are approved along different paths. Considering European regulations associated with child restraints, vehicles are designed with respect to UN ECE R16 (Safety belt and restraint systems, (UN ECE, 2007) and UN ECE R14 (Safety belt and Isofix Anchorages, (UN ECE, 2007). Child restraints are designed and approved with respect to UN ECE R44 (Child Restraint Systems) (UN ECE, 2007) and UN ECE R16. Therefore the only regulatory common ground for both the vehicle and the child restraint is UN ECE R16. To ensure an acceptable level of compatibility between the 2 systems additional efforts are necessary. Since the adoption of Isofix in UN ECE regulations the geometrical compatibility between CRS and vehicles has improved since both system have to meet ISOFIX volumetric requirements. Figure 8 illustrates a CAD volumetric check of the rear seat of a family car.

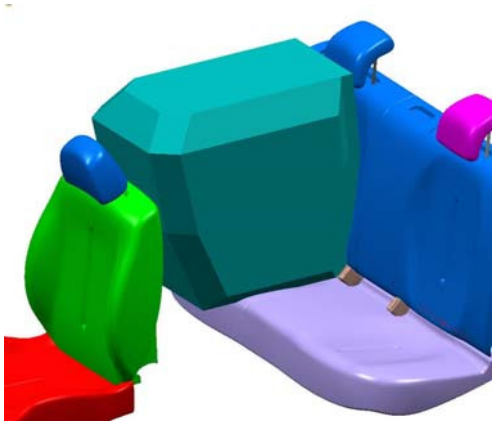

Figure 8 - CAD volumetric check using ISOFIX gabarit on C4 vehicle

VEHICLE DESIGN AND TRENDS IN STRUCTURAL STIFFNESS

There are other aspects in the design of vehicles that have to be considered in relation to child restraints. Among the most important aspects one can mention:

- the length of the seat belt buckle,
- the position of the headrest which may or not interfere with the CRS installation,
- the space available between 2 rows of vehicle seats,
- the vehicle seat cushion stiffness, for instance the presence of an anti submarining rampe in the vehicle seat,
- the accessibility to ISOFIX bars
- location of Top Tether anchor, e.g. seat back or luggage compartment.

In terms of crash response the vehicle behaviour will obviously have an influence on occupant protection, including children. In order to comprehend that influence a study was conducted on the deceleration pulses obtained from EuroNCAP tests, involving 2 successive generations of the same models. The data was collected from frontal impact tests that were conducted on 3 car categories: super mini, family and MPV. To facilitate the interpretation of the deceleration data, these were translated into simplified pulses with initial and major deceleration plateaux. Figure 9a represents pulses as obtained from 6 vehicles, i.e. 2 vehicles per category. It can be seen that the 2nd deceleration plateau (17G) of a 2004 car is now attained by the first deceleration plateau of a 2005 super mini category. As a consequence of the structural integrity criteria, most of recent cars display a 2nd deceleration plateau at or above the 30 G level in the EuroNCAP offset tests, Figures 9b through 9c illustrate deceleration pulses as function of time for a super mini vehicle (9b), a family vehicle (9c) and an MPV (9d). For the super mini vehicle the comparison pulses show a slightly

higher 2nd plateau but a significant 1st plateau which is the double of that of the 2000 model. For the family and MPV as shown in Figures 9c and 9d, the 2nd plateau is much higher for the 2006 models with an increase of 34% to 47%.

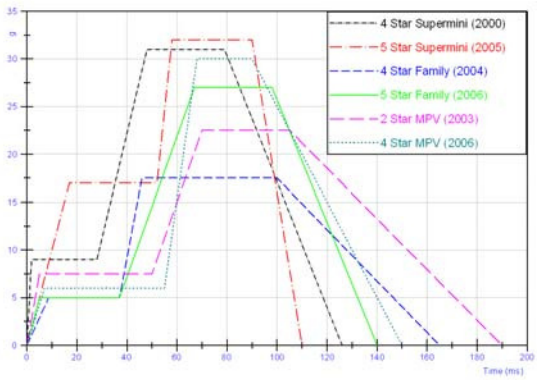

Figure 9a - Simplified deceleration pulses (B pillar) from various EuroNCAP tests (2000 to 2006 models)

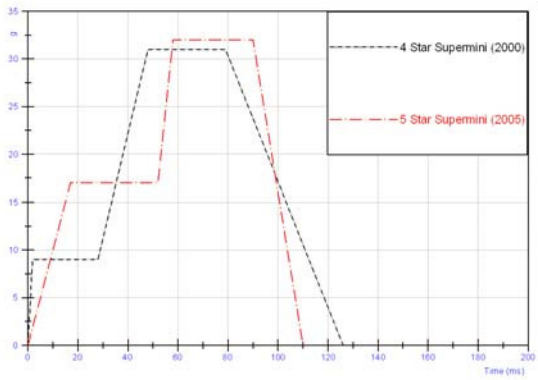

Figure 9b - Simplified deceleration pulses (B pillar) from super mini car tests, comparison of 2000 and 2005 models

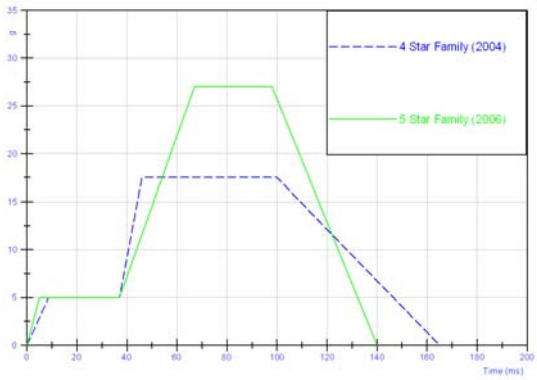

Figure 9c - Simplified deceleration pulses (B pillar) from family car tests, comparison of 2004 and 2006 models

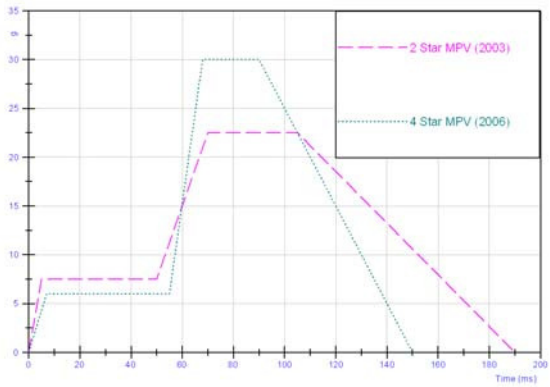

Figure 9d - Simplified deceleration pulses (B pillar) from MPV tests, comparison of 2003 and 2006 models

Although the number of cases is low, the data from the simplified deceleration pulses show a real trend in the increase of vehicle stiffness. The effect of this situation on occupant protection in case of impact translates into higher occupant loads . Figure 10a and 10b show time histories of the head and chest acceleration of the P3 dummy. The data was obtained from tests involving the same CRS model (ISOFIX) and MPV models from 2003 and 2006. In the case of the 2006 test the chest acceleration of the P3 shows a 35% increase (peak to peak) while the head acceleration has increased by 14%. In a crash situation involving a head on collision, i.e. with more overlap, the vehicle deceleration will be much higher, thus posing a real challenge for occupant restraint systems.

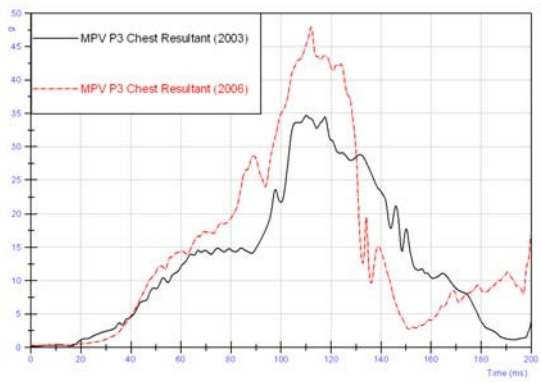

Figure 10a - P3 child dummy chest resultant acceleration time history, in MPV 2003 and 2006 EuroNCAP tests (same CRS).

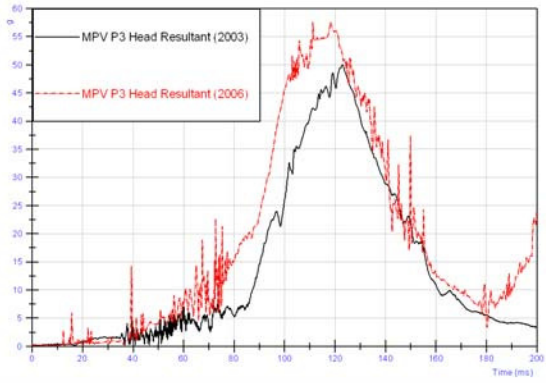

Figure 10b - P3 child dummy head resultant acceleration time history, in MPV 2003 and 2006 EuroNCAP tests (same CRS).

ACCIDENTOLOGY

Accidentology is a vast subject and given the scope of this paper, we will limit the discussion at the macro level. Based on the CHILD data set project analysis (Grant, 2006) it appears that in frontal impact the head is still the most injured body region in terms of AIS2+ for all types of CRS. Injuries to the extremities are also present in a significant proportion, close to that of the head except for rear facing child restraint. Neck injuries do not seem to be important in the data set, while thoracic and abdominal injuries are observed for all types of CRSs, and in particular for booster seats and for cases with adult seat belt.

CHILD project has investigated side impact accidents involving 287 children, 100 restrained with adult seat belt and 187 were secured in CRSs (Lesire, 2006). The sample was reduced down to 284 children for crash data availability. The data shows that the intrusion has a significant effect on injuries: 80% of restrained children on struck side without a direct intrusion had no severe injuries or no injuries at all, while 14% sustained severe injuries. For cases with direct intrusion 1/3 of occupants had serious or fatal injuries, 1/3 were moderately injured, and 1/3 not or slightly injured. The same study shows that over 300 mm of intrusion, more than 50% of cases showed MAIS 4+ injuries. As regards injuries to body regions, the study identified a high exposure of the head for shell systems (3/4 of AIS2+), booster seats and booster cushions (50% of AIS2+). Other body areas are also injured but the exposure varies with the restraint system. For instance the chest risk for AIS2+ goes from 4% with shell systems up to 11% for boosters and 14% for adult belt restraint. The investigation showed also an exposure of upper and lower extremities.

In summary the study showed a positive effect of CRS use in protecting children, the critical role of the intrusion in the vehicle, and the need to protect in priority body areas such as the head, the chest for all types of restraints, the abdomen and pelvis for booster seats and the neck for shell seats. It should be noted that protecting these body areas will be made possible with a combined effort on the vehicle, i.e. reducing the intrusion for occupants seating in rear seats, improving vehicle interior with regards to direct contacts with occupants, and enhancing the child seat design. The development of a standardized side impact method for CRS will certainly help achieving a better protection for children. The need for such a test procedure is also confirmed by another accident investigation from the University of Hannover (Otte, 2005) which also emphasised the good safety level reached in protecting children in accidents, and the need to reduce misuse rate, and more importantly in-depth research on injury mechanism and measures for car interior design.

KEY CHALLENGES AHEAD

Among key challenges ahead of us for improving child safety the side impact subject appears to be a dominant one. Certainly an agreed and repeatable test procedure for CRSs will help industry and regulatory bodies to provide and measure protection solutions. A complex side impact test procedure may have adverse effects in that it could not be manageable by all test laboratories In addition to the test procedure, child safety in side impact will benefit from a combined approach integrating features on the CRS and an improved interior car design. Examples of improving side impact protection are shown in Figure 11. Requirements for energy absorptions might be challenged by other considerations such as occupant comfort or vision.

UN ECE R44 regulation allowed to reach a satisfactory level of child safety as shown in various accident investigations (Otte, 2005). As the knowledge advances it is sometimes worth revisiting the regulation to allow for innovations to be introduced. For instance UN ECE R16 (safety belts) was amended in 1996 to allow the introduction of load limiters on vehicle seat belts. Accident investigations carried out on cars equipped with such features showed a real benefit in terms of adult safety. In the case of UN ECE R44 some requirements may need a revisit. The requirement limiting the vertical head displacement of the dummy in the sled test needs a review to allow further improvements in booster seats and large rear facing seats (Clepa, 2006).

The misuse as shown by various studies remains present even in countries with a long standing safety education. This challenge is and will be a constant challenge that needs a continuous effort from all stakeholders, in promoting proper use of child restraints and also in explaining the benefits of systems such as ISOFIX.

Figure 11: Enhancing side impact protection (2 generations of group 2-3 booster seat). Left 2004 design, right 2006.

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UN ECE Regulation 14-06concerning the approval of vehicles with regard to safety-belt anchorages, ISOFIX anchorages systems and ISOFIX top tether anchorages

UN ECE Regulation 44-04 concerning the approval of restraining devices for child occupants of power-driven vehicles ("child restraints").