CHILD RESTRAINT SYSTEM FOR CHILDREN IN CARS – CREST RESULTS

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ABSTRACT

Child restraint systems (CRS) for cars are intended to protect children in the case of a car accident. Unfortunately their effectiveness is still too low: in the range 30-50 % when it would be expected to be much higher. The low effectiveness of child restraint systems can partly be explained for the youngest passengers by their greater cervical vulnerability and for the oldest (from 3 to 12 years old) by the morphological immaturity of the pelvis. However, tools available to evaluate the effectiveness of CRS are very poor, as well as knowledge on injury mechanisms and criteria.

The CREST project was created to develop the knowledge on child behaviour and tolerances, the final aim being to propose new test procedures for determining the effectiveness of CRS using instrumented child dummies. Eleven partners were involved, namely Fiat Auto-SpA (with Elasis), INRETS, PSA Peugeot Citroën, Renault, TNO Automotive, TUB, RICE, BAST, GDV, MUH, VTI.
The method used in this project was to collect data from accident investigations and from reconstruction crash tests in order to determine the physical parameters (forces, accelerations and deformations on the child) which correspond to the various child injury mechanisms. Hence, limits should be prescribed under which injuries could be avoided.

This paper presents roughly the methods used for the achievement of this project and the main results. In particular, data from the 56 accident reconstructions are presented and injury criteria are evaluated against reconstruction results.

INTRODUCTION

Protection systems for child passengers in the European Union must comply with ECE regulation 44 which aims at ensuring a good safety level. From the accident protection viewpoint, this regulation consists mainly in a frontal impact test where physical measurements performed on dummies shall not exceed specified limits. Evaluation criteria cover kinematics and acceleration for the thorax.
The analysis of accidents involving children reveals that child restraint systems (CRS) in compliance with European regulations give highly contrasted levels of protection in real-world accidents. The main reasons for this are on the one hand the lack of biofidelity of the dummies, and on the other hand the insufficient biomechanical knowledge on injury mechanisms and associated physical parameters.
Unlike for the adult, child impact tolerance or behaviour cannot be determined directly by experiments on human bodies. The main sources of data up to now come from child free-fall studies, aircraft field investigations, animal testing, scaling from adults and very few post-mortem experiments on human subjects. The principle of this program was to perform reconstructions of well documented real-world crashes and to compare measured physical parameters with the corresponding sustained injuries.

Hence, the main objectives of the program were:

- to determine the physical parameters corresponding to various child injury mechanisms,
- to prescribe limits under which injuries can be avoided,
- to develop new test procedures for determining the effectiveness of child restraining systems for cars, using instrumented dummies.

METHOD

In order to achieve the objectives, the project was divided in four working packages (WP):

- WP1 consisted in a detail analysis of traffic accidents involving children using protection systems.
- WP2 consisted in experimental reconstruction of several selected accidents to acquire the biomechanical data necessary for limits to be set for the parameters measured on dummies.
- WP3 consisted in the acquisition of appropriate test tools to conduct the experimental work

(WP2), by improving dummies and measurement techniques.

- WP4 intended to propose test procedure improvements and to validate their feasibility.

Accident Data Collection (WP1)

About four hundred accident cases involving restrained children were gathered in France, Germany, Italy and Great Britain, according to a common and well defined methodology, which was described in a paper from Lesire, 2001 [1].
All cases were in-depth investigations, collected with two aims:

- the analysis of injuries in relation with the use of protection devices,
- the experimental reconstruction.

Figure 1. Accident case collection

For that, all dockets had to include two complementary parts:

- a medical docket including at least the description of all occupants with age, weight, position in the car and for all injuries, the typology and level of AIS.
- a technical docket including accident configuration, measurements of car deformations, information on restraining occupant system used and adjustments.

A specific form was developed for this purpose and a database was constructed and filled with all cases.
More details and findings from this part are presented in the paper from Lesire, 2001 [1].

Accident Reconstructions and Sled Tests (WP2)

Because the biomechanical tests with the body of a child are very seldom for obvious cultural reasons, because child is not an adult at reduced scale and the scaling approach does not allow the transfer of knowledge from adult to child, the crash test reconstruction of an actual accident with a fully instrumented dummy, having a comparable anthropometry, constitutes the right and appropriate methodology to acquire the missing biomechanical knowledge relative to the children. This knowledge is absolutely essential to be able to optimise the design of protection systems for child car passengers.

The objective was to establish correlations between the child injuries observed into the actual accidents and the dummy measurements obtained through the crash reconstructions.
The specific cases for reconstruction were selected according to several criteria:

- involved injury mechanism representative of the most often observed causes of injuries (for example brain and neck injuries for the youngest children or abdominal injuries for the oldest),
- fully documented file to limit the number of uncertainties on the actual accident conditions (for example the brand of the CRS and how it was used is of prime importance),
- to establish the limit of the protection criteria for a given body segment needs to reconstruct cases with and without injuries. So “good cases” to be selected will be cases without injury despite a high crash violence and, at the opposite, cases where injuries are observed despite a low or moderate violence.

Figure 2. Crash reconstruction

Work programme. The selected accidents, fully documented, were reproduced experimentally. These reconstructions were performed in conditions as close as possible to those of the corresponding real-world accidents, with vehicles identical to those involved in the actual accident, and the real occupants being replaced by dummies whose anthropometric characteristics are as close as possible to those of the real occupants. These dummies were as fully instrumented as possible.
Following each reconstruction, a close comparison was made with the real-world accident, serving as a reference. The comparison covered the vehicles’ internal and external deformations, in order to validate the quality of the reconstruction, and the measurements taken on the dummies in relation to the injuries sustained by the children during the actual accident.

The selection of the cases was made under the responsibility of WP2. A very critical task was to define the physical parameters of the accident (car speeds, variation and mean acceleration for the involved cars, impact direction, possible overlap…). It needs a very high experience in this field to reach the required quality of the reconstruction.

In order to guarantee the quality of the reconstructions, the partners responsible for the reconstruction were closely associated with the partner who provided the corresponding actual accident case; a direct contact was kept between the accidentologists having studied the accident and the partner responsible for the reconstruction. When it was possible, the car involved in the actual crash was kept available for the partner carrying out the reconstruction in order to make easier the comparison between the experimental reconstruction and the actual crash.

When the CREST project started, only the conventional TNO P-series dummies were available. It appeared very quickly to the experts that the behaviour of these dummies was not biofidelic. Two approaches were considered in order to get the best simulation of the dynamic behaviour and the best prediction of the injury risk to allow enhanced evaluation of the CRS performances: in a first step improvements of the existing dummies, then development by TNO Automotive of a new series of dummies, called Q dummies, improved for frontal and lateral impacts.

Modifications for frontal impact configurations were made by Renault and INRETS; these modifications are described in WP3. A P3, a P6 and a P10 were so modified and used in the subsequent reconstructions (they are called P3M, P6M and P10M). For side impact other modifications were necessary such as reducing the transversal stiffness of the thoracic and abdominal segments and as these modifications were difficult, even impossible on the current dummies, the experts agreed to wait for the new Q dummies for lateral as well as for frontal impact configurations.

For some accidents, these reconstructions were supplemented by a parametric study carried out by means of simpler tests performed on a crash simulator. This made it possible to check the influence of parameters such as the precise position of the CRS (its inclination, its fixation to the vehicle and possible slack in the straps, which cannot be ascertained by the investigation of accident research).

Results and achievements. As a whole, 56 full-scale reconstructions and 100 sled tests were achieved.

All data from this work were included in a database gathering photos, measurements, criteria, and summary of real accident and allowing row analysis of data. The content of this data base is substantial and unique, however it is still limited, taking into account the number of body segments involved and the different classes of ages of the children.

Synthesis of the analysis from the WPI & WPII databases. A review of all reconstructions was made in order to determine if the results are satisfactory and if the measurements can be used to compare with the injuries. For each case, a form was filled in order to answer the following items:

- shall we consider that the child kinematics is reasonable,
- can we explain injuries,
- do we have to consider the reconstruction for the analysis or
- do we have to consider the sled test and which one.

Thanks to this analysis, it was then possible to select the pertinent measurements and to associate them to the observed injuries, in order to constitute injury risk curves.

Injury risk curves. For head, thorax and pelvis, the analysis was done directly by comparing AIS levels of injuries with measurements (for instance head accelerations or HIC in relation with head AIS). For the neck, a more detailed analysis of injury mechanisms was made in order to associate the good physical parameters to each kind of injury. For instance, a dens fracture was associated to flexion or shearing whereas a spinal cord damage was associated to flexion and traction.

Some first results are presented in a following section.

Dummy Improvements (WP3)

The current child dummies (P-dummies) were developed in the late 1970's and early 1980's. The last two decades the protection offered to children travelling in cars has increased dramatically due to a better understanding of the dynamical behaviour of children and the resulting improvements to child restraint systems. To further improve child safety it seems necessary to replace the P-dummies with child dummies that are not only more advanced, but can also evaluate the protection offered to children in lateral impacts and the interaction of children with deploying airbags. Indeed, P dummies are quite rudimentary and are not able to evaluate the protection in detail.

It was the aim of the WPIII partners to develop a new series of child dummies (Q-dummies), taking into account the latest biomechanical and anthropometrical data knowledge and providing extensive instrumentation possibilities to the users of the dummies. Parallel to the hardware development of the dummies, mathematical models of the new dummies were developed. As the development of new dummies is a lengthy process, modifications have been made to the P-dummies in the beginning of the project to avoid delays in the work of WP2.

In WP3, Renault and INRETS have been responsible for the modifications to the P-dummies, TNO Automotive was responsible for the development of the Q-dummies and the TUB has developed the mathematical models of the Q3 and the Q6.

Modifications to the chest, pelvis and abdomen of the P-dummies were carried out and evaluated by Renault and INRETS. In addition to that the instrumentation capabilities of the P-dummies were improved. A new series of child dummies, called the Q dummies, was developed by TNO Automotive. The series now consists of three dummies: Q1, Q3 and Q6, representing respectively a 1, 3 and 6-year-old child. Mathematical models of the Q3 and Q6 were developed by the TUB, with assistance of TNO Automotive.

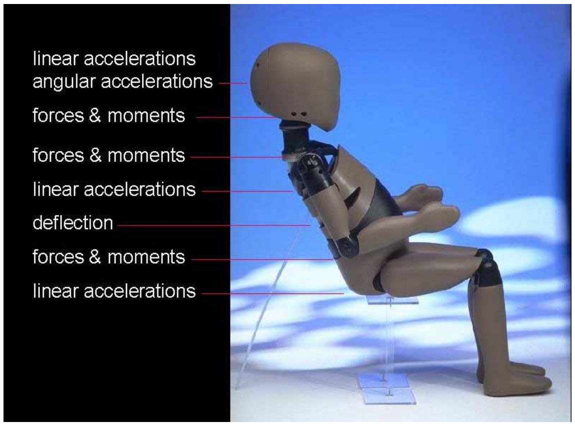

Figure 3. Dummy improvement: Q series

All dummies were used extensively by partners in more than 56 reconstructions and 290 sled tests. In general, CREST partners were very happy with the Q dummies because they show a significant improvement in comparison with the existing child dummies. During the evaluation of the dummies, CREST partners have expressed some concerns about the belt interaction of the Q dummies, both at the pelvis and the shoulder level. The design of the Q dummies has been modified based on those experiences. A new design for the pelvis area has been made and evaluated. The conclusion of this evaluation is that Q dummies now, show a realistic submarining behaviour. A new flesh representing shoulder part has been made, but has not yet been evaluated by the CREST Partners.

Procedures and Validation

The objective of this workpackage was to include CREST knowledge in procedures and to base improvements on results from CREST activity.

For frontal impact, a complete proposal, from test conditions to evaluation criteria, was set up. The new procedure didn't intend to be a reference for certification, but was made to be representative of the conditions were we found injuries on children and to be closer to modern car environment. It consists on:

- R44 03 basis.
- New pulse corridor based on CREST reconstructions, adjusted to be feasible in current test houses (Figure 4).
- Bench shape modification (representative of Renault and Fiat cars and including anti-submarining device)
- Use of Q dummies
- New injury criteria with limits when possible.

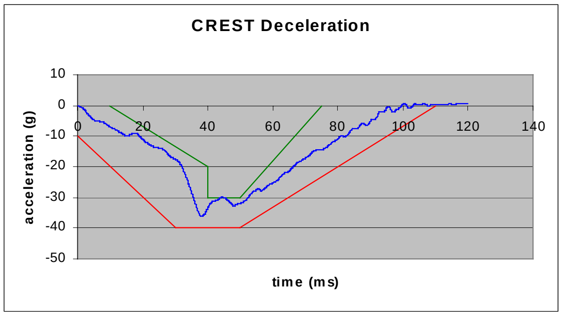

Figure 4. CREST pulse

It was agreed to ask CRS manufacturers to participate and to propose them to test their products or prototypes (like ISOFIX) against CREST procedure. This was decided as a mean to evaluate the coherence of the procedure. Renault contacted about 15 CRS manufacturers, among them 10 accepted to participate.

Hence, 70 CRS were tested with the new CREST procedure for frontal impact (Figure 5). The sample of CRS consisted on:

- 19 forward facing seats with harness tested with Q3 dummy (including 2 isofix)
- 6 forward facing seats with shield tested with Q3 dummy (including 1 isofix)
- 17 rearward facing seats or infant carriers tested with Q1 dummy (including 2 isofix)

- 5 rearward facing seats tested with Q3 dummy
- 23 booster cushions tested with Q3 dummy
- 3 booster cushions tested with Q1 dummy

Figure 5. Test procedure evaluation

<u>For side impact</u>, current procedures were not mature and it was not possible to propose improvements directly from CREST outcomes. However, recommendations can be made from accidentological findings [1], reconstruction knowledge, Q dummy experience and first findings on injury criteria.

RESULTS

Injury criteria

All results of reconstuctions and sled tests were analysed and used to construct injury risk curves. Since accident cases concern several ages, data were scaled to 3 years old, using geometrical and material failure factors [2].

As an example, figure 6 gives the level of head AIS in relation with the HIC (36ms) value corrected for 3 years old for frontal impact. Only results with Q dummies (and P1 ½ which is closer to Q than to P dummies) were used for the definition of injury risk curve. This latest, which was constructed using the certainty method, is given in yellow for AIS3+.

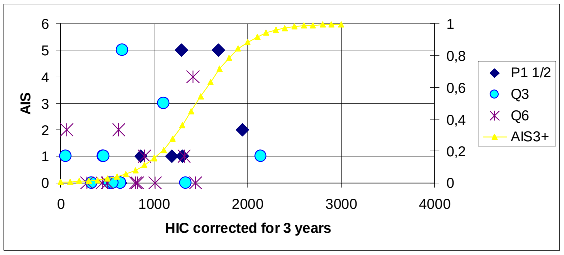

Figure 6. Injury risk curve for HIC (3 years old)

Figure 7 gives the level of Neck injury in relation with My corrected for 3 years old. It is obvious in this graph that we are still missing results of the definition of injury risk curves, in particular, cases with injury. It can only be said that a large amount of cases without injury demonstrate My values under 30 Nm and that some unexpected cases with high AIS are observed for low values of My.

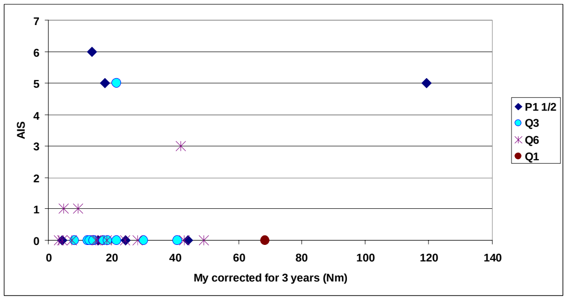

Figure 7. My versus AIS for Q dummies

Figure 8 gives the level of head AIS in relation with the 3ms head acceleration value corrected for 3 years old for side impact. This graph shows a clear limit between injury and no injury. However, more data are needed to confirm these figures, taking into account the uncertainties of reconstructions.

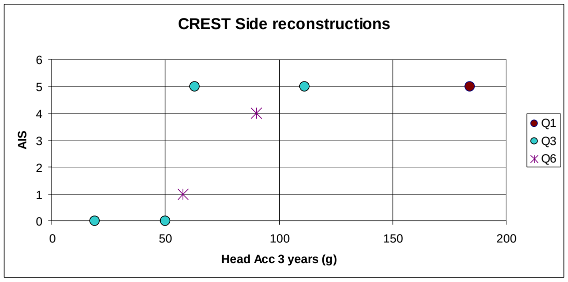

Figure 8. 3ms Head acceleration versus AIS

Procedure validation

Results of CRS tests were analysed and ranked with regard to the limits established by WP2 sub-group analysis.

Tests of the 70 CRS in the CREST configuration show that some CRS are only adjusted to the R44-03 regulation but cannot sustain more severe conditions. These tests give the distribution of physical parameters which allows, when compared to the limits proposed by WP2, to evaluate the difficulty to reach CREST specifications and the coherence of the procedure.

For instance, Figure 9 gives the distribution of HIC values for the whole sample (including Q1 and Q3). In this sample, only 37% of the CRS tested with Q3 dummy are below HIC=1113, which correspond to about 20% risk of AIS3+ whereas 61% of the CRS

tested with Q1 are below 791, which corresponds to the same risk for a 1 year old child.
Figure 10 shows that most rearward facing seats are under the limit whereas only a few boosters pass the criteria for Q3 dummy.

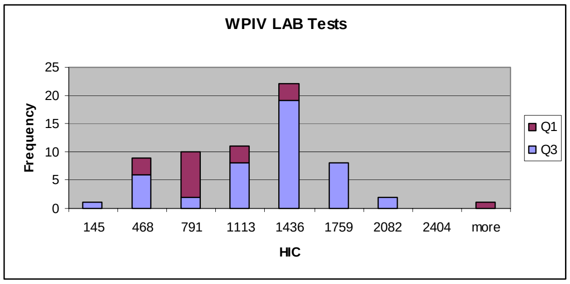

Figure 9. Distribution of HIC values

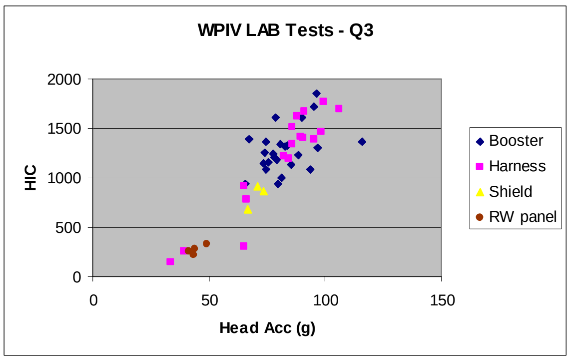

Figure 10. HIC versus Head acceleration

Figure 11 gives My flexion versus Fz traction. This graph shows that rearward facing seats demonstrate low values of My and Fz whereas boosters and 5 point harness seats have large values of Fz, some of them having also high My values.
This analysis shows the ability of the procedure to discriminate between good and not so good seats or concepts.

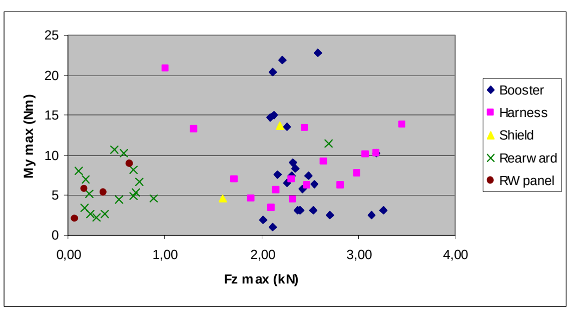

Figure 11. My versus Fz values

These tests allowed also to evaluate the difficulty to handle the tests as regard the pulse and the dummy durability. It was found that no major problems occurred, except weakness of Q3 shoulder and hip, which were also observed in WP2.

The CREST procedure for frontal impact was evaluated thanks to the test of numerous CRS, which can be considered as representative of the European market. It can be assumed that the procedure is coherent, the severity of the pulse and the level of criteria being balanced.

CONCLUSIONS

This research programme is a first step in the improvement of test procedures for assessing child restraining systems. However, still a lot of work is needed to consolidate some knowledge and in particular to address:

- neck or chest injury criteria and limits,
- abdominal tolerances,
- submarining behaviour,
- injury criteria for side impact.

Results have demonstrated the pertinence of such an approach in defining injury risk curves and the need to continue working in this way.
As far as certification is concerned, investigations are needed to improve the representativity of the procedure, in particular dealing with:

- car environment (bench shape, volumes, anchorage points …)
- deceleration pulse, assuming the conditions to be considered for CRS evaluation
- child ages

CREST has demonstrated the feasibility of such improvements and a way to deal with.

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