NEW PROGRAMM FOR THE ASSESSMENT OF CHILD-RESTRAINT SYSTEMS (NPACS) – DEVELOPMENT/RESEARCH/RESULTS – FIRST STEP FOR FUTURE ACTIVITIES?

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ABSTRACT

The protection of children in traffic, especially in cars, is one of the most important tasks facing our society. Children in cars are dependent on the assistance of their parents to provide them with adequate protection through the use of child restraint systems (CRS). Good advice to parents on how to use and fit CRS properly and which CRS offers the best protection are essential.

In Europe, due to the use of differing assessment criteria and rating schemes, the information provided to parents has been very confusing to date. Since there are still major differences in CRS use within EU member states, increased consumer information is a predominant European task.

The largest single advantage gained from this EU project "New Program for the Assessment of Child Restraint Systems" is that all members of the NPACS Project, representing the Governments of four European countries, research institutes, ICRT European consumer organizations and FIA automobile clubs, have cooperated to develop a scientifically based EU-wide harmonised test program and rating procedure. This program covers advanced test criteria in frontal and side impact, as well as comprehensive usability tests to reduce the potential for CRS misuse; misuse has been the predominant problem with CRS use for years. In addition, the NPACS procedure has not only been developed as to help parents and other purchasers of CRS, but also to encourage child seat manufacturers with their current and future designs, encourage new technologies to be brought to the market and to reduce the potential for misuse of their products.

INTRODUCTION

The NPACS consortium was funded in 2005 by governments of four nations, United Kindom, the Netherlands, Catalunia and Germany and five non governmental organisations, ADAC, ÖAMTC, AIT&FIA, ICRT and GDV and had the objectives to provide scientifically based EU wide harmonised test and rating protocols to offer consumers clear and understandable information about dynamic performance and usability of child restraint systems. The group worked on reliable methods of dynamic testing, the assessment of their ease of use, and periodically evaluation of the performance of test products.

The first phase was to develop test protocols and conduct accordingly the new test procedures in a second phase. For the first time a new generation of child dummies, FTSS Q-series, was used and new injury criteria were developed. The side impact, today this is not tested for child safety at mandatory tests, was developed to reflect real accident data in laboratory tests. Another focus of the project was handling and misuse, which are not covered by ECE R-44 as well. Therefore handling tests with inexperienced subjects under different test conditions were made to develop a protocol for CRS ratings. Special handling dummies were developed to allow consistent results for testing and rating. Despite challenges in the validation process of the NPACS program, NPACS developed test procedures. Some of them are applied by the European Test Consortium (ETC) for Child Restrain Seats in 19 European Nations since May 2007.

REVIEW OF TEST METHODES

In a first step all potentially CRS test methods over the world were studied and the information collected. So a wide range of information had to be compared, differences listed and potential advantages and disadvantages worked out. The sources which delivered possible information could

be found in the ISO Draft N589/N653, ICRT CRS-Testing, NHTSA 2004, Euro NCAP CRS protocol and JNCAP protocol.
For frontal side and rear impact scenarios the data of all relevant crash test configurations of national standard and consumer tests, such as Euro NCAP, JNACP, ANCP, ECE-R44, CREP, FMVSS 213, were collected to get a objective view of the boundary conditions for a dynamic child seat test.

DEVELOPMENT OF TEST METHODS

Frontal impact

To start at a basic level, analyse of existing in-depth accident databases should be done to establish characteristics of accidents involving serious and/or fatal injured children. In a second step a proposal of test speed, impact angles and velocity should be made. Also taking into account the big data base of EuroNCAP crashed frontal impact cars by their mass and pulse.
In an additional step a selection of 30 - 50 cars of EuroNCAP tests, ADAC-database and registration statistics delivered date for seat belt geometry, geometry of the seatback and seat base and the stiffness of the cushions.
This information lead to a range of seat back angles, showing a difference of 4° rearward, in comparison to the ECE test bench, but a good correlation of the seat base angle, which is close to 15° to the horizontal.

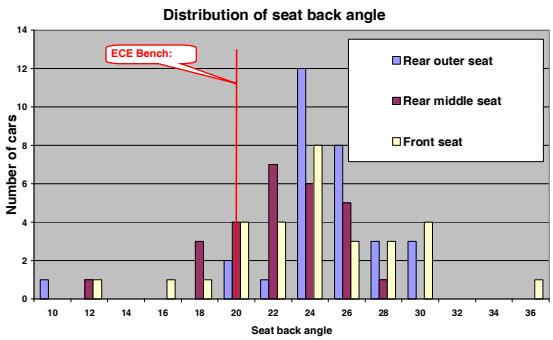

Figure 1. Distribution of seat back angle in comparison to the ECE R44 bench (1)

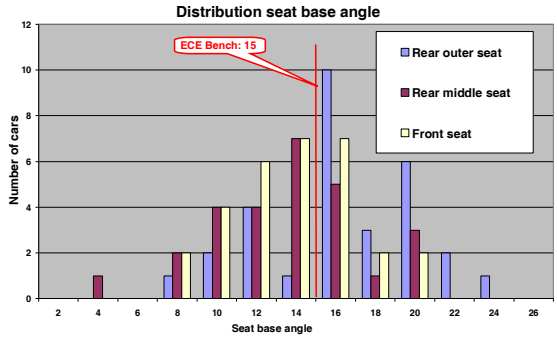

Figure 2. Distribution of seat base angle in comparison to the ECE R44 bench (1)

A quite huge variety of the upper and lower anchorage points could be measured while using different kind of vehicles. The biggest difference could be recognized in the horizontal distribution of the shoulder anchorage points, leading to the decision to test in most rearward, mid and most forward position of the d-ring loop and check out the influence of this anchorage point.

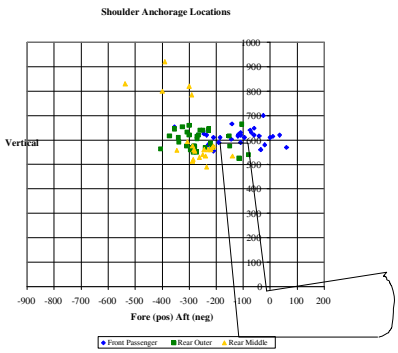

Figure 3. Distribution of upper anchorage point (2)

For the lower anchorage points inner and outer position of the seatbelt and locks a variation could be measured, but these points were allocated around the H-point area of the seat.

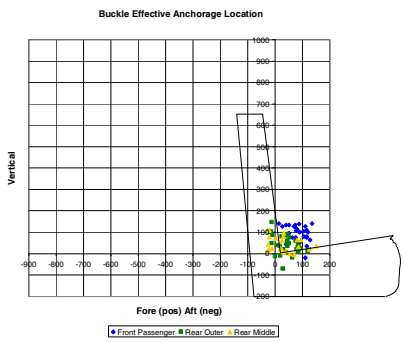

Figure 4. Distribution of lower anchorage points (2)

This evaluation lead to a specific seat bench with a certain seat belt geometry and a variation of the D-loop, the lock and lower anchorage point.

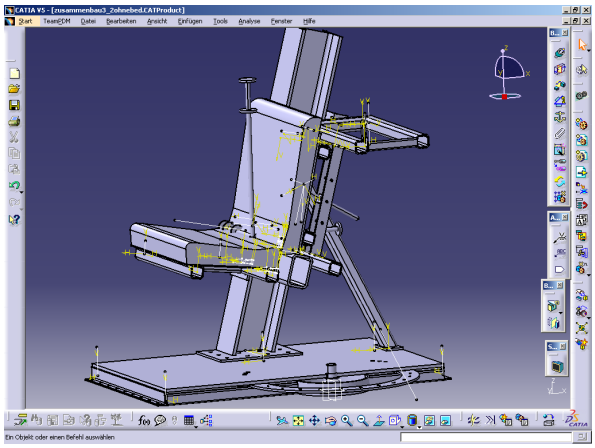

Figure 5. NPACS specific test bench (3)

To evaluate the frontal impact pulse NPACS has on one hand analyzed the B-pillar acceleration result of 23 vehicles tested by Euro NCAP. On the other hand the results of the EC CREST program, which examined accidents in Germany, France, Spain, UK and Italy, should be taken into account. Based on these results NPACS has defined an acceleration pulse for frontal tests.
The analyse of crash pulses of different vehicle sizes are shown in
Figure 6. There is a big variety in the length of the pulse, the frequency and the maximum acceleration. With the introduction of a 65kph pulse which is quite close in shape to the ECE-R44 pulse, but on a higher energy level, a lot of full scale pulses of several vehicle classes could be covered.
The developed NPACS frontal impact pulse is in between the borderlines of the CREST pulse requirement, so both terms were fulfilled.

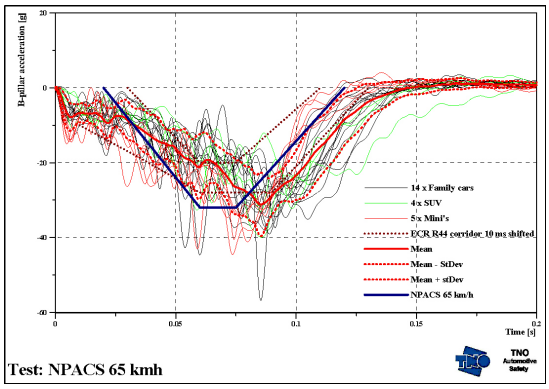

Figure 6. Deceleration pulses of Euro NCAP frontal offset tests and NPACS pulse (blue) (4)

In addition to the 0° frontal impact test a 30° test was considered as a relevant crash scenario, which lead to severe injuries. This type of test and in addition with the worst case belt geometry, which was the most forward one, the potential of CRS in a worst case scenario should be tested. But this chosen configuration led to extreme dummy loadings and even destroyed the dummies itself. Because of this the angular configuration was not taken into account for the rating in the near future.

Side impact

The work of EEVC WG18, show that side impacts cause the second highest number of fatal and serious injuries to restrained child car occupants. Therefore the introduction of a side impact test procedure is necessary, even there is no current dynamic side impact test in the European regulation.

In European consumer testing a side impact test is in use, with a fixed door system. A intruding door variant of ISO and some derivate are existing, too.

In order to get reliable data to compare full size and a sled test a number of 6 different CRS were tested in vehicles of 3 different classes, mini, small family and large family car. The test setup was done according the Euro NCAP/ECE R95 test procedure. On the struck side of the car 2 CRS and dummies were installed on the driver and passenger seat. The biggest intrusion, in this kind of side impact, is the B-pillar. To set up the worst case scenario the rearward facing CRS was placed on the rear bench of the struck side and the forward facing on the driver seat. In this case both kinds of CRS are charged with the maximum loading in the head form area, which is remembered as the most serious one.

The final decision which type of side impact should be introduced in the NPACS test procedure was taken in September 2005. It was possible with all three relevant test methods to differentiate CRS according their protection and to rate those seats. At the end he fixed door principle was dropped because an intruding door seems to be more realistic and could be seen in the full size crashes. The intruding door mechanism was pointed out to represent the side impact as its best. At the end the version of TUB was recognized as the most sufficient one, based on scientific research and introduced in the test procedure.

In Figure 7 the relation between the test results of the full size crashes and the different side impact test procedures could be seen. In this example the head acceleration of the forward facing CRS of Group 1 were used. The results of the sled tests are pointed out in the circle.

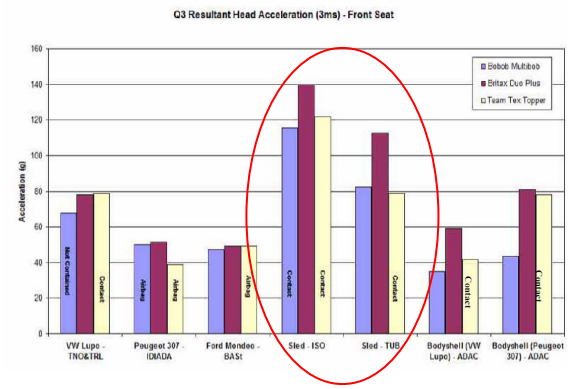

Figure 7. Comparison of side impact sled and vehicle tests (5)

It was considered that the most important body region in side impact, the head of the child, must be assessed according the head acceleration and the head containment.

Rear impact

One working package addressed the rear impact collision. In a scenario of purely rear impact and under 30° angular rear impact, rearward facing shells show pitching and in the angular situation possible contact to the outer surface. But a review of the accident data showed that rear impact accidents were a low priority for fatal and serious injuries to restrained children. This lead to the decision, not to introduce a rear impact dynamic test, right now.

Handling

Misuse data

The German GDV used their database to locate possible misuse during adjustment of the CRS, position in the car and belting of the child. These findings were separated in all single CRS weight classes and offered a good overview of potential risk while using a child seat.

Table 1.

misuse study of GDV (6)

4-point harness systems – Group I (Number of observed CRS = 12; misuse rate = 100%)		
Installation misuse	**Severity of misuse**	**No.**
loose seat attachment	medium (2) severe (3)	5
parents used their own mounting construction	medium	2
incorrect belt path	severe	1
incorrect use of the necessary, additional belts	severe	1
Securing misuse	**Severity of misuse**	**No.**
harness belt too loose	slight (1) medium (6)	7
belt buckle positioned too high	medium	5
weight/size of child above limit	severe	1
shoulder belt passing beneath the arm	severe	1

Handling Dummies

The GDV data showed a lot of problems which came up during the installation of a CRS and buckling up a child in a car. So the handling of a child seat is a very important issue to reduce severe injuries, because of misuse. To address this problem in the test procedure special dummies should be used to get information of the handling of the seat and the fixation of child in the seat. Additional information could be gathered out of the positioning of the dummy in the seat, possible adjustments, suitable belt routing or the fitment of the seat in the car. A special family of handling dummies, called "Kieler Kinder" should provide the information for the tester according the handling issue.

Figure 8 . Kieler Kinder, handling dummy and P-dummy

The positive effect of these handling dummies is a size which reflects the height, extremity length, weight, body sizes better than a 50%ile crash test dummy, e.g. the P- or Q-series.

For the final rating the seat has to be assessed according following criteria:

- Instructions
- Set up of cars/harness
- Installation
- Restraining child
- Ergonomics and comfort
- Cleaning and safety designs
- Removal of the occupant
- Removal of the ISOFIX seat

In a first consideration the use of a universal handling body in white was discussed, but due to a lot of problems caused by the enormous variety of vehicle geometry, differences in foams, seat belt anchorages the idea was cancelled. The handling test should now be carried out in a variation of different sized vehicles, 3 and 4 door cars, different seat belt geometry, but fulfilling the Gabarit specifications.

Dummy

For assessing the dynamic potential of CRS, child dummies have to be used according following boundary conditions:

- different size and weight, covering all ECE classes
- measurement capabilities according the need of NPACS
- the measurements need to be repeatable
- the dummies should be durable for the use in NPACS test scenarios
- the dummy family must be biofidelic

There are 4 different types of child dummies available on the market. In Europe the TNO P-series and Q-series, old and new version, are used for testing. In the USA the Hybrid III child dummies are used for CRS and out of position testing. Comparison testing was done by TRL in the same side impact situation with the 3 year old P,Q and HIII child dummies 3 times to show the repeatability. The best repeatability data for head and chest was delivered by the P3 dummy. But this dummy has one disadvantage due to the old construction the use of additional transducers in the dummy is restricted to head, chest and rudimentary neck measurement for frontal impact. The P-series is durable for the use in NPACS, also the Q.-series didn't show an damages in the different test hoses during their use in frontal and side impact. The big advantage of the Q-series is the more biofidelic behaviour and the possibility to measure not only head and chest acceleration. At the end the decision for the Q-series in it´s old version was driven by fulfilling most of the NPACS requirements. This dummy showed a good repeatability, good biofidelic response in the head and neck, the chest was estimated to be too stiff, it proved the durability in a lot of tests, covered nearly all required masses of the ECE R44 except the upper boundary of group III. For the Hybrid III only small data was available so this dummy was not taken into account.

Figure 9. Q-Series dummy family

Rating

For the overall rating, the results of the usability evaluation, the dummy reading of the frontal and side impact dynamic test and the observation of these tests are assessed. The individual results of these tests together are forming the overall rating of the CRS. Based on accident analyses, user and misuse surveys and on experience of studies and CRS tests the individual results of the test could be weighted against each other. The weighting proposed, on consultation with the NPACS Foundation Committee, is 50 percent for Usability, 25 percent for Frontal Impact and 25 percent for Side Impact. The reason for this weighting reflects the importance of a well installed CRS. Misuse of installation is the most common problem in the field, also pointed out in several studies. A well designed seat could show it's potential if the installation is not done correctly.

In general the rating is designed to work out differences between actual child restrains but still allow space for improvement.

It was considered that two effects, which are not measured will have a capping effect and reduce the score to 0 even when the seat scored points in the rated body regions. This effect will be caused in side impact by a failure to provide any head containment will lead to total score capping to the lowest band and in the frontal impact test, the total structural failure of the product will have the same effect. A third case, were capping could be applied is an abdominal loading of the dummy, caused by the lap belt. Because of insufficient assessing possibilities, only video data could be used, the abdominal rating is not used in the near future until a solution for a possible measurement is found.

VALIDATION

After the 1st phase of developing the test methods, pulses and the decision for the Q-dummy these methods should be validated according the repeatability and the reproducibility. This process included both the frontal and side impact test and in addition the usability test, too.

The result out of this huge test series should show a test procedure, producing reliable results of CRS even if this test were conducted in different test houses with different equipment and different dummies.

Frontal impact

Based on the data of the TWG the participating test labs built seat benches according the NPACS specification.

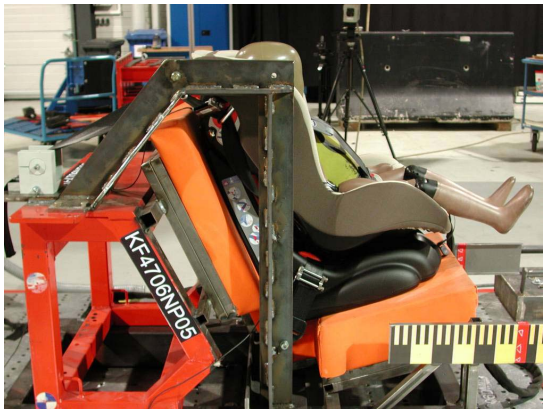

Figure 10. Frontal impact test design

In November 2006, frontal crash tests were conducted with the Chicco Key 1 (validation step 1A). The results were presented at the Validation Workgroup meeting in December 2006. The variations of the results of the test facilities are shown in Table 2.
Measurement variations between the test facilities for the frontal impact below.

Table 2.

Measurement variations between the test facilities for the frontal impact

	Basic tests				Additional tests	
	Q1, upright	Q1, reclined	Q3, upright	Q3, reclined	Q3, upright, 30°	Q3, upright, upper belt fore
Head a_{res}	20%	22%	6%	18%	6%	17%
Head excursion	23%	19%	13%	8%	16%	26%
Chest a_{res}	35%	40%	26%	25%	32%	27%
Chest compression	11%	14%	14%	14%	46%	18%
Neck M_{res}	57%	54%	55%	54%	11%	47%
Neck F_{res}	30%	25%	23%	15%	13%	18%
Pelvis a_{res}	22%	19%	18%	9%	8%	10%

Since the frontal impact test revealed major variations between the measurements, the analysing of the possible reasons was taken into account before continuing validation with other CRS.
Since different positioning of the seat belt retractor was identified as one potential cause for measurement variation, ADAC altered the retractor position for an additional test. Testing two extremely different retractor positions was aimed at demonstrating that different belt routing and belt webbing length may be the main cause for the measurement variations. The above tests show that the position of the belt retractor has little impact on the measurements, with a significant variation only for the neck moment:

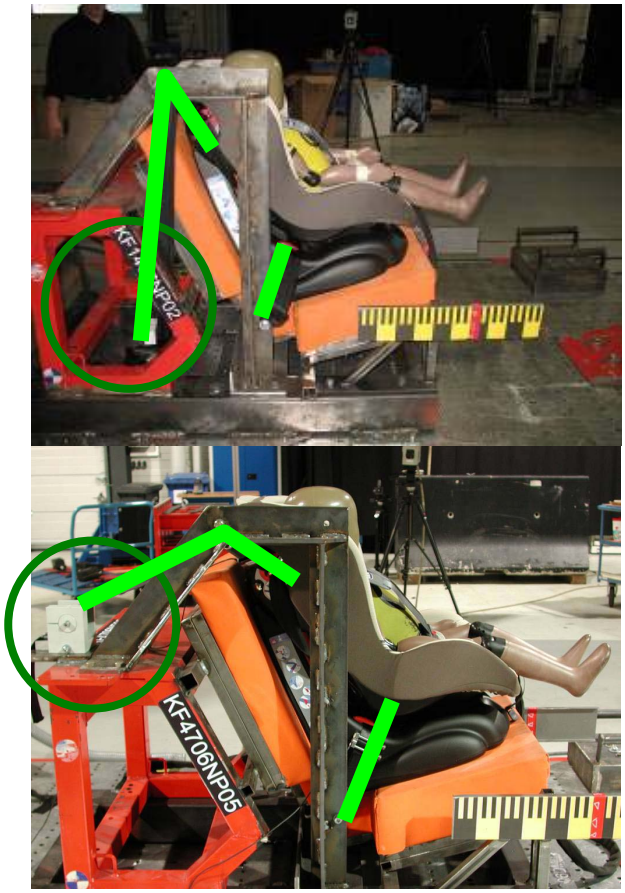

Figure 11. Testing different belt retractor positions (green circle

Table 3.

Influence of retractor position on the measurements and measurement variation in percent

	Retractor 1	Retractor 2	Deviation
Head a_{res} [g]	92	89	4%
Head excursion [mm]	490	500	2%
Chest a_{res} [g]	58	59	3%
Chest compression [mm]	36	n. a.	
Neck M_{res} [Nm]	34	29	17%
Neck F_{res} [N]	3506	3293	6%
Pelvis a_{res}	74	71	4%

Another reason why the test facilities obtain varying measurements might be attributable to inconsistent seat bench rigidity and belt attachment points. Also, the influence of different Q-dummy versions cannot be ruled out.
Excursion was measured using different methods. Since parallax-based errors may be the cause for the

measurement variation, it was agreed to use the ECE-R44 measuring method.
To improve the test procedure additional comparative testing will be needed for the frontal impact in order to identify the causes for major variations.
To discover differences in the rigidity of the test configurations, the belt forces and acceleration of the belt attachment points should be monitored.
In addition, all test facilities should use the same version of Q-dummy or even 1 dummy, which is circulated, to reduce the error potential.

Side impact

The first test on a new built test bench, according the specifications showed difficulties to remain within the corridors required in the protocol and that both the CRS mass and its attachment mechanism have an impact on the movement pattern of the intruding door. In addition, angular velocity was difficult to reproduce, which increased the problems to remain within the required corridor.

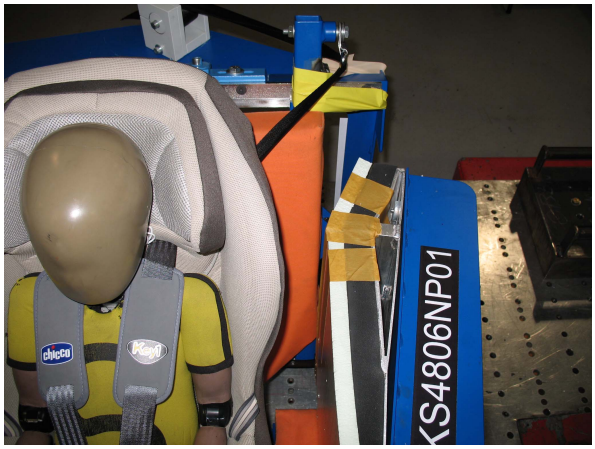

Figure 12. Side impact test setup with hinged door and belt routing

The Validation Workgroup verified the measurements (validation step 1A) at their meeting in December 2006. Three labs did tests with CRS and 2 different dummy sizes on their side impact test rig. Table 1 shows the variations between the measurements of these test facilities:

Table 1.

Variations between side impact measurements of the various test facilities (TRL, TUB and ADAC)

Measurements	Dummy: Q1	Dummy: Q3
Head a_{res}	12%	19%
Chest a_{res}	21%	19%
Chest compr.	18%	46%
Neck M_{res}	181%	58%
Neck F_{res}	46%	51%
Pelvis a_{res}	38%	26%

At subsequent meetings of the Validation Workgroup, some members pointed out that they faced major problems with the test setup and their measurements considerably differed from those of the other test facilities.
Since measurement results varied considerably it is useful to first identify the reasons for the variations before continuing the validation tests with other CRS.

In November 2007, the two remaining test labs, performing side impact validation tests, met for joint testing and an exchange of experiences for side impact tests. Overall, the following issues were identified for the need of optimisation:

- The corridor for the angular velocity of the door is not sufficient to deliver a reasonably exact description of the door movement. As a corrective, the inclusion of an angle over time requirement is needed
- Since different sensors and measuring methods deliver different angular velocity data, a uniform sensor should be specified and used by all test facilities.
- The initial distance between the centre of the tested CRS and the door panel should be specified.
- Dummy arm positioning is not sufficiently specified in the test protocol. This may influence the load transfer between the seat and the dummy thorax, and impact measurements. An additional description of the dummy installation procedure should help reduce the resulting measurement variations.
- To prevent that test setup alignment for every new CRS (and further CRS are needed for such additional test) a calibration routine should be implemented. This involves testing a calibration block (or a standard CRS initially) meeting all test protocol parameters. For subsequent CRS testing, the parameters remain

unchanged – corridors are no longer an issue.

To establish whether the above improvements reduce the test result variations, it was suggested to compare the measurements again at the Validation Workgroup meeting in January 2008. To exclude variations based on the dummy used (relatively frequent and unverifiable changes in the dummy versions), all test facilities should use the same dummy. This idea was not accepted by all parties and the next round robin test was conducted between only two test houses. Several problems seem to be solved an further improvement were made to achieve the corridors in different labs with different test rigs. But the results of this last round robin test, conducted under the NPACS Validation group, again showed deviation of the two participant labs in spite of new corridors, only one dummy used for the test. and the use of the calibration rig. Not only the reproducibility was checked, the repeatability was also an issue to have a focus on.

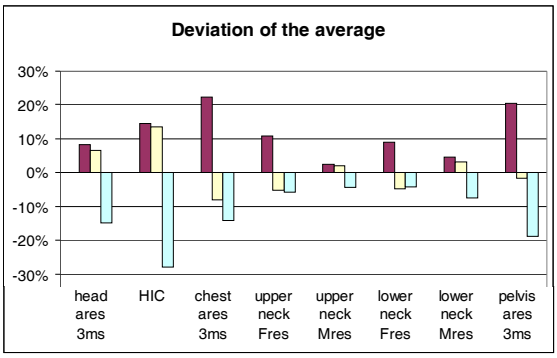

Figure 13. Deviation of the dummy readings (white and dark repeatability of same lab) (7)

RESULTS

One of the most challenging tasks is the protection of children in the traffic especially in cars. Adult occupants have the protection of frontal, side and curtain airbags, seatbelts with pretensioner and load limiter, retracting pedals, reinforced side structures and seats. The only possible protection of a child a a child seat. But a child seat which offers good protection must be installed in the right way otherwise it cannot provide the protection it could do. The target was and will be in future to push forward the development of child seats so that they can offer to bet possible protection and to minimize the handling mistakes and misuse possibilities.

A lot of different organisations in Europe are conducting CRS tests with different results. The NPACS-project, representing the Governments of four European countries, research institutes, ICRT European consumer organizations and FIA automobile clubs tried to bring all this knowledge together and used the latest test equipment on the market to form a new test and rating procedure for the European market.

A lot of research work was done to identify the worst case situations for dynamic and static tests to reflect the real world accidents and rate the seats for consumer information.

The following findings of the research in the NPACS program is proved and could be used for future activities:

- Test bench for frontal impact, reflecting modern car environment and geometry
- Frontal impact test pulse as a simplified frontal offset crash pulse
- The Q-series dummy were introduced and showed good performance in repeatability and durability combined with a good biofidelic relationship
- Handling dummies were developed and could be used for handling and usability tests
- A rating scheme based on accident data, which is taking into account the problem of misuse Usability and misuse tests

But there are still open issues which need further investigations:

- Influence of seat belt geometry on the test results
- The side impact is not validated right know, in spite of a lot investigation of corridors, calibration issues etc.
- Review of the injury criteria is needed
- The durability of the handling dummies must be improved

To come back to the question in the header: NPACS, First step for future activities? The answer of this question is yes. Some of the research results could be used for future activities, but the validation process showed the problems in the reproducibility especially in the side impact.

ACKNOWLEDGEMENTS

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