ASSESSING NEW CHILD DUMMIES AND CRITERIA FOR CHILD OCCUPANT PROTECTION IN FRONTAL IMPACT

Kate de Jager, Michiel van Ratingen
TNO Science and Industry (The Netherlands)
Philippe Lesire, Hervé Guillemot
LAB (France)
Claus Pastor, Britta Schnottale
BASt (Germany)
Gonçal Tejera
Applus+IDIADA (Spain)
Jean-Philippe Lepretre
UTAC (France)

On behalf of EEVC WG12 & WG18
Paper no. 05-0157

ABSTRACT

The European Enhanced Vehicle-safety Committee wants to promote the use of more biofidelic child dummies and biomechanical based tolerance limits in regulatory and consumer testing. This study has investigated the feasibility and potential impact of Q-dummies and new injury criteria for child restraint system assessment in frontal impact.

European accident statistics have been reviewed for all ECE-R44 CRS groups. For frontal impact, injury measures are recommended for the head, neck, chest and abdomen. Priority of body segment protection depends on the ECE-R44 group.

The Q-dummy family is able to reflect these injuries, because of its biofidelity performance and measurement capabilities for these body segments. Currently, the Q0, Q1, Q1.5, Q3 and Q6 are available representing children of 0, 1, 1.5, 3 and 6 years old. These Q-dummies cover almost all dummy weight groups as defined in ECE-R44. Q10, representing a 10 year-old child, is under development.

New child dummy injury criteria are under discussion in EEVC WG12. Therefore, the ECE-R44 criteria are assessed by comparing the existing P-dummies and new Q-dummies in ECE-R44 frontal impact sled tests. In total 300 tests covering 30 CRSs of almost all existing child seat categories are performed by 11 European organizations. From this benchmark study, it is concluded that the performance of the Q-dummy family is good with respect to repeatability of the measurement signals and the durability of the dummies. Applying ECE-R44 criteria, the first impression is that results for P- and Q-dummy are similar.

For child seat evaluation the potential merits of the Q-dummy family lie in the extra measurement possibilities of these dummies and in the more biofidelic response.

INTRODUCTION

Each year, 700 children are killed on European roads and 80,000 are injured [1]. It represents an unacceptably high burden on Europe’s society and economy. The fact that such poor results are observed, despite normal use of CRS (Child Restraint Systems) complying with the ECE 44 Regulation, underlines the high social importance of continued child safety research. Despite many initiatives being taken in Europe and elsewhere, progress made in child safety in the last decade can be considered small, in particular compared to the advancements made in adult occupant protection in that same period. Important contributors to this situation are the lack of biomechanical knowledge on injury mechanisms and associated physical parameters, specifically for children.

The European Commission (EC) has recognized that it is only through a decisive increase of the basic scientific knowledge that major steps can be achieved towards improved standards and more efficient design of CRSs. For this reason the CREST (Child Restraint Standards, 1996-2000) and CHILD (Child Injury Led Design, 2002-2006) projects were initiated to develop the knowledge on child behavior and tolerances. The outcomes of EC-CREST and EC-CHILD can be used to propose new test procedures for determining the effectiveness of CRS using improved child dummies and injury measures [1-3]. As a result of these projects the Q-series of child dummies are currently available for CRS testing [4, 5].

The European Enhanced Vehicle-safety Committee (EEVC) wants to promote the use of more biofidelic child dummies and biomechanical based tolerance limits in regulatory and consumer testing. It initiates the assessment of new child dummies and criteria for child occupant protection in frontal impact. Therefore, EEVC WG12 and WG18 carried out collaborative research following four basic steps: (i) identification of child injury causation in frontal impacts based on real world data, (ii) completion and consolidation of the specifications of the Q-series of advanced child dummies, (iii) recommendation for new injury criteria and tolerance limits for frontal impact, and (iv) a validation test program based on ECE R.44 test conditions, comparing P and Q dummy performance in frontal CRS tests. For the latter part, eleven European organizations including OEMs, research institutes and child restraint manufacturers performed 300 tests covering 30 available child seats. These seats represent the majority of existing child seat categories on the European market.

The paper starts with an overview on child injury causation. This overview presents a synthesis of frontal crash investigations including those performed under the CREST and CHILD projects. Next, the development and evaluation of the Q-dummy family (including Q0, Q1, Q-18 months, Q3 and Q6) are described. In addition, the situation regarding newly proposed child dummy injury criteria is given. Thereafter, the validation of P- and Q-dummies and criteria are described. An in-depth analysis of 300 test results covering 30 child seats will be presented, showing the effect and potential benefit of introducing new test dummies and criteria into legislation. Finally, conclusions are drawn and recommendations are given.

CHILD INJURY CAUSATION

The EEVC WG 18 on Child Safety was created in October 2000. One of the first tasks of this group was to review the European accident statistics with respect to child car occupants and injuries in all type of car crashes. For this purpose, the most important existing databases in Europe have been examined. Data from the International Road Traffic Accident Database (IRTAD) show that in 1998 on average 2 children were killed each day. The tendency for Europe over the past ten years is that the total number of children killed as car occupant is decreasing. This can be seen as one of the effects of the general adoption of a European regulation on child restraints. An overall positive effect of restraint use by children when travelling in cars is found. The rate of severe injuries is more than twice as high for unrestrained children than for restrained children in frontal impact, which is the most common crash configuration. The risk of being severely injured as car occupant is very small for correctly restrained children up to a delta V of 40 km/h in a frontal impact. However, special attention should be paid to avoid CRS misuse and to make sure that clear information is forwarded to the public area about child safety and injury risk related to accidents.

In order to draw more detailed conclusions, WG18 has accessed and examined the following databases: CREST (as developed in the European collaborative research project), CCIS (the Co-operative Crash Injury Study in the UK), GIDAS (German In Depth Accident Study), GDV (German Insurance), IRTAD and LAB (Laboratory of Accidentology and Biomechanics in France). All of these databases have specific definitions and data collection methods, which makes it difficult to merge the data for analysis. Nevertheless for frontal impact, generally sufficient information was available in each database to classify injury causation according to the different group of child restraint system used. The CRSs were put in categories according to the weight group existing in the ECE R44-03:

Carrycots (Group 0): The number of crash cases available with this kind of restraint system is too low to conclude about the general injury mechanism.

Rearward facing infant carrier (Group 0/0+): These systems seem to offer good protection to their users in frontal impact. Severe head injuries are most frequently observed injuries with such CRS suggesting that introduction of effective padding may significantly reduce head injury risk. Three different injury mechanisms are hypothesised: impact by the shell with the dashboard (67% of rearward facing infant carriers is put on front passenger seats), direct impact of the head on supporting object and rebound. For these systems, limbs are also representing a high number of injuries, but only a few are considered as severe injuries. Therefore limb injuries are of less priority.

Rearward facing system with harness (Group I): Most popular in Northern Europe, rear facing CRS have been seen to be more effective in frontal impact when compared to forward facing CRS. Severe head injuries are less frequent in frontal impact with such devices than with rearward facing infant carriers. Limbs (especially arms) can also be injured.

Forward facing systems (Group I): For this type of system head injury is still a big issue. Impacts are one cause, but diffuse brain injuries are also observed due to angular acceleration that can occur either with or without impact. The neck is an important area to protect for children in such devices (younger than 4 years of age) even if these injuries are not very frequent. Chest and abdominal injuries are not very frequent with such systems but are found.

Forward facing system with shield (Group I and shield systems (Group II): The main sources of data are from the UK and France where these devices are not very popular. Therefore, no accident data are available at this time but some observations from experts were collected. Head contact with the top of the shield and risk of ejection (total or partial) are likely scenarios causing injuries.

Forward facing seat and adult seatbelt (Group I/II/III): In most of the analysis of databases these systems were considered as booster seats (see below). In addition, the risk of neck injuries is as high as for forward facing systems with harness (see forward facing systems (group I) above).

Booster seat and adult seatbelt (group II/III): Head is still the most important body area in terms of frequency of injury, but the relative importance of abdominal injuries increases with such restraint systems. The penetration of the seatbelt in the soft organs creates injuries at the level of liver, spleen, and kidney. For these systems, the protection of the abdominal area is clearly a priority to ensure a good protection of children using a CRS on which they are restrained by the adult seatbelt. The chest does not seem to be a priority in terms of frequency of injuries, nevertheless, as the chest cavity protects vital organs, it remains an important body segment. Focussing on severe injuries, ribs fractures are not very common because of the chest compliance for children, and internal injuries occur by compression of the chest by the seatbelt. No injury due to inertial loading has been noticed. The pelvis is not a priority body region in frontal impact. Limb fractures are numerous for children on booster seats and booster cushions, but do not seem to be a priority in terms of child protection for the moment.

Booster cushion and adult seatbelt (group II/III): The situation for these systems is the same as for booster seats with an increase of the number of chest injuries, certainly due to the fact that children using these CRS are generally older than the ones using booster seats.

Adult seatbelt: It was observed that a lot of children were only restrained by the adult seatbelt, while they could be better protected by using an additional CRS. The body segments that are protected for children restrained by the adult seatbelt only are the same as for the ones using booster cushions but with worse injury outcome, especially in the abdominal region.

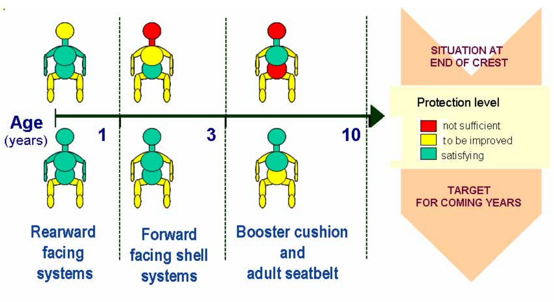

Figure 1. Level of protection for well-restraint children on appropriate CRS in the year 2000 and the target for the years thereafter.

The review of child occupant injuries related to CRS systems used in frontal impact has demonstrated that the whole priority should lie on protecting the head and neck from injury for infants and toddlers (Group 0/1), shifting to head, chest and abdomen as children grow up and starting to become taller (Group 2/3/adult belt) which is illustrated in Figure 1. It is important that new dummies and criteria reflect these injuries observed in the field. Consequently, injury measures were recommended for the head, neck, chest, abdomen/lumbar spine and pelvis.

DEVELOPMENT AND EVALUATION OF Q-DUMMIES

Background

The P-series is a series of crash test dummies representing children in the age of six weeks (P0), 9 month (P3/4), three year (P3), 6 year (P6) and 10 year (P10) old. The P-dummies ('P' from Pinocchio) were the first European child dummies to become official in 1981, when the ECE-R44 [6] regulation came into force. Later, the dummies were also adopted by other standards. The P-series, despite being simple in design and limited in measurement capability, gave a substantial contribution to the protection of children in cars. However, more knowledge on biomechanics related to children and the changing nature of exposure (airbags, belt systems) meant that the P-series became less appropriate over time. In the nineties the CRABI (Child Restraint AirBag Interaction) and Hybrid III child dummies were developed in particular to address the growing problem of child-airbag interaction in the US. In Europe, research has been focused on the development of a new child dummy series that would bring major improvements in terms of biofidelity and instrumentation and that could be used for a range of applications including side impact.

In 1993, the international Child Dummy Working Group (CDWG) was formed with the mission to develop the Q-series as the successor of the P-dummy series. This group, consisting of research institutes, CRS- and dummy manufacturers and OEM's, determined the anthropometry, biofidelity, measurement capabilities and applications for these dummies [7-10]. Under their surveillance, also the development of the first Q dummy, Q3, started. In 1997, this work was continued under the EC sponsored CREST (Child REstraint System sTandard) research program. Within the CREST and the consecutive CHILD (CHild Injury Led Design) projects, altogether the new-born (Q0), the 12-month (Q1), three-year old (Q3) and six-year-old (Q6) dummies were delivered and used in accident reconstruction. In 2003, the most recent dummy was added to the series: the Q1.5, representing a child of 18 months old. Figure 2 shows the Q-dummy family.

Figure 2. The Q-dummy family: (from left to right) Q1.5, Q3, Q0, Q6, Q1 and Q1 without suit.

Since their original release, the Q-dummies have undergone updates, in particular to improve the overall durability in frontal impacts, while maintaining the overall biofidelity and side impact performance of the dummy. The Q-dummies were particularly tailored to meet the (high-end) demands of EuroNCAP and NPACS testing [11]. This section summarises the status of the Q-dummy series today. The dummy design and performance particularly for frontal impact are described. In addition, the main differences with the US child dummy series are given.

Dummy description

Specific design features of the Q-dummies are the anatomical representation of body regions, use of advanced materials, dummy-interchangeable instrumentation, multi-directional use (frontal & side impact) and easy handling properties (limited components, easy assembly/disassembly, and simple calibration).

The dummy layout of the Q1, Q1.5, Q3 and Q6 is similar. The design of the head, the neck, the shoulder, the clavicle, the thorax, the lumbar spine, the abdomen and the extremities show a realistic anatomy compared to the human anatomy. The head and the clavicle are made entirely from plastics. The neck and the lumbar spine have a similar design: a combination of metal and a natural rubber. It is flexible and allows shear and bending in all directions. The thorax consists of a deformable ribcage and a rigid metal thoracic spine. The plastic clavicle is connected to the thorax at the front of the ribcage and to the shoulders at the arm side. The shoulders are made of natural rubber with metal end plates which are connected to the upper arm on one side and the thoracic spine on the other side. The lumbar spine is mounted between the pelvis and the thoracic spine. The abdomen is skin covered foam, which is enclosed by the ribcage and the pelvis. The pelvis consists of two parts: a metal pelvic bone and a plastic pelvis flesh. The extremities are a combination of plastics and metal. The Q1, Q1.5, Q3 and Q6 have a kinematical representation of the elbow, shoulder, hip and knee joints.

The anthropometry of a new-born child makes it difficult to maintain the dummy lay-out of the other Q-dummies for the design of the Q0. The limited space reduces the anatomical representations of body parts. For the Q0, its design results into eleven body parts: head, neck, shoulder block, two arms, thoracic spine, lumbar spine, thoracic flesh, pelvis block and two legs. The materials used are similar to those used in the other Q-dummies. The legs and arms have no knee and elbow joints, respectively; instead, the angles between upper and lower leg and upper and lower arm are fixed. The torso flesh foam part represents the ribcage and the abdomen. It is made of foam covered by a vinyl skin. The neck and lumbar spine have a similar design [4].

Anthropometry - To establish human-like dimensions for the Q-dummies, a special Child Anthropometry Database, CANDAT, has been built [8]. For this database, the newest available child data from birth to 18 years have been collected from different regions (US, Europe and Japan). Inconsistencies have been solved and gaps have been filled to calculate the averages for important body dimensions and mass (Figure 3).

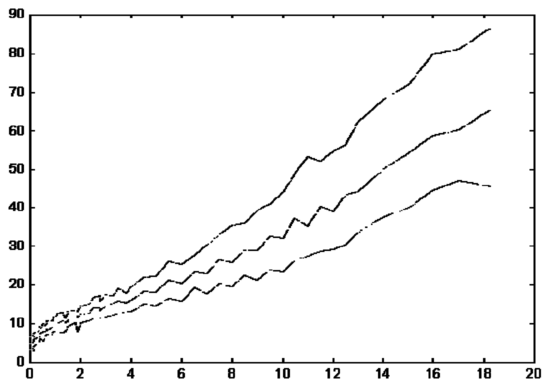

Figure 3. 5th, 50th and 95th Percentile child body mass (in kg) vs. age (in years) in CANDAT.

For adoption of the Q-dummy series, it is important that the body mass corresponds with the manikin body mass as defined in the regulations. In ECE-R44, a child restraint system falls into one of the five defined mass groups. Each mass group has a lower and upper boundary. Therefore, two child dummies are necessary to validate a child restraint system. Below, in Table 1, the body mass of the Q-dummy series is compared with the weight groups of ECE-R44. In Annex A, the main dimensions and the segment masses of each Q-dummy are compared with the manikin requirements as defined in ECE-R44.

Table 1.
ECE-R44 mass groups with corresponding Q-dummy

R44 Group	Limits	R44 Mass [kg]	Dummy age	Dummy mass [kg]
0	Lower	-	Q0	3.4
	Upper	<10	Q1	9.6
0+	Lower	-	Q0	3.4
	Upper	<13	Q1.5	11.1
I	Lower	9	Q1	9.6
	Upper	18	Q3	14.6
II	Lower	15	Q3	14.6
	Upper	25	Q6	22.9
III	Lower	22	Q6	22.9
	Upper	36	-	-

It can be observed that the mass groups are covered by the Q-dummy series except for the upper boundary of a group III seat. This Q-dummy is not yet available. The segment masses and the main dimensions of the Q-dummy series are slightly different from the manikins as defined in ECE-R44 which are based on the P-dummy anthropometry. The Q-dummy family, however, is based on a more recent anthropometric database (CANDAT).

Biofidelity - The availability on biomechanical data of children is poor due to the ethical difficulties with obtaining such data. Therefore, the following approach was chosen to derive a set of biomechanical response requirements for the Q dummy series. First, a set of human body responses to frontal and side impact have been discussed [12-17]. Second, a study was made of the characteristics of the human body, both of adults and children [9, 10]. Finally, scaling methods, combined with the data on human body tissue characteristics were used to derive child response characteristics from adult data. The scaling is based on differences between adult and child subjects in terms of geometry and stiffness [18-21]. For frontal impact, biofidelity requirements have been set-up for the head, the neck, the thorax, the abdomen and the lower extremities. For lateral impact the set of biofidelity requirements is extended with requirements for the shoulder and the pelvis. It should be noted that due to the (many) assumptions made in the scaling process, these requirements should be treated as design targets rather than strict specifications.

For the assessment of the biomechanical response in frontal impact, the head, the neck, the thorax and the abdomen are considered the most important body parts (head and neck only for Q0).

The biomechanical target of the Q-dummy heads is based on the rigid surface cadaver drop tests conducted by Hodgson and Thomas [22]. The head biofidelity for frontal impact has been assessed by a free-fall head drop test with a drop height of 130 mm. Table 2 shows the head biofidelity test results for the Q-dummy family.

Table 2.
The head biofidelity target vs. test result for the Q-dummy family

Peak resultant head acceleration [G]		
Q-dummy	Target	Test result
Q0	124 ± 33	120 ± 3
Q1	108 ± 29	112 ± 1
Q1.5	111 ± 29	111 ± 2
Q3	121 ± 29	116 ± 1
Q6	139 ± 37	122 ± 1

The neck response requirement for flexion-extension has been established by scaling human volunteer and cadaver data of Mertz and Patrick [23]. The assessment of the neck biofidelity head-neck pendulum test responses were performed for the assessment of the neck biofidelity of the Q-dummy series. Figure 4 shows the biofidelity performance of the Q3 dummy for flexion.

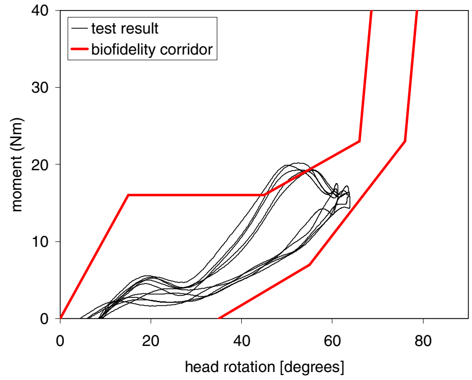

Figure 4. Q3 neck biofidelity corridor for flexion vs. test results.

The thorax frontal response requirement is based on two series of blunt-frontal, mid-sagittal impactor tests reported by Kroell [24, 25], Nahum [26] and Stalnaker [27]. Thorax impactor tests, using a dummy specific pendulum, were performed to assess the biofidelity of the thorax. Two different impact velocities are used, 4.3 m/s and 6.7 m/s. Figure 5 shows the thorax biofidelity performance of Q3 compared to linearly scaled corridors. It should be noted that linear scaling does not take into account damping and therefore is likely to underpredict the true force response of the actual child [28].

For the abdomen, a frontal belt loading requirement has been defined. It is based on living porcine experiments [16, 29]. Previous abdomen tests indicated that the segment is meeting the corridors, but additional test are being run to document the abdominal response for all dummies. The complete biofidelity results of the individual Q-dummy family dummies will be reported separately to the EEVC along with the recommendation for its use. From the data available at this time it is concluded that the biofidelity responses of the head (see Table 2) and the neck of all Q-dummies are within the corridor. The biomechanical performance of the Q1, Q1.5, Q3 and Q6 thorax show that it is a bit stiffer than its (linearly scaled) target, in particular at lower impact velocity.

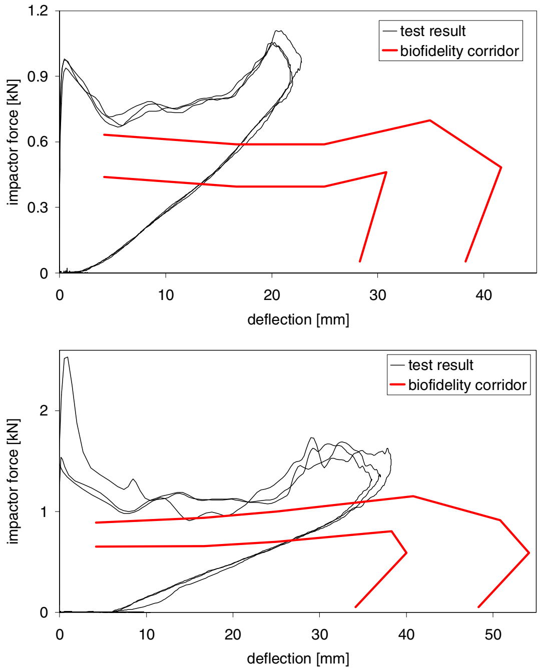

Figure 5. Q3 thorax biofidelity corridors vs. test results for 4.3 m/s (upper graph) and 6.7 m/s (lower graph) impactor velocity.

Injury assessment - The Q-dummy series allow the measurement of a number of responses covering the needs that follow from the field accident research. The set of instrumentation is similar for Q1 and Q1.5 and for Q3 and Q6. The type of load cells, the head angular velocity sensors and the accelerometers are generally interchangeable for all Q-dummies. Figure 6 shows the set of the instrumentation for Q1.5.

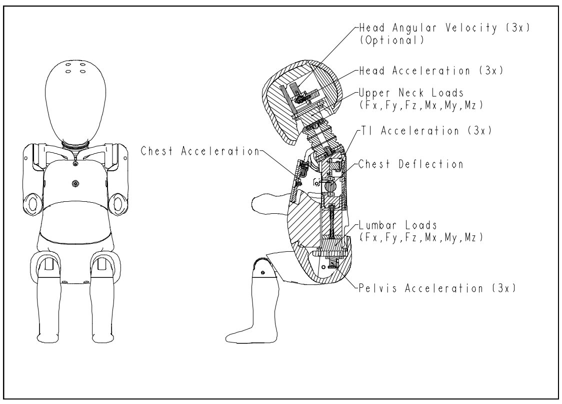

Figure 6. Q1.5 dummy instrumentation set.

In addition to the set of instrumentation for Q1/ Q1.5, the Q3 and Q6 have a lower neck loadcell (6-axis). Q3 and Q6 abdominal sensors are under evaluation [1, 30]. For Q0, the set of instrumentation is limited compared to Q1/Q1.5 due to space and performance limitations. The Q0 can, due to its size, only be equipped with head, T1 and pelvis accelerometers (3-axis) and an upper neck loadcell (6-axis).

Durability - The anticipated use of the Q-dummy series in EuroNCAP full-scale and NPACS body-in-white/sled testing make that the dummies have to be durable under test conditions that are more severe than ECE-R44. The definition and assessment of the durability level required for the Q-series are assessed on the ECE-R44 sled equipped with a rigid wooden seat instead of a CRS [31]. The crash pulse is based on a generalized vehicle B-pillar acceleration taken from actual EuroNCAP tests. The Q1 and Q1.5 are restrained with a 5-point belt over the shoulders and upper legs. For Q3 and Q6 a standard 3-point belt system is used. Thirty tests were carried out with each dummy with intermediate visual inspection to ensure that the dummies meet the durability requirements without any damage. It is concluded that the Q-dummies sustained the durability tests showing no damage.

Repeatability - The level of repeatability of dummy responses is often expressed in the coefficient of variation. For adult dummies, a coefficient of variation of 10% is considered to be acceptable. In case of child dummies, the coefficient of variation in sled tests depends on more factors compared to adult dummies. For example, in most test conditions the child dummies are restrained in a CRS and the CRS is attached with the car belt, both adding variability to the system. To assess the repeatability of the Q-dummy series the peak responses in the durability sled tests of Q1 and Q3, as described above, were used. In this test program the interference of a CRS has been avoided. The peak responses from the biofidelity test results of all Q-dummies have also been analysed to assess the repeatability of the Q-dummies. It shows that the coefficient of variation is 12% or less for relevant dummy measurements, which is considered acceptable from the user point of view.

Certification - For frontal impact tests a certification test is derived for the head, the neck, the thorax, the lumbar spine and the abdomen. All certification tests are component tests carried out on individual components or the full dummy. For Q0, only the head and neck have certification requirements. To perform the certification tests special equipment is required: a head drop table, a wire suspended pendulum for the thorax impactor test, a dummy specific pendulum (weight and diameter are dummy specific), an abdomen compression device, a part 572 pendulum and a dummy specific head form for the neck and lumbar spine certifications. The certification procedures and criteria are described in the respective dummy manuals [32, 33].

The recommended frequency of Q-dummy certification and the number of tests that can be performed between certifications strongly depends on the number, type and severity of the tests in which the dummy is used. Which certification tests have to be carried out depends on the dummy application (ECE-R44, NCAP) performed.

Comparison with US Child Dummy series

It is recognized that the development phase of the Q-series has largely run parallel in time to the development and enhancement of the Hybrid-III series in the US. The Hybrid-III family is fundamentally different from the Q-series in terms of design philosophy (scaling methodology), lay-out, and source information used.

In 1987 the development of the CRABI and Hybrid III child dummies started by two SAE task groups, the Hybrid III dummy family task group and the Infant dummy task group. The CRABI (Child Restraint Air Bag Interaction) dummies represent children in the age of 6, 12 and 18 month old for use in assessing airbag interactions with rear facing child restraints. The Hybrid III child dummies are representatives of 3, 6 and 10 years old children. These dummies are designed primarily for use in frontal loading conditions, with special attention given to OOP (Out-Of-Position) test conditions [34]. The anthropometry of these dummies has been derived from children in the United States. The biofidelity requirements were obtained by scaling the biomechanical response corridors for the mid-size adult male that were used to develop the Hybrid III dummy [34, 35], using dummy dimensions.

The main differences between the US child dummies and the Q-dummy series are identified on the anthropometry sources used, the biofidelity and the application. The anthropometry of the US child dummies focuses on US-databases, whilst the Q-series is based on a more global anthropometry. The set of biofidelity requirements as defined for the Q-dummy series is more elaborated than for the US child dummies. It has resulted in different mass and weight distribution between the two dummy types. The US child dummy biofidelity concerns mainly head, neck (and chest for the older dummies) requirements while the Q-dummy series also have requirements for all relevant body regions in front and side impact. The interpretation of biofidelity also shows differences. For example the head biofidelity requirement of the Q-dummy series is based on the non-fracture zone of impact while the CRABI and HIII child dummy head requirement focuses on the fracture zone. The Q-dummy series have a different field of application than the US child dummies since the Q-dummy series are optimised for CRS testing in ECE and side impact testing, while the US dummies have their background in airbag interaction testing and are used in FMVSS 213 and FMVSS 208.

CHILD DUMMY INJURY CRITERIA

One of the most challenging tasks in child safety is to establish correlations between the child injuries and child dummy measurements. Biomechanical tests with child subjects are undertaken very seldom, for obvious ethical reasons. Besides, a child is not a “small” adult and the scaling approach does not allow the direct transfer of knowledge from adult to child. For these reasons, crash test reconstructions of actual crashes with fully instrumented dummies having a comparable anthropometry, constitutes a right and appropriate methodology to acquire the missing biomechanical knowledge relative to the children. This approach is taken in the EC-CREST and EC-CHILD projects. It is clear, however, that this methodology requires many reconstructions to be performed. At this point in time insufficient reconstructions have been carried out to recommend new injury limits for all dummies. It is expected that the EC-CHILD project will supply sufficient reconstructions by mid 2006.

What is available at this time is based on child free-fall studies, aircraft field investigations and animal testing combined with response scaling from adults and dummies. The Hybrid III child dummies series have the most extensive set of injury criteria, based on the scaling methodology developed by Irwin and Mertz [35]. For the head, neck, chest and lower extremities injury criteria are determined:. For the P-dummies the set of injury criteria is limited to the head and the chest. These criteria are described in ECE-R44.

Injury criteria for the Q-dummy family have yet to be reviewed by EEVC WG12. Awaiting the outcome of the EC-CHILD project, the scaling methodology as used for the Hybrid III child dummies has been studied by EEVC WG12 and may be applied to the Q3-dummy head, neck and chest criteria. This has proven to be less straight forward as expected since biofidelity responses of the dummies are not identical. The results of the P-dummy and Q-dummy comparison presented below therefore focuses firstly on the existing ECE R44 criteria. In addition, the extra measurements taken for the Q-dummies are assessed with regards to their potential merits for child seat evaluation.

VALIDATION OF DUMMIES & CRITERIA

In this paper, the Q-dummies are compared to the existing P-dummies in an extensive validation program performed by eleven European organizations including OEMs, research institutes and child restraint manufacturers. Below, the test set-up and test matrix are described in detail. In addition, the data analysis with its preliminary test results is given.

Test set-up

The test procedure is essentially based on the current ECE-R44 (status of 4th February 2004; including Supplement No. 6). The test series exclusively focuses on the dynamic test procedure as described by ECE-R44 paragraph 8.1.3, frontal impacts. However, on the following points the test procedure deviates from the ECE-R44 dynamic test protocol. Firstly, only frontal impact sled tests are performed. No tests on trolley and vehicle body shell (ECE-R44 8.1.3.2) or tests with a complete vehicle (ECE-R44 8.1.3.3) have been conducted. Secondly, CRS with support legs (ECE-R44 7.1.4.9) have been tested. The test laboratory has chosen one suitable position for the support leg and has repeated this test. The position of the support leg on the floor is photographed. Thirdly, for all classes of ISOFIX CRS (ECE-R44 7.1.4.10) it is decided to perform one test with the anti-rotation device in use, if any. One change from the specification, given in Annex 6 of ECE-R44, is that the EEVC WG12/18 program allowed the use of a double sled with two benches on the trolley. Furthermore acceleration and deceleration based sleds are allowed.

The complete Q-dummy family is assessed and from the P-dummy family the P10 is excluded.

Table 3.
Assessment of dummies for a CRS per ECE-R44 group

Dummy		ECE-R44 group			
		0+	I	II	III
Small	P	P0	P¾	P3	P6
	Q	Q0	Q1	Q3	Q6
Intermediate	P	P¾	P1.5	-	-
	Q	Q1	Q1.5	-	-
Large	P	P1.5	P3	P6	-
	Q	Q1.5	Q3	Q6	-

Both dummy families are fully instrumented. Modelling clay for the P dummies is only used for appropriate kinematics and not as injury risk assessment. The Q3 and Q6 abdominal sensors are under evaluation in the EC-CHILD project and therefore not included in the dummies. The temperature of each child dummy has been stabilised in the range of 18°C to 22°C. Table 3 shows the assessment of dummies for a CRS per ECE-R44 group.

To fix the dummy position in the pre crash phase, masking tapes on the heads and arms are used, if necessary. Each test is repeated once with a new CRS. In case of breakage of the CRS, breakage of the dummy or "strong differences" between the two conducted tests, a third test is conducted.

Test matrix

The test matrix covers almost all existing CRS categories, including rear infant carry cot (isofix/universal), seats with harness (forward/ rearward, isofix/universal), shield systems (isofix/ universal), boosters with backrest, booster cushions and multi-group. Therefore 30 CRSs are selected and 300 tests are Table 4 summarizes the test matrix. More details are given in Annex B.

Table 4.
Test matrix P- & Q-dummy comparison

Type of CRS	# of tests	# of CRS
G0+ RWD FC	**68**	**6**
Infant carrier universal	36	3
Infant carrier isofix basis	12	1
Combination CRS used RWD	8	1
Combination CRS-RWD isofix	12	1
GI FWD & RWD HARNESS	**116**	**11**
FWD FC universal	64	6
FWD FC isofix + top tether	20	2
FWD FC isofix + support leg	12	1
RWD FC classical (non-isofix)	8	1
RWD FC isofix	12	1
GI FWD SHIELD	**12**	**1**
FWD FC isofix	12	1
BOOSTER + BACK	**32**	**4**
Universal	32	4
MULTI I,II,III same config	**40**	**3**
Universal	40	3
MULTI I, II, III differ config	**52**	**5**
Universal – shield	20	1
FWD universal – harness	32	4
	300	**30**

Data analysis

For the data analysis a database has been developed to compile all test results: measurement signals, photographs and videos. In addition, a summary of all test results per laboratory will be given. Because of the fact that the test program is recently completed, only a preliminary data analysis can be conducted at this time. This analysis focuses on current ECE-R44 requirements, dummy kinematics, and extra measurement signals of the Q-dummies.

ECE-R44 – It is known that sled acceleration will influence the dummy measurements of ECE-R44. In addition, it is known that different types of CRS belonging to the same ECE-R44 group may show slightly different outcomes. Therefore, for a valid comparison between P- and Q-dummies, only tests where both P- and Q-dummies are tested at the same test facility and in the same CRS are selected for the data analysis. For the maximum head excursions, this means that 276 of in total 300 tests are available for the current analysis. For chest accelerations, data on ECE-R44 requirements are not yet complete at the time of this analysis. Therefore, only a subset of 106 tests can be used for this analysis.

Kinematics – The dummy kinematics are studied by analyzing the videos of the test and the timing of the maximum head excursions. The results of the timing are obtained in the same manner as the maximum head excursion itself.

Extra measurements for Q-dummies – The analysis of the extra measurement signals taken for the Q-dummies focuses on the findings of the individual laboratories. Injury criteria for these extra measurement signals are not yet available as mentioned before.

Data are expressed as means with the standard error of the mean (s.e.m.). A 95% confidence interval for the mean can be determined as mean ± 1.96*s.e.m.. The s.e.m. gives an impression of the variability of the estimated mean (standard deviation is s.e.m. * n). Differences between means were tested by t-tests. A t-test probability of $p<0.05$ is considered as statistically significant.

Test results

The test program is performed without any notifying problems. The Q-dummy family shows good durability under ECE-R44 frontal impact test conditions. No Q-dummy part has been replaced during the test program.

ECE-R44 – The preliminary results of the P- and Q-dummy comparison according to ECE-R44 requirements for head and chest are summarized in Table 5 and Table 6, respectively.

The similarity of the sled acceleration for the P- vs. Q-dummy tests is evaluated. This is done by comparing the mean values and the s.e.m. of the maximum sled accelerations for both P- and Q-dummies per ECE-R44 group. For all dummy comparisons, t-test results have shown that the maximum sled acceleration can be considered to be similar for P and Q. This means that if the input of the test (maximum sled acceleration) is similar for P- and Q- dummies, the dummy responses (head excursion) may be compared. The head excursions are compared between P- and Q-dummies in the same manner as the maximum sled acceleration. The maximum sled acceleration is compared between P- and Q-dummies by determining the mean and s.e.m..

Table 5.
Comparison of the maximum sled acceleration and head excursion in X and Z for P vs. Q in ECE-R44 group 0+, I and II

ECE-R44 group 0+ CRS				
Dummy	**P0**	**Q0**	**P1.5**	**Q1.5**
Maximum sled acceleration [G]				
mean	24.6	24.6	23.1	22.8
s.e.m.	0.8	0.8	0.7	0.6
n	6		6	
Head excursion in X [mm]				
mean	465	455	581	584
s.e.m.	17.5	16.5	33.4	30.1
n	6		6	
Head excursion in Z [mm]				
mean	459	459	598	632
s.e.m.	29.4	20.4	22.9	3.8
n	6		6	
ECE-R44 group I CRS				
Dummy	**P¾**	**Q1**	**P3**	**Q3**
Maximum sled acceleration [G]				
mean	23.0	22.7	22.4	22.4
s.e.m.	0.3	0.3	0.3	0.4
n	22		22	
Head excursion in X [mm]				
mean	399	398	457	457
s.e.m.	13.7	15.4	18.7	18.9
n	22		22	
Head excursion in Z [mm]				
mean	432	437	494	499
s.e.m.	57.0	60.5	60.5	64.0
n	20		22	
ECE-R44 group II CRS				
Dummy	**P3**	**Q3**	**P6**	**Q6**
Maximum sled acceleration [G]				
mean	23.5	24.1	22.4	23.1
s.e.m.	0.8	0.6	0.3	0.3
n	12		10	
Head excursion in X [mm]				
mean	396	389	490	453
s.e.m.	33.0	32.6	14.8	20.9
n	12		10	
Head excursion in Z [mm]				
mean	424	414	485	448
s.e.m.	72.6	93.9	81.0	92.9
n	12		8	

Table 6.
Amount of tests (in %) in which the max. res. chest acc. and the max. z-chest acc. are above 55 G and 30 G, respectively, for P vs. Q in ECE-R44 group 0+, I and II

Resultant chest acceleration > 55G			
ECE	**Dummy type**	**P**	**Q**
0+	P0, Q0 (n=4)	n.a.*	0
	P1.5, Q1.5 (n=8)	25	25
I	P¾, Q1 (n=14)	0	21
	P3, Q3 (n=13)	38	31
II	P3, Q3 (n=6)	67	33
	P6, Q6 (n=8)	25	0
Chest acceleration in Z-direction > 30G			
ECE	**Dummy type**	**P**	**Q**
0+	P0, Q0 (n=4)	n.a.*	0
	P1.5, Q1.5 (n=8)	25	25
I	P¾, Q1 (n=14)	0	21
	P3, Q3 (n=13)	38	31
II	P3, Q3 (n=6)	67	33
	P6, Q6 (n=8)	25	0

* no instrumentation

Table 5 shows that head excursions for P- and Q-dummies are similar under similar test conditions. None of the comparisons between P- and Q-dummy head excursions show statistical significant differences. This means that P- and Q-dummies do not discriminate for head excursion under ECE-R44 conditions.

The results in Table 6 give the impression that the P-dummies more frequently exceed the maximum resultant chest acceleration of 55 G and also the maximum chest acceleration in z-direction of 30 G. This is caused by the less stiff thorax of the Q-dummies. These findings are in line with previous comparison studies of P- and Q-dummies [31]. A statistical data analysis on the chest measurements has yet to point out if P- and Q-dummies show significant differences for these ECE-R44 chest criteria.

Kinematics – The video analysis shows two major differences in the general kinematics of P- and Q-dummy comparison. Firstly, the Q-dummy reaches a less 'wrapped' or 'pinned' position during the whole movement compared with the P-dummy. In ECE-R44 group I and II, the P-dummy rotates first upwards, then flexes forwards and so far downwards that the P-dummy head contacts the legs while, in most of the tests, the Q-dummy starts immediately with bending forwards and downwards. Secondly, the video analysis shows that the rebound of the Q-dummy starts earlier than for the P-dummy. These findings can be explained by the differences in dummy neck and thoracic-lumbar spine design. The Q-dummy neck design is able to induce neck moment. The P-dummy neck consists of an inner core of nylon rings and an outer shape made of urethane rings. This neck design makes it impossible to induce neck moments. For the thoracic-lumbar spine, the Q-dummy design has a lumbar spine which is similar to the neck design. Therefore the lumbar spine in the Q-dummy is also able to induce neck moments. The thoracic-lumbar spine of the P-dummy is completely rigid, which explains the large rotation in the pelvis.

The mean and the s.e.m. are also determined for the timing of the maximum head acceleration and the maximum sled acceleration. For ECE-R44 group 0+ and group II none of the comparisons between P- and Q-dummy head excursion timings show statistical significant differences. This result is also found for P¾ vs. Q1 in ECE-R44 group I. Not statistically significant are the results of the timing of the head excursions in X-direction for P3 vs. Q3 in ECE-R44 group I. It is assumed that an explanation for this result will be found by investigating the videos and the complete set of dummy measurements in parallel.

Although this preliminary result shows kinematical differences between P- and Q-dummies, the results for the ECE-R44 head requirements are not influenced by these findings.

Extra measurements for Q-dummies – The results of the extra measurements taken for the Q-dummies show a good repeatability of the test results for one Q-dummy type in the same CRS. The preliminary results indicate that the Q-dummies can discriminate between different CRSs in one type of ECE group, which is illustrated in Figure 7. These findings promote the added value of Q-dummies for child seat evaluation.

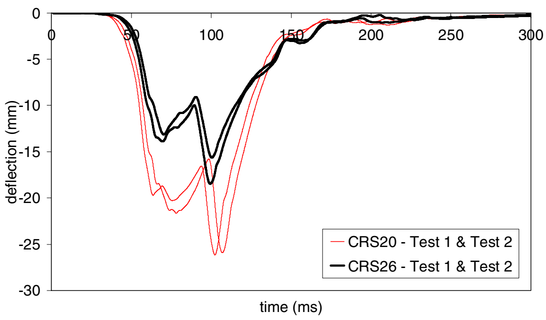

Figure 7. Chest displacement of Q3 in two different seats of ECE-R44 group I.

DISCUSSION & CONCLUSIONS

Within the EEVC, work is performed in order to promote new advanced child dummies and criteria for regulatory and consumer testing of child seats. The work, as presented in this paper, focuses on child occupant protection in frontal impact.

Starting from real world child injuries, priorities have been established with regards to what injuries are observed for what child ages and child seat types. The review of child occupant injuries covers all ECE-R44 CRS groups and the adult seatbelt. It has demonstrated that the priority should lie on protecting the head and neck from injury for infants and toddlers (ECE-R44 CRS group 0/0+/I), and the head, chest and abdomen for the older children (ECE-R44 CRS group II/III and adult belt).

The new child dummies, the Q-series, are able to reflect these injuries. More knowledge on biomechanics resulted in a new child dummy family which is more biofidelic and applicable for a range of applications. The Q-dummy family consists of Q0, Q1, Q1.5, Q3 and Q6 representing a newborn, 12 months, 18 months, 3 years and 6 years old child, respectively. These ages of the Q-dummies currently include the most important sizes required for testing the majority of child seats available on the market. However, in comparison with the P-dummy family, a dummy representing a child of 10 years is not available in the Q-series. The background information on which the Q-dummies are developed is collected and derived with ECE-R44 and side impact testing in mind. Through European cooperation (CDWG, EC-CREST, EC-CHILD) specifications have been agreed and dummies have been developed and validated. In this study, only the frontal impact biofidelity requirements are evaluated. For the head and the neck, the Q-results are within the corridor. The Q-thorax response is too stiff for its (linearly scaled) target. The measurement capabilities of the Q-series cover all needs of the injury causation study, except for the Q3 and Q6 abdomen. Abdominal sensors for these two dummies are under evaluation. In the final phase of development, most effort has gone into ensuring that the durability of the Q-dummies is up to the standard required for ECE, EuroNCAP and NPACS testing.

New child dummy injury criteria are under discussion in EEVC WG12. Therefore, the ECE-R44 criteria are assessed by comparing the existing P-dummies and new Q-dummies in ECE-R44 frontal impact sled tests. In this study, the most popular child seat configurations on the European market are taken into account. In total 300 tests are performed.

From the validation program, it can be concluded that the Q-dummy family is durable and the measurements show good repeatability. Applying ECE-R44 criteria, the P- and Q-dummy show similar results for head excursion in x- and z-direction. An in-depth analysis on the chest results of the P- and Q-tests is required, to be able to compare P- and Q- dummies according to the ECE-R44 chest criteria. Note that the actual velocity change of a deceleration sled is typically 52 to 54 km/h. This is more than the prescribed test speed of 50 +0/-2 km/h due to the rebound, which is typical for the ECE-R44 deceleration sled. At the time of this analysis, investigations towards the velocity change of the sleds were not yet completed. However, the similar maximum sled accelerations for all P- and Q-dummy comparisons indicate that the influence of the actual velocity change does not affect the outcome for the ECE-R44 head requirements (see table 5). From the findings of the extra measurements for Q-dummies, it is indicated that these measurements are able to distinguish between the performance of CRSs of one particular ECE-R44 group. This indication can be considered as the added value of the Q-dummy family for child seat evaluation.

From the results of the assessment of Q-dummies and ECE-R44 injury criteria in frontal impact as presented in this paper, the following conclusions are made:

- Head, neck, chest and abdomen need priority in protection (focus depends on age).
- Q0, Q1, Q1.5, Q3 and Q6 are available.
- ECE-R44 mass groups are covered as soon as Q10 is available (expected in 2006).
- Biofidelity targets, based on scaled criteria, are derived for the Q-dummies.
- Q-biofidelity results are good, except for the (linear scaled) thorax requirement.
- Q-measurements show good repeatability.
- Q-dummies are durable for ECE-R44 and EuroNCAP test conditions.
- P- and Q-dummies show similar results with respect to ECE-R44 requirements.
- For CRS evaluation, potential merits of Q-dummy family lie in the extra measurement capabilities.

RECOMMENDATIONS

Using the Q-dummy family for the assessment of all available ECE-R44 CRS groups, the Q-series need to be extended with a dummy, representing a 10 years old child. As mentioned in the conclusions the potential merits of the Q-dummy family for child seat evaluation lie in the extra measurement possibilities. Therefore it is recommended to further investigate new injury criteria. Subsequently, these criteria will be assessed with the Q-dummy test results from the validation program as presented in this paper. In near future, the analysis of the validation program will be finalized. Then, a recommendation for the implementation of the Q-dummy family in ECE-R44 can be made.

The child dummy assessment as described in this paper focuses only on ECE-R44 frontal impact loading. It is recommended to assess a similar program with child dummies for side impact, because side impact legislation is expected in the near future.

ACKNOWLEDGEMENTS

This work was financially supported by governmental bodies, OEM's and CRS manufacturers: Department for Transport (UK), RDW (NL), Institute for Highway Safety (BASt) (G), French Ministry of Transport (F), Swedish Ministry of Transport (SE), INSIA (ES), Applus+IDIADA (ES), FIAT (I), Britax (UK), Dorel (F), Team Tex (F), and PSA (F). The CRS manufacturers Britax/Römer, Chicco, Concord, Dorel, Fair, HTS, Jané, Kiddy, Play, Team Tex and Volvo are acknowledged for providing CRSs. FTSS Europe BV is acknowledged for kindly providing two complete Q-dummy families and supporting test engineers.

WG12 members are: François Bermond (INRETS, secretary), Klaus Bortenschlager (PDB, AUDI), Guilio Gertosio (FIAT), David Hynd (TRL), Luis Martinez (INSIA), Hakan Őhrn (Volvo), Claus Pastor (BASt), Michiel van Ratingen (TNO, chairman), Mats Svensson (CHALMERS), Xavier Trosseille (LAB).

EEVC WG18 members are: Friedrich Beisswaenger (MPA), François Bermond (INRETS), Farid Bendjellal (BRITAX), Manuela Cataldi (FIAT), Hervé Guillemot (LAB, chairman), Stephan Hartweg (AUDI), Kate de Jager (TNO), Marianne LeClaire (TRL, secretary), Jean-Philippe Lepretre (UTAC), Björn Lundell (Volvo), Britta Schnottale (BASt), Gonçal Tejera (Applus+ IDIADA), Thomas Turbell (VTI).

REFERENCES

[1] CHILD. website: www.childincarsafety.com.

[2] CREST. “Child Restraint System for Cars”. EC-contract number C-RTD SMT4-CT95-2019. 1996-2000.

[3] CHILD. “Child Injury Led Design”. EC-contract number G3RD-CT2002-00791. 2002-2006.

[4] De Jager, K. “Development and validation of a newborn child dummy: Q0”. JSAE Conference. 2004.

[5] Onvlee, W., Carlson, M. “Development and validation of updated Q-dummy family”. Int. Conf. Protection of Children in Cars. 2004.

[6] ECE-Regulation 44. “Uniform Provisions Concerning the Approval of Restraining Devices for Child Occupants of Power-Driven Vehicles (“Child Restraint System”). Version 03. United Nations. 5th June 1998.

[7] Beusenberg, M.C. “Information report: The Q-series of Child Dummies – Status Report and Prospects of the International Child Dummy Working Group.” TNO report 96.OR.BV.016.0/MB. 16th December 1996.

[8] Twisk, D., Beusenberg, M. "Anthropometric of Children for Dummy Design" ECOSA Product Safety Conference. Amsterdam. 1993.

[9] Happee, R. “Injury biomechanics of children, a literature survey on material properties and overall organism responses and tolerances”. TNO report 75131096. 24th September 1993.

[10] Twisk, D., Ruijs, P.A.J. "Anatomical and Biomechanical descriptions of children in the 0 to 10 years age range”. TNO report 95.OR.BV.006.1/DT. 1995.

[11] LeClaire, M., Bygrave, S. “Aims of the New Programme for the Assessment of Child restraint Systems”. Int. Conf. Protection of Children in Cars. 2003.

[12] ISO TR 9790. “Road Vehicles – Anthropometric Side Impact Dummy – Lateral Impact Response Requirements to Assess the Biofidelity of the Dummy”. (version referenced: ISO TC22/SC12/WG5, Document N455 – Revision 2, May 1996).

[13] Hodgson, V.R., Thomas, L.M. “Comparison of Head Acceleration Injury Indices in Cadaver Skull Fractures”. Proceedings of the Nineteenth Stapp Car Crash Conference, P-39. SAE paper 710854. 1971.

[14] Patrick, L.M., Chou, C. “Reponse of the human neck in flexion, extension, and lateral flexion”. Report VRI-7-3. SAE, 1976.

[15] Kroell, C.K., Schneider, D.C., Nahum, A.M. “Impact Tolerance and Response of the Human Thorax II”. Proceedings of the 18th Stapp Car Crash Conference, SAE 741187. 1974.

[16] Rouhana, S.W, Viano, D., Jedrzejcak, E.A., McCleary, J.D. “Assessing submarining and abdominal injury risk in the Hybrid-III family of dummies”. SAE publication 892440. 1989.

[17] Viano, D.C. "Biomechanical responses and injuries in blunt lateral impact". Proceedings of the 33rd Stapp Car Crash Conference. SAE 892332. 1989.

[18] Van Ratingen, M.R. “Biomechanically based design and performance targets for a 3-year old

child crash dummy for front and side impact". Second Child Occupant Protection Symposium. SAE 973316. 1997.

[19] "Human Mechanical Response Characteris tics". SAE Information report. SAE J1460 MAR 95. 1985.

[20] Wolanin, M.J., Mertz, H.J. "Description and basis of a three-year old child dummy for evaluating passenger inflatable restraint concepts". Proceedings of the 9th ESV conference. 1982.

[21] Roberts, A.K., Janssen, E.G., Cesari, D. "Review of cadaver responses to lateral impact and derived biofidelity targets for dummies". EEVC WG 9 report. 1990.

[22] Hodgson, V.R., Thomas, L.M. "Head impact response". Vehicle Research Institute Report VRI 7.2 SAE. 1975.

[23] Mertz, H.J., Patrick, L.M. "Strength and response of the human neck", SAE 710955. 1971.

[24] Kroell, C.K., Schneider, D.C., Nahum, A.M. "Impact tolerance and response of the human thorax". Proceedings of the 15th Stapp Car Crash Conference. SAE 710851. 1971.

[25] Kroell, C.K., Schneider, D.C., Nahum, A.M. "Impact tolerance and response of the human thorax II". Proceedings of the 18th Stapp Car Crash Conference. SAE 741187. 1974.

[26] Nahum, A.M., Gadd, C.W., Schneider, D.C., Kroell, C.K. "Deflection of the human thorax under sternal impact". International Automobile Safety Conference Compendium. SAE. 1970.

[27] Stalnaker, R.L., McElhaney, J.H., Roberts, V.L., Trollope, M.L. "Human torso response to blunt trauma". Human impact response: measurement and simulation. Plenum Press. 1973.

[28] Thunnissen, J., Happee, R., Eummelen, P., Beusenberg, M. "Scaling of adult to child responses applied to the thorax". Proc. of IRCOBI conference. 1994.

[29] Miller, M.A. "The biomechanical response of the lower abdomen to belt restraint loading". Journal of Trauma. 1989.

[30] Johanssen, H. "Injury risks of children-possibilities to detect abdominal injuries". Int. Conf. Protection of Children in Cars. 2004.

[31] Van Ratingen, M.R., Twisk, D. "Comparison of the Q3 and P3 dummy kinematics and kinetics in frontal and oblique impacts". Joint session of the European Vehicle Passive Safety Network, AAAM and IRCOBI. September 1999.

[32] Waagmeester, C. "Q0 user manual" TNO-report. September 2001.

[33] FTSS Europe, Kleveringweg 6-8, 2616 LZ, Delft, The Netherlands, phone +31 15 2192040, www. ftss.com.

[34] Berliner, J. et al. "Comparative evaluation of the Q3 and Hybrid III 3-year-old dummies in biofidelity and static out-of-position airbag tests". 44th Stapp Car Crash Conference. 2000.

[35] Irwin, A., Mertz, H.J. "Biomechanical basis for the CRABI and Hybrid III child dummies". SAE 973317. 1997.

ANNEX A: Anthropometric data of Q-dummies vs. ECE-R44

Body part	**Q0 [kg]**	**“new-born” [kg]**
Head & neck	1.1	0.7
Torso	1.5	1.1
Arms	0.25	0.5
Legs	0.55	1.1
Total mass	3.4	3.4

Dimension	**Q0 [mm]**	**“new-born” [mm]**
Chest depth	90	100
Shoulder width (maximum)	141	150
Hip width seating	98	105
Seating height	354	345

Body part	**Q1 [kg]**	**“9-months” [kg]**	**Q1.5 [kg]**	**“18 months” [kg]**
Head & neck	2.41	2.2	2.8	2.73
Torso	4.46	3.4	5.04	5.06
Upper arms	0.45	0.7	0.58	0.54
Lower arms	0.44	0.45	0.62	0.5
Upper legs	1.00	1.4	1.14	1.22
Lower legs	0.82	0.85	0.92	0.96
Total mass	9.6	9	11.1	11.01

Dimension	**Q1 [mm]**	**“9-months” [mm]**	**Q1.5 [mm]**	**“18 months” [mm]**
Back of buttocks to front knee	211	195	235	239
Back of buttocks to popliteus, sitting	161	145	185	201
Chest depth*	117	102		113
Shoulder width (maximum)	227	216	227	224
Hip width seating	191	166	194	174
Seating height	479	450	499	495
Shoulder height (sitting)	298	280	309	305
Stature	740	708	800	820

*Chest depth is measured on the centre line of the fixation point for the displacement sensor.

Body part	**Q3 [kg]**	**“3-years” [kg]**	**Q6 [kg]**	**“6 years” [kg]**
Head & neck	3.17	2.7	3.94	3.45
Torso	6.40	5.8	9.62	8.45
Upper arms	0.75	1.1	1.27	1.85
Lower arms	0.73	0.7	1.22	1.15
Upper legs	2.00	3	3.98	4.1
Lower legs	1.54	1.7	2.92	3
Total mass	14.6	15	22.9	22

Dimension	Q3 [mm]	"3-years" [mm]	Q6 [mm]	"6-years" [mm]
Back of buttocks to front knee	305	334	366	378
Back of buttocks to popliteus, sitting	253	262	299	312
Chest depth*	145.5	125	141	135
Shoulder width (maximum)	259	249	305	295
Hip width seating	200	206	223	229
Seating height	544	560	601	636
Shoulder height (sitting)	329	335	362	403
Stature	985	980	1143	1166

*Chest depth is measured on the centre line of the fixation point for the displacement sensor.

ANNEX B: Test matrix of P & Q-dummy family comparison

TYPE OF CRS	CRS CODE	P0 Q0	P 3/4 Q1	P 1,5 Q1,5	P3 Q3	P6 Q6	Nb tests
G0+ RWD FC							
Infant carrier Universal	"01"	X	X	X			12
	"02"	X	X	X			12
	"03"	X	X	X			12
Infant carrier Isofix basis	"04"	X	X	X			12
Combination CRS used RWD	"05"	X		X			8
Combination CRS-RWD isofix	"06"	X	X	X			12
GI FWD & RWD HARNESS							
FWD FC Universal	"07"		X	X	X		12
	"08"		X		X		8
	"09"		X	X	X		12
	"24"		X		X		8
	"11"		X		X		8
	"12"		X		X		8
FWD FC isofix + top tether	"13"		X	X	X		12
FWD FC isofix + support leg	"14"		X		X		8
	"15"		X	X	X		12
RWD FC classical (non-isofix)	"16"		X		X		8
RWD FC isofix	"17"		X	X	X		12
GI FWD SHIELD							
FWD FC isofix	"19"		X	X	X		12
BOOSTER+BACK							
Universal	"20"				X	X	8
	"21"				X	X	8
	"22"				X	X	8
	"23"				X	X	8
MULTI I/II/III same config							
Universal	"10"		X		X	X	12
	"25"		X	X	X	X	16
	"26"		X		X	X	12
MULTI I/II/III differ config							
Universal - shield	"27"			X	X		8
FWD Universal - harness	"29"		X		X		8
	"30"				X	X	8
	"31"		X		X		8
	"32"				X	X	8