CHILD ADVANCED SAFETY PROJECT FOR EUROPEAN ROADS (CASPER), BETTER KNOWLEDGE AND BETTER TOOLS TO IMPROVE THE REAL PROTECTION OF CHILDREN IN CARS

Philippe Lesire
LAB PSA Peugeot-Citroën/Renault, France
Heiko Johannsen
TU Berlin, ILS Kfz, Germany
Rémy Willinger
Université de Strasbourg, France
Alejandro Longton
IDIADA, Spain
Alan Kirk
Loughborough University, UK
Philippe Beillas
Université de Lyon1, IFSTTAR LBMC, France
Anita FIORENTINO
Fiat Automobiles Group

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ABSTRACT

This paper is a synthesis of the results obtained in the different parts of the EC CASPER project and considers sociological approaches, technical works, and field and accident data. From parent's behaviour and wishes that show cultural differences, to human modelling works, this project widely covers the topic of child safety in cars.

The CASPER project has brought a significant amount of field data that have been useful for a better understanding of the situation and used as basis for all the other tasks of the project. Consequent steps forward have been made in the development and improvement of tools usable for the approval of Child Restraint Systems (CRS) and in this aim a large collaboration with the GRSP Informal Group on CRS took place. Results have been presented and discussed in workshops with main participants and stakeholders of the child safety area.

INTRODUCTION

Considering the whole region of Europe, the World Health Organisation (WHO) reported that in 2008 the number of children 0 to 14 years old that died because of road traffic accidents was 4,408. Focussing on 20 EU countries, in 2009, 747 road traffic fatalities of children 0 to 14 years old were counted in the International Road Traffic and Accident Database (IRTAD). Based on these accident data, it is obvious that in spite of the significant improvements in recent years in vehicle safety, the current number of deaths and casualties added to the social and economic costs is still unacceptable. Fatalities and injuries should be reduced by all the available ways: public regulation, prevention/education of road users, road infrastructure, compatibility between vehicles, active, passive and tertiary safety devices. The CASPER project has been based on these approaches with the aim to improve the global protection of children in cars, using the research results obtained both in previous European projects financed by the European Commission (such as CREST and CHILD), and also the knowledge acquired through the collaboration with other European organizations such as EEVC WG 18, ISO/TC22/SC12/WG1 and NPACS. The activities have been supported by research addressing many fields such as in depth road accidents data collection and analysis, the influence of the impact of societal behaviour of adults in transport situations and technological based solutions to improve the safety of children.

CASPER addresses two main aspects:

- The analysis of the reasons and consequences of misuse of CRS's and of the influence of the conditions of transportation of children, as compared to the certification test procedures.
- The improvement of the efficiency of child protection through the development of innovative tools in order to provide to CRS manufacturers the possibility to develop and test their products at a lower cost, with new methods, and at a same guarantee efficiency.

The first point has been treated in reports on the conditions of use of CRS and related consequences in accidents. They include messages to be forwarded through information campaigns. Positive effects on the protection of children derived from these reports could be seen in a short time. This would solve a large part of the issue of child occupant safety. The improvement of the behaviour of dummies, associated to new sensors, as well as dummies and child human numerical models are necessary to propose improved test procedures, based on road reality issues. Here, the effect on the protection of children will be realised in the longer term but complementary to the improvement of rate of correct use of children.

The project has mobilised a large part of the European scientific and business expertise in the field of passive safety related to children: 7 European countries are involved, with 15 partners who have a long experience in child safety with complementary profiles. The consortium of CASPER did not involve any CRS manufacturer as the preferred solution was to disseminate results in existing working groups in which a large number of CRS suppliers are involved, to organize regular workshops and to disseminate results in international conferences.

ORGANISATION OF THE WORK

The work plan of the CASPER project is to use as much as possible existing data related to injuries of children and to collect the missing information, which can help to find reliable solutions for improved protection of children in road accidents. Dummy modifications and modelling, creation of tools of new generation such as human models, analyse the possible solutions both on the side of vehicles and CRS. For this, the work has been organized around five technical work packages (WPs) with specific objectives and deliverables.

WP1 has been considering the protection of children based on the use of crash test dummies. First at the hardware level (enhancement of biofidelity, improvement of measurement capabilities), with the aim of proposing new protection criteria usable in test procedures for the evaluation of CRS performance. Secondly with the completion of the Q series FEM models family.

WP2 has defined, developed and validated child human body segments corresponding to 5 different sizes (ages). Whole-body child human models have been created by assembling the previously described body segments, although the validation process needs to be continued.

WP3 aimed to understand the travelling conditions of children in cars and the main issues in terms of lack of protection in accidents. A large amount of field and accident data have been collected and analysed. The results have been used as the basis of determining the issues to be solved, and to highlight priorities for the actions to be taken for a rapid improvement of the situation. They have led to proposed evolutions of child dummies and the definition of human models characteristics.

WP4 has evaluated possible solutions based on the real traveling conditions of children, the previous information and enforcement campaigns. It has also defined possible actions of communication and education, and evaluated the proposals of test procedures for a new regulation of CRS approval.

WP5 has been organizing the dissemination and the exploitation of the project results as well as networking with other organisations involved in the field of child protection in road transport such as the GRSP informal group on CRS, in charge of writing a new text for CRS approval.

RESULTS

As CASPER has been considering child safety issues with a global approach, it has been necessary to base all research activities on field data in the different areas of car child safety. For this, data from previous projects and results available in the literature were used, and they were completed with the collection of data specific to the different task topics. For some studies, existing collection methodology used in the past have been adapted, in some other areas, such as a sociological approach, it has been necessary to set up the methodology, and to validate it before starting to collect data. The data collected were mainly focussed around two topics: accident data (from different types and sources) and misuse data (descriptive, quantitative, etc.). Each set of data have been analysed and results are reported in public deliverables.

ACCIDENT DATA

One of the priorities of this task was to make a status point on child fatalities in cars [1]. Then in depth investigations of accident cases (fatal or not) were necessary to provide accident cases for the establishment of injury criteria using car passenger accidents [2] and other accident types [3].

Report on fatality studies

According to WHO, an estimated 122,571 children in the age group of 0 to 14 years old died because of road traffic accidents in 2008. This represents 1.3% of children dying before the age of 15 and approximately 10% of road traffic accident fatalities world-wide. In these figures all kinds of transport modes and pedestrians are included. For some countries no data exist, and for many countries underreporting is known, thus the WHO includes some best estimates. The database screening and literature review shows clear limitations referring to the focus on children fatalities as car passengers. No current numbers on child fatalities as car passengers for the whole world can be found in published data from WHO or the IRTAD database. As a more detailed study was available for the French situation, CASPER has been looking at what could be the priorities to limit child in car fatalities, knowing that the study results are representative of the French situation but generalisation of results to other countries should be done with some caution. For frontal impact fatalities in France, the priority is to improve the quality of use of restraint systems. When the child is correctly restrained, very few fatal cases are observed in conditions similar to the frontal test of the current regulation. In side impact, the current level of protection does not seem sufficient, the level of intrusion and the direct impacts with intruding objects are important for children on the struck side. For roll-overs the priority is to protect children from being ejected from the car and from projection inside of the car. The rate of correctly restrained children in this type of fatal accident is very low in France, which indicates that existing systems when correctly used could be preventing these fatalities. Rear impact remains rare in the French fatality study.

Looking now at European figures, and focussing on children from 0 to 13 years old, there are 392 fatalities recorded as car or taxi passengers in EU-23 for 2008, involved in 337 accidents. Just under one third were killed in single vehicle accidents, half in 2 vehicle accidents and one fifth in 3 or more vehicle accidents. Of the 2 vehicle accidents, 55% of fatalities are in accidents involving 2 cars, followed by 23% in accidents involving a heavy goods vehicle (HGV). Car passengers account for 44% of all child fatalities, closely followed by 37% for pedestrians. Child car passenger fatalities (0 to 13 years old) account for 1.1% of all road accident fatalities (37,265) in EU-23 for 2008 and 7% of all car passenger fatalities. Over a 10 year period the reduction in child car passenger fatalities is estimated to be 50% for the EU-19 countries with data available, higher than the improvement of 32% for all fatalities. For fatality rates by population, the EU-23 rate is 0.55 per 100,000. National level data in Europe has no information on restraint use and therefore, of course, no detail on misuse, which has been shown in detailed studies such as the CREST, CHILD and CASPER projects to have an effect on injury outcome. Large efforts are made in road accident investigation in the CASPER project as little detailed information is available to the level of detail required.

Focussed car accidents in depth investigations

Real world accident cases are collected to ensure that information on child kinematics, injury causation, injury criteria and CRS performance (including misuse where understood) is available to the project in order to support further activities in injury criteria, dummy/model development and the understanding of misuse. This has an implication for how the analysis should be interpreted as the database is not representative of the overall child car passenger crash population. However, the database does give an indication of which body regions are being injured in different CRS types or for different ages of children and gives insights into restraint conditions that lead to injury. The combined dataset, including the number of data available from the three EC child occupant safety projects (CREST, CHILD and CASPER) is one of the largest collections of in-depth road accident data focused on restrained child occupants. Overall there are 1301 restrained children in the combined database, 954 in frontal impacts, 341 in lateral impacts and 6 in rear impacts. Of these restrained children, 30% have a maximum abbreviated injury score (MAIS) of 3 or above. The consideration of misuse remains a challenge and the knowledge continues to grow with the collection of further accident cases, experiences from field surveys and sled testing

An analysis for frontal impacts is carried out using the more recent CHILD and CASPER cases, considering 483 restrained children, 37% using the adult seat belt only and 63% in additional CRS. Injury severity levels by body region for each CRS type are examined. Head injuries are important to consider for all CRS types in frontal impacts but the relative importance decreases from rear facing CRS through to children using just the adult seat belt. Neck injuries feature in this dataset only for forward facing harness systems, especially at the AIS ≥ 3 level. Thoracic and abdominal injuries are present for all forward facing restraints but particularly for booster systems, followed by just using the adult seat belt. Likewise extremity injuries follow a similar pattern although upper extremity injuries fall away at the AIS ≥ 3 level. A relationship is observed between cases where misuse has been identified and higher rates of serious injury.

Similar analysis for lateral impacts is carried out, also using the combined CHILD and CASPER database, considering 148 restrained children, 35% using the adult seat belt only and 65% in additional CRS. When injuries are known, 46% have a MAIS ≥ 2 and 34% have a MAIS ≥ 3. Struck side children have greater proportions of serious injury or fatality than non-struck side children. For these struck side children the rates of higher injury levels are much higher when there is direct intrusion to the area in which they are seated. At over 300 mm of maximum intrusion, 68% of the 41 restrained children on the struck side are MAIS ≥ 2, 44% are MAIS ≥ 4 or have fatal injuries. Injury severity levels by body region for each CRS type are examined. For struck side children the head is the most important body region for all restraint types. At the AIS ≥ 3 level thoracic and lower extremity injury also feature for all restraint types except lower extremity for rear facing CRS. For the non-struck side the number of injured children is low but a similar pattern to struck side children is evident with head, thoracic and lower extremity injuries.

Focussed accidents from other types (domestic, cyclists, pedestrians)

This kind of accident, often offers more simple configurations than car accidents. The aim was to collect some of them and to check that they can contribute to the validation of the models built in the CASPER project and to further develop injury risk functions, as the method chosen is the reproduction through physical or virtual reconstructions of loads sustained by children during real car accidents. The involved project partners looked for interesting paediatric domestic, pedestrian and cyclist accidents to reconstruct, with the aim of getting more information about injury mechanisms and injury risk functions.

The database contains 25 domestic accidents, 16 pedestrian cases and 6 cyclist accident cases. As there was no experience with the simulation with dummy models of domestic accident cases, a validation of the method was necessary. Selected cases involved children of approximately 3 years of age, which is the age that corresponded at that time of the project to the only validated LS-Dyna FE Q dummy model. The simulation results show that the head a3ms and HIC values do not correlate in the same way as observed from car occupant tests. The data points from the simulation do not help for the development of injury risk functions for the head. The possible reasons are that the loading conditions are different for analysed domestic and car occupant accidents or that the dummy model is not suitable for reconstruction of this kind of accident or that the dummy, and the associated dummy model, are not validated for this type of loading condition. In a next step, drop tests with the physical dummy and dummy model were executed and compared. This comparison showed that the results were comparable.

Domestic cases were used with human body FEM head and neck models, not to validate these cases but to use them in addition with road cases in order to derive some head tolerance limits to specific head injuries observed. That means that they used developed head neck finite element models to reconstruct numerically domestic and road accident cases and to extract some mechanical parameters like intra-cerebral pressure, von mises stress, energy etc. in order to correlate these parameters with the observed injuries.

FIELD DATA COLLECTION

Activities in this area are all based on a common subject: the quality of CRS use. Two aspects were considered in the CASPER project, the first one focusing on sociological aspects of CRS use [4] in order to have a better understanding of parameters leading to situations not being the optimum in terms of protection of children, the second one on technical aspects of the restraint system use and misuse to see how could solutions be applied to enhance the situation [5]. These activities are completed by a dynamic testing program of misuse situations (described in the section Applications).

Report on social approach to child safety:

The CASPER approach was to use different sociological methodologies in order to rapidly get information about the way parents behave with their children during car travel and about their belief and knowledge regarding road safety. First a questionnaire was developed to gather data on demographics, travel patterns, CRS use, child position in the car, but also information regarding how parents perceive the way they secure their children, the way they drive, how they choose the systems and what kind of improvement they expect. This questionnaire, distributed on-line, collected 998 answers throughout Europe. The survey gives trends about parents' behaviour and beliefs concerning road child safety. This approach by a questionnaire was completed by the focus group method. It is a technique involving the use of in-depth group interviews to gather detailed data and to understand how people construct their reality. In addition to the classical methods used, an electronic survey on a larger scale has been undertaken. For this, the form used for the field data collection was modified and translated into 5 languages to be used for a large scale electronic survey in Europe. Results were analysed focusing on Italian and French data for which both types of survey were available. As a summary of results it can be said that people generally over-estimate their driving capacities and their ability to correctly use restraint systems. ISOFIX is not known by a large majority of parents and better information on the right moment to switch from one system to the next one is necessary. Globally parents also find that CRS are complicated to use and they may allow their children to use only the seatbelt for short journeys, or if traveling in somebody else's car. Due to the co-operativeness and behaviour of the children in the car, 72% of parents answered that the presence of children can cause an accident. The focus group study insisted on the fact that external pressures such as time constraints can influence this behaviour of the parents. The focus group study also showed that though most of the parents answered in the survey that safety was a key factor, the comfort of the child was in fact paramount for the parents. CASPER has established a methodology to effectively conduct such focus groups regarding traveling with children. This approach could also be very efficiently completed by the observation of the real behaviour of parents in the everyday life through naturalistic studies.

Misuse studies

Misuse of child seats is still a widespread and serious problem. This is true for all three studied regions (Berlin, Lyon and Naples) even if there were also significant regional differences, for example, a very high rate of non-use cases in Naples compared to other places. The main problem with the use of CRS is the correct belt path of the vehicle belt and the general installation of the child seat in the vehicle. Both problems could be prevented by the use of ISOFIX. Field studies have shown that less than 4% of the CRS were fixed with ISOFIX in the vehicle. The market penetration of this system is extremely low considering that the vehicle fleet equipment of ISOFIX anchorages was around 50% in 2011. External factors, such as the available time and the trip purpose, have influence on the securing quality. Parents want to secure their child correctly, but there is still a great need for the simplification of the usability of child seats.

Results collected in Lyon during the CHILD and CASPER surveys were compared with the aim to estimate the evolution in CRS usage and misuse. No significant difference was found in terms of appropriate use: more than 80% of appropriate use according to the weight of the children, the rate of inappropriate use being mainly due to a change of CRS too early for the child with similar patterns in 2003 and 2011. The average rate of misuse found was about 65% in 2011 (71% in 2003) which confirms that many children are still incorrectly secured in cars. The main differences between the two surveys concern forward facing systems with harness: installations of the children in this CRS group were better in 2011 than in 2003 with a decrease of some serious misuse, such as incorrect harness use. Regarding booster seats, the most frequent misuse situations were the same in 2011 and 2003, with the lower belt guides often not used and the chest part of the seatbelt under the arm (instead of having it on the clavicle). Most of these misuse situations could probably be reduced by giving better information on the safety effect of misuse to parents.

Collaboration between CASPER and the Safety Road Institute of Belgium (IBSR) has resulted in an additional data collection conducted in different areas of Belgium. It took place in September 2011, with a complete study of the restraint conditions for 1500 children. Results at a global level show the same tendencies as in the other studies: many children are not correctly restrained, the use of CRS decreases a lot for children older than 6 years, and too many parents are not aware that the situation is not correct. For the first time the number of ISOFIX systems was large enough to compare “classical attachment CRS” and “ISOFIX systems”. The use of ISOFIX is more common in big cities than in the countryside. The global rate of misuse with ISOFIX systems compared to the “classical” ones is 2.3 times lower. Considering only forward facing CRS with harness, the rate of misuse is nearly divided by 3 compared to the systems fixed by the seatbelt. The reduction of the proportion of misused systems is smaller but still visible on booster seats equipped with rigid ISOFIX anchorages compared to standard booster systems.

IMPROVEMENT AND DEVELOPMENT OF TOOLS

Initial investigations for hardware and numerical tools

Prior to any new development or improvement of the tools used for the evaluation of the performance of CRS, it was necessary to define the state of the art based on the knowledge from previous EC projects and to determine what were the priorities in terms of protection for children of different ages [6]. The objective of this work was to identify the various child injury mechanisms in frontal and lateral collisions and to determine the associated physical parameters, in order to provide injury risk curves or at least to recommend limits. Priorities are given in terms of injury mechanisms necessary to be reproduced in accident reconstructions and simulations both by child dummies, child dummy models and child human models. They are given for each dummy corresponding age and for the following body regions: head, neck, thorax and abdomen. As result of this analysis, a focus has been defined in the CASPER project on limits to be found on the head-neck segments for youngest children (6 weeks, 6 months, 1 year and 3 years) and on the abdomen and thorax for older children (3 and 6 years). Consequently, injury criteria are needed on these areas and corresponding injury mechanisms are integrated in the specification of child models.

Dummy improvements

Following the analysis of relevant injuries, it was found necessary to identify the shortcomings of the dummies then a prioritization was made and an estimation of the necessary work on the different items. Works were then focussed on the 3 main priorities [7,8]:

Abdomen sensor system The objective was to progress on the development of an abdominal sensor system that could be used to assess the risk of abdominal injury for the Q dummies. Of the three available solutions, one was selected by the project partners based on availability, forecasted acceptability and cost, and likelihood to be able to solve the identified shortcomings of these systems. The Abdominal Pressure Twin Sensors (APTS), originally developed and prototyped within the CHILD project were selected and further development work towards an industrialization of the sensor was conducted. The new work conducted in CASPER includes the characterization of the APTS in multiple loading scenarios, and the development of possible solutions to solve a number of shortcomings that were identified. Finite Element models of the sensors that were developed outside of the CASPER project were also used to support the sensor development phase. Candidate injury criteria were then evaluated based on the results from 17 accident reconstructions involving 19 instrumented dummies restrained by a three point belt. Injury risk curves were built for maximum pressure and pressure rate based criteria. The confidence intervals were found to be sensitive to the scaling approach, especially since injury and non-injury points were almost without overlap. Further work on the improvement of the risk curves is needed. It could include a study of the scaling assumptions between dummies and the addition of points based on further testing or comparison with PMHS data. Other perspectives include the quantification of the repeatability and reproducibility of the system, and the definition of in-dummy calibration procedures. The sensors were also implanted in the Q10 dummy and additional Q3 testing with shields and harness systems were performed.

Evaluation of the lumbar spine stiffness The stiffness of the lumbar spine is one of the parameters influencing the rotation of the pelvis under the lap strap and its subsequent penetration into the abdominal cavity. Physicians and physiotherapists think that the lumbar stiffness is too high. It is interesting to note that the lumbar spine stiffness is much lower in the P series than in the Q series. Overall, the spine stiffness (lumbar and thoracic) could affect the kinematics. Tests were performed on the Q3 dummy to evaluate its lumbar spine stiffness in flexion. The stiffness was found to be similar to the stiffness of the HIII 3 Y.O. dummy. In the absence of better biomechanical reference, it was decided to take no further action on this issue and focus on the gap at the groin.

Auxiliary equipment for Q dummies to improve belt interaction response Several proposals were made to reduce the risk for the belt to lock itself into the gap at the groin of the Q3. Two proposals were selected for the current task: creation of a soft abdominal insert to fill the gap made of silicon, and reinforcement of the dummy suit realised with additional patches to be positioned as a prototype solution. Two prototypes were built. The prototypes can be used independently or together. These solutions are relatively generic and could be adapted to the Q6 or the Q10 if needed. An evaluation of the prototypes in sled tests was performed. It confirmed the interest of the solution to prevent the penetration of the belt in the gap at the groin. While it is believed that the gap issue should be tackled for the dummy used in future regulation, it must however be noted that even in the case of a successful and complete evaluation, more work will be needed to transform the prototypes into an industrial solution. It should be noted that ultimately, the influence of any dummy modifications proposed in this report should be investigated for repeatability and reproducibility. However, this is beyond the scope of the current task.

SIMULATION TOOLS

LS-DYNA dummy models

In order to complete the Q-dummy FE model family Q, Q1,5 and Q6 dummy models were generated on the basis of the Q series physical dummies using information from the existing Q3 dummy model (e.g., material data) [9,10]. Component level and full dummy level's validations were performed to evaluate the FE model performance. The test conditions assumed are standard dummy certification tests. Compared with these physical test data generated, the model responses are satisfactory. For future model updates it is suggested to validate the performance in conditions that are closer to real crash configurations. Sled test data generated in CASPER might be used for this purpose if models of the sled set-up, including seats, are available. Prior to the development of the CASPER Q dummy models, model quality requirements were discussed at the beginning of the project with experts from the industry. It was decided to include in the development of the models suggestions from these discussions. The model has to be representative of the latest hardware level, and include correct implementation geometry, mass, inertia and material properties. The model has to be able to give response similar to the dummy sensors, and the required time step is approximately 1 microsecond without mass scaling. Once developed, it has to go through a detailed report of validation process based on dummy certification tests and simplified loading tests representing relevant loading conditions. In addition the modelling of a Q10 model was started.

Q1 and Q1.5 FEM The Q1 and Q1.5 models were created on the basis of the physical Q1 Dummy Rev B Dec 2008 and the physical Q1.5 dummy Rev B July 2009. The Q1 model was developed first and the Q1.5 was obtained by scaling and local remeshing from Q1. For both sizes a Beta V1.0 release model has been prepared. The model has been used by project partners in virtual testing procedures. More validation works are needed to improve the performance of the models and bring them to a tool usable by the industry.

Q6 dummy model The Q6 model was created on the basis of the physical Q6 Dummy Rev A Dec 2008. All the requirements were considered when developing the models as far as possible. On the simplified loading conditions it has to be remarked that no test data were available for the Q dummies. As CASPER did not have the budgets for generating such data this recommendation could not be fulfilled and validation is done only on the certification tests. It should be noted that they do include full scale dummy tests, assuming impacts on the thorax. A Beta V1.0 release model has been prepared. The model has been used for the determination of accident reconstruction scenarios prior to perform a physical test with dummy. It has also been used in the validation of side impact test procedure in combination with models of generic CRS and using the virtual test environment developed in CASPER.

Q10 modelling works At the end of the CASPER project, Q10 prototypes were recently delivered by the EU EPOCh project and the first Q10 CAD data were made available. During the 2 month extension of the project, works was initiated in CASPER with the aim to complete the Q dummy family. The development of the model of the Q10 mesh and assembly was started. This work has been based on the prototype version of the dummy, and characteristics used for this work are based on the Q6 material.

At the end, the following parts of Q10 models have been meshed and assembled: head, neck, neck shield, shoulder, chest, lumbar spine, chest deflection sensor (IR-TRACC) in frontal and lateral, upper and lower arms and upper and lower legs. The pelvis abdomen area was not meshed during the CASPER project as last minute hardware changes did not allow sufficient time for completion. However, this work will be finished outside of the frame of the CASPER project. Then the model validation can be started with the first component tests such as certification tests are available. This work can only be finalized once the dummy becomes an industrial version.

Human body modelling

The development of finite element models (FEM) of children was one of the aims of the CASPER project. Such models can be used as complementary tools to dummies in order to simulate the response of a child subjected to impact loading. One possible application for such models is the development of model based injury criteria and tolerance values by simulating the child response in accident configurations. It is similar in principle to the work performed using dummies and accident reconstructions in the CASPER project. The Consortium decided to focus on the models of the head-neck for youngest children (6 weeks, and 6 months, 1 year and 3 years) and on the abdomen and thorax for older children (3 and 6 years). Partners from different institutes were developing models of body segments that have to be merged to have complete human body models of different sizes. It was necessary to proceed step by step in order to ensure that all parts would be compatible, that the interface between parts would allow them to be meshed and that in the end different full body models would be able to be run. Once the size of the mathematical models for each body segment in terms of the anatomical structures have been defined, detailed anatomical [11] and mechanical properties [12] for development of the specified mathematical models were investigated.

Child geometry for modelling purposes This task aims to provide essential information related to children for external data but also for data on the geometry of bones and internal organs. Data were collected both from literature and by collecting missing data. The external geometry of 71 children have been measured and 29 anthropometric dimensions were taken for each leading to a total of more than 2800 measurements. This work is based on a measurement survey which allowed acquiring anthropometric data in two approaches: classical (sitting and standing measurements) and in a car, with different restraint systems. These data can be used to develop the corresponding numerical child body model. In particular, they could be used to develop the 6 years old numerical model using scaling technique. Results from this work could be considered for improvement of test procedures, dummies (and associated models), cars and CRS designs. Internal geometrical data of different ages were obtained from whole body CT scans. From anonym medical images of two subjects, the 3D geometry of the skin, bones, and the main soft organs has been reconstructed and transmitted to other CASPER partners in order to develop the corresponding numerical model.

Report on child mechanical parameters The objective was to provide data on the mechanical properties of children and validation data contributing to the development of specific human segments and whole body models per age. An in-depth literature review has been performed and reported. Even if it is obvious that lots of data are missing, no experimental work on this item has been conducted in the CASPER project. Scaling methods have been used as far as possible to fill the lack of data. Starting points for a mechanical definition as well as sources of experimental data for validation of the segment model and human body models were listed. Mechanical properties for child body segments at different ages have been synthesized from the literature. It can be concluded that there is a lack of data and that biomechanical researches to characterize the child human body have to be strongly encouraged. It can also be stated that the data that exist has been helpful to proceed to a first generation of children body models for safety research purposes.

Finite Element Models (FEM) of children

The objective was first to set child segment models based on the geometrical and mechanical properties for each child age under consideration. So partners have shared the work and body segments to be developed were head, neck, thorax, abdomen and lower legs. The coupling of the segment models has been organised as well by attributing to each institution a specific coupling issue. Finally the methodology for accident simulation has been set.

Mainly due to the late arrival of the complete bodies of child human models, and to their levels of validation, it has not been possible to propose numerical injury limits using complete child models on the different body segments to be protected per age groups as first planned. So partners have essentially worked with the body segments they have developed in order first to improve the response of the models and validate them against different scenarios. Loadings similar to the one of real accidents were used and applied on a model of a given body segment (head, abdomen, etc.). This allowed to show the sensitivity of the different parts of the child human body models to loading conditions and for some of them give an overview of what injury criteria could be achievable in future works. Some positioning tools for models have been developed in the project.

6 week old human model For this child's age, it was proposed to limit the development of FEM to the meshing of the head neck system of the six week old child (6 W.O.C.) [13]. The model developed in this project includes the main anatomical features of a newborn head. Concerning the neck, a simplified model was developed just to reproduce a global behaviour of this structure and to allow a good kinematics of the head. The developed 6 W.O.C. finite element head-neck model was based on the geometrical 3D reconstruction of slices obtained by CT scanners.

6 month old human model As for the 6 week old FEM, it was decided to focus on head and neck only for the development of a 6 month old child FEM (6 M.O.C.) [14]. The new finite element head model simulates closely the main anatomical features: skull, sutures, fontanel, falx, tentorium, subarachnoid space, scalp, cerebrum, cerebellum and brainstem. The neck model integrates the first thoracic vertebra, the seven cervical vertebrae, intervertebral discs and the upper and lower ligament system.

1 year old human model Body segments constituting this 1 year old child FEM have been developed separately by different partners and meshed after validation of the different parts. The starting point of the 1 Y.O.C. model is the DICOM data coming from an 11months 21 days old child. [14]. The new finite element head model simulates closely the main anatomical features: skull, falx, tentorium, subarachnoid space, scalp, cerebrum, cerebellum and brainstem. Based on a scan of a 1 YOC, the surfaces of each of the cervical vertebrae were reconstructed. The cervical vertebrae were modelled using shell elements, the intervertebral discs with brick elements and the ligaments with spring elements. The FE model of the 1 YOC upper and lower bodies was developed following the anatomical image as stated in the general description of this model. It includes a complete skeleton of the chest rib cage, the spine, and other bones such as humerus, ulna, radius, clavicle, pelvis, femurs, tibias, fibulas, foot bones. The main anatomical features of soft tissues and internal organs were represented with certain simplifications, especially for internal organs. The validity of the thorax model was evaluated by simulation of thorax frontal impact. Response of the thorax model is rather stiff, and there is needs for adjustments of soft tissue material properties. Meshing works have been conducted in order to obtain a complete body of 1YOC FEM. The developed model of the whole 1YOC body totals 99,168 elements, and the node number is 110,753. Mechanical properties have been implemented and complete body validations were initiated, to first check the robustness of the model. When possible, real world accident cases physically reconstructed were used as input for the model for further validation.

3 year old human model As for the 1 YOC FEM, body segments of the 3 year old child FEM have been developed by different partners in the aim of merging them to obtain a complete body 3YOC FEM after the validation of the different parts. The starting point of this model is the geometry coming from DICOM data of a 3.25 years old child [15]. The complete model is composed about 170 000 elements. Concerning the 3 YOC head-neck FEM, 21 accident cases have been reconstructed (13 domestic accidents and 8 road accidents). For all reconstructed accidents global parameters have been calculated like HIC (using a dummy head FEM) and specific parameters like brain Von mises strain stress, pressure. Focussing on road accident cases reconstructed, the same conclusions can be done which can demonstrate the usefulness of finite element model to extract more specific mechanical parameters. The neck model integrates the first thoracic vertebra, the seven cervical vertebrae, intervertebral discs and the upper and lower ligament system. A detailed thorax and abdomen including lungs, kidneys, spleen, heart, liver, abdominal area, combined muscle, inner soft tissue, ribcage and thoracic vertebrae have been modelled. To define injury criteria for the abdominal area of the 3 year old child, the approach chosen was to compare the numerical dummy loads, measured in accident reconstruction cases taken from the CASPER database with the loads on the 3 YOC model. The correlating injuries occurred in the real accident would therefore be the basis for the injury criteria definition. The simulations with 3YOC model should show that the model is capable of estimating the abdominal injury risk. For the reconstruction with the 3yoc model, appropriate cases were chosen from the CASPER database with loads measured with the APTS and MFS systems. An attempt was undertaken to compare these both readings with the conclusion that no valid comparison is possible due to the complete different load sensing principles. The lower limbs model includes, femur, tibia, fibula, foot, pelvis, ligament system and flesh. After the validation work, the model has been coupled to the Head/Neck and to the Pelvis model. Simulation and validation work for the combined model were limited due to the late delivery of the body segments by the partners.

6 year old human model The objective was to develop a six years old child finite element model developed in this project in terms of meshing segment per segment [16]. The boundaries of the model (near the neck and the lower extremity) were shared with the groups working on the neighbouring models. For simulation and validation work that purpose, the neighbouring segments have been simplified. The validation of the 6 YOC FEM has only been performed on the different body segments using simplified neighbouring body segments when a full body setup is needed for the simulation. No simulation test has been performed in the frame of the CASPER project with a 6 YOC fully FE complete body model. The development of a 6 Y.O.C has been done by scaling down existing adult FE head-neck model. With the 6 YOC head-neck FEM 15 accident cases have been reconstructed, 3 domestic accidents and 12 road accidents. The neck model integrates the first thoracic vertebra, the seven cervical vertebrae, intervertebral discs and the upper and lower ligament system and has been established by scaling down the adult neck model developed previously. A finite element model of the abdomen and thorax of the 6 Y.O.C. was developed for the current project. It includes skeletal structures and major organs meshed using surface or solid elements. Its geometry was developed based on a combination of CT-scan data, average literature data and positioning data from a previous study. In particular, the spine was modified to account for the seated posture. Using material parameters from the literature, the model was run against 6 validation setups. These setups correspond to published datasets collected in two recent studies using child PMHS, and one study based on porcine testing. The setups include loading to the thorax and abdomen using various belts and one impactor. After adjustment of some of the material properties, the model was found able to approximate all test responses. A finite element model of the lower limbs of a 6 YOC was developed; It includes all bones, muscles and skin. Hip, knee, and ankle are modelled with the help of 6 DOF mathematical joints.

Multi-body full body human models (MBM)

Multi-body human models are simpler to create and to use than the FEM. Their robustness is easier to achieve and the time needed to run a simulation is far lower than with FEM. For this reason it seemed interesting to develop child human MBM. The automotive industry can use such tools for a first validation of scenarios. Then FEM and physical tests can be useful to validate a chosen option, but the number of these tests can significantly be reduced by first using MBM.

2 sizes of MBM have been created in CASPER using for each similar techniques: a 6 Week old [13] and a 6 month old children [14]. As base model for the baby model the TNO's facet 50th percentile human occupant model was used and scaled down towards baby dimensions using the

MADYMO/Scaler. Since scaling from adult to children is not straightforward, a literature survey was performed to the mechanical properties (stiffness or force-displacement curves) and injury criteria for the body segments that are most vulnerable for babies in a car crash. Next, validation data were sought in order to validate the model's responses to impact. And finally, the robustness of the model was checked by performing simulations with the baby model in a group 0 seat. It was concluded that 2 robust and calculation time efficient baby models have been created. Mechanical properties and injury limits of the head, neck and thorax of babies between 0 and 3 months old are available. However, validation data of babies of this age are very limited. Scaling of validation tests of other age children would be needed to extensively validate this baby model.

APPLICATIONS

Test procedures

Within the CASPER project existing test procedures were reviewed with respect to their relevance and ability for improving safety taking into account accident data [17]. For frontal impact it was concluded that the test set-up as defined for the new European Regulation UN-ECE R129 sufficiently reflects the passive safety needs to maintain high levels of occupant protection. However, future activities should analyse modification of the seat cushion angle for booster type CRS. While the chosen seat cushion angle reflects average car conditions it might be worthwhile for booster type CRS to take into account worst case conditions which is expected to be more flat.

For rear impact no modifications are proposed as the current standard seems to offer appropriate safety performance. Regarding roll-over it is proposed to add an additional requirement for the head displacement. While the current criteria is just analysing the relative head displacement during roll it seems relevant to apply the same absolute limit as done for frontal impact regarding the head excursion limit in Z direction above CR point. It is proposed that a new threshold for maximum head excursion for all impact types should be negotiated between CRS and car manufacturers.

Finally CASPER supported the GRSP Informal Group on CRS while developing and validating a new side impact test procedure. This test procedure consists of a flat intruding panel and an accelerated test bench. Within the CASPER consortium two deceleration sled facilities and one acceleration sled facility were used to implement the test procedure. The new test procedure is sufficiently repeatable and reproducible. In addition it is adequately challenging for products being on the market today, especially regarding dummy readings for the smallest dummy of the CRS age group and head containment for the largest dummy of the CRS age group. Especially the validation of the side impact test procedure was supported by simulations in addition to the testing. Furthermore the new frontal and lateral impact test procedures of the new ECE Regulation were implemented as FE models.

Injury risk functions for dummy approach

Test procedures can be fully efficient only if some injury criteria are available. Once the CASPER accident reconstruction database was developed, available data from previous accident reconstruction programmes were imported. Quality checks for the input data were performed and when necessary, corrections took place. Then, 36 new full-scale reconstructions and 2 sled tests performed in the CASPER project were regularly uploaded. 70 datasets of dummy readings are available for frontal impact, distributed across all dummy sizes, and 23 for lateral impact with very few cases for small dummies, as the focus was made on Q3 and Q6. First draft of injury risk curves for Q dummies for frontal impact were presented in 2007 based on the results of the CHILD project. However, the risk curves for the neck were based on scaling of adult data. In addition risk curves for the abdomen and chest were missing. Based on accident reconstructions from the CREST, CHILD and CASPER projects, injury severity levels were paired with dummy reading results [18]. For the head in frontal impact conditions, reliable numbers of data points are available to derive injury risk curve with a high confidence using the survival method. For the neck in frontal impact conditions a trend for Q1 and Q1.5 dummies can be observed that scaled data from adult seems to describe the injury risk quite well. For the chest neither resultant acceleration nor the chest deflection seem to be injury risk predictive. For the chest compression this is likely caused by belt interaction problems of the Q dummies for 3-point belts and/or issues in the test with respect to the use of the chest compression sensor (e.g., wrong installation, wrong treatment of data).. The further developed APTS abdominal sensor shows good prediction of injury risk although the number of cases is still low. For lateral impact only an injury risk curve for head a3ms was derived. For the other body regions the number of cases with injuries is too low.

It is important to state that the developed injury risk limits are based on comparing Q dummy readings with injury severity and are therefore only applicable for Q dummies. However, the advantage of this approach is that no scaling between human and dummy is necessary because the curves were already derived using the tools they should be applied to.

The table below shows the proposed CASPER injury criteria. It has to be noticed that for the head injury limit, the value available was only applicable in case of head contact which is not the case with the new proposed one as it is based on injury cases that were almost equally distributed amongst contact and non-contact cases. The neck load limits proposed by EEVC were based on the scaling of adult data, with the CASPER data it is possible to confirm the scaled data at least for Q1 and Q1.5. For Q3 and Q6 it is recommended to define limits based on the state of the art CRS performance in order not to allow worsening of the situation compared to today.

	Head a3ms	HIC	Neck FZ	Neck MY	Chest a3ms	Chest deflect.	Abdomen	Head lateral a3ms
Reference Dummy	Q3	Q3	Q1	Q1	Q3	Q3	Q3	Q3
Unit	g	-	kN	Nm	g	mm	bar	G
CASPER 20% risk	75	NR*	1 (no injuries below)	No sufficient data	NR* but necessity of limit for chest	No sufficient data	0.9	55
CASPER 50% risk	120	NR*	1.3 (only AIS 3+ above)	No sufficient data	NR* but necessity of limit for chest	No sufficient data	1.3	85

* NR= Not recommended

Chest measurements remain an issue: biomechanically, a chest deflection based metrics is considered to deliver correlation with injury risks but the reconstruction results to date do not allow the collection of usable deflection data with confidence. Except for the head in frontal impact conditions the risk curves still suffer from a lack of data points. That means that further research is necessary to improve the confidence. This is particularly true for lateral impact.

Development of relevant parts for virtual test procedures

Virtual modelling and testing will become more and more important for child safety development. Therefore all relevant parts for virtual frontal and lateral test procedures were developed in the CASPER project [17].

Virtual test procedure The virtual test procedure consists of separate parts. Therefore the parts for the simulation are also included in separate files. The benefit of this approach is that the main simulation file is easier to use. Changes in the separate files can be made simple; the files can be easily exchanged and also be used for other simulations. The specific included files are the test bench, the belt anchorage, the ISOFIX anchorage, the sled belt system, the sled pulse, the Q dummy models, the CRS models and the impactor shape used for side impact. They can be easily included or excluded in the main file to analyse differences or to change between frontal and lateral impact. During the CASPER project the parts for the sled test environment were configured and now are available in the LS-Dyna code. First analyses with frontal, lateral and 30 degrees impact showed that they are useable. Also the comparisons between experimental and virtual test results under different test conditions are acceptable. Problems with the simulation stability mostly occur from solid material definitions in the dummy or CRS which are deformed too much under high severity impact conditions. Important for good virtual test results are well validated models, especially the dummy and CRS parts.

Models of CRS 3 sizes of generic models of CRS have been created in order to validate the different sizes of dummy and human models developed in the CASPER project: Group 0+, Group 1 and Group 2/3. All of them went through a validation process in combination with virtual test environment models. For each CRS the separate parts were meshed and assembled together and defined with basic materials. The basic seat parts such as cushion, backrest, head rest and covers were defined as elastic material. Sets with moveable parts are pre-defined to make a simple transformation and/or rotation possible, for example for the backrest and headrest adjustment. The dummy model is defined in the release posture and had to be positioned in the CRS model. The internal dummy positioning definition allows a simple positioning with a pre-processor. Similar to the dummy positioning via pre-simulations another pre-simulation is necessary for belt positioning.

Misuse test program

The performance of a CRS is strictly influenced by the quality of its use. During the CASPER project misuse of CRS has been observed in the field and tested dynamically, in order to evaluate the effect of these misuses on the protection of children. The study of the influence of 3 different types of misuse has been undertaken in CASPER: use of CRS not in accordance with the user manual instructions, dummy postural changes, and appropriateness of the restraint system. Each situation always being compared to results obtained in similar test conditions with a correctly used appropriate restraint system. The experience in CASPER has also shown the difficulties in running comparable field studies in different locations: it is necessary to define clear parameters for the assessment of misuse severity [5]. All subjective influences should be excluded as much as possible. It has to be remembered that results are only applicable to the tested configurations (CRS, dummy, type and severity of impact), but global tendencies can be outlined:

Dummy behaviour: dummies are not able to measure the full range of injury risks (e.g. effect of having the seatbelt twisted for children using a booster seat, excessive slack in harness, etc.).

Dummy instrumentation: in many cases, differentiating events using standard dummy readings is not an easy task. Films are helpful to see differences in global kinematics. Abdominal sensors are also good predictors to prevent injuries in this area. For the moment these sensors are not part of the standard equipment of Q series dummies but are at an advanced stage of prototypes.

Inappropriate use: The use of inappropriate CRS for children too young can lead to the ejection of the upper part (escape at the level of shoulders) or of the complete body from the CRS that can lead to serious injuries. This statement is mainly based on films combined with the knowledge that children and child dummies behave differently in these conditions due to a difference of shoulder rigidity. When used with a larger dummy than it has been designed for, a CRS can show additional injury risks because of a higher head excursion (risk of head impact with vehicle interior), additionally there can be a risk of CRS structural integrity issues due to the overloading (depending on the CRS characteristics, only high quality products were tested in this series) leading to the risk of projection or ejection of the child and the CRS together. Tests conducted with a Q6 without CRS led to a dramatic increase in the abdominal pressure with a high risk of submarining compared to the same test performed with a CRS.

Wrong use of practical functionalities: can lead to misuse for which the effect varies from no visible effect to the total destruction of the CRS. The non-use of ISOFIX connectors on a booster seat does not decrease the level of protection considering dummy readings. On shell systems, misuse of ISOFIX connection or anti-rotation device lead to a higher global excursion and therefore a higher risk of impact of the child with the vehicle interior. In some cases, failure of the CRS base has been observed. It is important to remember that if tested CRS had been of a lower quality some integrity issues may have occurred.

Postural effect: when the child dummies are positioned in more relaxed (and more realistic) postures, the risk of sustaining serious injuries is higher for the head and for the abdomen. Some head impacts and seatbelt penetrations into the abdominal areas have been observed on films and dummy readings. In some postures, only the film is able to indicate that the dummy behaved differently than in the reference tests.

Wrong seatbelt route on boosters: is a critical misuse that leads to not restraining the upper part of the child dummy or to strong forces applied onto the lower rib cage and abdominal areas. When combined with postural situations, these misuse situations become even more critical for the safety of the considered children.

Possible solutions for CRS in terms of use

The purpose of this report [19] is to provide applications and research results for the improvement of child protection systems. As well as considering the effect any CRS improvements would have on policies or any legislation that would need to be created or improved. The issue of cost and subsidies for child restraints is considered. Research on the effectiveness of interventions is reported and recommendations on future policies are made.

Results from the sociological survey carried out as part of the CASPER project proved to be an extremely valuable resource, as many of the proposed solutions are based on information gathered in the survey. Recent statistics show that a large percentage of CRS are misused, this project aims to reduce this figure by implementing innovative designs and creating new legislation. To list some of the ways CRS are being misused: they are being incorrectly installed i.e. putting a rearward facing device in a forward facing position or incorrectly fastening the seatbelt to the device. Parents play a key role in child safety and this is researched in great depth within this project. Research was carried out in two ways: preventing these types of CRS misuse as well as researching other problems with CRS such as transporting children with disabilities. The proposed solutions are presented alongside any issues that might occur. One of the key areas of CRS improvement is Car-to-CRS communication, this ties in with integrated CRS as the idea is to make CRS fully homologated for the car. ISOFIX involves having anchors built into the car which CRS can fix onto. The next step is to develop Car-to-CRS communication so that the CRS can benefit from the cars safety features. Car manufacturers can also build CRS directly into the car creating integrated CRS which are also considered in this document.
At the moment CRS are predominantly used in cars, however they could also be used in aeroplanes, trains and buses. Results would have then to be optimised for each of the different situations. During this project the CASPER consortium investigated and evaluated the systems which are currently available or currently being developed. This was done by analysing the demands and applications in terms of research, development and approval of CRS for child protection.

Communication

It is very important to communicate to children that the correct use of the seatbelt is crucial for their safety and that it has to be combined with the use of a booster seat until their size is close to the one of adults. Messages for parents should start with the fact that children always need to be restrained while travelling in cars. The choice of an appropriate CRS, it's installation in the vehicle and the correct seatbelt route for children on boosters are essential requirements to guarantee the highest level protection for children. Some systems are easier to use than others, equipped with indicators telling if installation and adjustments of different parts are correct (such as ISOFIX). Of course, they still require a minimum of attention to be correctly installed and it's important to check their compatibility with the vehicles in use before purchasing them.

Dummy and human models*:* accident simulation methodology

The objective was to use virtual reconstructions of real road traffic accidents as well as domestic accidents in order to calculate mechanical parameters for some relevant segments and to correlate these parameters with observed injuries. The methodology is applicable to investigate various injury mechanisms of child body segments, including the head, neck, thorax and abdominal injuries in different restraints, loading conditions, various age and size of children. The validity of the child segment models was expected to be evaluated by using available experimental data and accident data. Concerning road accidents reconstruction methodology with whole human body models, guidelines are provided for MBM of children.

For FEM child models, methodologies to define criteria for different body segments have been proposed, based on road accident case replications (loading conditions based on measurement from child dummy crash test were used to assess FEM and injury related parameters can be calculated from simulations) or on domestic accidents (fall cases simulation). Finally guidelines for whole body model reconstructions have been proposed in case of road accident reconstructions.

Numerical and experimental injury criteria

Modelling children is not an easy task. Firstly, there is little data on the mechanical properties of the different anatomical structures for evident ethical reasons, which poses a real biofidelity problem for FEM. Furthermore, there is no available validation to date for the different body segment models and different children's ages. One of the only ways to overcome this lack of data is through the reconstruction of a large number of accidents. During the CASPER project some accidents were collected both domestic and road accidents per age. But even with a consequent effort of partners, the number of physical reconstructions is still too low to establish clear tolerance limits to specific injury mechanisms for all ages and all body segments. However several mechanical parameters were extracted from these finite element models, with the aim of identifying the mean criterion able to predict, for example, loss of consciousness and bone fractures.

The report "Synthesis on numerical and experimental injury criteria" [20] reports mechanical properties used and validations per segment and per age as used to determine as a first attempt injury criteria by reconstructing numerically with the developed finite element models selected accidents (domestic and road accident cases).

Three focused analyses are proposed. The first concerns the 1YOC finite element model. It presents mechanical properties implemented under Ls-dyna code as well as road and domestic accident reconstructions results in order to establish some tolerance limits to specific head injury criteria. Then validation of the thorax, abdomen and lower limb are presented separately. Work undertaken with the complete meshed model are also presented in this report. The second part of this document aims to describe 3YOC FEM. It shows the validation performed on isolated body segments by partners. The last part focuses on the 6YOC FEM mechanical properties, validations and first attempt to tolerance limits. It ends with the presentation of the coupling of all segments that should lead to a whole 6YOC FEM.

CONCLUSION

The growing demand for greater mobility in Europe has made individual transportation an essential feature of modern living. Children are more and more often transported in cars, even daily from home to school, and so the risk of becoming involved in an accident has consequently increased. Consequently, there is a big interest to encourage the deployment of innovative technologies that should lead to the introduction of safer products on the market. All available strategies should be applied in order to reduce the number of injured and killed children on the roads.

Thanks to increased knowledge in the field of injury mechanisms, the development of new designs for more efficient restraint systems and a better ease of use will become a high priority for the car and CRS manufacturers.

The CASPER project has defined the priorities to enable progress in this field of child occupant protection. The prevention of injuries resulting in a major permanent disability has important social implications, and more for children, but more generally the reduction of injury severity is correlated with lower cost of medical care and hence a lower social cost of accidents. CASPER is contributing to better protection of children by enhancing the development of designs, methods, tests, and tools that will reduce the risk of injuries. It was clear since the beginning of the project that CRS manufacturers and organisations such as ISO, IHRA, EEVC and all standards organisations were waiting for this information. With expectations being rather large it has been necessary to cover a lot of subjects. Globally, significant progress has been made during the CASPER project and most of the new knowledge acquired has already been taken on board by the relative working groups. The establishing of an International working group for the revision of the standards for CRS approval has been a very good opportunity to have results from research projects integrated as soon as validated in the new proposals. The rather long process of improvement of the situation by the presence on the market of new protective devices has been shortened due to the rapid availability of results. The first CRSs answering all the new requirements could be already on the market only one year after the end of the project. Of course it will take time before these CRS represent a large proportion of CRS sales but having them developed and available is the first and necessary step for the improvement of the situation. This new generation of CRS will also improve the rate of correct use of systems as one of the requirements is to make them easier to install with clear indications of the correct use on the systems themselves. In parallel, requirements for the car manufacturers have also been introduced in the concept of these new CRS in order to ensure a better compatibility between CRS and vehicles.

This project has contributed to the harmonisation of passive safety research on child safety worldwide, and it has underlined that some of the issues such as abdominal injuries could be addressed. The methodology to do so is not only applicable in Europe, even if adaptations of the sensor to other dummies could be required. The harmonisation of the research methods and tools would enable the comparison of the situation in the different areas of the World. Effectively, it is well understood in developed countries that children when travelling in cars have to be restrained and how it has to be done. What is necessary here is to enhance the safety culture of parents so they do things in a better way. But what is also important (more important in terms of potential number of children to be saved) is to spread child safety worldwide and particularly in the emerging economies where motorization is growing at the greatest rate. This could also improve the cost effectiveness of regulations because the necessity for the car industry to comply with different regulations in various countries, as it is the case often now, can be avoided.

The short-term exploitation of the outputs of CASPER has to be communication and educational programs. It should be implemented by the application of methodologies and procedures for the development of improved child restraint systems, providing better protection for children in cars. In the medium and long term, the number of children killed or injured in cars should be considerably reduced if both communication/education and improvement of systems are conducted in parallel, so parents will learn what is important to do while the CRS and car manufacturers will improve their restraint systems quality and compatibility.

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UK Loughborough cases, collected during the EC CREST/CHILD projects, include accident data from the United Kingdom Co-operative Crash Injury Study, collected up to 2006. CCIS was managed by TRL Ltd on behalf of the Department for Transport (Transport Technology and Standards Division) who funded the project with Autoliv, Ford Motor Company, Nissan Motor Europe and Toyota Motor Europe. The data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham, the Vehicle Safety Research Centre at Loughborough University, and the Vehicle & Operator Services Agency of the Department for Transport. The views expressed in this work are those of the authors and not necessarily those of the UK CCIS sponsors.
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