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CASPER – Improvement of child safety in cars

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Abstract

The EC CASPER (Child Advanced Safety Project for European Roads) project aims at decreasing injuries and fatalities of child occupants. This goal represents a major social and economic benefit for the whole European Community. CASPER has carried out a two way approach for improving child safety. Results are complementary. Firstly, the improvement of quality of use of restraint systems is certainly a good way for a rapid and consequent improvement of the situation, secondly, it is necessary to give guidelines and reliable tools to design protection devices that are easier to use, have a higher level of crash performance and are used for a large proportion of children. CASPER involves a consortium of 15 European partners representing a good balance between industry, medical and technical universities, road state institutes and organizations specialized in road safety issues for a 36 month project. This project was accepted under the *GA n°218564* of the *FP7-SST-2007-RTD-1-program* of the European Commision that is partially funding the project. Data from previous European projects were used as a basis.
In-depth accident investigations, misuse (incorrect use of a restraint system) and sociological field data collection took place and were analyzed. Existing tools used for the evaluation of protection of children were improved while missing ones were developed. These are used to address issues identified by the field data analysis. In addition to proposals of improvements for the Q-series crash test dummies, further development of injury risk curves both for frontal and side impact is ongoing. Finite element models have been developed for child dummies and for human child bodies. An analysis of test procedures was done in order to define the highest priorities. CASPER is now finalizing the tools and proposing solutions that could be applied to improve child safety in cars, whilst evaluating if some of these solutions could be transferred to other transportation modes.

Keywords: Child safety; restraint system; reasearch project; human modelling; accidentology; field data

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1. Context

The transportation of children in cars is more and more common in the European countries, so children are far more exposed today to the risk of accident as car passenger than ever. The usage rate of child restraint systems (CRS) is increasing in Europe and the level of protection offered by these systems, which have to comply with a European regulation (R44-04), is increasing for most of the systems too. Even with this, the number of fatalities of children in traffic accidents remains too high and its variation is not uniform across the European countries. A significant reduction of the injuries and fatalities of children in cars represents a major social and economic benefit for the whole European Community. The target for reducing by half the global number of fatalities in the decade 2000-2010 in Europe has not been reached even if it strongly went down. By declaring 2010-2020 as a new decade for road safety, a clear message was given to research projects dealing with the protection of road occupants. Since the 1990's collaborative works have been conducted to improve the child safety in cars. The European Commission has partially funded such research works since 1996, with the CREST project and then the CHILD project. During these two projects, a lot of progress was made on the availability of tools to evaluate the quality of restraint systems, such as a new generation of child crash test dummies, the Q-series, and through the development of prototype sensors to ensure better protection of the abdomen of children involved in road accidents. After the end of the CHILD project a new project dedicated to the protection of children in cars was established. Methodologies used in the previous projects for field data collection and definition of injury risk curves were kept in order to enable a continuity and compatibility with the outcomes of this collaborative project called CASPER (Child Advanced Safety Project for European Roads). It is composed of 15 partners from 7 European countries (Appendix 1), all chosen for their expertise and complementary skills in the domain of child safety research. This new project was set up for a duration of 36 months, starting in April 2009. Its total budget is 5.6 million Euros with a funding of 3.8 million Euros from the European Commission. This project is under the umbrella of the COVER project (ref 1) that is ensuring good co-operation and dissemination of results for projects accepted in the 7th framework funding program of the European Commission dealing with biomechanics (THORAX, THOMO, EPOCh and CASPER). Regular exchanges with the EPOCh consortium, in charge of developing a 10-12 year old child dummy, and an active contribution to the CRS informal group of GRSP (Global Road Safety Partnership), in charge of proposing a new regulation for the approval of CRS, have occurred during the life of the project.

The work programme has been organized around four technical work packages, one support work package in charge of the collaborations and the dissemination of the data and another one in charge of the administrative part of the project, ensuring the link with the European Commission.

This project has two main objectives that are complementary to improve the real level of protection of children in cars. The first one is the improvement of the rate of correctly restrained children in cars, and the effect of this can be effectively seen in a short-term. This is done through the analysis of the reasons and the consequences of the conditions of transportation of children, both scientific and sociological aspects. The second one is the improvement of the efficiency of child protection which includes tools and test procedures that are used to evaluate the protection of children in cars for approval and consumer information tests. This second point – even if taking longer before any improvement can be observed in the field – is a necessary and continuous work: children are benefiting today of better protection thanks to the work conducted since the nineties and even before, when pioneers grouped their energy and propose systems such as ISOFIX.

2. Improvement of rate of correctly restrained children

2.1. Field data

According to the field studies conducted before the start of the CASPER project, the main issue in the area of child safety, after the clear non-use of restraint systems, is misuse. Misuse can lead to situations in which the level of safety becomes very low. Most of the studies done in Europe show that the rate of misuse for children travelling in cars varies from 60 to 80% depending on the location of the study and of the definitions used (ref 2&3). Then additional work has been conducted and published mainly focusing on technical aspects, in order to rate the effect of these misuse on the protection of children, and to alert authorities, car and CRS manufacturers and to find solutions (ref 4). As CASPER intends to provide updated data on this subject, misuse field surveys have been conducted by different partners, using a data collection form that addresses both technical and sociological data. Previous recent studies were considered to build this form, in order that it is possible to compare results from studies. The objective was to collect data for about 100 children by each team. Unfortunately, the number of topics covered by the interview made it difficult to finish in less than 10 minutes and a large numbers of drivers were frustrated by this. It was then decided that a minimum of data was to be collected and that each team was authorized to change the way of collecting optional data within the laws on confidentiality in place in the country where the study took place. On the topics of use and misuse, a large collaboration was offered during the presentation of the methodology in the annual conference in Munich and three main opportunities have been realized. The data from the French CEDRE project (ref 5) were included in the CASPER sample, the Royal Automobile Club of Catalonia have expressed the wish to use the CASPER data collection form and a collaboration on the collection of use and misuse data in Belgium was created (ref 6).

Additionally, to measure the influence of misuse on child protection a dynamic test program was undertaken considering configurations observed during the surveys.

But just a technical approach to this issue did not seem sufficient, so it was proposed to also consider a sociological approach of child safety, particularly focusing on misuse. For this purpose, two complementary actions were conducted. The first one is directly linked to the misuse data collection surveys. The collection form has been extended in order to have a clearer view on the level of drivers' knowledge about child safety, the place where CRSs were purchased and the way they looked for child safety information before purchasing a CRS. This information was linked with the actual misuse situation of the interviewed driver. The second action is the integration in the project of a sub-task specific to a sociological approach of child safety. This type of approach is something new in child safety related research work conducted at European level. Two methods were used: one being quantitative and the other one being qualitative. The first one brings answers to some of our questions using a closed list of answers and is distributed on a large scale and possibly in different countries. It was afterwards extended to an on-line internet survey in order to get information from countries where the paper version has not been distributed. The electronic form is available in seven languages. The second method works on a smaller sample as it consists of the analysis of discussions between parents on the subject of child safety, guided by a sociologist analyzing results from the opened discussion occurring during focus groups. The combination of both methods enables us to better understand the habits of parents with their own children and their level of knowledge on child safety items. The methodology of this sociological approach of child occupant safety was presented in a workshop in Munich in 2009 and 2010, and the first results were shown during the mid-term project workshop with data from 3 countries (ref 7).

2.2. Analysis

The analysis of available field data is the input for all technical tasks, highlighting issues and giving the priorities. They are also the base for the proposal of solutions. New accident cases of cars with restrained children on board and corresponding to severity criteria have been analysed (ref 7&8) showing that the priorities are different according to the ages of children (and by the way of the type of restraint systems used) but also according to the level of injuries that it is intended to protect children from.

Results from field studies show that the number of not, or not correctly, restrained children is still too high, and also that if the rate of misuse is relatively stable, the proportion of severe misuse, that leads to critical situations, has decreased in recent studies. Misuse rate is not uniform across the different types of restraint systems, in particular the installation of rear facing infant carrier is rarely right. Maybe it's also because it's the first system that parents have to install and because this operation has to be repeated for most of them for each journey. It's also clearly been found that even if a large majority of parents know the legal rules concerning the transportation of children in cars in their countries that does not mean that they are able to choose the appropriate CRS. For example, 23% of children weighing less than 9 kilograms are already transported forward facing when they should still be installed in a rearward facing system which would be more effective to protect them because of the fragility of their cervical spine. Globally, appropriate restraint systems are left as soon as the children's weight gets close to the lower limit of use of the restraint systems of the next category (group). The level of school education has an influence on appropriateness of the choice of the CRS and more generally on the level of knowledge about child safety which has been found in previous studies to be an influential parameter regarding the rate of misuse observed in surveys. Parents are overestimating their behavior in terms of child protection in the same way that they over estimate their driving capabilities. The parents who concede that they may make mistakes while using CRS, do not know what they do wrongly. Parents are balanced between recognizing that accidents occur more often on short trips and by the fact that they declare to be more permissive on this kind of journey (the ones of every day) and saying at the same time that child safety is a priority. General and focused information campaigns are necessary to first let them know the problem and its size, and then to help them to restrain their children correctly each time they use their cars. Furthermore, a continuous programme is necessary to maintain the level of knowledge for future generations of parents.

3. Improvement of the quality of the restraint systems

The methodology used to obtain injury risk curves for child dummies is derived from accident data for which injury details, restraint conditions and accident scenario are all well known. They are reconstructed in crash-test laboratories using similar vehicles and CRS, using child dummies of a size as close as possible to the considered children. Once the test results are validated (similar deformations of the cars, reproduction of injury mechanisms by the child dummy), a correlation is then made between the injury/non-injury of the child and the dummy readings on different body segments. This means of course that a large number of reconstructions are performed before having injury risk curves for the different sizes of dummies and for different types of impact. This methodology can only work if the child dummies are sufficiently biofidelic to reproduce properly the kinematics and the injury mechanisms observed in car accidents. One of the tasks of the research project is dedicated to the improvement of the existing dummy behavior.

3.1. Child Dummies

During the previous CHILD project, it appeared that under certain circumstances the child dummy kinematics were questionable. For example, it was difficult to reproduce a phenomenon called submarining, that is observed on children under certain loadings conditions during which the child sustains a rotation of its pelvis that makes it slip under its seatbelt, often leading in a crash to severe abdominal injuries. Partners in the CASPER project considered this as a key point which could have two origins (or a combination of the two): the first one that the stiffness of the lumbar spine is too high and it does not allow a sufficient rotation of the pelvis, the second being an issue of interaction between the seatbelt of the vehicle and the lower part of the child dummy.

Lumbar spine: based on the experience of previous research activities on child dummies, the lumbar spine stiffness of the Q3 dummy warranted further investigation, as it seems to be too stiff. As preliminary work, a series of tests were conducted to compare it with the one of the Hybrid III 3 year old dummy, as defined in its calibration procedure. Results obtained showed no or little difference. As no other biomechanical data were available to validate the stiffness value, it was decided not to conduct any other tests and if biomechanical data becomes available it would be interesting then to reconsider this work and to check this for all sizes of child dummies.

Seatbelt / dummy interaction: during the CHILD project, it appeared that under certain circumstances the interaction between the child dummy and the seatbelt was not appropriate. On the Q3 dummy and in a lower level on the Q6 dummy in the seated position a gap exists between the thigh and the pelvis flesh. If the seatbelt of the vehicle is positioned below this gap, when the dummy moves forward during the crash the seatbelt gets stuck into this gap and is not able to continue its route onto the abdomen. To solve this issue, CASPER partners proposed 3 possible solutions to be integrated on the child dummies and tested them through a dynamic test program. They are presented in Figure 1. The first solution is composed of 2 silicon inserts that fill the existing gap between the thigh and the pelvis on each side, this solution gives satisfactory results in the test program. The second proposal is to add thin patches on the suit of the child dummy in order to have a more rigid structure that does not enable the penetration of the seatbelt into the gap. Different sizes and thickness of patches were tested, the thin ones are not sufficiently strong to avoid the problem, and the thickest ones could lead to another type of interaction if the seatbelt is not located on the patch at the beginning of the test. The intermediary thickness patches seem to be the best compromise. The last solution is to reduce the gap by design of the dummy. This solution was already integrated in the newly designed Q10 in the EPOCh project (ref 9), but for the Q3 and the Q6, that are already widely spread in crash test laboratories, changing the design of this area would create too many differences between the dummy versions. The proposal for the CASPER accident reconstructions was finally, for tests for which the seatbelt is positioned in the thigh/pelvis area, to use patches. On the medium term, the patches could be included into the dummy suit, in order to limit the effect of their manual positioning.

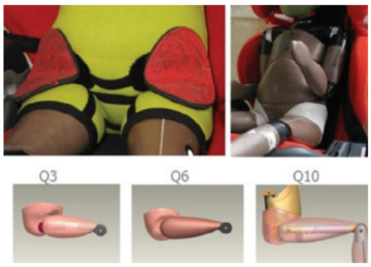

Fig. 1

- top left : patches
- top right : silicon inserts
- bottom : design evolutions

3.2. New tools

Although the improvement of child dummy biofidelity is an important thing, it is also necessary to enlarge their capacity to predict injuries by the implementation of sensors that could measure physical values on parts of the body where children get injured. The Q-series dummy family developed through European projects since 1996, is far more instrumented than the P-series still currently used for regulation purpose. Nevertheless there is no instrumentation available for the abdomen. Research initiated during the CHILD project started to develop two types of sensors to predict abdominal injury risks (ref 10). The first one is a surface force sensor made of 20 force sensors integrated in a skin that is installed on the dummy. It allows good precision on the locations of seatbelt loading on the abdomen. The second one is based on the measurement of the pressure in two bladders filled with gel that are located inside the abdominal block of the dummy on both sides. At the beginning of the CASPER project, another prototype, developed for the Hybrid III 6 year old dummy was shown, so partners intended to evaluate it, if possible; but due to delays in its availability and due to its dummy-related design, it was not considered as a possible option for the Q dummies. CASPER had to select the system that showed the best combination between its capacity to predict abdominal injuries, its ease of use, its durability and its repeatability. The second challenge was to define the necessary changes for the system to go from the prototype stage to an industrial product that could be fitted in the Q dummies of sizes corresponding to the ones where children are using the vehicle seatbelt to be restrained (Q? and Q?). The skin force sensor had shown some stability issues because of the type of force sensors used. The twin pressure sensor system was finally chosen. An intensive testing program was set up to characterize its response to different loading conditions. Some minor changes on the design of the sensors were realized in order to improve its durability, and the definition of the gel to be used has been changed. Special attention was kept that the sensor performance after its modifications showed compatible results with the results obtained prior to the modification and that the points already gathered through accident reconstructions in CHILD can still be used for the construction of injury risk curve for the abdominal segments of Q3 and Q6.

In parallel to physical tools, it is necessary to develop numerical tools that are going to be used very early in the process of the CRS's development. The finite element models (FEM) of Q3 being already available as a commercial product and the one of Q0 being already developed in the CHILD project, it was decided to complete the numerical dummy family in the CASPER project by the development of FEM models of Q1, Q1½ and Q6. These models of Q dummies are based on the dummy characteristics and every part has been developed to represent a physical part of the dummy. All of them have been validated according to the dummy certification procedure tests to check if their response was similar to the one of a physical dummy. They were meshed to obtain a model of a complete dummy. The FEM of Q dummies developed in the frame of the CASPER project are now at the stage of beta versions, which means that they need further validation work before being available for the industry for safety device development or evaluation. Concerning the Q10, the dummy being not defined at the beginning of the project, it was not planned to develop the corresponding model in the frame of CASPER. However, a preliminary dummy model within the CASPER frame would be developed based on the current prototype version.

In the CHILD project some work were conducted to create a FEM of the head and of the neck of a three year old child. These parts were then merged with the torso and extremities of the Q3 dummy model. This first approach of child human FEM was extended in the CASPER project. A partnership on the development of different parts of different sizes of children was established. It was decided to create complete body models for the following ages: 6 months, 1 year, 3 years and 6 years old. For each body region and for each size, it has been first necessary to define or collect all the geometrical data by measuring children for the external ones and to use post mortem CT scans for the internal ones. It was then followed by a large literature review of the material properties of the different components of each part that could be used for these child-human models. When ready, the parts corresponding to the same age have been meshed together. It is now necessary to validate the complete models using simple test configurations. Then child-human models could be used in simple sled tests configurations, and later on under similar loading conditions to the ones of accident reconstructions, the final objective being to define numerical injury criteria for the human models. CASPER partners have also developed and used a methodology for accident reconstruction using human FE models, available as a public deliverable.

3.3 Evaluation process

To ensure that the progress made on CRS is beneficial to all children, it is necessary to regularly review the test procedures that are used to approve them. One of the tasks of the CASPER project was specifically dedicated to this work. It began with a review of literature of the existing approval test procedures. In the analysis of the sample of French data available on fatal accidents (CASIMIR – ref 11), it appears that the issues were different according to the type of impact. The most frequent crash configuration in which children are killed being the frontal impact, an in depth analysis was necessary to see in which conditions. It was found that a large number of the children of this sample were not correctly restrained, or have been involved in a crash for which the crash severity was extremely severe and much higher than the level of protection that can be expected from any CRS. For side impact, the situation was different and it seems that the number of children killed that seem correctly restrained was significantly higher, showing that the protection of children in this crash configuration does not seem to be sufficiently covered by the current European regulation. For roll-overs about 80% of children killed have been ejected because of non use or incorrect use of restraint, showing that for this crash configuration the priority is to get children correctly restrained. Finally for rear impacts, which represent less than 5% of the children killed in cars in France, the protection offered by the current regulation seems satisfactory. According to these results, works on procedure were focused on side impacts. They were conducted in collaboration with the CRS informal group of GRSP (ref12), which defined different configurations in order to select the one that is easily reproducible in different test laboratories and which is taking into account the most important factors to be covered in side impact such as intrusion and protection of the head of children. Once the test procedure set up had been defined, CASPER partners have run tests both on acceleration and deceleration sleds to validate the procedure. Other partners also performed some crash tests in cars to be able to compare the levels of loading of the CRS.

Another important item to ensure the protection of children in cars is the compatibility between car and CRS. CASPER has issued a list of potential problems such as the impossibility to reach the seatbelt buckle once a CRS is installed using the lower ISOFIX anchorages, the head restraint interaction with high back CRS or the review of interactions between curtain airbags and the head of the child. In addition some surveys and naturalistic studies have clearly shown that children are rarely seated like child dummies are installed in a test procedure (ref 13). A test program has been established to measure the influence of the dummy positioning on the performance of CRS and to the misuse that can be associated to it in some cases.

3.4 Solutions

Using a combination between field studies and the misuse testing program it was shown how few children are really at their best level of possible protection when travelling in cars. Experts from the CASPER team rated misuse severity according to the estimated decrease of protection for each of them and have organized a list of the issues which have to be treated in priority. Countermeasures or technical solutions were put in front of the three main issues of each CRS category. A complementary work was conducted looking at the solutions or concepts available on the market. Based on their experience and without testing these solutions experts were asked to define strength and weakness for each proposal for the five following categories: Social and culture; law and regulation; CRS car interface; research; misuse and CRS issues. This document is a synthesis of the outcomes in different aspects of the protection of children in car. The possible transfer of some of the solutions to other transportation mode will be issued at the very end of the project.

One of the issues encountered during the life of the project was the validation of FEM models. It was possible to use simple test configurations for dummy parts using the dummy calibration procedure tests, but this was not saying that the models perform correctly in car crash conditions. For that it is necessary to have a set of FEM models of CRS and restraint systems (harness, seatbelt,…). Three generic models of CRS were developed in CASPER: rearward facing infant carrier, forward facing harness child seat and high back booster seats. This was a first step to be able to validate both the dummy and the child human models. In most of the accident reconstructions, an additional accelerometer has been installed to be used as input for the numerical simulation. Readings from the dummy in the test and of the models in the simulation can then be compared.

By their numerous collaborations, participations to workshops and dissemination activities the CASPER partners have proposed updates that define possible improvements to ensure a better level of protection for children in cars to a large spectrum of stakeholders, from legislators to national road institutes to consumer organizations and with CRS manufacturers.

3.5 Important points to note

This paper was written whilst the project was not yet finished and final results are not yet known, but they will be available by the time of the conference. What is going to be shown in the final presentation will be accordingly updated. All public final results will be made available on the website of the project (ref 14).

With the CASPER project being a research program, all the works and findings will not necessarily be integrated in the industrial versions of evaluation tools. Further work is still needed and these results should be integrated in further evolutions or generations of tools. Their evolution is also limited because the biomechanical knowledge for children is not sufficient, and the use of pediatric data is not legally the same in the different countries.

4. Conclusions

The CASPER project conducted a large research programme on child safety not only inside its consortium but also through collaborations. A lot of results are now available in many areas of child safety: field studies from different countries on the use and misuse of CRS, accident data for restrained children, injury criteria for frontal impact, the completion of the Q-family dummy models, a system to evaluate the protection of the abdomen for children in cars and of course many working methodologies that have been improved during the life of the project. As there is a continuous need of getting updates on field data, the methods were made public and will certainly be useful to other teams or to set the basis of a new research project.

The CASPER project has started work in a domain that was new for a child occupant safety related project, introducing some socio-cultural approach of the child safety to have a better understanding of misuse and the reasons for misuse. Now that the methodology has been tested and first results obtained are promising, it is necessary to have these types of studies extended to bigger samples, representative of the overall situations in the different countries.

In future research works, it would be beneficial to fully understand the real situation to complete these technical and sociological approaches with the conduction of naturalistic driving studies, which are based on the observation of the car occupants. It would be interesting to know with a large sample of children what are their activities, their postures, and how they are really protected during the duration of the journey by the observation of their restraint systems characteristics and adjustments. A more global observation could also include the influence of the presence of children in cars on drivers' habits, in order to measure the changes in the driving itself (parents often say that they drive more carefully with children on board) but also to quantify how much children are a source of distraction for the driver.

On technical points, one of the promising research areas is the improvement of the child human FEM and the definition of all the necessary steps to promote them from research works to a tool that is available to develop adapted restraint systems for CRS and car makers using numerical tools. Of course, if more biomechanical data becomes available, the improvement of the human model at the level of research has to be considered. The aim being to improve their behaviour and their capability to better reproduce all the injury mechanisms encountered in real accidents and finally to be able to propose more realistic injury criteria to protect children from a larger number of injuries. In addition it is expected that the child human models help to better understand pediatric biomechanics.

Some of the outputs of the CASPER project are going to be transferred for the protection of children in other transportation modes than cars. The future extension of research work on child safety could also consider children with special needs and the so-called vulnerable users such as pedestrians and cyclists. The typology of injuries being relatively different than the ones of child car occupants it would be necessary to adapt and develop some of the existing methodologies and work on the tools for the evaluation of the protection of these specific road users. No statement on this topic for future activities was done in the CASPER consortium at the time of writing this paper.

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Appendix A. List of the CASPER partners :

GIE Recherches PSA Peugeot-Citroen / Renault, Technical University of Berlin, Université de Strasbourg, Applus Idiada, Institut français des sciences et technologies des transports, de l'aménagement et des réseaux, Loughborough University, FIAT group Auto Spa, Medical University of Hannover, CHALMERS Univeristy, Bundesanstalt für Strassenwesen, TNO, Humanetics,Europe, Ludwig Maximilian University, Verein für Fahrzeugsicherheit Berlin, Centre Européen d'Etudes de Sécurité et d'Analyse des Risques.