Misuse of Child Restraint Systems – an important Problem for Child Safety
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Abstract – The performance of Child Restraint Systems (CRS) largely depends on the quality of its use. Unfortunately several studies proof that CRS are misused for two thirds of the children using CRS. Within the FP7 CASPER project analysis of misuse was an important topic. Emphasis was put on the analysis of misuse and its reasons, the analysis of consequences resulting from misuse based on accident data, accident reconstructions and crash tests. Additionally an investigation of technical possibilities to reduce the misuse risk or to reduce the severity of consequences resulting from misuse was done.

INTRODUCTION

Besides the dynamic performance of Child Restraint Systems (CRS) in sled tests, the actual use of the system has an important effect on child safety. Past experience from field studies and accident investigations show that a majority of children are not correctly restrained when travelling in cars [1-4]. This includes cases of unrestrained children, children using the car belt without CRS, CRS that are not correctly installed in the car, children that are not correctly restrained in the CRS and the use of an inappropriate CRS.

Within the CASPER project field studies were conducted in order to analyse the restraining situation of children in different European regions. In addition to the technical data of the CRS installation and restraining situation of the child, a sociological approach helped to better understand the circumstances that lead to incorrect restraining of children.

Furthermore the risk resulting from misuse was analysed based on comparative sled tests and last but not least published solutions to reduce the risk were reviewed.

RESULTS OF MISUSE FIELD STUDIES / CURRENT SITUATION

For the EU-Project “CASPER” a CRS misuse field study was conducted at different places in Europe. The aim of this project part was on the one hand to get an update of misuse behaviour and to see its development during the last years. On the other hand this study allows a comparison of child safety behaviour in different regions.

The interviews took place in Naples, Berlin and Lyon and surrounding areas. They were divided into two parts. The first one was the observation and assessment of the securing situation of the child in the car; the second part was a short interview with the car driver.

As basis for the analysis of the study 104 cases from both areas Berlin and Lyon as well as 108 cases from Naples were analysed. That means the data base consists of 316 cases.

Basic data

A look to the age distribution (Figure 1) of the children in this study shows that there are few observations in the group from 10 to 12 years and limited numbers in the group up to one year of age, which is normally the group of rearward facing CRS. In this lower age group, some differences may be observed: 20% of children are younger than 1yo in the Berlin data while about 4% in Lyon and 8% in Naples samples. Statistical tests performed with the CHI-2 test confirm these observations: p<0.05 when comparing Berlin and Lyon or Berlin and Naples samples while the age distributions are not statistically different between Naples and Lyon data (p=0.22). The data collection strategy (mostly
near a city park with recreational facilities in Lyon, in a variety of locations in Berlin and in connection with the company Christmas party in Naples) may have affected this distribution.

The comparison of age and weight of the children from Berlin, Lyon and Naples is shown on Figure 2a. Linear regressions were performed with calculation of confidence interval at 95% (Figure 2b): no significant differences between Berlin, Lyon and Naples data were found in the limit of this interval. For all groups the scatter of weight increased with increasing age. The relationship between weight and age was well in line with the dummy characteristics (Figure 2a).

A similar picture emerges when comparing body size and age of children (Figure 3a). The distributions are statistically similar for all three survey locations within a confidence interval at 95% (Figure 3b) and again, the Q-dummies fit well within the cloud. Only the Q10 dummy, which
represents a 10.5 years old child.

limited data was collected for thi

![Diagram](image)

**Figure 3**: a) Comparison of dummies (top) b) Lit

**Information on CRS**

The distribution of the CRS wh
data (Figure 4 and Figure 5). M6
Sixty percent of all children w
travelling on an adult's lap. In
drespectively. However it has to b
locations. While in Berlin cases of
children in vehicles were consid
12 years old in a car were cons
CRS. These different selection c
individual regions. Also, based c
very likely. A non-use rate of 60
even taking into account all the c
usage rate of CRS in Germany i
[1].

The high rate of infant carriers (p
partly explained by the different s
still seldom used. On all three s
an ISOFIX seat.
Plotting the CRS classes as a function of the age of the children suggests an overall age-appropriate selection of CRS classes (Figure 6). Infant carriers (class 0+) are used mainly for all children up to one year; some are still in the age group 1 to 5 years in use. While CRS in Class 1, suitable for children aged 9 to 18 kg, are mainly used by the 1 to 5 year old, some are in use for younger children. In most cases, these seats are not suitable for children in this age group and their use constitutes a misuse. CRS of class 2/3 (15 to 36 kg) are suitable for children from about 4 to 5 years. According to the distribution shown in Figure 6, their use is age-appropriate. Unsecured children, or children restrained only by the safety belt were observed in all age groups.
Information on misuse

For the evaluation of the securing situation, it should be first defined how to deal with cases where the children were secured in a CRS or were secured only by the safety belt in the car. Since the term "misuse" refers to the misuse of CRS, and is used in this sense in the current study, the term “misuse” can only be applied to cases where a CRS was in use in some way. Accordingly, only those cases are considered for the following analyses. This classification is consistent with older field studies [1-4]. Only the following diagram (Figure 7) takes into account all cases, to present an overall picture of the current securing situation in the comparison of the three study regions.

![Figure 7: Securing quality](image)

In general the results of this study confirm the results of former evaluations [1-4]: only one third of the children are properly secured in the vehicle, two thirds are wrongly or not secured. However, in the older studies, cases were selected only, if a CRS was in use, which was the same selection criterion in Berlin.

Depending on the region, differences could be observed. While in Berlin the rate of correct use was about 49%, it was only 31% in Lyon and 23% in Naples in part due to the non-use of CRS. If removing the non-use cases out of the three locations, the correct use rate becomes 50% (n=101) in Berlin, 37% (n=87) in Lyon and 58% (n=43) in Naples, and the average becomes 47% (n=231).

Grouping data from all sites leads to a misuse rate (taking into account only cases where a CRS was used) of 53% (Figure 8). It is important to note that this rate does not reflect the protection of children in cars as children without CRS, which are especially as risk, are not considered. Taking only into account the data from Berlin gives similar results (50% misuse). Regional differences may be more marked on the rate of non-use (as already seen above between Lyon and Naples).

Overall, these results could suggest a reduction of the CRS rate of misuse with time. While this could be an encouraging trend, it needs to be taken with caution as methodology, sampled population and investigator training may differ between studies and locations. This is illustrated by the difference of age distribution between locations. Future studies and analyses should be performed to determine if it is a positive trend or a methodological artefact.
A closer look at the securing misuse shows what problems arise most often. The most common is the slack in the belt system of the CRS, which can be detected in more than 25% of all misuse cases. Furthermore, twisted belts in the CRS or in the vehicle were found in 13% of the cases, however, it has usually no direct impact on the safety of the occupants, but it can cause belt slack because the belt cannot be tightened properly. The non-use of the lower lap belt guides in class 2/3 seats is another common problem. This could result in some accident cases in the direct loading of the abdominal region by the belt, which might obtain abdominal injuries. Belt under the arm (7%) could also result in inappropriate loading of the thoracic and abdominal regions and injuries.

Quite often (6%) the children are too small (very seldom too large) for the used CRS, which means that its belt geometry cannot be properly adjusted for the child. In the worst case, the child is clearly too small for a Class 1 seat, and thus could be more exposed to the risk of neck injuries that it will suffer because of his large head weight in comparison to the neck muscles, which also occur in relatively small car decelerations.

**Most often observed securing misuse:**

- Slack in harness (baby shell, class 1) 26%
- Lower belt guide not used (class 2/3) 18%
- Car belt twisted (class 2/3) 13%
- Wrong shoulder belt position (class 1; 2/3) 11%
- CRS belt under arm of child (class 2/3) 7%
- Child to small for CRS (class 1; 2/3) 6%

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Figure 8: Comparison of misuse rate with older field studies [1-4]. Only the cases for which a CRS was used were included for the three locations.

A look at the distribution of misuse suggests that more misuse occur when securing the child in the CRS (securing misuse) than misuse in relation with the installation of the CRS in the car (installation misuse). However both misuse types were often observed (Figure 9).

Figure 9: Type of misuse
Looking at the types of misuse related to the installation of the CRS in the car (Figure 10), the most common problems are the car belt path, the lack of shoulder belt guide use in a class 2/3 seat with a backrest, the insufficiently tightened car belt and the bulk seat fixation. These misuses are critical and may lead to serious injuries if an accident occurred. The most common misuses have in common that they could be prevented by the use of ISOFIX.

The assessment of the installation misuse shows that most of the cases were rated by the interviewers as severe misuse (Figure 10). There are some differences between the three study regions, but these were probably due to the small sample size and the general difficulty in assessing the severity of errors.

**ANALYSIS OF REASONS LEADING TO MISUSE**

Apart from the details directly related to the technical aspects of the restraint conditions, information about the transport situation was collected. The aim was to better understand the situation and try to find which specific circumstances could lead to misuse. The following analysis includes cases where the child was not secured in a CRS and includes data from all three regions.

First, the travel time was compared with the misuse frequency (Figure 11). The correct use of child safety seat seems to increase with travel time, however the tendency is not very pronounced. This trend cannot be seen for misuse or non-use cases.
Another interesting point is a possible link between the securing quality and the travel purpose. In the questions, the travel purpose could be: ride to school / nursery, shopping, vacation, leisure activity and other rides. This analysis suggests that there is a relationship between securing quality and travel purpose (Figure 12). Driving to school, kindergarten or shop, which may be associated with a certain time pressure, was more likely to lead to poor restraint of the child, children in leisure or recreational trips tend to be better secured. Because of the special situation in Naples, where all interviews took place in conjunction with a company Christmas party, there is a large group of “other” in the statistics of the travel purpose.

During the interview, all drivers were asked whether they believe that their child was secured in the vehicle correctly. A majority of respondents replied “yes”, and only a small proportion was unsure or stated that this was not the case (Figure 13). However the comparison of these data with the actual installation quality shows that misuses were present in almost 60% of the situations that were perceived as correct by the drivers. In cases where the drivers were not sure or not expecting that everything was done correctly, the misuse rate was even higher (Figure 14).
According to this result, a majority of drivers believes that the restrained child is properly secured and is not aware of the misuse. The misuse is not a known situation that the driver accepts while knowing better, but seems the result of a lack of knowledge about the correct use of CRS. It is also unknown if some parents could have been aware but refused to admit it in front of the investigators.

The study has shown that external factors, such as the trip purpose, have influence on the securing quality. The ride to kindergarten or to school, which is a daily situation where parents may have less time, resulted in a higher rate of misuse. Trips with greater travel time or a relaxed environment, such as vacation trips, was associated with a better securing quality.

Finally, the results of the study and the interviews with the drivers have shown that parents want to secure their child correctly. However, lack of information or a misunderstanding of the user manual lead to a high misuse rate. Obviously there is still a great need for the simplification of the usability of CRS. At the same time it should be the aim of the manufacturer of CRS to ensure that also frequently observed misuse does not automatically lead to a significant loss of the protective potential of child CRS.

**SOCIOLOGICAL ASPECTS ABOUT MISUSE**

The misuse survey included several questions that could help understanding some of the sociological aspects associated with CRS misuse, such as parental attitudes, habits and behaviours and driver perception relating to child transportation in cars. Globally the sample is composed by 317 observations, equally distributed between the three countries (104 Germany, 104 France, 109 Italy) but for time constrains the collection of this information was not always possible. The “unknown” or missed answers are excluded by each variable percentage. The driver was always the person answering the question even when there were other adult occupants in the vehicle.
• **Gender (n=314):** The whole survey was mainly composed by males (61%), highlighting the fact that men are more likely those who drive the car with their family. Women were only the 39% of the cases.

• **Age (n=261):** Most of the men were between 36 and 45 years of age (57%), and the majority of the women were between 31 and 40 years (55%).

• **Family situation (n=221):** The great majority of drivers reported they lived as couple (91%), with one child (43%). Consequently the average number of children per family in the sample is 1.40, which is not representative of the three countries where the survey was given.

• **Educational level (n=175):** The majority of the driver sample had a high level of education (95%). This is comprehensive of high school (47%) graduate 1%, university 47%.

• **Driving experience (n=240):** 90% of the sample had a considerable amount of experience on the road. They had been driving for more than 10 years, and the 49% of them had been involved in a road accident as driver.

• **Location of residence (n=230):** 50% of the drivers reported that they lived in a large town, about one third of participant reported that they lived in a small town (34%), 16% of participants reported that they lived in the countryside.

• **Age of the car (n=289):** 27% of drivers had a car of the last two years (2010-2009), 55% had a car between 3 and 10 years old, 18% of the participants had a car older than 10 years.

**CRS purchasing (n=162):** 82% of the driver bought the CRS in a specialist shop (nursery shop) or in a supermarket and they did not ask for advices at selling point (56%).

As explained at the beginning of this paper the misuse surveys is composed by 316 cases and **misuses were detected in 59%** of the cases: misuse of CRS installation (17%) and misuse of fixing the child in the child restraint system (39%). Considering the whole survey (n=317 observations), **misuses were detected in 53%** of the cases (n=167 observations), even if in 32 observations both kind of misuses (CRS installation and securing child in CRS) were detected at the same time.

For this reason, considering the possibility to have the same observation with one or two misuses, the misuse sample was composed by 199 cases 61 misuses of CRS installation (31%) and 138 misuses of securing the child in CRS (69%)

When a misuse was detected, the main responsible for the misuses was the driver (Figure 15 and Figure 16). In details:

- Considering only the misuses in CRS installation (61 cases), the driver was mainly responsible for 66% of the cases (Figure 15);
- Considering only the misuse in securing child in CRS (138 cases) the driver was responsible for 57% of the cases. (Figure 16) For this kind of misuse the percentage of children that secure themselves (25%) was relevant and 78% of the driver thought that the child protection was alright.

![Figure 15: Misuse & CRS installation (n=61)](image-url)
With reference to the gender of driver and to the kind of misuse, as shown in Figure 17 below, a misuse was caused more often by driver males (54%) than by driver females (46%). The misuse gender distribution is quite similar to whole sample, but analysing the misuse types it is very interesting to point out that:

- Driver males generally made misuse when securing the Child in the CRS (64%, vs. 36% for females)
- Instead the driver females made misuse when fixing CRS to the car (53%, vs. 47% of the males).

Another interesting analysis is related to the relationship between the driver’s age and the misuse status (Figure 18):

- Younger drivers (until 35 years) were most likely to make a misuse (45%, against the 29% of no misuse cases). The younger drivers’ misuses are mainly related to fixing the CRS to the car (57%)
- The distribution between misuse cases and no misuse cases was similar in the age group 36-40. For this age group, when a misuse was detected, it was mainly linked to securing the child into the CRS (36%).
- “No misuses” were more relevant in the age group over 40 years old (40% of correct use against 27% of misuse cases). For this group when a misuse was detected, it was mainly related to securing the child into the CRS (37%). The older parents (over 40 years), had mainly 1 child (76%), with an average age of 6 years. When a misuse was detected it was mainly related to securing the child into the CRS (37%); they didn’t have difficulty in CRS installation because they used mainly seat belt (41%), or booster (with backrest and only cushion – 27%).
Finally when a misuse is detected, as shown in Figure 19 below, the main responsible person for the misuse is the driver. He is responsible of 72% of misuse in CRS installation and of 60% in fixing the child in the CRS.

About misuse in fixing the child in CRS, 29% of children fix themselves, and generally the driver does not check the correct use of the restraint by the child before the trip. This percentage goes up until 37% if the analysis is linked only to misuse in fixing the child into the CRS.

CONSEQUENCES RESULTING FROM MISUSE BASED ON ACCIDENT RECONSTRUCTION / MISUSE TESTS

During the EC CHILD project, field studies on the situation of use and misuse of CRS were conducted and considering that this point was a major issue in the child safety area, the decision to create an ad-hoc group on the item of misuse was taken. The aim was to increase the partnership already existing in the CHILD consortium to other participants such as CRS and car safety devices manufacturers. This group based on the exchange of voluntary work, has been looking at available field data, through their own way of collection but also to the material available in the accident in-depth investigation cases of the CHILD project. After this, a dynamic testing program has been set up to define the effect of misuse on the protection of children. Results were reported in a document made publicly available at the end of the project [6]. This public report is regularly updated and can be found on the CASPER website. Results have also been published at the end of the CHILD project [7].

The test set up is depending on the possibilities of the test facilities but with a common methodology: misuse tests are compared with a reference test performed according to R44, so the test severity cannot
be considered as the cause of any failure. In the end, 77 tests in bodies in white tests and 16 regulation bench tests were conducted in the first period leading to the study of the situation of 160 child dummies. In addition to this previous works, more than 60 configurations have been tested in the frame of the CASPER project, with the performance of 25 tests in car environment and 13 on regulation bench.

Of course all misuses do not represent the same danger in terms of protection decrease. The evaluation of this point is somewhere delicate and subject to interpretation of the evaluator. Recently some works have been conducted on this point that confirms this statement [8]. In the following paragraph, the evaluation is done for frontal impact (the most frequent configuration) and it is based on two main parameters: the dummy readings, and the visual observation of the dummy kinematics on the high speed videos. It seems that both are necessary because in case of reproduction of an event (e.g. head impact), child dummies are often the best tool to use (indications on duration of event, level of severity), but they are not sufficient indicators in case of “non-event”, which does not correspond necessarily to the absence of injury risk. For example, if there is an excessive dummy head excursion during a test but that no impact occurs, the risk of head injury by impact on a rigid vehicle component is higher in that case than in the reference test, even if measurements from the child dummy show similar results. In configurations with non-event, videos are then, the most appropriate tool to be used to compare differences between the reference tests and misuse configurations. It is important to note that one of the limits of the analysis is the fact that results are only valid for the tested CRS in the environment of the test. For example, a misuse reproduced on a high quality CRS could lead to no evidence of decrease of protection, but the same misuse occurring on a lower quality system could lead to a total breakage of the system. Knowing this and taking into account the fact that tests were mostly performed with CRS that could be ranged from “reasonably good performance” to “excellent ones”, the first global statement is still that in none of the misuse situations show better protection than the reference tests. For nearly all types of CRS, the head is more at risk in case of misuse because of the larger displacement of the head (risk of head impact). CRS for which the seatbelt is used to restrain children show a higher risk of injuries in the abdominal area. For further analysis, it is necessary to put the different misuses reproduced into categories (illustrated on Figure 20). The first one is the wrong fixation of the CRS to the car using the seatbelt or ISOFIX connectors (e.g. wrong seatbelt route, only one ISOFIX connector engaged, wrong support leg adjustment, …). In some cases, the integrity of the CRS is not ensured anymore and base and shell are separated. This leads to a high risk of ejection of the children, or at least to a severe impact with the car interior. The risk is similar if the CRS integrity is kept but that the CRS is not restrained anymore. Most of the other situations are giving more liberty of freedom to the CRS which correspond to a higher risk of sustaining an impact with the vehicle interior or that could lead to a structural rupture in case of more severe event.

![Figure 20: Misuse of CRS fixation (left), misuse of restraining child in CRS (centre), misuse of seatbelt restraining the child (right)](image)

The second category of misuse is the wrong adjustment of the parts restraining the child in its CRS. This kind of misuse is often observed in field studies and different configurations have been tested. The first strong result is that for an important part of misuses of this category, the dummies do not respond in the expected way. Effectively, through the in-depth accident studies of frontal impacts, it is assumed that in case of excessive slack in a harness, the child is moving forward, the shoulders slip-off from the harness and the upper part of the torso being not restrained anymore, the child’s head is continuing its movement forward with a high risk of impacting the front seatback in front of the child or the B pillar of the vehicle. Tests performed in this program and accident reconstructions have
shown that independently of the amount of slack introduced into the harness, the child dummy had a too rigid torso and shoulders that make it stay restrained by the harness. It has then been difficult to give a more scientific point of view than the one of the experts in accidentology in these configurations. When the harness is located under the arms or when it has been transformed into a three point (in a wrong re-assembling process after washing the cover for example) the buckle of the harness tends to penetrate the abdominal area, and becomes a source of injuries. This can sometimes be combined with the penetration of the lower straps of the harness in the abdomen of the dummy. Of course in case of excessive slack in one of the adjustable part of the CRS, the risk of ejection from the restraint system is high and would lead to no protection at all.

The third category is the wrong route of the seatbelt to restraint the child which leads to very impressive kinematics in a lot of cases. Most of the time the abdominal area is overloaded by the pelvic or thoracic parts of the seatbelt, and sometime by both of them. In case of restraint applied only to the lower part of the trunk, the risk of hard impact of the head against a rigid part of the car is very high. Some seatbelt routes observed in field studies with children on boosters nearly lead into the ejection of the child from the body in white.

Inappropriate use (Figure 21) and postural tests performed were not necessarily considered as misuse situations but leads to similar results: children with a too small stature are at risk considering ejection (but still difficult to show with a dummy), CRS in which children heavier than the range for which it is approved can sustained structural damages as the loadings will be higher than the ones it is approved for. Risk of projection becomes then high.

Tests with dummies using the seatbelt of the vehicle (with or without booster systems) positioned in postures close to the one observable in the real life were conducted and compared to results of test in standard positions. It was difficult to discriminate wrong postures tests from the ones of the regulation tests using only the standard dummy readings except in case of head impact. The abdominal pressure sensor developed in the CHILD and CASPER projects and that is used in the Q dummies was the only predictive indicator of a major injury risk. Videos were also helpful to check the most appropriate dummy kinematics. It is important also to note that the posture used by children often lead to misuse of the seatbelt because of comfort issue (seatbelt under the arm, additional excessive slack, …).

**ANALYSIS OF POSSIBILITIES TO REDUCE THE MISUSE RISK OR TO REDUCE THE SEVERITY OF CONSEQUENCES RESULTING FROM MISUSE**

Before going into a detailed analysis of technical solution, it is important to notice that some CRS products on the market are proposing isolated solutions, such as visual and/or audio indicators of correct adjustments of the different parts of the CRS. These types of solutions are helpful for parents that have little knowledge in the safety area and that are in need for help [9]. Their generalisation could lead to a global reduction of the misuse situation of CRS on the roads. But as most of these indicators are not mandatory, it is up to each CRS manufacturers to equip their systems with such solutions to make them easier to use. The CASPER project has been reviewing some existing solutions and concludes that it was difficult to find solutions that were acceptable for all parts involved in the "child safety chain", from the engineering and commercial services of the CRS manufacturer to the children and parents including legislators and scientific researchers in child safety. Nevertheless, these relatively simple indicators of correct use were often considered as a good balance for all parts and have been rated for most of them with positive score. Most of the proposed solutions by CRS
manufacturers have been presented in the International Conference “Protection of children in cars” that is one of the most important yearly conferences on the field of child safety in vehicles. The following section is based on the review of the proceedings from this conference. Possible technical solutions for different CRS and misuse types were presented from 2003 to 2010 and were analysed with regard to technical solutions for misuse.
In a first step the solutions can be separated between solutions for CRS with integral harness and solutions for boosters.

Solutions for CRS with integral harness

For harness systems, the most important or most frequently seen misuse types are “incorrect seatbelt route” and “harness not sufficiently tightened”. In addition rearward facing CRS are found installed forward facing. Group 1 CRS are often used too early (for children from 6 month) and left also too early for the use of booster seats.
The discussed solutions are partly already available on the market, regulatory solutions in different countries or concept studies.
To address the problem of the not sufficiently tightened harness, two concepts were shown in [10-12]. The first system gives a visual indication of the harness tension. A mechanical working flap is attached to the harness strap, implemented in the shoulder padding. As long as the harness is not properly tensioned, the flap is in a raised position. In this position a corresponding negative pictogram is visible. When the harness tension is adjusted properly, the flap comes down flat to the shoulder padding and a positive pictogram is visible. The second described solution is an audible indicator. When the correct harness tension is reached during the tensioning procedure, this is indicated by audible clicks.
The revised Australian and New Zealand CRS standard includes a seating height related marking [13]. Stickers on the CRS indicate the height of the shoulders of a child that fits in the restraint. The markings show the lowest shoulder height, below which the CRS should not be used and the highest shoulder height, above which the CRS has to be changed. In parallel, dimension controls have been included in the Australian and New Zealand standard to ensure that the categories of CRS are linked to each other (maximum size of one CRS fits to the minimum size of the next CRS).
A concept Group I CRS addressing numerous misuse cases by technical solutions was presented in [14] (Figure 22). To control the seat belt rout and the tension, the vehicle belt has to be routed using one of the upper belt guide clamps. Spring-load levers with an integrated push button on both sides of the guide allow detecting the correct belt tension and belt path. The installation direction (forward/rearward) as well as the upright position of the CRS is controlled by push buttons on the back of the CRS. This ensures the fitment to the backrest of the vehicle seat.

![Figure 22: Concept Group I CRS](image)

The incorrect harness tightening is addressed by a new harness tensioning device. The integrated harness is tensioned by large turning handles on both sides of the CRS. For the consumer the tensioning is easier due to the reduction of the needed force and the better positioning. The correct harness tension will be indicated by a haptic feedback, as soon as an integrated slipping clutch detects sufficient belt force (Figure 23).
Two accelerometers, on the backrest of the CRS and on the upper part of the shoulder harness, analyse the angle between the shoulder harness and the CRS seat back. Here the correct position of the shoulder harness is controlled (Figure 24). A miniature switch inside the buckle of the integrated harness connected to a sound interface gives a warning, if the child unbuckles during a trip. To make it possible for consumers to check whether a CRS was exposed to an accident, a very thin conductor with a small weight was attached to the back of the CRS. The conductor will break after a certain level of acceleration is reached and give a visible indication on the possible exposure to an accident. Information on mistakes during the installation process is given to the user via a LC-display. An interface like this display can give a direct feedback to the consumer about a misuse and can offer information on the solution.

Specific to ISOFix child restraint systems, [15] describes the design of a global indicator for ISOFix and Top Tether fixation. The Top Tether includes an elastic indicator adjusted to the correct tension of the tether. The elastic indicator is connected to the central positioner of both ISOFix connectors of the CRS. All three anchorages, both ISOFix connectors and the Top Tether have to be correctly attached to the vehicle to receive a positive visual indication of correct installation (Figure 25).
Solutions for boosters

For booster with and without backrest, the most common misuse cases are the seat belt under the arm during the driving phase, incorrect seatbelt routing, and misuse based on geometrical incompatibility between the booster and the vehicle. The non-use of CRS increases especially for older children. One solution described in [16-19] are integrated CRS. In [16, 19] it is seen, that booster seats integrated in the vehicle are more accepted by the children (less childish). This could increase the use of boosters for older children from an age of 8 years on. Additionally the handling of integrated boosters was seen easy and fast. So the correct usage of the booster could be increased. [18] shows the possibility of 2-stage booster cushions with a high position for smaller children up to a height of 1.20 m and a lower position for the taller children. The 2-stages approach allows a better thigh support for a more upright seating position. The increased height and the booster being designed together with the vehicle allow the children to participate in the safety benefits of the car related safety systems.

In [17] the concept of a self-adjusting integrated child restraint system is demonstrated. The child (or adult) is detected by a webcam. After several image processing steps, the actual height of the occupant is distinguished. A motor driven mechanical system modifies the seating height to a correct position according to the height measurement. Based on an anthropometric database the seat is adjusted to the best position for the use of the 3-point belt system for this occupant. The system adjusts the height and the side protection (Figure 26).

Harness systems and lap belt positioning devices in addition to the booster seat can be used on the Australian market. [20] shows different possibilities according to the Australian/ New Zealand Standard 1754:2004. The harness system restrains the upper part of the body and stays in position even if the child moves during the travel. An additional lab belt positioning device, attached to the booster shall keep the lap belt of the vehicle and also a harness system correctly positioned. [21] analysed the vehicle rear seats to get an impression whether it could be possible to modify this seat in a way, that could allow children (aged 6 years and above) to use the 3-point seatbelt only. The use of pre-tensioner and seat ramps and the modification of the belt anchorage points could lead to rear seat that could be used by taller children without CRS. A problem that was not addressed was the incompatibility between the thigh length of children and the length of the seat cushion. The cushion was too long for the children’s legs.
The CRS presence and orientation detection was demonstrated by [22]. Presence and orientation of a CRS equipped with resonators can be detected on a vehicle seat with adequate sensors. The gathered information can be used for the passenger airbag deactivation for rearward facing CRS on the passenger seat. Additionally the information can be used to address individualized strategies for safety systems for different CRS types.

Summary and Conclusion

Recent field studies that were conducted in Berlin, Lyon and Naples showed that approx. two thirds of the children travelling in cars are not correctly restrained. However, important regional differences exist. Slack in the harness, slack in the car’s belt and wrong belt path were reported most often. Most of the interviewed parents believe that they do restrain their children correctly so it is concluded that misuse is mainly a result of lack of knowledge.

Within the analysed sample males and young drivers are overrepresented to install CRS incorrectly.

Sled tests show higher risks for the head in misuse conditions mainly caused by larger head displacement. In cases with booster seats abdominal loading normally increases in misuse conditions. One problem that was observed in accident studies was impossible to be reproduced in dummy tests. While in a number of accident it was concluded that the harness slipped off the shoulders during the accident it remained under all possible circumstances (slack in harness, harness position far outside but on the shoulders) at the dummy shoulders. Different dummy postures were only possible to be “detected” by the abdominal loading. Other parameters did not correlate with the subjective rating of the respective situation.

Several solutions for avoiding misuse situations are proposed or on the marked already, e.g., audible, visible or tactile information regarding the correct harness tension. These systems were not yet seen in misuse field observation therefore it is hardly possible to judge their effectiveness in real live conditions. The same is true for ISOFIX CRS which were observed in less than 5% of the cases.

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