

REAR SEAT SAFETY IN FRONTAL TO SIDE IMPACTS – FOCUSING ON OCCUPANTS FROM 3YRS TO SMALL ADULTS

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ABSTRACT

This study presents a broad comprehensive research effort that combines expertise from industry and academia and uses various methodologies with applied research directed towards countermeasures. The project includes real world crash data analysis, real world driving studies and crash testing and simulations, aiming at enhancing the safety of forward facing child occupants (aged 3y to small adults) in the rear seat during frontal to side impacts.

The real world crash data analyses of properly restrained children originate from European as well as US data. Frontal and side impact crash tests are analyzed using different sizes of crash test dummies in different sitting postures. Side impact parameter studies using FE-models are run. The sitting posture and behavior of 12 children are monitored while riding in the rear seat. Also, the body kinematics and belt position during actual braking and turning maneuvers are studied for 16 rear seat child occupants and for various child dummies.

Real world crash data indicates that several of the injured children in frontal impacts, despite being properly restrained, impacted the vehicle interior structure with their head/face resulting in serious injury. This was attributed to oblique crashes, pre-crash vehicle maneuvers or high crash severity. Crash tests confirm the importance of proper initial belt-fit for best protection. The crash tests also highlight the difficulty in obtaining the real world kinematics and head impact locations using existing crash

test dummies and test procedures. The side impact parameter studies indicate that the vehicle's occupant protection systems, such as airbags and seat belt pretensioners, play an important role in protecting children as well.

The results from the on-road driving studies illustrate the variation of sitting postures during riding in the rear seat giving valuable input to the effects of the restraint systems and to how representative the standardized dummy seating positioning procedures are. The results from the maneuver driving studies illustrate the importance of understanding the kinematics of a child relative to the seat belt in a real world maneuver situation.

Real world safety of rear seat occupants, especially children, involves evaluation of protection beyond standard crash testing scenarios in frontal and side impact conditions. This project explores the complete context of rear seat protection in impact situations ranging from front to side and directions in between highlighting the importance of pre-crash posture and behavior.

This research project at SAFER (Vehicle and Traffic Safety Centre at Chalmers), where researchers from the industry and universities cooperate with the aim to further improve safety for children (from 3y) to small adults in the rear seat, speeds up the process to safety implementation due to the interaction between academic and industrial researchers.

INTRODUCTION

World wide, road traffic was the second leading cause of death among 5-14 year olds in 2002 (WHO, 2004). In US, for every day in 2006, an average of 5 children 14 years and younger were killed and 568 were injured in motor vehicle crashes (NHTSA, 2006).

According to US statistics, 52% of the rear seat occupants are less than 13 years old, 14% are 13 to 15 years, and 34% are older than 15 years (McCray et al., 2006). On average a 12 year old is of similar size as a 5th percentile female, thus by focusing on the children, solutions driven by the data analyses will cover small size adults as well.

Summarizing crash data (NASS-CDS 1991-2005) on rear seated children aged 4-12 years, second to rollover, the highest MAIS3+ injury risk was seen for side impacts situations (Bidez, 2006). However, there were more children injured in frontal impacts, due to the high frequency of frontal impacts compared to other crash direction. Furthermore, several of the injured were restrained, indicating that current restraint systems have potential for further improvements. Thus, there is a need to address protection in both side and frontal impacts for restrained rear seated children, as well as oblique impacts.

For the smallest children, the safest restraint for optimal protection is rearward facing. Swedish and US data show that children in rear facing restraints are better protected both in frontal and side impacts (Tingvall 1987, Carlsson et al. 1991, Kamrén et al. 1993, Stalnaker 1993, Tarrrière 1995, Isaksson-Hellman et al. 1997, Jakobsson et al. 2005, Henary et al., 2007). Rearward facing seats are used around the world for infants and offer the optimal protection, recommended in Sweden up to the age of 3-4 years.

When the child has reached 3-4 years of age and sitting forward facing in the car, there are still differences as compared to adults. The iliac spines of the pelvis, which are important for good lap belt positioning and for reducing risk of belt load into the abdomen, are not well developed until about 10 years of age (Burdi et al. 1968). The development of iliac spines, together with the fact that the upper part of the pelvis of the sitting child is lower than of an adult, are realities that must be taken into consideration, in order to give a child the same amount of protection as an adult.

Belt-positioning boosters were introduced in the late 70s (Norin et al. 1979). The boosters allow the geometry of the adult seat belt to function in a better way with respect to the child occupant. The booster elevates the child, so that the lap part of the adult seat belt can be positioned over

the thighs, which reduces the risk of the abdomen interacting with the belt. The booster also encourages the children to sit comfortably with their legs, helping avoid slouching, which leads to poor seat belt geometry (DeSantis Klinich et al. 1994). Other advantages of belt-positioning boosters are that the child, by sitting higher, will have the shoulder part of the seat belt more comfortably positioned over the shoulder and will also have a better view.

The belt-positioning boosters may have backrests (so called high back boosters). The backrests were initially intended to route the diagonal part of the seat belt in an optimal position over the child's shoulder and chest. In recent years, the designs of the backs of the boosters have evolved towards large side supports both at the height of the torso and the head. The child restraint manufacturers emphasized two reasons for this; to provide improved side impact protection and to provide comfort for children by keeping them upright when relaxed or asleep to help provide protection at all times.

Integrated (built-in) belt-positioning boosters are available in some cars. These systems were developed in order to simplify usage and to minimize misuse (Lundell et al. 1991). An observational laboratory study of 130 children concluded that an integrated booster had many advantages compared to an accessory booster regarding both safety and comfort, such as easy and quick to handle resulting in significant lower misuse rate (Osvalder and Bohman, 2008).

As a further development of integrated boosters, Volvo Cars offers a rear seat safety concept for enhanced overall protection for children aged 4 to 10-12, including a 2-stage booster and progressive load limiter adapted to the child (Jakobsson et al. 2007). The 2-stage booster was designed to help provide an even better fit for an even broader range of sizes of forward facing children. In its high position, it provides good seat belt fit for the smaller children. In its low position it offers a more adapted thigh support (reducing likelihood of slouching) for the larger children, as compared to when using the adult seat position.

Belt-positioning boosters are effective tools to help protect children from injuries, decreasing the probability of injury in frontal impacts as well as other crash directions (DeSantis Klinich et al. 1994, Isaksson-Hellman et al. 1997, Warren Bidez and Syson 2001, Durbin et al., 2003, Jakobsson et al. 2005, Arbogast et al. 2009). Durbin et al. (2003) showed that the seat belt syndrome related injuries to the abdomen and spine were nearly eliminated in crashes with children seated correctly on boosters compared to those restrained by seat belts only. Children aged 4 to 8 and using booster were 45% less likely to sustain injuries than similarly aged

children who were using the vehicle seat belt only (Arbogast et al., 2009). Children in side impacts derived the largest relative protection from booster seats, with a reduction in risk of 68% and 82% for near-side and far-side crashes, respectively, with no difference in high back versus backless boosters. The authors mainly acknowledge the enhanced better shoulder belt fit by the booster as the main contributor, knowing that side impact crashes often have a substantial frontal component (Arbogast et al. 2005).

The rear seat children also benefit from seat belt technology such as pretensioner and load limiters. Sled tests using a HIII 6y showed that belt load limiting and pretensioning resulted in reduced head, neck and chest loading as well as forward displacement (Bohman et al. 2006). Sled tests by Forman et al. (2008) reported that, compared to standard 3pt belt, the belt load limiting and pretensioning system resulted in a statistically significant decrease in average maximum internal dummy chest deflection of 29%, in 48 km/h test speed, for the HIII 6y. These results agreed with tests where a child-size PMHS was used (Lopez-Valdes et al. 2009).

Although in some countries, booster use is recommended up to approximately 10-12 years of age, the highest age groups within this range are not as frequently restrained using boosters. US statistics (CHOP, 2008) shows higher injury risks within the age group 9-12 year as compared to the younger age group (4-8 years), suggesting that the age group of 9-12 years requires extra focus since they fall between the traditionally booster restrained 4-8 year old children and they are still smaller than the teenager and small adults that are correctly restrained by the seat belt.

Over the years, the rear seat has been a safer place than the front seat (Braver, 1998, Smith and Cummings, 2004), but for the last years a new trend has been noticed, showing that the rear seat might be less safe compared to front seat (Kuppa et al. 2005, Kent et al. 2007). Some possible explanations are increased stiffness of new vehicles, which has been compensated in the front seat with load limiters and pretensioners while in many vehicles the rear seat safety is lagging behind. Although the technology has been introduced in the rear seat of some vehicles; such as anti-submarining floor ridge in 1982 (Lundell et al. 1981), 3pt seat belts and head restraints in all positions in 1986 (Karlbrink and Mellander 1987), seat belt pretensioners and load limiters, the wide implementation is still to come. Currently, programs that conduct consumer rating tests are in the process of integrating the 5th % adult female dummy in the rear in side impact tests, but the lack of legal requirements in this scenario does not drive the continuous improvement of

rear seat safety. Therefore, there is a great need to focus the safety in the rear seat to enhance knowledge in order to take the right actions to reduce injury numbers and severity, especially focusing the population of most common rear seat occupants.

Improving safety for rear seat occupants requires enhanced knowledge in several areas, involving research regarding crash test dummy development, real world crash investigations, protection system evaluation and development, also taking restraint handling and attitude aspects into account. To address this, the objective of the present study is to present a joint research project encompassing these areas with the aim to further enhance the safety for forward facing occupants (aged 3y to small adults) in the rear seat in the event of frontal to side impacts.

METHODS

This study presents a broad comprehensive research effort that combines expertise from industry and academia at SAFER (Vehicle and Traffic Safety Centre) in Sweden in the joint effort to improve safety in order to reduce the number and severity of injuries of forward facing children (up to small adults) in the rear seat of passenger cars.

The project runs 2009-2011 with a planned continuation of an additional three years and combines the work by three PhD students (two industrial PhD students and one academic PhD student) and several senior researchers. The project group consists of researcher from Autoliv, Saab Automobile, Volvo Cars and Chalmers University of Technology and is associated with the Children's Hospital of Philadelphia and Karolinska Institutet. Seminars and workshops are held involving other researchers in the area; for knowledge sharing and for input to the research agenda.

Using various methodologies with applied research directed towards countermeasures, this project aims at mapping the causes of injuries occurring to restrained children 3 – 12 years old in frontal to side impacts. The overall objective is to establish guidelines for evaluation methods as well as protection principles, also taking restraint handling and attitude aspects into account. The project contains real world crash data analyses, real world driving studies, and physical and virtual crash testing/simulations, also including a focus on the child occupant test tools.

Real world crash data analysis

The aim of the real world crash data analysis is to get an overview of crash characteristics, injuries and injury causation. The injury frequency and crash characteristics are identified by literature review and field data analysis. The

causes of injuries are identified through analysis of real world crashes in available databases with the focus on the most important load cases where AIS2+ injuries (moderate injuries to fatalities) occur to children in frontal, oblique and side impacts.

One of the published studies from the project examines in-depth crash investigations from two National Highway Traffic Safety Administration (NHTSA) databases, the National Automotive Sampling System–Crashworthiness Data System (NASS-CDS; 1997–2008) and the Crash Injury Research and Engineering Network (CIREN; 1996–2009) (Bohman et al. 2011a). The selected sample criteria were all frontal impacts with principal direction of force (PDOF) of 11, 12, and 1 o'clock involving rear-seated, three-point seat belt properly restrained (with or without booster) children from 3 to 13 years with AIS2+ head injuries. Cases were analyzed using the BioTab method of injury causation assessment in order to systematically analyze the injury causation scenario for each case. BioTab is a case analysis method used by the CIREN network.

In another study, NASS-CDS data from 1994 to 2007 was queried for severely injured (MAIS3+ or fatality), rear seat occupants involved in near side collisions (Bohman et al. 2009). Belted as well as unbelted occupants were included and analyzed separately. Case vehicles included cars, vans and SUV's, with no restrictions on car model or age. The data was weighted to become representative of the national U.S. population of tow-away crashes during 1994 to 2007. The occupants were divided into two groups; 13 years and older formed the "adult group" and occupants aged 4-12 years formed the "child group".

Thirdly, one study aimed at describing the characteristics of near side impact crashes in which children seated in the rear seats were injured was conducted (Andersson et al. 2011b). This study was based on cases from NASS-CDS (1997-2007), CIREN and Chalmers (2004-2006). The children were between 3 and 13 years old and they were properly restrained.

Real world driving studies

As a part of the project, children riding in actual vehicles were studied in order to find out more about how children behave when seated in different restraints in the rear seat of vehicles. The sitting posture and behavior of children were monitored while riding in the rear seat, both in driving studies on roads and on a test track with braking and turning maneuvers.

The aim of the **on-road driving studies** was to increase the understanding of the natural sitting behavior of children during a car ride, specifically to identify the preferred sitting

posture and the seat belt positions relative to the torso, using different types of restraints during an actual ride in the rear seat of a passenger car. The aim of the **maneuver studies** was to quantify the kinematics of child occupants during swerving and braking maneuvers with a focus on the child's inboard lateral movement and seat belt position relative to the child's shoulder with the aim of monitoring body kinematics and belt position.

A first on-road driving study was conducted to identify common seating positions and to investigate the effect of high back booster seatback designs on the choice of children's sitting postures during riding for six children between 3 and 6 years (Andersson et al. 2010). Vehicles equipped with a video camera were used in real traffic situations. The children were positioned in high back boosters in the rear right seat of a passenger car, while a parent was driving a pre-determined trip for 40-50 minutes, for each of the two boosters. Two markedly different boosters were chosen. One of the high back boosters had small head side supports (10.5 cm) and no torso side supports, while the other had large head (20 cm) and torso side supports (Figure 1).



Figure 1. The two types of high back boosters used in the driving study by Andersson et al. 2010.

A second driving study on roads was performed to identify the preferred sitting posture and the seat belt positions relative to the torso of 8- to 13-year-old children, when seated with and without a booster (without backrest) during ride in the rear seat of a passenger car (Jakobsson et al. 2011). A total of six children made two rides each in a test vehicle, traveling about 40 minutes in two types of restraints; seat belt only and using booster. The parent drove the car. Data was collected through observations, using video recordings inside the car. Four film cameras were fixed in the vehicle providing a front view of the child, a perpendicular lateral view of the child, an oblique view of the child and a front view of the road.

For both studies, the children's different sitting postures were defined according to a classification system based on the position of the head and torso in the sagittal and lateral directions. Film analysis was used. The duration

of each sitting posture that each child assumed was quantified and their activities were documented. Also, for the second study, the shoulder belt position relative to the torso was categorized and the duration of each shoulder belt position was quantified.

A maneuver driving study was conducted on a closed-circuit test track involving braking and turning maneuvers with 16 children aged 4-12 years restrained in the right rear seat of a modern passenger vehicle. The test set up and the analysis of the turns are described in Bohman et al. 2011b. A professional driving instructor drove the test vehicle and a parent was seated in the front passenger seat. While traveling at a velocity of 50 km/h, the vehicle was quickly turned 90° to the right. The children were unaware of when the turns and braking would take place. The children were exposed to two turns and one braking in each of two different restraint systems. The restraint status of the children varied according to their stature. Children from 105-125 cm stature were using boosters, with and without backrest. The taller children (135-150 cm) were using a backless booster and seat belt only. Four film cameras were fixed in the vehicle providing a front view of the child, a perpendicular lateral view and two different oblique views. Vehicle data including velocity, acceleration in forward and lateral direction and steering wheel angle was recorded together with shoulder belt force. Film analysis was used to quantify the lateral position of the child relative to the position of the shoulder belt throughout the event. Also, the same test set up was run using different sizes of child crash test dummies. This data is to be analysed and compared to the child data.

Crash testing and simulations

With the aim of evaluating different restraint properties, physical crash testing as well as virtual crash simulations were conducted and analyzed. Frontal and side impact crash tests were performed using different sizes of child crash test dummies. Side impact parameter studies using virtual crash test simulations for two sizes of occupants were run.

With the aim of evaluating thoracic protection for rear seat occupants, four tests of two different mid size passenger cars with and without side airbags were analyzed (Bohman et al. 2009). The tests were performed according to IIHS side impact crash test protocol using SIDII dummies in the rear seat position on the struck side.

Inspired by the results in Bohman et al. (2011a), reconstructions of some typical real life cases with head injuries in frontal and oblique impacts were performed using the HIII 10y crash test dummy. Oblique impacts tests were run with a PDOF of 20 degrees. Tests were also run with

the dummy pre-positioned in a pre-maneuver positions, such that it was moved 6 cm inboard the vehicle resulting in an initial shoulder belt position far out on the shoulder, see Figure 2. These tests form an important part of the total project for connecting the results from the driving studies and real world data analyses, and are still to be published.

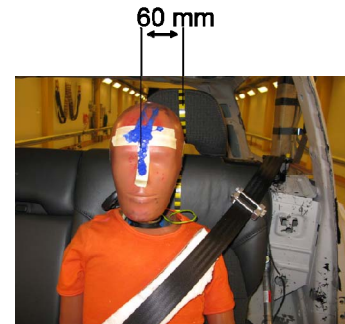


Figure 2. Dummy seating position in the pre-maneuver position in the frontal impact crash testing

A finite element model of a vehicle and occupants of two sizes was developed and used with the aim to investigate the effects of crash related car parameters on injury measures for small occupants in near side impacts, (Andersson et al. 2011a). The occupant models used in the study were the SIDII and the THUMS 3-year-old, see Figure 3. The protective effects were evaluated in both optimal and common non-optimal occupant postures. The selection of sitting postures was based on the results from the driving studies.



Figure 3. The THUMS 3-year-old model in an optimal sitting posture restrained by seat belt in the rear seat using a backless booster (Andersson et al. 2011a)

Test tools for small occupants

Inventory of existing crash test dummies and dummy models representing small occupants of ages 3-12 years is included as a part of the joint project and is ongoing. This includes a review of

published evaluations and other experience from the use of these tools in crash testing, including the biomechanical validation / evaluation. Also, child crash test dummies are being used to reconstruct the kinematics of the children in the maneuver tests.

As a part of this study, Bohman et al. (2010) evaluated the seating position of the HIII 6y crash test dummy compared to the children's preferred sitting postures as seen in the study by Andersson et al. (2010). The child dummy was seated according to three different seating procedures; FMVSS213, the modified FMVSS213 (Reed et al 2003) and the NPACS. Two different types of high back boosters were used.

RESULTS

Real world crash data analyses

In the review by Bohman et al. (2011a) containing 27 cases of rear-seated children restrained by seat belts in frontal crashes who sustained AIS2+ head injuries, three distinct injury causation scenarios were identified. These include head contact with seatback, head contact with side interior, and no evidence of head/face contact, Figure 4.

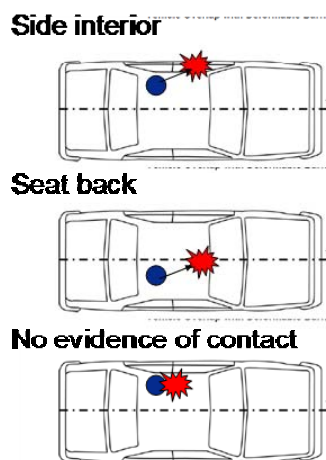


Figure 4. Illustration of injury causation scenarios in the study by Bohman et al. 2011a

Head injuries with seatback or side interior contact typically included a PDOF larger than 10 degrees (similar to IIHS and EuroNCAP offset frontal testing) and vehicle maneuvers. For the seatback contact scenario, the vehicle's movements (due to oblique impacts and/or maneuvers) were likely to contribute to occupant kinematics inboard the vehicle, causing a less than optimal restraint of the torso and/or torso roll-out of the shoulder belt. For the side interior contact scenario, the PDOF and/or maneuvers forced the occupant toward the side interior. The cases without evidence of head/face contact were

characterized by high crash severity and accompanied by severe injuries to the thorax and spine.

In the side impact analysis of MAIS3 to fatally injured rear seat occupants (Bohman et al. 2009), the importance of protecting the thorax against injuries caused by contact with the side interior was revealed. This applied to all occupants four years and older. In fact, it was found that of all MAIS3+ injured restrained occupants 13 years and older, 59% had AIS3+ thoracic injuries and 38% had AIS3+ head injuries. For MAIS3+ injured children, age 4-12, 51% had AIS3+ thoracic injuries and 54% had AIS3+ head injuries. Compared to adults, children sustained less fractures and more lung injuries.

The results of the study of near side impact crashes in which properly children seated in the rear seats were injured are to be published (Andersson et al. 2011b).

The real world crash data analyses lead to increased understanding of the injury patterns and causation in the different crash restraint scenarios so that interventions to mitigate the burden of injury can be further advanced.

Real world driving studies

In the driving study on actual roads with the 3 to 6 years old subjects, using two different types of high back booster designs (Andersson et al. 2010), it was found that the design with large side head supports resulted more often in seating positions without head and shoulder contact with the booster's back, Figure 5.



Figure 5. Examples of sitting postures in the study by Andersson et al. 2010

There was shoulder-to-booster back contact during an average of 45% of riding time in the seat with the large head side supports compared

to 75% in the seat with the small head side supports. The children in the study were seated with the head in front of the front edge of the head side supports more than half the time, in both boosters. Laterally, the children were almost constantly positioned between the side supports of the booster in both seats. The observed seating positions likely lead to reductions in the desired protective effect by the side supports in side impact, and may increase the probability of head impact with the vehicle interior in case of an impact.

For the larger children in the second driving study on actual roads, differences in lateral sitting posture and shoulder belt position could be seen comparing with and without booster usage. The booster helped position the belt at the mid of the shoulder and the sitting postures were more stable for all the children when using boosters as compared to when no booster was used. More details can be found in Jakobsson et al. 2011.

In the maneuver study involving a total of 64 maneuvers with 16 children experiencing two turns in each of the two restraint conditions, mainly the upper body kinematics and belt position on the shoulder was studied. Snapshots of sitting postures before and during the swerving maneuver are shown as an example in Figure 6. The children moved laterally about the same distance regardless of stature or restraint system, however due to initial seat belt position and other factors it resulted in differences of slipping off the shoulder. More details can be found in Bohman et al. 2011b.



Figure 6. Sitting posture before and during the swerving maneuver in the study by Bohman et al. 2011

Further studies will follow within the project evaluating the child passenger kinematics during the braking sequence in the maneuver study.

The real world driving studies provide valuable contribution to the understanding of the real world usage and effect of the restraint systems.

Crash testing and simulations

The full scale side impact tests by Bohman et al. (2009) showed that a side airbag in the rear seat

offers potential for injury reduction for restrained occupants in the crash severities causing the majority of severe injuries in real world crashes. The thoracic side-airbag was shown to reduce the average rib deflection by 50% corresponding to an AIS3+ injury risk reduction from 36% to 3%. At the higher impact speed, a thoracic side airbag reduced the thoracic injury risk from 93% to 24%.

The unpublished oblique frontal impact sled test with the HII 10y resulted in torso roll out similar to the findings by Bidez et al. (2005). When the dummy was pre-positioned in a pre-maneuver positions, as illustrated in Figure 2, it resulted in a torso roll out of the shoulder belt, which was not the case in the same frontal impact situation when the dummy was in a standard seating position. The crash tests also highlighted the difficulty in obtaining the real world kinematics and head impact locations using existing crash test dummies and test procedures. Results from these tests are still to be published providing valuable data for the overall understanding of potential head injury causation mechanisms.

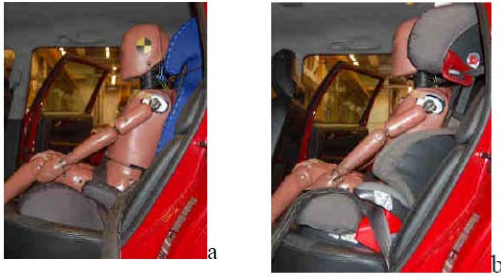
The side impact simulation parametric study reveals valuable insights regarding the vehicle's safety systems (such as the airbags and seat belt pretensioner) effect on the injury measures for both the THUMS 3-year-old and the SIDII models. The results show that the systems play an important role in protecting children as well. More details can be found in Andersson et al. 2011a.

The physical and the virtual crash tests provide valuable contribution to the project for guidelines of protection principles.

Evaluation methods - test tools for small occupants

Several different crash test dummies are used throughout the project, as well as the two FE occupant models, THUMS 3y and SIDII. There are demonstrated areas of improvement needed for these dummies in order for them to adequately represent a real child.

In the study by Bohman et al. (2010), the seating position of the HIII 6y was compared to the preferred sitting postures of child passengers in the naturalistic study by Andersson et al. (2010). The results show that in the high back booster with the small side supports, the children spent 75% of their time in a position similar to the HIII 6y in the same booster positioned according to FMVSS213 (Figure 7a) and NPACS. In the high back booster with the larger side supports, the children spent 45% of their time in a position corresponding to the HIII 6y seating position (Figure 7b). The rest of the time, the children had no contact with their shoulders resulting in their head partly or completely out of the side wings.



Figures 7a-b. The HIII 6y seated according to the FMVSS 213 seating procedure in the two seats, respectively (Bohman et al. 2010)

An ongoing study of the child crash test dummies ability to replicate child passengers' kinematics in the maneuver situations will reveal possible improvement areas of the dummies for their feasibility in facilitating dynamic pre-positioning in such events.

DISCUSSION

This project combines a diverse set of methods as well as a broad range of partners in a comprehensive research project (including 3 PhD students) addressing an understudied area of safety – protection of properly restrained young occupants in the rear seat.

The results from this comprehensive multi-stage project offer valuable input to safety system development, dummy design and test methods development. Specifically, the data stresses the need to further investigate the pre-crash situation for the children in the rear seat, including initial belt-fit, the possible effect of pre-crash maneuvers and the challenges of a real world impact direction is rarely pure frontal or lateral.

Real world safety of rear seat occupants, especially children, requires evaluation of protection systems beyond standard crash testing in frontal and side impact conditions. This project explores the complete context of rear seat protection in impact situations ranging from front to side and directions in between, focusing the real world needs for total enhanced safety.

Although several methods are combined in this study, an even deeper and more complex approach is needed to cover the complete spectra within the scope. The results within the project encourage more research efforts in several areas, such as:

- Overcoming the limitations in real world data collection today in determining the influence of possible critical pre-crash events.
- Increased focus on rear seat occupants, including mapping and evaluating effects of sitting postures at time of impact, both in real world data and in testing.

- Driving studies both in normal on-road driving and critical situations to collect more data on the behavior and kinematics of the children in the rear seat.
- The child occupant models and dummies need to better replicate the real world injury causation scenarios. Special challenges apply to the pre-crash phase.

This study summarizes a research project at SAFER (Vehicle and Traffic Safety Centre at Chalmers), where researchers from the industry and universities cooperate with the aim of further improving safety for children (from 3y) to small adults in the rear seat. The project speeds up the safety implementation process due to the interaction between academic and industrial researchers.

CONCLUSIONS

This study summarizes the research activities within a comprehensive multi-stage project of rear seat safety for small occupants.

The real world crash data indicates that several of the injured children, despite being properly restrained, impacted the vehicle interior structure with their head/face resulting in serious injury. This was attributed to oblique crashes, pre-crash vehicle maneuvers or initial poor belt fit.

Crash tests confirmed the importance of proper initial belt-fit for best protection. The crash tests also highlighted the difficulty in obtaining the real world kinematics and head impact locations using existing crash test dummies and test procedures. The parametric side impact simulation studies indicated that the vehicle's occupant protection systems, such as airbags and seat belt pretensioners, play an important role in protecting children as well.

The results from the on-road driving studies illustrate the variation of sitting postures during riding in the rear seat giving valuable input to how representative the standardized dummy seating positioning procedures are. The results from the maneuver driving studies illustrate the importance of understanding the kinematics of a child relative to the seat belt in a real world maneuver situation.

The results help to drive the rear seat safety development in frontal to side impacts by providing knowledge and by identifying important tasks for the research agenda.

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