# Rear seat safety – focusing occupants from 3 years to 5th percentile female in frontal to side impacts, part 2

# Säkerhet för baksätet – fokus på åkande från 3 år till 5e percentilens kvinna i frontal- till sidokollision, del 2

**Public report**


## Project within Fordons- och trafiksäkerhet


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# Content

# 1. Summary

The overall objectives are to reduce the number and severity of injuries of forward facing children (from 3-4 years old up to small adults) in the rear seat of passenger vehicles. This project follows on a prior project (FFI 2009-01458) and aims at further enhance the safety of booster-seated children (aged 4-12) and small adults in the rear seat of passenger cars. The focus was real-world aspects of child safety, comprising the whole context of the vehicle and child restraints, and a variety of crash situations, including pre-crash events.

Real children sit in a variety of sitting postures in cars. On-road driving studies show that children take different postures due to comfort, visibility or activities. The results from three studies with 18 children in a variety of restraints (performed within this and the prior project), showed that for only a portion of the time, they are sitting upright with contact to the seatback, i.e. similar to the standardized crash test dummy position.

Approximately 40% of the crashes are preceded by evasive maneuvers. When exposing child volunteers to evasive braking they will move forward by up to 0.2m, when shoulder belt remains on the shoulder. Child volunteers were exposed to evasive braking and steering events, using different types of boosters. Depending of the size of the child and the booster used, they might slide out of the shoulder belt in steering events. The volunteer data was also used to validate an active child Human Body Model, as a first step to develop a tool that can be used for evasive maneuvers.

The booster is essential for the child enabling good interaction to the seatbelt. In addition, the vehicle protection systems play an important role for the child protection. Hence, for enhancing real-world safety it is essential to replicate in-vehicle situations. Unfortunately, this is not how child restraints are certified today.

This project demonstrates that child crash test dummies benefit from side airbags and advanced seatbelt technologies. In addition to the in-crash protective systems evaluated in this project, pioneering maneuver and run-off-road tests with crash test dummies were analysed to evaluate the effect of an electrical reversible seatbelt retractor (pre-pretensioner) to help keep the occupant restrained by the seatbelt during such an event.

International multidisciplinary workshops were held and concluded, among other things, that future advancements need to be data driven and incorporate multiple disciplines. Engineering advancements should strive towards less complex solutions and the shared responsibility between the child restraint and the vehicle was highlighted.

The results from this project contribute to identification and quantification of important real-world needs, as well as evaluation and development of countermeasures. It is concluded, that from a real-world perspective, the vehicle and child restraint should be designed together targeting a range of acceptable common user positions; sitting postures preferably guided by comfort and positive means. Such designs will ensure robust function of the protection systems for these young occupants, and advance the development of countermeasures that protect children in real-world crashes, also including dynamic events prior to a crash.

# 2. Sammanfattning på svenska

Det övergripande syftet med projektet är att reducera antalet dödade och svårt skadade barn och små vuxna, som sitter i baksätet i passagerarbilar. Detta projekt följer på ett tidigare projekt (2009- 1458) och syftar till att undersöka och kvantifiera behoven för skydd av barn och små vuxna åkande i bilens baksäte, med fokus på barn som använder bältesstol eller bälteskudde tillsammans med bilens bälte (4-12 år), för att driva utvecklingen inom området riktad mot riktiga barn i verklig trafik. Ett delsyfte är också att verka för att Sverige bibehåller sin ledande roll inom barnsäkerhet.

Till skillnad från krockdockor vid krockprov, sitter barn i en mängd olika sittställningar i bilen. Utförda körstudier på väg visade att faktorer såsom komfort, sikt och aktiviteter påverkar deras sittställning. Resultat från tre körstudier med totalt 18 barn (från detta och det föregående projektet) visade att barnen endast under en begränsad del av resan sitter i den upprätta sittställningen som krockdockan placeras i vid krockprov av barnskydden.

Ungefär 40 % av krockarna föregås av en kraftig manöver (sväng, inbromsning eller båda). I projektet utfördes manöverstudier med barn i olika skyddssystem, som utsattes för kraftiga svängar och inbromsning. Vid en inbromsning rörde sig barnen c:a 0,2m framåt, då de hade bältet korrekt över axeln. Vid en kraftig styrning rörde sig barnen sidledes, olika mycket beroende på storlek på barnet och typ av skyddssystem. I vissa fall gled barnen ur diaongalbältet. Inom projektet skapades även en första version av aktiv barndatormodell för att undersöka utmaningarna inom det området.

Bältesstolen eller bälteskudden är nödvändiga för att barnet skall få en bra interaktion med bilbältet. Krockprov utförda inom projektet visar att bilens skyddssystem är viktiga för att skydda barnet. Det är tydligt att barnen liksom vuxna gynnas av avancerad bältesteknik såsom bältesförsträckare både i frontalkollision och i sidokollision. Projektet har även utvärderat potentialen i reversibla bältessträckare som kan aktiveras innan en krock. Banbrytande prov med krockdockor i svängar och avkörningssituationer visade att dessa kan hjälpa barnet i baksätet att sitta kvar inom bältets skyddande område.

Centrala slutsatser från projektet för att möta behoven inom verklig trafik är att det är viktigt att återskapa bilmiljön så realistiskt som möjligt vid utvärdering av barnens extra skyddssystem. Tyvärr är det inte så det sker idag, och detta projekt har bidragit till att lyfta upp denna fråga internationellt. Likaså är det viktigt att förstå verkliga barns beteende i bil under färd och vid kraftiga manövers för att kunna möta upp behoven av deras skydd vid en krock. Trenden för större bältesstolar och deras framträdande huvudsidostöd påverkar barnets sittställning och ökar behovet av bilens skydd.

Projektet har haft tät interaktion med internationella forskar representerande en stor bredd av kompetenser. Slutsatser från gemensamma workshops lyfter fram utvecklingen av barnskydd skall sträva mot minskad komplexitet och att hela systemet av bil och barnskydd måste inkluderas inom barnsäkerhet.

# 3. Background

Child restraint systems are effective in reducing fatalities and severe injuries among child passengers. The smallest children are optimally protected using rearward facing child seats, while children from approximately age 4 years can use the vehicle seatbelt. However, these older children need to use boosters to adapt to the seatbelt designed for the adult population (Reed et al. 2008). Specifically for children, the increased usage of transportation modes, such as taxis and car sharing, will require flexible and easy-to-use solutions in order to maintain high protection.

Belt-positioning booster cushions were introduced in the late 1970s as a Swedish innovation (Norin et al. 1979). The booster elevates the child, and positions the lap part of the vehicle seatbelt over the thighs, which reduces the risk of abdominal interaction with the lapbelt. In addition, the booster encourages the children to sit comfortably with their legs, helping to avoid slouching and increasing the likelihood of good seatbelt geometry (DeSantis Klinich et al. 1994). Other advantages of boosters are that the child, by sitting higher, will have the diagonal part of the seatbelt more comfortably positioned over the shoulder and will also have a better view.

Today, an increasing number of boosters have backrests (so called booster seats or highback boosters). The backrests were initially intended to provide head support in cars without head restraints, and to help route the diagonal part of the seatbelt over the child's shoulder and chest. In recent years, the designs of the backrests have evolved towards large side supports both at the height of the torso and the head. The child restraint manufacturers emphasize two reasons for this; to provide improved side impact protection and to provide comfort for children by keeping them upright when relaxed or asleep (Bendjellal et al. 2011).

Integrated (built-in) boosters were developed in order to simplify usage and to minimize misuse (Lundell et al. 1991). This was confirmed by Osvalder and Bohman (2008) providing evidence that misuse was almost eliminated when using these types of boosters. In 2007, a second generation integrated booster was introduced providing two levels in height, adapting to the growing child (Jakobsson et al. 2007).

Several parts of the world are banning booster cushions, claiming lack of head protection in side impacts. The Australian regulation, as well as the UN ECE R129 type approval require protruding head side supports to pass the side-impact rig-test method – a method that does not include real-world vehicle protection characteristics. Recently, an amendment to UN ECE R44 was added requiring all newly approved booster cushions (without backrest) to be forbidden for children below 125cm in stature.

Over the years, an increase of booster usage is seen globally. In Sweden, the main increase in child restraint usage (including boosters) occurred during the 1980s, and was a result of increasing child restraint availability, introduction of rear seat seatbelt laws, and intense and unanimous public education and communication activities (Jakobsson et al. 2005). In 2007, a child restraint usage law came into effect, requiring all children of stature up to 135cm in Sweden to use an appropriate child restraint system.

The children in the rear seat also benefit from seatbelt technologies such as pretensioner and load limiters. Sled tests using a HybridIII (HIII) 6y crash test dummy showed that retractors with belt load limiting and pretensioning resulted in reduced head, neck and chest loading as well as decreases in forward displacement (Bohman et al. 2006, Forman et al. 2009). The results emphasized the need to adapt the load limiting level to the size of the occupant.

# 4. Purpose, research questions and method

Improving safety for rear seat passengers requires enhanced knowledge in several areas involving multiple disciplines. This joint research project aims at further enhance the safety of booster-seated children (aged 4-12) and small adults in the rear seat of passenger cars, addressing child and rear seat occupant protection beyond standardized crash testing scenarios. The purpose is to provide knowledge on real-world safety developments, providing state-of-art knowledge and helping to set the agenda for future research and developments. In addition, the purpose is to provide a widened international network and a competence sharing platform to the involved partners in the field of child safety and rear seat safety in particular, and occupant safety, biomechanics, and accident analysis in general.

The research questions address

- How do the current real-world situations look like for children involved in car crashes regarding fatalities, long-term consequences and in terms of pre-crash events?
- What are the natural behaviour patterns of children during riding in cars and what does it mean in terms of sitting postures and activities?
- What is the effect on children's kinematics and restraint interaction when they are exposed to pre-crash manevuers?

Various methodologies of applied research are included, comprising real world crash data analysis and driving studies with children, in addition to testing and simulations, evaluation and development of tools, and international coordination of knowledge around these topics.

This project is a continuation of the successful work from a preceding project (FFI 2009-01458), adding to the publications and PhDs serving as the basis for the Swedish research platform in the area of rear seat safety. A summary of the project was presented and published at the ESV conference 2017 (Jakobsson et al. 2017).

## Real-World Crash Data

Real-world crash data was analyzed to provide insight into areas of importance for child occupant protection. Studies within the preceding project (FFI 2009-01458) included investigations of potential head injury mechanisms for restrained forward facing children in the rear seat (Bohman et al. 2011a) and investigations of injured children in side impacts

(Bohman et al. 2009, Andersson et al. 2011). These studies are also summarized in Jakobsson et al. (2011a).

Within this project, additional four real-world crash data studies were performed; addressing different topics which all provide input to enhance the safety of children in cars.

**Child occupant fatalities in Sweden** Child car occupant fatalities in Sweden were summarized over a time period of 55 years (Carlsson et al. 2013). Four different data sources were used, enabling inclusion of all crash-related fatalities among 0–14 year old car occupants during 1956–2011. The data was summarized to study the development of child safety over the years. Based on in-depth data from 1992-2011, the characteristics of the crash and the injuries were investigated, including crash direction, restraint use, crash opponent and injured body region.

**Long-term consequences** Insurance data was used to study injuries with long-term consequences to children aged 0-12 (Bohman et al. 2014). Data included reported car crashes from 1998 to 2010 with at least one injured child. 2619 injured children with 3704 reported medical diagnoses were included. If the child had not recovered within one year after the injury, medical specialists made an assessment of the degree of permanent medical impairment (PMI).

**Pre-crash maneuver occurrence** Pre-crash maneuvers and some causation factors of serious motor vehicle crashes involving child passengers were quantified by Stockman (2016, paper I). The National Motor Vehicle Crash Causation Survey (NMVCCS) conducted by the National Highway Traffic Safety Administration (NHTSA) between July 2005 and December 2007 was used. NMVCCS identified pre-crash factors via investigation of vehicles and crash scenes, and structured on-scene interviews with crash participants. The critical reason for each crash was assigned to a single driver, vehicle or environmental factor. The selected sub-samples for the study by Stockman (2016, paper I), included 841 (weighted 308,743) drivers with at least one child passenger, and as a point of reference; 5,661 (weighted 2,209,082) single drivers, and 1,544 (weighted 537,787) drivers with only passengers older than 14.

**Restraint usage in Sweden** Using Volvo Cars Accident database on crashes with Volvo cars in Sweden, information on restraint usage for 4-10 year old children was analyzed (Jakobsson and Lindman, 2015). The years 2000–2013 were selected enabling comparison before and after the introduction of the restraint usage law in 2007 for children up to 135cm.

## Driving Studies with Children

As an important input to understand child occupant protection, studies with children riding in actual vehicles were performed. Specifically, the sitting postures, kinematics and behaviour of children were monitored while riding in the rear seat, both in a **naturalistic driving study** and rigged studies **on roads** and on a test track with extensive braking and turning **maneuvers**.

**Naturalistic driving study (NDS)** In a joint project together with Monash University, a NDS was conducted (Charlton et al. 2013, 2016). The study included 42 families and 81 child passengers aged 1-8. Each family drove the test vehicle for 2 weeks. Video recordings were made on the rear seat occupants, the driver and the surrounding traffic. For a subset of 18 families with 35 child passengers, a Kinect camera captured motion data from which head position coordinates were derived (Arbogast et al. 2016).

**On-road driving studies** One study was made within this project, complementing two prior studies performed during the preceding project, adding to the aim to increase the understanding of the natural behaviour of children during a car ride. In these three studies, sitting posture and behaviour of in total 18 children were monitored with video recordings while riding in the rear seat using different types of child restraints. Specifically, the aim was to identify the preferred sitting postures and the seatbelt positions relative to the torso using a selection of different types of restraints, as shown in Figure 1.

*Figure 1. Child restraints used in the on-road driving studies.*

*Left; the two booster seats used in Andersson et al. (2010). Middle: the booster cushion used in Jakobsson et al. (2011b). Right; the integrated boosters and the booster seat used in Osvalder et al. (2013).*

The first study was conducted to investigate the effect of booster seat backrest designs on the choice of children's sitting postures (Andersson et al. 2010). Six children (3-6 years old, 90-125cm) were monitored when taken for a ride on a pre-determined trip for 40-50 minutes for each booster seat type; one with smaller head side supports (10.5cm) and no torso side supports, and the other with larger head (20cm) and torso side supports, see Figure 1. The second driving study was performed to identify the preferred sitting posture and the seatbelt positions relative to the torso of children (8-13 years old, 135-150cm) when restrained with and without a booster cushion (Jakobsson et al. 2011b, Figure 1). Six children were monitored when traveling about 40 minutes in each of the two different restraints.

The third study (performed within the present project) included six children (7-9 years old, 130-145cm), who travelled one hour on an integrated booster (IBC) and one hour on a booster seat (Osvalder et al. 2013, Figure 1).

For all the 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. The duration of each sitting posture that each child assumed for one second or longer was quantified, and their activities were documented. In addition, in the second and third study, the shoulder belt position relative to the torso was categorized and the duration the shoulder belt remained in each position was quantified. In the third study, subjective data regarding discomfort and attitudes was also collected from questionnaires and interviews.

**Maneuver studies** Kinematics and seatbelt position during evasive braking events and steering maneuvers were quantified for 34 children (Bohman et al. 2011b, Stockman et al.

2013a, Baker et al. 2017a and 2017b). Using the same passenger car (Volvo XC70, MY 2010), two studies comprising different types of restraint systems were performed. The studies were conducted on a closed-circuit test track. The child was restrained in the right rear seat. While traveling at a velocity of 70 km/h, the professional driver applied full braking and while driving at 50 km/h the driver quickly turned the vehicle 90 degrees to the right, exposing the child to a forward or inboard motion.

In the first study, performed during the preceding project, 16 children aged 4-12 years old were included (Bohman et al. 2011b, Stockman et al. 2013a). The restraint of the children varied according to their stature, each child tested two types of restraints in both braking and steering events. Children of 105-125 cm stature were using booster seat or booster cushion. Children of 135-150cm were using the booster cushion or seatbelt only.

The second study comprised 18 children aged 5-10 (Baker et al. 2017a and 2017b). The children were restrained using two different boosters; the booster cushion as in the prior study, and the vehicle's integrated booster. All children were exposed to both braking and steering events using each restraint.

For the two studies, the children were monitored by video cameras, enabling quantification of the sagittal and lateral child kinematic response as well as quantification of the shoulder belt position throughout the event.

## Testing and Simulations

With the aim of evaluating different restraint properties, protection principles, and capabilities of existing test tools; physical crash testing and virtual crash simulations and low-severity / maneuver tests were conducted and analyzed.

**Crash testing and simulations** A number of frontal and side impact crash tests were performed with different sizes of child crash test dummies in the preceding project and presented previously in Jakobsson et al. (2011a). In addition, a side impact parameter study using virtual crash simulations for two sizes of occupants was presented in Jakobsson et al. (2011a) and Andersson et al. (2012). The side impact parameter study was followed by a simulation study using the SIDIIs on the struck side in the same passenger car model, including head and thorax–pelvis air bags (Andersson et al. 2013). The vehicle model was impacted laterally by a barrier in two different load cases. The crash test dummy was chosen to be representative of a young adolescent and positioned in six different sitting position representing common sitting positions for awake and asleep children.

A number of crash tests were run with the Q10, investigating its capabilities as well as evaluating the performance of restraint properties. Seven frontal sled tests simulating the EuroNCAP ODB 64 km/h (full frontal mounted mid-sized car body) and seven side impact tests simulating EuroNCAP AE-MDB tests (small vehicle, intruding door velocity of 7.5m/s), were performed (Bohman and Sunnevang, 2012). The Q10 was tested using a booster seat and booster cushion, respectively. In the frontal impact tests, the effect of seatbelt pretensioner, load limiter and various belt geometries, were evaluated. In the side impact tests, the effect of the thorax side airbag and the inflatable curtain was evaluated (Bohman and Sunnevang, 2012).

To investigate the influence on occupant excursion of a far-side positioned Q6, a sled test series were run simulating the EuroNCAP AE-MDB side impact test of a Volvo car. In four tests, the Q6 was restrained using an integrated booster (upper stage), with and without activation of the seatbelt pretensioner (two tests of each). In two additional tests, the Q6 was restrained using a booster seat (Britax Kidfix XP) with and without fixation (ISOFIT) to the ISOFIX anchorages.

**Low-severity / maneuver tests** Non-injurious frontal impact tests were performed comparing the shoulder belt and torso interaction of the Q10 to the behaviour of the HybridIII (HIII) 10y and three child volunteers (Arbogast et al. 2013a). The test set-up included a seat with a three point belt on a low acceleration sled.

With the purpose of evaluating the capability of the crash test dummies to replicate kinematics and restraint interaction of real children in evasive steering and braking events, crash test dummies were exposed to the same maneuvers as the children in the maneuver studies (Stockman 2012, Stockman et al. 2013a and 2013b). The Q6, Q10, HIII 6y, and 10y were exposed to two braking events and two steering events using the same restraints as the children of their size. The Q6 and HIII 6y were compared to the kinematic response of children of stature 105–125 cm. The Q10 and HIII 10y were compared to children of stature 135-150cm. In addition, the Q3 and HIII 3y were exposed to two braking events and compared to the kinematic response of the shorter child volunteers (105–125 cm).

To evaluate potential countermeasures, steering maneuvers and run-off road events were run with Q6 and Q10 (both using integrated boosters) and the HIII 5th female (restrained by a seatbelt only), to compare the effect of activation of an electrical reversible seatbelt retractor (pre-pretensioner) (Bohman et al. 2016, Stockman et al. 2017). In the study by Bohman et al. (2016), the crash test dummies seated on the outboard rear seat position were exposed to an evasive steering maneuver when driving in 40km/h causing an inboard movement of the crash test dummy. In Stockman et al. (2017), two different types of run-off road events were simulated using a rig test with a vehicle rear seat mounted on a multi-axial robot simulating a road departure event into a side-ditch, and an in-vehicle test setup with a Volvo XC60 entering a side-ditch with a grass slope, driving inside the ditch, and returning back to the road from the ditch. The crash test dummies were positioned in the outboard rear seat position. In both studies, tests were run with different levels of pre-pretensioner forces in addition to reference tests with the pre-pretensioner inactivated. Kinematics and shoulder belt position were analyzed.

## Development of tools

Brolin et al. (2015) implemented postural control in the MADYMO human facet occupant model of a 6-year-old child (Cappon et al. 2007) using feedback controlled torque actuators. Control parameters were tuned and the active HBM was compared to the experimental data from braking and steering events with child volunteers. In addition, a small parameter study was run to study the influence on occupant response by the shape of the acceleration pulse in steering events.

### International Coordination of Knowledge

International multidisciplinary workshops were held to identify high-priority research topics and strategizes toward their implementation. The workshops started in 2009 and have been held every second year in September, hosted by the project team and SAFER. The participants of the workshops were worldwide leaders in the fields of child occupant protection, biomechanics and auto safety. The overall structure for the two-day workshops was as follows: the first day included presentation of relevant topics with the focus on 'pressing issues in child and adolescent occupant protection' in addition to reviewing progress of research priorities identified during previous workshops, and during the second day discussions on high priority areas as defined based on the first day discussions. An important part was to summarize and present the workshop discussions at the International Conference Protection of Children in Cars in Munich, enabling a wider dissemination and contributing to setting the agenda of future research and development (Arbogast et al. 2011, 2013b, 2015 and 2017).

# 5. Objective

The overall objectives are to reduce the number and severity of injuries to forward facing children (from 3-4 years old up to small adults) in the rear seat of passenger vehicles, and to help maintaining Sweden as a hub for child safety research, contributing to setting the global agenda of child safety.

The project aimed to further enhance the safety in the rear seat by identifying the real-world needs, also taking restraint interaction and attitude aspects into account. More specifically, the targets were to establish guidelines for evaluation methods and protection principles also including the influence of kinematics and behaviour of a child during normal car riding and in manoeuvre situations. More so, it targeted to summarize and disseminate state-of-art knowledge contributing to setting future research and development needs, influencing vehicle and child restraint designs as well as future standards and regulations.

# 6. Results and deliverables

The combination of methods provide real-world knowledge on child occupant safety in the rear seat, including input from real-world crashes, child postures and behavior in cars and insight into child kinematics in crashes and during potential pre-crash events. Efforts of evaluation and development of tools to simulate realistic child occupant situations are taken, which are essential steps to make possible evaluation and further development of protection principles for the booster seated children in the rear seat of passenger cars. Selected results from the different studies are summarized.

## Real-World Crash Data Analysis

**Child occupant fatalities in Sweden** With the exception of initial increase during the first 10 years (mid 1950s to mid 1960s), crash-related fatalities among 0–14 years old car occupants have been declining ever since (Carlsson et al. 2013). Compared to the highest numbers of fatalities occurring in 1960s–70s, a drop of 83% was seen to 2010 with similar trend irrespective of the age of the child. This is a higher percentage decrease than the corresponding figure of 78% for the whole population, irrespective of age. In total, 24% of the fatally injured children were unrestrained and the majority of those were ejected from the vehicle. Among the restrained children, 56% were considered to be appropriately restrained for their age according to Swedish recommendations. Crash severity, complex crash situation, fire and drowning were factors that contributed to the fatal outcome, even though the restraint usage was considered to be optimal. The head was the primary injured body region.

**Long-term consequences** Among the injured children, 2% sustained an injury resulting in permanent medical impairment (PMI), of which 75 percent were at AIS 1 or AIS 2 level (Bohman et al. 2014). 68% of all injuries resulting in PMI were AIS 1 injuries to the cervical spine, with the majority occurring in frontal or rear-end impacts. The older children (≥6 years) had a significantly higher risk (3% versus 1%) to sustain a PMI injury to the cervical spine than the younger children. The head was the second most commonly injured body region for injuries resulting in PMI, which were predominantly of AIS≥2. In addition, mild traumatic brain injuries at AIS 1 were found to lead to PMI.

**Pre-crash maneuver occurrence** Of all drivers in the selected sample, 40% made an avoidance maneuver prior to crash (Stockman 2016, paper I). The most common avoidance maneuver was braking only, followed by a combination of braking and steering, and steering only. In all three sub-samples, driver error was the single most important critical reason for the event immediately preceding the crash. Of the driver errors, inadequate surveillance was the most common error in all groups followed by internal distraction. While passengers were the most common reason for internal distraction for drivers with child passengers and drivers with only passengers older than 14 sub-samples, single drivers were assigned internal distraction error, mainly due to focusing on other internal objects, retrieving objects from the floor or seat, or adjusting the radio.

**Restraint usage in Sweden** Jakobsson and Lindman (2015) summarized data from Volvo cars in Sweden showing that the restraint usage rate among 4-10 year old passengers (up to 135cm) increased from 63% on average during the six years before the law, to 79% on average for the six years after (2007-2013). The remaining 21% were using the seatbelt only, although they were both required by law to use a booster as well as needing it for their best protection.

## Driving Studies

It is obvious that children do not always sit as crash test dummies, which are ideally upright positioned according to seating protocols prior the crash tests. The children’s sitting postures and positions are influenced by comfort and activities (voluntary) as well as vehicle dynamics (involuntary), such as evasive maneuvers.

**Naturalistic driving study (NDS)** In the joint project with Monash University (Charlton et al. 2013, 2016), the ranges of head positions for child car passengers were quantified for the first time in a naturalistic setting. Head positions were analyzed for the subset of 35 children with available Kinect data (Arbogast et al. 2016). The average range of fore-aft head position changed with restraint type; increasing from forward facing child seats (218mm), to booster seat (244cm), to seatbelt only (340 mm). In general, those in the center seat position demonstrated a relatively smaller range of head positions. A shift of head position inboards the vehicle was seen, mainly due to interaction with other occupants and to view out through the front window.

**On-road driving studies** In the first on-road driving study (Andersson et al. 2010), the booster seat equipped with large head side supports more often resulted in a sitting posture without the head and shoulder being in contact with the booster's backrest, and consequently the head being further away from the seat backrest. This was probably due to decreased visibility as a result of the large side supports. Shoulder-to-booster backrest contact was noted during an average of 45 percent of the journey time in the seat equipped with the large head side supports, compared to 75 percent in the seat equipped with the small head side supports.

In the second study (Jakobsson et al. 2011b), the shoulder belt was placed on the mid shoulder for a substantially longer part of the time when seated on the booster cushion, compared to using the seatbelt only, see Figure 2. Furthermore, all children were positioned in a more upright lateral posture for a greater extent of time, when using the booster cushion. When using the seatbelt only, the children changed body posture more frequently, and some children compensated for discomfort by rotating their upper body away from the shoulder belt.

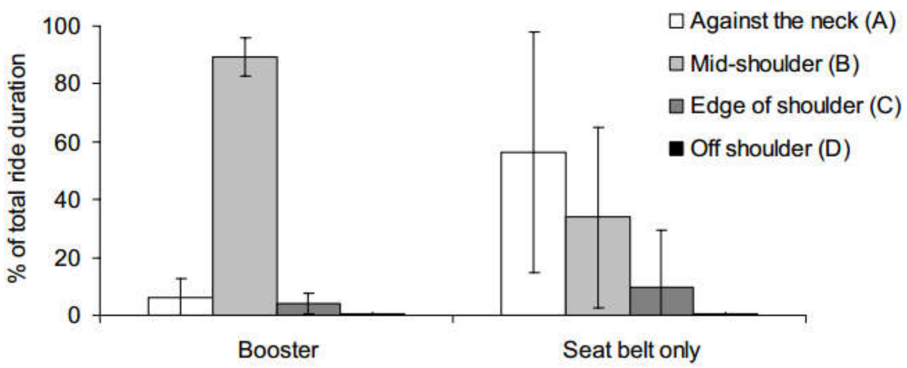



*Figure 2. The distribution of shoulder belt position durations, shown as a percentage of the total ride duration. The averages (incl. standard deviations) of all children are presented by restraint type (Jakobsson et al. 2011b).*

In the third study (Osvalder et al. 2013), the most frequent sitting posture when using the integrated booster was with the entire back and shoulders against the seat backrest and the head upright. When seated on the booster seat, the shoulders were seldom against the backrest. The most frequent lateral posture for both boosters was upright with the seatbelt in contact with the neck or mid-shoulder. Moderate and extreme forward and lateral postures occurred occasionally. The sitting postures and seatbelt positions were influenced by the children's activities and perceived discomfort during the ride. Some examples are shown in Figure 3.

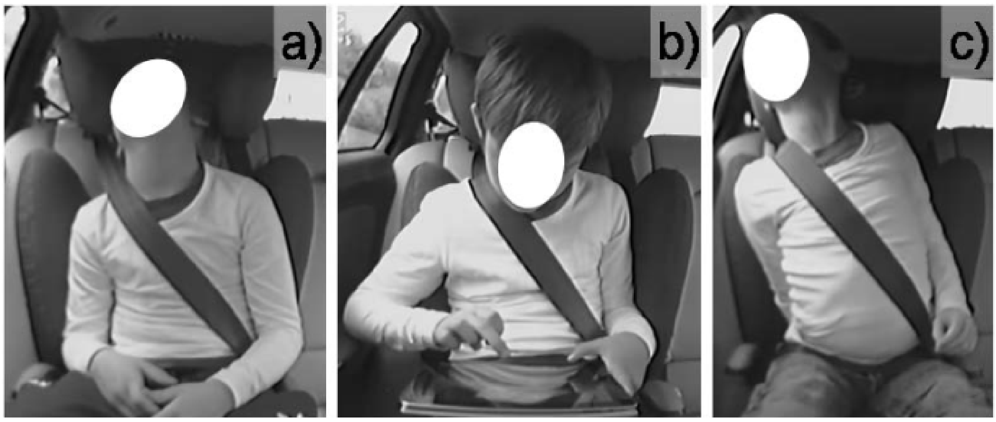



*Figure 3. a) An example of sleeping posture, b) a forward leaning and slightly rotated posture while playing, c) Indication of some discomfort (Osvalder et al. 2013).*

**Maneuver studies** The kinematic responses and seatbelt interaction of the child volunteers were influenced by the size of the child and the restraint system used.

During the braking events, shorter children moved forward and downward with a greater flexion motion of the head compared to the taller children who had a more upright forward motion (Stockman et al. 2013a, Baker et al. 2017a). The children moved forward by up to 0.2m, when the shoulder belt remained over the shoulder. A schematic plot, representing the trajectories or the child volunteers in Stockman et al. (2013a), is shown in Figure 4. The backrest of the booster seat affected the initial position of the child relative to the vehicle and thus resulted in a more forward position at maximum displacement. For all the children, the maximum forward head position was forward the position of the booster seat's side supports.


*Figure 4. Schematic plot representing trajectories for forehead targets for child volunteers (Stockman et al. 2013a).*

In the first test series with steering maneuvers (Bohman et al. 2011b), the seatbelt slipped off the shoulder in 20% of the maneuvers, varying by age of the child and the restraint system used. Among the shorter children, shoulder belt slip-off occurred in almost 67% of the trials when using a booster cushion while for taller children belt slip-off did not occur, irrespective of restraint type use.

In the second maneuver study (Baker et al. 2017b), initial seatbelt position on the shoulder and torso differed depending on booster and child size, which influenced how children engaged with the seatbelt during the steering. When a larger portion of the seatbelt was initially in contact with the torso, children tended to engage the seatbelt more, causing the belt path to become more curved; they moved with the seatbelt and tended to have less inboard head displacement and less outboard motion of the seatbelt on the shoulder.

## Evaluation and Development of Tools

The tests performed provided important insight into some limitations of the existing tools, and set the boundary for their use. Although existing crash test dummies were found feasible to use as loading devices during evasive maneuvers while in the restraints, developments of child occupant tools capable of simulating events when muscle activation influences the kinematics are needed. Development of an active child Human Body Model was made and showed potential as a first step approach.

**Crash testing and simulations** In frontal impacts, the Q10 was shown sensitive to belt pretensioning, with activation of the pretensioner reducing acceleration to the head, thorax and pelvis by 13-27%, but having a marginal effect on chest deflection (Bohman and Sunnevång, 2012). The Q10 was also shown sensitive to the combination of load limiter and pretensioner, further reducing head and thorax acceleration. Compared to a standard seatbelt, neck tension was reduced by half and chest deflection was reduced up to 37%. Among the parameters evaluated, the Q10 was most sensitive to shoulder belt geometry. Depending on starting position, various shoulder belt slippage occurred. As a consequence of shoulder belt slippage, large effects on chest deflection were found. With the shoulder belt starting at a mid-shoulder position, it travelled towards the neck during the crash, resulting in low chest deflection. However, if the shoulder belt's starting position was 20mm further out on the shoulder from a mid-shoulder position, the chest deflection response increased by 50% compared to the mid-shoulder routing.

In the side impact sled tests, it was found that the Q10 was sensitive to the thorax side airbag, showing a reduction between 50-65% for chest deflection and 17-25% for pubic loading (Bohman and Sunnevång, 2012). Using the booster seat in combination with no thorax side airbag, chest injury risk reduction was not seen, although pubic loads were reduced by 18%.

**Low-severity / maneuver tests** In the non-injurious sled tests, it was found that for the two crash test dummies (Q10 and HIII 10y) and the child volunteers, the shoulder belt moved toward the neck during the loading (Arbogast et al. 2013a). The magnitude, as well as the rate of the shoulder belt movement, was greatest for the Q10. This may result in an underestimation of chest deflection when using Q10, due to off-loading the chest deflection sensor. Further studies with other belt geometries and crash modes should be explored to confirm these findings.

*Figure 5. Maximum forward displacement of child volunteers (top), Q6 (bottom left) and HIII 10y (bottom right) kinematics in evasive braking maneuver of 1g.*

The comparison of crash test dummies to the child volunteers in the evasive steering and braking events, showed that the crash test dummies can be used in some load cases when the test setup, the time duration, and the focus of comparison with child occupants lies within their capacity (Stockman 2012 and 2016, Stockman et al. 2013a and 2013b). The capacity of the crash test dummies to replicate the kinematic responses of child occupants is limited due to the crash test dummies being too stiff and due to their obvious lack of muscle response, as illustrated in Figure 5. It was found that they can be used as a loading device for the seatbelt and booster, when the shoulder belt is on the shoulder. However, they are limited when out of the protective zone offered by the restraint. The crash test dummies were found not suitable for determining realistic child responses nor to determine the location of the head.

**Development of tools** The active child Human Body Model (HBM), developed based on the MADYMO human facet occupant model of a 6 year old child showed potential to study the protective properties of restraint systems in pre-crash scenarios (Brolin et al. 2015). The head and sternum displacements of the active child HBM were within one standard deviation of the experimental data, while the original HBM showed limited ability to capture the volunteer kinematics. Figure 6 shows the active child HBM compared to volunteers at start and at maximum head displacement for a 1g braking event (Stockman et al 2013a), a 0.8g steering event (Bohman et al. 2011b), and a 0.6g steering event (Baker et al. 2017b). The parameter study on steering event characteristics illustrated that the shape of the acceleration pulse highly influences the peak head displacement of child occupants.

*Figure 6. The active child HBM compared to volunteers at start and at maximum head displacement for a braking event (top row), a 0.8g steering event (middle row), and a 0.6g steering event (bottom row), (Brolin et al. 2015)*

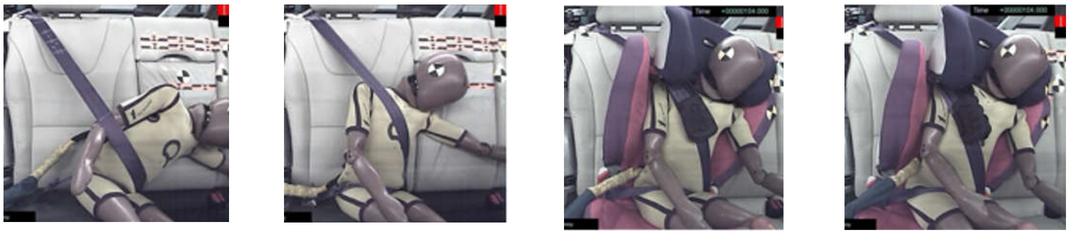
## Evaluation of countermeasures

It is clear that methods beyond existing regulatory and consumer information tests provide additional information needed to evaluate countermeasures addressing real-world needs. Varying sitting postures and positions in crash testing (or simulations) as well as including complex events will help guide development of protection principles for real world situations.

**Crash testing and simulations** The side impact simulation parametric study presented by Andersson et al. (2012) concluded that the head and thorax-pelvis airbags have the potential to reduce injury measurements for the 3 and 12 year old occupant sizes evaluated. The seatbelt pretensioner was also shown effective for the near side occupants, provided that the lateral translation of the torso is managed by other features. It was also concluded that the importance of lateral movement management is greater the smaller the occupant.

The results from the side impact simulations with different sitting positions on the near-side, showed the importance of including real-world common sitting positions, beyond the nominal crash test dummy position, for improved and robust safety for child occupants (Andersson et al. 2013). The results differed for the different positions, with negative trend of protection when deviating from the nominal position.

Side impact crash tests with the Q10 positioned on the struck side, showed that the thorax side airbag reduced the chest deflection by 50-65% and the pubic loading by 17-25% (Bohman and Sunnevång, 2012).



***no pretensioner, IBC*** | ***pretensioner, IBC*** | ***pretensioner, booster seat without ISOFIT*** | ***pretensioner, booster seat with ISOFIT.***

*Figure 7. Maximum lateral excursion of the Q6 in side impact*

The in-house EuroNCAP side impact sled tests with the far-side seated Q6 showed that activation of a seatbelt pretensioner had a substantial effect, reducing maximal lateral head excursion by 230mm (Figure 7, Jakobsson et al. 2017). No difference in extent of lateral head excursion were seen when comparing IBC and booster seat, irrespectively if attached to the ISOFIX or not. The Q6's head reached further inboard when using the booster seat, due to differences in starting positions.

Although it is not clear whether the Q10 seatbelt interaction is reflective of the real-world, the frontal impact crash tests by Bohman and Sunnevång (2012) provided insights into the overall benefits of pretensioner and load limiters for this size occupant, showing reduction to the loading of the head, neck and chest.

**Low-severity / maneuver tests** The effect of a seatbelt pre-pretensioner to help keep child sized crash test dummies in position in run-off road events and evasive steering maneuvers was shown in Stockman et al. (2017) and Bohman et al. (2016).

In the study with evasive steering maneuvers, the shoulder belt slipped off completely with inactive pre-pretensioner for the Q6 and the HIII 5$^{th}$ female, and partly slipped off for the Q10 (Bohman et al. 2016). When activating the pre-pretensioner, the shoulder belt stayed on the shoulder for all three crash test dummies and the inboard lateral excursion was reduced compared to no activation of the pre-pretensioner. Figure 8 compares the maximum inboard position for the three tests of pre-pretensioner settings; inactive, low and high level force.


*Figure 8. Q6 (top row), Q10 (middle row) and HIII 5th female (bottom row) in starting position (left column), and maximum inboard position for the three pre-pretensioner settings (Bohman et al. 2016)*

In the two simulated run-off events, the activation of the pre-pretensioner resulted in reduced lateral excursion of the crash test dummies (Stockman et al. 2017). For all three crash test dummies (Q6, Q10 and HIII 5th female), the shoulder belt remained on the shoulder and supported the side of the lower torso during the events, when the pre-pretensioner was activated, independent of force-level. In the rig test, the crash test dummy was exposed to rapid inboard lateral loads relative to the vehicle and the displacement for each crash test dummy was reduced when the pre-pretensioner was activated compared to tests with standard seatbelt. Shoulder belt slip-off occurred for the Q6 and Q10 in tests where the pre-pretensioner was inactivated. During the in-vehicle tests, the outboard rear seated crash test dummy was exposed to an inboard movement when entering the road again after driving in the ditch. The maximum inboard head displacement was reduced in tests where the pre-pretensioner was activated compared to tests with a standard seatbelt.

## International coordination of knowledge

With the specific goals of the **2011 workshop** to critically review the state of knowledge, and translate the 'Decade of Action' framework to child-specific priorities, high priority research topics were identified and strategies were defined toward their implementation (Arbogast et al. 2011). These included advancing the fundamental science of child occupant protection in several key disciplines and leveraging current knowledge to accelerate child occupant protection in countries where traffic safety is in its infancy. It was also emphasized that the entire field must work together to ensure that child road traffic safety is prioritized in funding decisions.

In the **2013 workshop** the following eight research priorities were identified (Arbogast et al. 2013b):

1. Head injury mitigation
2. Quantify fundamental mechanics of children
3. Develop paediatric specific biomechanical research tools
4. Define realistic postures & positions of child occupants
5. Establish collaboration with rapidly motorizing countries
6. Conduct nationally or regionally representative child crash surveillance
7. Adapt AIS scale to include cost, disability and variations with age
8. Stimulate development of advanced restraints in rear rows emphasizing child occupant protection

As an example of the results of the priority of establishing collaboration with rapidly motorizing countries was the initiation and execution of a joint child safety conference in China together with Shanghai Motor Vehicle Inspection Centre (SMVIC) in Shanghai in October 2014 and 2015.

During the **2015 workshop**, the identified research priorities from 2013 were addressed and advancements were noted (Arbogast et al. 2015). With a future-oriented perspective, five important questions were identified as critical to tackle through informed and engaged dialogue from a variety of stakeholders:

1. How do we best get advanced models and biomechanics data used and accepted?
2. Child occupant protection is currently complex. How do we make typical behaviour safe?
3. Our field primarily focuses on fatalities and serious injuries. Should less severe injuries be prioritized?
4. How do we ensure adequate data collection in emerging markets to address specific needs? What education or innovative technology is needed?
5. How do we ensure existing and emerging restraints are fully evaluated in diverse loading conditions for "real kids" in “real cars”?

It was concluded that future advancements need to be data driven and incorporate multiple disciplines. Engineering advancements for better child restraints should strive towards less complex solutions. The approach should be to take what families do most often and make it safe, and to highlight the shared responsibility between the child restraint systems and the vehicle. In addition, regulation and consumer ratings programs must consider child occupants and follow fundamentals, models and biomechanics knowledge should integrate into restraint design quicker, and new markets may need new solutions.

In the **2017 workshop,** the discussions were dedicated to a future-oriented perspective and identifying particular challenges facing our society to continue to improve the safety of children in cars (Arbogast et al. 2017). Through this multi-disciplinary dialogue, the following five questions were identified and discussed as we thought they were critical to tackle through informed and engaged dialogue from a variety of stakeholders.

1. How do we define the non-nominal cases to focus attention on?

2. How do we make these issues important for people?
3. How to we define the value proposition for safety? How does it vary by people's traits and by situations? How to use to drive design?
4. What are the strategies to make it easier to do the right thing; don't punish them for doing the wrong thing.

Following the workshops in 2009, 2013, 2015 and 2017; a one-day seminar were held including presentations by the international guests and by the project team (SAFER seminars, 2009, 2013, 2015, 2017). Approximately 50-70 people participated in the seminars. The purpose of the seminars was to share state-of-the art research to a wider community, including peer-researchers as well as consumer information specialists.

## Contribution to the objectives of the FFI program

The results of this project has provided knowledge and outreach, which have impacted regulation and consumer information programs, in addition to increasing international awareness and helped to strengthen Sweden as a hub in vehicle safety. By this, the results of this project have contributed to the goal of the Vision Zero of reducing fatalities and injuries in traffic as well as increasing Swedish vehicle industrial competitiveness. Specifically it has impacted child and rear seat car passenger protection, influencing international awareness by providing facts regarding real children in real traffic. Examples are that EuroNCAP decided to use a booster cushion for the Q10, highlighting the importance of vehicle contribution for child passenger protection; and that exemptions for the booster cushion was included for the ECE R129, and not completely banned which was ongoing. Simply, the project's deliverables have made international researchers and authorities aware of the importance of considering the whole context of child safety and not only a single certification of a child restraint. The project has created and disseminated facts to help in this development. This knowledge is of increasing importance when moving towards higher degree of automation and car sharing concepts, without jeopardizing our positive trend towards Vision Zero of reducing fatalities and injuries.

The overall objective of this project was to improve safety of forward facing children (up to small adult size) in the rear seat of a passenger vehicle. The objective was to go beyond the scope of today's global focus within legislation and consumer rating activities and produce results to drive the developments towards real-world child safety needs. This has been achieved by good timing of execution and documentation of ground-breaking studies (eg. driving and maneuver studies) in peer-review journals in combination with conference presentations reaching out and influencing those taking decisions of importantacne for child safety developments.

The combination of partners, including vehicle manufacturer, a safety system supplier, and the academia in collaboration with international connections such as Children's Hospital of Philadelphia (CHOP), Monash University in Australia, EU projects and researchers at University of Michigan Transport Research Institute (UMTRI), Ohio State University and others in USA, comprise a unique and strong combination, including multidisciplinary expertise. Traditionally, child safety work has been carried out in task groups with more narrow expertise and with only indirect possibilities to ultimately influence the car design. The project combined the activities of two PhD students, effectively combining industrial and university based research. The project design facilitated quick feedback into the vehicle industry, involving the main actors of vehicle safety design in Sweden. The design of the car itself with its built-in protective systems is the key to further progress in the rear seat safety, also for smaller occupants. Although small in size in an international perspective, the project has been very successful both in quick and state-of-the art research findings as well as leading the discussions (through international workshops) making an impact on the global agenda for child safety developments.

Internationally, Sweden is respected as a nation with great knowledge, experience and development of child safety. This project has helped to maintain and develop the competence for the partners in the project as well as others from eg. industry, academy and NGOs that can profit from workshops and seminar. The participants in the project have close connection to several international fora, such as ISO working group on Child restraint systems in cars and the informal working group of Enhanced Child Restraint Regulation within UN ECE. The project is a role-model of contributing to and benefiting from the SAFER research environment. The project's context and network are essential aspects, both when addressing reduction of fatalities and injuries in traffic as well as increasing Swedish vehicle industrial competitiveness.

# 7. Dissemination and publications

## 7.1 Dissemination

| How are the project results planned to be used and disseminated? | Mark with X | Comment |
|---|---|---|
| Increase knowledge in the field | x | Significant contribution, exemplified by the amount, variety and novelty of studies, and their publications and outreach by presentations. |
| Be passed on to other advanced technological development projects | x | Project results are used as input to future rear seat developments by the industrial partners. The studies on the effect of seatbelt pre-pretensioners in low severity situations are examples of this. |
| Be passed on to product development projects | x | The results on dummy evaluation and performance have been used in in-house testing and development of vehicles for production. |
| Introduced on the market | x | The project results have been used as input for the design of Volvo Cars' most recent 'comfort covers', sold as accessories for the integrated booster. |
| Used in investigations / regulatory / licensing / political decisions | x | The project results have influenced regulations, ISO-standards and rating tests (eg EuroNCAP) |

**<u>Examples of dissemination</u>** in addition to the publications and conference presentations listed in Chapter 7.2:

- Arranging the **SAFER seminars** “Child Occupant Protection: Latest knowledge and Future opportunities”
    - SAFER 2009: https://www.saferresearch.com/events/safer-seminar-child-occupant-protection
    - SAFER 2013: https://www.saferresearch.com/events/child-occupant-protection-latest-knowledge-and-future-opportunities
    - SAFER 2015: https://www.saferresearch.com/events/child-occupant-protection-latest-knowledge-and-future-opportunities-0
    - SAFER 2017 https://www.saferresearch.com/news/successful-child-safety-seminar-presentations-available
- Multiple industry presentations and interaction by project team researchers and visiting researchers.

**Presentations:**

- “Child occupant fatalities in Sweden” study update, presented at Transportforum, VTI, Linköping, January 2016
- “Vetenskapsfestivalen” in Göteborg, April 2015
- FFI’s Resultatkonferens, September 2015
- “Vinnova’s forskningsdag”, November 2014
- NTF’s Child safety day 2014
- Education activity for health carer (BVC) by NTF Skaraborg, 2014
- TRIPP International Course on Traffic and Transportation, IIT Delhi, India, December 2014.

- Project partners participated on SAFER/NTF’s podcasts: ”Liv och trafik kunskaps-pod”;
    - Katarina Bohman ”Bortglömda barnen” in January 2016
    - Lotta Jakobsson “Sveriges Barn i Bil-expert gillar Bakåtvänt” in May 2015.

**Examples of media reporting:**

- January 2016: More than 24 articles reporting about the Child occupant fatalities in Sweden study update, presented at Transportforum (Anna Carlsson)
- January 2016: Child safety in Japanese media (Lotta Jakobsson)
- April 2016: Child safety in South Korean media (Lotta Jakobsson)
- June 2014: TV4 Vetenskapsradion, Norsk forskningstidning, Berlinske tidende (Katarina Bohman), press release: http://ki.se/nyheter/krocksakerhet-eftersatt-for-barn-i-bil?_ga=2.219211225.1185730104.1507121734-1632017167.1507121734
- September 2014: SVT, TV4, DN mm incl internationell media (Project team), press release: http://www.chalmers.se/sv/nyheter/Sidor/Bilbarnstol-ar-inte-sakrare-an-balteskudde-for-aldre-barn.aspx
- Maj-Juni 2014: Child safety in Chinese media (Lotta Jakobsson)
- Maj 2014: Swedish media on Chalmers’ Honorary Doctor Kristy Arbogast

## 7.2 Publications and conference presentations

The current project has resulted in a total of 2 PhD theses, 13 peer-reviewed articles and 10 conference publications, in addition to 8 conference presentations (without publications) and 3 Master Theses; as listed below.

### PhD theses:

Bohman K. **Car safety for children aged 4-12 – Real world evaluations of long-term injury outcome, head injury causation scenarios, misuse, and pre-crash maneuver kinematics**, Thesis for doctoral degree (PhD), ISBN 978-91-7549-124-0. Karolinska Institutet, Stockholm, Sweden, 2013

Stockman I, **Safety for Children in Cars – Focus on Three Point Seatbelts in Emergency Events**. Doctoral Thesis Department of Applied Mechanics, Chalmers University of Technology, 2016. ISBN: 978-91-7597-468-2.

### Master theses:

Elisa de Faveri, **Kinematic response and shoulder belt position for child volunteers when exposed to steering manoeuvres in different restraint systems**, Master's thesis 2013:35, Chalmers University of Technology, Dept of Applied Mechanics, Division of Vehicle Safety, Göteborg, Sweden 2013

Edward Illingworth, **Active Muscle Control in Pre-Crash Simulations: Implementation of Muscle Control in Upper Extremities of the MADYMO facet occupant model of a 6 year old**, Project work, Department of Applied Mechanics, Chalmers University of Technology, Göteborg, Sweden, 2014.

Sofie Helmersson, Maria Rehnberg**, Innovative Child Restraint Harness** Master's thesis 2015:16 Department of Applied Mechanics, Chalmers University of Technology, Göteborg, Sweden, 2015.

### Peer-reviewed articles:

Arbogast K, Locey C, Bohman K, Seacrist TY. **Relative kinematics of the shoulder belt and the torso: Comparison of the Q10 ATD and paediatric human volunteers**. *Ircobi Conference*, Gothenburg, Sweden, 2013

Arbogast KB, Kim J, Loeb H. Kuo J, Koppel S, Bohman K, Charlton JL. **Naturalistic driving study of rear seat child occupants: Quantification of head position using a Kinect™ sensor**, *Traffic Inj Prev*, 2016:17(1), pp168-174

Baker G, Stockman I, Bohman K, Jakobsson L, Svensson M, Osvalder A-L, Wimmerstedt M. **Kinematics and shoulder belt engagement of children on belt-positioning boosters during emergency braking events**. *Ircobi Conference*, Antwerp, Belgium, 2017

Baker G, Stockman I, Bohman K, Jakobsson L, Osvalder A-L, Svensson M, Wimmerstedt M. **Kinematics and shoulder belt engagement of children on belt-position boosters during evasive steering maneuvers**. *AAAM* (in press) 2017

Bohman K, Stigson H, Krafft M. **Long-term medical consequences for child occupants 0-12 years injured in car crashes**, *Traffic Inj Prev* 2014:15(4)

Bohman K, Arbogast KA, Loeb H, Charlton JL, Koppel S, Cross SL**. Frontal and oblquie crash tests of HIII6y child ATD using real-world, observed child passenger postures**, *Traffic Inj Prev* (In Press), 2017.

Brolin K, Stockman I, Andersson M, Bohman K, Gras LL, Jakobsson L. **Safety of children in cars: A review of biomechanical aspects and human body models**, *IATSS Research* 38 (2015), pp. 92-102 DOI information: 10.1016/j.iatssr.2014.09.001

Brolin K, Stockman I, Subramanian H, Gras L-L, Östh J. **Development of an Active 6-Year-Old Child Human Body Model for Simulation of Emergency Events**. *Ircobi Conference*, Lyon, France, 2015

Carlsson A, Strandroth J, Stockman I, Bohman K, Svensson MY, Wenäll J, Gummesson M, Turbell T, Jakobsson L. **Review of child car occupant fatalities in Sweden during six decades**, *Ircobi Conference*, Gothenburg, Sweden, 2013

Osvalder A-L, Hansson I, Stockman I, Carlsson A, Bohman K, Jakobsson L. **Older Children's Sitting Postures, Behaviour and Comfort Experience during Ride – A Comparison between an Integrated Booster Cushion and a High-Back Booster,** *Ircobi Conference*, Gothenburg, Sweden, 2013

Stockman I, Bohman K, Jakobsson L. **Kinematics and shoulder belt position of child anthropomorphic test devices during steering maneuvers.** *Traffic Inj Prev*. 2013;14(8):797-806.

Stockman I, Bohman K, Jakobsson L, Brolin K. **Kinematics of child volunteers and child anthropomorphic test devices during emergency braking events in real car environment**. *Traffic Inj Prev*. 2013;14(1):92-102

Stockman I, Bohman K, Jakobsson L. **Pre-pretensioner effect on child sized dummies during run-off road events**, *Traffic Inj Prev*. 2017 May 29;18(sup1):S96-S102. and Proc of *25th Int. ESV Conf*., Paper no. 17-0125, Detroit, USA, 2017

## Conference publications:

Arbogast KB, Bohman K, Stockman I, Jakobsson L. **Child occupant protection: Latest knowledge and future opportunities – Results of a workshop in Gothenburg, Sweden**. *11th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2013

Arbogast KB, Bohman K, Brolin K, Jakobsson L. **Child occupant protection: Latest knowledge and future opportunities – Results of a 2015 workshop in Gothenburg, Sweden**. *13th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2015

Arbogast KB, Bohman K, Jakobsson L. **Protecting children and youth in cars: highlighting non-nominal cases and the user experience**. *14th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2017, in press

Bohman K, Stigson H, Krafft M, **Long-term medical consequences to children injured in car crashes and influence of crash directions**. *11th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2013

Bohman K, Jakobsson L, Stockman I. **Retention of rear seat occupants during evasive steering maneuver – effect of seatbelt pre-pretensioner.** *14th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2016

Charlton JL, Koppel S, Cross S, Rudin-Brown C, Kuo J, Arbogast KB, Loeb H, Eby D, Bohman K, Svensson M, Jakobsson L, Stockman I. **Naturalistic observation of children in cars: an international partnership**. *11th Int. Conf. Protection of Children in Car*s, Munchen, Germany, Dec 2013

Charlton JL, Koppel S, Cross S, Kuo J, Rudin-Brown C, Arbogast K, Loeb H, Eby D, Bohman K, Svensson M, Stockman I, Jakobsson L. **The Child Safety in Cars International Collaborative Study: Early findings and lessons learned.** *14th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2016

Jakobsson L, Broberg T, André K. **Compact Child Seat – a concept designed around the users**. *11th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2013

Jakobsson L, Lindman M. **Booster usage in cars 2000-2013, in Sweden**. *13th Int. Conf. Protection of Children in Cars*, Munchen, Germany, Dec 2015

Jakobsson L, Bohman K, Svensson M, Wimmerstedt M. Rear seat safety for children aged 4-12: **Identifying the real-world needs towards development of countermeasures**, *Proc of 25th Int. ESV Conf.*, Paper no. 17-0088, Detroit, USA, 2017

## Conference presentations with no publication:

Bohman K, **Attitude, handling, comfort and safety– a car safety approach for children in the rear seat**. *1st international child safety conference in China*, Shanghai, China, Oct, 2014

Bohman K. **Long-term medical consequences to children injured in car crashes and influence of crash directions**. *International conference on Children and Road* , Dublin, Ireland, April 2015

Bohman K, **Misuse of booster cushions – an observational and attitude study during buckling up in Shanghai.** *2nd international child safety conference in China*, Shanghai, China, Oct, 2015

Brolin K, Gras L-L, Stockman I. **Active Spine Modeling Representing a 6 Year-Old Child,** *7the World Congress on Biomechanics*, Boston,USA, July 2014

Jakobsson L. **Rearward facing for optimal protection**, *1st international child safety conference in China*, Shanghai, China, Oct, 2014

Jakobsson L. **Child safety technology developments –Experiences from Northern Europe**, *2nd international child safety conference in China*, Shanghai, China, Oct, 2015

Stockman I, Bohman K, Jakobsson L, **Hur kan bil och barnskydd samarbeta för att skydda barn (ålder 4-12) i bil? -Resultat från ett FFI-projekt**, Tylösandsseminariet, Halmstad, Sweden, September 2017

Svensson MY, Bohman K, Brolin K, Jakobsson L, Stockman I; **Safety for Children in the Rear Seat – A review of the progress at the SAFER Centre**, *INFATS*, Chongqing, China, Nov, 2014 (presentation + abstract)

# 8. Conclusions and future research

Real-world safety of child rear seat car passengers, involves evaluation of protection beyond crash-testing in standardized frontal and side impact conditions. This project explores a wide context of rear seat performance and emphasizes that child occupant protection is to be regarded as a multi-faceted system, combining vehicle protection and child restraint systems. Understanding how real children sit and behave in cars is essential.

Studying the children during normal riding clearly shows that the child restraint is only a part of the real-world protection. It is obvious that children interact with and benefit from the vehicle protection systems. It is also clear that the design of the child restraint influence the protection capabilities. The trend of increased head side supports will likely increase the forward leaning postures, which will expand the protection contribution needed from the vehicle. From a real-world protection perspective, it is beneficial if the vehicle and child restraint designs encourage controlled sitting postures, preferably guided by comfort, helping to restrict the variability in user positions.

Future research needs to be directed for the future changes of mobility, such as car sharing, car pooling and automated driving cars, to ensure that children will be provided safe rides during these circumstances.

# 9. Participating parties and contact persons

The project partners are Volvo Cars, Autoliv Research and Chalmers University of Technology with the main participants throughout the project:

- **Katarina Bohman**; Autoliv Research, Industrial PhD student
- **Isabelle Stockman**; Chalmers, PhD student
- **Mats Svensson**, Chalmers
- **Maria Wimmerstedt,** Volvo Cars
- **Lotta Jakobsson**, Volvo Cars, project leader and contact person (lotta.jakobsson@volvocars.com; +46 766 210314)

In addition, the following researchers have contributed in selected parts of the project:

Children's Hospital of Philadelphia, USA

- **Kristy Arbogast**, awarded Chalmers' Honorary Doctor 2014 as a result of her project contribution

Autoliv

- **Ola Boström**
- **Rikard Fredriksson**
- **Cecilia Sunnevång**

Chalmers

- **Karin Brolin**
- **Anna Carlsson**
- **Anna-Lisa Osvalder**, and team

Volvo Cars:

- **Magdalena Lindman**

# References

References **in blue** are deliverables within the project (also listed in Chapter 7.2):


Andersson M, Bohman K, Osvalder A-L. **Effect of booster seat design on children's choice of seating positions during naturalistic riding**. *AAAM*, 2010

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