SAFETY FOR THE GROWING CHILD
– EXPERIENCES FROM SWEDISH ACCIDENT DATA

Lotta Jakobsson
Irene Isaksson-Hellman
Björn Lundell
Volvo Car Corporation
Sweden
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ABSTRACT

During the past 40 years, different child restraint systems (CRS) have been developed to improve protection for children of different sizes and ages. Development of more effective CRS, and a higher frequency in use of the restraints, in addition to enhanced vehicle safety, has resulted in an increased level of child safety.

This study examines accident data with Volvo cars in Sweden to evaluate child safety with respect to age, size and impact situation (including impact severity in frontal impacts); identifying optimal restraints as well as potential areas needing more attention. A total of 3670 children, aged 0-15 years, involved in car crashes 1987-2004 were selected from Volvo's statistical accident database.

The injury-reducing effect of the child restraint systems was high overall. The highest injury-reducing effect was found in rearward-facing child restraints for children up to 3-4 years of age, offering an injury-reducing effect of 90% compared to an unrestrained child. Belt-positioning boosters from 4 to 10 years of age were found to have an injury reducing effect of 77%.

Compared to adults, this study indicates that children have a generally lower AIS 2+ injury rate, except for abdominal and lower-extremity injuries. Abdominal injuries are mainly found in children using only a seat belt, emphasizing the need for belt-positioning boosters.

A tendency of higher injury risk was found when the growing child switches from one restraint to another, i.e. when the child is at the youngest age approved for the restraint. Thus, the total injury-reducing effect would increase if all children were to use the child restraint system most appropriate for their size and age. The challenge is to spread information as well as enhance design to encourage everyone to use the appropriate child restraint system and to use it correctly.

INTRODUCTION

The development of child restraint systems (CRS) for cars started in the early 60s. During the past 40 years, different child restraint systems have been developed to improve protection for children of different sizes and ages. Isaksson-Hellman et al. (1997) showed a clear trend of steadily increased safety for children in cars during these years in Sweden. This was due to the increased frequency in use of restraints, and the development of effective CRS. The rearward-facing CRS was shown to be especially effective. The percent of restrained children in Volvo cars in Sweden 1977-2004 is shown in Figure 1.

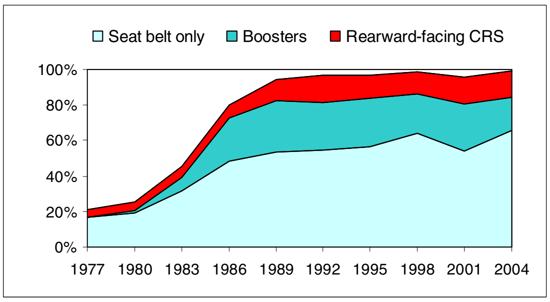


Figure 1. Percent of restrained children in Volvo cars in Sweden 1977-2004.

The different groups of restraint systems covered in this study are rearward-facing CRS (RF CRS), forward-facing belt-positioning, booster seats and cushions (boosters), and adult seat-belt only, Figure 2. Please note that forward-facing CRS for ages 1-4 with integrated child harness are very rare in Sweden, and therefore not included in this study.

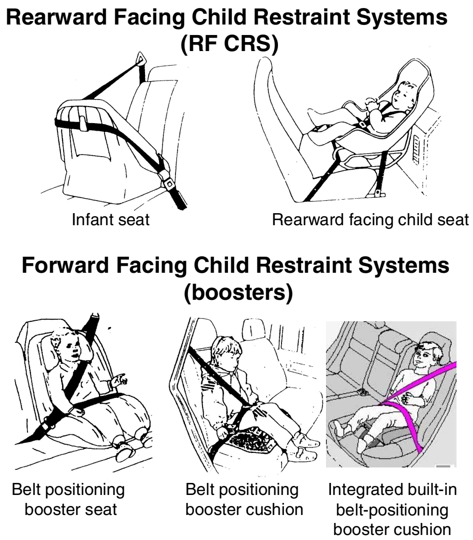


Figure 2. Analyzed child restraint systems

Rearward-Facing Child Restraint Systems

In 1964 professor Bertil Aldman introduced a rearward-facing child seat (Aldman, 1964). The purpose of this seat was to enhance support to the spine and head in the event of a frontal impact, i.e. to distribute the forces over a large part of the body. Small children have a different anatomy compared to adults; especially the proportion of the head's mass and height compared to the total body mass and height (Figure 3), and also the strength and development of the neck and cervical vertebrae (Burdi et al. 1968).

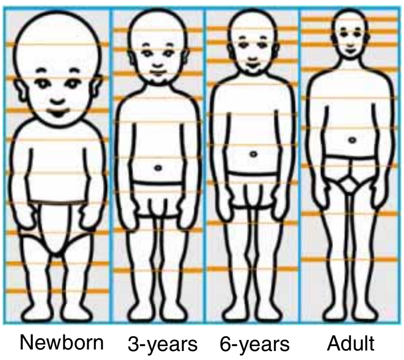


Figure 3. Body proportions for the growing child (source: Burdi et al. 1968)

The combination of high head mass and a weaker and more fragile neck in small children makes rearward-facing CRS the ultimate restraint system for this category of occupant. Several studies have pointed out the benefits of this restraint system, and it is recommended for use as long as possible; at least until 3-4 years of age (Tingvall 1987, Carlsson et al. 1991, Kamrén et al. 1993, Stalnaker 1993, Tarrière 1995, Isaksson-Hellman et al. 1997).

The two main groups of rearward-facing CRS are the infant seat and the rearward-facing child seat, Figure 2. In all rearward-facing CRS, the child is restrained by a harness, comprising a 3-, 4- or 5-point belt system. The infant seat is used from newborn to approximately 9 months old and is attached to the car by the adult seat-belt. The rearward-facing child seat, which is found mainly in the Scandinavian countries, can be used up to the age of 3-4 years. It is usually attached to the car by the adult seat-belt and an additional strap between the forward part of the CRS and the car structure below. In recent years, an international standard for attaching child restraints to cars has been introduced. It is called ISOFIX and in the USA also LATCH (Turbell et al. 1993, Langwieder et al. 2004).

Belt-Positioning Booster Seats and Cushions

When the child has reached approximately 3-4 years of age, it can be turned forward-facing in the car. The mass of the head is proportionally less and the neck is stronger. There are, however, still major 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 the design, in order to give a child the same amount of protection as an adult.

Belt-positioning booster cushions were introduced in the late 70s (Norin et al. 1979). In Sweden there are three main forward-facing systems: booster cushions, booster seats and integrated booster cushions, Figure 2. The systems are used with the adult seat belt restraining the occupant together with the booster seat or cushion. The integrated (built-in) cushions were developed in order to simplify usage and to minimize misuse (Lundell et al. 1991). They can be found in the rear seats of Volvo cars from 1990, in the mid-seat or outboard position (depending on car model) and always together with 3-point seat-belts. The forward-facing CRS often used in USA, where the child is restrained by a harness or by a shield in the CRS, are very rare in Sweden and are therefore not included in the present study.

The booster allows the geometry of the adult seat belt to function in a better way with respect to the child occupant. The booster raises 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. An important feature regarding booster cushions is the belt-positioning device; keeping the belt in position during a crash. The booster also gives the child a more upright position, so he/she will not scoot forward in the seat to sit comfortably with their legs. This is a more safe position since slouching may result in very bad 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.

Adult Seat Belt Only

When a child has grown to a height of approximately 140cm and the pelvis is also fully developed, the adult seat belt can be used without a booster. The conventional three-point belt is the best seat belt system. Volvo's studies have shown that three-point belts have a 15% better injury-reducing effect (AIS 2+ injuries) as compared to lap-belt only (Lundell et al. 1991).

Misuse

Several different definitions of misuse exist. Common types of misuse include incorrect or no mounting of the CRS, or the child not properly restrained in the CRS. Several studies have discussed these issues and can give an idea of its proportions (Tingvall 1987, Petrucelli 1986, Kamrén et al. 1993, Hummel et al. 1997). In the present study, this aspect of misuse is not possible to evaluate, since the cases are not possible to separate in the analyzed material.

Another type of misuse is a child not using the restraint designed for its size and age. The study of Isaksson-Hellman et al. (1997) showed that the maximum effect of a restraint system is not attained if the child is not using the optimal CRS for its age. Also, a tendency of higher injury risk was identified when the growing child switches from one restraint to another, i.e. when the child is at the youngest age recommended for the restraint. The present study, using the same data source complemented with more recent cases, focuses the safety of the growing child, with respect to age, stature and weight.

METHOD

A dataset of children in Volvo's statistical accident database is analyzed. Crashes involving Volvo cars in Sweden in which the repair costs exceed a specified level (currently SEK 45 000) are identified by the insurance company Volvia (If P&C Insurance). Photos and technical details of the cars (e.g. damage) are sent to Volvo's traffic accident research team. The owner of the car completes a questionnaire (shortly after the crash) to provide detailed information about the crash and the occupants. Injury data is gathered from medical records and analyzed by a physician within Volvo's traffic accident research team. Injuries are coded according to the Abbreviated Injury Scale (AIS, AAAM 1985). This forms the basis of Volvo's statistical accident database.

Occupants below 16 years of age involved in crashes occurring from 1987 to 2004 are selected for this study; a total of 3670 occupants, 47% girls and 53% boys. In Figure 4 the distribution of age, stature and weight of the children are shown. Infants are included in the 1 year old group.

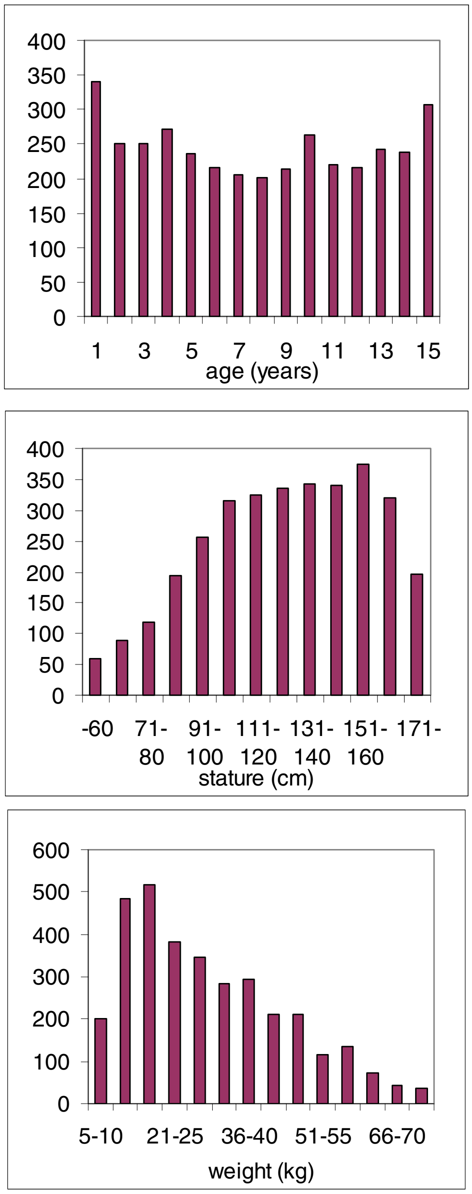


Figure 4. Distribution of age, stature and weight

The variations with respect to stature and weight of the child occupants are shown in Figure 5.

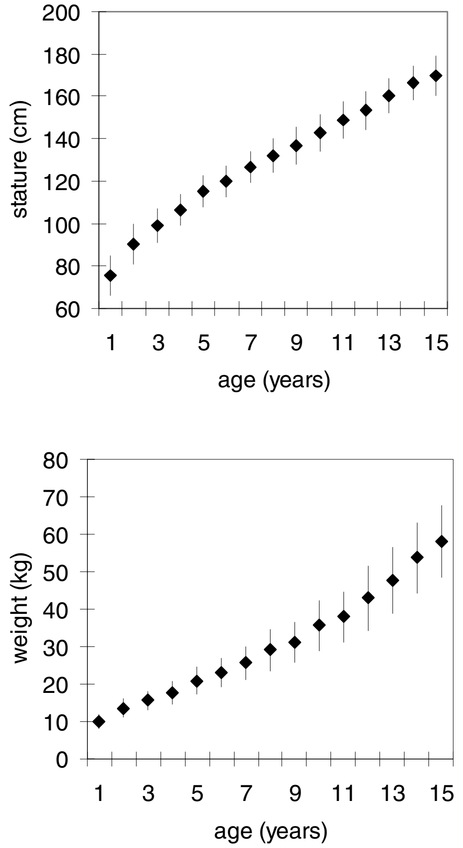


Figure 5. Variation in stature and weight, respectively, versus age; mean values and standard deviation.

The injury rate is calculated as the number of injured of a certain level of AIS divided by the total number of occupants in the group considered. Rearward-facing CRS are infant seats and rearward-facing child seats (in Sweden recommended up to age 3-4), Figure 2. The forward-facing booster includes belt-positioning booster cushions (including integrated built-in cushions) and booster seats. In these, the child together with the booster is restrained by the adult seat belt, Figure 2. Unfortunately, information regarding incorrect or no mounting of the child restraint system, or the child not properly restrained in the system is not available in the material. The number of children traveling in the different restraint systems and seating positions are shown in Table 1. The distribution of crash types is shown in Table 2. The distribution of child restraint systems versus age is seen in Figure 6.

For comparison, a subset of adult passengers is extracted from the database. A total of 3422 restrained front and rear seat passengers aged 20 to 40, involved in crashes occurring 1987 to 2004, is selected.

Table 1.
Number of child occupants with respect to seating position and restraint usage; seat belt only, rearward-facing CRS (RF CRS), forward-facing, belt-positioning booster seat (booster), belt-positioning booster cushion (cushion), integrated built-in booster cushion (int. cushion).

Restraint type	Front seat	Left rear seat	Mid rear seat	Right rear seat	**Total**
unknown	20	25	18	29	*92*
seat belt	571	535	241	634	*1981*
unbelted	16	58	41	53	*168*
RF CRS	353	21	22	58	*454*
booster	37	71	14	100	*222*
cushion	104	288	37	294	*723*
int. cushion	0	2	23	5	*30*
Total	*1101*	*1000*	*396*	*1173*	*3670*

Table 2.
Distribution of crash types.

Crash type	Number of child occupants	Distribution of crash types
Frontal impacts	1421	39%
Side impacts	869	24%
Rear end impacts	362	10%
Multiple impacts	297	8%
Rollovers and turnovers	184	5%
Multiple events	199	5%
Large animals	166	5%
Run-off road	78	2%
Side swipes	70	2%
Other	24	1%
	3670	

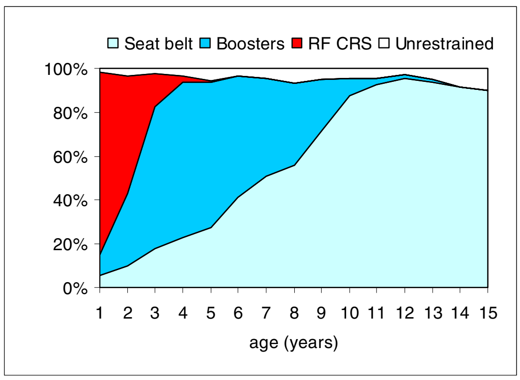


Figure 6. Distribution of restraint systems versus age.

RESULTS

Differences: Adult vs. Child Passengers

When comparing child and adult passengers (drivers are excluded), the injury rates are generally lower for restrained children as compared to restrained adults (aged 20-40), except for abdomen and lower extremities (Figure 7). The figure shows the distribution of injuries for all impact situations. Considering frontal impacts only, the same trend is seen.

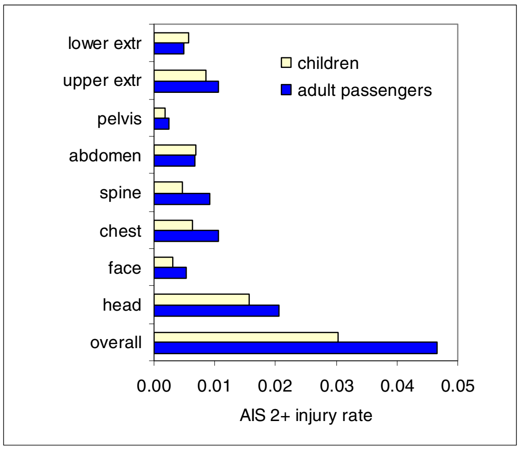


Figure 7. AIS 2+ injury rates (overall and per body part) for restrained adults in passenger seats (age 20-40y, N=3422) and restrained children (age 0-15y, N=3375), all impact situations, accident years 1987-2004.

Restraint System Effectiveness

The overall AIS 2+ (MAIS 2+) injury rates for children using/not using restraints of different types are shown in Figure 8.

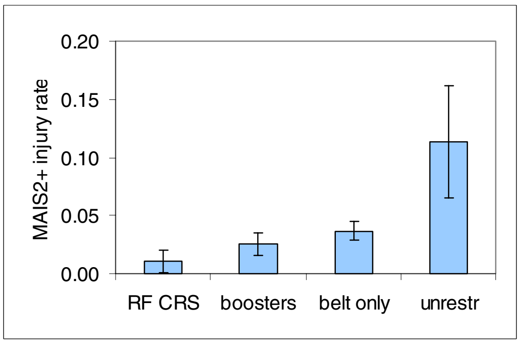


Figure 8. MAIS 2+ injury rates per restraint system (incl. 95% confidence intervals).

Figure 8 shows the very high level of protection for children in rearward-facing CRS (RF CRS). When restrained in belt-positioning booster seats or cushions (boosters), less than 3% were injured at level MAIS 2 or greater. Calculating the overall effectiveness of restrained compared to unrestrained children, the injury-reducing effect is used (Isaksson-Hellman et al, 1997). The overall injury-reducing effect MAIS 2+ for belted only is 68% with the confidence limits (C_L, C_U) = (48%, 80%), for boosters 77% with (C_L, C_U) = (60%, 87%), and for RF CRS as high as 90% with (C_L, C_U) = (74%, 96%) as compared to unrestrained children.

In Figure 7 all restrained children are included. Several of these children are not using the recommended child restraint system for their age and size. Figure 9 shows the MAIS 2+ injury rates at the age groups where the switch between the different restraint systems occur. Even though there is no statistically significant difference in injury rates, the effectiveness of the different restraint types is clearly demonstrated within the different age groups.

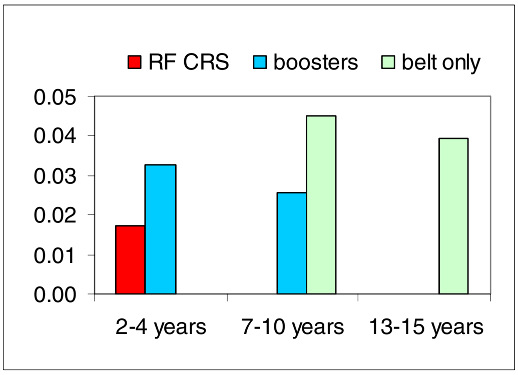


Figure 9. MAIS 2+ injury rates for children of specific age groups in different restraints.

As can be seen in Figure 9, there is a noticeable increase in MAIS 2+ injury rate if the growing child switches from rearward-facing to a forward-facing booster at around 3 years of age. The injuries to the 2-4 year-olds in boosters are mainly head injuries. Two children in frontal impacts sustained spine fractures; one of them a combination of fatal head and neck injuries. The injury rate in a booster decreases somewhat when the child grows older. At the switch to the adult belt only, between age 7 and 10, there is a remarkable increase in injury rate. The injuries for these children are spread over the whole body, with a distinct difference in abdomen injuries, which are only seen for the belted-only children. More than half of the MAIS 2+ injured belted-only children aged 7-10 had AIS 2+ abdominal injuries.

Injuries to Restrained Children

Among the 3375 restrained children (with known injury degree) there are 680 children with MAIS 1 injuries and 102 with overall AIS (MAIS) 2+ injuries. Five of the 102 injured occupants were restrained in a rearward-facing child seat. Three of them were injured in a frontal impact and two in multiple sequence accidents. The five rearward-facing children received AIS 2+ injuries to the head, chest, or lower and upper extremities.

A total of 128 AIS 2+ injuries are found for 72 children restrained by seat belt only, and a total of 38 AIS 2+ injuries to 25 children in boosters are found. Several children had injuries to multiple body areas. The AIS 2+ injuries to the restrained forward-facing children can be seen in Figure 10, divided by body part and impact situation. Head injuries are the most frequent AIS 2+ injuries, for frontal, side as well as other impact situations. Head injuries in frontal and side impacts will be explored further in this study. The head is by far the most injured body region in side impacts, while in frontal impacts the injuries are more evenly distributed over the different body parts. In the present study, injuries to the torso area, abdomen and lower extremities in frontal impacts will be studied further, as well. Upper extremity injuries are also among the most frequent AIS 2+ injuries. Six of the 20 AIS 2+ upper extremity injuries are injuries to the clavicle. They will be included in the section on injuries to the torso area. The remaining AIS 2+ upper-extremity injuries are mainly fractures to the arm bones. The mechanisms of these injuries are probably of the same type of mechanisms as for adults.

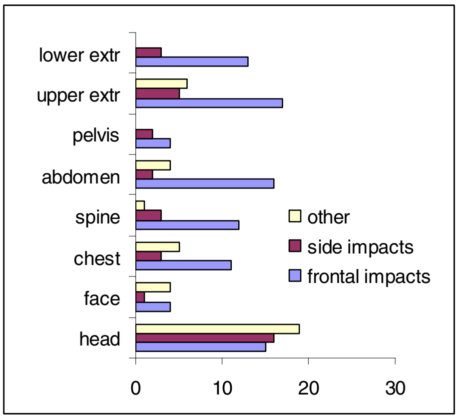


Figure 10. Number of AIS 2+ injuries to children in seat belt only (72 children) and boosters (25 children) shown by body part and impact type.

The growing child is an important aspect when designing child restraint systems. Several combinations of impact situation and body area will be discussed further in this paper with respect to occupant size and age, and when possible, with respect to impact severity. The distribution of Equivalent Barrier Speed (EBS, Mackay and Ashton 1973) versus degree of injury in frontal impacts can be seen in Figure 11. Frontal impacts account for 39% of all cases in this material and 50% of all the MAIS 2+ injured occupants. Figure 11 shows that impact severity is an important factor with respect to injury outcome in frontal impacts.

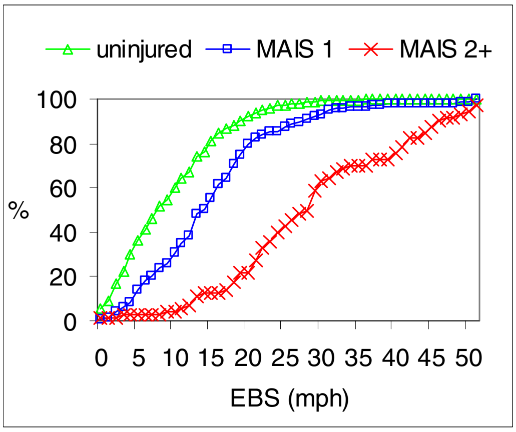


Figure 11. Cumulative distribution of EBS versus uninjured, MAIS 1 and MAIS 2+ injured occupants in frontal impacts.

<u>Rearward-Facing CRS</u>

The children traveling in rearward-facing CRS in a frontal impact are plotted in Figure 12, with respect to EBS and age, weight and stature.

As can be seen in Figure 12, the majority of all children in rearward-facing CRS are uninjured, even at high EBS. The children with MAIS 2+ injuries are mainly found at high EBS, while MAIS 1 injured children are found at any EBS. The severely injured one year-old child at EBS 26mph, was sitting facing rearward in the front passenger seat and sustained severe (MAIS 4) head injuries due to local intrusion. The one year-old child with MAIS 2, also sitting in the front passenger seat, sustained a lower extremity injury and minor head concussion. A third MAIS 2+ injured child, who was in a very high severity impact, sustained severe injuries (AIS 4) to the head and lungs as well as fractures (AIS 2) to the legs and one arm. The car he was traveling in collided with a large truck. The driver of the car sustained fatal injuries.

As demonstrated by Figure 12, the rearward-facing seat offers good protection for the small child in frontal impacts. In this dataset, frontal impacts account for three of five rearward-facing children with MAIS 2+ injuries. The other two were injured in multiple sequence crashes with somewhat uncommon situations. In the data, there are no rearward-facing children with injuries more than AIS 1 in side or rear-end impacts.

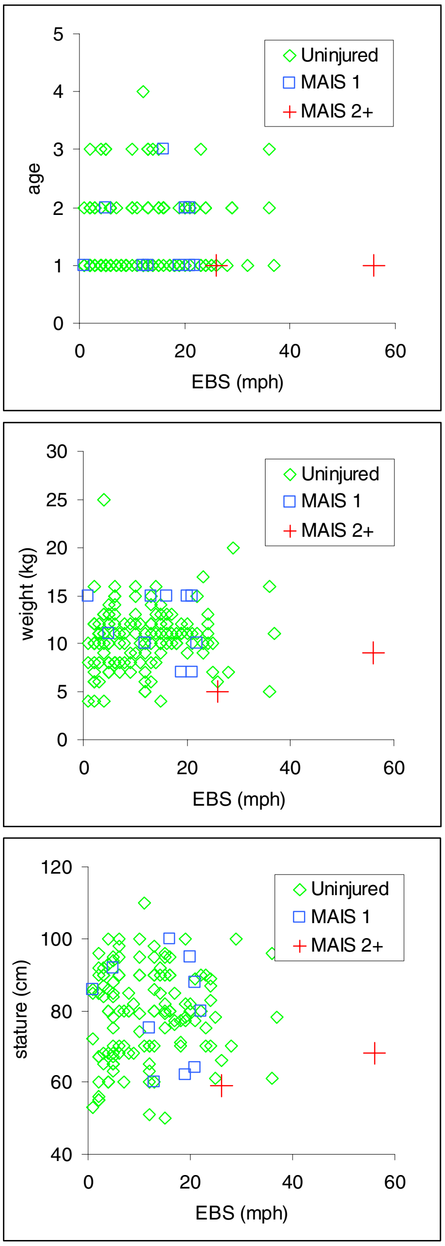


Figure 12. Distribution of injured (overall injury) and non-injured, rearward-facing children in frontal impacts, EBS vs. age, weight and stature. One injured (MAIS 4) two year-old child with unknown weight and stature is beyond the EBS scale (very high EBS).

Head Injuries in Side Impacts

In side impacts, the most common body area injured is the head (Figure 10). Head (including face) injury distribution for age versus stature is shown in Figures 13a, b, for all occupants in side impacts and near-side occupants only, respectively. The children are all restrained, belted-only or using boosters. Near-side occupants are those sitting on the struck side of the car during the crash.

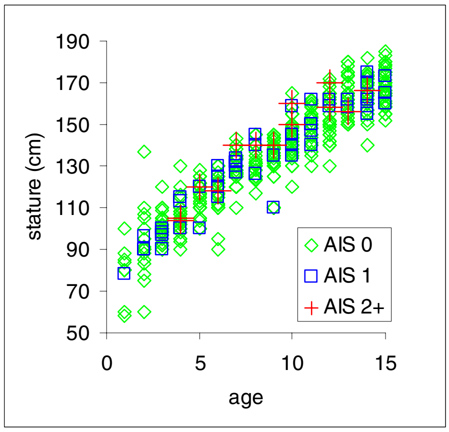


Figure 13a. Distribution of <u>head injury</u> AIS for forward-facing children (boosters and belted-only) in side impacts, stature vs. age.

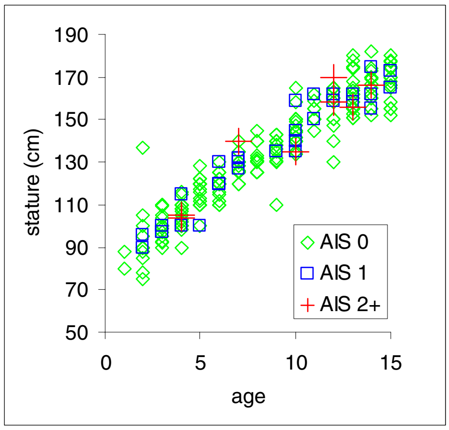


Figure 13b. Distribution of <u>head injury</u> AIS for forward-facing children (boosters and belted-only) in <u>near-side</u> side impacts, stature vs. age.

No relation between increased age/stature and injury rate is found for children in side impacts (Figures 13a, b). This is seen also when separating belted-only occupants and those using boosters, as well as near-side and far-side occupants.

The overall AIS 2+ injury rate for head (including face) injuries in side impacts is higher for children sitting on the near side; 3.1% as compared to 1.8% for those on the far side. The most frequent AIS 2+ injuries are brain concussions and skull fractures, rather evenly distributed between the children on the near side and far side. The most usual impact location is the side structure. Some of the far-side children have struck the back of the front seats. As for adults, head (including face) injuries are in most cases sustained by the occupant impacting hard structure.

Head and Face Injuries in Frontal Impacts

In Figure 14, head and face AIS is plotted for EBS vs. age and stature for forward-facing children in frontal impacts. As can be seen, EBS has the largest influence on AIS 2+ injuries. The two-year old (using lap/shoulder belt and booster) with head AIS 6 sustained a combination of fatal head injury and cervical spine fracture at EBS 50mph.

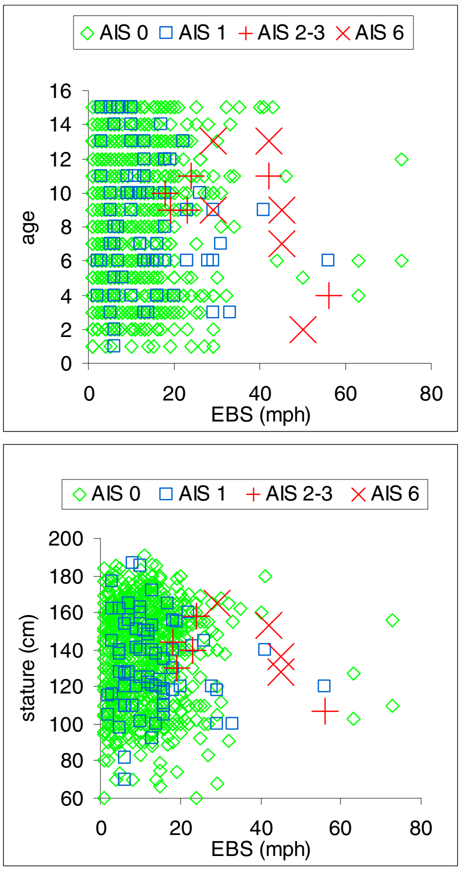


Figure 14. Distribution of head and face injury AIS for forward-facing children (boosters and belted-only) in frontal impacts, EBS vs. age and stature.

Among the total of 30 AIS 2+ head and face injuries for the 12 restrained forward-facing children in frontal impacts, the most common injuries are fractures (30%) (equally distributed between skull base, nose/maxilla and forehead) edema (26%) and concussion (20%). The most common AIS 1 injuries to the head and face are abrasions (23%), cuts (19%), contusions (17%) and pain (10%). The injury distribution for children is similar to that for adults. When studying the combinations of head injuries for the individuals, the mechanisms for AIS 2+ head injuries seem to be impact-related. The exception for this is the typical combination of fatal head and neck injury for the smallest forward facing children, as exemplified by the 2-year old at EBS 50mph, which occurred without head impact.

Abdominal Injuries in Frontal Impacts

The distribution of abdominal injuries can be seen in Figures 15 a, b, for children in frontal impacts, belted-only and in boosters, respectively. Abdominal injuries of AIS 2+ are found at higher EBS.

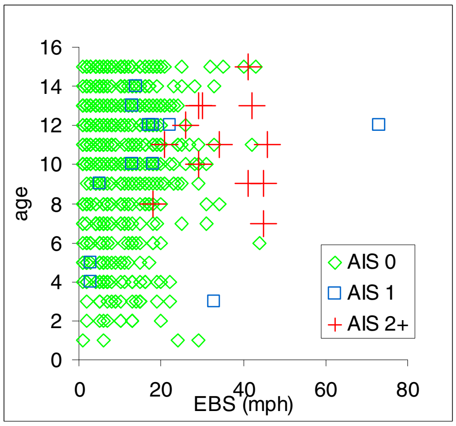


Figure 15a. Distribution of <u>abdominal injury</u> AIS for children restrained by <u>belt only</u> in frontal impacts, EBS vs. age

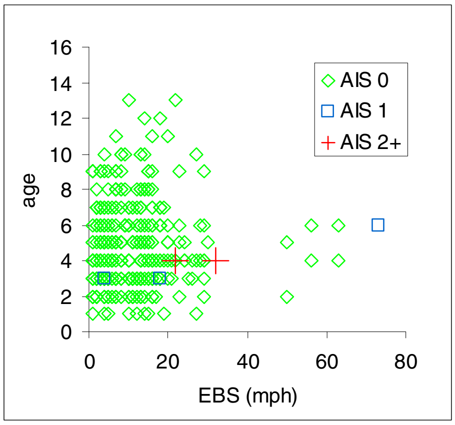
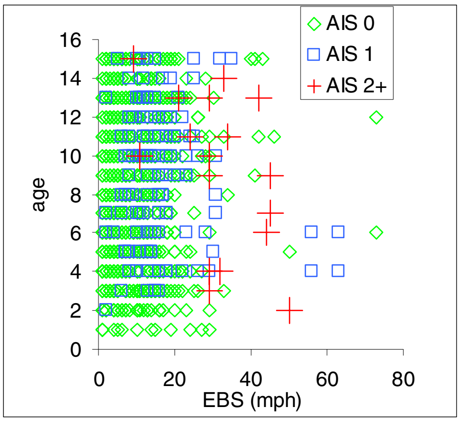


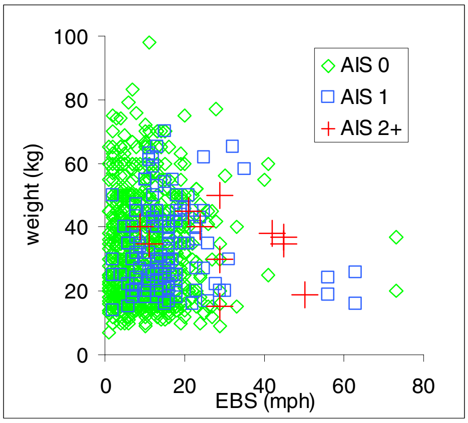
Figure 15b. Distribution of <u>abdominal injury</u> AIS for children in <u>boosters</u> in frontal impacts, EBS vs. age

The abdominal AIS 2+ injury rate is less for children restrained in boosters as compared to belt-only restrained; 0.8% as compared to 1.7%. The positive trend of reduction of AIS 2+ abdominal injuries if using a belt-positioning booster seat or cushion, as shown in Figures 15 a, b, confirms earlier studies (Isaksson-Hellman et al. 1997, Hummel et al. 1997). One of the two injured 4 year-old children using boosters was involved in a severe impact with a large truck in which only a younger sister in a rearward-facing child seat survived the crash. Both of the four year-olds were seated on booster seats with very poor guidance of the lap belt. During the crash, the belt slid up into the abdomen and the loads were transferred into the soft tissues; resulting in fatal abdominal injuries for one of them, and internal abdominal injuries, AIS 2, for the other.

Torso Injuries in Frontal Impacts

Injuries to the torso (chest, clavicle, shoulder and throat) are shown in Figure 16 with respect to age, weight and stature versus EBS, for all forward-facing restrained children (belted-only and boosters).





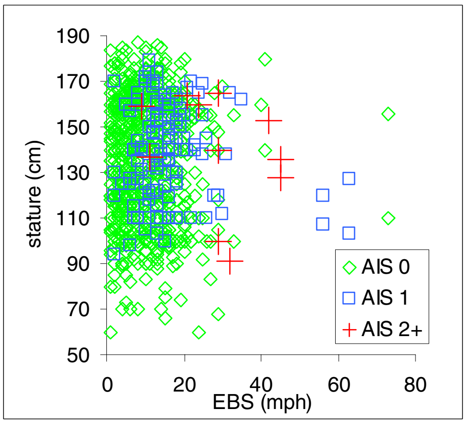


Figure 16. Distribution of torso injury AIS for forward-facing children (boosters and belted-only) in frontal impacts, EBS vs. age, weight and stature.

The injuries to the torso area are distributed evenly with respect to occupant size and age (Figure 16), and also between those wearing seat belt only and those in boosters. As can be seen in Figure 16, there is a general trend that AIS 2+ injuries are related to increased impact severity.

The most frequent AIS 2+ injuries to the torso are fractures (43%) to ribs, clavicle and sternum, together with bleeding, ruptures and contusions to inner organs (17% on each). The most common AIS 1 injuries are pain (56%), contusions (21%) and abrasions (20%). The types of injuries indicate that the most common injury mechanism for most torso injuries is probably belt interaction. Similar injury trends and injury type distribution are seen as for adults, indicating that the injury characteristics, and thus the mechanisms for these injuries, are probably not unique for children.

Lower extremity injuries in frontal impacts

The AIS 2+ injury rate of lower extremity injuries to children is as high as for adults, see Figure 7. Lower extremity injuries to forward-facing children are mainly found in frontal impacts (Figure 10). In order to understand the mechanisms of child lower-extremity injuries, and to evaluate whether they are different for children as compared to adults, the distribution of lower-extremity AIS is plotted for age versus EBS, for belted-only children (Figure 17a) and children in boosters (Figure 17b), respectively.

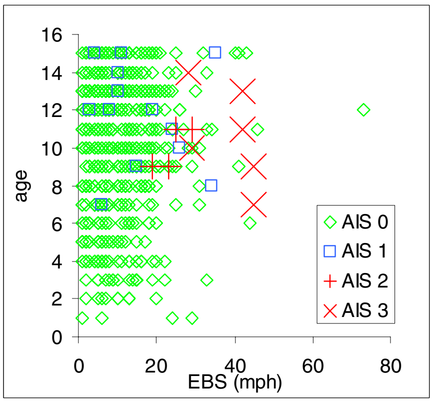


Figure 17a. Distribution of lower extremity injury AIS for belted-only children in frontal impacts, EBS vs. age

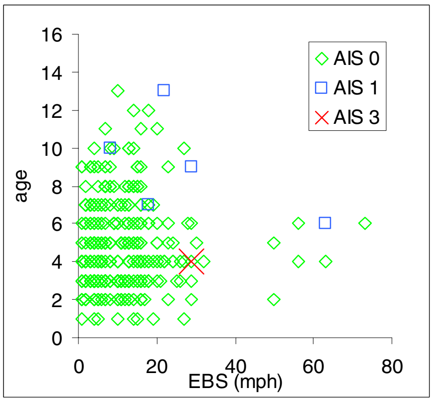


Figure 17b. Distribution of lower extremity injury AIS for children in boosters in frontal impacts, EBS vs. age

The AIS 3 injuries in Figures 17a,b, are femur fractures. They occur typically at higher impact severity than the AIS 2 injuries, which are fractures below the knee. As can be seen in Figure 17b, there is only one small child (with lap/shoulder belt and booster) who sustained lower extremity AIS 2+. All the other AIS 2+ injured children were 7 years or older, and all of them were 130 cm or taller and restrained by seat belt only. For these children, the injury mechanisms would be similar as for adults; the knees interact with structure in front of them and are broken when high loading is transferred

DISCUSSIONS

Over the last three decades, total protection for children has increased through a combination of increased usage (Figure 1) and the performance of the child restraint systems (Isaksson-Hellman et al.1997). The data in this study is from Volvo cars in Sweden. In Sweden, the way of transporting children in cars differs to some extent from other countries. Also, the overall use of restraints for children is as high as 95%, which might not be representative for several other countries and car brands. The aim of this study was to show the great benefits of the existing child safety systems, and to use the detailed data to suggest potential areas for further improvement.

The protection of the growing child in the car is a question of designing child-restraint systems specifically for the needs of the child. Age as well as stature and weight are important aspects with regard to the specific needs. Earlier studies have found that children are best protected if they travel rearward-facing up to the age/size when the mass of the head is proportionally less and the neck is stronger; at least to age 3-4. After this, the restraints need to compensate for the development and the size of the pelvis to accommodate a good belt geometry; at least up to age 10, preferably older. This study emphasizes the good performance of the safety systems evaluated. The switch of restraint is also highlighted. An increase in injury rate indicates that children turn forward-facing too early and do not stay in belt-positioning seats long enough. This also suggests that adaptable booster seats are desirable; that is, seats that can be adjusted to the size of the growing child.

In this paper, the good performance of rearward-facing CRS is demonstrated. The performance of rearward-facing seats is shown by the low injury rate. Only three children sustained MAIS 2+ injuries in frontal impacts and they were all exposed to relatively high severity impacts. In contrast to this, the two-year old forward-facing child (in a lap/shoulder belt and booster) sustaining the combination of fatal head injury and cervical spine fracture typically illustrates the vulnerability of the neck and head for small children in forward-facing boosters. This child's five-year old sister, sitting next to him in the rear seat (using the same type of restraints), sustained no injuries. This two-year old would have been better protected in a rearward-facing CRS. Other cases of this type of injury mechanism are described in Fuchs et al. (1989) and Stalnaker (1993). The rearward-facing child seats are designed primarily for frontal impacts, however the outcome for side and rear-end impacts indicates a good performance also in these situations. In this data, no rearward-facing child sustained MAIS 2+ injuries in side or rear-end impacts.

A large part of this study deals with injuries to restrained, forward-facing children, mainly aged 3 and over. In this data, the head is the most frequently injured body region. In frontal impacts, injuries to head/face as well as the torso area, abdomen and lower extremities are studied in detail, and will be discussed with respect to the possible mechanisms. For the youngest children in boosters, injuries to the cervical spine in a frontal impact are the highest priority, although they are not frequent in this data. Because of relatively few children below age 4 in boosters in this data, only one case is available to illustrate this mechanism. Among the injuries studied, abdominal injuries for belted only children and the combined head and neck injury for the smallest booster children in frontal impacts were found unique for children, and need special care. Injuries to the torso area, head and lower extremities seem to be of the same mechanisms as for adults, and need general care and focus on adaptivity in all safety system development.

For most head injuries to forward-facing children, in frontal impacts as well as in side impacts, the main injury mechanism is the head impacting into something. The exception is the fatal combination of skull base fracture and neck injury for small forward-facing children in frontal impacts, which does not require a head impact to occur. The head impact mechanisms, both in frontal and side impacts, are not unique for children. In side impacts, measures for adults will probably benefit children as well. In frontal impacts, measures to avoid head impacts are encouraged for children as well as for adults.

For forward-facing children in frontal impacts, the injury mechanisms of the injuries to the torso area (chest, shoulder, clavicle and throat) are probably interaction to the shoulder part of the lap/shoulder belt. There are no major differences in injury pattern as compared to adults. Injuries of AIS 2+ were mainly found at higher impact severity. Injuries to the lower extremities of forward-facing children were explored to evaluate if there were any unique mechanisms for children as compared to adults. All except one of the lower-extremity injured children were rather tall (>130 cm) and restrained by seat belt only. The lower extremity injuries that children were exposed to occurred at rather high impact severity, especially the femur fractures. The mechanisms of lower-extremity injuries for these children would be of the same kind as for adults; the knees interact with the structure in front of them and are broken when high loading is transferred.

The importance of a belt-positioning boosters for forward-facing children, in order to avoid abdominal injuries by the abdomen slipping under the belt, has been shown previously (DeSantis Klinich et al. 1994, Isaksson-Hellman et al. 1997, Warren Bidez and Syson 2001). The data presented in this study support these findings and emphasizes the importance of belt-positioning systems, and that the booster is designed to hold the belt firmly on the pelvis or thighs during a frontal impact. It is recommended for children up to the age of 10 to use a belt-positioning booster. However, Figures 15 a, b, suggest that even the 11-12 year-old child would probably benefit from such a device.

The injury reducing effect of the child restraint systems is high. However, the total injury-reducing effect would increase if all children used the child restraint system most appropriate for their size and age. Future challenges for improved protection are to spread information as well as enhance designs to encourage everyone to use the appropriate child restraint system and to use it correctly.

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