Volvo Research: Safety for the Growing Child

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INTRODUCTION

The development of child restraint systems (CRS) in cars started in the early 1960s. During the last 40 years, different child restraint systems have been developed to optimize the protection for children of different sizes and ages. In a prior study (Isaksson-Hellman et al., 1997) a clear trend of steadily increased safety for children in cars during these years was shown. This was due to the increased frequency in use of restraints and the development of effective CRS. The rearward facing CRS was shown especially effective. The percent of restrained children in Volvo cars in Sweden 1977-2003 is shown in Figure 1.

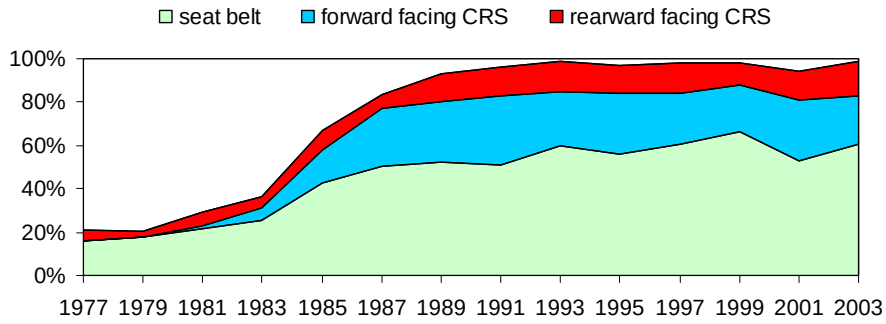

Figure 1. Percent of restrained children in Volvo cars in Sweden 1976-2003.

The study of Isaksson-Hellman et al. (1997) showed that, when a crash occurs, the maximum effect of a restraint system is not attained if the child is not using the optimal CRS for its age. Optimal CRS are rearward facing for children up to 3-4 years of age and belt-positioning booster seats from 4 to 10 years of age. A tendency of higher injury risk when the growing child switch from one restraint to another, i.e. when the child is at the youngest age recommended for the restraint was identified. This study, using the same material, complemented with more recent cases, focuses the safety of the growing child, both with respect to age, stature and weight.

METHOD

A dataset of children in Volvo's statistical accident data base is analyzed statistically. 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 Insurances). 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 1990). This forms the basis of Volvo's statistical accident data base.

Occupants below 16 years of age, involved in crashes occurring between the years 1987 and 2004 are selected for this study; a total of 3624 occupants, 47% girls and 53% boys. In Figure 2 the distribution of age, stature and weight of the children are shown.

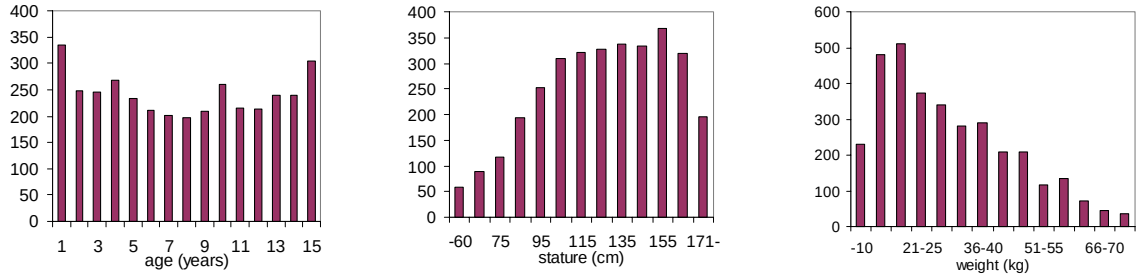

Figure 2. Distribution of age, stature and weight, respectively.

The variations with respect to stature and weight for the child occupants are shown in Figure 3.

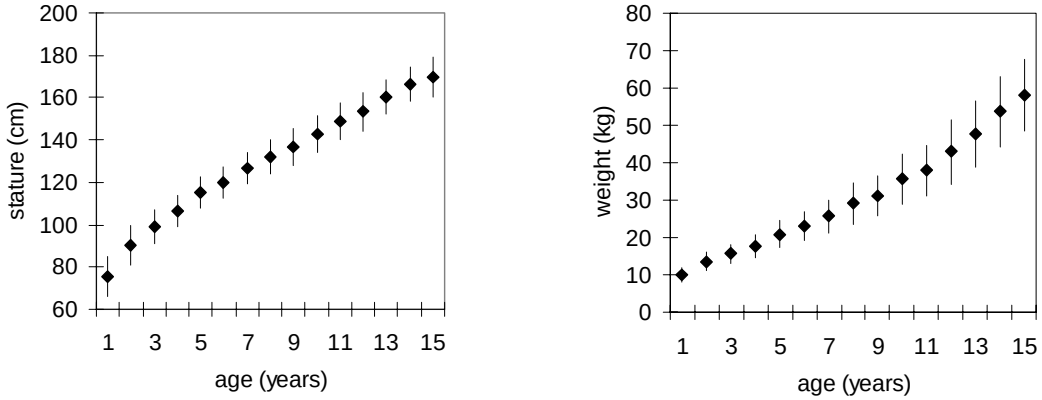

Figure 3. Variation in stature and weight, respectively, versus age; mean values and standard deviation

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). The forward facing CRS includes belt-positioning booster cushions (including integrated built-in cushions) and booster seats. In all forward facing CRS in Sweden, the child together with the CRS is restrained by the adult seat belt. The number of children travelling in the different restraint systems and seating positions are shown in Table 1. The distribution of crash types is shown in Table 2.

Table 1. Number of child occupants with respect to seating position and restraint usage; seat belt only, rearward facing CRS (rwd CRS), forward facing belt-positioning child seat (fwd seat), 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	24	18	27	*89*
seat belt	560	527	238	625	*1950*
unbelted	16	58	41	53	*168*
rwd CRS	350	20	22	56	*448*
fwd seat	37	71	13	99	*220*
cushion	104	286	37	292	*719*
int cushion	0	2	23	5	*30*
Total	*1087*	*988*	*392*	*1157*	*3624*

Table 2. Distribution of crash types.

Crash type	*Number of child occupants*	*Distribution of crash types*
Frontal impacts	1404	39 %
Side impacts	853	24 %
Rear end impacts	356	10 %
Multiple impacts	292	8 %
Run off road	77	2 %
Side swipes	70	2 %
Rollovers and turnovers	184	5 %
Multiple events	199	5 %
Large animals	165	5 %
Other	24	1 %
	3624	

For comparison, a subset of adult passengers are extracted from the database. A total of 3373 front and rear seat passengers aged 20 to 40, involved in crashes occurring between the years 1987 and 2004 are selected.

FINDINGS AND DISCUSSIONS

Differences adult and child passengers

When compared to 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, pelvis and lower extremities (Figure 4). The figure shows the distribution of injuries for all impact situations. Considering frontal impacts only, the injury rate for abdomen is even higher for children than for the adults.

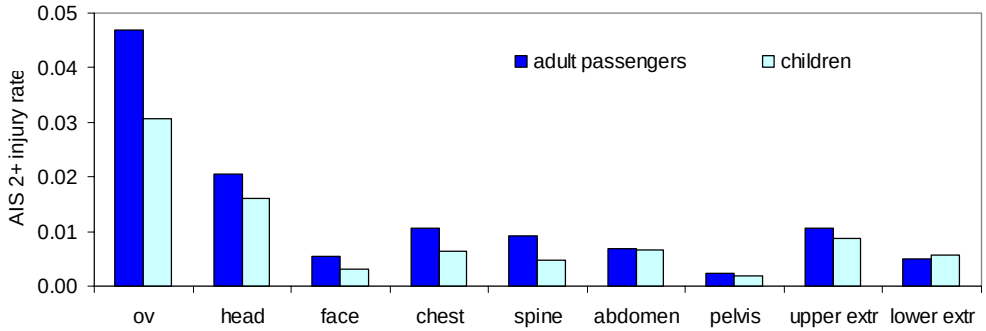

Figure 4. AIS 2+ injury rates (overall and per body part) for restrained adults in passenger seats (age 20-40y, N=3373) and restrained children (age 0-15y, N=3332), all impact situations, accident years 1987-2004.

Restraint system effectiveness

In Figure 4 all restrained children are included. Several of these are not using the recommended child restraint system for their age and size. Over the last decades, the total protection of children has increased, which is a combination of the increased usage (Figure 1) and the performance of the child restraint systems. In Isaksson-Hellman et al (1997), the injury reducing effect was shown to be very high using a child restraint system; 96% for rearward facing CRS, 77% for forward facing CRS and 59% for seat belt only. Thus the possible protection performance has high potential, considering all children travel in the best possible restraint for its size and age. In order to achieve this, not only good systems, but widely spread information regarding these systems is necessary. Also, in order to enhance a totally good effectiveness, a correct usage (such as correct attachment and tightened belt) is necessary as well. This dataset does not contain any information regarding misuse but other studies have found this to be a significant issue.

Injuries to restrained children

Among the 3332 restrained children there were 668 children with MAIS 1 injuries and 102 with overall maximum AIS (MAIS) 2+ injuries. Five of the 102 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 AIS2+ injuries to the head, chest, lower and upper extremities.

As can be seen in Figure 5, the AIS2+ injuries to the children in forward facing CRS are mainly head injuries. Injuries to the other body parts are found in frontal impact, however in side impacts only a few injuries beside head injuries are found.

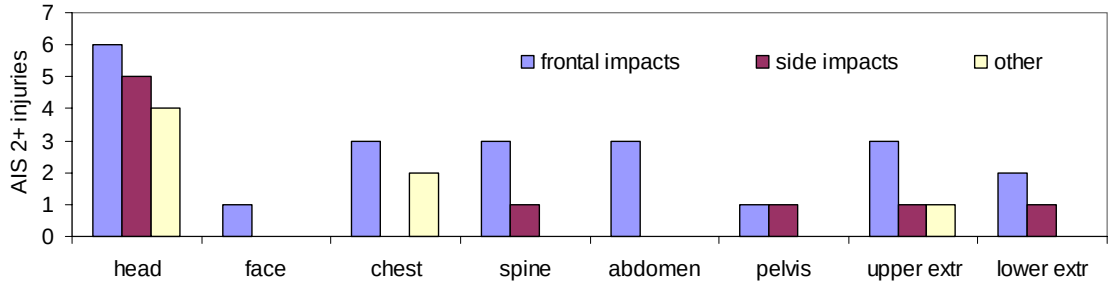

Figure 5. Number of AIS2+ injuries to children in forward facing CRS (N=25) separated in body parts and impact type.

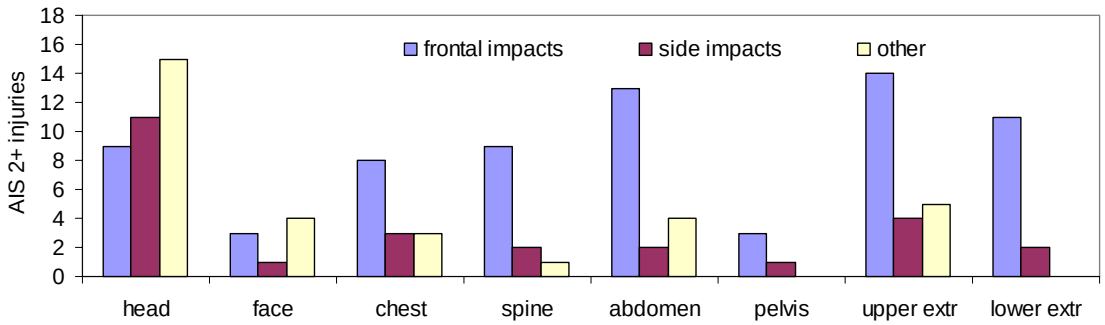

Figure 6. Number of AIS2+ injuries to children in seat belt only (N=72) separated in body parts and impact type.

Among the MAIS2+ injured children restrained by seat belt only, 128 AIS2+ injuries were found. As can be seen in Figure 6, injuries were found to all body parts. For all forward facing children, upper and lower extremity injuries are among the most frequent AIS2+ injuries, especially for children using seat belt only. The mechanisms of these injuries are, however, probably not unique for children.

The following situations and injuries are highlighted and will be discussed further:

- Rearward facing CRS offers good protection
- Head injuries in frontal and side impacts
- Abdominal injuries in frontal impacts

The growing child is an important aspect when designing child restraint systems. The highlighted areas above will be discussed further down with respect to occupant size and age, and when possible, with respect to impact severity. As can be seen in Figure 7, one of the most important factors influencing injury outcome is impact severity. Figure 7 shows the distribution of Equivalent Barrier Speed (EBS) versus degree of injuries in frontal impacts. Frontal impact accounts for 39% of all cases in this material and 45% of all the MAIS 2+ injured occupants.

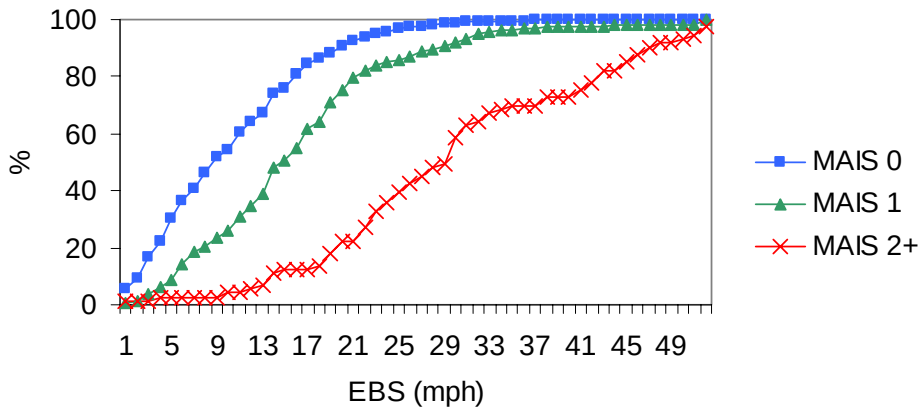

Figure 7. Cumulative distribution of EBS versus uninjured (MAIS 0), MAIS 1 and MAIS 2+ injured occupants in frontal impacts.

Rearward facing CRS

The children travelling in rearward facing CRS in a frontal impact are plotted in Figure 8 with respect to EBS and age, weight and stature.

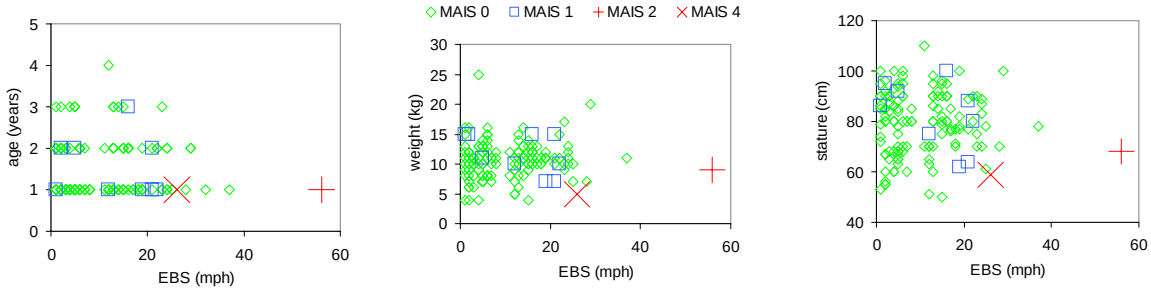

Figure 8. Distribution of injured (overall injury) and non-injured rearward facing children in frontal impacts, EBS vs. age, weight and stature. An injured (MAIS 4) two year-old child with unknown weight and stature is outside the graph (very high EBS).

As can be seen in Figure 8, the majority of all children in rearward facing CRS are uninjured, even at relatively 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 rearward facing in the front passenger seat and sustained severe head injuries due to local intrusion. As demonstrated by Figure 8, the rearward facing seat offers a good protection for the small child in a frontal impacts. In this dataset, frontal impacts account for three of five children with MAIS2+ injuries. The other two were injured in multiple accidents with somewhat uncommon situations.

Head injuries in frontal and side impacts

Head injuries is the most frequent injury type for forward facing children, (Figures 5 and 6). In Figure 9, head AIS is plotted for EBS vs. age, weight and stature for forward facing children in frontal impacts. As can be seen, EBS has the largest influence on AIS2+. The two-year old (in a forward facing CRS) with head AIS 6 at low EBS sustained the typical fatal combination of head injury and cervical spine fracture. This case typically illustrate the vulnerability of the neck and head for small children in forward facing restraints.

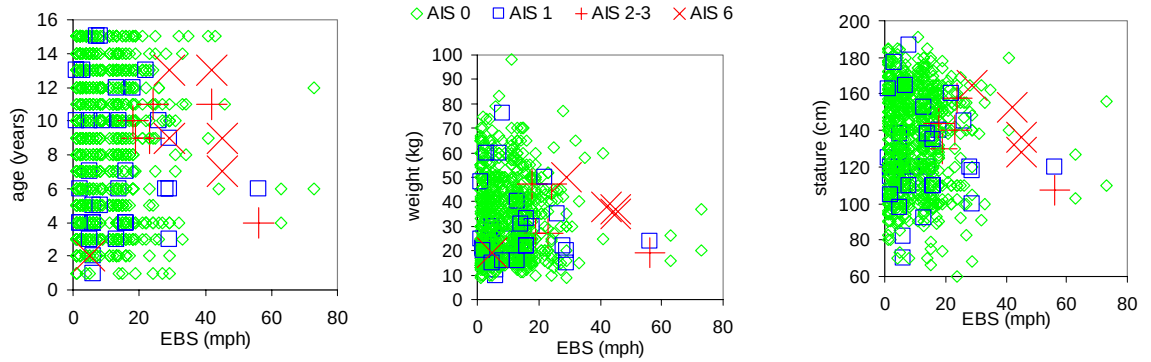

Figure 9. Distribution of head injury AIS for forward facing children (forward facing CRS as well as belted only) in frontal impacts, EBS vs. age, weight and stature.

For children restrained by seat belt only (Figure 10a), head injuries resulting from side impacts are somewhat distributed towards older and taller children. This is not as obvious when using forward facing CRS (Figure 10b). The head injuries are in most cases sustained by the occupant impacting hard structure. This injury mechanism is not unique for children.

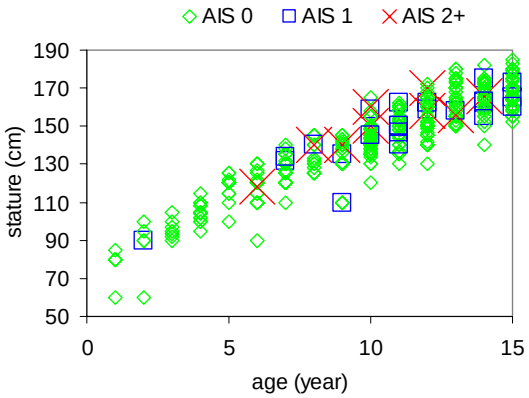

Figure 10a. Distribution of head injury AIS for children restrained by belt only in side impacts, stature vs. age.

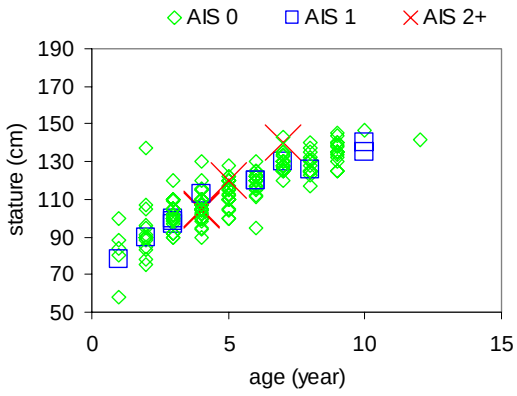

Figure 10b. Distribution of head injury AIS for children in forward facing CRS in side impacts, stature vs. age.

Abdominal injuries in frontal impacts

The distribution of abdominal injuries can be seen in Figures 11a,b for children in frontal impacts, belted only and in forward facing CRS, respectively. Abdominal injuries of AIS2+ is found at higher EBS. AIS2+ abdominal injuries is less frequent if the child is restrained in a forward facing CRS as compared to belted only. It is recommended for children up to the age of 10 to use a belt-positioning forward facing CRS. However, even the 11-12 year old children would probably benefit from such a device.

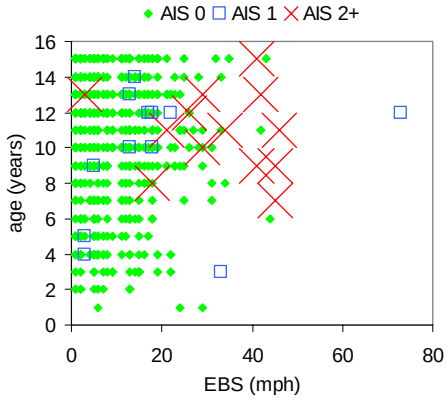

Figure 11a. Distribution of abdominal injury AIS for children restrained by belt only in frontal impacts, EBS vs. age

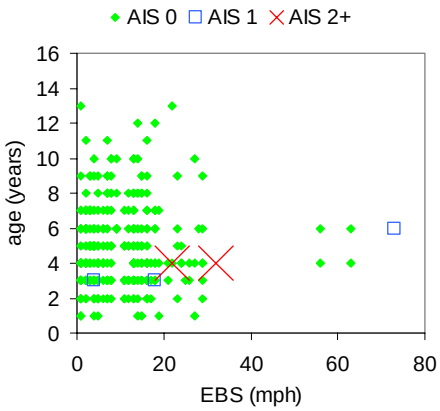

Figure 11b. Distribution of abdominal injury AIS for children in forward facing CRS in frontal impacts, EBS vs. age.

Safety for the growing child

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. In this paper, the good performance of rearward facing CRS is demonstrated. A rearward facing child restraint system is recommended as long as practically possible, at least to the age of 3-4 years for children of mid-size. This type of child restraint system is needed to support the proportionally larger head and the weak and not fully developed neck in case of a frontal impact. Older and larger children who are facing forward have specific needs as compared to adults, especially with regard to possible abdominal injuries in case of a frontal impact. Depending on the seat belt geometry and the size and age of the child, a belt-positioning CRS is needed to reduce likelihood of belt-abdomen interaction by slipping over the pelvis.

The injury reducing effects of the child restraint systems are high. However, the total injury reducing effect would increase if all children 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.

REFERENCES

Isaksson-Hellman I, Jakobsson L, Gustafsson C, Norin H. Trends and effects of child restraint systems based on Volvo's Swedish Accident Database. *Proc. of Child Occupant Protection 2nd Symposium*, SAE-973299, 1997

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