REAR SEAT SAFETY FOR CHILDREN AGED 4 AND ABOVE – A NEW INTEGRATED 2-STAGE BOOSTER CUSHION

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ABSTRACT

Safety benefits are seen if children aged 4 to 12 use booster cushions. The aim of this study is to present a new rear seat design, including integrated 2-stage booster cushions together with progressive load-limiters and extended inflatable curtains.

The integrated 2-stage booster cushion, launched 2007 in Volvo V70 and XC70, is an evolution of the first generation integrated booster cushion introduced 1990. The 2-stage booster cushion is designed to help an even better fit to more sizes of children. In its high position, the seat belt fit, ride comfort and visual aspects for the smaller children are taken into consideration. In its low position it offers a more adapted thigh support (reducing likelihood of slouching) for the larger children, as compared to when using the adult position. Recommended use of the cushion is for children aged from 4 years to 10-12 years old. Together with the integrated 2-stage booster cushions, the seat belts are equipped with pretensioners and progressive load limiters, which are adapted for the child.

The total safety performance of the new integrated 2-stage booster cushion with progressive load limiter is a combination of usage rate, misuse aspects and crash performance. It is anticipated that the usage will increase due to availability and ease of use, increased acceptance from older children and comfort. Clinics have shown that misuse is less likely using integrated boosters as compared to accessory boosters. The crash performance will be enhanced by more adapted seating position and belt fit, reduction of misuse and by the, for the child, adapted pretensioner and progressive load limiter as well as increased coverage area of the inflatable curtain.

The integrated 2-stage booster cushion and the progressive load limiter working as a system has potential for increased safety by attracting increased usage by a larger span of child occupant sizes together with a more adapted crash performance.

INTRODUCTION

The development of child restraint systems for cars began in the early 1960's. 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) and Jakobsson et al. (2005) showed a clear upward trend of steadily increased safety for children in cars during this time period in Sweden. This was due to the increased frequency in the use of restraints, and the development of effective child restraint systems.

Belt-positioning boosters

Belt-positioning booster cushions were introduced in the late 1970's (Norin et al. 1979). Today, there are three main belt-positioning boosters; booster cushions, booster seats (including seat backs) and integrated (built-in) booster cushions. The systems are used with the adult seat belt which restrains both the child and the booster. The integrated boosters 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 1991 onwards, in the mid-seat or outboard position (depending on car model) and always with 3-point seat belts.

A 4-year-old child has specific car safety needs. The iliac spines of the pelvis, which are important for good lap belt positioning and to reduce the risk of belt load into the abdomen, are not well developed until a child is about 10 years old (Burdi et al. 1968). The development of iliac spines, in conjunction with the fact that the upper part of the pelvis of the seated child is lower than that of an adult, are realities that must be taken into consideration in the booster design.

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 (guiding horns); keeping the belt in position during a crash by restraining the booster. This feature is not necessary for integrated boosters. The booster also sets the child in a more upright position and more adaptive thigh support, so he/she will not scoot forward in the seat to find a more comfortable leg position when seated. Slouching may result in sub-optimal belt geometry (DeSantis Klinich et al. 1994). Other advantages of belt-positioning boosters are, by sitting higher the shoulder part of the seat-belt will be more comfortably positioned over the shoulder of the child and thus, the child will also have a better view.

Rear seat safety development

Safety standards for passenger cars have been steadily improving for several decades, even in the rear seat. Three-point belts in the outer seating positions in the rear seat were introduced in the late 1960's. Three-point retractor belts were introduced on some markets in 1972 and in 1975 became standard for Volvo cars in all markets. A further improvement to the rear seat was the anti-submarining floor ridge introduced in 1982 in the Volvo 760 model (Lundell et al. 1981). In the rear centre seat the lap-belt was the only belt available for several years. However, improvements to the rear centre belt began in 1986, with the introduction of a three-point belt and head restraint for the centre seat as an accessory on the Volvo 700 saloon model (Karlbring and Mellander 1987). This became standard equipment for the rear centre seat starting with the Volvo 900 saloon in 1990 (Lundell et al. 1991) and estates in 1992 (Lundell et al. 1994). All new Volvo models are fitted with them still. Height-adjustable head restraints were introduced with the three-point belts in the rear centre seat. These were necessary prerequisites for the integrated booster cushions offered as an optional feature (Lundell et al. 1991 and 1994). The present study takes us to the next generation of rear seats for children, enhancing protection further.

The aim of this study is to present and evaluate the safety potential of a new rear seat design, including 2-stage booster cushions together with progressive load-limiters.

NEW INTEGRATED 2-STAGE BOOSTER CUSHION WITH PROGRESSIVE LOAD LIMITERS

The 2-stage booster cushion, Figure 1, has evolved from the first generation integrated booster cushions as introduced in 1990. The 2-stage booster cushion was designed to provide an even better fit for an even broader range of sizes of forward facing children. In its high position, the seat belt fit, ride comfort and visual aspects are taken into consideration. In its low position it offers a more adapted thigh support (reducing likelihood of slouching) for the larger children, as compared to when using the adult seat position. Recommended use of the cushions is for children aged from 4 years to 10-12 years old. The technical description and handling of the booster is found in Jakobsson et al. (2007).

Figure 1. The new integrated 2-stage booster cushion, low and high position, respectively

Figure 2. Photo of two children using the integrated 2-stage boosters.

In its low position, the integrated booster is designed for larger children, fitting children 115-140 cm / 22-36 kg. In its high position, the booster fits children 95-120 cm / 15-25 kg. Figure 2 illustrates the belt fit for two children of different sizes using their most adaptable stage of sitting.

The thickness of the foam has been chosen to give adults sitting on the booster in its folded down adult position as good comfort as possible. Adults, being heavier than children, require thicker foam to be comfortably seated. A lot of care has been taken not to jeopardize adult comfort. Therefore, the booster cushion has been designed to the lowest possible height so that the comfort foam can be as thick as possible and that the step between the rear seat foam and the booster foam is not perceived. The packaging size of the 2-stage booster is equal to the first generation of booster, providing an equal level of adult comfort.

An attitude and handling focus group session was performed using 17 children aged 7 years old and their parents testing both accessory and integrated boosters (Bohman et al. 2007). The integrated booster was rated good with respect to ease of use, fast to buckle up, the user feeling secure when handling, no lap-belt misuse and stability when entering/leaving the car. The new 2-stage integrated booster offers these benefits and adds further benefits for adapting the seat to both smaller and older children.

One of the main functionalities of the booster is to offer the child a more adapted thigh support. Anthropometry data of children's thigh length (from the buttock to the inside of the knee) is shown in Figure 3. As can be seen, almost no children aged 12 years or under have a thigh length that allows them to sit comfortably in the adult seat. Thus, slouching is a very probable effect of attaining comfort for many children if using an adult seat. The booster, which is shorter than the adult seat, will allow the child's knees to bend comfortably at the edge of the booster and encourage a more upright and safe sitting posture.

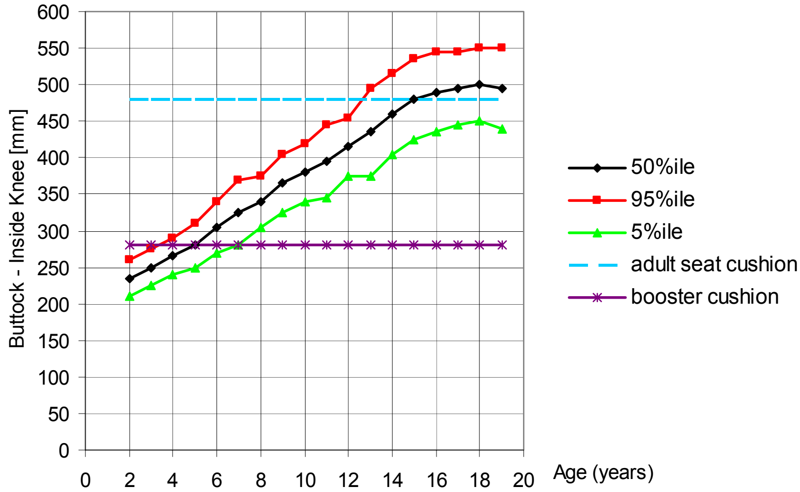

Figure 3. Buttock to inside knee length for children and young adults (ref Pheasant 1986). Upper horizontal line is the adult seat cushion depth. The lower horizontal line is the booster cushion length.

Another functionality is the raising effect of the booster and this aspect in side impacts. The average eye heights for children of different ages when seated are plotted in Figure 4, showing the three different positions; adult seat, stage 1 and stage 2 respectively. In this Figure, the lower coverage level of the inflatable curtain (IC) is indicated. Due to initial seating posture and kinematics during a crash, this level is approximate and serves only as an indication. As can be seen, the gain in height using the booster as compared to the height of the adult seat will offer children better adaptability of the safety systems of the car.

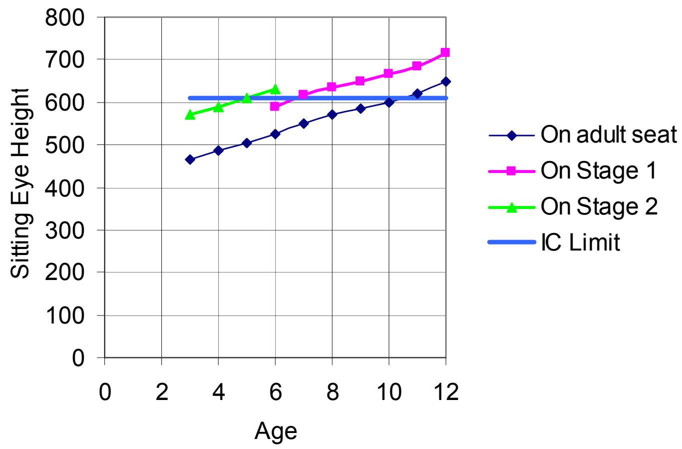

Figure 4. Eye height for children when seated (50%-ile boys, ref Pheasant 1986). Horizontal line is the approximate level of the Inflatable Curtain (IC).

There are also well-being advantages with using boosters such as in the higher positioned boosters even the younger children can look out through the side window and thereby enjoy the ride more. It not only calms the child but can induce feelings of harmony and happiness. As a result they are less likely to 'distract' the driver. In a large questionnaire based survey conducted in Australia, 71% of the children traveling in boosters reported that they liked being elevated so they could look out of the window better (Charlton et al. 2006).

Together with the integrated 2-stage booster, the seat belt is equipped with a pretensioner and load limiter to further enhance the crash performance. The pretensioner is pyrotechnical with increased pretensioning effect compared to the existing V70 introduced 1999. Increased pretensioning effect is introduced to further remove initial slack in the belt system at the early phase of the crash.

The first stage with low load limiting is initially active when the seat belt is loaded during impact. After a certain turning angle of the seat belt's bobbin, the first stage is locked by a mechanical sleeve and the higher load limiting level is active for the rest of the impact.

Progressive load limiting allows the occupant to experience improved crash performance depending on weight of the occupant and crash severity. The setting of the progressive load limiter and the design of the integrated booster cushion is based on extensive frontal impact testing using different dummy sizes and impact severities. The aim was to achieve a robust performance for the variety of occupant sizes and severities, especially focusing on children, who represent almost 50% of all rear seat occupants. Although designed for children aged approximately 4 to 12, the child dummy sizes used in the testing are the existing 3, 6 and 10--year-old child dummies.

SAFETY POTENTIAL PREDICTION

The importance of a belt-positioning booster for forward-facing children, to avoid abdominal injuries caused by the abdomen slipping under the belt, has been shown in several studies (DeSantis Klinich et al. 1994, Isaksson-Hellman et al. 1997, Hummel et al. 1997, Warren Bidez and Syson 2001, Durbin et al. 2003). The overall effectiveness (MAIS 2+) of boosters is estimated as 31% as compared to using seat belt only and as high as 75% as compared to no restraint at all (Jakobsson et al. 2007). Getting all children of appropriate age and size to use boosters offers a potentially substantial safety benefit.

Booster usage varies greatly for different countries. Less than half of the children aged 4 to 12 in Volvo cars in Sweden use boosters (Jakobsson et al. 2007). For those above 7 only 15% use a booster. In a questionnaire based survey in Australia (Charlton et al. 2006), which covered 700 parents with children 4 to 11 years old, 42% of the children included in the survey were appropriately restrained based on the height criteria (<140cm should use boosters). Data from the US shows a substantial increase in booster usage in the 4 to 8 year age group from 4% in 1999 increasing to 27% in 2004 (Arbogast and Winston 2006). Although the trend is positive, the overall booster use rate in the US is low and the booster seat use of children above 8 years of age also needs to be addressed (as illustrated in Figure 3). In a study conducted in Spain only 9% of children aged 6 to 12 used child restraints (unspecified type) (Tejera 2006).

Field data from integrated boosters (Jakobsson et al. 2007) indicate that the acceptance of integrated boosters seems to be higher for older children as compared to accessory boosters. It can then be speculated that by offering an integrated booster, usage will increase along with the overall potential safety benefit.

For the children using boosters, different types of misuse affects the performance. The frequency of misuse varies depending on which study is analyzed, but the share is substantial. According to a study carried out in the US by NHTSA (2004), 39.5% of the 664 children inspected in belt-positioning boosters were considered as critical misuse. The most commonly occurring cases of misuse were improper fit of shoulder belt followed by loose belt, improper fit of lap belt and inappropriate age/fit. Morris et al. (2000) studied 164 children in belt-positioning boosters in the US and identified misuse in 20% of the cases. The most common misuse was incorrect positioning of shoulder belt, followed by child inappropriate in size, inappropriate seat belt for booster and seat belt routed incorrectly. In Germany, the misuse rate for booster cushions was reported to be 46.8% according to a study by Fastenmeier and Lehnig (2006). A Spanish study carried out as a part of the EU-project CHILD, identified that nearly 50% of the children, aged 6 to 12 restrained with a child restraint (unspecified type), had some type of misuse (Tejera 2006). The most common misuse was having the seat belt placed behind the back of the child. Data from France in the same study indicates figures of booster misuse as approximately 65%. The most commonly occurring cases of misuses were lap belt over belt guiding, twisted seat belt and seat belt behind the back.

In an attitude and handling focus group study, all children questioned (7 years old) managed to handle the seat belt correctly in the integrated booster, while 5 out of 7 had incorrectly handled (misused) the belt with the accessory boosters (Bohman et al. 2007). Using a Hybrid III 6-year-old dummy with incorrect belt routing over the guiding horn of the accessory booster in a frontal impact test, it was shown that when the lap belt was above both guiding horns, the dummy slid off the booster causing the dummy to submarine with potential abdominal injuries as a result (Bohman et al. 2006). Integrated boosters have an advantage with respect to this type of misuse, since no such guiding horns are needed. With regard to incorrect belt routing of the shoulder belt because of discomfort, the integrated booster has been designed in conjunction with the seat belt geometry which could potentially reduce this type of misuse. A 2-stage booster increases this potential by further adapting the seat belt geometry to different sizes of children, as illustrated in Figure 2.

A questionnaire based study on 4 to 11-year-old children in Australia (Charlton et al. 2006) reported that one of the reasons for moving the child from booster to adult seat belt only (69%) was primarily that the child was too big for the booster. Other major reasons were that the child disliked sitting in a booster, the child had reached the upper weight limit recommended, the child would be more comfortable using a seat belt only and that the child thought they were too 'grown-up' for a booster. The study concludes that the design of boosters should have the capacity to seat bigger children as well as being more appealing to children. Children do not grow in distinct steps and they naturally strive to be seen as 'grown-up'. This is important and not always in line with using the same child safety system from the ages of 4 to 10-12. By offering a two-stage concept, integrated in the car, it is believed that the level of acceptance will increase and thus enhance overall protection.

One reason for abdominal injuries for children using a seat belt only is the phenomena of slouching (DeSantis Klinich et al. 1994). If thigh length is shorter than the seat cushion, slouching is natural to increase comfort. As shown in Figure 3, not many of the children below 12 will sit upright with knees bent comfortably when using the adult seat only. The low stage of the new booster is for children 6 years and above. It is designed to be comfortable for this group and should reduce the likelihood of slouching as compared to adult seating position, thus increasing safety.

The performance of belt pretensioners and load limiters for child protection was illustrated by Bohman et al. 2006 and van Rooij et al. (2003). Using a Madymo HybridIII 6-year-old dummy, van Rooij et al. showed that the combination of a belt pretensioner (to tie the child to the vehicle deceleration at an earlier phase) and a force limiter (to limit peak chest loading) was very beneficial. Head, neck and chest values were substantially reduced when compared to the reference; a reduction of 15% to 70%. Bohman et al. (2006) used a Hybrid III 6-year-old dummy and four different types of boosters (one integrated), comparing the effect of a pretensioner and a load limiter. Adding a pretensioner to the standard retractor reduced the chest acceleration from 16-25%, HIC_{15} 42-47%, N_{IJ} 0-24% and neck tension 10-17%, having a limited effect on the chest deflection. Adding a load limiter to the pretensioner, the chest acceleration and neck loadings were further reduced. Additionally the effect of load limiting reduced the chest deflection by 23% and 27% compared to a standard retractor for the accessory boosters and the integrated booster, respectively. The HIII 6-year-old dummy was best protected using an integrated booster and seat belt with pretensioner and load limiter (reductions from 21 to 50% compared to worst condition). The integrated 2-stage booster with the progressive load limiter will, as a system, enhance performance across a wide range of occupant sizes and impact severity, thus increasing overall protection.

When introducing the world's first integrated booster (Lundell et al. 1991) tests were presented showing the differences in performance between integrated boosters and accessory boosters. Bohman et al. (2006) found that when comparing an integrated booster and an accessory booster, the integrated booster offers a more direct coupling to the seat belt system, without slack introduced by a loose cushion. In addition, the lap belt force with an integrated booster was lower than the lap belt force with an accessory booster. Most types of boosters offer good protection if used correctly. But knowing that correct usage is not always the case, the robustness for misuse is an important aspect of the safety of a booster.

Jakobsson et al. (2005) showed that head injuries were the most frequent injuries to children in side impacts and the head injuries sustained by children were of similar types and mechanisms as for adults. Using the integrated booster, children will gain height (Figure 4) and thereby enhance adaption to the safety systems in the car in a side impact as compared to sitting on the adult seat. Integrated systems designed to perform with the rest of the car safety systems will increase overall protection.

The total safety prediction of the new integrated 2-stage booster with progressive load limiter cannot be calculated in absolute numbers at present. However, overall protection is expected to increase as usage increases, by increased acceptance and comfort, together with the safety performance of a robust and adapted system.

DISCUSSIONS

The protection of the growing child in the car is a question of designing child-restraint systems specifically for the needs of the child. A child's age, size, and even feelings are important aspects with regard to the specific needs. For the children in the age group of 4 to 10-12, restraints need to compensate for the development and size of the pelvis to accommodate belt geometry for good protection during a crash. This study presents an appealing way of pleasing the needs of the growing child.

In order to avoid abdominal injuries by the abdomen slipping under the belt during a frontal impact it is advisable for children up to the age of around 10 to 12 years old to use belt-positioning boosters. Data from different places in the world shows that, at present not many children above 7 use boosters, even though thigh length and pelvis size and development is not compatible with an adult seat. Safety potential is substantial if booster usage is increased worldwide and by offering an integrated 2-stage booster in the car, the availability, functionality and acceptance is anticipated to result in an increase, although it is difficult to state this in absolute numbers.

For those using boosters, the misuse factor is substantial. Worldwide, the most common booster misuse factor is incorrect routing of the seat belt. Studies have shown that integrated boosters are found to be easier to use for lap belt positioning. The 2-stage system is believed to further adapt to the different sizes of children for shoulder belt comfort and placement.

This study presents an integrated 2-stage booster with progressive load limiter. This is a result of many years research in child safety and safety of the rear seat occupants, and a natural step in rear seat safety development at Volvo Cars. In a study in 1997 (Isaksson-Hellman et al.), it was concluded that the safety systems available offered good protection and that the areas of concern were; not using the restraints or not using the appropriate restraint for the child's age and size. The importance of adapting the child safety system to the growing child, when considering both acceptance and performance, is anticipated to make a positive impact on better overall safety.

CONCLUSIONS

The study presents a new rear seat safety concept for enhanced overall protection for children aged 4 to 10-12. The integrated 2-stage booster and the progressive load limiter working as a system has the potential to increase safety by encouraging increased usage by a large cross-section of child occupant sizes together with a more adapted crash performance for the children.

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