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Improving Rear Seat Safety—A Continuing Process

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Abstract

This paper will give an overview of the safety of the rear seat of passenger cars. Accident experience for the rear seat, involving unbelted occupants and occupants wearing three-point belts and two-point lap-belts, will be summarized. Different means of improving the safety of the rear seat for both children and adults, in particular the centre position, will be discussed. The three-point retractor belt is an important safety item, which in some car models has been available for the rear outer seating positions for several years. This has not been the case for the rear centre seating position. Two different types of three-point retractor belts for the centre position in sedan models will be presented. A child cushion integrated in the folding armrest in the centre position will be described. This child restraint has recently been introduced for sedan models and is used together with a standard fitted three-point belt.

Introduction

Safety in passenger cars in industrialized countries has steadily increased for many years. There are several reasons for this. Naturally overall changes such as improvements in the traffic system and in the structure of the cars have affected safety.

The development of the interior protection systems has also had a large influence. These have become more effective as seat belts have improved and in certain cases are equipped with pretensioners, and new protection systems in the form of airbags have been added.

Legislation regarding the installation and usage of restraint systems also influences the total safety. Legal requirements regarding the mandatory installation of seat belts have been introduced in many countries, e.g. requirements regarding the installation of the three-point belts in the rear seat. Requirements regarding the mandatory usage of seat belts also exist in many countries.

Safety in the Rear Seat

During this development, the measures intended to increase safety have, in most cases, applied to the front seat. Safety in the rear seat has lagged a few steps behind but front seat development has helped to call attention to the rear seat as well.

Perhaps the most important means of increasing safety is through the usage of the seat belt. This was shown in a report regarding just this, presented during the 8th ESV Conference in 1980 (1). It was based on traffic accident information obtained from 2000 relatively serious accidents involving Volvo cars with rear seat passengers in Sweden. All the cars were equipped with three-point belts in the outer positions and a lap-belt in the centre position. The injury-reducing effect[1] of the belt for injuries in the AIS 1-6[2] range was 52% for children (1-14 years) and 28% for adults (>14 years).

Krafft et al showed at the 12th ESV Conference in 1989 (2) an injury-reducing effect for children of over 50% and for adults of 22-55%. NHTSA, in its Final Rule for requirements regarding the fitting of three-point belts in the outer positions of the rear seat, estimated that lap shoulder belts are 41% effective in reducing the risk of death (3).

In many countries, requirements already exist stating that passenger cars shall be equipped with three-point belts in the outer positions of the rear seat, e.g. Sweden since 1969, USA since December 1989. On the other hand, unfortunately, many still lack requirements regarding installation of belts in the rear seat. Safety will also be improved if car manufacturers fit belts in the rear seat of a higher standard than those laid out in the legislation of the respective countries. Volvo cars in the 200 400 700 900 800 series, for example, have three-point belts in the outer positions of the rear seat as standard for all markets since the introduction of these models. This means, for example, for the 200 series since 1974. In other words this also applies to those markets where the installation of such belts is not a legal requirement.

The mandatory usage of belts in the rear seat is the law in several countries. In Sweden this has been the law since July 1986.

An analysis of Volvo's traffic accident material up to 1990 has been carried out regarding the proportion of passengers in the rear seat and the frequency of seat belt usage in the rear seat. In total, the material contains information for over 15 000 accidents. All types of accidents are included in the data. A summary of the results for the outer positions in the rear seat is shown in Table 1.

It is clear from Table 1 that the frequency of belt usage has increased markedly during the interval 1986-1990 compared with earlier. We have found that the greatest reason for this has been our law regarding mandatory usage of rear seat belts. The figures for usage during 1986-1990 can be somewhat too high since they

[1] The injury-reducing effect (e) is defined as $e = \frac{\text{injury rate, unrestr. - injury rate, restrained}}{\text{injury rate unrestrained}}$

[2] AIS = Abbreviated Injury Scale.

Table 1. Seat and Belt Usage for Rear Outer Seating Positions (Three-Point Retractor Belt)

Year	1976-80	1981-85	1986-90
No. of accidents	3006	3580	9295
No. of occupants	674	942	1894
No. of belted occupants	74	251	1545
Average usage of left & right seats (%)	11.2	13.2	10.2
Belt usage (%)	11	27	82

are based on the occupant's own information, and can be assumed to be exaggerated after the arrival of the law in 1986.

In order to create a safe environment in the rear seat it is, of course, not only important that belts exist in the car, and are used, but also that they provide effective retention during an accident. Good retention requires an optimised belt and also a good shape of the seat cushion and floor. One example of the latter can be given in Volvo's 700 and 800 series, where the floor under the front edge of the cushion has been raised to help prevent submarining (4).

A comfortable seat belt also contributes to increased usage and in this way an improvement in the total safety. The ESV report from 1980 by Norin et al shows that the frequency of usage for the three-point retractor belt in the rear seat was approximately double that for the fixed three-point belt with manual length adjustment (1).

One important reason for improving the rate of belt usage in the rear seat is that unbelted rear seat occupants increase the injury risk for front seat occupants. This has been confirmed by our own crash testing. Evans gives an estimate of 4% increased fatality risk for front seat occupants caused by unbelted rear seat occupants (5).

The Safety of The Rear Centre Seating Position

The measures introduced to increase safety in the rear seat have, for the most part, applied to the outer positions and not the centre position. One essential reason is that it is difficult to equip this position with a three-point belt, because it is difficult to find an upper attachment point for the three-point belt that gives the necessary strength as well as a good belt geometry. The fact that the measures have not been directed towards the centre position also depends upon the fact that this position is not used very often. According to Volvo's analysis of accident data, the centre position is used in approximately 3-5% of all journeys, as shown in Table 2.

A reduction in the usage of the centre position during the period 1986-1990 can be noted. There is a similar reduction for the outer positions. Apparently the average number of rear seat occupants has decreased. A definite explanation to this does not exist.

Table 2. Seat and Belt Usage for Rear Centre Seating Position (Lap-belt)

Year	1976-80	1981-85	1986-90
No. of accidents	3006	3580	9295
No. of occupants	125	182	241
No. of belted occupants	9	34	168
Centre seat usage (%)	4.2	5.1	2.6
Belt usage (%)	7	19	70

Those people who sit in the centre position in the rear of a five seat car have only had a lap-belt for protection. The three-point belt improves the situation in frontal crashes because the upper part of the body is prevented from folding forwards, thereby avoiding bending of the lumbar spine, intrusion of the belt into the abdomen and head impact. The retractor also makes manual adjustment of the lap-belt unnecessary, thus avoiding the risk of a loosely-fastened belt, which gives poor restraint. Still another advantage with the three-point retractor belt, which has already been mentioned, is that it is convenient to use and is therefore likely to increase the usage rate.

In order to show the potential for safety improvements to the rear centre position, the injury rates for the centre and outer positions are given in Table 3. These figures are based on the same accident data, involving Volvo vehicles, as Tables 1 and 2. The injury-reducing effect derived from Table 3 is shown in Table 4.

As can be seen in Tables 3 and 4, a three-point belt will provide better protection in a crash than a lap-belt. It is, however, important to point out that the lap-belt gives a substantial injury reduction compared with being unbelted.

Table 3. Injury Rate for Rear Seat Occupants

Injury rate	Central rear seat		Outer rear seat	
	Lap-belt	Unrestrained	3-point belt	Unrestrained
AIS 1-6	28.4%	33.8%	26.9%	42.9%
AIS 2-6	5.1%	10.7%	5.4%	13.4%

Table 4. Effectiveness of Rear Seat Belts

Injury rate	Lap-belt in centre seat	3-point belt in outer seats
AIS 1-6	16%	37%
AIS 2-6	53%	60%

As can also be seen in Table 3, the risk of injury to unbelted occupants is greater in the outer positions than in the centre position. On the other hand, the risk of injury to belted passengers is approximately the same in the outer positions as in the centre position. This indi-

cates that a two-point belt is not as effective in reducing injury as a three-point belt, which can also be seen in Table 4. Table 4 shows the injury-reducing effect of the lap-belt and the three-point seat belt.

As can be seen in table 4 there is a clear injury-reducing effect, both for the lap-belt and the three-point belt. However, it is greater for the three-point belt.

An estimate by Evans shows that lap-belts in the outer positions are 18% effective in preventing death (5). A corresponding estimate by Evans for lap-shoulder belts is that they are 43% effective in preventing death (6). NHTSA estimates that the rear seat lap-only belts are 32% effective in reducing the risk of death (3), while the corresponding figures for lap-shoulder belts is 41% (3).

If, on the basis of the figures in Table 4, we assume that a three-point belt has the same injury-reducing effect in the centre position as it has in the outer positions, we can expect a reduction of 25% for AIS 1-6 injuries and 15% for AIS 2-6 injuries if a three-point belt is installed instead of a two-point belt in the centre position (Table 5).

Table 5. Injury-reducing Effect of Changing from Lap-Belt to Three-Point Seat Belt in the Centre Position

Injury rate	Injury-reducing effect
AIS 1-6	25%
AIS 2-6	15%

An increase in safety for the central position of the rear seat corresponds with Volvo's continuing efforts to improve safety in our cars, and to develop our cars with three completely satisfactory positions in the rear seat regarding comfort and safety. An important step in this direction was the introduction of the three-point retractor belt and head restraint for the centre position as an accessory for the 700 series sedan cars in 1986 (7).

A three-point retractor belt in the centre position of the sedan model was introduced as standard equipment in the 900 series in August 1990 (model year 1991) and in the new 800 series in June 1991. As far as we know, this is the first time a three-point belt has been fitted as standard in the centre position of the rear seat of a passenger car. At the same time, an adjustable head restraint was introduced as standard in the same position, which has further contributed to increasing safety. The belt and head restraint are described in more detail in a later chapter.

Integrated Child Safety in The Rear Seat

The introduction of the three-point belt in the centre position of the rear seat has been a basic condition for, and has made it possible to develop, integrated child protection for this position. An integrated child seat was introduced at the same time as the standard fitted three-point belt in the 900 and 850 series sedan cars. This will be described in a later chapter.

We have chosen the centre position for an integrated child protection because this position is especially suitable for children. This position is often more uncomfortable for adults and is most often the position left over for children when all the other positions are taken by adults. In addition, children often like this position because they can get a better frontal view through the front seats. Another reason, which has been mentioned previously, is that with a three-point belt installed, the centre position becomes the safest position in the car.

The idea of integrated child protection has been presented earlier on a number of occasions. During the 12th ESV Conference in Göteborg in 1989, Renault presented an integrated child seat in the outer positions of the rear seat (8). A similar idea has been shown in Renault's concept car, Cover, presented in May 1991. Another report by Karlbrink et al from the ESV Conference in 1989 showed a protection system integrated in the backrest section of the front seat (9). Volvo also showed a prototype of the integrated child seat described in this report at the ESV Conference in 1989.

Three-Point Accessory Belt for the Rear Centre Position

As has been already mentioned, a three-point retractor belt was introduced as an accessory item for the 700 series sedan cars in 1986 (7). The retractor is fitted above the rear shelf with special brackets (Figure 1). The brackets provide the anchorage with the necessary strength and move the upper attachment point to the right height. The installation is covered with a plastic cover. The lower end of the belt is fastened in the same attachment point as the ordinary lap-belt. A head restraint as an accessory also exists for the centre position, and contributes to further increasing the safety of this position.

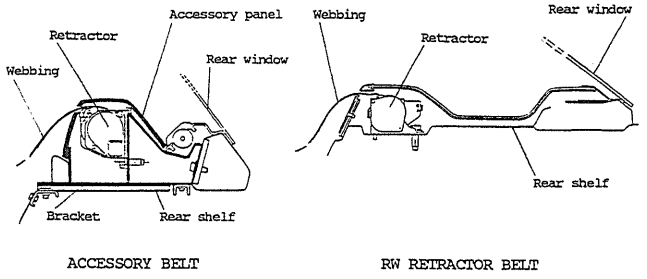

Figure 1. Installation of Retractors on Rear Shelf in 700 Series (Left) and 900 Series (Right) (Difference in Vertical Position of the Rear Shelf Between the 700 and 900 Series is Shown)

Three-Point Standard Belt for the Rear Centre Position

The technology surrounding this belt is described below. The description mainly concerns the 900 series, but the technology is very similar for the 800 series.

Conditions Concerning the Vehicle

During the concept phase of the 900 series sedan model, it turned out that the conditions gave the possibility of attaching the belt to the rear shelf, keeping a good balance between belt geometry, design, visibility and luggage space. The rear shelf provided a possible load-bearing structure for the attachment of a retractor. Therefore a preliminary concept study was initiated. One aim of the study was to place three belt retractors on the rear shelf and thereby one three-point belt in the centre position. Based on the accessory belt introduced earlier and the structural measures necessary to achieve the correct strength and geometry, the following guidelines were drawn up for a cost and weight effective solution:

- a newly developed belt retractor with inverted belt output geometry in order to achieve the correct height geometry
- fastening the belt retractor directly to the plane of the rear shelf
- legal requirements and internal Volvo requirements regarding safety, geometry and strength
- adapting the belt to the integrated child seat for children in the age range 3-10 years

Results of the Concept Study

During the development of the "Reverse Winded Retractor," the belt retractor presented special problems. The first concerns creating sufficient strength in the component parts and attachments of the retractor. Due to the fact that collision forces go directly into the retractor without a seat belt guide, these forces become greater than during a traditional installation with seat belt guide. The loads are guided into the retractor creating a greater bending moment in the attachment plane. This results in other system requirements, e.g. legal requirements, also becoming more difficult to meet. The character of the loading means that the loads into the car body structure, apart from shearing, also have a bending moment component. The development of this retractor was carried out by Autoliv Sweden. (Figure 1).

The geometry which resulted from the concept study produced the desired height position for the belt retractor for all the positions, without the need to introduce any brackets or seat belt guides. The retractor is attached directly onto the plane of the rear shelf. The rear shelf has been raised by approximately 100 mm when compared to the earlier 700 series. The desired position in the other directions (longitudinal and lateral) could also be attained based on the desired belt geometry for different passenger sizes and without conflicting with the standard fitted head restraint.

A good balance between design, visibility, luggage space, etc, was possible for the other requirements. One problem is provided by the Australian requirements for the zone for attachment points. These requirements contain a limitation regarding the position of the upper seat belt guide point rearwards in the vehicle and in our opinion provide an unnecessary limitation for a correct location of the upper attachment point in the rear seat. (Figure 2).

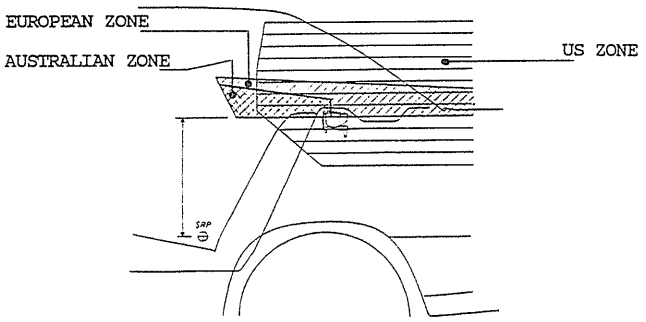

Figure 2. Attachment Point Zones According to Different Regulations

With reference to structural strength, the new concept produced new conditions for absorbing loads. Partly by the rear shelf being used as an attachment point, partly through the increased forces due to the seat belt guide not being used, and partly through the geometry of the RW retractor, apart from shearing forces, producing a bending moment. The local strength was reached on the outer positions by using load distributing brackets. The global strength for these positions was reached by taking up the loads in the body sides and wheel housing.

It became necessary to introduce a spot-welded hat profile for the centre position along the rear seat backrest in order to ensure the global strength. A local reinforcement was integrated in this reinforcement near the retractor attachment.

The results of the preliminary study were, from a cost and weight effectiveness point of view, to be able to offer a three-point belt for all three positions in the rear seat. This in combination with the standard head restraint fitted in all three positions provides fully adequate passenger seating with regard to safety and comfort. The concept also gives rise to the following advantages:

- Low friction losses when taking out and releasing the belt because there is no seat belt guide
- A good belt geometry by placing the seat belt exit from the retractor right behind the passenger's shoulder
- A height-adjustable head restraint on the centre position provides good safety for various sizes of passenger from children to adults and in addition good vision backwards when the centre position is not being used
- The possibility of an integrated child seat in the centre position
- The possibility to fit conventional child seats increases in the centre position, as child restraints requiring three-point belts can be used

The new belts fitted on the rear shelf are in production in the 900 series sedan models as from the 1991 model and were introduced in the new 800 series in June 1991.

Child Cushion for The Rear Centre Position

Conditions

One of the conditions during the development of the 900 series sedan models and the 800 series was that the armrest in the centre position in the rear seat should be able to be replaced with an integrated child cushion. The following conditions were specified (the description applies to the 900 series, but is very similar for the 800 series):

- The cushion should be able to be used for the same ages as the conventional cushions, i.e. children in the age group 3-10 years (groups 2 and 3 according to ECE Regulation 44).
- The centre position should be equipped with a three-point belt and adjustable head restraint as standard.
- The space for the cushion was limited by the outer measurement for the ordinary armrest.
- When the child cushion was folded together it should function as a normal foldable armrest.
- The cushion and armrest should have common attachment points in the car body.
- Legal requirements and internal Volvo requirements regarding safety, geometry and strength should be met.

Technical Solution

The integrated child cushion is constructed in two parts, a seat cushion and a backrest. Both have a steel framework which is cast in expanded polypropylene (EPP). The padding is glued onto the EPP surfaces. The cushion is upholstered in the same material as in the rest of the interior, and the covering is removable for washing (Figure 3).

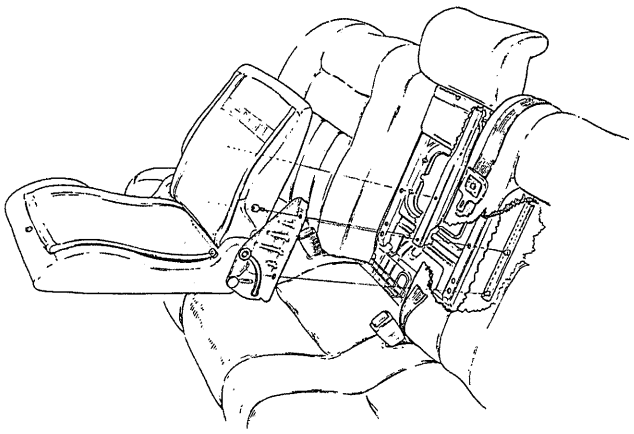

Figure 3. Child Cushion

The backrest and cushion are connected to each other by a hinge system which blocks the backrest both forwards and backwards in relation to the cushion when it is folded up. In addition, the seat cushion is locked to the car body.

All forces which occur in the cushion during a collision are absorbed by the cushion's attachments to the backrest of the rear seat. This is therefore reinforced with two brackets.

The stiffness of the cushion, brackets and backrest of the rear seat is adjusted to retain a controlled movement of the occupant during impact. This results in low injury criteria and helps prevent submarining.

One difference between the 900 and 800 vehicles is worth noting. The 800 rear seat has a narrower armrest and the width is unsatisfactory for a child cushion. Therefore, a special mechanism was developed which widens the cushion when it is unfolded.

Dynamic Testing

The development testing regarding crash safety has primarily been carried out on a sled. Most tests were done according to ECE Regulation 44. This implies specified deceleration pulses with a speed of 50 km h in frontal impact and 30 km h during simulation of a collision from the rear. In order to verify the sled tests, full-scale tests at 30 mph have also been carried out.

The dummies used are the European TNO P3, P6 and P10, i.e. corresponding to the ages 3, 6 and 10 years.

The testing has shown that the integrated cushion affords good protection to children in the age range 3-10 years, during both frontal collisions and collisions from the rear. The results show that the protection is at the same level as, and in some respects better than, a normal accessory cushion.

When comparing the integrated child cushion with the traditional child cushions, their patterns of movement differ from each other during the course of an accident. Since the integrated cushion is fixed at the rear edge, it is prevented from moving longitudinally and therefore a more controlled course of events is obtained during an accident.

During development, there was considerable variation in dummy response in certain test series. When investigating this, it was found that child dummies gave certain doubt regarding their repeatability. Since increasing resources have been invested in order to develop built-in child safety equipment, it is of the utmost importance that the measuring equipment can be trusted. Therefore the same requirements for the checking and calibration of the adult dummies should be used for the child dummies. At present this is not the case with the European dummies.

Test Results

An example of test results from sled testing according to ECE Regulation 44 and from a frontal barrier crash is given below.

The ECE regulation stipulates that the resultant chest acceleration should be below 55 g:s and the vertical chest acceleration below 30 g:s.

It should be noted that the European dummies were not originally intended for measuring head injury criteria (HIC).

Figure 6. Used as a Child Cushion in the 900 Series

Figure 7. Child Cushion in the 850 Car

During the development of the child cushion it has been observed that the integrated child protection is not consistent with the legislation in certain markets. This constitutes an unfortunate obstacle for safety development.

The testing has also indicated that the repeatability of the child dummies can be a problem. A calibration routine corresponding to that which exists for adult-sized dummies is desirable also for child dummies.

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