TRANSPORT RESEARCH LABORATORY

The protection of children in cars — final report

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Executive Summary

Child restraints are designed as accessories to be used to provide protection for children in the event of car accidents. They provide protection normally over and above that provided by the vehicle manufacturer for young vehicle occupants. They have to be attached to the vehicle structure. Under the ECE Regulation for Child Restraints (ECE Regulation 44), child restraints, as accessories, can be for one or more specific vehicles, for a limited range of vehicles or for universal use. In the latter category they are attached to the vehicle using the adult seat belt. While this has resulted in child restraints which are effective at reducing the risk of injury to their users, their attachment by means of the adult belt can cause difficulties. These difficulties can result in reduced performance and increased misuse. Alternatives in the specific vehicle category, either through special connections or through built in child restraints, can avoid these problems. However, there remains a need to develop a universal system. Such a system has developed during the course of this project; ISOFix. The development of this attachment system appears to offer the opportunity of providing a universal attachment for child restraints with improved performance and reduced misuse.

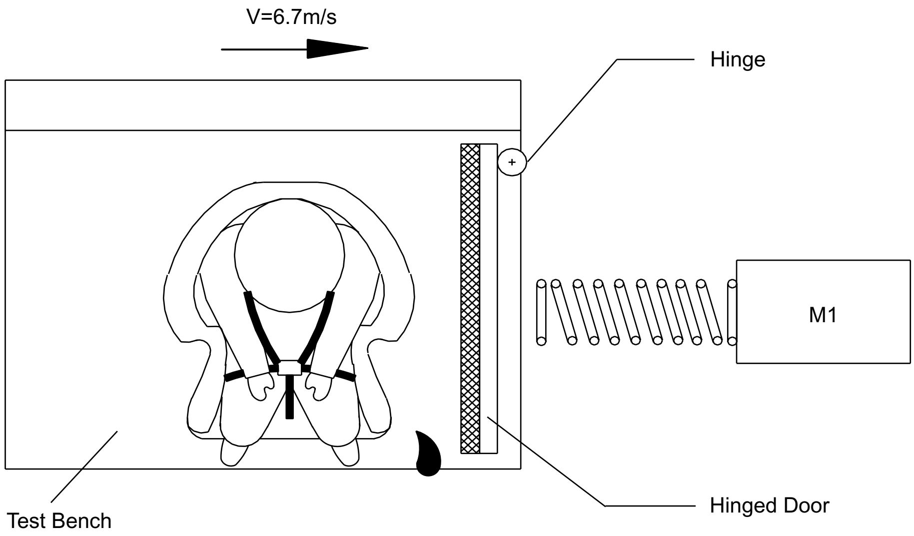
To expedite the development of such a universal system, a UK working group (UNIFix) was formed by TRL which comprised CRS manufacturers, car manufacturers and a UK university. The aim of the group was to develop a UK contribution to the international activity being coordinated through the International Organisation for Standardisation (ISO). The objectives of the UNIFix group were to develop a proposal for a system that would minimise the potential for misuse, minimise the dependence of CRS performance on the vehicle seat and to develop a standardised attachment system suitable for universal use. Initial trials led to the development of a rigid attachment system, originally with two connections to the rear and one to the front of the child seat. Further development led to the splitting of the front attachment to two anchor points. Prototypes were produced and this four point attachment system was demonstrated to result in very low misuse rates and a markedly improved dynamic performance, in frontal rear and in side impacts. The UNIFix 4-Point attachment concept was presented to ISO and was accepted as the basis for the development of the ISOFix standard.

Subsequent user trials and production cost estimates led to the conclusion within ISO that a simple system, based on just the two rear attachment points, together with an anti-rotation system, would be preferable overall. The research programme was revised to provide data on the relative merits of top tethers and pre-tensioning systems (using precompression of the vehicle seat cushion). While the pre-compression system proved satisfactory for single vehicle approval, where the vehicle seat itself formed part of the dynamic test evaluation of the whole system, the performance on a range of real vehicle seats proved too variable for universal approval. The top tether appeared to provide good anti-rotational restraint which was independent of the vehicle seat cushion properties. Technical support has been provided to the GRSP Ad-Hoc Group on ISOFix, which has reported that either the top tether or the use of a front support foot could prove satisfactory anti-rotation devices as the basis for a universal approval under ECE Regulation 44. ISOFix with two rear rigid attachments and one of these anti-rotation systems would provide a good basis for a universal system with greatly reduced misuse rates and an improved dynamic performance in accidents.

Side impacts are second only to frontal impacts in resulting in serious or fatal injuries to restrained children in car accidents. Nearly as many restrained children are killed in side impacts as in frontal impacts (35 percent in side impacts, including side swipes compared with 38 percent in frontal impacts). However, there are currently no dynamic sled test requirements for the protection of children in child restraints in Europe. TRL is working through ISO on the development of a side impact test procedure for child restraint systems as part of this Child Restraint project. The preferred method would be for a sled-based test procedure which would be as simple as possible while resulting in the development of child restraints with enhanced side impact protection that would work well in real car impacts.

In car side impacts, the side structure initially intrudes into the passenger compartment at close to the impact velocity of the striking vehicle, but the total velocity change of the struck car is only about one half of this impact velocity. TRL developed a method, which attempted to replicate the essential interactions in a real car impact. This method uses a test bench on a sled, which replicates the struck vehicle chassis acceleration, while the intruding door motion is replicated by a hinged door mounted on the sled. The research, forming part of this project, was aimed at evaluating the practicability and suitability of this approach.

Full scale side impacts performed by TRL in the development of the EEVC Side Impact Test Procedure were reviewed to provide a basis for the selection of the target chassis (sled) deceleration profile and the door velocity profile. The struck vehicle chassis accelerations were noted from accelerometers located at the base of the non-struck side B-pillars. The inner door skin velocities, relative to the undeformed car structure were calculated from the integration of the difference between the inner door skin and B-pillar lateral accelerations. The motion of the door in the experimental arrangement was generated by impacting the door with a mass-spring system. (See figure over) With this arrangement, it was found that both sled acceleration and the door velocity profiles could be generated that were very close to the proposed corridors developed from the full scale vehicle tests. The door hinge was positioned at the rear of the door to simulate the rear seating position in the vehicle or at the front of the door to simulate the front seating position.



Child restraint side impact test

Tests with this experimental arrangement demonstrated that this was a practical way to evaluate the performance of child restraints under side impact conditions. However, the motion of the door relied on its inertia and the dynamics were affected unrealistically by the presence and stiffness of the child restraint and its attachment. Also concerns were noted regarding the suitability of the P series child dummies for side impact use. This hinged door concept has been adopted as the draft ISO standard but it is recommended that the door be positively driven and that the performance of the Q series dummies is evaluated in place of the P series.

This project included accident studies at four levels. Firstly there was the questionnaire study in which forms were distributed with a sample of most child restraints sold in the UK. The analysis of these forms provided a large database of accident information, although the level of detail was restricted. At a second level, accident data from the TRL CCIS database, which gives far greater detail, were analysed. Thirdly, accidents involving a fatally injured restrained child have been analysed from police fatal accident files and coroners' reports. Finally the collection and analysis of a serious injury database has been attempted. The databases have proved to be complementary and all confirm the benefits of using child restraints. The benefits of using restraints specially designed for use by children was demonstrated, particularly where protection is provided in lateral impacts. The observations have shown the need to provide improved protection in side impacts and to avoid loading from luggage by improved seat strength.

1 Introduction

Cars are generally designed with adult passengers in mind. Safety features and restraints are all designed to provide protection for adult occupants. The protection of children is usually left for parents to ensure by purchasing and installing specially designed child restraints. Some vehicle manufacturers include child restraints in their list of accessories but the normal source for parents is the high street retailer.

Some vehicle manufacturers had started to fit 'built-in' child restraints, normally in the rear seat, by the start of this project. This was a special option choice at the time of purchase and usually was for a single child restraint seating position only. At the time that this project commenced, consideration was given to increasing the responsibility of car manufacturers for the protection of child occupants by mandating 'built-in' child restraints. However, it became clear that this was an expensive option, particularly as not all cars would be used by families with young children. An alternative, which was considered to have most of the advantages of the built-in system without some of the disadvantages, was just being considered through the International Organisation for Standardisation, ISO. This system, which offered the opportunity to plug child restraints onto specified anchorages, was being called ISOFix.

This project included the support of research needed to further the ISOFix concept to make it suitable for a fully universal child restraint attachment system which would overcome some of the problems being experienced with the existing systems. At this stage, these conventional systems relied on the adult seat belt for attachment to the vehicle structure. Adult seatbelts were designed to be a good fit for adults and this led to numerous practical difficulties for universal child restraint systems. This report describes the development of the ISOFix system during the period of this project.

Child restraints have been shown to be very effective at reducing the risk of injuries in car accidents. They are designed and tested primarily with frontal impact in mind. During the period of this project, additional padding requirements for the head in side impact contact zones were added to ECE Regulation 44. However, only frontal and rear dynamic tests are included in the Regulation. Accident studies have shown that nearly as many restrained children are killed in side impacts as in frontal impacts. Car side impact requirements, introduced in ECE Regulation 95 in 1998, do not include protective measures for children, or indeed any rear occupant. Protection for restrained children has to be provided by the child restraint itself. The interaction effects of the car acceleration and the internal panel dynamic intrusion are complex. A new test procedure would be required to evaluate the protection provided by the child restraint under these complex interactions. This project included research and development of a side impact test for child restraints as a contribution to the work of ISO on this subject. The aim is eventually to develop a satisfactory ISO standard for side impact testing of child restraints that might be suitable for inclusion within ECE Regulation 44. This report describes the research and development of the test procedure to date.

As with any study of occupant protection, it is essential to understand how children are injured or killed as car occupants in road accidents. It is also important to know how child restraints, approved to current standards, perform in accidents, so that modifications, if needed, can be made to those standards. This project included accident studies at four levels. Firstly there was the questionnaire study in which forms were distributed with a sample of most child restraints sold in the UK. The forms included questions about the restraint type, the child occupant and any injuries sustained in the accident. The analysis of these forms provided a large database of accident information, although the level of detail was restricted to that which can be requested from a parent. At a second level, accident data from the TRL CCIS database was analysed. This gives far greater detail about injuries, the vehicle and the accident, but the number of children in this database was rather small. Thirdly, it has been attempted to analyse every accident involving a fatally injured restrained child through acquisition of police fatal accident files and coroners' reports to provide information about the performance of child restraints in the most severe accidents.

In previous projects, this has been the extent of the child occupant accident studies. It has been a concern that, while the questionnaire study saw many minor accidents and the fatal injury study included the severe end of the injury range, there was relatively little detailed information about seriously injured children. This has previously been considered to be too complex and costly to undertake due to the relatively few cases seen in the UK and their wide geographical spread throughout the country. However, this project included the first attempt to generate a reasonable database of seriously injured children. This report describes the results of analyses of all of these databases.

2 Accident analyses

2.1 Analysis of child restraint questionnaire database

TRL has monitored the performance of child restraints in accidents since the early 1970's by distributing a simple accident questionnaire with some child restraints with the co-operation of child restraint manufacturers. The child restraint purchaser is requested to keep the accident questionnaire with, for instance, the vehicle log book. In the event of an accident in which a child is present (not necessarily restrained) it is hoped that the questionnaire would be completed and returned via a Freepost address to TRL.

There have been two styles of questionnaire forms to date, and two databases. The first accident enquiry form was a very simple questionnaire designed to work with a database handling software that was restricted in the amount of descriptive data that it could store. As more detailed information was needed, the form was redesigned to include some more specific details and to include recent child restraint design types. A new database was created, using software that could handle the extra descriptive data.

The new style of form is shown in Appendix A. There have, therefore, been two stages of analysis of the child accident questionnaire forms, firstly the analysis of the database containing the data from the old style forms, reported in 'The Performance of Child Restraint Systems in Accidents', (Stratford et al, 1997), and secondly the more recent analysis of the new database containing data from the revised style of forms.

This section presents the analysis of the database containing the data from the new style forms (phase II) together with a review of the principal results from the earlier analysis on the data collected on old style forms (phase I).

2.1.1 Analysis

Phase II sample is not very large. Naturally, some time will pass before sufficient accidents have occurred, involving children in the child restraints associated with the new forms. It is expected that this will be larger in future years as this is anticipated to be an ongoing study. Phase II contains details of accidents from 1995 to 1999. During this time 104 forms were returned, detailing incidents involving 151 children.

Table 1 shows the child seating position for all accidents. The majority of the children in phase II, (73 percent), were sitting in the rear seat position which concurs with phase I. Forty two percent of the children in phase II were seated in the rear left position, 23 percent in the right rear position and only 8 percent were seated in the rear centre. The results for the two phases are compared in Figure 1.

Twenty six percent of children in phase II were seated in the front passenger seat position, which is significantly more than the figure of 7 percent, from phase I. None of the vehicles containing these children had a passenger air bag fitted as standard so it cannot be shown whether the presence of a passenger side airbag has an influence on the choice of seating position for children. Nor can it be determined whether parents are switching off the front passenger air bags when installing child restraints in the front passenger seat, nor, if they are failing to disable the airbags, what effect this is having on the restrained child. This information should be obtainable in future studies.

A comparison of the child seating positions in phases I and II are shown in Figure 1 below.

Table 2 shows the types and distribution of restraints that were in use across the two phases. In phase II 47 percent of children were restrained in a safety seat, which is comparable to 51 percent in phase I.

Twenty seven percent of children were restrained with the use of a booster type system which is more than double the amount (12 percent) used in the earlier study. However,

Table 1 Child Seating position – all accidents

	Phase I		*Phase II*	
Child seating position	*Total*	*Percentage*	*Total*	*Percentage*
Front passenger	702	7%	39	26%
Rear left	2394	24%	63	42%
Rear centre	1263	12%	12	8%
Rear right	1937	19%	35	23%
Rear unknown	3824	38%	0	0%
Extra rear row left	0	0%	1	1%
Extra rear row centre	0	0%	1	1%
Extra rear row right	0	0%	0	0%
Unknown	40	<1%	0	0%
Total	10160	100%	151	100%

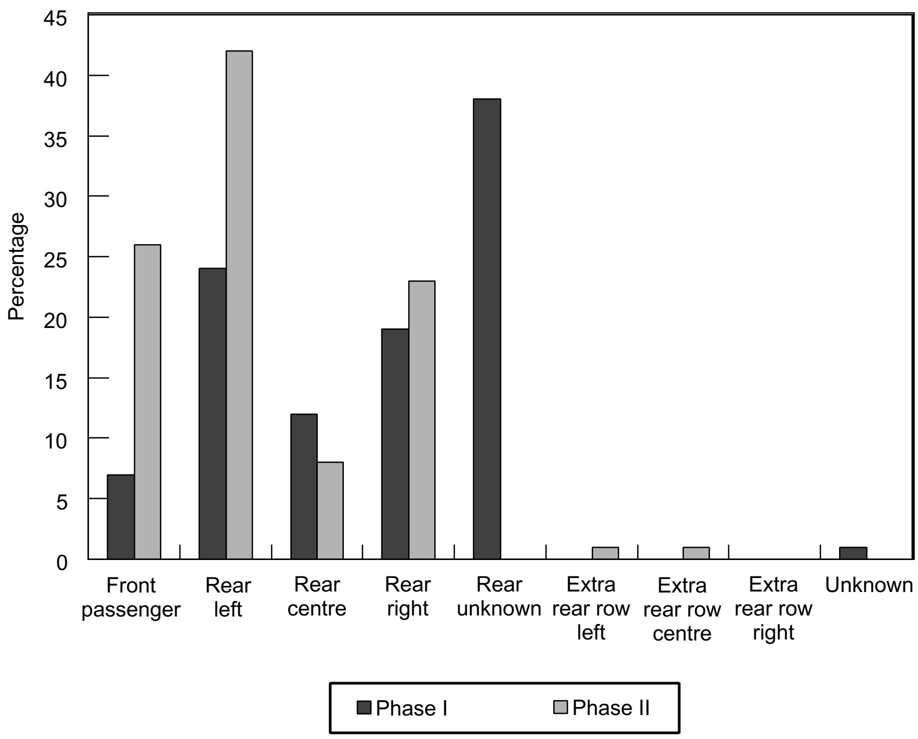


Figure 1 Child seating position

Table 2 Child restraint usage – all accidents

	Phase I		*Phase II*	
Child restraint	*Num -ber*	*Percen -tage*	*Num -ber*	*Percen -tage*
Infant carrier	471	5%	26	17%
Restrained carry cot	230	2%	0	0%
Unrestrained carry cot	149	1%	0	0%
Child safety seat (metal framed)	-	-	32	21%
Child safety seat (plastic framed)	-	-	38	25%
Child safety seat (unknown frame)	5184	51%	1	<1%
Booster seat / chair	1254	12%	16	11%
Booster seat separate backrest	-	-	13	9%
Booster cushion	-	-	10	7%
Impact shield	10	<1%	3	2%
Modified adult seat belt	91	1%	0	0%
Child safety seat built into the vehicle	-	-	0	0%
Child Harness	1345	13%	-	-
Adult seat belt	503	5%	9	6%
No restraint	747	7%	1	<1%
On adult's lap	115	1%	0	0%
Other	32	1%	2	15
Unknown	29	<1%	0	0%
Totals	10160		151	

only 18 percent of these children were four years or older, much less than the 27 percent in phase I. This is probably due to the increased availability of the less expensive booster seats for Group 1 recently, whereas in the phase I period, the main booster system available was the booster cushion, intended essentially for Groups 2 and 3. The influence of this trend should be monitored in the future.

In phase II 17 percent of children were restrained by infant carriers, although 24 percent of the children were aged nine months or less. In phase I only five percent of children were restrained using infant carriers, although 13 percent were aged eight months or less. Of the children aged nine months or less the use of infant carriers has increased from 36 percent in phase I to 75 percent in phase II.

The use of the adult belt has remained about the same, with six percent use in phase II and five percent in phase I. The age range of children using the adult belt in phase II was from six years upwards.

In phase I three percent of children travelled in carrycots (where one percent of the carrycots were unrestrained), one percent were restrained with a modified adult belt and one percent were placed on an adults lap. In phase II, however, no children were transported in a carry cot, a child harness or a modified adult belt as these restraint systems have been largely superseded. There were no reports of the use of a child seat built in to the vehicle seat, but these would have been only coincidental as the users of these would not have received a questionnaire unless they also purchased a separate child restraint. There were no children in phase II sitting on an adults' lap, which is encouraging.

Tables 3 and 4 show the age distribution across phases I and II. The age bands in the two phases are grouped slightly differently, with phase II giving a more detailed breakdown of the age distribution. The age band that contained the largest group of children in phase I, 36 percent, was the 9 – 23 months band. The age band that contained the largest group of children in phase II, 24 percent, was the 0 – 9 months band. This difference in distribution remains even when the numbers are adjusted for the different age groupings in the two phases.

Table 3 Age distribution Phase I

	0–8 mths	*9–23 mths*	*2 yrs*	*3 yrs*	*4 yrs*	*5–7 yrs*	*8–10 yrs*	*11 yrs and above*
Total	1302	3773	1421	1016	622	950	319	719
Percentage	13%	36%	14%	10%	6%	10%	3%	8%

Table 4 Age distribution Phase II

Age	*Number*	*Percentage*
0 - 9 months	36	24%
10 - 18 months	26	17%
19 - 24 months	16	11%
2 years	30	20%
3years	17	11%
4 years	5	3%
5years	6	4%
6years	2	1%
7 years	4	3%
8 years	1	1%
9years	1	1%
10years	4	3%
11years	1	<1%
12+ years	1	<1%
Unknown	1	<1%
Totals	151	100

Some of the age bands in phase II were grouped together, in order to match the age bands of phase I and show a comparison across the two phases. This is illustrated in Figure 2. Phase II contains a much greater percentage of young babies than phase I.

Table 5 shows the distribution of the highest injury sustained by any body region (MAIS) for each child. Most of the children in both phases (83 percent in phase I and 78 percent in phase II) were uninjured. The injury distribution suggests that either the accidents in these samples were minor or child restraints are providing good protection for children.

Table 5 Child occupant injury – all accidents

	Phase I		*Phase II*	
MAIS	*Number*	*Percentage*	*Number*	*Percentage*
0	8407	83%	118	78%
1	1568	15%	29	19%
≥ 2	181	2%	4	3%

Figure 3 shows a comparison of phases I and II child injury levels, in all accidents. This shows that a slightly greater proportion of children were injured in phase II.

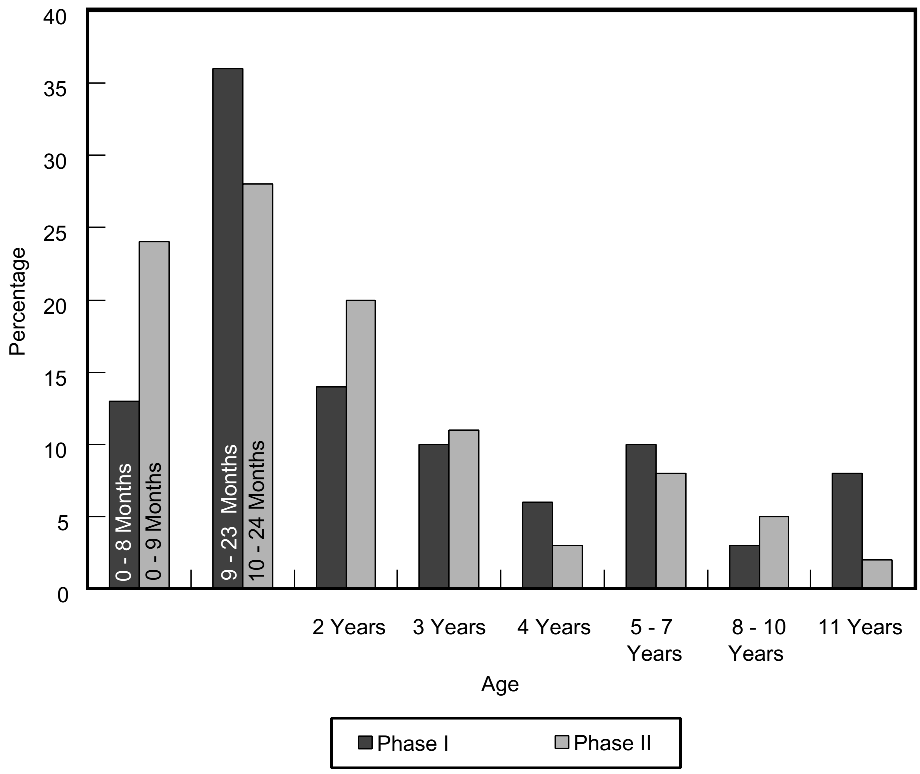


Figure 2 Comparison of age distribution in Phases I and II

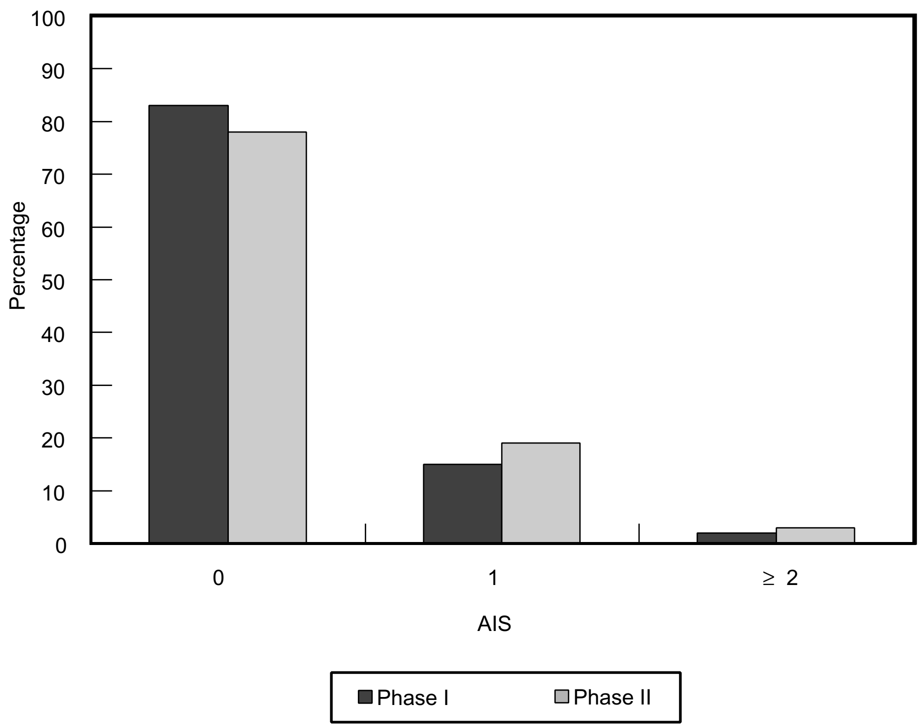


Figure 3 Comparison of MAIS between Phases I and II

Table 6 gives the distribution of accident impact type across the two phases. The highest proportion of the accidents recorded in phase II were rear impacts, which could be due to the method of data collection; a person may be less likely to return their questionnaire form if the accident has been their fault. However, the number of accidents in this sample is still low, especially in comparison with phase I. In phase I the distribution between full front and full rear impacts was more even, with 22 percent of full front and 23 percent of full rear impacts.

Table 6 Distribution of accident impact type

	Phase I		*Phase II*	
Impact direction	*Number*	*Percentage*	*Number*	*Percentage*
Left front corner	1145	11%	7	7%
Full front	2273	22%	15	14%
Right front corner	1810	18%	8	8%
Left side	524	5%	10	10%
Left rear corner	422	4%	7	7%
Full rear	2362	23%	45	43%
Right rear corner	485	5%	4	4%
Right side	718	7%	4	4%
Unknown	411	5%	4	4%
With roll over	286		9	

Figure 4 is a graphical representation of the accident impact types over both phases. The graph clearly shows that there was a greater percentage of frontal type impacts in phase I than in phase II so far, and most of the impacts in phase II were rear impacts.

Table 7 shows the injury severity distribution with respect to impact direction.

In phase II the greatest proportion of injuries of severity AIS2 or more was in side impacts. However, the three children with serious injuries in side impacts in this phase were involved in the same accident. The highest injury was sustained by a child seated on the struck side of the car. Thus with the small sample size for phase II so far, this accident would have distorted the results. In phase I, two percent of children were seriously injured in both frontal and side impacts.

Both phases show that there is a greater number of children with no injuries in rear impacts than in front impacts, which is probably due to the good load distribution of forward facing child restraints for this direction of impact.

Table 8 shows the number of accidents reported per year, up to the beginning of May 1999. In phase I a much greater number of forms were distributed to child restraint manufacturers. The largest sample of phase I was between 1980 and 1984. The largest sample recorded for phase II was in 1998. The number of returned forms has been increasing each year, as anticipated, although the forms are quite often returned a number of months after the accident occurred.

Table 9 shows injury distribution with respect to the restraint type used.

In phase I, the restraints with the highest proportion of uninjured occupants and the lowest proportion of moderate or severe injuries were the infant carrier, child safety seat and restrained carry cot. Although the sample size is still rather low these observations seem to be confirmed by the results from phase II with the addition of booster seats with backrests and booster cushions.

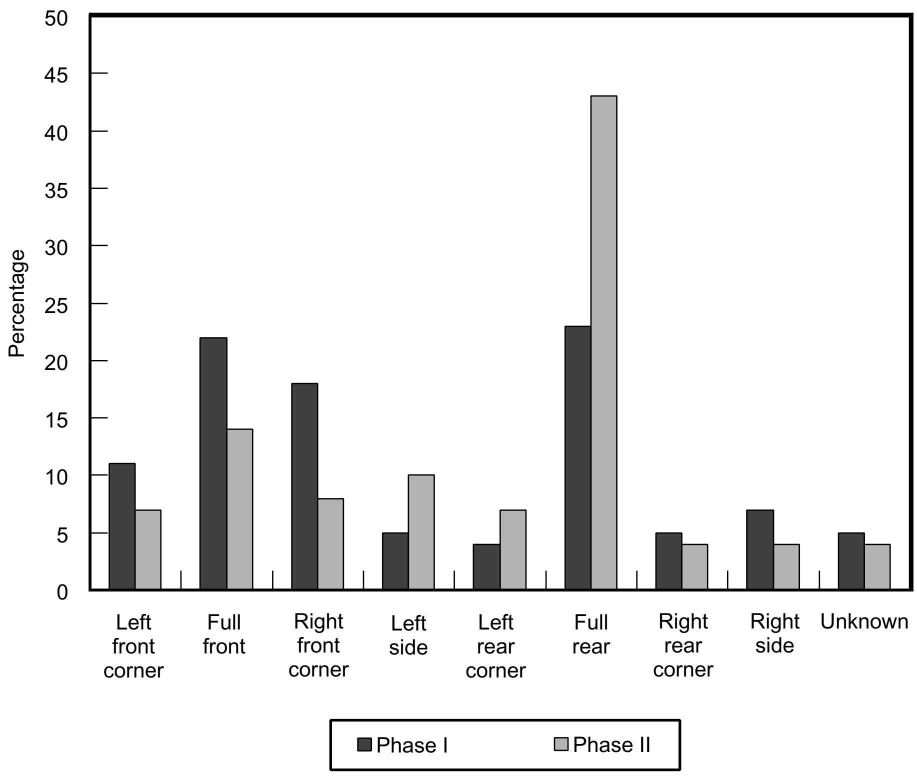


Figure 4 Comparison of impact location between the two phases

Table 7 Injury distribution with respect to impact direction

	Phase I						Phase II					
Impact direction	*AIS 0*		*AIS 1*		*AIS > 2*		*AIS 0*		*AIS 1*		*AIS > 2*	
Front	4156	79%	973	19%	99	2%	32	78%	9	22%	0	0%
Right side	-	-	-	-	-	-	3	33%	3	33%	3	33%
Rear	2930	90%	300	9%	39	1%	67	82%	14	17%	1	1%
Left side	-	-	-	-	-	-	9	90%	1	10%	0	0%
Side (both)	999	81%	216	17%	27	2%	[12	63%	4	21%	3	16%]
Unknown	0	0%	0	0%	0	0%	7	78%	2	22%	0	0%
Totals	8085	83%	1489	15%	165	2%	118	78%	29	19%	4	3%

Table 8 Number of accidents reported per year

Year	*Number*	*Number per year*
Phase I		
<1970	433	-
1971-74	1368	342
1975-79	2577	515
1980-84	4601	920
1985-89	1027	205
1990-93	143	36
Phase II		
1995	1	1
1996	12	12
1997	29	29
1998	46	46
1999	56	56
Unknown	2	-

In phase I, of the children restrained only by the adult belt, 26 percent sustained injuries. In phase II, of the children restrained only by the adult belt, 56 percent sustained injuries. The comparable figures for children in child seats were 14 percent and 16 percent respectively. The children who were restrained by the adult belt were over the age of six, with an average age of nine. This sample suggests that older children who are restrained by only the adult belt are not so well protected as those restrained by child restraints, although the caution expressed previously about the low sample size for phase II applies here.

In phase I, 19 percent of the children restrained by a booster seat/chair sustained injuries (mainly minor) while in phase II, the figure is 38 percent. The mass range of children in phase II using booster type chairs, seats or cushions was 9 - 25kg. The age range was from ten months to seven years, with an average age of 2 years.

In phase I 30 percent of children restrained by impact shields were injured. In phase II all three of the children who were restrained by the impact shields sustained moderate to serious injuries. These restraints were all in the same car, which was impacted from the side, by a lorry.

Only one child was unrestrained in phase II compared with 7 percent unrestrained in phase I. In one frontal impact accident there were two children, one sitting on either side of the rear seat of the car, one restrained by an adult seat belt and one unrestrained. The unrestrained child sustained nasal injuries which required hospital treatment while the restrained child had no injuries. This suggests that, even though the adult belt alone is less than ideal, in minor accidents it can help to restrain a child effectively.

In one side impact accident in phase II, there were two children both sitting on the non struck side of the car; one child restrained by an impact shield and the other restrained

Table 9 Child restraint type and injury distribution – all accidents

	Phase I						Phase II					
Child restraint type	*AIS 0 - No injury*		*AIS 1 - Minor injury*		*AIS > 2 Moderate – serious injury*		*AIS 0 - No injury*		*AIS 1 - Minor injury*		*AIS > 2 Moderate – serious injury*	
Infant carrier	433	91%	34	8%	4	<1%	22	85%	4	15%	0	0%
Child safety seat (metal framed)	-	-	-	-	-	-	28	88%	3	9%	1	3%
Child safety seat (plastic framed)	-	-	-	-	-	-	32	84%	6	16%	0	0%
Child safety seat (ALL)	4479	86%	654	13%	51	1%	51	84%	9	15%	1	2%
Booster seat / chair	1021	81%	223	18%	10	1%	10	63%	6	38%	0	0%
Booster seat with separate backrest	-	-	-	-	-	-	11	85%	2	15%	0	0%
Booster cushion	-	-	-	-	-	-	9	90%	1	10%	0	0%
Impact shield	7	70%	3	30%	0	0%	0	0%	0	0%	3	100%
Restrained carry cot	206	89%	20	9%	4	2%	-	-	-	-	-	-
Unrestrained carry cot	129	87%	15	10%	5	3%	-	-	-	-	-	-
Child harness	1093	81%	225	17%	27	2%	-	-	-	-	-	-
Modified adult belt	69	75%	19	20%	3	5%	-	-	-	-	-	-
Adult seat belt	374	74%	116	23%	13	3%	4	44%	5	56%	0	0%
No restraint	468	62%	222	30%	57	8%	0	0%	1	100%	0	0%
Other	44	77%	11	19%	2	4%	1	50%	1	50%	0	0%

by a booster seat with separate backrest. The child that was restrained by the impact shield was knocked unconscious while the child that was restrained with the booster seat with backrest received no injuries. The backrest may have afforded some head protection, which is essential in side impacts, and therefore prevented head injury.

In order to compare the performances of different child restraint systems in more severe impacts, a category of ‘serious accident’ was defined. The criteria for a serious accident, used in the phase II analysis, was such that an adult sustained an AIS of ≥ 2 or the car was written off at an age of less than three years old. Twenty two percent of the accidents in phase II were serious. Table 10 shows the injury distribution with respect to restraint type used in the serious accidents.

In phase I there were 1211 children involved in serious accidents, 59 percent of whom were uninjured. The restraint systems with the greatest proportion of uninjured were the infant carrier (83 percent), the child safety seat (65 percent) and the restrained carry cot (62) percent. The highest incidences of serious injuries were sustained by children sitting on an adult’s lap (25 percent) and unrestrained children (21 percent). The analysis clearly shows that, as the restraint system used moves away from systems designed specifically to restrain children, the likelihood of injury increases substantially.

In phase II there were only 30 children involved in serious accidents, 21 of whom were uninjured, five had minor injuries and four had more serious injuries. Of the children who had the more severe injuries one was restrained in a child safety seat and three were restrained by impact shields.

The child restrained by the safety seat was seated in the rear of a stationary vehicle, that was impacted in the rear by a car travelling at high speed. The child sustained fractures to the tibia and fibula. There was no information on the form indicating the cause of the leg injuries nor what contacts were made.

The three children restrained by the impact shields were all in one vehicle, containing four children, which was hit by a lorry that impacted into the right hand side of the car. Of the three children seated in the rear of the vehicle two were restrained in impact shields, one on the struck side and one in the rear centre position. The other child restrained in an impact shield was positioned in the front left hand seat. The child seated in the rear, on the struck side, received fatal injuries. The other two children restrained in impact shields received cuts and bruises and were knocked unconscious.

2.1.2 Conclusions and recommendations from the questionnaire study

There have been two phases of analysis of the child accident questionnaire data.

The questionnaire study provides useful information on restraint usage. The number of forms that are being returned in phase II is increasing each year, as anticipated.

2.1.2.1 Child seating position all accidents

The most popular seating position for a child in both phases was in the rear left position; 24 percent in phase I and 42 percent in phase II.

The number of children positioned in the front passenger seat has increased from seven percent in phase I to 26 percent in phase II, but this may be distorted by the sample size. The vehicles in both studies were too old to have air bags fitted as standard. Information regarding the use of restraints in front seats with passenger air bags should be available in later studies.

2.1.2.2 Child restraint usage all accidents

The most popular method of restraint across the two phases was the safety seat. The use of booster type seats has more than doubled from 12 percent in phase I to 27 percent in phase II, yet the proportion of children older than four years has decreased from 27 percent to 16 percent. This suggests that there is an increasing tendency to place younger children in booster type systems.

Table 10 Serious accidents – Injury with respect to restraint type

	Phase I				*Phase II*			
Child restraint type	*Sample size*	*AIS 0 %*	*AIS 1 %*	*AIS >2 %*	*Sample size*	*AIS 0 %*	*AIS 1 %*	*AIS >2 %*
Infant carrier	59	83%	15%	2%	6	50%	50%	0%
Child safety seat (metal framed)	-	-	-	-	6	83%	0%	17%
Child safety seat (plastic framed)	-	-	-	-	7	100%	0%	0%
Child safety seat (All)	624	65%	32%	3%	13	93%	0%	7%
Booster seat / chair	149	57%	40%	2%	2	50%	50%	0%
Booster seat separate backrest	-	-	-	-	4	100%	0%	0%
Booster cushion	-	-	-	-	2	50%	50%	0%
Impact shield	1	[100%]	0%	0%	3	0%	0%	3%
Restrained carry cot	26	62%	27%	11%	-	-	-	-
Unrestrained carry cot	18	56%	33%	11%	-	-	-	-
Child harness	126	56%	34%	10%	-	-	-	-
Modified adult belt	12	42%	42%	16%	-	-	-	-
Adult belt	85	39%	55%	6%	-	-	-	-
Adult’s lap	12	33%	42%	25%	-	-	-	-
Not restrained	89	35%	44%	21%	-	-	-	-
Unknown	10	50%	40%	10%	-	-	-	-
Totals	1211	718	424	69	30	21	5	4

Of the children aged nine months or less, the use of infant carriers has increased from 36 percent in phase I to 75 percent in phase II.

The use of the adult belt has remained about the same, about five percent, across the two phases. No children in phase II were restrained by just the adult belt under the age of six.

2.1.2.3 Age distribution

In phase I the 9 – 23 months age band contained the greatest number, 36 percent, of children, while in phase II. the greatest number of children (24 percent.) was in the 0 - 24 months age band.

2.1.2.4 Child occupant injury (all accidents)

The restraint methods are effective; 85 percent of children in child restraints were uninjured in phase I and 82 percent were uninjured in phase II. Two percent of children had moderate to serious injuries in phase I and three percent in phase II.

2.1.2.5 Distribution of accident impact type (all accidents)

The direction having the greatest proportion of impacts in both phase I and II was the full rear, with 23 percent in phase I and 43 percent in phase II.

2.1.2.6 Injury distribution with respect to impact direction

In the results from both phases, there is less likely to be a injury in a rear impact, probably due to the good load distribution to the child's body provided by forward facing child restraints or the vehicle seat.

Both phases show a relatively high frequency of serious injury in side impacts. In phase II 16 percent of the children involved in a side impact sustained serious injuries while none of those who were involved in frontal impacts was seriously injured. However this comparison may have been distorted by the low numbers involved. The equivalent figures for phase I, with a much greater sample size, are two percent for both front and side impacts,

2.1.2.7 Injury distribution and child restraint type (all accidents)

In phase I, the restraints with the highest proportion of uninjured occupants and the lowest proportion of moderate or severe injuries were the infant carrier, child safety seat and restrained carry cot.

The proportion of children restrained by a booster seat/ chair sustaining minor injuries, has more than doubled between phases I and II, rising from 18 percent to 38 percent.

In phase I, 30 percent of the children restrained by an impact shield were injured. In phase II all of the children restrained by impact shields sustained moderate to serious injuries, but the sample was very small and this result is unlikely be representative.

The proportion of children injured when restrained by the adult belt only has more than doubled between phase I and II. In phase I only 26 percent of the children restrained by the adult belt sustained injuries while in phase II, this figure was 56 percent. The comparable figures for children in child seats were 14 percent and 16 percent respectively.

The presence of a backrest with side wings can help to minimise head injuries in side impact.

2.1.2.8 Injury distribution and child restraint type (serious accidents)

In phase I, 1211 children were involved in serious accidents, 59 percent of whom were uninjured and 62 percent of the restrained children were uninjured.

From phase I, the restraint systems that afforded the best protection were the infant carrier, the child safety seat and, to a lesser degree, the restrained carry cot. The proportion uninjured were 83 percent, 65 percent and 62 percent and the proportion moderately or severely injured were 2 percent, 3 percent and 11 percent respectively. Systems that are not designed specifically for restraining children were less effective. The equivalent proportions for the adult belt were 39 percent uninjured and 6 percent moderately or severely injured.

The high risk of injury from sitting on an adult's lap is demonstrated by the proportion moderately or severely injured: 25 percent.

In phase II 30 children, all restrained, were involved in serious accidents, 21 (70 percent)of whom were uninjured. The sample size is too low to draw reliable conclusions at this stage.

There were no cases of children sitting on an adult's lap in phase II, so this danger may well now be appreciated by parents.

2.2 Analysis of serious injury sample

The questionnaire study obtained data mainly at low accident severities. The very severe end of the accident-injury spectrum has been examined through a special fatality study (Section 2.3) Information on the performance of child restraint systems (CRSs) within both of these studies is weak for moderate and serious non-fatal injuries. A pilot study was carried out by TRL to determine the feasibility of obtaining serious injury data to child car occupants, through medically based sources. Based on the predictions of this pilot study a three-year investigation has been carried out.

The pilot study indicated that data on between 40 and 60 accidents per annum could be obtained through a multi-hospital based notification system, sampling road traffic accidents in which a child aged less than 16 years, (later amended to <13), sustained serious injury. Following the pilot study, the serious injury study was commenced under sub-contract by VSC Ltd.

Six hospitals agreed to participate in the final study. (Southampton General, Pool General Hospital, John Radcliffe II – Oxford, Alder Hey Children's Hospital – Liverpool, Royal Preston Hospital, Royal Oldham Hospital). Unfortunately it took significantly greater effort to obtain appropriate clearances to extract medical data through the appropriate research and ethics committees than was expected and case notifications were significantly less than was originally predicted. Possible changes to the collection methodology were discussed late in the project following which two other data collection strategies were adopted to increase the studies case data base. Firstly by analysis of a sub-sample of the road traffic accident fatality files held by TRL, in which a child had been seriously injured and secondly by means of a press cuttings retrieval service. This latter methodology was examined with a view to determining if it could be used in any later study and to identify whether cases may have been missed by the hospital based notification system.

2.2.1 Hospital reported cases

Six hospitals co-operated in the scheme. Within the time frame of the study only nine in-depth cases became available, significantly less than had been originally expected. Cases were included where a child had been admitted or came through the casualty department with a fracture.

2.2.1.1 Key observations

The quality of the data obtained in these cases is high as the researchers had access both to the vehicles and to injury data. For the first time in an accident study comprehensive video footage was taken of each case, including predictions of vehicle kinematics using model vehicles. The limited number of cases does not permit specific comment on the general performance of child restraint systems associated with children sustaining serious injury. It was noted that vehicle based improvements would have reduced the severity of several of the injuries. The few cases suggest that the restraint of children by adult belts and their interactions with booster seats is the restraint configuration with the greatest problem. The suggestion is made that simple booster cushions without lateral support, should not be used by younger children.

2.2.2 Serious injuries identified within the TRL fatality files

An analysis of the fatality database, held by TRL, indicated the existence of 233 relevant cases in which at least one child aged less than 13 years was seriously injured. Two sub-samples of the data were examined; the first 70 cases in chronologically ascending order and the last 35 in descending order. Resources did not allow for all records to be fully examined. Of the 60 accidents in which useful information was obtainable, 123 child casualties were recorded, of whom 79 were seriously injured.

2.2.2.1 Key observations

The cases generally came from a high-energy accident database and as such the likelihood of severe injury is high irrespective of restraint use. Data in the files are comprehensive and information has been recorded on other injury groups in addition to the seriously or fatally injured occupants. Only 28 (35 percent) of the seriously injured children were confirmed to have been using a restraint system. Seven were using a child seat, three a child harness and one a booster seat. Sixteen were using the vehicle (adult) restraint and one was using it with another occupant. No serious injury was sustained in a rear facing restraint. The data suggest that the restraint provided by the use of adult belts by children and the interactions with booster seats is not optimal and supports the findings from the Hospitals based study in limiting the age range of children that should use certain types of booster seat. Additional loading from ‘luggage’ was found to increase injury risk and ‘survival’ space was a limiting factor in controlling injury risk. Incompatibility between vehicles was another factor that increases injury risk to children.

2.2.3 Press cuttings service

The press cuttings service operated for a fifty-five day trail period during which time 58 accidents were noted involving 101 child casualties.

2.2.3.1 Key observations

Photographic evidence of the damage to the vehicles was shown in the clippings for 21 percent of the cases, giving a good ‘first impression’ of the accident, its severity and type. Further photographic information was obtained for these cases by requesting ‘proofs’ of all available photographs from the publishers. In most of these cases it was thought that it would have been possible to trace the vehicles via the relevant police forces through established links.

In 76 percent of the cases the associated hospital was named. There was some slight evidence to indicate that the accidents may tend to be biased towards the more severe ‘public interest’ end of the impact spectrum. Three fatal accidents were recorded, one of which appeared to be worthy of further investigation, being a child fatality in a booster seat in an accident in which a fatality might not have been expected.

The press cuttings service would be a useful, low cost, case identification system for any future study. Improvements could be made reducing duplication as it has been discovered that press articles and stories are ‘networked’. It is a fast information retrieval system with a four-day turn around. A suitable information retrieval system would be necessary to obtain adequate medical data on the seriously injured children who were not admitted into the existing participating hospital network. The press cuttings data quality in itself is poor, but significant improvements would be possible. The trial period confirmed that no serious injuries bypassed the hospitals involved in the main part of the study.

2.2.4 Conclusions on the Serious Injury Study and Implications for legislation and standards

- Video coverage of these cases was attempted. It was time consuming to obtain and review, but it was considered to be a very useful medium to obtain a better understanding of the accident and vehicle damage than a collection of simple photographs with associated textural descriptions. It was a high cost information recording system with some significant advantages but any future use should be carefully controlled and limited to ‘interesting’ cases only.

- Case notification and data collection did not work as well as was initially anticipated but changes to collection strategies did expand the sample size and indicated that other methods of notification could be used with success in future studies i.e. the press cuttings service.
- Further valuable information on seriously injured restrained children is available within the fatality files at TRL and this should be extracted before the files are destroyed.
- Lap belts give poor restraint for children, as for adults, and installation of three point belts for all seating positions should be encouraged.
- Booster cushions, particularly when used by young children, do not give good upper body support and their use by this age group should be discouraged and the recommendation should be the use, as a minimum, of booster chairs.
- Improvement in the strength of vehicle seat backs is necessary to reduce additional loading from unrestrained luggage. The effectiveness of the revised seat back strength requirement should be evaluated in future studies.
- The fitting of HGV under-run guards would benefit children as well as adults.
- Impact compatibility between different classes of vehicle is seen to be a problem that affects child injury risk.
- Children are seen to be vulnerable in side impacts. Future progress in side impact standards for vehicles should also consider interactions with children, particularly in the rear seat.
- Child restraint evaluation in side impacts should be considered in future changes in child restraint test standards.
- Protection of the child's head should be a priority in future standards.
- A number of injuries are seen within the data sets which are not detected by existing dummies (e.g. leg fractures). Some of these are associated with the global accident rather than the performance of the CRS itself and it is therefore difficult to see how improvements in CRS design could influence these types of injury.
- Restraint misuse was seen again within the samples. Further efforts should be made to reduce the potential for misuse through engineering and educational means.

2.3 Analysis of fatal accidents to restrained children

The Transport Research Laboratory has monitored the efficacy of child restraint safety systems (CRS), in high severity accidents which involved a child fatality, for the Department of the Environment, Transport and the Regions (DETR) for more than 20 years. This monitoring has been achieved through retrospective studies of fatal accidents, identified through the UK 'Stats19' accident database. For the period of this contract, the child fatal injury study was performed under sub-contract by VSC Ltd. The study ceased in 1994.

Prior to 1994 the Stats 19 database included information on the use of a restraint systems but, with the increase in restraint usage following the seat belt wearing legislation, this variable was omitted on the assumption that 'it would be difficult to obtain a reliable answer from the casualty. In addition the accuracy of recording restraint use was not high, particularly for adults. Even so, for the child restraint study, the variable did permit the early exclusion of some unrestrained cases. The 1994 accident data include both restrained and unrestrained information, thus more cases were investigated and rejected for non restraint use than for previous years. Analysis of the 1994 data has not been completed in the current project, due to cases being sub-judice (8 cases) and no returns from police & coroners (9 cases). Since the information has been obtained from a fatality database the accident severity is generally very high with a 'high' likelihood of serious or fatal injury. Thus it would be expected that some fatalities in this sample might not be preventable.

2.3.1 Impact direction

The child fatality sub-contract ended in 1995 and covered the accident years 1990-1994. During the five year accident period, 100 cases were studied involving 106 child fatalities. The breakdown in accidents by impact direction is shown in Table 11. This breakdown highlights the relatively large number of fatalities in side impact.

Table 11 Distribution of impact direction – fatal injury study

Impact type	*No of fatalities*	
Frontal	41	(38%)
Side	30	(28%)
Sideswipe	7	(7%)
Rear	8	(8%)
Rollover	3	(3%)
Multiple & Complex	13	(12%)
Immersion in water	2	(2%)
Not known	2	(2%)

2.3.2 Age distribution

Table 12 presents a breakdown of fatalities by age. The numbers of child fatalities less than 2 years of age (34 percent) is very high and may reflect the ability of the child to survive a high energy impact or the high usage of child restraints in this age group. The peak at 8 years of age may reflect changes in vehicle occupancy or seating position.

Table 12 Distribution of child fatalities by age

Child's age (years)	*Number*
<1	19
1	17
2	9
3	7
4	4
5	5
6	4
7	4
8	10
9	5
10	3
11	8
12	3
13	8

2.3.3 Restraint type

Table 13 presents a breakdown of restraint types seen in the sample. The high incidence of three point 'adult' belts compared to the age distribution in the sample may indicate a tendency for children to use adult belts too early and may indicate that they are less effective than specifically designed child restraints.

Table 13 Distribution of restraint type – child fatality sample

Restraint type	*Number*
Infant carrier	6
Child seat (4 point tethers)	2
Child seat (2 point tethers)	1
Child seat (lap belt)	4
Child seat (3 point belt	16
Two way seat (lap belt)	1
Two way seat (3 point belt)	2
Child seat (attachment not known)	10
Booster cushion (lap belt)	1
Booster cushion (3 point belt)	2
Booster seat (lap belt)	7
Booster seat (3 point belt)	1
Some form of cushion (3 point belt)	1
Lap belt	1
Child harness	4
Three point belt	44
Not known	3

2.3.4 Remedial measures

The primary objective of the study was to try to identify any failings in the current generation of child restraints and to make appropriate recommendations that might reduce this severity of injury to children. As was mentioned earlier the cohort stems from a high energy sample of accidents, many of which might be 'unsurvivable' even with a significantly improved child restraint.

All of the cases were critically reviewed to assess whether any engineering action could have mitigated or prevented the fatal outcome. This form of analysis is subjective but is based on the researchers' many years of experience in accident investigation and analysis.

Table 14 presents this subjective analysis. It should be noted that, for some fatalities, more than one countermeasure could be proposed and for many of the cases no countermeasure could be suggested. It should also be noted that this retrospective study is based on a review of police and coroners' written records supplemented with police photographs. Thus the data were not gathered with a view to in-depth accident analysis. The recommendations and countermeasures are thus based on limited 'at the scene', vehicle and medical data.

This subjective analysis has divided the countermeasures into three sub-divisions: CRS-based, vehicle-based and accident-based. Some of the vehicle-based countermeasures are already being addressed through new or improved vehicle standards and protection systems (e.g. air bags, side impact protection). From a child restraint design position, the analysis suggests that the biggest problem and opportunity for improvement lies in the attachment of the CRS to the vehicle. The second is based on the containment of the child within the restraint. The CRS user or parent is the only person who can only make adjustments to the child harness in use. Thus there is little scope for regulation-based improvements in this area apart from ensuring ease of use and adjustment. Better harness adjustment through reduction in misuse might be achievable through standards. Other than this, the remedial action must be through advice and education. The biggest improvement, based on this fatality study, seems to be focused on improvements regarding the coupling of the CRS to the vehicle. These would be appropriate for Standards action and are within reach through the adoption of ISOFix-based restraint systems.

Table 14 Potential countermeasures considered to be likely to mitigate fatal injuries

Counter measures	*Number of times that the counter measure might have mitigated the fatal injury*
CRS fixation/use counter measures	
Use child restraint appropriate to age	1
Use/fitment of crotch Strap to prevent submarining	1
Correct mounting of CRS	3
Remove slack from child restraint (correct adjustment)	3
Use booster cushion with adult belt	1
Three point belt rather than lap belt	4
Use CRS tethers instead of adult belt	3
Prevent harness failure	1
Provide side impact protection in CRS	1
Place CRS in a different seating position	1
Prevent loading by adult	3
More stable anchoring of CRS	1
Use of a Group 0+ rear facing infant carrier	3
Vehicle based counter measures	
Fit front passenger air bag	1
Improved folding rear seat back	1
Prevent fire	1
External counter measures	
Under-run guard on back of HGV/PSV	1
Under-run guard on front of HGV/PSV	5
Provide central crash barrier	3
Rear under run guard on light goods vehicle	1
Frangible fence (e.g. wire mesh rather than wooden post and rail fences)	2
Provide stronger parapet or barrier to protect bridge	1
Protect off-road object with crash barrier.	1

A number of 'improvements' have already been introduced in vehicles and child restraint design. ISOFix based CRS are starting to appear in specific vehicle approval form. Thus there is a need to continue this type of child injury monitoring to determine if the 'countermeasures' are reducing child injury as expected and also to determine if further improvements might be possible.

2.3.5 Conclusion and implications for legislation and standards from the Fatal Injury Study

The five year fatality study has highlighted the fact that some 'engineering' improvements may be possible which could reduce the incidence of fatal injures to children in cars.

- Improved fixation of CRS to vehicle – Improvements are very likely with the adoption of ISOFix type restraints which could be achieved through improved CRS and vehicle standards.

- Reduction in misuse through better CRS design, possibly achieved through improved CRS standards.
- Improved awareness of the importance of restraint adjustment. This requires improved public awareness.
- Easier child harness adjustment systems potentially achieved through improved CRS standards.
- Improved side impact protection would have a major benefit. A new ISO CRS side impact test procedure is under development which could result in a new standard.
- Vehicle design improvements. Many improvements are entering the vehicle fleet, including air bags and better side impact protection, all of which could have an influence on child safety.

The efficacy of these recommended improvements should be monitored.

3 Development of ISOFix

3.1 Introduction

In 1964 the British Standard for (adult) seat belts was amended to include a section dealing with child restraints. This was the first national standard for child restraints and contained a dynamic test. A new system of restraints for children was developed independently in the UK and Sweden. In the UK, they were primarily forward facing child restraints, either bucket shell seats with integral straps or an independent harness system, with two shoulder straps and a lap strap. They were attached to the vehicle by means of straps bolted to the floor and parcel shelf. In Sweden, rearward facing child restraints for children up to about 6 years old were favoured. These were usually fitted to the front passenger seat and the larger ones leant against the fascia. These both gave a stable system but installation was carried out by the parents, thus limiting acceptance. As rear seat belts began to appear in the 1980's it was recognised that the adult seat belt system could provide a simple and universal method for securing the child seat, leading to an increase in usage rates. However this method has resulted in interaction problems with the vehicle seat and a high proportion of misuse, reducing the performance of the child restraint. (Roy et al, 1994)

In 1991 the Swedish delegation to ISO/TC 22/SC 12/ WG1 proposed a new concept for interfacing the child restraint and vehicle. This system was based on a rear facing child restraint (the preference in Sweden) with two plug-in connectors (Shraeder truck airline connectors) at its base, fixing it rigidly to the vehicle at the seat bight. This idea was developed further to include an attachment at the front of the vehicle seat and the two systems were named ISOFix and DELTAfix respectively. The term ISOFix has since been expanded to describe any universal rigid system provided in car seating positions for the attachment of any child restraint.

The UK DoT (now DETR) recognising the potential advantages of such a system wished to encourage its development by including it as part of the child restraint research project at TRL. To this end, a UK working group was formed by TRL which comprised, among others, CRS manufacturers, car manufacturers and a UK university. The aim of the group was to develop a UK response and view to the Swedish proposal and to develop a consensus for a UK proposal to ISO. This would be given the name UNIFix to distinguish it from the international effort.

3.2 The UNIFix working group

3.2.1 Objectives of UNIFix

Initial discussions of the working group focused on the current progress of child safety products and regulations. It was agreed that the stability and performance of the current range of products might not be as good as suggested by the standards, since testing occurred in an artificial, idealised environment. The reality is that the performance of the child seat is a function of the vehicle seat, and the performance and anchorage locations of the adult belt, which are both beyond the control of the child restraint manufacturer. Thus the principal aim of developing UNIFix/ISOFix was to reduce misuse problems.

Following these discussions a set of objectives for any universal method of coupling the child restraint and vehicle seat were developed. These requirements were classified into three groups and presented in the Table 15 .

Table 15 UNIFix objectives for a universal system for attaching child restraints to vehicles

Essential features	*Highly desirable features*	*Nice features*
OK for adults' use of seating location	Simple to use, low cost, cost effective	For a UNIFIX CRS to be used in a non-UNIFIX seat location
Minimise misuse potential	Improve general driving and seating stability	Potential use in other vehicles (mini buses and for disabled restraints)
Suitable for both front and rear seats	Improve dynamic performance. (side and roll over)	—
Usable in 'folding' seats	—	—
Suitable for all groups of CRs	—	—
Minimise dependence of CRS performance on the vehicle seat	—	—
'User friendly'	—	—
Standardised attachment and release method	—	—
No additional injury risk to any occupant in impacts	—	—
Prevention of accidental release	—	—

3.2.2 Selection of possible attachment configurations

The task force investigated the potential range of locations for the attachment points for a child restraint and car seat. The possible variations of top, centre and bottom of the backrest, the front and rear of the seat cushion and the use of flexible or rigid attachments are very large. These were limited to 14 practical combinations (Figure 5) which, based on the experiences of the task force members were reduced further to the five most promising. These were B, F, G, J and N and would undergo dynamic testing.

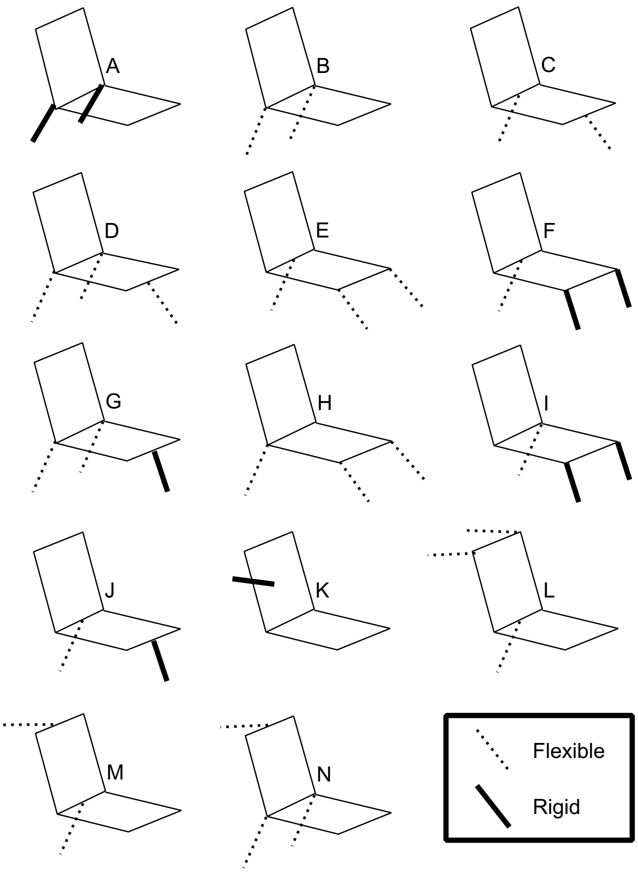


Figure 5 Initial UNIFIX anchorage configurations

Simulations of these five configurations were produced using a forward facing; frame child seat and adult seat belt buckles and tongues as attachments. These were subjected to front, rear and side impacts and the results are shown in Table 16.

The results led to the conclusion that arrangement G gave the best combination of performance and practical use. Arrangement N was also considered but was rejected due to the difficulty in defining the location of the top anchorage for an attachment that would suit all vehicle sizes and be independent of the backrest rake without adjustment.

A second series of dynamic tests was performed using arrangement G (subsequently referred to as the ‘Basal 3-Point’ system) to determine the force generated at each anchorage and the effect of the degrees of freedom at the forward anchorage. The acceleration pulses were those specified in ECE Regulation 44. The results of these tests are shown in Table 17, for forward, rear and side impacts.

The typical force maximum applied to each rear anchorage was about 4-5kN and about 5-6kN at the front anchorage. The results led to the conclusion that the front anchorage would have to be rigid to withstand tensile and compressive force, but suggested no significant difference between a rigid or pivoting front anchorage.

Table 17 Forces on anchorages in tests of ‘Basal 3-Point’ system

Impact direction	*Child restraint*	*Front anchorage*	*Rear anchorage (kN)*	*Front anchorage (kN)*
Frontal	Forward facing	Rigid (1)	4.9	6.2
		Pivoting	4.6	5.9
		Rigid (2)	3.1	3.6
	Rear facing	Pivoting	4.5	6.2
		Rigid	3.8	5.0
Rear	Forward facing	Rigid	2.9	3.2
Side			3.4	0.8
‘Typical’ maximum force			4-5 kN	5-6 kN

Table 16 Dynamic test results on prototype UNIFIX child seats with different attachment arrangements

		Front impact (ECE R44)		Rear impact (ECE R44)		Side impact (NZS5411)	
Attachment positions	*Child restraint model*	*Head FWD movement (mm)*	*Chest (g)*	*Head FWD movement (mm)*	*Chest (g)*	*Head FWD movement (mm)*	*Chest (g)*
B	A	490	72	—	—	655	39
B	B	567	45	—	—	—	—
J	A	380	45	147	26	711	39
J	B	543	46	—	—	—	—
F	B	528	43	—	—	—	—
G	A	400	44	240	32	656	52
N	A	404	44	—	—	461	38
N	B	436	44	—	—	—	—

3.2.3 Anchor design and location

It was intended that the ISOFix system should be capable of being fitted to all passenger seat locations and possibly all cars. Therefore, a decision was taken to define the UNIFix attachments such that the part on the vehicle would be as simple as possible with the more expensive latching mechanism fitted to the child restraint. A set of requirements for a design was agreed upon and a number of potential anchorage designs were considered. These included, conventional seat belt tongues, rings, holes in plates, and bars. After much discussion the preference was for horizontal bars onto which a latch could attach. A stress analysis was performed to ensure sufficient strength characteristics could be obtained to support the impact forces from the restraint, whilst minimising size to permit a small latch profile. It showed that 6mm diameter steel bars 25mm in length, supported firmly at each end could deliver the required strength with a safety margin of 50 percent, (i.e. a factor of safety of 1.5).

An investigation of car seat design and dimensions was made with co-operation of the UK vehicle manufacturers represented on the task force. This information together with vehicle internal dimensions and width data of typical child restraints, given by the child restraint manufacturers, was used to define the location in space for the attachment bars.

A 280mm separation was decided upon for the rear attachment points. This was determined from a combination of the strong structures of the car front seats and the maximum width that would permit three child seats across the rear of most family cars. They would be located toward the back of the backrest cushion so that an adult passenger would not feel them. A funnel aperture would guide the latch onto the attachment bar.

The first proposal made to ISO by the UK task force was based on the 3 point system with a single attachment at the front of the car seat, which had a fixed geometrical relationship to the rear attachments. Whilst the prototypes of this system were functional several concerns about this configuration were expressed at the ISO meeting. Namely, the attachment point must be far enough forward to avoid the front of the seat cushion in all vehicles. Alternatively it must lie within the seat cushion, an option unacceptable to the car manufacturers. (Turbell et al, 1993).

The UNIFix group continued their work and investigated the use of adjustable front anchorages. The car manufacturers represented on the group explained that modern seat designs have the strongest structures at the outer edge of the seats and that loads should be distributed here. From this it was decided that there should be two front anchorages at the front edge of the seats. The separation was selected to be 280mm, the same as for the rear attachments.

3.2.4 Child restraint and vehicle seat fixtures

The child restraint and car interface was specified by means of two fixtures. They described the attachment locations and maximum physical dimensions of the child restraint.

The child restraint fixture (CRF) represented the child restraint and the maximum profile it could have and controlled the location and access to the anchorages in the vehicle using representations of the latches of a child restraint. The front profile had a sliding adjustment to provide the range of lengths between the front and rear anchorages whilst their relative height was controlled by specifying a limit to the angle range of the base plate.

The vehicle seat fixture (VSF) represented the car seat and anchorages. The profile defined the maximum space available to child restraint manufacturers in which to fit the restraint and matched the maximum surface profile that the vehicle manufacturer can work to in designing the location of the car anchorages.

The use of these two fixtures should therefore ensure that any child restraint built to the maximum dimensions of the VSF will fit into that seating position into which the CRF will fit; an essential usability requirement and a aid to reduction of potential misuse.

3.2.5 The Proposal to ISO (4-Point UNIFix Concept)

The UNIFix 4-Point attachment concept was presented to ISO at a Nov ’93 meeting. The presentation was accompanied by a demonstration of both forward and rear facing prototypes fitted to a vehicle seat. After much discussion concerning the reasons behind the double front attachment system it was agreed that the UNIFix principles would form the basis of the ISOFix standard. (Lowne et al, 1994**).** An ad-hoc group was formed to create a draft ISO standard for consideration. The other WG1 members would evaluate the concept against local conditions and TRL was asked to take responsibility for the technical drawings of the child restraint and vehicle fixtures.

3.2.6 Dynamic Testing of ISOFix

A great deal of early testing had established the feasibility of ISOFix and the forces that it could withstand. However, it was now felt that further testing was needed for the development of products. A series of dynamic tests were performed at TRL using a car body shell adapted to accept an ISOFix child restraint. Frontal and rear impact tests were conducted to the ECE R44 pulse whilst the side impact tests used a crash pulse derived from full-scale vehicle tests at TRL. Two groups were evaluated, Group 0 rear facing infant carriers (P¾ Dummy) and Group 1 forward facing child chairs (P3 dummy). Comparisons were made between conventionally attached and ISOFix child restraints and the results presented in Tables 18 and 19. (Paton et al, 1996)

The results show a significant performance improvement in the head acceleration measured in dummies placed in ISOFix child restraints in comparison with that for conventional child restraints during front and side impacts. Chest acceleration for all dummies showed a similar pattern. The head excursion data clearly indicates the advantages of the ISOFix system.

3.2.7 User trials

The ISOFix concept had now advanced to such a stage where user trials were deemed necessary. An objective of ISOFix is to simplify the attachment procedure, therefore the user trials needed to compare the ‘usability’ and

Table 18 Dynamic test results comparing 3ms exceedence and head injury criteria for adult belt and ISOFix attached child restraints

		Head						*Chest*		
		Rear		*Side*		*Front*		*Rear*	*Side*	*Front*
Child group	*Child restraint*	*Acc(g) 3ms*	*HIC*	*Acc(g) 3ms*	*HIC*	*Acc(g) 3ms*	*HIC*	*Acc(g) 3ms*	*Acc(g) 3ms*	*Acc(g) 3ms*
Group 0	Conventional infant carrier	35	231	37	244	52	435	29	30	52
	ISOFix rear facing infant carrier	38	204	24	124	54	275	33	21	33
Group 1	Conventional forward facing child seat	45	255	55	506	103	1437	46	34	47
	ISOFix forward facing child seat	40	244	34	235	51	587	23	20	39

Table 19 Dynamic test results comparing head displacement for adult belt and ISOFix retained child restraints

CRS type	*Child group*	*Impact direction head*	*Displace -ment (mm)*
Conventional rear facing	Group 0 Infant carrier	Rear	567
ISOFix rear facing	Group 0 Infant carrier	Rear	282
Conventional rear facing	Group 0 Infant carrier	Frontal	114
ISOFix rear facing	Group 0 Infant carrier	Frontal	85
Conventional forward facing	Group 1 Child seat	Frontal	695
ISOFix forward facing	Group 1 Child seat	Frontal	435

possible misuse of ISOFix against existing adult belt retained child restraints. The term usability in this instance referred to the ideal situation whereby a child restraint can be given to a parent that has never seen one before and who will have no difficulties with repeatedly fitting it to their car, or fitting their child to the child restraint.

Twenty-two female subjects were used from three separate mother and toddler groups. Half were supplied with graphical fitting instructions before the experiment. Each subject attempted to fit four types of child restraint into the test vehicle (Rover 418) whilst being filmed. Two conventionally attached child restraints; one forward facing and one rear facing, and two ISOFix child restraints; one forward facing and one rear facing were used. After each attempt the subject was asked to complete a questionnaire and after all attempts their opinions were recorded.

The study found that, within a short time, a high proportion of those parents tested could fit the ISOFix child restraint correctly and that parents experienced with adult belt retained child restraints still fitted these incorrectly. The stability and safety aspects of ISOFix increased parents' confidence in the child restraints and two thirds said they would be willing to pay more for ISOFix.

During 1994 support for the 4 point ISOFix system within WG1 had been confirmed. Several car manufacturers including Ford and Chrysler of the USA and a group representing the German car industry had communicated their intentions to implement the system. In addition Renault and Saab had agreed to support the proposals. The ISO standard was on its 6th draft stage and it was anticipated that it would need only a few dimensions and other aspects to be reviewed further before finalisation. However, by the 8th draft there were still dimensional requirements that had not been finalised. In order to hasten this process, it was agreed to split the ISOFix standard (ISO/WD 13216) into the following parts:

Part 1 Dimensions (including lateral spatial requirements) and basic requirements.

Part 2 Strength requirements of anchorages.

Part 3 Spatial requirements in vehicle.

Meanwhile, wishing to make use of their long experience with top tethers and out of concern for the simplicity of the ISOFix concept, which it argued was lost in the 4 point system, Transport Canada supported the development of an earlier version of the UNIFix configurations (Figure 5, variant 'N'). This was intended initially as a National alternative to the 4-point system and resulted in a prototype known as CANFIX.

This comprised two rear attachments secured to the two ISOFix anchorage points located behind the vehicle seat bight. In forward facing child restraints the CANFIX system also incorporated a top tether secured to the vehicle tether anchorage fitted on the parcel shelf of Canadian and Australian cars. The use of an adjustable top tether overcame the problem of the variation in seatback height and rake foreseen by the UNIFix group, although at the cost of needing user adjustment and hence the risk of misuse. Anticipating this, the first prototype included a type of interlocking system to combat the high frequency of non-use of tether straps in existing systems. The complexity of the interlock resulted in this being omitted in further proposals from Canada.

Such partial usage of the ISOFix attachments had been discussed at that point, but for compatibility purposes it was stressed that all four points must be installed in the vehicle and that the term 'ISOFix' should only be used to describe a child restraint that uses all four attachments.

3.2.8 The performance of ISOFix in side impacts

Further concern had been expressed regarding the side impact performance of ISOFix. It was suggested at ISO WG meetings that the rigid nature of the 4-point attachment system might increase the risk of injury in struck side impacts. A less rigid attachment system would allow a child restraint to be displaced laterally away from the impact. In order to investigate this hypothesis, TRL performed six full-scale side impact tests, according to the EEVC side impact test procedure.

The centre rear and struck side rear seating positions were used in a family sized hatchback. A TNO P3 dummy was restrained in either a conventional child restraint or in a prototype ISOFix restraint that employed the same child seat shell design. The results are shown in Table 20.

Table 20 Full-scale side impact tests with conventional and ISOFix retained child seats

		Head		*Chest*
Child restraint	*Restraint position*	*Peak accel (g)*	*HIC*	*Peak accel (g)*
ISOFix	Centre	24	41	22
ISOFix	Centre (repeat test)	20	31	23
ISOFix	Struck Side	38	39	75
ISOFix	Struck Side (repeat test)	35	33	60
Conventional	Centre	141	456	41
Conventional	Struck Side	37	69	82

The results showed that ISOFix mounted child restraints do not increase the risk of injury to children in side impacts when compared to conventional adult belt retained seats. When positioned on the struck side of the vehicle there was little difference in the peak head acceleration between the ISOFix and conventional child restraint and if HIC is considered then ISOFix shows safety performance improvements over the conventional child restraint.

In the central seating position the dummy peak head acceleration and HIC values were much greater for the conventional child restraint. This occurred because translation and rotation of the conventional seat during the impact resulted in contact between the dummy head and the intruding door structure. It must be noted here that the conventional child restraint was retained by an adult lap belt only when in the central seating position.

This pattern of results is repeated for the dummy chest acceleration. On the struck side there were small reductions in chest acceleration in tests with the ISOFix restraint, whilst in the central seating position the peak acceleration was halved for the ISOFix child restraint. These tests demonstrate that there was no evidence to support the claim that ISOFix might increase the injury risk to children in side impacts when compared with less rigid attachment systems. In fact ISOFix actually provided benefit to the child dummy in these tests.

3.2.9 The GM usability clinic

To go alongside the usability study performed by TRL and others from Germany and Sweden, General Motors in the US conducted a usability clinic of five attachment systems. The study objectives were to measure customer reactions to the proposed child restraint installation systems and to provide consumer data with respect to education and communications in the area of child safety and child restraints. The attachment systems evaluated were ISOFix (4-point), CANFIX and three American alternatives known as Dual Strap Manual, Single Strap and Dual Strap Retractor. These US systems were all based on soft anchors at the vehicle seat bight with a top tether. A total sample of 399 people had been used for the study. The results showed a preference for the soft anchor systems with a top tether. The two ‘hard anchor’ systems, ISOFix and CANFIX, were rated least preferred. These were perceived to be hard to manage and bulky by the study respondents who also felt that the metal parts were dangerous to children and may damage the car exterior during installation. In addition they noted that the child restraints had no utility outside the vehicle.

There were several objections to the study from within ISO Working Group 1. Firstly, the ISOFix prototype used had not been designed according to the specifications in ISO/WD 13216. Sharp corners and metal parts, which were present on the GM prototype, could easily have been avoided, and if a foldaway example had been used for the attachments, it would have influenced the handling outside of the vehicle. It was also pointed out that German, UK and Swedish studies had shown more positive results for ISOFix especially concerning successful mounting.

3.2.10 Evaluation of alternative ISOFix concepts

Around the time of the publication of the GM clinic, WG1 members voted on the latest draft of part 1 of the standard. The outcome showed some support for different anchorage philosophies particularly among Canada, Australia and New Zealand members, who were in favour of a three-point attachment system including a top tether and some European car industry members who proposed a 2-point system. During the latter months of 1996 the situation had moved from almost unanimous support for the 4-point system to a point where there was a need to take a step back and look at the status of development of alternative proposals. In addition to the 4-point system (Scheme A), whose development was suspended, there were three alternatives. A system using the two rear attachments from the 4-point system with a top tether, (Scheme B, essentially the CANFIX proposal), a proposal from the German car industry, which used the same two rear attachments but employed a pre-compression device to limit rotation (Scheme B’) and a proposal from GM in the US, which used dedicated adjustable straps with a top tether (Scheme C). In addition a compromise was proposed which included both B’ and C was labelled D.

Within WG 1 an Ad-Hoc Group, chaired by TRL, was created to evaluate the alternative ISOFix concepts. TRL designed a research programme to compare the dynamic performance of these systems and how parents would use them. Prototypes were produced based on a single design of child seat shell. Forward and rear facing Group 1 and rear facing Group 0 child restraints were subject to front and rear impacts according to ECE R44 test conditions and side impact using the R44 test bench and New Zealand side impact pulse. Various degrees of slack were introduced into the system to determine the sensitivity to misuse. In addition a small user trial was undertaken to determine user reaction to the different systems and likely misuse modes. Subjects were given pictogram instructions and asked to install the child restraints in the rear seat of a small saloon car which had been adapted to accept Scheme A, B and C seats. Both the dynamic tests and the user trial included a conventional child restraint for comparison.

The results of the dynamic tests performed with no slack showed that all of the systems provided improved performance in frontal impacts when compared with the conventionally retained child restraint. In side impacts there were noticeable improvements over the conventional system for the rigid anchor concepts, however, the performance of the soft anchor system (Scheme C) was worse than that of the conventionally retained child restraint.

User trials showed that adjustable systems were likely to be left with some slack. Therefore it was important to consider the effects of misuse on relative performance. Scheme A, the 4-point system had no adjustment therefore was not susceptible to the addition of slack. Scheme B' and Scheme C were particularly susceptible to the addition of slack in the attachment system, with respect to head and chest acceleration and head displacement in front impacts. Scheme C was also sensitive to slack in side impacts. The large Group 1 rear facing child restraints showed that the use of a top tether could be beneficial even in side impacts. The research team concluded that Scheme B (2 rigid attachments with a top tether) appeared to be the best design concept. This was based on the test results under the expected conditions of use indicated from the user trials and taking into account the observations and opinions noted in the small user trial (Lowne et al, 1997).

3.2.11 Forward rotation control of ISOFix

ISO now resolved to concentrate on developing a well-defined proposal for a standard based on a 2-point rigid attachment system with an anti-rotation device. However agreement could not be reached on the form the anti-rotation device would take. Some experts argued for the better stability and performance offered by a top tether. The representatives of the European and Japanese vehicle manufacturers did not agree, and insisted that a top tether was unnecessary. They favoured the pre-compression method as a means of limiting rotation and were reluctant to incorporate the tether in their vehicles particularly as markets existed where there was no use for the tether, for example rear facing child restraints.

In order to make further progress, which had slowed due to the hostility to top tethers, it was agreed within ISO to include a separate part of the standard for top tethers. The structure of ISO/WD 13216 Child Restraint Systems - Anchorages In Vehicles And Attachment To Anchorages was amended to become:

Part 1 Seat bight anchorages and attachments.

Part 2 Top tether anchorages and attachments.

Part 3 Child restraint dimensions and vehicle space.

This enabled progress to be made on Part 1 of the standard which was approved and published.

3.2.12 European regulatory activity

In order to further the legislative progress of ISOFix, the UK DoT (now DETR) proposed amendments to ECE Regulation 44 (Child Restraints) and Regulation 14 (Safety Belt Anchorages) to incorporate ISOFix (ECE/GRSP 1997a and b). These amendments were developed by TRL in collaboration with VSE and were based on the ISOFix specification. The proposal included rigid anchorages and mandatory top tethers for forward facing systems. The performance requirements were raised, with the original values retained for an additional test with the top tether unattached to deal with the potential misuse situation. Members of ECE/GRSP questioned why the top tethers were proposed to be mandatory when they were not in the ISO specification.

Both vehicle and restraint manufacturers accepted the problem of child restraint forward rotation and the need for its control, but agreement on the method could not be reached. The European car manufacturers were opposed to the inclusion of top tethers as they felt they were open to misuse and would mean the inclusion of a further anchorage point in their vehicles. They proposed that the assessment of an ISOFix child restraint on the Reg. 44 test bench should be sufficient to gain universal approval. However the restraint may perform differently in a car, depending on the car seat characteristics.

This led TRL to propose a research programme to develop a dynamic test which would evaluate car seats with respect to 2-point attachments only. This would be used to formulate a set of performance requirements to control the child restraint - car seat interaction. This was deemed necessary because a 2-point ISOFix child restraint may perform well on the Reg. 44 test bench without being truly universal. This is due to the wide range of cushion depths, stiffnesses and profiles seen in vehicles today. For example, if a cushion was thick but soft the child restraint would rest on its surface but under frontal impact conditions rotate forwards allowing a high relative velocity to be reached. The sudden stop at the end of travel when the seat cushion is fully compressed would generate potentially injurious accelerations and possible neck injury. Thus a two-point attachment system without a top tether is dependent on the seat cushion properties.

The proposal called for some control of the minimum basal area and location for the child restraint, to ensure sufficient strength to withstand the reaction force without failure. A prototype ISOFix child restraint that complied with the performance requirements when tested on the Reg. 44 test bench would be built to this minimum dimension. Dynamic tests would then be performed, perhaps with a pre-compression system to evaluate the dynamic properties of a range of seat cushions and limit the resultant forward rotation and peak acceleration. The DETR was willing to undertake such a research programme providing support from the car industry could be secured. However, as this was not forthcoming, this approach was not continued.

In a further attempt to make progress within GRSP, an Ad-Hoc group within GRSP was formed, under the chairmanship of VSE, to resolve the situation. The TRL research programme was revised to provide technical support to assist in the Ad-Hoc Group deliberations.

3.2.13 Static and Dynamic tests of 2-Point ISOFix concepts

TRL conducted static and dynamic tests on three purposely designed child restraints. The performance of these restraints was compared on the Reg. 44 test bench and in three actual car body shells. This enabled conclusions to be drawn regarding the suitability of the Reg. 44 test bench for certification of 2 point ISOFix systems, which is potentially sensitive to the vehicle seat characteristics. The car models were selected as having seats with possible problems for 2-point ISOFix designs; deep cushions (Cars A and B) or a short cushion (Car C).

A framed type Group 1 forward facing child restraint formed the basis for CRS used in the tests. This was modified to optimise its performance on the Reg. 44 test bench, whilst compromising its universal use. This was achieved by increasing the overall length of the child restraint and limiting the forward contact area with the seat cushion to a single front rail. These measures ensured maximum pre-compression of the Reg. 44 test bench seat cushion, resulting in a high reaction against forward rotation. In addition, increasing the child restraint length to the maximum allowed on the Reg. 44 test bench created a device that could pass the Reg. 44 dynamic requirements but could ‘fall over’ the front of the seat in a vehicle with a small cushion and understructure dimensions.

A second design used the same basic framed CRS but adapted to attach to the ISOFix anchorages. The design of CRS used had a relatively short base design.

The final child seat evaluated was a Group 0+ infant carrier. A production Group 0+ device was modified to incorporate ISOFix anchorages.

Static tests determined the resistance to rotation of each child restraint on the Reg. 44 test bench. As predicted, the child restraint with the greatest contact area between its base and seat cushion (Group 0+ rear facing) resulted in the highest moment, until the child restraint frame reacted against the rigid seat base. Tests conducted in the body shells determined how the seat cushion characteristics of the vehicles varied for each child restraint.

Dynamic tests evaluated the performance of the child restraints on the Reg. 44 test bench and in each body shell in order to establish if there was a difference. The results are presented in Table21.

From Table 21, the forward facing Group 1 ISOFix child restraints exhibited better performance in terms of head and chest acceleration and head excursion than the corresponding conventionally retained child restraints on the Reg. 44 sled test bench. However, dummy head and chest acceleration and head excursion was greater for the

Table 21 Dynamic performance of conventional and 2-point ISOFix child restraints on the ECE Reg. 44 test bench and in car rear seats

Test vehicle	*Child restraint* Type	Group	Dummy	*Anchorage* mode	*Head Res. (3ms) g*	*Chest Res. (3ms) g*	*Head excursion mm*
Sled	ISOFix std frame	FF 1	P3	ISOFix 2pt	52.4	41.5	482
Sled	ISOFix front rail	FF 1	P3	ISOFix 2pt	56.8	38.4	485
Sled	Conv’t front rail	FF 1	P3	L&D	81.4	46.6	503
Sled	Conv’t std frame	FF 1	P3	L&D	71.2	48.3	549
Sled	Conv’t infant	RF 0+	P 1.5	L&D	46.5	46.5	650
Sled	ISOFix infant	RF 0+	P 1.5	ISOFix 2pt	57.8	53.8	750
Sled	ISOFix infant	RF 0+	P 1.5	ISOFix 2pt+L&D*	51.4	50.6	710
Car C	Conv’t front rail	FF 1	P3	L&D	54.0	38.0	539
Car C	ISOFix front rail	FF 1	P3	ISOFix 2pt	52.9	42.3	524
Car B	Conv’t std frame	FF 1	P3	L&D	62.6	45.8	553
Car B	ISOFix std frame	FF 1	P3	ISOFix 2pt	52.5	42.5	513
Car A	ISOFix std frame	FF 1	P3	ISOFix 2pt	62.9	52.6	559
Car A	ISOFix std frame	FF 1	P3	ISOFix 2pt+L&D#	57.1	50.6	522
Car A	Conv’t std frame	FF 1	P3	L&D	62.9	45.1	553
Car A	ISOFix infant	RF 0+	P 1.5	ISOFix 2pt	56.4	51.7	834
Car A	ISOFix infant	RF 0+	P 1.5	ISOFix 2pt+L&D*@	60.3	45.2	742
Car A	ISOFix infant	RF 0+	P 1.5	ISOFix 2pt+L&D**	42.3	57.3	672
Car A	Conv’t infant	RF 0+	P 1.5	L&D	51.7	48.9	619
Car A	ISOFix infant	RF 0+	P 1.5	ISOFix 2pt+L&D*	52.2	53.5	816

All ISOfix anchors set at 300N horizontal pre-load
 # Diagonal adult belt used as asymmetrical top tether (looped round plastic side wing)
** Diagonal adult belt used as asymmetrical top tether (through existing guides). Lap portion under CRS base*
*** Diagonal adult belt used as asymmetrical top tether (locked to seat top at head). Lap portion under CRS base*
@ Lifted on acceleration and remained ‘up’ due to belt reel in. All following tests employing L&D, carrier taped lightly to cushion.

rear facing Group 0 ISOFix restraints than the conventionally attached equivalent CRS. Improvements were recorded when the adult lap and diagonal belt was employed as an asymmetrical top tether, but not to the level of the conventional restraint.

In comparison with the vehicle body shells, the Reg. 44 sled test bench gave the desired ‘worst case’ result in terms of head and chest acceleration and head excursion for the conventional child restraints. However the results demonstrate that, despite using a pre-compression of 300N, the 2-point ISOFix CRS is vulnerable to changes in seat cushion characteristics and exhibited a greater magnitude of head and chest acceleration and head excursion in some car seats than on the R44 test cushion. This was true for both forward facing child restraints and rear facing infant carriers, where increased rotation of the restraint about the ISOFix attachments could result in increased head excursion and tensile neck/spine loads.

The European vehicle manufacturers rejected the use of a top tether as a method to control rotation about the ISOFix anchorages, in part due to the scope for misuse. However a potential misuse condition of the pre-compression method of anti-rotation is that the user might not fully utilise the compression facility, treating it only as an adjustment mechanism.

TRL conducted further dynamic tests using the Car A and Car B body shells only. A forward facing group 1 child restraint was positioned and adjusted so that the back of the restraint just contacted the vehicle seat back. In addition further evaluation tests of the ISOFix child restraint employing a top tether were conducted to investigate the effect of a top tether on non-compression misuse and to assist in the development of improved anti-rotation features. These results are presented in Table 22.

Table 22 shows that the effect of misuse of the pre-compression system for a seat without a top tether was negligible for Car B, the vehicle with a thick but relatively stiff seat. For the soft seat in Car A, the effect of this type of misuse was noticeable, increasing the forward head excursion by over 100mm. The chest resultant acceleration showed little difference for both vehicles in the compressed and un-compressed state. However the chest vertical acceleration in the un-compressed condition was nearly double that for the compressed condition, although it was still below the limiting value in ECE R 44.

In both vehicle body shells, the use of a top tether reduced the effect of non-compression of the seat cushion. This was particularly noticeable in Car A. This is further evidence that the use of a top tether removes the sensitivity of the child restraint to the seat characteristics, in this case the thick soft cushion of Car A.

These further tests have shown that there is a potential misuse condition that can lead to a decrease in the dynamic performance of the 2-point ISOFix system in some car seats.

This and other test results from other research institutes and manufacturers led the Ad-Hoc Group to conclude that some anti rotation device, other than the car seat cushion, such as a top tether or a front support foot would be required.

3.3 ISOFix development summary

The ISOFix concept describes a universal, rigid system provided in car seating positions for the attachment of any child restraint. Over a period of ten years, this has developed from an initial proposal to ISO/TC 22/SC 12/WG 1 by a group from Sweden into an international effort involving vehicle manufacturers, child restraint manufacturers, government agencies and research organisations.

TRL has been involved since the beginning. The UNIFix task force, created to form a UK response to the Swedish proposal achieved the co-operation of vehicle and child restraint manufacturers in the development of an alternative proposal to ISO. The UNIFix group succeeded in influencing the ISO working group resulting in a proposal for a 4-point attachment system that was to form the basis for the international standard.

Dynamic tests performed at TRL were able to show the benefits of the ISOFix system. Results from tests using an adapted body shell showed significant performance improvements for ISOFix over conventional lap and diagonal belt retained child restraints for rear facing group 0 and forward facing group 1 child restraints. The design had reached such an advanced stage that user trials were performed which were favourable for ISOFix. In addition concerns regarding the struck side impact performance of ISOFix due to its rigidity, were shown to be unfounded by full-scale vehicle tests.

Ultimately, some representatives to WG1 deemed the 4-point attachment system too complex and too costly. In a short period support for the system declined, leading to the development of alternative proposals which included the use of top tethers, pre-compression devices and even soft anchors. TRL developed a research programme to compare

Table 22 Dynamic performance of compressed and un-compressed 2-point ISOFIX child restraints in vehicle body shells and effect of top tether use

Test vehicle	*CRS*						*Head*	*Chest*
	Type	*Cushion*	*Group*	*Dummy*	*Anchorage mode*	*Res. Acc*	*Res. Acc*	*Head excursion*
Car A	ISOFix std frame	compressed	FF 1	P3	No top tether	62.9	52.6	559
Car A	ISOFix std frame	un-compressed	FF 1	P3	No top tether	59.3	50.3	673
Car A	ISOFix std frame	compressed	FF 1	P3	Top tether	55.9	43.3	536
Car A	ISOFix std frame	un-compressed	FF 1	P3	Top tether	48.1	49.0	554
Car B	ISOFix std frame	compressed	FF 1	P3	No top tether	52.5	42.5	513
Car B	ISOFix std frame	un-compressed	FF 1	P3	No top tether	66.1	45.6	510
Car B	ISOFix std frame	compressed	FF 1	P3	Top tether	62.9	58.8	491
Car B	ISOFix std frame	un-compressed	FF 1	P3	Top tether	66.0	46.9	495

the dynamic performance of these systems and how parents would use them. The 2-point rigid attachment scheme with a top tether appeared to be the best design compromise in terms of safety performance, user opinion and estimated cost.

ISO resolved to concentrate on a 2-point attachment system with some measure for controlling forward rotation of the child restraint. Agreement could not be reached on the form this would take. A top tether appeared the best option in terms of stability and performance and was favoured in North America, Australia and New Zealand. European car manufacturers felt this unnecessary and pressed for the pre-compression of the car seat cushion to limit rotation.

TRL recognised the limitations of such a system, which could create a child restraint that was sensitive to the seat cushion properties. This could potentially create a situation whereby a child restraint is approved on the ECE Reg. 44 test bench but whose dynamic performance is decreased if fitted to a vehicle with a softer or shorter seat cushion. Dynamic tests using the Reg. 44 test bench and three car body shells confirmed this hypothesis and also highlighted the potential misuse conditions of the pre-compression method and their effects.

In the future it is anticipated that further evaluation of ISOFix and anti-rotation methods would be necessary in order to develop appropriate standards that both improve safety performance whilst eliminating the potential for misuse.

4 Development of a side impact test procedure (ISO)

4.1 Introduction

There currently are no dynamic sled test requirements for the protection of children in child restraints in Europe. However, side impacts are second only to frontal impacts in resulting in serious injuries to restrained children in car accidents (Langwieder et al, 1996). Nearly as many restrained children are killed in side impacts as in frontal impacts (35 percent in side impacts, including side swipes compared with 38 percent in frontal impacts. See Table 11, Section 2.3.1).

As a consequence, TRL is working through ISO on the development of a side impact test procedure for child restraint systems as part of this Child Restraint project.

For a suitable standard, the preference would clearly be for a sled-based test procedure which would be as simple as possible while resulting in the development of child restraints with enhanced side impact protection that would work well in real car impacts. The initial proposals to ISO, from Sweden and the Netherlands, were based on the R44 sled with the test bench rotated to face sideways. A representation of the car side was rigidly fixed to the laboratory floor and arranged such that the car ‘door’ would pass over and in front of the R44 test bench, impacting the side of the child restraint.

4.2 Side impact test development

In car side impacts, the side structure initially intrudes into the passenger compartment at close to the impact velocity of the striking vehicle, but the total velocity change of the struck car is only about one half of this impact velocity. It is not possible to replicate these two characteristics with the fixed door approach proposed initially to ISO. Either the test is too weak if the velocity change is replicated, or too severe if the intrusion impact velocity is replicated.

The Technical University of Berlin proposed a two sled approach where one sled replicates the door velocity and holds the car ‘door’ while the second replicates the vehicle chassis acceleration and the CRS is mounted on a seat on this sled. This method can get close to the environment of an actual car impact but is somewhat complex for a Standard or regulatory test.

TRL proposed an alternative which was simpler than the two sled system but which attempted to replicate the essential interactions in a real car impact. This method uses one sled, which replicates the struck vehicle chassis acceleration, while the intruding door motion is replicated by a hinged door mounted on the sled.

The research forming part of this project was aimed at evaluating the practicability and suitability of this approach.

4.2.1 Chassis and door motion requirements

To provide a basis for the selection of the target chassis (sled) deceleration profile and the door velocity profile, full scale side impacts performed by TRL in the development of the EEVC Side Impact Test Procedure were reviewed for the required data. The struck vehicle chassis accelerations were noted from accelerometers located at the base of the non-struck side B-pillars. The inner door skin velocities, relative to the undeformed car structure were calculated from the integration of the difference between the inner door skin and B-pillar lateral accelerations.

Since the inner door motion was represented by a hinged door, the relative lateral velocity was approximately converted to angular velocity of the door by assuming that the intrusion was developed by ‘hinging the inner door skin about the relatively stiff car structure around the C-pillar. The assumption was made that this hinge point was approximately 600 mm from the point of attachment of the inner door accelerometer.

Figure 6 shows the lateral acceleration of the chassis of six cars, ranging from a Rover Mini to a large Jaguar, together with a proposed corridor for the sled acceleration profile.

Figure 7 shows the inner door rotational velocity, derived from the calculated translational velocity of the inner door skin of the six cars.

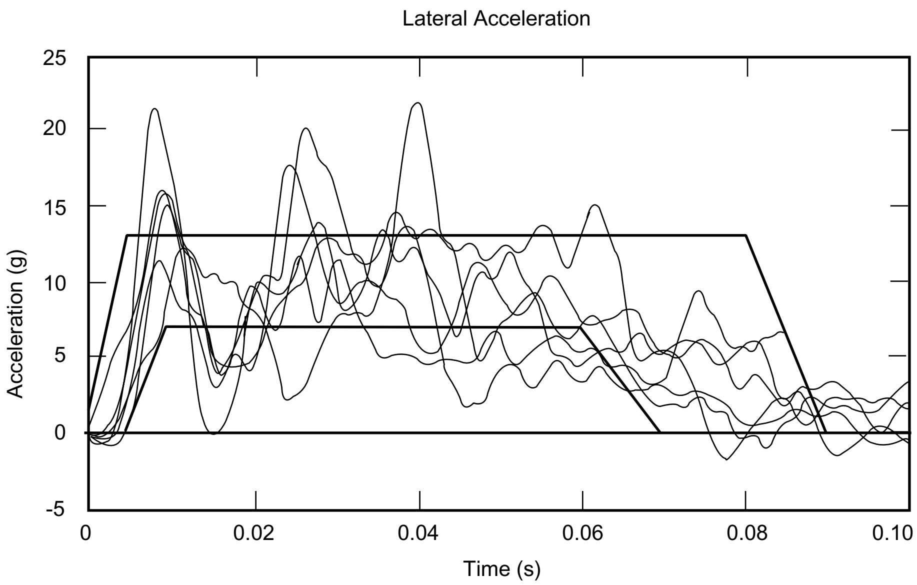


Figure 6 Non-sruck side B-pillar lateral acceleration

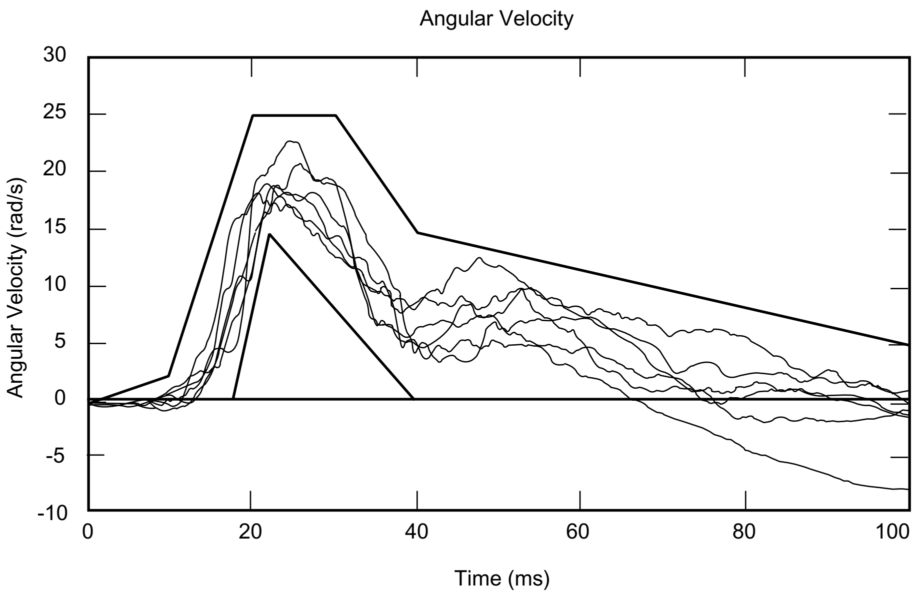


Figure 7 Angular door intrusion velocity, 6 cars

4.2.2 First configuration (fixed impactor beam)

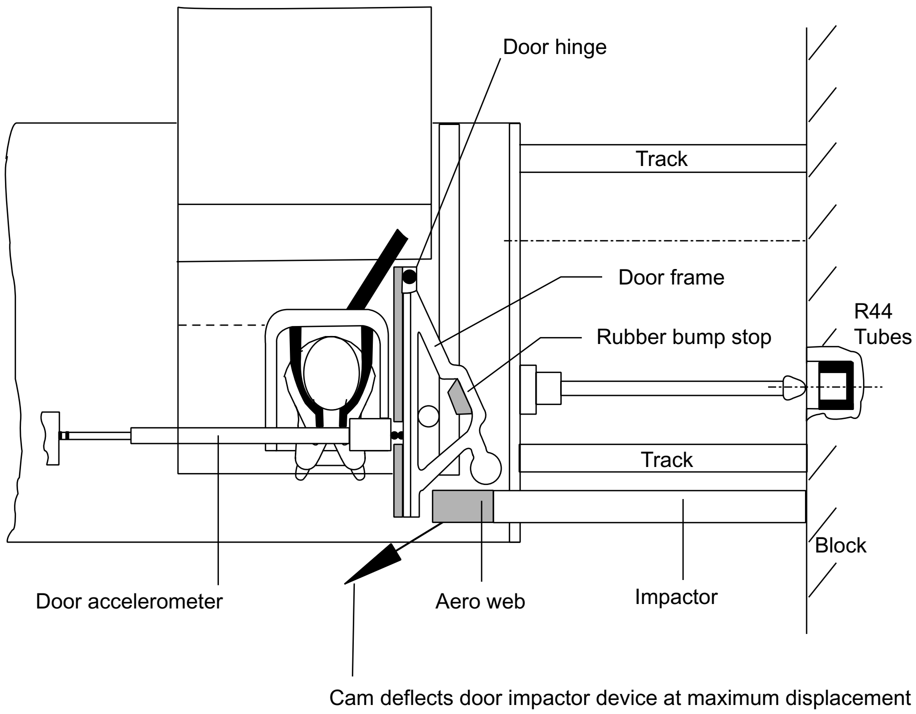


Figure 8 Side impact test method, first configuration

4.2.2.1 Test equipment

The standard ECE R44 seat was mounted laterally on the sled, a door frame and 25mm thick plywood door was mounted on a hinged frame which enabled the door to swing rearward, relative to the sled track, into a CRS mounted on the ECE R44 seat, using 44.03 anchorage positions.

As the sled decelerated, the door was pushed into the CRS by an impact beam. The impact beam was pushed sideways and thereby disconnected from the door when it had reached its maximum inelastic displacement position. The door continued against a rubber bump stop thus simulating the elastic displacement, which was recoverable. Figures 8 shows the test arrangement.

The impact beam impacted the door directly in the first few tests. In order to extend the duration of door acceleration, a softer impact was required. Initially, approximately 200mm of ECE R44 Tube was mounted vertically on the impact face, (coded T in the results table) and later approximately 150mm of Aluminium honeycomb was mounted on the impact face , (coded A in the results table).

4.2.2.2 CRS and dummy

A TNO P3 dummy was mounted in a forward facing CRS . The CRS was anchored to the ECE R44 seat using the 03 configuration.

4.2.2.3 Parameters measured

The following parameters were measured; uniaxial sled acceleration, sled velocity, triaxial dummy head and chest acceleration , uniaxial CRS acceleration, uniaxial door acceleration and system displacement.

4.2.2.4 Results and discussion

The results of these first tests are given in Table 23. The sled test results are compared with those from the full scale side impact tests which were performed in the evaluation of ISOFix and standard CRS attachment methods in side impacts, which are summarised at the top of the results table.

Table 23 Table of results of first dynamic tests with hinged door

Test number	*Sled ΔV m/s*	*Stop dist. mm*	*Decel g*	*Initial impac -tor type*	*Door accel g*	*CRS decel g*	*Chest reslt accel g (3 ms)*	*Head reslt acc g (3 ms)*
Target	–	–	–	–	–	120-130	70-80	30-40
3010	3.2	75	–	–	–	–	–	–
3011	5.3	112	–	T*	–	–	—	
3012	8.0	209	–	T-	–	–	–	–
3024	11.2	370	12.0	T	84.0	73.0	26.0	47.9
3025	13.5	481	22.2	T	277.7	67.0	43.9	93.1
3026	8.8	436	11.0	-	262.4	51.3	24.2	43.4
3027	8.8	352	12.8	-	268.2	50.7	25.9	42.1
3031	13.0	544	19.7	A*	142.1	53.4	43.9	81.9
3032	8.8	384	12.5	A	89.1	60.6	35.1	50.9
3033	11.1	431	16.6	A	237.6	65.7	36.8	58.5
3034	13.3	494	22.6	A	87.0	83.0	43.6	96.7

* *T – Impactor with tube interface*
A - Impactor with aluminium honeycomb interface (see text)

When the test was carried out without an energy absorber mounted between the impactor and the door the maximum inner door acceleration (278g) exceeded the mean full scale test vehicle value of approximately 150g by a considerable margin. The pulse time was also very short. In order to increase this, either a section of ECE 44 tube or a block of aluminium honeycomb was fixed to the impact end of the impactor.

Test T3031, using aluminium honeycomb, seemed to give a better agreement between the sled and vehicle tests for the maximum inner door acceleration.

The dummy responses were of the same order as those in the car tests, except that the head and chest accelerations were reversed. Careful inspection of the high speed films reveals that, in the car tests, the armrest pushed the CRS away. Further testing with a simulated armrest did not improve the responses.

The input conditions used in T3031 seem to achieve a dummy response and a maximum door acceleration of an acceptable order of overall severity. However the inner door acceleration pulse time needed to be increased in order to increase the energy input to the CRS.

4.2.2.5 Conclusions from first test series

This test series demonstrated that a hinged door system could be developed based on the existing R44 test sled, which could produce impacts to child restraints of similar severity to full scale tests. However, the particular arrangement with the fixed impactor beam was unable to generate the necessary door velocity while retaining the correct sled velocity change. The door needed to reach a rotational velocity equivalent to a translational velocity of the edge of the door of about 12m/s, relative to the sled.

4.2.3 Second configuration (mass-spring method)

Following the results of the first series, an alternative means of generating the hinged door motion, in which energy could be returned to the door, was developed. With this method the centre of percussion of the hinged door struck a free mass via a spring. Initially, the spring is compressed. As it is compressed, the door is driven backwards relative to the sled and the mass driven away from the door. Subsequently, the spring expands again, returning energy to the door. Figure 9 shows the revised test configuration.

The initial values for required mass and spring characteristics required to achieve the desired door velocity profile were determined by mathematical simulation. As the sled acceleration and door velocity are defined from full scale vehicle tests and the initial CRS to door separation determined from measurements taken in a range of cars, the only variable remaining that can be used to adjust the test severity was the door mass. Initially, a door mass of about 6kg was used, but this produced much lower dummy and CRS accelerations than the full scale test. The door mass had to be increased to 30kg and M1 to 100kg in order to achieve approximately equivalent results.

With this arrangement, it was found that both sled acceleration and the door velocity profiles could be generated that were very close to the proposed corridors. Some preliminary tests demonstrated that the severity of impact to the child restraint was of the same order as seen in the full scale vehicle tests (Table 24).

Table 24 Preliminary results with the spring-mass hinged door system

Test	*Max door angular velocity (rads/sec)*	*Resultant 3ms chest acceleration [peak accel] (g)*	*Resultant 3ms head acceleration [peak accel] (g)*	*Lateral CRS acceleration (g)*
Full scale vehicle test	15-25	56 [67]	35 [37]	120
Test 3524	17.5	65 [69]	61 [75]	103
Test 3525	16.5	66 [82]	61 [107]	85

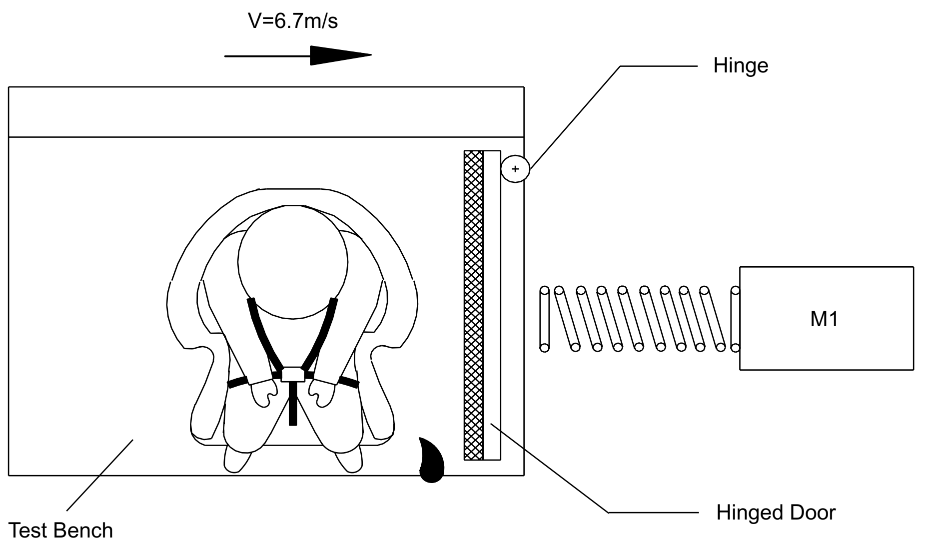


Figure 9 Side impact test method, second configuration (mas-spring method)

The door velocities and sled acceleration generated are shown in Figures 10 and 11. These were considered to be sufficiently close to the draft requirements and the dummy and CRS accelerations sufficiently close to those seen in the vehicle tests that it was concluded that this method could be used for the evaluation of the hinged door concept. (Paton et al,1998)

This methodology was presented to the ISO Working Group and it was provisionally accepted as the basis for the draft ISO Standard on side impact protection for child restraint systems.

4.3 Evaluation of the hinged door concept

4.3.1 Introduction

The objective of the single sled hinged door method was to develop a simple and reproducible side impact test, with intruding side structure which could be used to evaluate the side impact protection afforded by child restraint systems. To be effective, it has to be capable of distinguishing good systems from poor systems. In the absence of sufficient detailed accident data to be able to measure the effectiveness of different makes of CRS, a standard CRS was altered in ways that were considered to produce marked changes in the protection level in side impacts.

It is an important factor in the design of a CRS to ensure that the head of the child is fully contained during side impacts. The ability of each CRS to achieve this was investigated by the addition of a vertical plate mounted to the top of the hinged door, approximately at the position of the side glazing in a car. This was designed to give an indication of excessive lateral head excursion. Before each test, paint was applied to the head of the dummy in the CRS to highlight all head contacts during impact.

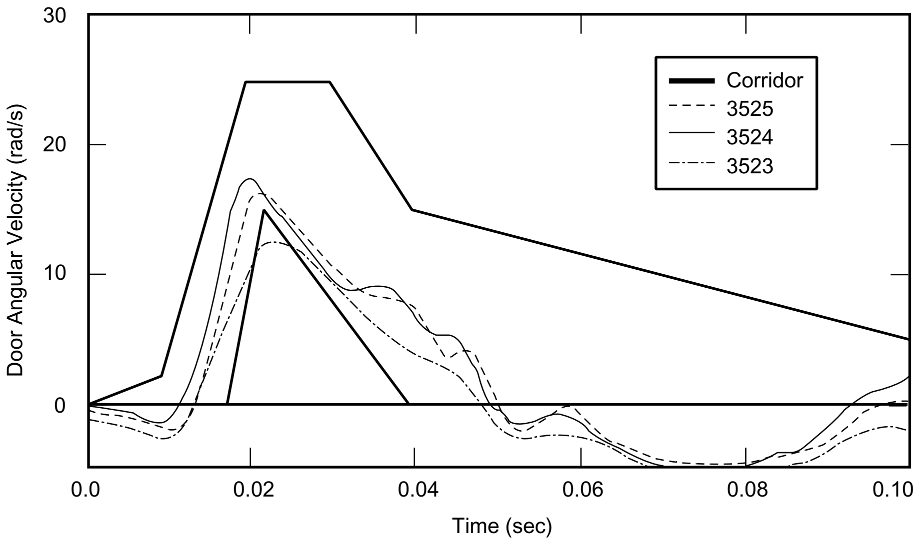


Figure 10 Examples of door velocity profiles for the mass-spring method

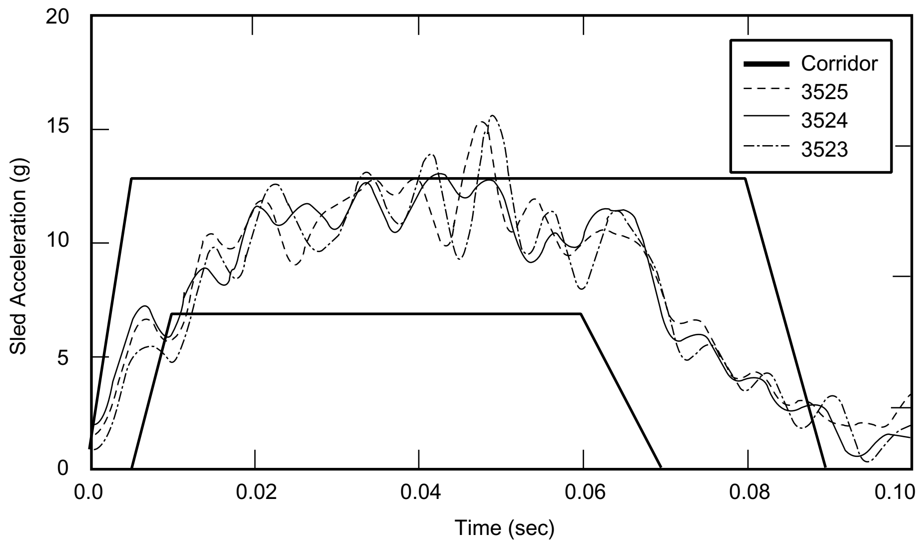


Figure 11 Examples of sled acceleration profiles for the mass-spring method

4.3.2 Test procedure

The impact system consisted of a sled which ran on rails and was propelled by elastic ropes. The standard ECE R44 test seat was mounted laterally on the sled and the child seat installed in accordance with ECE R44. The impact velocity of the sled was 25kph as defined in the draft ISO standard.

The angular velocity of the intrusion panel was achieved by employing the spring mass type system attached to the catching system of the test rig. The hinged door was made to latch at 19°. A rotary potentiometer was used to measure the angular velocity of the intruding door panel. The test arrangement is shown in Figures 12 and 13.

Figure 12 CRS positioning on test seat

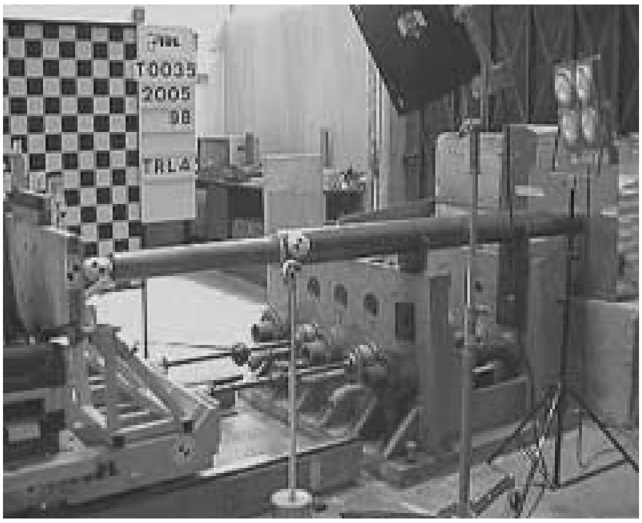


Figure 13 Sled impactor and catching system

In addition to the sled deceleration and door angular velocity, dummy head (tri-axial), chest (tri-axial) and CRS lateral (uni-axial) accelerations were recorded to allow comparison for each seat. The dummy used in each test was the TNO P3. The kinematic motion of the dummy and CRS during the impact event was recorded using high-speed video equipment.

4.3.3 Child seats

A standard forward facing child safety seat was chosen to form the basis of this experiment. It has design features common to many current CRS, such as side impact energy absorbing padding and integral harness. The perceived ability of this CRS to protect children was either enhanced or degraded by modifying the seat shell or padding and each resulting seat assigned a classification letter.

4.3.3.1 Seat Type A - enhanced side impact protection

Riveted extensions to the side wings of the CRS and the addition of Conforfoam© to the padded area for increased energy absorption were designed to produce enhance performance.. The original child seat cover was stretched over the extensions and taped in position. This restraint is shown in Figure 14.

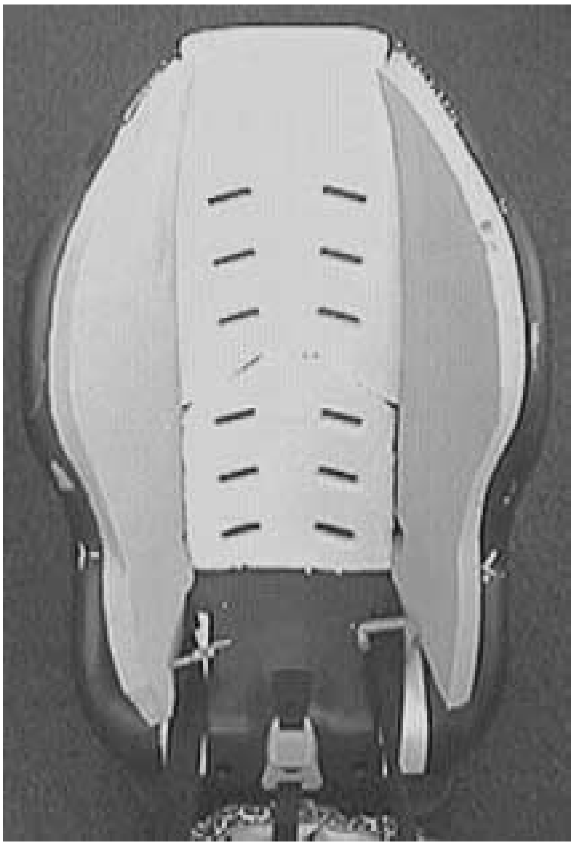


Figure 14 Seat Type A

4.3.3.2 Seat Type B - standard CRS

This was the standard CRS with no alterations made. In Figure15 the seat cover has been removed to show the location of the standard energy absorbing padding.

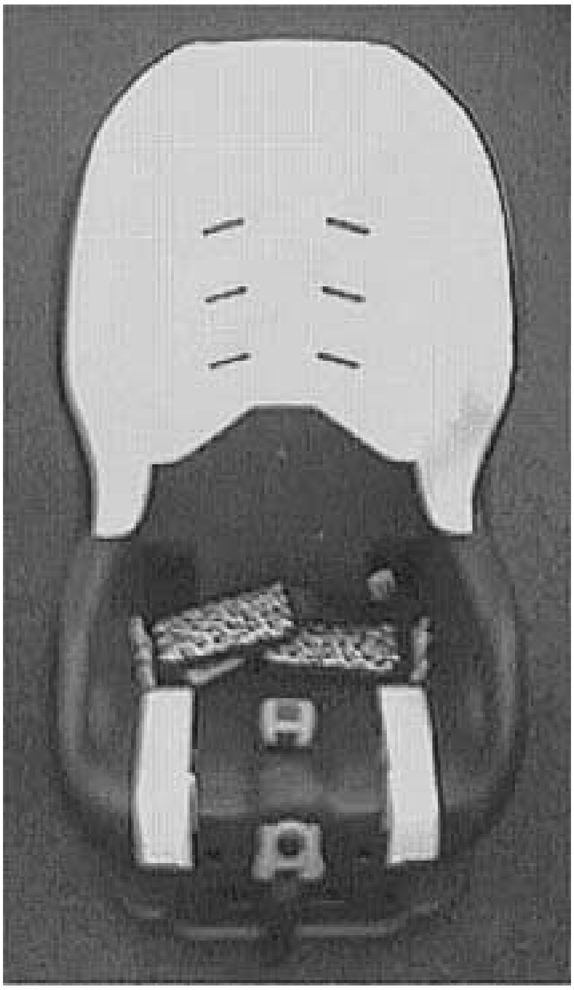


Figure 15 Seat Type B

4.3.3.3 Seat Type C - energy absorption degraded

All energy absorbing padding was removed from the CRS and the seat cover refitted. See Figure 16.

4.3.3.4 Seat Type D - side impact protection degraded.

The existing side wings were cut from the CRS to leave a back plate and padding. The seat cover was then refitted and tape was used to ensure that it remained taut. This restraint is shown in Figure 17.

Figure 16 Seat Type C

Figure 17 Seat Type D

4.3.4 Results

The peak resultant acceleration for the head and chest were calculated together with the 3ms exceedance value. A summary is provided in Table 25 below.

In struck side impacts it is important for the restraint to retain the child within the confines of the seat and its energy absorbing padding. Seat type B, the standard CRS could not be guaranteed to contain the child's head within its shell. In test 23 the head of the child made contact with the panel on the intruding door. This resulted in high head accelerations, seen in Table 25. When the seat did contain the child it performed well giving much lower head accelerations (test 19).

A better performance might have been expected with the enhanced seat, type A. Although the child dummy was fully contained within the seat, the head accelerations were higher than expected. This can be attributed to the material chosen as the energy absorbing padding on the extended side wings. Conforfoam© is not only temperature dependent but also highly rate dependent. Generally,

Table 25 Summary of results for different side impact protection levels

Test	*Dummy*	*Seat*	*Head to panel contact*	*Head resultant acceleration*		*Chest resultant acceleration*		*Sled peak accel. (g)*
				Peak value (g)	*3ms value (g)*	*Peak value (g)*	*3ms value (g)*	
TRL22	P3	Type A	No	59.7	55.3	39.1	37.1	13.5
TRL19	P3	Type B	No	40.9	37.5	40.9	39.5	13.6
TRL23	P3	Type B	Yes	159.1	87.3	31.9	29.5	13.2
TRL20	P3	Type C	Yes	187.6	97.0	37.3	33.8	13.0
TRL24	P3	Type C	Yes	47.23	40.79	36.30	34.51	13.1
TRL21a	P3	Type D	Yes	199.4	122.7	32.8	31.0	12.8

Conforfoam© is considered to have very good energy absorption qualities but, under these conditions, the material selected by the CRS manufacturer is clearly superior. The rigidity of the production energy absorption material meant that the polystyrene removed from other child seats could not be formed into the desired shape to fit the extended wings of this seat.

The test procedure was able to recognise when child restraints of lower quality were used. Higher head acceleration levels were recorded in the seat with all padding material removed. Without the energy absorbing foam there was less friction between dummy and seat. The head made initial contact with a side wing of the seat but was not contained by it and then made contact with a rigid post on the intrusion panel. The repeat test with this seat type, test 24, did not duplicate the results. The acceleration levels were much lower than expected and cannot be relied upon. The low friction between dummy and seat allowed the head to slide on the wing and then rotate. This action reduced the impact energy sufficiently to give lower head acceleration when the dummy finally made forehead contact with a rubber strip on the intrusion panel.

The highest levels of head acceleration were observed for the seat with no side impact protection. This is because no energy was lost by contact with the seat. Instead the only head contact was with the rigid post on the intrusion panel.

The variability of the results in these tests is of some concern. It should be noted that the TNO P3 dummy used in these tests was not designed for side impacts. Deformation of the dummy is not possible due to its steel skeleton. This makes it stiff, resulting in spurious high acceleration levels. It has a limited neck structure; this could be an important factor when investigating head movement of the dummy. Also it is possible for the harness of the child seat to become caught in the shoulder gap between the arm and torso of the dummy. The Q series of child dummies has been designed to be more compliant and is considered to be more suitable for side impact testing.

4.3.5 Conclusions from the evaluation study

- The results show little variation in chest response for all seat types.
- The results show somewhat higher variation in the head acceleration in these tests. Despite this, the results demonstrate that the test procedure was able to distinguish between dummy head response for different levels of side impact protection.
- It is recommended that the Q series dummy is used in future side impact evaluation studies.

4.4 Representation of vehicle intrusion patterns

4.4.1 Introduction

The use of a flat door panel which is hinged at the ‘rear’ edge was designed to simulate, in a simple manner, the intrusion of the inner door skin adjacent to the rear seat of a car. Thus this test simulates the impact to a child restraint in a rear seat on the struck side of the vehicle experiencing a side impact. Similar logic would lead to the conclusion that, to simulate the impact to a child restraint located in a car front seat position, the door would be hinged at the ‘front’ edge.

The simulation was based on the examination of cars subjected to the EEVC Side Impact Test Procedure, now used in ECE R95 and EuroNCAP. To ensure that this was not misleading, deformation patterns in side impact accident cases were reviewed

4.4.2 Method

A sample of 102 accident cases was collected from the CCIS database and relevant details entered into a spreadsheet noting Estimated Test Speed (ETS) and the relative car intrusion dimensions. Side intrusion position of the struck vehicles varied along the length of the vehicles and in the length of the damage. It was decided to normalise the side impact intrusion patterns at positions labelled A, B, C, D, E and F, (see Figure 18). Position C is approximately the ‘B’ pillar location; position A is roughly the ‘C’ pillar location, and the ‘A’ pillar is located between positions F and E.

To grade the intrusion profiles according to accident severity (ETS), four speed bands were chosen: 0 to 20 km/h, 20 to 40 km/h, 40 to 60 km/h and 60 to 107 km/h (107 km/h being the highest speed in the last group).

4.4.3 Results from accident data

One hundred and two accident cases were examined in total. The cases were sub-divided according to severity (ETS), but the samples in the sub sets were not of equal size. However a clear picture was formed from the data collected.

The average intrusion pattern, together with the maximum and minimum intrusion levels, for the four accident severity bands are shown in Figures 19 – 22.

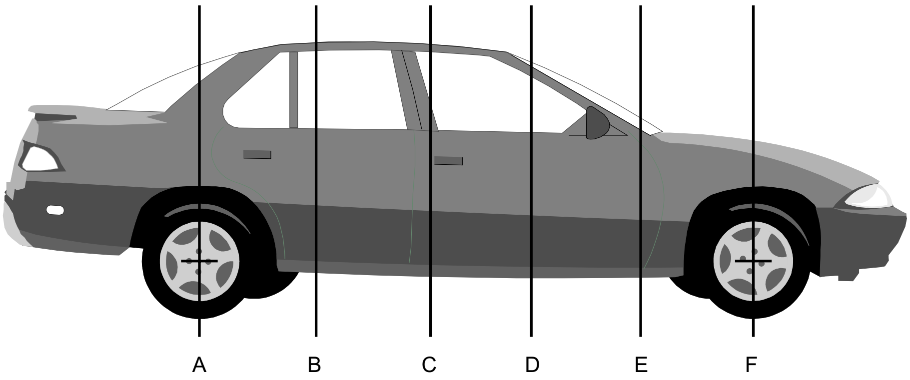


Figure 18 Location of intrusion measurements

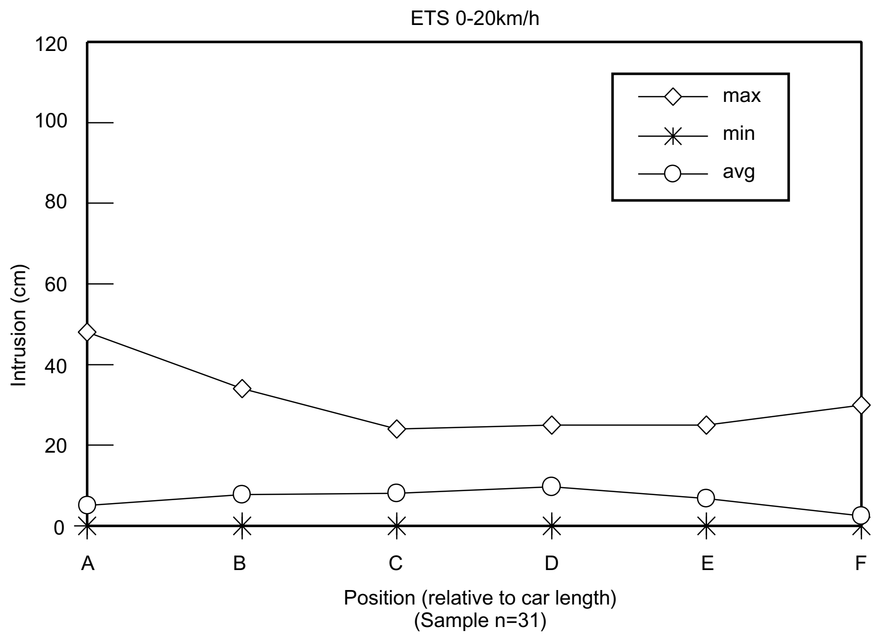


Figure 19 Intrusion profiles (ETS 0-20km/h)

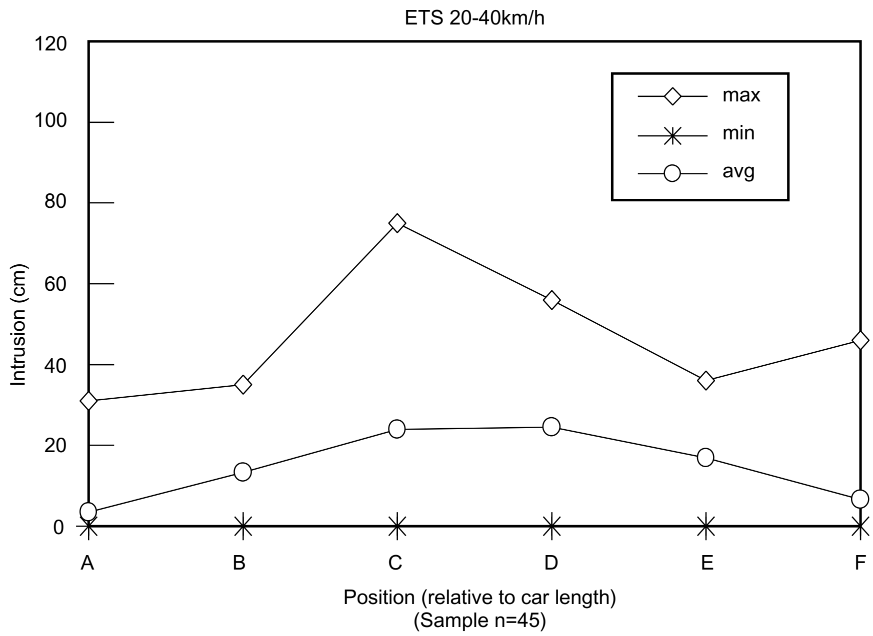


Figure 20 Intrusion profiles (ETS 20-40km/h)

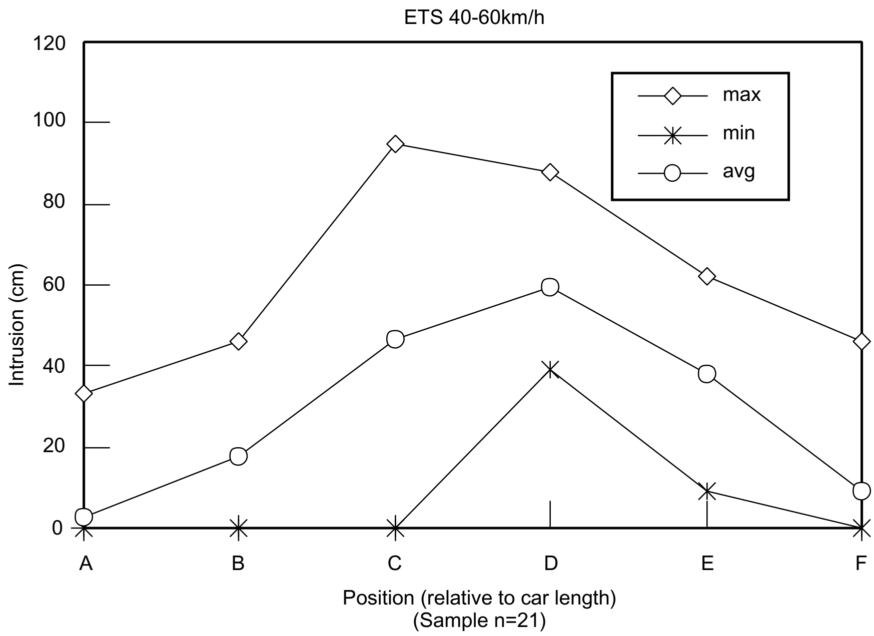


Figure 21 Intrusion profiles (ETS 40-60km/h)

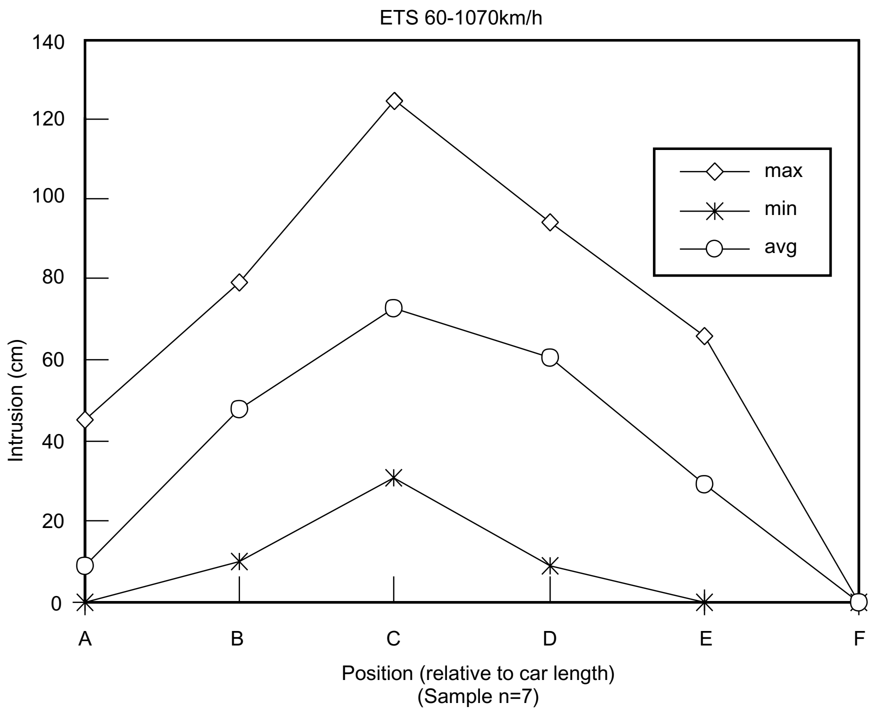


Figure 22 Intrusion profiles (ETS 60-107km/h)

At the lowest ETS band (Figure 19) no obvious intrusion profile is evident although it could be argued the average result shows a slightly increased intrusion depth near position 'D' between the A and B posts. The average intrusion profile for the second level ETS band (Figure 20) shows the more characteristic pattern seen in side impact tests. The average depth of intrusion at positions 'C' and 'D' appear to be greater than the other positions. This pattern is repeated, although at greater intrusion values, for the third and fourth level test band (40 to 60 km/h Figure 21 and greater than 60km/h, Figure 22)

From these results, it can be seen that the intrusion pattern in real accidents support the observations in the full scale side impact tests. The intrusion for the rear seat position represents a deformation which is greatest at the location of the B-pillar and is effectively hinged at the rear near the C-pillar, Similarly the intrusion pattern for the front seating position represents a deformation which is greatest at, or just ahead of, the B-pillar and is effectively hinged at the A-pillar. This confirms that a hinged door is a reasonable representation of the deformation seen in actual accidents, with the hinge at the forward edge for front seat conditions and at the rear edge for the rear seat configuration. However, the dynamic shape of the intrusion pattern cannot be determined from these static measurements.

4.4.4 Alternative door profile

This flat door representation of the intruding structure is a simplification of the reality of side impacts where the intruding profile is flatter where it is away from the 'hinge' (C or A pillar) than close to the 'hinge' point (Figure 23). The impact of the flat door may be unrealistic at the area far from the hinge.

To evaluate the possible effects and practicality of using a profiled door, a revised hinged door was created.

4.4.4.1 Door profile

To determine an appropriate door profile, a number of vehicles which had been subject to the EC Side Impact Test Procedure were measured. The profiles of the final intrusion pattern were measured using a 3-D measuring arm for two vehicles, and the profile of the internal door skin at the level of maximum intrusion was measured for 12 cars.

Measurements of the twelve cars were taken at the front and rear of the seat cushions at seat height, and again at the front of the seat cushions at a height which gave maximum intrusion. Measurements were also taken at the A, B and C pillars, at window height.

Based on a mean profile from these results a profile for the new door was designed. Figure 24 shows a schematic of the new profile for the hinged door. The profile was constructed mainly from wood, with inner webs for strength.

Figure 25 shows the new profile for the hinged door. The side of the door which impacts the child seat was covered with a polyurethane pad, as specified in the draft ISO child restraint side impact standard of October 1997.

This configuration represents the situation for the rear seating position. A different profile would be required for the front seat situation, so this method would not be so simple to convert from front seat to rear seat configurations as would the flat door.

4.4.5 Test programme

Six impact tests were performed with this door design, hinged at the rear edge, representing the rear seat position. Figure 26 shows the new profile set-up on the hinged door frame, ready for testing. The door was positioned so that the initial gap, between the door and the CRS, was kept the same as it would be in the set-up for the flat door.

The tests involved forward and rear facing child

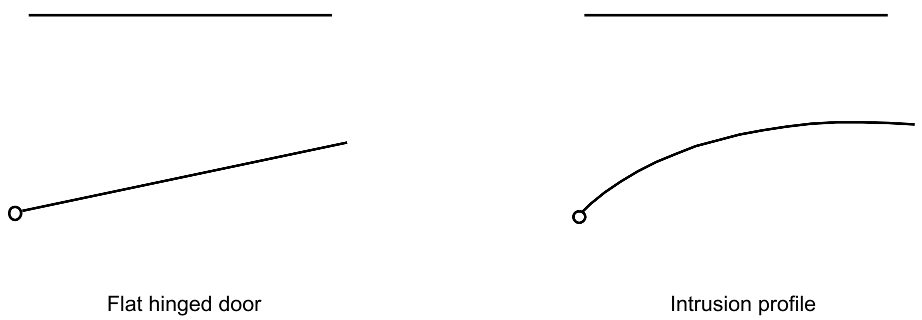


Figure 23 Representation of intruding structure

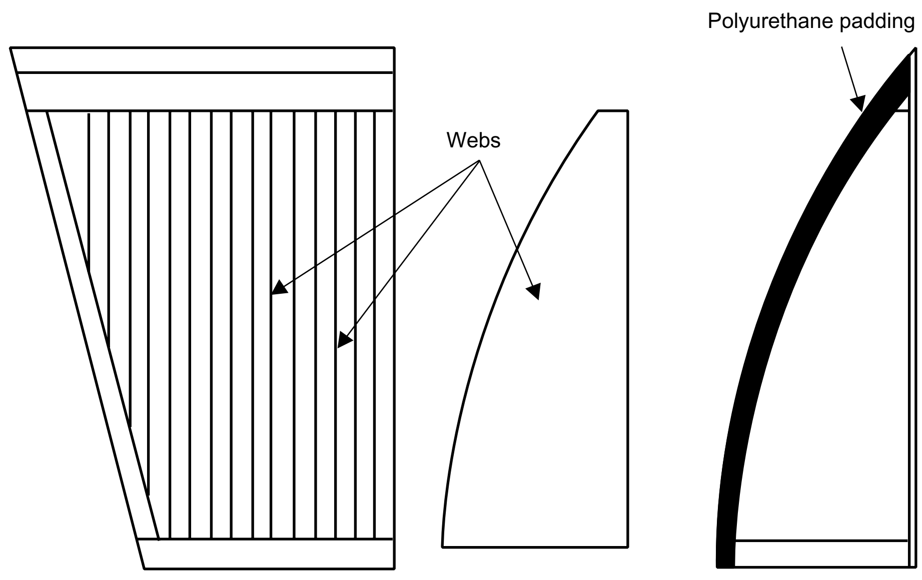


Figure 24 Schematic of the new profiled hinged door

Figure 25 Prototype profiled door

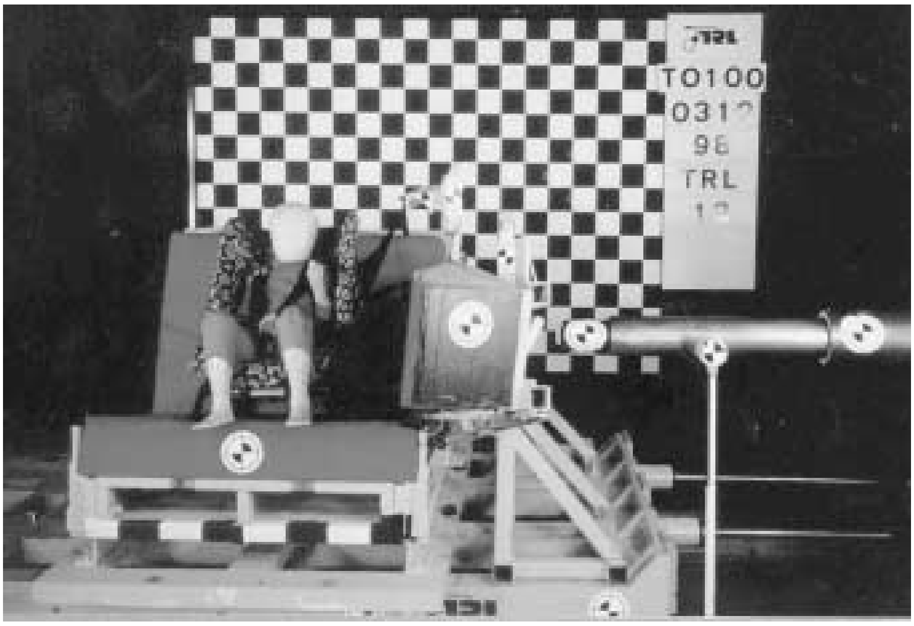


Figure 26 Test configuration with the profiled door

restraints with the appropriate P3, $P1\frac{1}{2}$ and $P\frac{3}{4}$ dummies. The sled acceleration and door velocity characteristics were kept the same as those currently specified for the flat door test.

4.4.5.1 Test results

Table 26 shows the results for the test configurations used in this programme while Table 27 shows comparable results for a full scale side impact test and sled tests with a flat door.

The results for the profiled door seem to be rather variable with the current dummies. However, within the limitations of this variability, compared with the flat door, the profiled door appears to reduce chest acceleration for the forward facing child restraint, but may increase the head acceleration. For the rear facing child restraints there seems to be a reduction in head acceleration, but a slight increase in chest acceleration. The disadvantage of a booster seat, which fails to prevent head contact with the door, can be seen from the high head acceleration values.

Further investigation with a more suitable dummy would need to be undertaken before the influence of the curved door could be established with confidence. However, the profiled door appears to be a practical test tool and seems to generate a more realistic loading regime to the child restraint than the flat door. It is a little more complex than the flat door method.

Table 26 Profiled door test results

Test	Dummy	Seat	Head: Peak resultant (g)	Head: 3-msec (g)	Chest: Peak resultant (g)	Chest: 3-msec (g)	CRS	Head contact with door structure?	Sled peak g
TRL 13	P3	Forward facing with harness	104.1g	70.6g	37.8g	28.2g	108g	Yes	13.2g
TRL 14	P1 ½	Rear facing with harness	75.6g	52.4g	103.0g	71.0g	200g	No	12.5g
TRL 15	P1 ½	Rear facing with harness	42.9g	36.4g	75.1g	63.7g	207g	No	12.5g
TRL 16	P ¾	Rear facing with harness	115.4g	74.5g	112.3g	34.5g	218g	Yes	13.0g
TRL 17	P3	Forward facing Booster seat + adult belt	282.2g	110.8g	39.1g	36.1g	55g	Yes	13.0g
TRL 18	P3	Forward facing Booster seat + adult belt	57.4g	44.9g	46.0g	32.3g	42g	No	13.0g

Table 27 Full scale vehicle and flat door test results

Test	Dummy	Seat	Head: Peak resultant (g)	Head: 3-msec (g)	Chest: Peak resultant	Chest: 3-msec (g)	CRS	Head contact with door structure?	Sled peak g
Vehicle	P3	Forward facing with harness	37	35	67	56	120	–	–
3524	–	–	75	61	69	65	103	–	–
TRL 3	P3	Forward facing with harness	–	[60]	48.3	41.2	–	–	13.6
TRL 5	P1 ½	Rear facing with harness	84.6	70.1	87.4	62.6	–	–	13.7

4.5 Front and rear seating positions

It has been recognised that the hinged door procedure which had been developed, represented the intrusion conditions for a child restraint located in the rear seating position in the vehicle. Under these conditions, the area of greatest intrusion is that adjacent to the B-pillar. As a consequence, the loading conditions to the child’s head and thorax will be greatest for a rear-facing child restraint.

In the front seating position, the situation would be reversed. Again the greatest intrusion is adjacent to the B-pillar (see Figures 19 – 22). In this situation, the loading conditions to the child’s head and thorax would be for a forward facing child restraint. It would be desirable to be able to evaluate the protection given to the child occupant under both front and rear seating position impact conditions.

To assess the potential for the hinged door method to be able to test under front seat conditions, the test equipment was revised such that the hinge was relocated at the front edge of the door.

Figure 27 shows the orientation used in the development of the test procedure, representing the rear seat configuration. Figure 28 show the test bench configured for the front seat orientation.

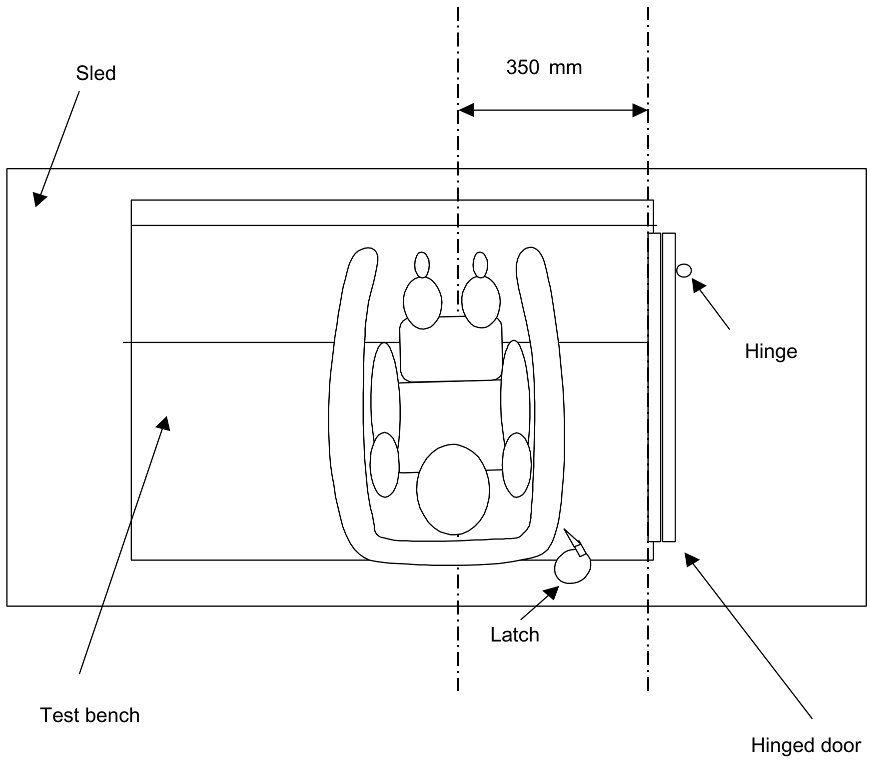


Figure 27 Test bench with rear seat orientation

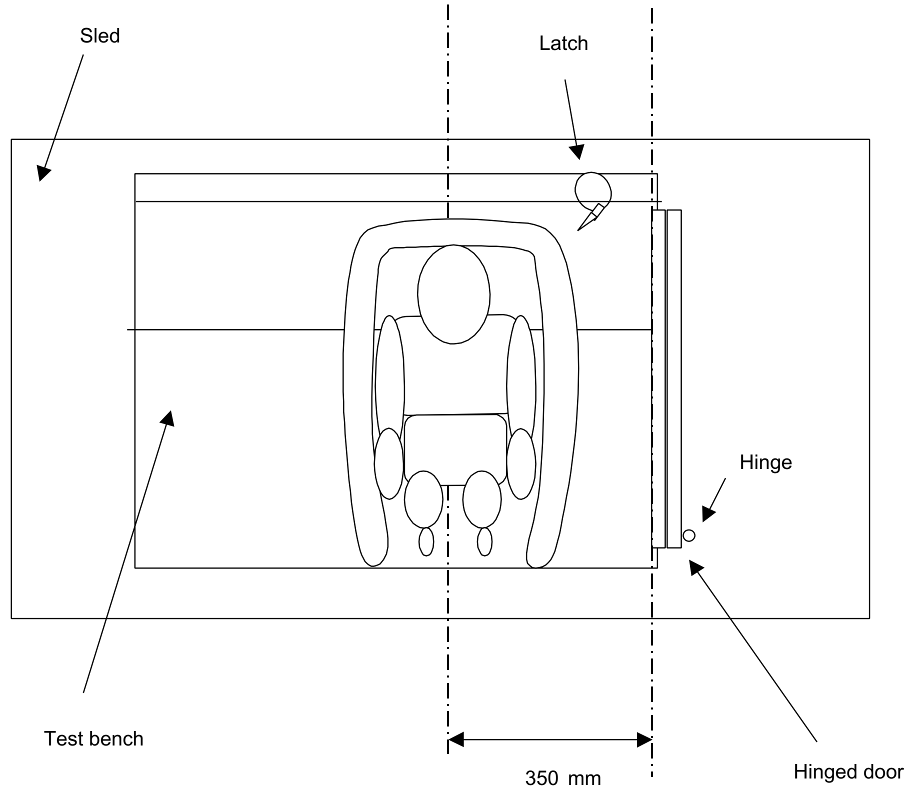


Figure 28 Test bench with front seat orientation

Tests were performed with forward and rear facing child restraints under both test conditions. Both forward and rear-facing child restraints used integral harnesses. The P3 dummy was used in the forward facing CRS and the P1½ in the rear-facing CRS.

The results are shown in Table 28.

Table 28 Comparison of front and rear seat configurations for forward and rear-facing CRS

	Forward facing CRS TNO P3 dummy		*Rear facing CRS TNO P1½ dummy*	
	Chest accel. (g - 3 msec)	*Head accel. (g - 3 msec)*	*Chest accel. (g - 3 msec)*	*Head accel. (g - 3 msec)*
Front seat configuration	98.4	47.2	49.8	62.0
Rear seat configuration	41.2	[60]*	62.6	70.1

One of the three head acceleration channels failed during the test. This figure was estimated from the remaining channels.

It can be seen that, as expected, the chest acceleration was greatest for the forward facing CRS under the front seat test conditions whereas it was greatest in the rear seat configuration for the rear-facing CRS. This was also true for the head acceleration with the rear-facing CRS. It was not the case for head acceleration in the forward facing CRS.

Examination of the high speed film records of these tests demonstrated that the hinged door concept can be used to simulate both the front and rear seating positions. If this were further developed into a child restraint standard, this would add to the number of tests required. However, it may be sufficient to test only the ‘worst case’ configuration, which is indicated in Figures 27 and 28.

5 Project summary and conclusions

5.1 Accident studies

- The questionnaire study has shown that the use of restraints is effective at reducing injury risk, 85 percent of children in child restraints were uninjured in phase I and 82 percent were uninjured in phase II. compared to 62 percent of unrestrained children in phase I. Two percent of restrained children had moderate to serious injuries in phase I and 3 percent in phase II in comparison with 8 percent of the unrestrained children in phase I. (There was only one unrestrained child in phase II by the end of this project).
- In phase I, the restraints with the highest proportion of uninjured occupants and the lowest proportion of moderate or severe injuries were the infant carrier, child safety seat and restrained carry cot. Although the sample size is still rather low these observations seem to be confirmed by the results from phase II with the addition of booster seats with backrests and booster cushions.
- From the Serious accidents sub-sample in the questionnaire study, the restraint systems that afforded the best protection were the infant carrier, the child safety seat and the restrained carry cot. Systems that are not designed specifically for restraining children were less effective.

- Injury was less likely in a rear impacts, probably due to the good load distribution to the child's body provided by forward facing child restraints or the vehicle seat.
- Both phases show the importance of protection from serious injury in side impacts than in front or rear impacts. In phase II of the questionnaire study, 16 percent of the children involved in a side impact sustained serious injuries while none of those involved in frontal impacts sustained a serious injury. These figures may have been distorted by the low numbers involved. In phase I two percent were seriously injured in both side and frontal impacts.
- The presence of a backrest with side wings could help to minimise head injuries in side impact.
- The Serious Injury and Fatal accident studies confirmed the risk of injury in side impacts. In the serious injury study, children were seen to be vulnerable in side impacts. Child restraint evaluation in side impact should be considered in future changes in child restraint test standards.
- In the remedial measures review of the fatal accidents it was concluded that improved side impact protection would have a major benefit.
- Future progress in side impact standards for vehicles should also consider interactions with children, particularly in the rear seat.
- Lap belts give poor restraint for children, as for adults, and installation of three point belts for all seating positions should be encouraged.
- Booster cushions, particularly when used by young children, do not give good upper body support and their use by this age group should be discouraged and the recommendation should be the use, as a minimum, of booster chairs.
- Improvement in the strength vehicle seat backs is necessary to reduce additional loading from unrestrained luggage. The effectiveness of the revised seat back strength requirement should be evaluated in future studies.
- A number of injuries are seen within the Serious Injury data sets which are not detected by existing dummies (e.g. leg fractures). Some of these are affected by the in-vehicle environment and it is therefore difficult to see how improvements in CRS standards could influence these types of injury.
- Restraint misuse was seen again within the samples. Further efforts should be made to reduce the potential for misuse through engineering and educational means.
- The five year fatality study has highlighted the fact that some 'engineering' improvements may be possible which could reduce the incidence of fatal injures to children in cars:
  - Improved fixation of CRS to vehicle (e.g. with the adoption of ISOFix type restraints which could be achieved through improved CRS and vehicle standards).
  - Reduction in misuse through better CRS design, possibly achieved through improved CRS standards.
  - Improved awareness of the importance of restraint adjustment. This requires improved public awareness.
  - Easier child harness adjustment systems potentially achieved through improved CRS standards.
  - Vehicle design improvements. Many improvements are entering the vehicle fleet, including air bags and better side impact protection, all of which could have an influence on child protection.

5.2 ISOFix

- A universal dedicated child restraint attachment system has been developed initially through a UK working group, followed by the use of this as an ISO Standard.
- Based on the research described in this report, the amendment of the ECE Regulation 44 to permit a universal system based on the two point ISOFix, together with a top tether or front support foot is recommended.

5.3 Side-impact test procedure

- A sled-based side impact test procedure has been developed, in which the car door inner panel intrusion and the car chassis acceleration are separately controlled. The intruding structure is represented by a hinged door attached to the sled.
- Although the results show too much variation in the head and chest acceleration, the results demonstrate that the test procedure was able to distinguish between dummy responses for different levels of side impact protection.
- The test procedure has been shown to be practical but the variation in results is too high and the door motion affected by the presence and characteristics of the child restraint. It is recommended that the hinged door be positively driven and that the Q series dummy is used for the future development of this method into a test procedure suitable for use in a Regulation.

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CONFIDENTIAL **Accident Enquiry Form - Child Restraint** **CONFIDENTIAL**

This questionnaire has been prepared by the Transport Research Laboratory for the United Kingdom Department of Transport and the Regions. Returned forms are being used to study the performance of child safety restraint systems, the results of which will lead to improved safety standards and better restraint systems. The form is being distributed in collaboration with several child restraint manufactures who are cooperating in this study.

Please keep this form with your insurance policy or your log book and only complete and return it in the unfortunate event of you being involved in an accident. Please return this form, even if the child(ren) are not injured, to the FREE POST address overleaf. **No stamp is required.**

Vehicle make and model, type (e.g.. saloon, estate, hatchback), year of manufacture, left hand drive, any unusual features?

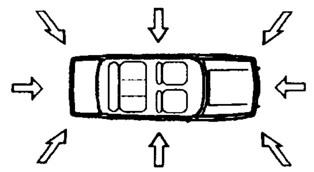
Accident
Date of accident ? ..../......../.......... (day/month/year)
Were you driving on the Left or Right hand side of the road ? L / R
Where and how did it happen (please give details of road condition, situation on road etc.)

please continue on a separate sheet if necessary

Where was the point and direction of impact on your vehicle ?
(most serious if more than one; show on sketch provided)

Tick box for: Rollover ☐ Underneath ☐ Above ☐

Rear Front



What was the extent of the damage to your vehicle ?
(please give as much detail as possible, including probable cost of repair)

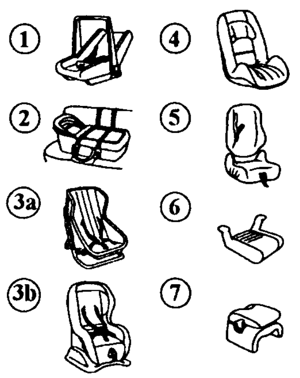
please continue on a separate sheet if necessary.

Please fill in for each child, under 14, who was traveling in the car.

Age (years/months) **Child 1....... Child 2....... Child 3....... Child 4....... Child 5.......**
Approx. weight (kg) **Child 1....... Child 2....... Child 3....... Child 4....... Child 5.......**

Was the child restrained ?
If so, please indicate how

	Restraint type (No. 1 - 12)	Forward facing	Rearward facing
Child 1	....	☐	☐
Child 2	....	☐	☐
Child 3	....	☐	☐
Child 4	....	☐	☐
Child 5	....	☐	☐



Examples

1. Infant carrier
2. Carrycot
3a. Child safety seat (metal frame)
3b. Child safety seat (plastic frame)
4. Booster seat / chair
5. Booster seat separate backrest
6. Booster cushion
7. Impact shield
8. Modified adult seat belt
9. Child safety seat built into vehicle
10. Adult seat belt
11. No restraint used
12. On adults lap
13. Other (please state)............................

How was the child restraint held in the car ?
(Please enter No. 1 - 6)

Child restraint 1...................................
Child restraint 2...................................
Child restraint 3...................................
Child restraint 4...................................
Child restraint 5...................................

Examples:

1. adult shoulder and lap belt
2. adult shoulder belt only
3. adult lap belt only
4. Fixing kit supplied with restraint
5. ISOFIX
6. other (please state).....................

What make/model of child restraint (CRS) was used for each restrained child
(please add the safety standard that the seat conforms to? e.g.. B.S. 3254, European Standard E.C.E. R44.--)

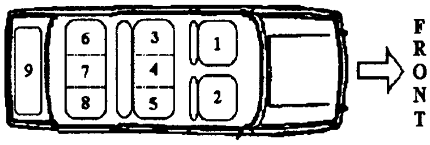
CRS 1...
CRS 2...
CRS 3...
CRS 4...
CRS 5...

Where was each child positioned at the time of the accident ? (refer to diagram)

Position
(No. 1-9)

Child 1..................
Child 2..................
Child 3..................
Child 4..................
Child 5..................

Seating Positions



Please state which position the driver was in ....

Was a child injured?
Please give details of injuries to each child, including severity, extent and where on the body they were injured.

Injury

Child 1...
Child 2...
Child 3...
Child 4...
Child 5...

Were there any other adults in the car? **Yes** ☐ **No** ☐

Where were the adults positioned ? (refer to above diagram for seat positions)

Adult 1 .... **Adult 2** .... **Adult 3** .... **Adult 4** .... **Adult 5** ....

Please give details (including severity and extent) of any injuries to the adults

Adult 1 ....
Adult 2 ....
Adult 3 ....
Adult 4 ....
Adult 5 ....

Please send to:

TRL Ltd.
FREEPOST (Licence SCE1927)
Old Wokingham Rd
Berkshire
RG45 6ZY

(This section is optional)

Name..
Address..
....
....
....
Post Code...

THANK YOU FOR YOUR COOPERATION

crsqst3

Abstract

This project on the protection of children in cars, encompassed three main themes; Accident studies, the development of a dedicated child restraint attachment system (ISOFix) and the development of a side impact test procedure for child restraints. Accident studies were undertaken at four levels; a questionnaire study, analysis of the TRL CCIS database, accidents involving a fatally injured restrained child and the analysis of a serious injury database. The analyses all confirm the benefits of using child restraints. The observations have shown the need to provide improved protection in side impacts and to avoid loading from luggage by improved seat strength. An experimental sled-based method for evaluating the performance of child restraints, under side impact conditions, has been developed. The method replicates the essential interactions in a real car impact using a test seat on a sled to provide the struck vehicle chassis acceleration, while the intruding door motion is simulated by a hinged door mounted on the sled. Tests with this experimental arrangement demonstrated that this was a practical way to evaluate the performance of child restraints under side impact conditions. TRL has contributed to the development of ISOFix through the International Organisation for Standardisation (ISO). The report describes the research leading to the draft proposal for an ISO Standard and concludes that ISOFix with two rear rigid attachments together with an anti-rotation system, such as a top tether, would provide a good basis for a universal system with greatly reduced misuse rates and an improved dynamic performance in accidents.

Related publications

PA3342/98 *Development of a sled side impact test for child restraint sytems* by I P Paton, A P Roy and R W Lowne.1998 (price £5)

PA3126/94 *The front impact performance of a sample of current UK child restraint systems when mounted in car body shells* by A P Roy and A K Roberts. 1994 (price £5)

PA3122/94 *The development of a unified child restraint-to-car system: a contribution to the ISOFix discussions* by R W Lowne and T Turbell. 1994 (price £5)

RR289 *Restraint use by car occupants, 1982-1989* by J Broughton. 1990 (price £20, code B)

CT44.2 In car safety: children update (1995-1999) *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

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