The Influence of Asymmetrical Lower Belt Anchorage Locations on the Crash Performance of Child Restraint Systems

C. G. Huijskens, E.G. Janssen, R. Verschut
TNO Road-Vehicles Research Institute
Crash-Safety Research Centre
Delft, The Netherlands

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ABSTRACT

Several field studies have shown that a large percentage of child restraint systems (CRS) are used incorrectly. This is not only due to the sometimes complex design of the child restraint system and/or the sometimes poor quality of the users instructions, but also due to interface problems between a child restraint system and a passenger car. The car rear bench, the nowadays standard available seat belts and the lower belt anchorage locations are not designed to accommodate child restraint systems. One specific problem in this respect is the fact that child restraint systems, approved according to ECE-Regulation 44, are tested using a simulated car bench with symmetrical belt anchorage locations, while rear outboard seating positions in passenger cars often have asymmetrical belt anchorage locations. These different anchorage locations will influence the crash performance of the child restraint system in real accidents and will probably lead to a less optimal effectiveness of the system.

In an attempt to address this issue, the TNO Crash-Safety Research Centre started a literature survey and an experimental research programme. The performance of a forward facing child restraint system with a harness belt in standard ECE-R.44 dynamic sled tests has been compared with the performance in sled tests using a real car rear bench with symmetrical, as well as asymmetrical lower belt anchorage locations. Several test parameters have been varied and their influence has been analyzed in terms of dummy head displacement and head accelerations and chest accelerations. The effect of the belt anchorage location on the restraint effectiveness (Ride-Down-Effect) of the child restraint system has been studied.

A summary of the literature survey will be presented. Among other results, it will be shown that the dummy head displacement, in this most frequently used child restraint system, is increased by 50 percent if asymmetrical belt anchorage locations are used rather than symmetrical locations. This makes head contact with the car interior very likely in a real car crash. Therefore it is recommended, that regulations with respect to child restraint system are compatible with regulations concerning car seats and belts.

INTRODUCTION

The safety of children in passenger cars is an important area in the field of passive safety. Parents, product designers, legislators and researchers have a special duty to this vulnerable group of road users, since young children are not able to make judgements about safety themselves. Severe injuries not only have implications for children and their families in the longer term, but they also place a considerable burden on society.

The first European legislation on child restraints, ECE-Regulation 44, came into force on February 2, 1981 [1]. It contained requirements with respect to the safety as well as other properties, such as ease of use and durability. Since then ECE-R.44 was amended several times and currently it contains a large number of requirements. Stimulated and guided by this regulation and by consumers tests, manufacturers of child restraint systems succeeded in reaching higher safety levels. Studies have shown that the use of child restraint systems reduces the risk of serious/fatal injuries by a factor seven [2]. Moreover, a large number of different designs became available, for babies or infants, for the front seats or rear seats, forward facing or rearward facing. All these types of design have their advantages and disadvantages. One specific problem for almost all types of design is the possibility to use the restraint system incorrectly. One reason for incorrect use is the fact that the seats and seat belts of passenger cars are not always designed to accommodate child restraint systems. Another reason is the development of combination child restraint systems that can be used in several configurations. These systems, with ECE-R.44 approval, seem to introduce specific misuse problems.

In an attempt to address this issue, the TNO Crash-Safety Research Centre defined a research programme. The first phase of the programme focused especially on neck injuries sustained by young children in a frontal crash, when using forward facing systems with harness belts. Comparisons with other types of child restraint systems were made and several test parameters, including misuse parameters, were varied. A summary of the results obtained in this part of the research programme is contained in ref. [3].

The results of the first phase indicate that the influence of 'incorrect use' when using a forward facing child restraint systems with harness belts on the crash performance of child restraint systems should be further investigated. Moreover, the influence of 'car interface' problems should be evaluated in detail, since these form a special group of problems. This led to the start of a second phase of the research programme with the aim:

to analyze the influence of several 'misuse' and 'car interface' parameters on the dummy loads by performing dynamic sled tests.

Especially the most frequently used restraint systems for children between 9 months and 3 years of age, i.e. forward facing seats supported by a tube-frame, are studied in this research programme.

A summary of the results, with respect to misuse and interface problems, obtained in this research programme is contained in the present paper.

LITERATURE REVIEW

Introduction

As a precursor to the experimental research programme, a limited literature survey was carried out, which reviewed specific problems with respect to put the child in the child restraint system and to install the child restraint system in the car. A non-optimal or even incorrect fixation could increase the risk of injuries induced in the child during an accident.

Child restraint systems are being developed and sold in Europe for three different categories:

- *universal CRS;*
- *semi-universal CRS;*
- *specific CRS.*

The last two categories are also called 'non-universal'. Universal child restraint system are systems that can be used in all passenger cars. Non-universal child restraint system can only be installed in certain types of passenger car. Most common are the universal systems and since 'misuse' and 'interface' problems are typical for these systems, the literature survey has been focused particularly on universal child restraint system.

Four child mass groups are included in ECE-R.44, with advised age limits:

- Group 0 :	*up to 10 kg;*	*(up to 9 months)*
- Group I :	*9 - 18 kg;*	*(9 months - 3 years)*
- Group II :	*15 - 25 kg;*	*(3 years - 6 years)*
- Group III:	*22 - 36 kg;*	*(6 years - 10 years)*

An incorrect use of a child restraint system is defined as:

- misuse *of the system by the parents due to the complex and/or poor design, or because they are not following the user's instructions and/or due to the poor quality of these instructions;*
- *a non-optimal or even bad fit of the child restraint system due to* interface *problems between system and car.*

The difference between ***'misuse'*** and ***'interface problems'*** is not always obvious, and in a certain way they are influencing each other. In the following sections both aspects will be addressed. This study is focusing especially on forward facing systems of Group I.

Field Studies

Recently a field study has been conducted in the Netherlands aimed at investigating the type and frequency of misuse of child restraint system [4]. It was concluded that 70% of the systems are used incorrectly.
The rearward facing baby seats scored best (an error score of 35%) and the seats with harness belts scored worst (an error score of 75%). The most frequently observed errors in this field study were:

- *too much slack in hamess belt (50% of CRS with harness belt);*
- *location of the standard car belt buckle (33%);*
- *too much slack in car seat belt (25%);*
- *child too heavy or too light for used CRS (14% of CRS with label).*
- *routing of the standard car belt (12%);*

By HUK-Verband, a questionnaire has been developed and sent to 6110 users of child restraint system ('parents') who had reported to HUK, that they had problems "when choosing and buying" and "when installing and using" child restraint systems [5]. HUK received usable information from 1282 parents covering 1903 child restraint systems, representing 37 different models. In about 67% of all cases the parents stated that they had problems with the use of the child restraint system. The causes for these problems were among others:

- Lap belt always has to be readjusted	*18.6%*
- Shoulder belt runs across child's neck	*18.2%*
- Removing seat from car is troublesome	*15.0%*
- Buckles are difficult to open and close	*13.2%*
- Fastening belt slips out of guide	*12.4%*
- Fastening belts are too short	*8.5%*
- Seat never in straight position due to wheel arch	*6.3%*

Impact shield systems and 4-point harness belt systems in the ECE-R.44 Group I seem to cause a disproportional large number of problems in this study. The questionnaire was not specially developed to assess misuse of child restraint system, however the list of problems presented above indirectly indicates misuse of these systems.

The effectiveness of a child restraint system during a car crash is considerably reduced if the system is used incorrectly. One study, recently conducted in the USA by Kahane [6], calculated the following effectiveness rates for child restraint system (with a top tether strap):

- correct use: effectiveness of	*71%;*
- partially incorrect use: effectiveness of	*44%;*
- entirely incorrect use: no effectiveness.	

So child restraint systems must be used correctly in accordance with user's instructions. However, even then a reduction in effectiveness is possible due to interface problems between a child restraint system and a passenger car.

Compatibility Studies

Several studies have shown that the location of the rear seat anchorage points in current passenger cars differ considerably from the ECE-R.44 anchorage points used for approval of the child restraint system. The inboard and outboard lower anchorage points in cars are located more forward (and higher) than the ECE-R.44 points [7, 8, 9]. The belt anchorage locations in a car are chosen to avoid submarining of adult occupants [7]. However, this can result in too much slack when these anchorage points (and/or car belts) have to be used to restraint a child seat with a tube-frame. Furthermore ECE-R.44 uses symmetrical anchorage points, while the outboard seating positions of the rear bench in cars often have an asymmetrical anchorage location.

The more forward position of the anchorage points and the fact that the longitudinal distance to the back of the front seat is less than the ECE-R.44 head displacement limit of 550 mm for most (French) cars [7], can result in impacts of the child head against the back of the front seat. In ref. [3] it is concluded that the occurrence of severe neck injuries is often associated with head impacts. Improvement of anchorage locations is considered very important to improve the performance of child restraint system [7, 8, 9], also with respect to the risk of severe neck injuries [10].

A working group of the International Standardization Organisation has set-up a list of possible interface problems [11]. Among others, items mentioned in this list with respect to the car are:

- *location of belt anchorage points not suitable for CRS;*
- *length of standard belt not suitable for CRS;*
- *arrangement of belt buckle not optimal for CRS;*
- *no adequate space, because car seat is too countered;*
- *retracting force of belt too low;*
- *height adjustment not provided;*
- *motorized belt function can not be turned off;*
- *interaction with and/or influence of airbag, belt tensioner, automatic roll-over bar.*

With respect to the child restraint system, the following problems are mentioned by ISO [11]:

- *can not be fastened with existing car belts;*
- *special fastening straps required;*
- *unusual belt routing;*
- *child restraint system is 'oversized';*
- *no compliance to car seat;*
- *no clear users instruction with respect to seating position, belt routing, etc.*

It is obvious that interface problems are more common for 'universal' child restraint system than for 'specific' child restraint system, which are designed for one single car type.

In the HUK study [5] mentioned in the previous section, the parents were asked whether they were satisfied with the possible ways of fastening the system in the car. This question was answered by 39.3% with "no". Reasons given for the dissatisfaction were among others:

- *fastening inadequate*	*25.8%*
- *installing/removing awkward*	*19.5%*
- *additional material necessary*	*8.0%*
- *belt guide too complicated*	*7.7%*
- *belt position inconvenient*	*5.4%*
- *system not anchored firmly*	*5.1%*
- *existing belts unusable*	*5.1%*
- *anchorage points missing*	*4.7%*

The individual systems differ significantly from another in this respect. The owners of 4-point harness belt child restraint system and of ECE-Group I impact shield child restraint system expressed a larger dissatisfaction. Only relatively few parents stated that the criterion for decision to purchase a child restraint system was the suitability to fit well in the car.

RESEARCH PROGRAMME

Test parameters

It is decided to perform a series of dynamic sled tests in which several ***misuse*** and ***car interface*** parameters are varied. The following sections describe the child restraint system, the dummy, the anchorage locations, the test bench and the general test set-up.

Child restraint system

All tests are carried out with the same child restraint system, which is a *universal forward facing seat equipped with a 4-point harness belt (without crotch strap)*, suitable for children with body weights of 9 to 18 kg (i.e. ECE-R.44 Group I). Both shoulder parts have a quick action-adjuster. Also the lap part has a quick action-adjuster, which is integrated in the buckle.

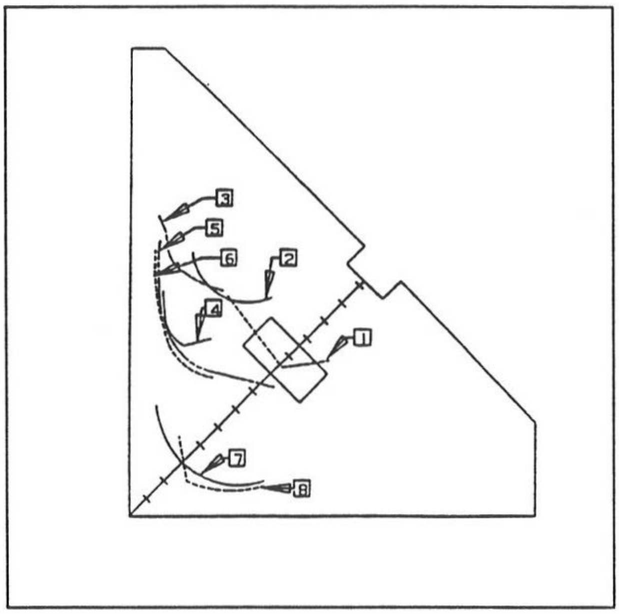

Figure 1: Curve 7 shows the contact point area of the used harness system on an accommodation fixture device [14].

With regard to the manufacturer's instructions, the tube-framed child restraint system is fixed to the sled test bench conform ECE-R.44 specifications by a *static 2-point belt (without buckle)*. This particular **standard harness system** is chosen because of the extreme low car belt contact point (area) for the 2-point belt. [see Fig. 1]

Dummy measurements

The TNO-P3/4 child dummy is selected for inclusion in this research programme. The dummy represents a child of 9 months old and is prescribed in ECE-R.44 [1]. The total body weight of the P3/4 dummy is 9 kg and the standing height is 0.71 m. Head and chest accelerations of the dummy are measured and also the dummy's horizontal head excursion is measured.

Anchorage locations and test benches

In the first and second test series, the standard ECE-R.44 test bench is used as well as the standard ECE-R.44 symmetrical anchorages.

In the third and fourth test series, the ECE-R.44 test bench is replaced by Peugeot 205 GRD rear bench, which is mounted in the same position as in the real vehicle. The Peugeot 205 rear seat bench configuration is chosen in this research programme, because of the **extreme** location of the outboard anchorage. Figures 2 an 3 show that the anchorage positions are located asymmetrical; the outboard anchorage point is located more forward than the inboard anchorage point. Figure 2 also shows that the vertical height of the outboard anchorage position is located ca. 5 cm above the horizontal Cr-line of the rear seat bench. This outboard anchorage position makes it very complicated to correctly install a tube-framed child restraint system with a low car belt contact point (area).

In the fifth test series the standard ECE-R.44 lower belt anchorage locations are replaced by positions more representative of modern European passenger cars.

These 'Proposed positions' (see Figures 2 and 3) are based on an IOCU study [12], in which it is concluded that the outboard anchorage location should be placed 7 cm in front of the vertical Cr-line and 8 cm below the horizontal Cr-line (see Figure 2).
The inboard anchorage location should be placed on the vertical Cr-line and 10 cm below the horizontal Cr-line. It can be seen also in the figures 2 and 3, that both anchorage points are located more forward than the standard ECE-R.44 locations.

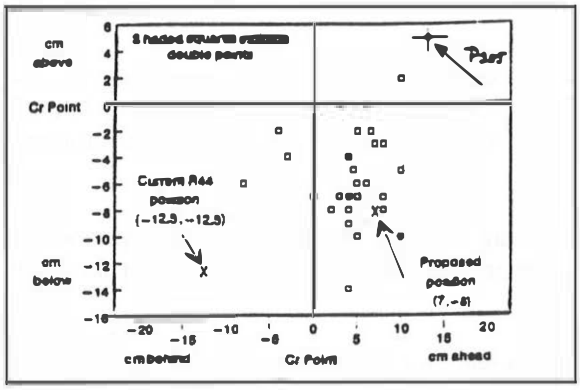

Figure 2: The 'outboard' anchorage points

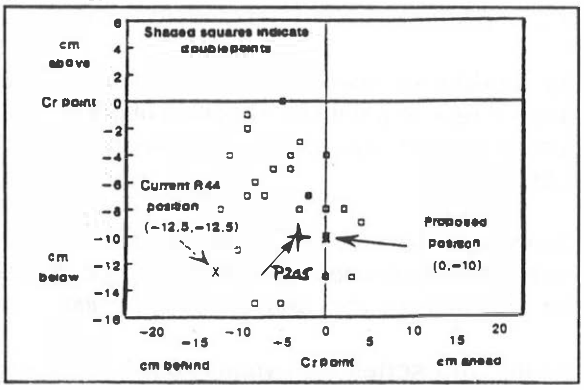

Figure 3: The 'inboard' anchorage points.

Test set-up

The standard harness system included in this programme is subjected to a series of frontal dynamic sled tests at 50 km/h. The sled tests are carried out in accordance with the specifications of ECE Regulation 44 [1]. All tests are carried out in duplicate. The sled velocity and sled deceleration are recorded during the tests and high speed films are made to analyze the dummy kinematics. Parameter changes and/or variations with respect to the standard ECE-R.44 test conditions are described below and summarized in Table 1.

Test series	Restraint system	Test bench	Anchorage location	Type belt	Test conditions
First test series with standard ECE-R.44 test bench					
1A	FF/4-point	ECE-R.44	ECE-R.44	2-p static	normal position
1B	FF/shield	ECE-R.44	ECE-R.44	2-p static	normal position
Second test series with standard ECE-R.44 test bench					
2A	FF/4-point	ECE-R.44	ECE-R.44	2-p static	sleeping position
2B	FF/4-point	ECE-R.44	ECE-R.44	2-p static	2 cm harness slack
2C	FF/4-point	ECE-R.44	ECE-R.44	2-p static	4 cm car belt slack
Third test series with Peugeuot 205 car bench (left outboard seating position)					
3A	FF/4-point	P. 205	P. 205	2-p static	normal position
3B	FF/4-point	P. 205	P. 205	2-p static	sleeping position
3C	FF/4-point	P. 205	P. 205	2-p static	2 cm harness slack
Fourth test series with Peugeuot 205 car bench (centre seating position)					
4A	FF/4-point	P. 205	P. 205	2-p static	normal position
4B	FF/4-point	P. 205	P. 205	2-p static	sleeping position
Fifth test series with standard ECE-R.44 test bench					
5A	FF/4-point	ECE-R.44	IOCU	2-p static	normal position
5B	FF/4-point	ECE-R.44	IOCU	2-p static	sleeping position
5C	FF/4-point	ECE-R.44	IOCU	automatic	normal position

Table 1: Summary of all dynamic test parameter changes and/or variations.

In the **first series** with the standard ECE-R.44 bench, the *'standard harness system'* is compared with an *'impact shield system'*.

In the **second series** with the standard ECE-R.44 bench, three different test conditions are varied. The test conditions *'2 cm extra harness slack'* and *'4 cm extra car belt slack'* are chosen to evaluate the influence of these *'misuse parameters'* on the crash performance of the standard harness system. The test condition *'sleeping position'* is chosen to evaluate the influence of this *'interface problem'* on the crash performance of the standard harness system.

In the **third series** the dynamic crash tests are carried out with the standard hamess system fixed to the left rear seat outboard position of the Peugeot 205 with asymmetrical anchorage positions. The test conditions are *'normal position'*, *'sleeping position'* and *'2 cm extra harness slack'* in the child restraint system.

In the **fourth series** the dynamic crash tests are carried out with the standard hamess system fixed to the rear centre position of the Peugeot 205 with symmetrical anchorage positions. The test conditions are *'normal position'* and *'sleeping position'*.

In the **fifth series** the dynamic crash tests are carried out with the standard harness system fixed to the standard ECE-R.44 test bench with the asymmetrical anchorage positions as proposed by the IOCU [12]. The test conditions are *'normal position'* and *'sleeping position'*. Additionally, the influence of a *'standard 3-point automatic adult belt'* on the crash performance of the child restraint system is analyzed in this configuration.

TEST RESULTS

Ride-Down-Effect

The influence of the different lower belt anchorage positions on the crash performance of the child restraint system, is evaluated with the so-called Ride-Down-Effect [13]. The child restraint system should decelerate the child smoothly by using the crash deformation path of the car. The Ride-Down-Effect is calculated to asses the amount of the car deceleration shared by the child (see Annex).

For comparison reasons all dummy results of the standard ECE-R.44 crash test (Mode 1A) with symmetrical anchorage locations and the P3/4 dummy in the normal position are presented in this paper as 100%. Table 2 gives the (average) results and percentages of the (duplicated) dynamic tests carried out for all different modes (i.e. standard, misuse and interface modes). Figure 4 shows a graphical presentation of the (average) percentages.

Test series	RDE calc.	RDE perc.	Head Exc. calc.	Head Exc. perc.	Head Res. calc.	Head Res. perc.	Chest Res. calc.	Chest Res. perc.
1A	**54**	**100**	**416**	**100**	**55**	**100**	**33**	**100**
1B	57	106	340	82	87	158	42	127
2A	46	85	405	97	51	93	33	100
2B	56	104	429	103	53	96	32	97
2C	38	70	441	106	58	105	31	94
3A	11	20	625	150	80	145	60	182
3B	6	11	627	151	79	144	65	197
3C	16	30	638	153	71	129	74	224
4A	35	65	417	100	78	142	56	170
4B	50	93	454	109	73	133	52	158
5A	34	63	573	138	74	135	44	133
5B	34	63	552	133	61	111	41	124
5C	24	44	472	113	62	113	39	118

Table 2: Calculated results and percentages of all dynamic crash tests.

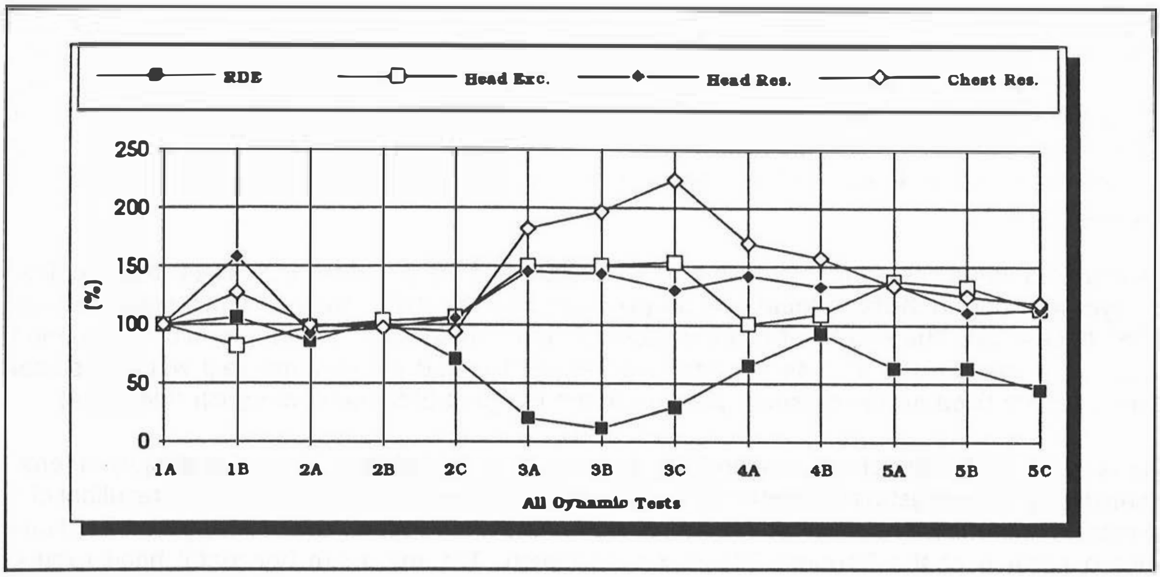

Figure 4: Graphical presentation of all dynamic crash tests.

Standard Modes

The different modes in which the chosen harness system in **normal position** is evaluated, are the standard ECE-R.44 test bench with symmetrical anchorage locations (Mode 1A), the Peugeot 205 rear seat bench with asymmetrical anchorage locations on the outboard position (Mode 3A), the Peugeot 205 rear seat bench with symmetrical anchorage locations on the centre position (Mode 4A) and the standard ECE-R.44 test bench with asymmetrical anchorage locations as proposed by the IOCU (Mode 5A). Figure 5 shows the four different installation modes compared with each other (Mode 1A=100%). Additionally, the results of the impact shield system (Mode 1B) are also shown.

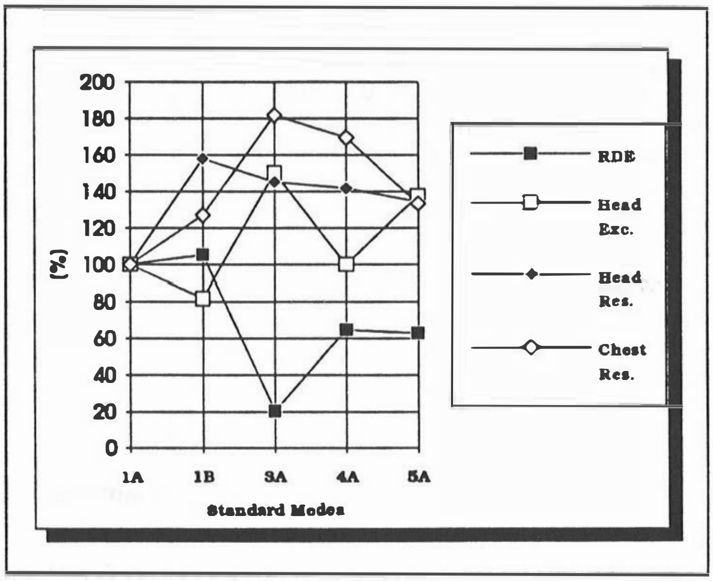

Figure 5: Standard modes.

It can be seen from figure 5 that **both different type of child restraint systems** have approximately the same RDE-percentage (Mode 1A=100% and 1B=106%). The horizontal head excursion of the P3/4 dummy with the impact shield system is approximately 18% lower compared to the horizontal head excursion of the dummy in the standard harness system, while the resultant head acceleration as a result of the dummy's head-to-shield impact is approximately 58% higher. The resultant chest acceleration of the dummy with the impact shield system is also approximately 27% higher.

However, when the standard harness system is fixed in **normal position** on the left **outboard position of the Peugeot 205 rear seat bench**, the RDE-value decreases to 20% (Mode 3A). The influence of this poor fixation due to the car asymmetrical anchorage locations is largest when the chest accelerations of the P3/4 dummy are considered, of which the resultant increases with 82%. Also the resultant head acceleration and horizontal head displacement increase in this configuration with ca. 45 - 50%.

When the standard harness system is fixed in **normal position** on the **Peugeot 205 rear seat centre position** (Mode 4A), the ride-down-effect calculation gives a percentage lower than 100%, but it is better than the RDE-percentage with the system on the rear seat outboard position of the Peugeot 205.

Probably because of a better fixation with the symmetrical anchorage locations in this configuration, the horizontal head displacement of the P3/4 dummy is similar to the horizontal head displacement in the standard ECE-R.44 test (Mode 1A) and approximately 50% better than the horizontal head displacement of the dummy with the restraint on the rear seat outboard position (Mode 3A). However, the results for the resultant head and chest acceleration are respectively 42% and 70% worse compared to the standard ECE-R.44 test and are roughly similar to the results with the restraint on the rear seat outboard position.

If the standard harness system is fixed in **normal position** on the **standard ECE-R.44 test bench with the asymmetrical anchorage locations as proposed by the IOCU**, the ride-down-effect decreases to 63% (Mode 5A). The results of this configuration have more or less average values between the results of the standard ECE-R.44 dynamic test (Mode 1A) and the dynamic test with the standard harness system fixed on the outboard position of the Peugeot 205 rear seat bench (Mode 3A).

If the resultant head and chest accelerations are analyzed according to the general injury criteria for children using a child restraint system (i.e. max. head excursion of 550 mm; max. head resultant of 80g and max. chest resultant of 55g), the worst values are measured with the harness system fixed on the outboard position of the Peugeot 205 rear seat bench. The maximum horizontal head excursion reaches a mean value of 625 mm, while the resultant chest acceleration reaches a level of 60g.

Misuse Modes

In figure 6 the ride-down-effects and the dummy results of two misuse modes, which in field studies are often observed, are illustrated. These two misuse modes are respectively **too much slack in the car seat belt** and **too much slack in the 4-point harness belt of the restraint**. The dummy results of both modes are compared with the results of the dummy in the standard ECE-R.44 test (Mode 1A=100%).

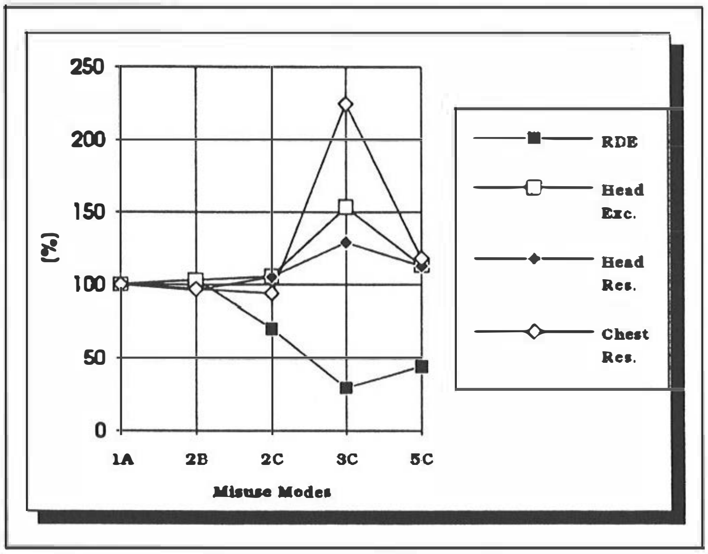

Figure 6: Misuse modes.

When the P3/4 dummy under similar ECE-R.44 test conditions is put in the standard harness system with **too much slack in the harness belt** (Mode 2B; RDE=104%), the influence on the horizontal head excursion and the resultant head and chest accelerations are limited when compared to the same results of the standard ECE-R.44 test (Mode 1A). Introducing *'2 cm extra slack in the harness belt'* seems to have a marginal effect on the dummy responses. The dummy is decelerated by the standard harness system when the slack in the harness belt has been taken up at a time t_r (see Appendix) which is somewhat longer than the time t_r in the standard ECE-R.44 test This results in a ride-down-effect which exceeds the 100%.

The worst misuse mode is observed when the standard harness system is fixed *'on the outboard position of the Peugeot 205 rear seat bench and the dummy put in the system with 2 cm extra slack in the harness belt'* (Mode 3C). The poor fixation of the standard harness system in this configuration results in a ride-down-effect of only 30%. Due to a certain combination of extra slack in the harness belt and a poor fixation of the standard harness system, the resultant chest acceleration of the dummy increases to approximately 224% and the horizontal head excursion of the dummy reaches the value of 638 mm which is the highest value measured during the complete testprogramme.

Figure 6 shows that under similar ECE-R.44 test conditions, **too much slack in the 2-point car seat belt** (Mode 2C) has less negative influence on the dynamic crash performance of the standard harness system (RDE=70%) than when the same system (without lock-off devices) is fixed to the test bench using a **3-point inertia reel belt** (Mode 5C; RDE=44%). The dummy results when the system is fixed with *'4 cm extra slack in the 2-point static car seat belt'* are approximately 10% better than when a *'3-point adult belt'* is used to fix the standard hamess system.

Interface Modes

Figure 7 illustrates the ride-down-effects and the dummy results when the standard harness system is fixed to the test bench in a **sleeping position**. The influence of the standard harness system in a reclined position on the crash performance of the child restraint system is compared to a similar configuration on different benches (i.e. ECE-R.44 and Peugeot 205). The results in terms of horizontal head excursion, resultant head and chest accelerations are compared with the standard ECE-R.44 test (Mode 1A; RDE=100%)

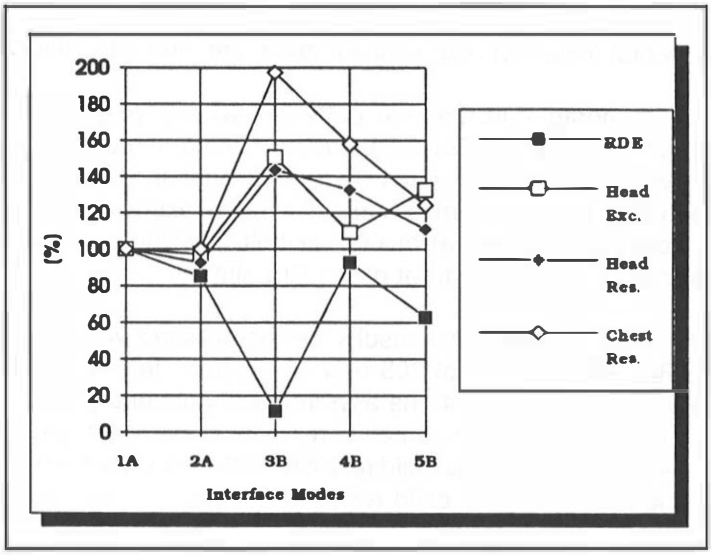

Figure 7: Interface modes.

Figure 7 shows that this **'Interface problem'** does not have much influence on the ride-down-effect when the standard harness system in a reclined position is fixed to the sled bench conform the ECE-R.44 test specifications (Mode 2A). However, *'when the standard harness system in a reclined position is fixed to the outboard position of the Peugeot 205 rear seat bench'*,
the worst ride-down-effect (Mode 3B; RDE=11%) is calculated. All dummy responses increase strongly, as a result of the poor fixation with asymmetrical anchorage locations.
Compared to the standard ECE-R.44 test results, the resultant chest acceleration increases from 100% to 197% and the resultant head acceleration from 100% to 144% and the head excursion from 100% to 151%.

The absolute value for the resultant head acceleration is 79g and for the resultant chest acceleration 65g. The measured horizontal head excursion exceeds the ECE-R.44 criteria with an average value of 77 mm.

The configurations with the standard harness system in a reclined position fixed to the centre position of the Peugeot 205 rear seat bench (Mode 4B) and with the asymmetrical anchorage locations as proposed by the IOCU (Mode 5B), do not have such extreme effects on the dummy responses as when the standard harness system in a reclined position is fixed to the outboard position of the Peugeot 205 rear seat bench (Mode 3B). The results of 'Mode 5B' have more or less average values between the results of 'Mode 1A' and 'Mode 3B'.

DISCUSSION AND CONCLUSIONS

From figure 5 (standard modes) it can be concluded that under similar ECE/R.44 test conditions fastening different types of child restraint systems has no important influence on the calculated ride-down-effect.

Figures 6 and 7 show similar trends: Most parameters and/or variations do not have important influences on the crash performance of the used harness system when the standard ECE-R.44 test conditions are considerd.

The most important criterion for putting the child in the restraint system, as well as for fastening the restraint system itself, seems to be the amount of slack. The amount of slack results in too much (horizontal) head excursion of the child, which could lead to severe head contact of the child with the interior of the car during an accident. The inadequate fixation of the child restraint system results in a (much) lower ride-down-effect and at the same time higher resultant head and chest accelerations.

Analysing the series of dynamic tests presented in this paper, the used standard harness system and the used 3-point adult belt configuration in the rear of the Peugeot 205 are both very extreme. In fact the worst 'incorrect use' configurations are studied in this research programme.

The anchorages in the rear outboard seating position of the Peugeot 205 are very unsuitable for fastening a tube-framed child restraint. The outboard anchorage point is placed extreme forwards and above the Cr-lines (Figures 3). In combination with a low contact point (area) for the car belt, the fixation of the tube-framed harness system results in a most inadequate installation. In other words the attachment point (area) of the car belt, passing over the tubes and inboard the frame of the child restraint system, is in front of the Cr-point.

The worst dynamic test results are established with the standard harness system on the outboard position of the Peugeot 205 rear seat bench. In this configuration the amount of slack is largest due to the poor fixation with the asymmetrical anchorage locations and the risk of injury is expected to be the largest when the used child restraint system is placed in the reclined position. It appears that the sleeping position of the child restraint system has a very negative effect on its crash performance, when at the same time the child restraint system can't be adequately installed as a results of the forward positions of anchorages, especially the outboard anchorage position.

In this research programme the dynamic tests carried out with the asymmetrical anchorage points as proposed by the IOCU, show intermediate values of the dummy results between the results of the standard ECE-R.44 and the Peugeot 205 tests when the used harness system is fixed with a standard 2-point static belt.
Additionally, when the harness system is fixed to the ECE-R.44 test bench using an inertia reel belt, the dummy results are worse compared to the standard ECE/R.44 test results and the test results of the configuration with 4 cm extra slack in the car belt.

REFERENCES

1. ECE 44 Regulation
Uniform conditions conceming the approval of restraint devices for child occupants in power-driven vehicles. Amendments 01/02/03, 1981.

2. Langwieder, K. and Hummel, Th.
Children in cars; Their injury risks and the influence of child protection systems.
Proceedings of the 12th ESV Conference, Gothenburg, 1989.

3. Janssen, E.G. et al.
Cervical spine loads induced in restrained child dummies.
Proceedings 35th Stapp Car Crash Conference, San Diego, 1991.

4. Schoon, C.C., Huijskens, C.G. and Heykamp, A.H.
Misuse of restraint systems for children in the Netherlands.
Proceedings 1992 International IRCOBI Conference on the Biomechanics of Impact, Verona, 1992.

5. Langwieder, K. and Hummel, Th.
New aspects for optimizing child restraint systems - experiences from accidents, trolley tests and interviews. Presented at 13th ESV Conference, paper no. 91-S3-O-16, Paris, 1991.

6. Kahane, C.J.
An evaluation of child passenger safety:the effectiveness and benefits of safety seats.
Report DOT HS-806 889 National Highway Traffic Safety Administration, Washington, 1986.

7. Pincemalle, Y. et al.
APR proposal for child protection in cars. Presented at 13th ESV Conference, paper no. 91-S3-W-16, Paris, 1991.

8. Economic Commission for Europe/TRANS/SC1/WP29/GRSP/R.72
Considerations regarding the development of regulation no. 44. August 1991.

9. ISO/TC22/SC12/WG1/Ad hoc group - anchorage
A summary of the group's findings and recommendations. May 1992

10. Tarriere, C. et al
Initial conclusions of an international task force on child restraining systems.
Presented at 13th ESV Conference, paper no. 91-S3-W-19, Paris, 1991.

11. ISO/TC22/SC12/WG1
Interface vehicle/CRS - installation of CRS in vehicles, problems which may influence misuse.
Document N 198, October 1990.

12. GRSP/Ad Hoc R44/Doc N6
A contribution from IOCU to the 1st meeting of the GRSP Ad Hoc Group on the revision of regulation 44 (18th - 19th November 1992)

13. Lutter, G., Kramer, F. and H. Appel:
'Evaluation of Child Safety Systems on the basis of Suitable Assessment Criteria'. Proceedings 1991 International IRCOBI Conference on the Biomechanics of Impacts, Berlin, September 1991.

14. ISO/TC22/SC12/WG1
Use of an accommodation fixture device as a means of compatibility assessment for child restraint system to vehicle seat belts.
Document N 207, December 1990.

ANNEX

Ride-Down-Effect

The restraint system should decelerate the occupant smoothly by using the crash deformation path of the sled. The so-called Ride-Down-Effect (RDE) is calculated to assess the amount of the sled deceleration shared by the child. (see ref. [13]):

$$RDE=(S_v-S_r)*100\%/S_v$$

S_v=maximum outer deformation path of sled
S_r=deformation path of sled up to the time t_r at which the restraint system comes into effect

To determine the Ride-Down-Effect, the resulting thorax deceleration is required, as well as the time function of the sled deformation path which can be determined by double integration of the sled deceleration (see figure below). To determine the time t_r, at which the system comes into effect and the slack in the car belt has been taken up, a straight line is placed on the rising curve of the resulting thorax acceleration. The line connects the points on the curve representing 25% and 75% of the (first) peak acceleration (see figure 8). The intersection of the line with the time axis marks the point in time t_r from which the restraint system is assumed to take effect. At this time, the sled has already passed through a deformation path S_r. This path substracted from the maximum dynamic deformation path and thus describes the percentage of the car deceleration shared by the child. According to this calculation RDE=100% means that the child is decelerated immediately, without belt slack etcetra, while RDE=0% indicates that the child is not decelerated until the maximum dynamic sled deformation path has been reached.

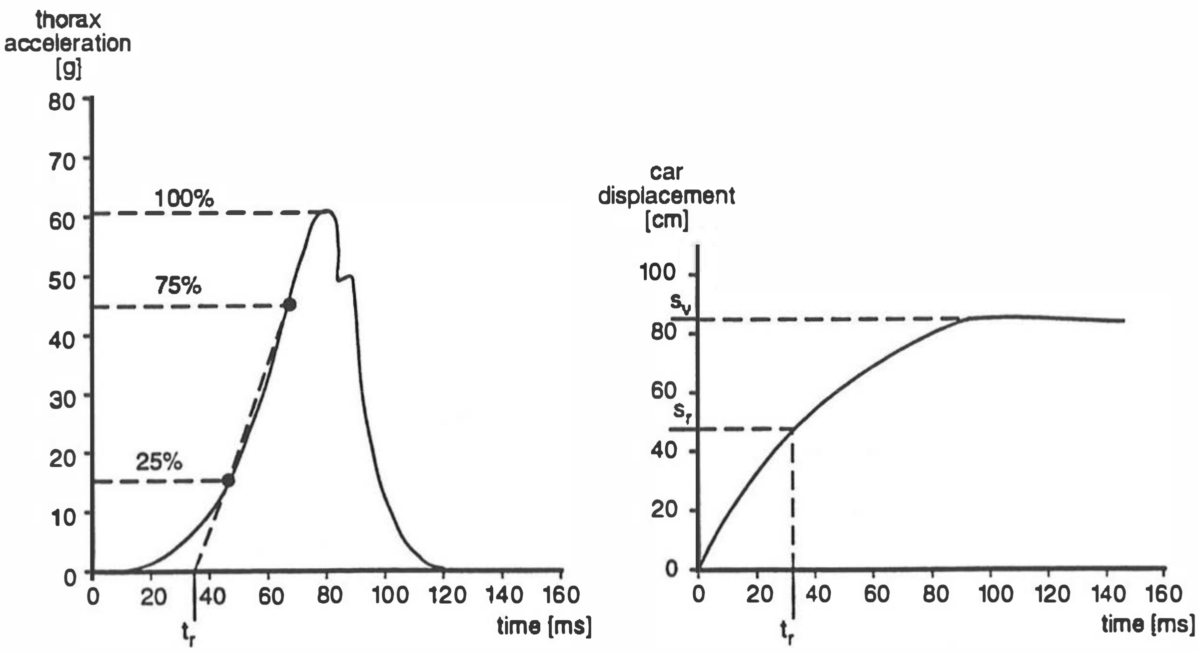

Figure 8: Resultant thorax acceleration versus time showing the definition of t_r and the car displacement versus time showing the definition S_r and S_v.