Paper Number N-007

A Comparison of the Performance of Dedicated Child Restraint Attachment Systems (ISOFIX)

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ABSTRACT

Problems with the current methods of attaching child restraints to the vehicle structure have led to the development of new attachment systems. These proposals have been coordinated by the International Standards Organisation (ISO) with the intention of generating an international standard system for the attachment of child restraints - ISOFIX. These proposals attempt to balance the requirements for good dynamic performance in impacts with the requirements for ease of use, low misuse and the cost and complexity of the child restraint and of incorporating the system into the vehicle design. This research programme was designed to compare the dynamic performance of a range of systems and how they would be used by parents. Prototype child restraints designed to four different schemes being proposed for ISOFIX were produced based on a single design of child seat shell. These were subject to frontal, side and rear impacts. Various degrees of slack were introduced into the systems to determine the sensitivity to misuse. In addition, a small user trial was undertaken to determine the user reaction to the different systems and likely misuse modes. Both the dynamic tests and the user trials included a conventional child restraint using the same child seat shell for comparison. The results demonstrated that all systems could perform well, particularly in the frontal impact tests, provided that any adjustment in the attachment system was pulled tight. However, some systems were particularly sensitive to slack. Overall, those systems with rigid attachments performed best, particularly in side impacts. These were favoured also by the user group.

INTRODUCTION

It has long been recognised that special provisions have to be made to protect child car occupants in the event of an accident. The interiors of cars and the protection systems are designed with adult occupant sizes in mind. Special child restraints have been designed for use by the child passengers. Except for recent systems which are built-in to some versions of a few vehicle models, the usual child restraints have to be attached to the vehicle structure. Before adult seat belts were routinely provided in all seating positions, it was normal practice in Europe for child restraints to have their own dedicated straps to attach the child restraint system (CRS) to the vehicle structure. As adult belts have become universally fitted in most countries, the CRS has evolved to be restrained by the adult belt itself, commonly using the three-point belt system to provide both lower and upper restraint in Europe but often using the lap belt in the USA. In

The use of the adult seat belt has advantages over the earlier systems in that it simplifies the attachment and allows easy transfer between vehicles, thus encouraging the use of a CRS. However, experience in many countries has shown that there are also disadvantages. Adult seat belts are designed to restrain adults and not child restraints. As the adult belt system is improved to optimise the restraint of an adult, for instance by moving the lower anchorages forward to reduce the possibility of submarining, so the performance of the restrained CRS can deteriorate. There can be hardware conflicts, for instance, where the adult belt buckle is positioned just where the belt should wrap around the CRS to ensure a tight adjustment. There is considerable scope for misuse, resulting in a very high rate of misuse observed in surveys.

To circumvent these and other problems, a universal dedicated child restraint attachment system has been proposed and has been discussed and developed within a Working Group of the International Standards Organisation (ISO). After a number of early proposals, the scheme adopted for development into a standard was based on four horizontal 6mm bars at defined locations in each seating position intended for use with this CRS concept. [1] After the development of the draft standard based on this system had been almost completed, some disadvantages in the concept became apparent. Several alternatives were proposed; two based on the rear two attachment points of the 4-point system and a third based on a strap, buckle and tongue system. A fourth system intended to be a compromise between a rigid and a strap-based system also was proposed.

This paper describes a user trial and a series of dynamic tests on the different systems which were performed to assist in the deliberations on the preferred system for adoption as an international standard,

DESCRIPTION OF SYSTEMS.

The different systems were given letter codes to distinguish them. The original 4-point system was labelled A, a system using the two rear attachment points together with a top tether was labelled B, another system using the same two rear points but with an alternative method for controlling the rotation by pre-compressing the CRS into or against the vehicle seat was labelled B_, the system using dedicated adjustable straps (with buckle and tongue) and a top tether was labelled C and the compromise proposal, intended to

Canada and Australia use is made of an additional top tether to improve the restraint of the CRS.

include both B_ and C was labelled D. Each system is described below.

SCHEME A: (Figure 1) Scheme A comprises two forward and two rear lower attachment points designed to attach to 4 locations on the vehicle structure at locations with controlled positions. The attachment system will fix the child seat in a given position in space. The maximum dimensions of the CRS are controlled by a fixture within which the CRS must fit and attach to the anchorages. Space for the CRS within the vehicle will be guaranteed by another fixture, marginally larger than the first, which must fit into the vehicle and attach to the vehicle anchorages. This system requires no adjustment by the user and keeps the CRS entirely independent of the vehicle seat.

SCHEME B: (Figure 2) Scheme B comprises the rear two anchors of Scheme A together with a top tether. The location of the rear anchors for Scheme B is the same as for scheme A. The location of the top tether anchorage is specified in a similar manner to that in the corresponding Australian and Canadian standards. As with scheme A, the maximum dimensions of the CRS are controlled by a fixture within which the CRS must fit and attach to the anchorages and the space for the CRS within the vehicle will be guaranteed by another fixture, marginally larger than the first, which must fit into the vehicle and attach to the vehicle anchorages. This system requires adjustment only of the top tether and keeps the CRS largely independent of the vehicle seat.

SCHEME B_: (Figure 3) The intention with this scheme is to use the rear attachment points and anchors of scheme A but with a self tightening attachment mechanism. The first sample demonstrated had a ratchet system allowing the CRS, once the two rear attachments had latched to the anchor pins, to be pushed back into the vehicle seat thus providing some pre-loading of the reaction surfaces. An alternative system with a loading bar which pushes against the vehicle seat back, compressing the CRS into the seat cushion, also has been demonstrated. The pre-compression systems need to be adjusted by the user but the system still remains somewhat dependent on the vehicle seat characteristics. The maximum dimensions and space within the vehicle are controlled by fixtures.

SCHEME C: (Figure 4) In this scheme, there are "soft anchors" in the form of seat belt tongues mounted on stiffened webbing, protruding from the joint between backrest and seat cushion (seat bight). The

CRS has a matching strap (adjustable) with a matching buckle on the end. There is a top tether, specified in a similar manner to that for scheme B. Both of the lower attachment straps and the top tether require adjustment by the user but, if they are correctly adjusted, the performance should be largely independent of the vehicle seat. There is no procedure to ensure that any CRS would fit in any vehicle.

SCHEME D. This scheme is intended to encompass both scheme B' and scheme C. It has two lower rear attachments and one optional top tether. The lower anchorages may by rigid and behind or ahead of the seat bight in a specified range or they may be `soft'/semi-rigid and ahead of the seat bight within a specified range and may be foldable. Both rigid and flexible attachment systems must cope with the whole range of the possible anchor positions.

USER TRIALS

The purpose of this user trial was to determine how each of the systems was attached and adjusted by typical users. In particular, attention was paid to the types of misuse and to the amount of slack left in each system. It was also intended to seek the views of the users on the different schemes although this will give only a limited indication of the opinions of potential users due to the size of the sample. Another, more detailed user trial has been performed using examples of morst of the schemes described here[1]

Prototype child restraints to schemes A, B and C were produced by Britax, all using the same basic shell, especially for this study. It was not possible to produce a prototype to scheme B_ in the time available for these trials. As scheme D is essentially a combination of B_ and C, no separate prototype for scheme D was produced. In addition, a conventional CRS was included in the trial. To remove any possible affect on the user's response, all of the prototypes used the same basic shell as the conventional CRS.

The subjects of the TRL user trials were all parents of young children in the age range 1 - 4 years. The sample size was 29 for the conventional CRS, Schemes A and B, and was 17 for scheme C with top tether while without top tether it was 12 (this is a variant of scheme D where the top tether may be optional)

The subjects were given pictogram instruction sheets as guides for installation. They were asked to install the child seats into the rear seat of a small 4-door saloon (sedan) car which had been adapted to accept scheme A, B and C restraints.

The subjects were asked to install the CRS, remove it and then reinstall it to explore the frequency of re-tightening on reuse. Also some subjects were asked to install the CRS in close proximity to another CRS already installed in the vehicle to compare the possible difficulties.

Finally, the opportunity was taken to solicit the users' view on the different systems, although the sample size limits the confidence that can be placed on these comments.

RESULTS OF THE USER TRIALS

CORRECT FITMENT. Table 1 shows the degree of misfitment observed. The errors observed were classified into 'Minor' and 'Not Fitted Correctly'. 'Minor' errors included not seating the CRS well into the vehicle seat before tightening the adult belt or attachment straps or not adjusting the adult belt, top tether or attachment straps tightly enough (in the judgement of the observer). 'Not Fitted Correctly' included not using the webbing lock, not adjusting the top tether at all or not attaching it or incorrect routing of the adult seat belt.

All of the alternative systems were 'Well Fitted' more frequently than the conventional system. There was only one case of 'Not Fitted Correctly' in the alternative systems and that was a failure to use the top tether in Scheme B. (This could have occurred with either B or C since the design of top tether was identical in these samples.)

Scheme A was fitted correctly by all subjects while Scheme B was fitted correctly by three quarters of the subjects and Scheme C by about one half of the subjects.

SLACK. In order to quantify the amount of slack that remained in the CRS attachment system after adjustment, two positions at the top and bottom of the child seat shell were identified and their position with respect to a fixed object within the vehicle were measured when the attachment straps were just tight. i.e. there was zero slack in the attachment straps but without any extra tension applied. In addition, where there was a top tether present, the adjusted length of the tether strap at zero tension was measured.

When 14 of the subjects had fitted the CRS to their satisfaction, the CRS was pulled forward, using the child seat integral harness, with a force of approximately

50N. The distances of these points and the top tether length were then measured again to assess the slack with which the seats were fitted. Tables 2 and 3 show the proportion of subjects with less than or equal to the zero tension settings and at zero tension + 25mm. Scheme A does not involve any user adjustment and so has not been included in this analysis

A high proportion of users adjusted Scheme B to at least the zero slack condition and all of them adjusted the CRS to less than a 25mm slack.

A large proportion of the subjects fitted the Scheme C CRS to more than zero slack and over half left the system with more than 25mm slack. This is a higher proportion than with the conventional CRS.

When some of the subjects were asked to refit the CRS after removal, it was noticed that several did not attempt to readjust the straps. In some cases this would have been necessary due to the slightly different positioning of the CRS within the contours of the vehicle seat. No attempt to quantify this was made in this study, but the fact that it occurred in a user trial when the subjects were being observed is notable.

In the final assessment of usability, a conventional CRS was fastened in the centre seating position and some of the subjects were asked to attach Scheme A, B and C systems in the adjacent seating position. Schemes A and B seemed to present relatively little problems but the attachment of Scheme C was difficult. There was very little room for the subject's arm and hand between the two child restraints for both attachment of the buckle and the subsequent adjustment of the strap. In a two door car, a similar problem would exist between the CRS and the side of the vehicle. It is conjectured that this is likely to lead to a greater incidence of slack adjustment, although no attempts were made to quantify this in this survey.

It is clearly important to explore the effects of slack on the dynamic impact performance of these systems, especially for Scheme C where the incidence was high.

USER COMMENTS AND OBSERVATIONS. The sample size is too small for this to be considered to be a reliable measure of the opinions of potential customers and users of the different systems, but the subjects views are summarised briefly below as an indication of the opinions of this subject group. Reference [2] gives the results of a more comprehensive user trial.

Scheme A Once fitted, this CRS was extremely stable but it was heavy and sometimes difficult to manoeuvre. The effort involved was seen as a drawback by some subjects, although the second time a subjects fitted the Scheme A CRS, they found it much easier. This system was found to be self explanatory, particularly in comparison with the struggle to fit a conventional CRS experienced by some subjects despite these being relatively familiar to them. One subject was concerned that the seat was too firmly held in place.

Scheme B Many subjects liked this system, particularly the ease of fitting into the rear latches. The top tether was difficult to reach (but is within Canadian guidelines) and the attachment of this tether was easier than releasing it after tensioning. Most subjects thought that this system was a good compromise.

Scheme C Attachment appeared easy in terms of buckle use but many felt that they could not tighten the system without the top tether (a Scheme D variant) sufficiently to make it stable, in comparison with schemes A or B. Even with a top tether, some subjects were unhappy about the stability. Overall, this was the least liked system.

DYNAMIC TEST PROGRAMME

The dynamic test programme was planned to evaluate the performance of child restraints to each of these schemes both with forward facing and rear facing child restraints. Special prototypes of ECE Group 1 sized forward and rearward facing seats (approx 1 - 4 years) and ECE Group 0 rearfacing infant carriers (approx. up to 9 months) were used in this test programme. The main part of the dynamic test programme subjected Group 1 forward facing and Group 0 rearfacing CRS to frontal and side impacts.

In a second series of tests, the effect of the use of top tethers, lower tethers and a pre-compression system on the dynamic performance in front, side and rear impacts with Scheme B and B_ versions of rearfacing Group 1 CRS was evaluated. The top tethers used in both rearfacing configurations was a divided strap attached to each wing of the CRS so that there would be no contact with the child occupant's head. The front and side impacts were performed according to the ECE R44 test conditions while the side impact used the

R44 test bench but with the New Zealand side impact pulse.

None of the prototypes used for the dynamic test used real latches. The intention of the test programme was not to evaluate the performance of prototype latches. Thus the attachment was made by a 6mm bar located through a hole in the attachment arm in the location where the latch would be. The dynamics of the CRS would thus be the same as would be seen with a latch, provided the latch did not fail. For Scheme C, standard buckle and tongue hardware were used. All top tethers used tether hooks from standard Australian products.

The standard attachment method required the child restraint to be attached, with the 15kg dummy in place, and 50N tension applied to each strap. For the standard CRS, this was attached by the standard ECE-

In the test series with the rearfacing Group 1 CRS, comparisons were made between the use of a top tether in front and side impacts, a lower tether in rear impacts and a pre-compression system in rear and side impacts. The pre-compression system used in this version of Scheme B_ used a "handle" attached to and pivoting about the two attachment arms of the CRS, close to the test seat back (Figure 23). To apply pre-compression to the child restraint system, a vertical force was applied to the child restraint seat and simultaneously a rearward force was applied to the handle. The handle was then locked in this position. Two levels of pre-compression were used, based on simple trials with three female subjects. The lower level was 100N on the child seat and 150N to the handle and the higher level was 200N to the child seat and 300N to the handle

MEASUREMENTS. Measurements were made of:
- head displacement or excursion,
- head acceleration (triaxial),
- chest acceleration (triaxial).

The distinction made in this paper between excursion and displacement is that displacement is defined as the maximum movement with respect to the original position (sled frame of reference) while the excursion is the maximum forward (or upward) position with respect to the Cr point on the sled, the junction of the surface of the backrest cushion and the seat cushion.

In the frontal impacts for Group 1 forward facing CRS and Group 0 rear facing infant carriers, the most forward extent of the head displacement was measured with respect to the original pre-impact position of the most forward part of the head. For side impact, this

R44.03 'standard' retractor and the integral webbing clamp applied. This is referred to as "tight" in the figures. For Group 0 and Group 1 forward facing Scheme B_, the standard, `tight' adjustment was made by applying 800N to the CRS and fastening the 6mm bolt in the appropriate hole in the attachment arm at that location.

The effect of slack and of unattached top tether were examined as instances of likely misuse. The stages of slack were: (1) just no slack-no tension with the CRS resting against the test seat backrest, (2) the same adjustment but with the CRS resting against a 25mm board between it and the backrest, and then the board removed and the CRS pushed back before test and (3) as 2 but with a 50mm board. For the scheme B' CRS, the stages of increasing slack were: (1) 200N force (instead of 800N), (2) no pre-load.

was measured with respect to the initial position of the *centre* of the head. For the Group 1 rearfacing CRS, the head was not always visible so, in this instance, the displacement of most forward part of the dummy's head or CRS backrest was measured. In the side and rear impacts, the standard measurement methods were used.

It should be noted that, in order to complete an extensive test programme, no replications were performed. Caution should therefore be exercised in drawing conclusions from small differences. Trends which are consistent over a range of tests would add confidence to the results.

INTERPRETATION OF THE RESULTS.

For restrained children, head excursion is probably the most important aspect for performance in frontal impacts. Most serious and fatal injuries to restrained children in crashes that are essentially frontal arise because the child's head impacts something. This can either be something inside the vehicle, deformed or undeformed, or an intruding object and, except when the intrusion has reached the original position of the child, this can be reduced by limiting the forward excursion of the child's head.

In side impacts, the most critical situation for restrained children will be direct impact to the child or through the CRS by the intruding structure for children seated on the struck side. For those seated in the centre or non-struck side, it is important for the CRS to prevent the child from moving far enough towards the intruding structure that impact takes place. While ISO is developing a test procedure for evaluating the performance of the CRS on the struck side in side impacts, this is not sufficiently advanced to be used in these trials. Here the centre or non-struck side situation is simulated, so it is the head excursion here also that is most critical.

DYNAMIC TEST RESULTS.

The results of all the dynamic tests are given in figures 5 to 22.

Figure 5 presents the head and chest resultant accelerations (3-millisecond exceedances) for frontal impacts with front facing Group 1 child restraints. With the exception of the head acceleration for scheme B', all of the samples gave an improved performance in comparison with the standard child restraint. The improvement in the head acceleration for scheme A was marginal and within experimental error. The good performance of the head and chest accelerations with scheme C is of interest but it should be remembered that these tests were all performed with tightly adjusted attachment straps.

Figure 6 presents the head and chest resultant accelerations (3-millisecond exceedances) for the side impacts. In all cases the head accelerations were lower for the alternative schemes than for the standard CRS, as was the case for the chest accelerations except for Scheme C.

Figure 7 displays the maximum head displacement for front and side impacts. For this critical feature, all of the alternative schemes showed an improvement with respect to the standard CRS with the exception of scheme C in side impacts. The improvement with scheme B_ (frontal impact) is marginal. The previously observed good performance with scheme A with regard to head displacement was again noticed (1). It is noticeable that all of the alternative schemes with rigid lower anchors (A, B, B_) performed very well in side impact.

EFFECT OF SLACK, FORWARD FACING CRS - Figure 8 shows the effect of increasing slack and absence of top tether on head displacement in frontal impacts. The standard CRS shows surprisingly little sensitivity to increasing slack (up to 25mm). This is possibly because, even with 50N tension in the adult belt, there is still some slack in the system. When used without a top tether, Scheme C deteriorates to greater head displacement than the standard CRS. The diagonal part of the three point belt used with the standard CRS clearly provides some additional restraint against forward rotation of the CRS.

Figure 9 shows the effect of increasing slack and absence of top tether on head acceleration in frontal impacts. Scheme B does show some sensitivity to slack but always remains better than the standard CRS, even at 25mm slack. Scheme B_ is worse than the standard CRS in the `tight' condition and the performance deteriorates further with increased slack. Scheme C is sensitive to slack but remains better than the standard CRS up to 25mm slack. The results with further increased slack and without top tether deteriorate to somewhat worse than the standard CRS.

Figure 10 shows the effect of increasing slack and absence of top tether on head displacement in side impacts. The alternative schemes with rigid lower anchors are not very sensitive to slack nor absence of top tether, but the already poor performance of scheme C in side impacts does deteriorate further.

Figure 11 provides an alternative way of presenting the results to give the combined responses of both head acceleration and head displacement. Ideally the responses should be in the lower left part of this chart. The arrow lines show the changes in the responses with increased slack and (for scheme C) the removal of the top tether. Scheme B effectively becomes Scheme B_ when the top tether is removed. The anticipated effect is shown by the dotted arrow. It should be noted that this chart has a suppressed zero for both axes.

The conventional system shows remarkably little change with increased slack. Scheme A does not change since slack cannot be added. A potential misuse that might be considered is failure to attach the front latches. This would also turn this system into a loose scheme B_. Scheme B shows little sensitivity to increased slack but a larger change would be expected with removal of the top tether. Scheme B' shows increases mainly in the head acceleration with increased slack. Scheme C is much more sensitive to increased slack and to missing top tether, increasing both head acceleration and head displacement.

As the neck of the TNO P-series dummies is not designed based on known biofidelic performance, the test results can be presented in a similar way but using the chest acceleration in place of the head acceleration. Figure 12 presents the results to give, in this case, the combined responses of both chest acceleration and head displacement. Again the responses should ideally be in the lower left part of this chart. The arrow lines show the changes in the responses with increased slack and (for scheme C) the removal of the top tether. The anticipated effect of removing the top tether with Scheme B shown by the dotted arrow.

Again, the conventional CRS is relatively insensitive to increased slack, although the chest acceleration increases more than the head acceleration did. Scheme A is not susceptible to increased slack by design. Both schemes B and B_ are fairly insensitive to increased slack. Scheme C shows a greater sensitivity to increased slack. Interestingly, the chest acceleration decreases when the top tether is removed, although head displacement continues to increase.

EFFECT OF SLACK, REARWARD FACING CRS - Figure 13 shows the effect of slack on head acceleration for rear facing infant carriers in front impacts for Schemes A, B and C in comparison with a conventional rearfacing infant carrier restrained by a 3-point, lap/shoulder seat belt. When correctly adjusted, Scheme B produces a higher head acceleration than the conventional CRS although it seems to be less sensitive to slack. Schemes A and C both result in lower head accelerations than the conventional CRS. However, the acceleration for all rearfacing Group 0 systems was well within conventionally acceptable limits.

Figure 14 shows the effect of slack on head displacement in frontal impacts for this CRS Group. All systems except for Scheme A show an improvement

Figure 17 shows the combined effect on head displacement and chest acceleration of increased slack in side impacts for the rearfacing Group 0 CRS. Schemes A and B (and C when tightly adjusted) are in the lower left section of this chart, showing a better performance for combined head displacement and chest acceleration than the conventional CRS. When the attachment straps of the Scheme C CRS are adjusted with moderate slack (25mm) the results extended beyond the conventional CRS. The changes with increased slack were far less with the Scheme B and conventional CRS.

REARFACING GROUP 1 CRS- Figures 18-22 show the results of the front, side, and rear impact tests with the rearfacing Group 1 systems with a top tether or a pre-compression device (handle).

Figure 18 shows the effect of changing `slack' on head excursion for these two systems in frontal impacts. Compared with the results without a top tether, the addition of a top tether reduces forward excursion, even with 50mm slack in the tether strap. The use of the precompression device does not seem to produce an improvement. This is because the result presented for these systems is excursion, or head forward position with respect to the Cr point. Applying pre-compression

over the conventional CRS and A shows an improvement over the conventional system when any degree of slack is present.

Figure 15 shows the effect of slack on chest acceleration in side impacts with these Group 0 restraints. Neither the conventional CRS nor the Scheme B systems appear to be sensitive to slack as far as chest acceleration is concerned. Scheme C appears to be more sensitive and, although resulting in lower chest acceleration when tightly adjusted, produces the highest chest acceleration when there was 25mm slack in the attachment straps. Nevertheless, all of the chest accelerations appear to be within reasonable limits.

Figure 16 shows the effect of slack on head displacement for rear facing infant carriers in side impacts for Schemes A , B and C in comparison with a conventional rearfacing infant carrier restrained by a 3-point, lap/shoulder seat belt. When tightly adjusted, all schemes show better restraint than the conventional CRS. However when moderate slack (25mm) is applied to the attachment straps, Scheme C showed a large increase in head movement. As with the forward facing CRS the benefit of rigid attachments in side impacts is demonstrated.

with this system tends to compress the test seat, placing the head and CRS top further forward before impact.

Figure 19 presents the effect of slack on chest acceleration with these systems. The addition of a top tether increases chest acceleration slightly, as might be expected from a more restrained system. The addition of slack in the tether strap reduces this back to the no-top-tether condition. The lower degree of pre-compression also appears to increase the chest acceleration but the higher level reduces it. The changes are quite small.

The results shown in figure 20 indicate that the effects of a top tether and precompression on the head displacement in side impacts with these CRS are quite small, as might be expected. There is an indication that a top tether might reduce the head excursion by a small amount.

Figure 21 shows the effect of a top tether and pre-compression device on chest acceleration in side impacts. Here there does appear to be a benefit from the provision of a top tether, although all of the values are relatively low.

Finally, figure 22 show the maximum vertical position with respect to the Cr point (vertical excursion) and the maximum rearward displacement of the head with respect to its pre-impact position (displacement) for rear facing Group 1 seats with rigid attachments and a rear tether or the handle pre-compression device. The most effective method for limiting both motions was the use of the rear tether.

DISCUSSION

The results of the dynamic test performed with ideal adjustment of the attachment systems showed that all of the alternative systems performed as well or better than the conventional system attached by the adult seat belt in the front impacts. For head excursion, which is probably the more important parameter, Scheme A provided the best result followed by B, C and B_, the latter being little different from the conventional system. For head and chest acceleration, Schemes C and B produced the lowest result.

For the side impact tests with tight adjustment, the differences between the rigid and 'soft' attachments were quite marked. Schemes A, B and B_ gave noticeable improvements over the conventional system for both head displacement and head and chest acceleration. Both chest acceleration and head displacement for the Scheme C CRS were worse than that the conventional CRS.

However, the user trials demonstrated that, even when being observed, the adjustable systems were likely to be left with some slack in them. This was

From these tests, based on the likely condition of use, Schemes A and B appear to offer the best all round opportunity to provide good protection in impacts. If the opinions of the subjects in the small user trial are taken into account, then Scheme B appears to be the best design concept from this group. However, it is clearly important to find ways to encourage the use of the top tether and its correct adjustment. It would be advisable to ensure that the system provided adequate protection in the event that the top tether was not used or left slack.

CONCLUSIONS

1 Several dedicated attachment systems for child restraints, which have been proposed as alternatives to the use of the adult seat belt, have been subjected to a user trial and all have been found to result in a lower rate of misuse than the conventional system.

2 The system with webbing attachment was more frequently incorrectly fitted than those with rigid attachment and resulted in greater slack, particularly when re-fitted a second time. It also presented more

particularly noticeable when the systems were refitted for a second time or attached in close proximity to a second CRS with Scheme C where adjustment of the lower straps was necessary. Slack in the top tether was another misuse condition that could be expected to be found in normal use. It is therefore important to consider the effects of these misuse condition on the relative performance of the different schemes.

Scheme A does not require user adjustment and is not therefore susceptible to the addition of slack in the attachment system. A potential misuse system which could be considered is the failure to fasten the front attachments, although this was not observed in this user trial. This would effectively turn the Scheme A CRS into a Scheme B device without a top tether, or Scheme B_ device with any pre-compression.

Schemes B_ and C were particularly sensitive to added slack in the attachment system, both with respect to the head and chest acceleration and for head displacement in front impacts. Scheme C was also sensitive to slack in the side impacts. The benefits of the rigid attachment in side impacts is again apparent.

The large, Group 1 rearfacing CRS showed that the use of a top tether can be beneficial for these CRS also, even in side impacts. The use of a lower tether seems to be the better way of reducing head rearward motion, although this is not likely to be critical in this impact mode.

difficulties in attachment in the presence of a second child restraint.

3 When well adjusted, all of the systems provided good performance in frontal impacts. However the performance of the webbing based system in particular deteriorated with increased slack.

4 In side impacts, the benefits of the rigid attachment systems in terms of reduced head excursion were apparent.

5 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, Scheme B (2 rigid attachments with a top tether) appears to offer the best design concept..

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable assistance of Britax in producing prototypes of the different schemes both for user trials and for the dynamic test programme.

Table 1. Proportion of users misfitting the CRS

	Conventional CRS	Scheme A (4 -point rigid)	Scheme B (2-point rigid + Top Tether)	Scheme C (2 lower straps only, no top tether)	Scheme C (2 lower straps + top tether)
Fitted well	13 (45%)	29 (100%)	22 (76%)	6 (50%)	10 (59%)
Minor errors	8 (27.5%)	0	6 (21%)*	6 (50%)	7 (41%)
Not fitted correctly	8 (27.5%)	0	1 (3%)	0	0

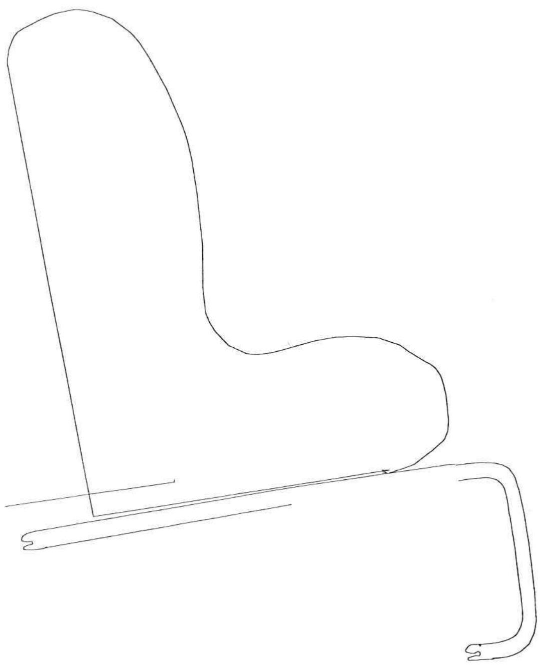
* Three subjects tightened the top tether such that it lifted the CRS off vehicle seat, but this has not been classified as an error here.

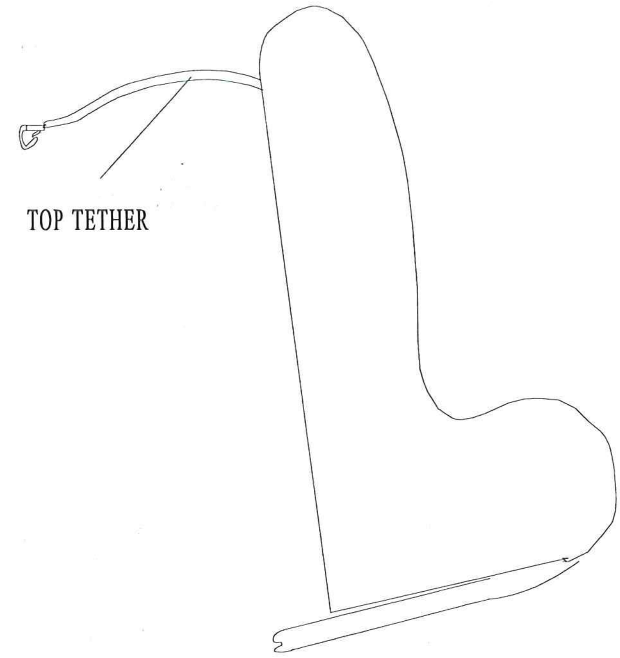
Table 2. Number and Proportion of subjects with ≤ {zero slack; zero tension} adjustment (N= 14)

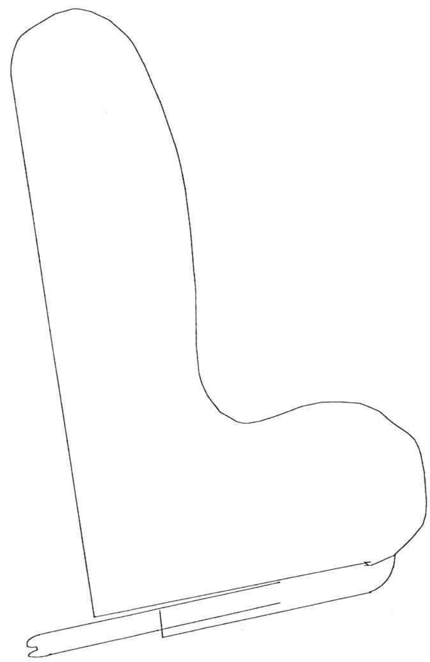
	Conventional CRS	Scheme B	Scheme C
Top tether	-	13 (93%)	11 (79%)
Top of child seat shell	7 (50%)	14 (100%)	3 (21%)
Bottom of child seat shell	2 (14%)	-	3 (21%)

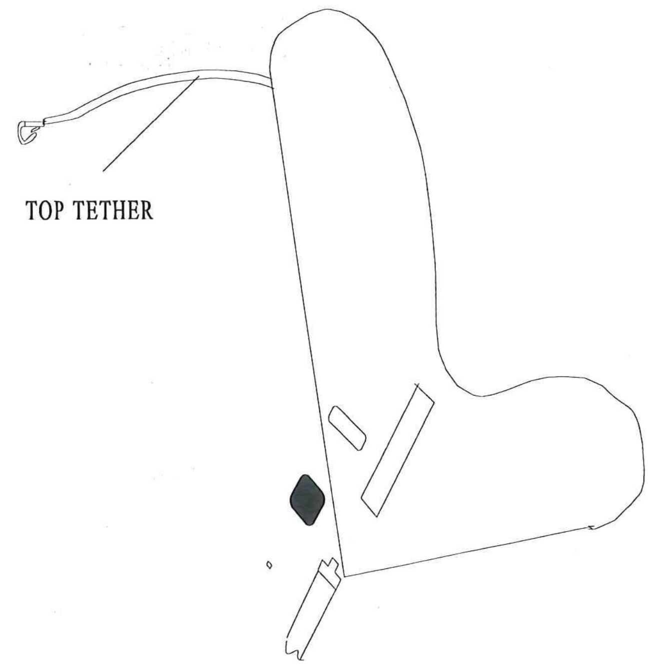
Table 3. Number and Proportion of subjects with ≤ {zero tension + 25mm} (N= 14)

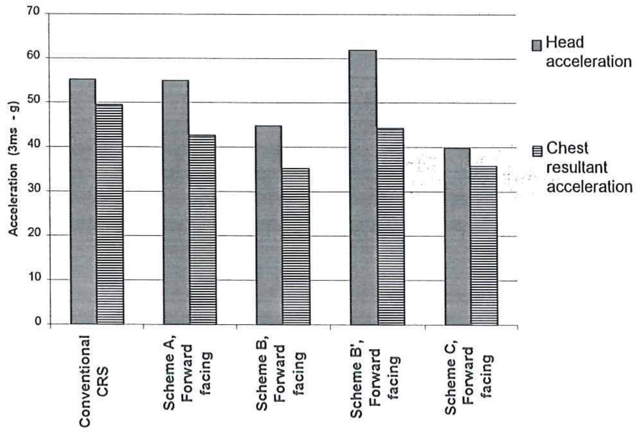
	Conventional CRS	Scheme B	Scheme C
Top tether	-	14 (100%)	13 (93%)
Top of child seat shell	9 (64%)	14 (100%)	8 (57%)
Bottom of child seat shell	7 (50%)	-	10 (71%)

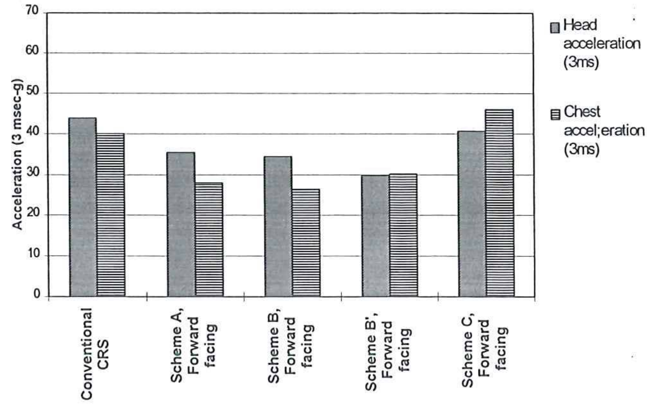


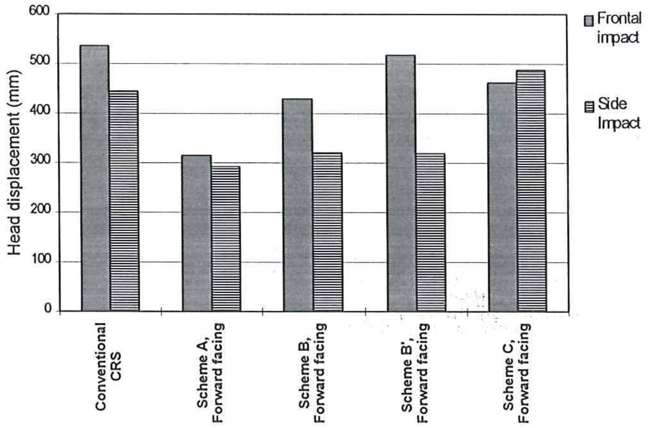

TOP TETHER

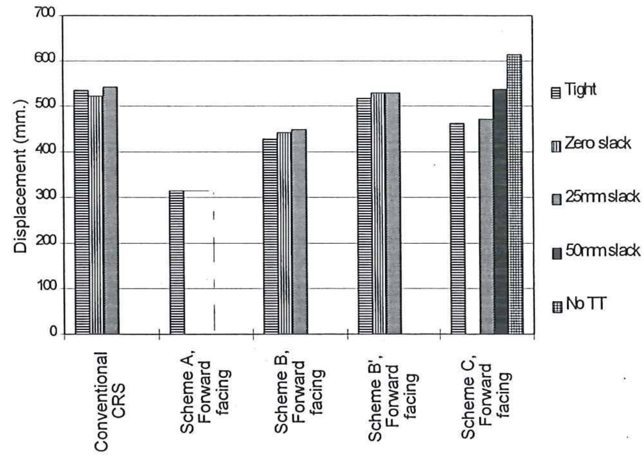


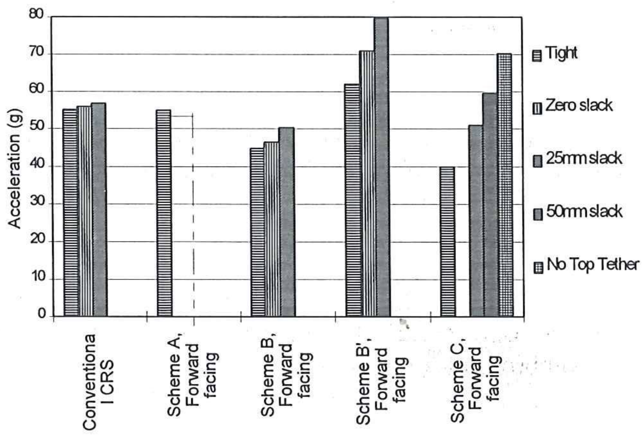

TOP TETHER

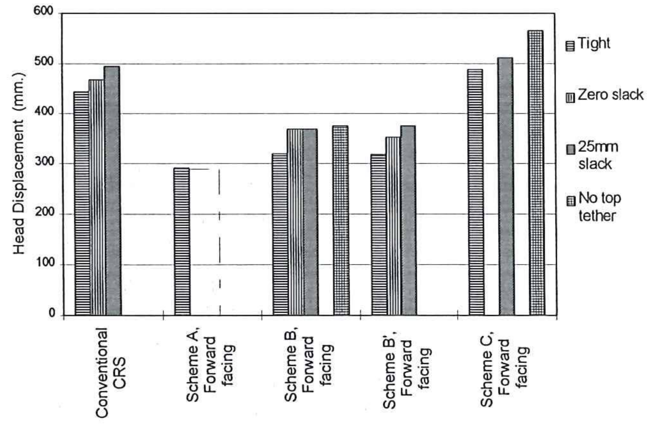

Acceleration (3ms - g)
Head acceleration
Chest resultant acceleration
Conventional CRS
Scheme A, Forward facing
Scheme B, Forward facing
Scheme B', Forward facing
Scheme C, Forward facing

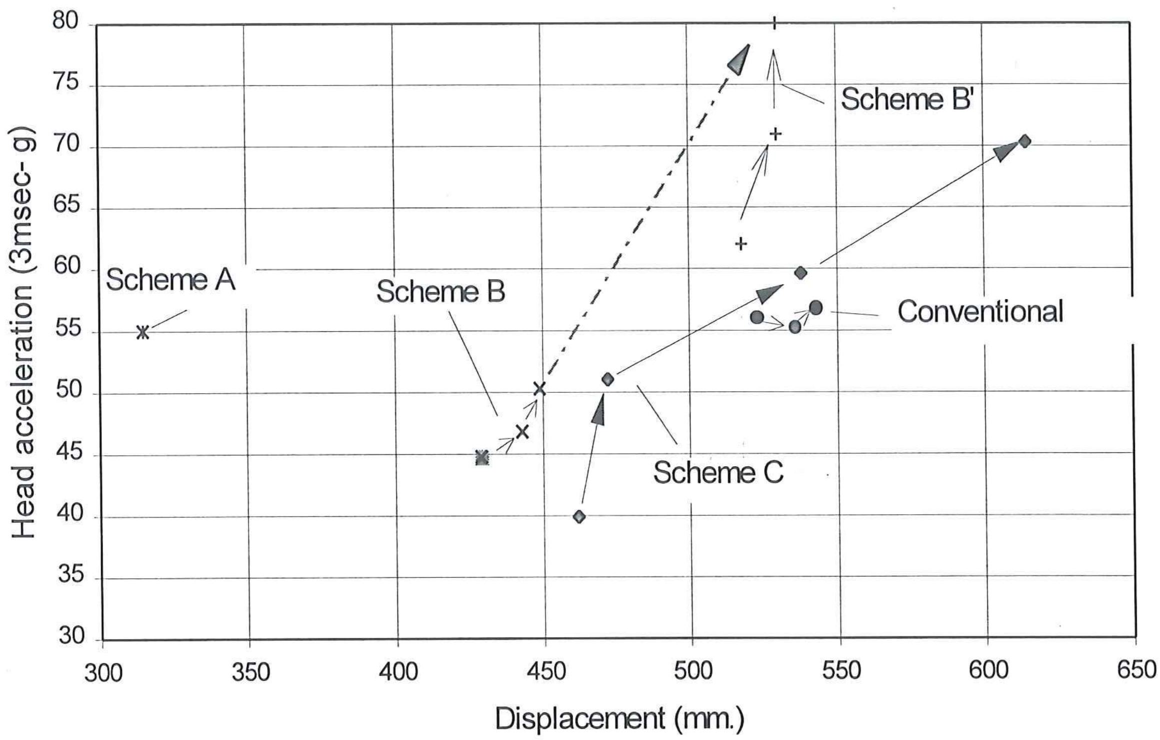

Acceleration (3 msec-g)
Head acceleration (3ms)
Chest accel;eration (3ms)
Conventional CRS
Scheme A, Forward facing
Scheme B, Forward facing
Scheme B', Forward facing
Scheme C, Forward facing


Head displacement (mm)
Frontal impact
Side Impact
Conventional CRS
Scheme A, Forward facing
Scheme B, Forward facing
Scheme B', Forward facing
Scheme C, Forward facing

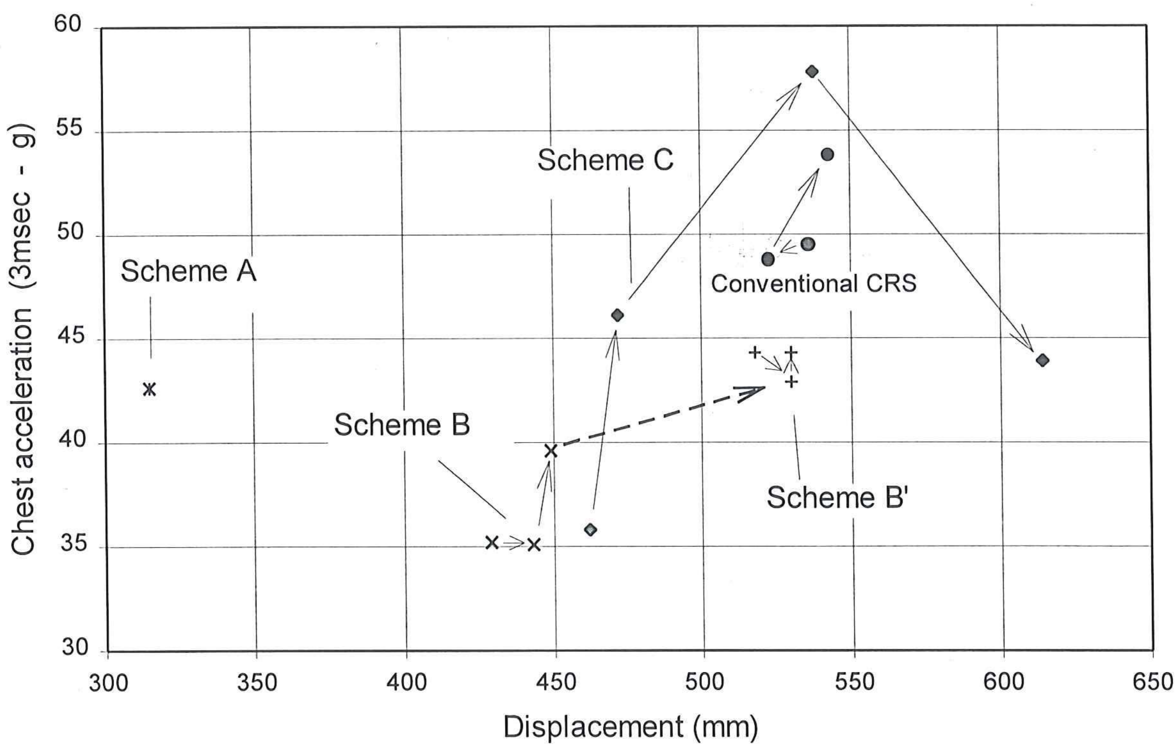

Displacement (mm.)
Tight
Zero slack
25mm slack
50mm slack
No TT
Conventional CRS
Scheme A, Forward facing
Scheme B, Forward facing
Scheme B', Forward facing
Scheme C, Forward facing


Acceleration (g)
Tight
Zero slack
25mm slack
50mm slack
No Top Tether
Conventiona l CRS
Scheme A, Forward facing
Scheme B, Forward facing
Scheme B', Forward facing
Scheme C, Forward facing

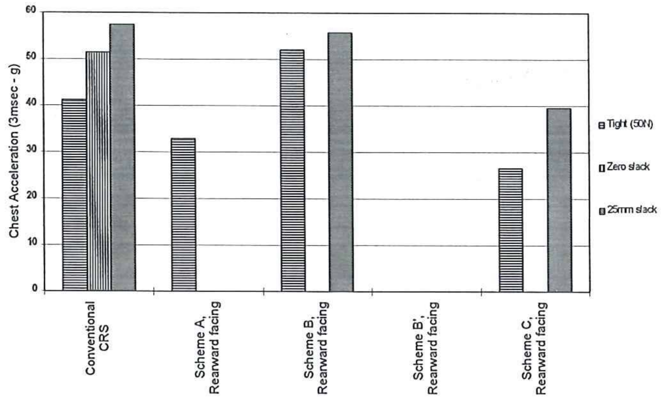

Head Displacement (mm.)
Tight
Zero slack
25mm slack
No top tether
Conventional CRS
Scheme A, Forward facing
Scheme B, Forward facing
Scheme B', Forward facing
Scheme C, Forward facing



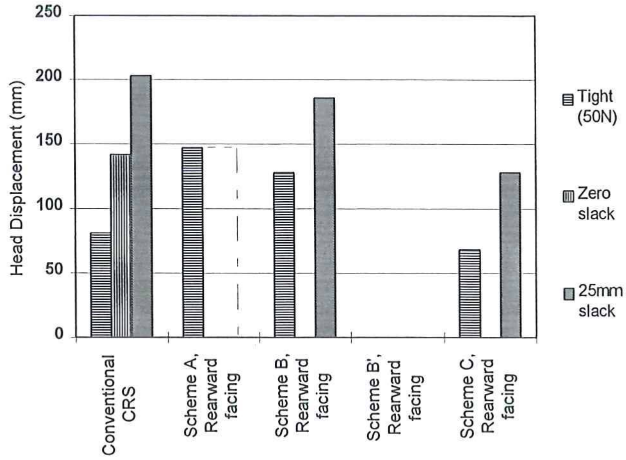
Head acceleration (3msec- g)
Displacement (mm.)
Scheme A
Scheme B
Scheme B'
Scheme C
Conventional



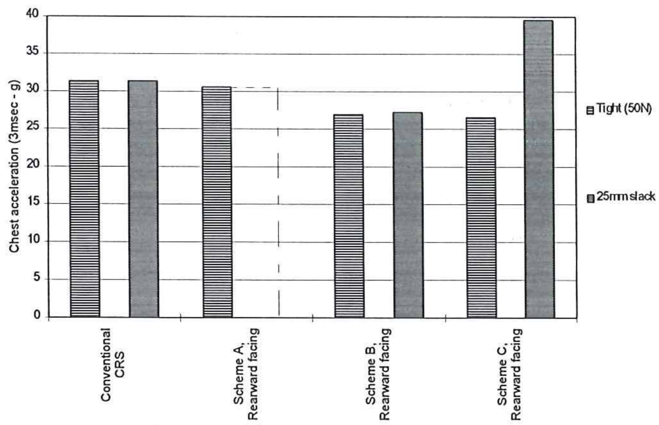
Chest acceleration (3msec - g)
Displacement (mm)
Scheme A
Scheme B
Scheme B'
Scheme C
Conventional CRS



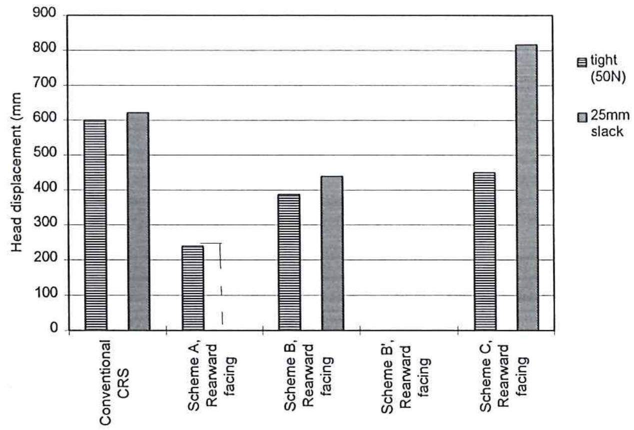
Chest Acceleration (3msec - g)
60
50
40
30
20
10
0
Tight (50N)
Zero slack
25mm slack
Conventional CRS
Scheme A, Rearward facing
Scheme B, Rearward facing
Scheme B', Rearward facing
Scheme C, Rearward facing



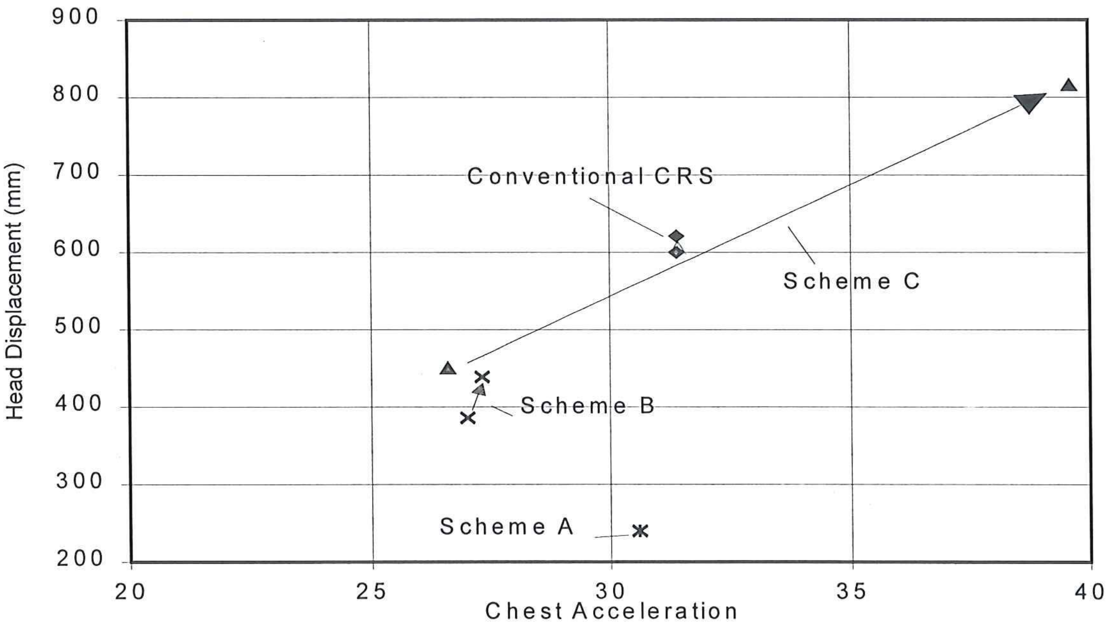
Head Displacement (mm)
250
200
150
100
50
0
Tight (50N)
Zero slack
25mm slack
Conventional CRS
Scheme A, Rearward facing
Scheme B, Rearward facing
Scheme B', Rearward facing
Scheme C, Rearward facing



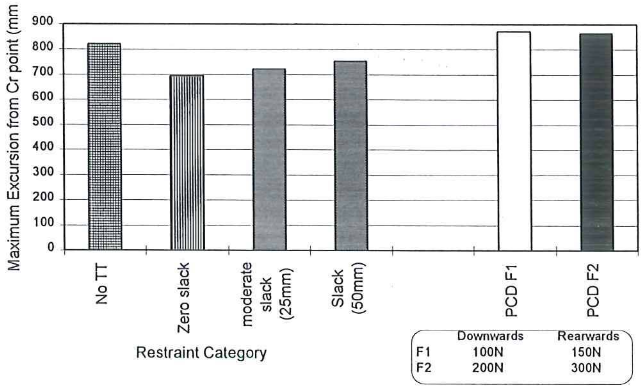
Chest acceleration (3msec - g)
40
35
30
25
20
15
10
5
0
Tight (50N)
25mm slack
Conventional CRS
Scheme A, Rearward facing
Scheme B, Rearward facing
Scheme C, Rearward facing

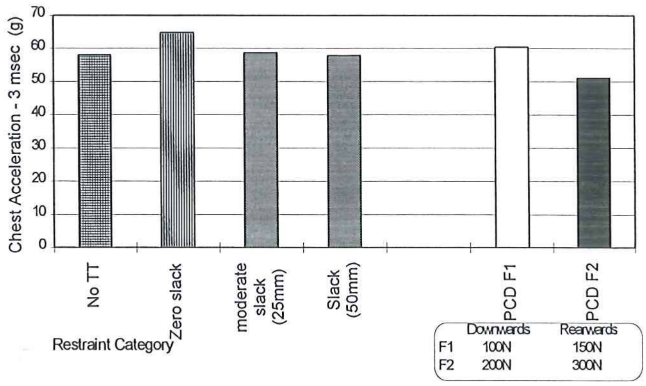


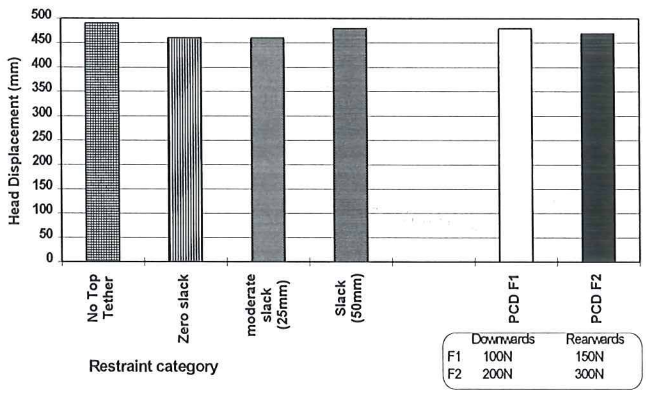
Head displacement (mm
900
800
700
600
500
400
300
200
100
0
tight (50N)
25mm slack
Conventional CRS
Scheme A, Rearward facing
Scheme B, Rearward facing
Scheme B', Rearward facing
Scheme C, Rearward facing

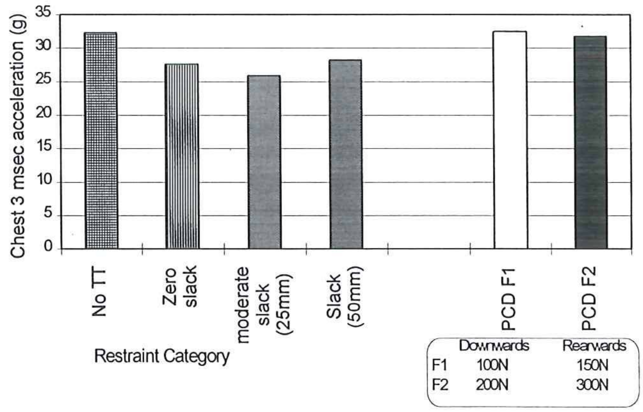


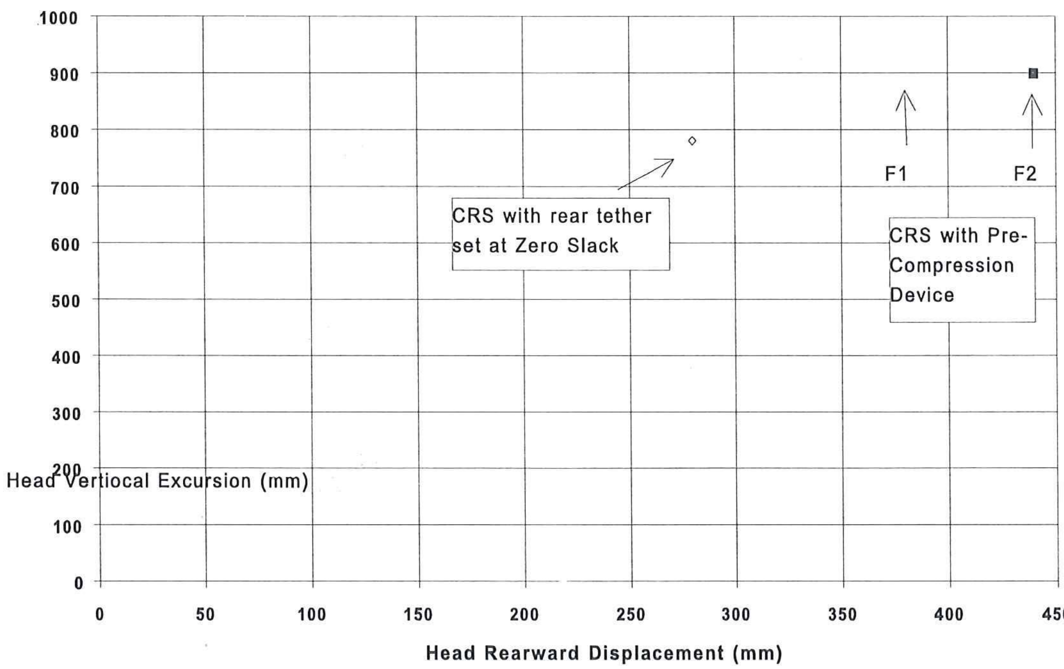
900
800
700
600
500
400
300
200
Head Displacement (mm)
20
25
30
35
40
Chest Acceleration
Conventional CRS
Scheme C
Scheme B
Scheme A


Maximum Excursion from Cr point (mm
900
800
700
600
500
400
300
200
100
0
No TT
Zero slack
moderate slack (25mm)
Slack (50mm)
PCD F1
PCD F2
Restraint Category
Downwards Rearwards
F1 100N 150N
F2 200N 300N


Chest Acceleration - 3 msec (g)
70
60
50
40
30
20
10
0
No TT
Zero slack
moderate slack (25mm)
Slack (50mm)
PCD F1
PCD F2
Restraint Category
Downwards Rearwards
F1 100N 150N
F2 200N 300N


Head Displacement (mm)
500
450
400
350
300
250
200
150
100
50
0
No Top Tether
Zero slack
moderate slack (25mm)
Slack (50mm)
PCD F1
PCD F2
Restraint category
Downwards Rearwards
F1 100N 150N
F2 200N 300N


Chest 3 msec acceleration (g)
35
30
25
20
15
10
5
0
No TT
Zero slack
moderate slack (25mm)
Slack (50mm)
PCD F1
PCD F2
Restraint Category
Downwards Rearwards
F1 100N 150N
F2 200N 300N


1000
900
800
700
600
500
400
300
200
100
0
Head Vertiocal Excursion (mm)
CRS with rear tether set at Zero Slack
F1
F2
CRS with Pre-Compression Device
0
50
100
150
200
250
300
350
400
450
Head Rearward Displacement (mm)

1. Turbell, T, R Lowne, B Lundell and C Tingvall. ISOFIX - A new concept of installing child restraints in cars. SAE paper 933085, Child Occupant Protection, SP-986 1993.

1. Pedder, J., J Garie, D Pasco, M Deibert and M Lumley. Usability Trials of Alternative ISOFIX Child Restraint Attachment Systems. Proc. Second Child Occupant Protection Symposium, Orlando Nov. 1997