LOADINGS TO CHILDREN IN CARS IN FRONTAL COLLISIONS – EXPERIENCE FROM ECE-R44 TEST BENCH RESULTS COMPARED WITH CAR RESULTS

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ABSTRACT
The ISOFix system was developed to reduce the degree of misuse during the attachment of child restraints to vehicles, and to improve the dynamic performance of child restraints above that of systems attached by the adult belt. This paper discusses the issues involved and the practicalities of obtaining ECE R44 approval for an ISOFix system. Tests with ISOFix restraints designed for specific vehicles along with more general ISOFix restraints are reported. The results show that, where a car has been designed to work with an ISOFix restraint and the ISOFix restraint has been developed by testing in such cars, a two point ISOFix restraint can give equivalent performance to conventionally attached restraints. However, to be confident that an ISOFix CRS, that is assessed on a generic test, bench will perform well in any car with ISOFix anchorages, an additional feature that reduces the influence of the seat cushion could be necessary.

KEY WORDS: Child Restraint Systems; Frontal Impacts; Infants; Regulations; Restraint Systems.

IN THE 1960s, A NEW SYSTEM of restraints for children was developed. At that time, 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, although rearward facing child restraints for front seat use were favoured in Sweden (Aldman 1966). The forward facing systems were attached to the vehicle by means of straps bolted to the floor and parcel shelf (Makinen 1973). The rear facing seats 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. In addition, the coupling of the child restraint to the car structure was not so firm.

In 1991 a new concept for interfacing the child restraint and vehicle was proposed. This system was based on a rear facing child restraint with two plug-in connectors at its base, fixing it rigidly to the vehicle at the seat bight. This led to the international development of a standard for the attachment system, through the International Organisation for Standardisation (ISO), known as ISOFix (Turbell 1993). The term ISOFix applies to the defined two lower rear attachments, based on two horizontal anchor bars, together with an anti-rotation system, to avoid excessive forward motion as the child restraint pivots about these anchorage bars. This simple but rigid attachment system offers the opportunity both to reduce the degree of misuse and to restore the dynamic performance obtained by the original systems with their dedicated attachment methods.

The rigid bar attachment system has been adopted in the USA and Canada, where the anti rotation system that has been adopted is the use of a top tether. In Europe, the systems that have been approved so far have been for particular vehicles, under the specific vehicle type approval classification of ECE Regulation 44. In these systems, the child restraint has been tested in the vehicle seat for which its approval is sought and usually the anti-rotation system has relied on the reaction from the car seat cushion. Clearly, the potential advantages of the ISOFix system can only be fully realised when universal child restraint systems can be made available. The principle of attachment to the two rear horizontal bars and the reliance on the car seat cushion for the anti-rotation device, means that this system is more dependent on the performance and dimensions of the car seat than any previous system (Paton 2000). This raises the question of whether the assessment of the performance on the standardised car seat used in the ECE Regulation 44 test bench can reliably ensure satisfactory performance on the whole range of real car seats.

This paper presents the results of two test programmes designed to provide information to assist in this evaluation.

TEST PROGRAMMES

The two series of test programmes were performed by TRL and GDV. The GDV tests used a prototype ECE Group 0+/1 seat in forward and rear facing modes. The seat was based on a conventional CRS with an impact shield for the forward facing configuration. The CRS was installed on the ECE-R44 seat both conventionally and using the ISOFix system with the adult belt, for the forward facing configuration, and both conventionally and using the ISOFix system for the rearward facing configuration. The effect of the addition of a front support foot was evaluated for all conditions. Performance on the ECE-R44 test bench was compared with that in two car bodyshells, designed for use with ISOFix child seats, that were approved for use in these cars. The bodyshells that were chosen had a stiff cushion (vehicle 1) and a slightly softer cushion (vehicle 2).

The GDV investigation was intended to shed light in particular on a number of issues. Firstly to question the differences that result between the ISOFix performance on the ECE-R44 seat and a real rear car seat. Secondly to see if the test results differ between ISOFix attachment in a hard rear seat and a slightly softer rear seat. Finally, to investigate if ISOFix attachment in the vehicle would result in a marked improvement in the accelerations and excursions of the dummy compared to conventional attachment using a 3-point seatbelt.

The TRL investigation was in two stages. The first used three prototype ISOFix seats. A frame-type forward facing child restraint formed the basis for the two Group 1 CRSs used in the tests. This was used with its standard frame and also modified to optimise its performance on the Reg.44 test bench. This was achieved by increasing the overall length of the child restraint (whilst keeping it's size representative) 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. The standard and front rail frames were adapted to attach to the ISOFix anchorages, for comparative testing.

The third child seat evaluated was a Group 0+ infant carrier. This was also modified to incorporate ISOFix anchorages for comparative testing. Static and dynamic tests were conducted on the ECE R44 test bench and in three car bodyshells, not approved for specific vehicle ISOFix CRS but with strong ISOFix anchorages attached to the rear seating position. The car models were selected as having seats with possible problems for 2-point ISOFix designs; a rear seat with short understructure and a 150mm thick cushion (vehicle A), a seat with a thick, 200mm, soft cushion (vehicle B), and a seat with a thick, 185mm, stiff cushion (vehicle C).

The second stage of the investigation used current Group 0+ and Group 1 CRSs, which were modified in order to attach to ISOFix anchorages and to include an anti rotational tether or foot support. These CRSs were also tested in the three bodyshells not approved for specific vehicle ISOFix CRS but with strong ISOFix anchorages attached to the rear seating position.

CHARACTERISTICS OF SEAT CUSHIONS – TRL TESTS

Static tests determined the resistance to rotation of each ISOFix child restraint on the Reg.44 test bench (Paton 2000). On the R44 test bench the infant carrier, had the greatest contact area with the cushion and, as predicted, this seat generated the highest moment for a given distance of rotation. The CRS with the front rail generated lower moments until the bar reacted against the rigid base of the R44 test bench (7°), at which point the moment generated was similar to that produced by the infant carrier.

The static tests conducted in the vehicle body shells determined how the seat cushion characteristics of the vehicles varied for each child restraint. When reacting against the standard tubular ISOFix CRS the vehicle C rear seat appeared to be similar to the R44 bench. Vehicle A was much stiffer while vehicle B was much softer.

For the ISOFix framed seat with the front rail, again the seats in vehicle C appeared to be similar to the R44 bench, and that in vehicle B seems to be much softer. However, in vehicle A, the seat is initially stiffer, but the effective stiffness is reduced as the front rail passes over the front edge of the seat, thus reducing the resistive moment.

With the rear facing infant carrier the seat in vehicle A appeared almost as stiff as the R44 test bench, but the seats in both vehicle B and C appeared a little softer.

The full details of the comparative tests on the relative stiffness of the car seat cushions and the standard R44 test bench are given in Paton (2000).

RESULTS OF DYNAMIC TESTING

GDV TESTING: Figures 1 to 6 show the results of the GDV testing which were all carried out with the Group 0+/1 CRS. Figures 1 and 2 show the head excursions for the forward facing CRSs in the vehicles and on the R44 test bench. Figures 3 and 4 show the head and chest accelerations from the tests with the CRS in the forward facing position in the vehicle seats and on the R44 test bench. The results for the rear facing CRS in the vehicles and on the R44 test bench are shown in Figures 5 and 6. The conventionally restrained CRSs were tested on the R44 test bench and in vehicle 1. The ISOFix attached systems were tested in vehicles 1 and 2.

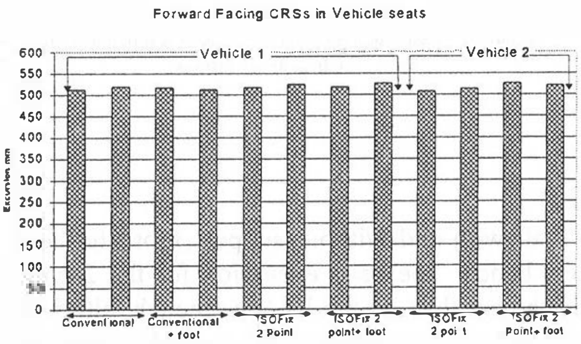


Figure 1 - Forward Facing CRSs in the Vehicles – Head excursions

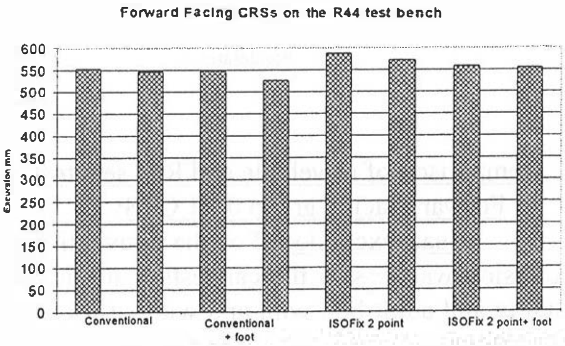


Figure 2 - Forward Facing CRSs on the R44 test bench – Head excursions

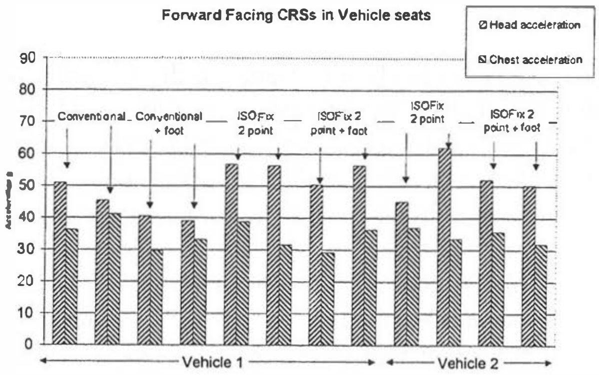


Figure 3 - Forward facing CRS in the Vehicles – Head and Chest Accelerations

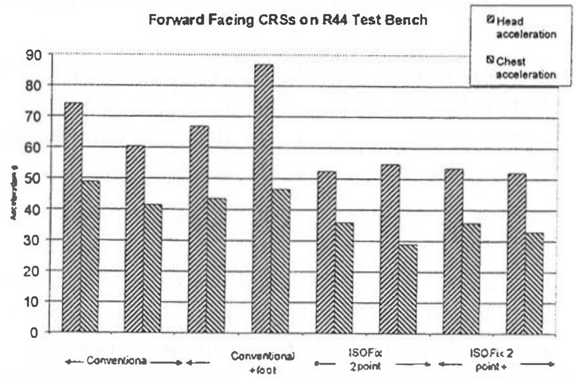


Figure 4 - Forward facing CRS on the R44 test bench – Head and Chest Accelerations

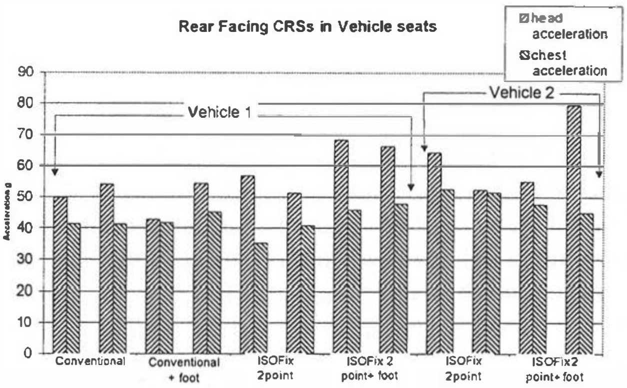


Figure 5 - Rear Facing CRSs in the vehicles – Head and Chest accelerations

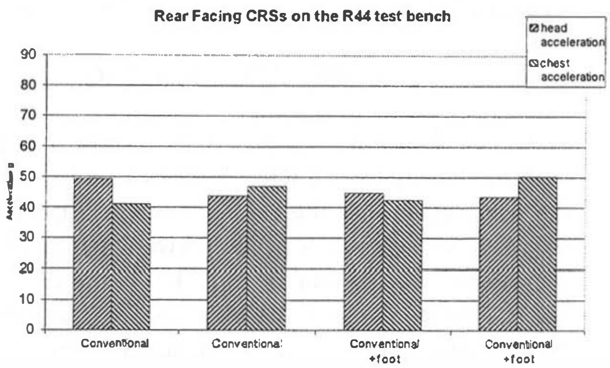


Figure 6 - Rear Facing CRSs on the R44 test bench – Head and Chest accelerations

Comparison of in-vehicle and R44 seat tests:

Forward facing group 0+/1 CRS:

Head excursion: For the conventional CRS, both with and without support foot, the head excursion was less in the car tests than on the R44 test bench. The head excursion for the 2-point ISOFix and adult belt with and without foot was less in the car than on the R44 test bench, although the differences were less when the foot was used. The difference in mean head excursion between vehicles 1 and 2 for the 2-point ISOFix without foot was of the same order as the difference between the vehicles and the R44 test bench results. The head excursions for the 2 point ISOFix and adult belt system on the R44 test bench were high and failed the R44 test criteria.

Head acceleration: The head accelerations for the Conventional CRS in the vehicles were less than those measured on the R44 test bench, both with and without the foot. This was particularly noticeable when the foot was used. For the 2-point ISOFix with adult belt, the results in the vehicles were similar or slightly greater than on the R44 test bench, the results in vehicle 2 were somewhat variable. When the foot was used with the 2-point ISOFix with adult belt, the results in both vehicles and the R44 test bench were similar.

The R44 test bench provided a worst case condition for the conventionally restrained CRSs both with and without the supporting foot. This was not the case with the 2-point ISOFix with adult belt system. The 2-point ISOFix with adult belt was sensitive to the car seat characteristics giving lower head accelerations on the stiffer seat.

Chest accelerations: The chest accelerations with the Conventional CRS were lower in the vehicle than on the R44 test bench, particularly when the foot was added. For the 2-point ISOFix with adult belt, they were slightly greater in the vehicles than on the R44 test bench but the in-vehicle test results were similar to those on the R44 test bench when the support foot was added.

Comparison of 2-point ISOFix with adult belt and conventional CRS:

Forward facing group 0+/1 CRS:

Head excursion: In the R44 test bench tests, the head excursions for the 2-point ISOFix with adult belt, both with and without the support foot were slightly greater than those for the equivalent Conventional CRS. This was also true for the tests in the vehicle.

Head acceleration: The head accelerations for the 2-point ISOFix with adult belt were lower than those for the Conventional CRS when tested on the R44 test bench. However, when tested in the vehicle, the head accelerations for the 2-point ISOFix with adult belt were higher than those measured with the Conventional CRS. These results apply both with and without the use of the foot support.

Chest acceleration: In the vehicle tests, the 2-point ISOFix with adult belt showed slightly lower chest accelerations than the Conventional CRS without the foot. With the foot, the results for the two CRS types were similar. In the R44 test bench tests, both results were lower for the 2-point ISOFix with adult belt than for the Conventional CRS.

Rearfacing group 0+ CRS (in-vehicle tests only):

Head acceleration: Without the use of a support foot, the head accelerations for the 2-point ISOFix with adult belt and Conventional CRS were similar. When the support foot was used, the head accelerations were higher for the 2-point ISOFix with adult belt than for the Conventional CRS.

Chest accelerations: The chest accelerations measured in the 2-point ISOFix with adult belt were lower than those for the Conventional CRS when the foot was not used. When the foot was used, the chest accelerations were slightly higher with the 2-point ISOFix with adult belt than with the Conventional CRS.

Effect of support foot:

Forward facing group 0+/1 CRS:

Head excursion: In vehicle 1 and on the R44 test bench, the use of the support foot had little effect on head excursion, both for the 2-point ISOFix with adult belt and for the Conventional CRS. There was a slight increase in the head excursion for the 2-point ISOFix with adult belt in vehicle 2, with the softer seat, when the foot was used.

Head acceleration: For the Conventional CRS, the use of the foot resulted in a decrease in head acceleration when tested in the vehicle but an increase when tested on the R44 test bench. For the 2-point ISOFix with adult belt, the use of the foot had little effect on head acceleration in either vehicle or on the R44 test bench.

Chest acceleration: There was a slight reduction in chest acceleration resulting from the use of the foot for the Conventional CRS when tested in the vehicle. In all other comparisons, the foot had little effect on the chest acceleration.

Rearfacing group 0+ CRS:

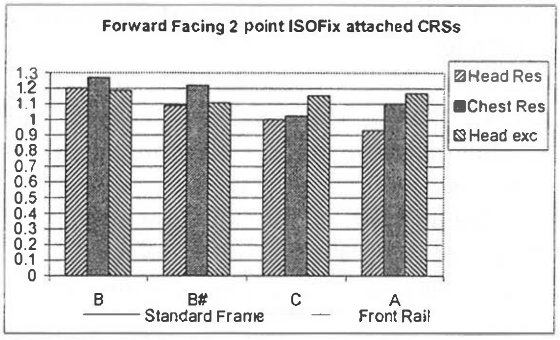
Head acceleration: The use of the foot had little effect on the head acceleration for the Conventional CRS whether tested in the vehicle or on the R44 test bench. For the 2-point ISOFix with adult belt, the head acceleration increased with the use of the foot for both vehicles (not tested on the R44 test bench).

Chest acceleration: As for the head acceleration, the use of the foot had little effect on the chest acceleration for the Conventional CRS whether tested in the vehicle or on the R44 test bench. In vehicle 1, the use of the foot led to an increase in chest acceleration for the 2-point ISOFix with adult belt, while it led to a decrease when tested in vehicle 2.

General effect of foot: The greatest differences in response between test on vehicle 1 and vehicle 2 with the 2-point ISOFix were observed for the head excursion with the forward facing CRS and for the chest acceleration with the rear facing CRS, both without the use of the support foot. The use of the foot removed this sensitivity to vehicle cushion stiffness.

TRL TESTING:

Comparison of R44 test bench and in vehicle test results: The first stage of the TRL test programme was designed to determine whether the results on the R44 test bench would be a good indication of the performance of the CRSs when placed in a vehicle seat. These results are shown in figures 7 to 9. For comparative purposes the dynamic test results are presented as a ratio of the values obtained in the vehicle shells and the values obtained on the R44 test bench. Figures 7 and 8 represent the results for the group 1 FF CRS.



# indicates the use of adult L&D as asymmetric top tether

Figure 7 - Forward Facing 2 point ISOFix attached CRSs veh/R44

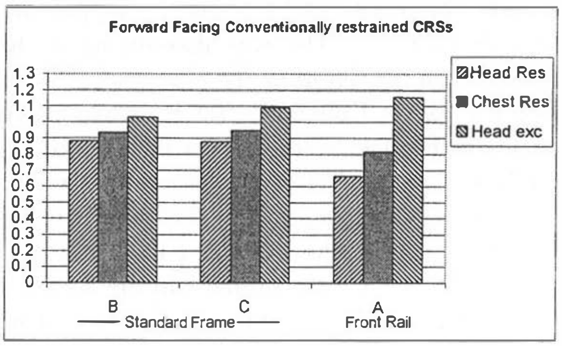


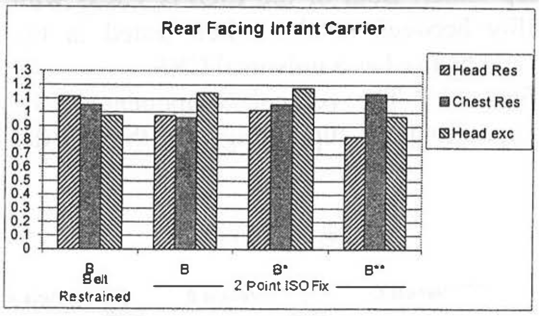
Figure 8 - Forward Facing conventionally restrained CRSs veh/R44

A ratio greater than 1 indicates a higher result in the vehicle than on the ECE R44 test bench. Figure 7 shows the results for the 2 point systems and 2 point with asymmetrical tether are mostly greater than 1, with differences of up to 25%, showing performance is better on the R44 test bench. In figure 8 the results for the conventionally restrained CRS are mostly less than 1 showing that the performance is better in the vehicles. The figures for the conventionally restrained CRS demonstrate that the R44 test bench generally gives a worst case prediction for their performance, however this was not so for the 2 point attached CRSs as their performance deteriorated when placed in the vehicle.

The results of the group 0+ infant carriers are represented in figure 9.

The result for the conventionally restrained head excursion is close to 1. However the head excursions for the 2 point system and 2 point with asymmetrical tether are well above 1, showing that the performance deteriorated when the systems were placed in the vehicle seats. However the performance of the 2 point CRS with the centrally located top tether was less than 1. These results show that the R44 was a good indicator of worst case performance for the conventionally restrained CRS and the 2 point CRS with the centrally positioned top tether arrangement. However this could not be said for the 2 point system and the 2 point system with the asymmetrical tether. Examination of the different kinematics of the 2 point CRS and the conventionally restrained CRS, and consideration of the attachment and reaction loads show that the performance of the 2 point attached ISOFix CRS is much more dependent on the vehicle seat cushion properties than the conventionally restrained CRS.

Comparison of anti-rotational systems: Having established that the 2 point ISOFix was too sensitive to the seat characteristics to be a universal system, the second stage of the TRL investigation was to compare the performance of two 3 point ISOFix systems, providing anti-rotational components. The Group 0+ and Group 1 CRSs used, were modified in order to attach to ISOFix anchorages and to include an anti rotational tether or foot support. These CRSs were tested in the three bodyshells, not approved for specific vehicle ISOFix CRS, but with strong ISOFix anchorages attached to the rear seating position. Figure 10 shows the head excursions for the forward facing CRSs.



*Tests conducted with adult L&D belt used as asymmetrical top tether
** Adult diagonal belt section locked to top of carrier to act as asymmetrical top tether

Figure 9 - Rear Facing conventionally restrained CRSs and ISOFix attached CRSs veh/R44

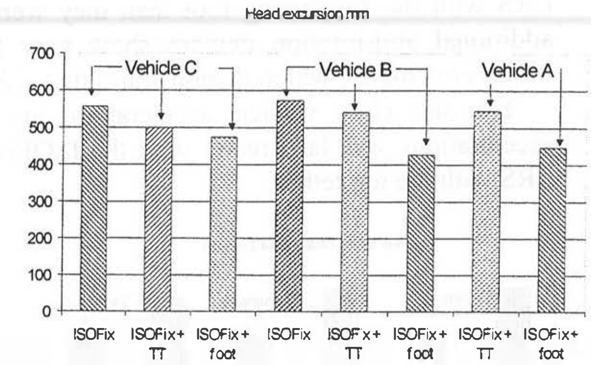


Figure 10 - Group 1 Forward Facing CRSs – Head excursions

The head excursions were improved by the addition of a dedicated top tether, bringing the performance the ISOFix CRSs within the R44 limits in all vehicles, and the performance of the CRS with the supporting foot was a substantial improvement on the 2 point ISOFix systems in all vehicles.

Figure 11 shows the 3ms chest resultant accelerations. In vehicle C the chest acceleration increased slightly with the use of the top tether but it was well within the R44 limit. The top tether in vehicle B decreased the chest resultant acceleration from just below the R44 limit to well within it. The CRS with the supporting foot device had much lower chest accelerations than the CRS with the top tether or the 2 point only ISOFix, where this comparison was possible.

Figure 12 shows the Group 1 Chest vertical 3ms accelerations for the ISOFix CRSs, with top tether and with the foot. The CRS with the top tether saw slightly increased chest vertical accelerations but these were well within the R44 limit, the maximum being 16g. However the CRS with the anti-rotational foot device saw very high chest vertical accelerations, mostly above the R44 limit.

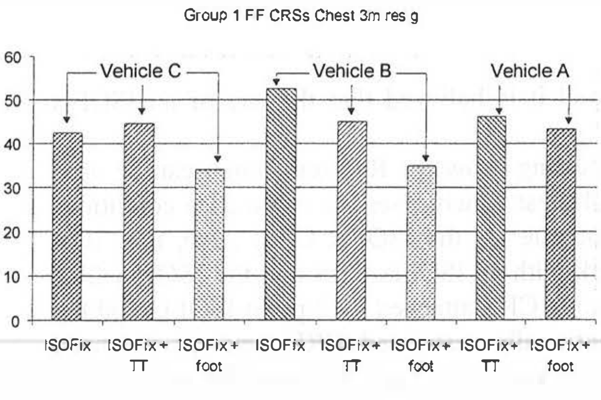


Figure 11 - Group 1 Forward facing CRSs – Chest 3ms resultant accelerations

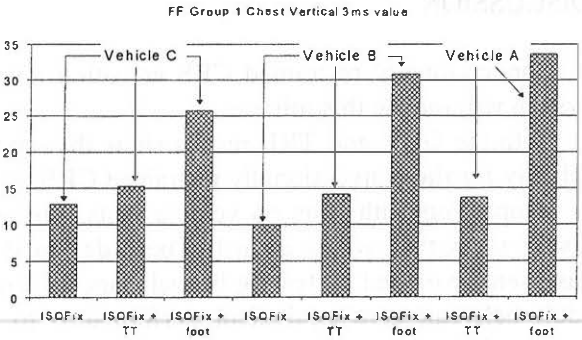


Figure 12 - Group 1 Forward Facing CRSs – compressive chest vertical 3ms acceleration

Figures 13 and 14 show the results for the 3 ms head and chest resultant accelerations, with the rear facing infant carrier. The 3ms head and chest resultant accelerations were, again, lower in the ISOFix CRS with the supporting foot than they were with the top tether. Both of the ISOFix CRSs with additional anti-rotation devices show very little variability between results, when tested in the different vehicles, which demonstrates that either system could be used as a universal CRS.

The 3ms chest vertical accelerations are shown in figure 15. The vertical component of the accelerations was far greater with the ISOFix device incorporating the supporting foot than in the CRS with the top tether.

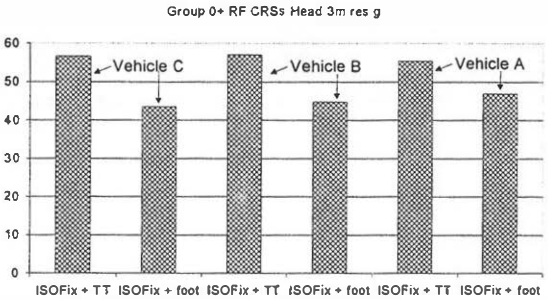


Figure 13 - Group 0+ rear facing infant carrier – 3ms head resultant accelerations

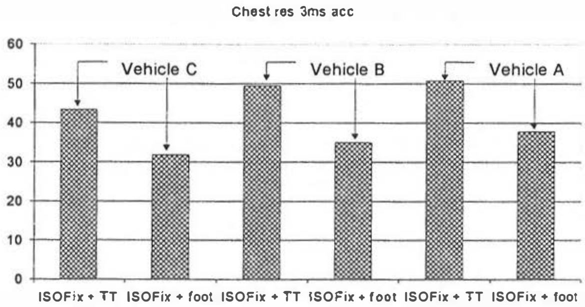


Figure 14 - Group 0+ rear facing infant carrier – 3ms chest resultant accelerations

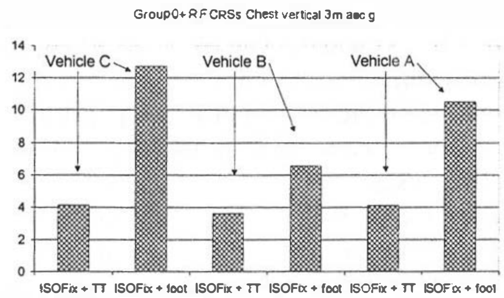


Figure 15 - Group 0+ rear facing infant carrier – compressive chest vertical 3ms acceleration.

DISCUSSION

Conventionally restrained CRS are often misused, and it is believed that the use of an ISOFix system will reduce this misuse.

Both the GDV and TRL results show that approval testing using the R44 test bench can be used reliably for the conventionally restrained CRS, as the R44 test bench gives the worst case conditions in comparison with tests on vehicle seats. This was not true for the ISOFix CRS. Also, the GDV results show that, where a car has been designed to work with an ISOFix CRS and the ISOFix CRS has been developed by testing in such cars, a forward facing CRS attached by 2 point ISOFix and the adult belt can give equivalent performance to conventionally restrained CRSs, except for head accelerations. However, it will be difficult to find a way to approve a 2 point system for use without the adult belt that is universal for all car seats, because it relies so much on the car seat characteristics. The results of the 2 point only attached rear facing seat were variable. The chest accelerations in the 2 point attached, rear facing seat were very different between the two vehicles, but the addition of a supporting foot clearly reduced this difference. This was due to the 2 point attached CRS's sensitivity to the car seat cushions.

The TRL tests, using vehicles for which specific vehicle type approval of ISOFix seats had not been sought, showed that ISOFix seats developed to produce good results on the R44 test bench could produce poor results when used in such vehicles. This is the situation that would occur with universal approval of ISOFix CRS, where the CRS would be developed and approved on the R44 test bench and only the anchorage position and strength would be assessed in the vehicle. The TRL results also showed that an additional anti-rotation device would remove the influence and variation caused by the different car seat characteristics, and would allow approval for a truly universal system. The supporting foot may be more difficult to approve as a universal system because it resulted in very high compressive chest vertical loading, although this could be reduced by incorporating a simple energy absorber in the support foot system. The top tether system reduced the influence of cushion on results without high chest vertical loading. Selection of the anti-rotational device should also take into consideration potential misuse and ease of educating users, along with consideration of harmonisation with the rest of the world.

CONCLUSIONS

1. Where vehicles and ISOFix CRS have been developed together, 2-point ISOFix CRS can give good performance and the R44 test bench is likely to give a worst case condition.

2. Where a 2-point ISOFix CRS design has been optimised on the R44 test bench and is then used in vehicles for which only the location and strength of the ISOFix anchorages have been assessed, the performance in vehicles can be very variable and worse than the R44 test bench.

3. Use of a supplementary anti-rotation device can remove the sensitivity to cushion characteristics and could be one method of providing universal approval for an ISOFix CRS.

REFERENCES

Aldman B, A Protective Seat for Children – Experiments with a Safety Seat for Children between One and Six, 8th Stapp car crash & field demonstration conference, 1964, Pages 320 - 328

Makinen J and N Feles, L P Garvey, The GM Child Love Seat, 17th Stapp Car Crash Conference, 1973, Pages 245 - 258

Paton I and A P Roy, M Le Claire, R W Lowne, Comparison of two-point ISOFix dynamic test performance on the ECE R44 test bench and car rear seats, IMechE Vehicle Safety 2000 conference, IMechE conference transactions 2000-2, 2000, Pages 297 - 311

Turbell T and R W Lowne, B Lundell, C **Tingvall**, ISOFix – A New Concept of Installing Child Restraints in cars, SAE International – Child Occupant Protection, SP-986, 1993, Pages 35 - 41