CHILD RESTRAINT PERFORMANCE IN SIDE IMPACTS WITH AND WITHOUT TOP TETHERS AND WITH AND WITHOUT RIGID ATTACHMENT (CANFIX)

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ABSTRACT

The need for improved side impact protection for child motor vehicle occupants is recognised internationally. This paper describes three separate test programs assessing the performance of Australian child restraint systems in side impact in terms of the head protection provided by the restraints.

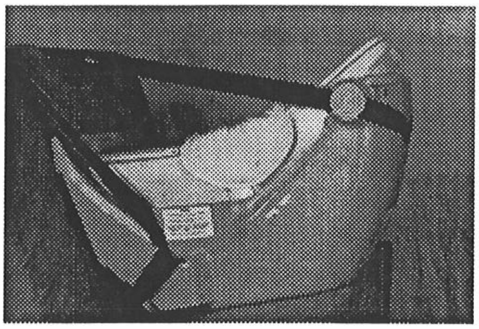
This work shows that:

- there is scope for the improved performance of the combination of top tether and adult seat belt in reducing the level of sideways movement in child restraints in side impact.
- the combination of top tether and adult seat belt can reduce forward movement in child restraints in oblique angle side impact.
- top tethers do not play a significant role in ensuring head retention within the child restraint in side impact.
- rigid attachment (CANFIX) significantly improves the performance of child restraints in side impact.
- six real world cases are also reviewed to illustrate deficiencies in existing child restraints in providing protection in side impact.

THE AUSTRALIAN STANDARD FOR CHILD RESTRAINT SYSTEMS requires that all child restraints be dynamically tested in front, rear, side and roll-over configurations. The dynamic test conditions for side impact simulation have been required since 1975. They involve a crash pulse of 32km/h and a deceleration of between 14g and 20g with the deceleration to remain above 14g for at least 20ms. The child restraints are mounted on a standard test seat which is fixed to the crash sled in a ninety degree (90°) (simulated side impact) orientation, Griffiths et al (1994). There is no requirement for including a simulated side door structure or intruding side structure. The test is therefore designed to assess the restraint's ability to hold the test dummy within the restraint during a side impact.

Australian consumer legislation requires that all child restraints on the Australian market comply to Australian Standard AS1754, Standards Australia (1991). In addition to the dynamic performance requirements, this Standard requires that all child restraints (except booster cushions) be supplied and therefore anchored to the vehicle using a top tether attachment and the existing adult belt system. The use of a top tether was adopted in Australia to restrict head movement in forward facing seats in frontal crashes. The use of a top tether was later found to improve the performance of Australia's first rearward facing infant restraints in side impact, Griffiths et al (1995). More recently, it has been shown that a top tether mounted high on the back of a forward facing child seat can significantly reduce neck forces in a dummy, in simulated frontal crashes, Brown et al (1995). However to the authors' knowledge the effect of a top tether on the performance of forward facing restraints in side impact has not been previously reported.

Figure 1: Seat belt/top tether anchorage system



In a year long study of approximately 200 children involved in crashes as motor vehicle occupants, conducted in New South Wales (NSW) in 1993 Henderson (1994) and Henderson et al (1994) reported that side impacts were now found to be the crash configuration most likely to result in significant injury. Thirty-four percent (34%) of children involved in side impacts sustained "moderate or greater injuries" compared to 23% of children involved in frontal impacts, Henderson (1994). This change is probably due to the original focus of development of child restraints for frontal impacts. The 1993 study also identified the head as the most important part of the body to be protected (in all impact types).

Improvements in the protection being offered to Australian children by child restraints in side impact is currently under review by the Roads and Traffic Authority of NSW (RTA). In particular, the need for increased head protection in side impact is being addressed through the development of improved draft test procedures for submission to the International Standards Organisation (ISO) and Standards Australia.

The need for improved child occupant side impact protection has also been recognised internationally. The ISO Committee has initiated a working group for the development of an international side impact test procedure for child restraint systems.

In addition to the need for improved side impact protection for children, the need to reduce the occurrence of misuse of child restraints has also been identified by Australian and International road safety professionals as an area requiring attention. Proposed countermeasures for more rigid attachment and for reducing the possibility of misuse are the ISOFIX and CANFIX concepts.

The ISOFIX concept, a rigid four point lower attachment system, is under development as a replacement for seat belts as a means of anchoring child restraints to motor vehicles. The alternative CANFIX system, which employs two rigid lower rear anchorages and a top tether, is particularly suited to the needs of Australia and Canada with their requirement for a top tether as compulsory equipment on child restraints and their complimentary motor vehicle design rules for child restraint anchorages (CRA's).

Pedder et al (1994) reported relatively low head excursion in frontal testing on a forward facing seat modified to the CANFIX system. Bell et al (1994) reported similar results for a forward facing seat incorporating the ISOFIX system. To the authors' knowledge no reports have been made regarding the performance of an ISOFIX or CANFIX derivative design in side impacts.

This paper describes three laboratory test programs aimed at assessing the performance of Australian child restraints in side impacts beyond the requirements of Australian Standard AS1754.

Finally six case studies of real world side impact crashes are reviewed to illustrate scope for improvement in current child occupant protection.

LABORATORY TEST PROGRAM METHODOLOGY

PROGRAM I TESTING As shown in Tables 1 & 2, Appendix A, (available from the authors', on request), a number of different makes and models of six point harness forward facing child seats and rearward facing infant restraints were evaluated in this test series.

Restraints produced for wider world markets without a top tether were also tested in this configuration (Tables 1 and 2, Appendix A).

All the devices were installed in accordance with the manufacturers' instructions, with the forward facing seats in the upright position. Each model of restraint was anchored in the left hand, rear seating position of a medium sized station wagon body shell, by an inertia reel lap sash (3 point) seat belt and top tether strap, as required. The original equipment top tether anchorage was located in the floor, immediately behind the seat and approximately 350mm in from the inner door panel. The vehicle body included the rear seat assembly, and the left hand side rear door, in which the glass was replaced with 6mm thick polycarbonate. The roof panel had also been removed to facilitate high speed cinematography.

The vehicle body was attached to a rebound sled and each restraint subjected to 45° and 90° simulated side impacts. The sled was calibrated in accordance with Australian Standard (AS) 3629.1, Standards Australia (1991) to produce a deceleration of between 14g and 20g and a ΔV of not less than 49km/h.

A new child restraint and adult seat belt was used in each test. To ensure standardised harness adjustment between each test, measured slack was introduced into the harness by placing a 25mm thick flexible pad between the back of the dummy and the child restraint. The harness system was adjusted tightly and then the pad removed.

An instrumented 6 months CRABI dummy was used throughout this program. This allowed the measurement of resultant head accelerations. Sign conventions, head acceleration co-ordinates and data filter classes were as specified in SAE J211, Society of Automotive Engineers (1988). The condition of the dummy was monitored after each test by visual inspection and instrument checks. Adjustments and maintenance were carried out as required.

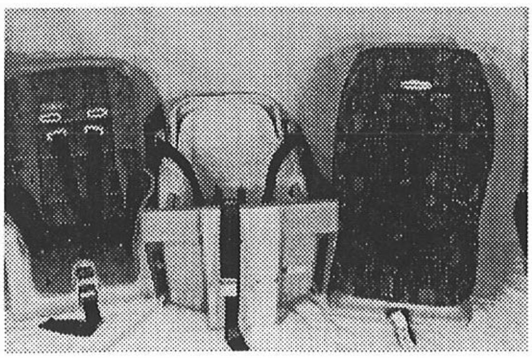
Two on-board high speed cameras were used to record the events. One was mounted over the rear door to photograph the infant restraints. The other was mounted on the vehicle floor pan in the position normally occupied by the front passenger's seat. This was used to film the tests on the forward facing seats.

PROGRAM II TESTING The performance of a range of rearward facing infant restraints, forward facing child seats and booster cushions was evaluated in this program, which was part of a more comprehensive evaluation of the dynamic test performance of child restraints on sale in Australia , Kelly, Griffiths (1995). The restraint systems tested are shown in Tables 3, 4 and 5, Appendix A. Some are also shown in Figure 2. The infant restraints and child seats were anchored to a standard test seat by a 3 point inertia reel lap/sash seat belt and top tether strap. The booster cushions were used in combination with a 3 point lap sash inertia reel seat belt.

The test seat, which is similar to the test seat in ECE44, Economic Commission for Europe (1981) was in accordance with AS 3629.1 with the addition of a simulated door structure positioned adjacent to the test seat on a rebound sled as shown in Figure 3.

For these tests, the top tether and seat belt anchorage geometries simulated those of a popular large Australian sedan. This placed the top tether anchorage

Figure 2: Child restraints involved in Program II Testing



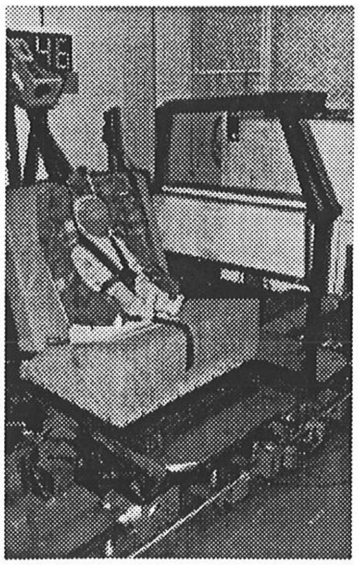


Figure 3: Test seat and simulated door structure

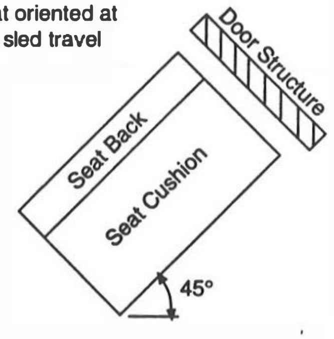


Figure 4: Test seat oriented at 45° to direction of sled travel

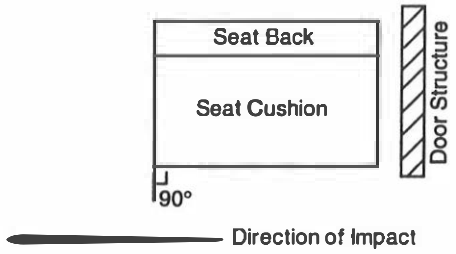


Figure 4a: Test seat oriented at 90° to direction of sled travel

approximately 95mm below and 350mm rearward of the top front edge of the seat back (Figure 4) and it was approximately 380mm inboard of the door skin.

The door which simulated the rear door of the same large family sedan comprised a light gauge steel tubing frame, a 6mm thick polycarbonate window and a half depth inner door skin manufactured from 0.7mm “Zinc Anneal” sheet (designated G2-ZF100). This material was developed by the Australian steel industry for this type of application.

Each restraint was subjected to simulated 45° and 90° side impacts (Figures 4 and 4a). The severity of the impacts was as described for Program I.

New child restraints and seat belts were used for each test. All the devices were installed on the test seat in accordance with the manufacturers' installation instructions, with the forward facing seats installed in the upright position. Harness adjustment was as earlier described for Program I.

The TNO P¾ dummy was used in the assessment of the infant restraints and forward facing seats, and the TNO P3, was used for the booster cushions. Instrumentation of both dummies allowed the measurement of head acceleration on three axes. As in Program I, the sign conventions, head acceleration co-ordinates and data filter classes were as specified in SAE J211. The same procedure was followed for maintaining the condition of the dummies as was followed during Program I.

One on board high speed camera was used to record the events. This was mounted over the back of the test seat to photograph head movement. A second camera recorded stationary side-on views of the impacts.

PROGRAM III TESTING As shown in Table 6 Appendix A, the performance of a forward facing, six point harness child seat and a rearward facing infant restraint were evaluated in this series of tests. For one test on each model of restraint, the restraint was anchored to a standard test seat by a 3 point inertia reel lap sash seat belt and top tether. A simulated CANFIX lower anchorage system was used for the other test on each restraint. The two modified restraints are shown in Figures 5 and 6 and the respective lower anchorage systems in Figures 5a and 6a. The test rig was the same as that described for Program II.

Each restraint was subjected to a simulated 90° side impact. The severity of the impacts was as described for Programs I and II. New child restraints and seat belts were used for each test and the manufacturer's installation instructions followed, where appropriate.The forward facing child seats were installed in the upright position.

The TNO $P^{3/4}$ dummy was used in these tests. Instrumentation of the dummy was the same as for Program II. Sign conventions, head acceleration coordinates and data filter classes were again as specified in SAE J211. The same procedure was followed for maintaining the condition of the dummy as was followed for Programs I and II.

Figure 5: CANFIX modified forward facing seat

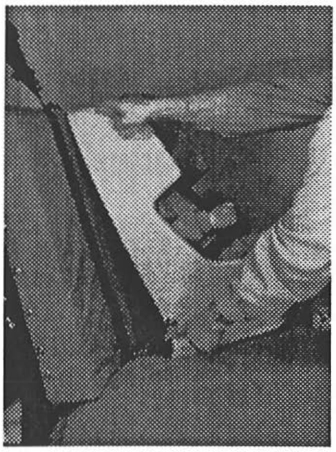


Figure 5a: CANFIX lower anchorage system - forward facing

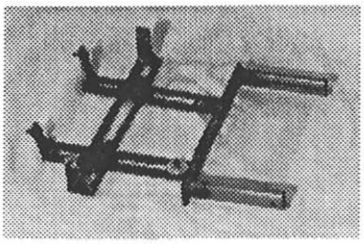


Figure 6: CANFIX modified rearward facing infant restraint

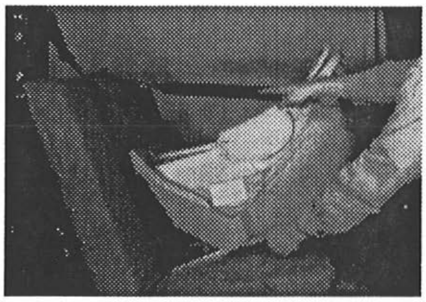
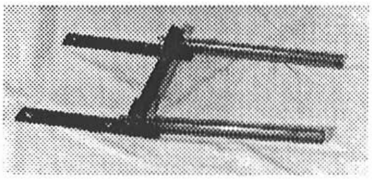


Figure 6a: CANFIX lower anchorage system - rearward facing infant restraint



SIDE IMPACT TEST METHODOLOGY

A side door structure was included in test methods of the work presented here, primarily to provide a means of assessing the ability of the restraint to retain the dummy's head and to manage crash energy. In the first program a real car body was used for this purpose. This was changed in the second and third programs to a simulated door structure, the inner skin of which was replaced between each run. A window structure was included in all three programs.

Crash energy management by the restraint systems was assessed using Head Injury Criteria (HIC) measurements. The limitation of using HIC to assess the head protection afforded in side impacts using less than ideal (in terms of biofidelity) child dummies is acknowledged by the authors. In this work HIC 36 has been used as a relative measure of the magnitude and duration of impact and is therefore being used as a comparative tool.

LABORATORY TEST RESULTS AND DISCUSSION

A full listing of the results obtained from the programs are given in Appendix B (Tables 7-17), which is available from the authors, on request.

The first program of tests was designed to study the effect of a top tether anchorage on the performance of rearward facing and forward facing child restraints in side impact. The 90° performance of these child restraints, in terms of HIC, are detailed in tables 18 and 19.

Table - 18: Test Results - Program 1 Infant Restraints 90° Tests

Restraint	Top Tether Y/N	Head Strike Y/N	HIC
Secure CS4	Y	Y	955
Century Shuttle	N	Y	1029
SNS Capsule	Y	N	1520
Century 1500A	Y	N	1682
Century Shuttle	Y	Y	1752
Secure CS4	N	Y	2211

Table - 19: Test Results - Program 1 Forward Facing Seats 90° Tests

Restraint	Top Tether Y/N	Head Strike Y/N	HIC
Secure CS4	N	N	201
SNS Series 3	Y	N	671
Secure CS4	Y	Y	1041
Secure CS4	N	Y	1382
SNS Series 3	Y	N	1490
Century 1500A	N	N	1717
Century 1500A	Y	N	1717

It can be seen from Table 18 that two of the four infant restraints, both with and without top tether, allowed the test dummy's head to contact the door structure. Table 19 shows a similar result for one of the forward facing child restraints. The Secure CS4 can be seen to have allowed a head strike both as a rearward facing infant restraint and a forward facing child seat. The Century Shuttle, one of the infant restraints which allowed a head strike to occur here, also allowed a head strike to occur when tested at 45°, using a top tether.

Thus, it would appear that a top tether does not provide a readily measurable benefit in terms of head retention, and that the ability of a child restraint to retain the occupant's head in side impacts is more a function of the design of the child restraint.

All of the restraints which prevented a strike were designed with relatively high sidewings adjacent to the dummy's head. However, sidewings in infant restraints can make it difficult to place infants in these restraints and to take them out. Deep sidewings also restrict sideways vision for the occupants of forward facing seats.

Deep sidewings were not present on those restraints which permitted head contact with the door structure in the first series of tests. Thus, the fact that the dummy's head was allowed to escape from these restraints suggests that design philosophy is being compromised in favour of user convenience. It follows that a priority of child restraint design should be that it minimises the risk of head contact with the vehicle interior, in side impact.

Although a number of restraints had sidewings which prevented head contact with the door structure, none had a substantial amount of energy attenuating material in their sidewings to control side impact energy. Hence, with head retention achieved, the next objective is to further increase head protection by providing energy absorbing material in the sidewings.

The need to pay greater attention to this area of crash performance is illustrated by the magnitudes of the HIC values produced in a large number of the Program II 90° tests in which the dummy's head did not contact the door structure. That is, the dummy's head was confined to the child restraint.

The HIC values from these tests are shown in Tables 20 and 21. Similar HIC values were recorded in two of the Program I 90° tests, in which the dummy's head did not contact the door structure (Tables 18 and 19). The child restraint contacted the door in every test in both series of tests.

Table - 20: HIC Values
Program II Infant Restraints
90° Tests

Restraint	HIC
Aprica	812
SNS Capsule	903
Secure CS4	938
Century 1500C	1184
Century Maxi 2500	1241
Klippan Two-Way	1258
SNS Galaxy	1828

Table - 21: HIC Values
Program II Forward Facing Seats
90° Tests

Restraint	HIC
SNS Series 3	762
Aprica	924
Galaxy	952
Century 1200C	1205
Century Maxi 2500	1257
SNS Eclipse	1292
Century 1500C	1405
Klippan Two-Way	1721
Klippan Recliner	1992

It can be seen that the HIC values produced in the Program I rearward facing infant restraint tests were generally higher than those produced in the Program II infant restraint tests. The stiffness characteristics of the door appears to be a factor in the higher HIC values produced in the Program I tests.

A similar comparison for the forward facing seats shows that apart from the inexplicably low HIC value (201) produced by the "Secure" restraint in the Program I tests, the HIC values from the two Programs are generally of the same order.

A large number of the HIC values in Programs I and II suggest significant head impact. This and the absence of significant levels of energy attenuating material in the sidewings of child restraints suggests that energy attenuation in side impact is not a high priority for child restraint manufacturers.

Illustrations of the authors' concern about the apparent lack of attention to side impact protection in child restraints are in the two highest HIC values (1721 and 1992) produced in the Program II forward facing seat 90° tests, (Table 21).

The two restraints, from the same manufacturer, are very similar in design and construction. The major difference between the two is that one is a dedicated forward facing child seat and the other a convertible, to be used rearward facing for infants and forward facing for older children. This restraint also produced the second highest HIC (1258) in the corresponding tests on infant restraints, (Table 20).

Both restraints comprise a moulded plastic bucket supported on a metal frame. Unlike most other child restraints, the plastic bucket does not present a flat surface to the occupants head, in side impact. Instead the inner surfaces of the sidewings are a complex of moulded shapes which would appear to add considerable stiffness to the sidewings. Metal components attached to the outside surfaces of the sidewings may have also contributed to the higher HIC values.

Table 22 shows the HIC values, from the first program of 45° tests on the rearward facing infant restraints which prevented head contact with the door structure. It can be seen that the HIC values produced by the two untethered restraints were considerably higher than the HIC values produced by two of the three tethered restraints. It is believed that the higher HIC values recorded by the untethered restraints were the result of the restraints being allowed to move further forward and to contact the more rigid part of the door structure near the "B" pillar.

Table - 22: Program I Infant Restraints HIC Values - 45° Tests

Restraint	Top Tether Y/N	HIC
SNS Capsule	Y	187
SNS Capsule	Y	348
Century Shuttle	N	724
Secure CS4	Y	779
Secure CS4	N	827

The second program of 45° tests (on tethered rearward facing restraints) produced relatively low HIC values which were generally of the order of the lower HIC values recorded in the corresponding Program I tests.

The outcomes here suggest that top tethers have scope to be of some benefit in reducing forward movement in rearward facing infant restraints in oblique angle side impact.

Head contact with the door structure was recorded in all of 45° tests involving the forward facing seats. Although the two untethered restraints in the first series of tests produced lower HIC values than their tethered counterparts in the first and second series of tests, it was found that the top tether generally limited the dummy's forward movement. Thus, head contact with the door structure was generally confined to a section of the inner door panel just forward of the mid point along the panel. In the case of the untethered restraints, the head strikes occurred further forward on the door. This may account for the lower HIC values recorded in these tests. More importantly, the results again indicate the potential for top tethers to limit forward excursion in oblique angle side impacts. By limiting the forward excursion there is less risk of contact with the vehicle interior and reduced exposure to intrusion.

Replacing the adult seat belt with a rigid lower anchorage system (simulated CANFIX) for two of the tests in the third test program, significantly reduced sideways movement of the child restraints. Contact between the child restraints and the door structure was avoided and as a consequence the HIC values (Tables 23 and 24) for these two tests were significantly lower than those produced in the two tests in which the combination of adult seat belt and top tether was used.

Table - 23: Program III Infant Restraint HIC Values

Restraint	Anchorage System	HIC
SNS Capsule	CANFIX	123
SNS Capsule	Lap Sash Seat Belt + Top Tether	812

Table - 24: Program III Forward Facing Child Seat HIC Values

Restraint	Anchorage System	HIC
SNS Series 3	CANFIX	256
SNS Series 3	Lap Sash Seat Belt + Top Tether	1086

The results show the scope for improvement in the current methods of child restraint attachment, in terms of controlling lateral movement.

The Program II booster cushion HIC values are shown in Table 25.

Not one of the boosters tested in this program was able to prevent the dummy's head contacting the door structure.

Five of the boosters have integrated backs and head height sidewings, with which the dummy's head made initial contact. It can be seen from Table 25 that the HIC values for these boosters were significantly lower than those produced by their backless counterparts. There was also a large difference between the best performing and poorest performing boosters with sidewings, in terms of HIC.

Table - 25: Booster Cushion HIC Values - 90° Tests

Restraint	Back and Sidewings Y/N	HIC
Klippan Easy Rider	Y	704
SNS Cruiser	Y	909
Caresse (6624)	Y	1090
SNS Travel Safe	Y	1351
Kiddy Safe (6625)	Y	1445
Klippan Optima*	N	3418
SNS Hi-Rider*	N	3636
SNS Comet*	N	4939

* These boosters do not have backs or sides.

These results clearly show the need for well designed sidewings in all child restraints, not just child seats and infant restraints.

The results also show clearly that backless boosters offer no real crash protection in side impact and that the sidewings in the present generation of Australian boosters are not as effective as the sidewings in some Australian forward facing child seats and rearward facing infant restraints, in terms of head retention.

Having regard to the good results from the third test program, using the simulated CANFIX arrangement, it would seem likely that booster cushion performance could also be enhanced by rigid attachment.

FIELD CASE REVIEW AND DISCUSSION

A number of field cases (Table 26) were selected to illustrate the performance of Australian child restraints in side impact. These cases were selected from the RTA's Vehicle and Equipment Safety Section's file of adhoc crash investigations. The cases presented here were chosen as evidence that observations made in the laboratory test programs presented in this paper also occurred in real crashes. These cases are, however, not necessarily representative of the total population of crashes involving children in Australia in side impacts.

REARWARD-FACING RESTRAINTS All cases involving rearward facing restraints presented here involve the Safe-N-Sound infant capsule. No case studies conducted by the RTA to data have involved any other type of rearward facing restraint. This is because until recently this was the only rearward facing restraint available. It is expected that other types of rearward facing restraints now available on the Australian market will start to appear in case studies in the future.

In most instances the rearward facing infant capsule has been observed to perform well in side impacts in the real world. Head retention is obtained in most instances with this restraint in crash sled tests. The cases presented here illustrate that severe head injury is observed in these restraints in cases where ejection (through improper use) or massive intrusion plays a significant role. In the intruding cases, the head is retained within the restraint but the intruding vehicle "pushes" the restraint into the child's head.

FORWARD-FACING RESTRAINTS Head retention in forward-facing restraints is a significant problem. In the real world cases presented here, one involved massive intrusion (with the child seated in the centre rear) and one involved less significant intrusion (with the child seated in the struck outboard position). In both instances, the child's head was allowed to contact the vehicle interior. It should be noted that the impact direction in both these case involves more of a 45° than a 90° impact and therefore a forward component to the child's movement. Retaining the head in the 45° configuration appears to be extremely difficult

BOOSTER CUSHIONS Head retention in booster cushions is again also a significant problem. However in the case of booster cushions it appears that even in the more straight forward 90° impact, without significant intrusion, no effective head restraint is available. The case presented here illustrates this clearly.

The real world cases presented here, illustrate how the inability of Australian child restraints to retain the head, and the lack of energy absorbing material, may result in serious injury.

The cases involving the rearward-facing infant capsule have shown that it retains the test dummy's head in laboratory tests. This illustrates the potential of introducing energy absorbing features, once head retention has been achieved.

In the forward-facing restraints, one device retained the head, but absorbed no energy, while the others were not able to retain the head.

Although the cases here are not necessarily representative of all side impacts involving children, it is useful to note that intrusion may be a greater factor in the cases where serious/fatal head injury occurs in devices where the head is retained. Less significant intrusion can result in serious/fatal head injury when the head is allowed to contact the vehicle interior directly.

The last field case presented here is an unfortunate but clear example of this phenomenon. In this case the head of a child restrained in a booster cushion in an outboard seat position in a side impact was allowed to come into direct contact with the opposing vehicle through an open window. This accident was a very survivable accident (no other occupant sustained any significant injury). The authors believe that had the head been retained within the restraint system, this child would have avoided serious injury.

Table 26: Side Impact Field Cases

Case	Direction of Impact	PPOF ΔV	Seating Position	Child Restraint	Intrusion	Child Restrained	Head Retained	Injuries	Contact Sources	Child Sex & Age	Other
VES 107	03	50	RR	SNS Capsule 02000 + BB	Not Significant	No	N/A	Fatal	-	4 months Female	Crash involved fair degree of rotation post crash
		50	CR (3rd)	Harness	Not Significant	Yes	N/A	Soft Tissue	UNKN	3 years	Child ejected through window
VES 201	9	42km	CR	SNS Capsule & Harness BB	Significant -Massive	Yes	Yes	Head Brain Hemm	Child Restraint	2 months	Intruding vehicle contacting CR and pushing CR onto head and MH
VES 105	8	40	LR	SNS Capsule +BB	Significant -Massive	Yes	No	Head Brain Hemm	Child Restraint	1 month male	
			CR	SNS Series III	-	Yes	No	LCN to head closed heading	Poss RODF Poss other restraint	3 years	
VES 106	10	25	CR	Century 1200	Medium	Yes	No	Fatal Severe Head Injuries	Side door structure	19 months	
VES 202	9	Not estimated	RR	Soft Booster	Not Significant	Yes	No	Severe Fatal Head	Direct contact with other vehicle	5 years	Head allowed to move out of window and contact other vehicle

COMMENTS ON ISOFIX DRAFT

There is a significant difference between side impact test methodology used here and that proposed in the draft ISO side impact test requirement. Most notable are the:

- ISO 30g sled deceleration requirement, as opposed to the 16g peak acceleration used here;
- ISO requirement for an intruding structure, as opposed to the non-intruding structure used here;
- ISO requirement for the height of the intruding structure to correspond in height to a representative door sill height, as opposed to the full height (closed window) simulated door structure used here.

In view of the magnitude of the resultant head accelerations and HIC values produced in the 32 km/h, 16g tests represented here, the proposed ISO 30g requirement with an intruding door structure is likely to assess restraint performance under the more demanding of side impact crashes.

There is a risk that in restricting the height of the intruding structure, as proposed in the ISO document, that poor child restraint performance will not be detected. It may well be that child restraints can be engineered to pass the test, by allowing the test dummy's head to pass over the top of the intruding structure (ie through the open window). The work reported here clearly illustrates the need to ensure containment of the occupant's head within the device under the widest possible range of crash configurations. It is important then that as well as attempting to detect contact with the lower door structure and its effect, the test should also attempt to detect head excursion beyond the confines of the device.

CONCLUSIONS

It is clear from the work reported here that:

- the conventional methods of restraining child restraints in motor vehicles with either an adult seat belt or a seat belt in combination with a top tether have scope for improvement in controlling lateral movement of the child restraint, in side impact
- the CANFIX arrangement of a rigid lower rear anchorage system and a top tether can significantly reduce sideways movements and hence the risk of injury through a collision between the child restraint and the motor vehicle side structure. Existing child restraint designs might be easily modified to bring them CANFIX specification.
- The scope for improvement in side impact protection, is the addition of features to restrain the head and absorb energy. Poor performance in some instances may result from a design philosophy which heavily compromises crash protection in favour of user convenience.

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