INTERACTIONS OF REAR FACING CHILD RESTRAINTS WITH THE VEHICLE INTERIOR DURING FRONTAL CRASH TESTS

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ABSTRACT

Transport Canada (TC) began in-vehicle crash testing of rear facing infant seats in 2007, as part of a large on-going comprehensive research program aimed at evaluating crashworthiness protection for child occupants of motor vehicles.

A recent study sponsored by the National Center for Statistics and Analysis and the National Highway Traffic Safety Administration in the United States (May 2010) found that, among children involved in motor vehicle crashes, infants had a greater frequency of head injuries than older children up to seven years of age.

The sample included 131 child restraints evaluated in 85 motor vehicle crash tests. Of the 131 crash tests, 126 were rigid barrier tests of which: 108 were conducted at 48km/h; 11 were conducted at 56 km/h; and seven were conducted at 40 km/h. Five offset deformable barrier tests, conducted at 40 km/h, were included in the sample. The majority or 117 tests involved rear facing infant seats; the remaining 14 tests were carried out with convertible seats installed facing the rear.

Elevated head accelerations above 80g were observed in 18% tests with a significant number occurring in the rear center seating position. Elevated head accelerations were found to result from four principal categories of impacts: direct head contact with the seat back in front of the dummy; contact between the child restraint and the forward seat back; dummy head contact with the child seat carry handle; and child seat with the center console located between the front seats.

The seat and dummy kinematics and the head accelerations are described for each impact type. Implications for future child restraint regulations are discussed.

INTRODUCTION

During the course of the infant seat testing initiated in 2007, certain interactions between the infant seat and the vehicle interior were observed to result in elevated head responses of the infant size dummy. In this present study, data from rear facing infant seat crash testing conducted up to 2009 are combined with new data obtained during the 2010 test program to further investigate infant seat interactions with the vehicle interior and to evaluate the head protection provided by rear facing infant seats meeting the current regulatory requirements of CMVSS 213.

Canadian accident databases do not contain the necessary information to estimate the frequency of head injury for Canadian infants involved in motor vehicle crashes. However, a recent study sponsored by the National Center for Statistics and Analysis and the National Highway Traffic Safety Administration in the United States (May 2010), cited head injuries as being the most common injury type for children involved in motor vehicle crashes. Specifically, the study, found that infants under one year of age had a greater incidence of head injury than older children aged one to seven. Considering that the lifetime financial costs for the treatment of head injuries in the United States have been estimated to range from $600,000 to $1.8 million, the head protection of children travelling in motor vehicles should be an important crashworthiness research priority.

This present study was conducted to investigate the interaction of rear facing child seats with the interior of motor vehicles, undergoing full frontal and offset barrier crash tests; and to investigate the effect that these interactions have on the head responses of infant crash test dummies restrained in the child restraints. The results of the study are intended to provide scientifically based evidence to guide: future regulatory direction; optimized designs of child restraints and the development of recommendations for the installation of rear facing child restraints in motor vehicles.

CURRENT REGULATORY REQUIREMENTS

The Canadian Motor Vehicle Safety Standard CMVSS 213.1 requires that infant seats have a continuous seat back that will support the rear of the child's head. The surfaces that may contact the head must be covered with compressible foam material which is required to meet a prescribed compression-deflection resistance.

To be certified for use in Canada, infant seats must undergo a dynamic test on an acceleration or deceleration sled. The seats are secured to a test bench, and subjected to a change in speed of at least 48km/h achieved within the limits of an acceleration corridor. Infant and infant/child seat seats installed in the rear facing configuration must not exceed a specified recline angle during the acceleration test.

The head of the crash test dummy restrained in the seat must respect excursion and head acceleration thresholds but there is no opportunity to evaluate the consequences of an impact. Neither the CMVSS 213.1 nor the equivalent FMVSS 213 test fixture includes any structure that simulates a front row seat back or center console.

METHODOLOGY

The infant seats were installed in the rear seats of 82 vehicles undergoing full frontal rigid barrier (FFRB) crash tests at 40, 48 or 56 km/h or offset deformable barrier (ODB) tests at 40 km/h.

Motor vehicles were purchased from Canadian dealerships and prepared in accordance with CMVSS 208 or FMVSS 208 “Occupant Restraint Systems in Frontal Impact”. Vehicle distribution by model year and type is presented in Table 1.

Table 1.
Distribution of test vehicles by model year and type.

Model Year	Passenger	SUV	Minivan	Total
2005	1			1
2006	1			1
2007	9	2	2	13
2008	9	6	1	16
2009	9	13	4(1)[1]	27
2010	19	4	1	24
Total	48	25	9	82

[1] Includes one 15-passenger van.

The international standards organization (ISO) nomenclature for seat location in a motor vehicle is used in this report. The numbers 14 through 19 refer to the following seat locations in the test vehicle:

14. Second row seat behind the driver
15. Second row middle seat
16. Second row seat behind the passenger
17. Third row seat behind the driver
18. Third row middle seat
19. Third row seat behind the passenger

Child Seat Selection & Installation

Child restraints were purchased from Canadian retailers. In certain limited cases, the child restraints were obtained directly from the manufacturer. The sample included 26 models produced by 13 different manufacturers. The child seats were installed following the instructions provided in the owner’s manual for the individual child seats. The distribution of infant and infant/child seats by location in the vehicle and installation method is shown in Table 2.

Table 2.
Distribution of infant and infant/child seats by seat location and attachment method.

Seat location	Rear facing infant			Infant/child CRS		Total
	No-Base	Base				
	Seat belt	Seat belt	UAS	Seat belt	UAS	
14	6	24	11	2	2	**45**
15	6	15	1	2		**24**
16	7	31	8	3	2	**51**
17		1	2			**3**
18			1	1		**2**
19		4		1	1	**6**
Total	**19**	**75**	**23**	**9**	**5**	**131**

The majority of tests (n=99) were installed with the accompanying base; 15 tests were carried out without the base; and 13 tests were carried out with an infant/ child restraint installed in a rear facing configuration.
The bases were attached either with the vehicle seat belt or with the lower anchors also called the universal anchorage system (UAS). In all cases the seat bases were attached very tightly to the car seat to reduce the amount of sideways movement. The bases were installed level to ground. The angle of installation was verified with an inclinometer at the time of installation and confirmed again immediately prior to the launch of the test vehicle. Infant/child restraints were secured with either the UAS or the vehicle seat belt, respecting the angle of inclination where possible, given the space limitations of the test vehicle.

For the majority of the tests, the driver and front passenger seats were placed in the foremost track position, leaving a space between the front seatback and the infant seat. In other tests, the driver and front passenger seats were placed either in the mid-track or rearmost position leaving less clearance between the infant seat and the front seatback. In some tests, the position of the carry handle differed from the manufacturer’s recommended location due to space limitations or to investigate the influence of handle position on infant seat and dummy kinematics.

Instrumentation

Tri-axial accelerometers were installed at the approximate center of gravity of the vehicle and at the base of each B-pillar. Two 12-month CRABI infant crash test dummies were used in the test series and instrumented with accelerometers in the head, chest and pelvis. One Q series dummy representing a 3-year-old child was used in one test of a rear facing infant/child seat child restraint. The processing of the data was carried out following the protocols established by the Society of Automotive Engineers (SAE J-211).

High-speed videos were used to record the crash event and the movement of the infant seat at a rate of 1000 frames/second. The rear passenger car doors were removed and replaced with beams in order to obtain a complete camera view of the infant seat during the crash test. An additional camera was installed in the roof of the test vehicle to obtain a front view of the infant seat(s) and crash test dummies.

RESULTS

The sample included 131 child restraints evaluated in 82 motor vehicle crash tests. Of the 131 crash tests, 126 were rigid barrier tests of which: 108 were conducted at 48km/h; 11 were conducted at 56 km/h; and seven were conducted at 40 km/h, and five were offset deformable barrier tests conducted at 40 km/h.

Table 3.
Incidence of elevated peak resultant head acceleration (>80g) by seat type, attachment and seating location

Location	Rear facing infant			Infant/child CRS		Total
	No-Base	Base				
	Seat belt	Seat belt	UAS	Seat belt	UAS	
14 / 16	0/13	8/55 14.5%	0/19	1/5[1] 20%	2/4 50%	11/96 11.5%
15	1/6 16.7%	9/15[2] 60.0%	0/1	0/2	0/0	10/24 41.7%
17 / 18 /19	0/0	1/5[3] 20.0%	1/3 33.3%	1/2[4] 50%	0/1	3/11 27.3%
Total	1/19 5.3%	18/75 24.0%	1/23 4.3%	2/9 22.2%	2/5 40.0%	24/131 18.3%

[1] peak 80g, clip 76g; [2]peak 88g, clip 76g; [3]peak 80g, clip 74g; [4] peak 83g, clip 77g;

Seat position was significantly correlated to elevated peak resultant head accelerations of 80g or more (Chi-square p=0.0021, Exact Pearson Chi-square p=0.0024). Table 3 identifies the incidence of tests where the peak head acceleration was 80g or greater as a function of seat installation, seat type and seat location in the vehicle. In all but four tests, identified in the table by footnotes, the corresponding 3ms head acceleration clip was 80g or greater. There was no incidence of elevated head accelerations in any of the five ODB tests.

One test in a vehicle undergoing a 56km/h barrier test resulted in a 3ms head acceleration clip of 84g without any contact with the interior of the vehicle. The infant seat was installed with its base behind the driver and secured with the seat belt. Review of the high speed video confirmed that the peak head acceleration occurred during the forward excursion of the seat. The infant seat did not contact the driver seat and the forward rotational motion was uninterrupted. The elevated head acceleration which was accompanied by a continuous neck tension was therefore deemed to be caused by inertial loading only. Since this study was conducted to investigate child seat interaction with the vehicle interior, this test was excluded from further analysis.

All of the cases with elevated head accelerations, included in Table 3, involved four types of interaction or contact with the vehicle interior:

1. Direct head contact with the seatback located forward of the infant seat (n=5);
2. Direct head contact with the carry handle of the infant seat (n=2);
3. Contact of the child seat with the seatback located forward of the infant seat (n=7);
4. Contact of the infant seat with the center console (n=10).

Detailed results are presented as a function of these four types of interactions.

Direct head contact with the seatback

There were 35 instances where the top of the dummy head contacted the seatback of the driver or front passenger seat, of these, 5 were severe enough to result in elevated head accelerations. All five of these infant seats were installed with the bases and secured with the seat belt. Three test vehicles had plastic trim panels covering portions of the driver and front passenger seat backs, the two others were covered with upholstery. Examples of the head contact recorded during the crash are shown in Figure 1. The test shown on the top was carried out at 56 km/h while the test shown on the bottom was conducted at 48 km/h. In this test, only the dummy seated behind the driver seat had head contact with the seat back trim. The scuff mark on the seat trim of the passenger seat, seen just above the dummy head in the bottom image was caused by infant seat contact.

Figure 1. Examples of head contact with driver seat back in two crash tests.

One of the five tests described above was an Eddie Bauer SureFit installed behind the driver seat of a Kia Berrego. The driver seat in this particular test was placed in the foremost seat track leaving some clearance between the infant seat and the driver seat back (Figure 2a). As can be seen in the freeze frame recorded during the test and shown in Figure 2b, the top of the dummy head contacted the plastic trim. The resulting peak head acceleration was 111g. Figure 2c shows the same installation repeated in an identical Kia Berrego, tested at the same speed but with the driver seat positioned further rearward, to eliminate the clearance. In this test no head contact with the driver seat back was observed. The freeze frame in Figure 2d confirms that the upper edge of the infant seat remained just above the dummy head. The head acceleration in this case was lower, attaining a peak resultant value of 74g.

The Eddie Bauer SureFit was also tested behind the driver seat of a Honda Pilot undergoing a 48km/h rigid barrier test. In this test the infant seat was touching the driver seat prior to the test and the dummy head did not contact the driver seat back.

a) Pre-test: clearance with driver seat

b) Head contact with driver seat during crash

c) Pre-test: no clearance with driver seat

d) No head contact with driver seat

Figure 2. Observed effect of seat clearance on head contact with the front seat in paired tests.

Direct Head Contact with the Carry Handle

There were seven occurrences of head contact with the carry handle. In all seven tests the top of the infant dummy head was observed to contact the handle following interaction between the carry handle and the front seat back during forward excursion. In one case, head contact with the carry handle resulted in an elevated head acceleration 3ms clip of 100g. One case had a peak acceleration of 88g with a 3ms clip of 76g.

Figure 3 illustrates these two cases where handle contact was observed. Both tests were carried out at 48km/h. The photo 3a is a freeze frame from the test where handle contact resulted in a 3ms head acceleration clip of 100g while the photo 3b on the bottom is from the test where handle contact resulted in the 76g acceleration clip. In both cases the contact between the head of the dummy and the handle occurred as a result of interaction with the front passenger seat back.

a) **Head contact with handle (head clip >80g)**

b) **Head contact with handle (head clip 76g)**

Figure 3. Video images of two infant seats where the dummy head contacted the carry handle.

Head contact with the carry handle was not observed in vehicles where there was no interaction between the handle and the seat back. This was observed in the test described above and shown in Figure 3a that resulted in the elevated head acceleration clip (100g). In this test, an identical infant seat was installed behind the driver seat and secured with the UAS. Both the driver and right front passenger seat were placed at the same seat track location. During the crash, there was no interaction between this seat and the driver seat back and no contact between the head of the dummy and the carry handle. The infant seat secured with the UAS, behind the driver seat had significantly less forward excursion the seat installed with the seat belt of the vehicle.

Contact of the infant seat with the seatback

Of the 107 infant/child seats installed behind a front or second row seat, 37 contacted the seat back during forward excursion. Of these 37 tests, four were severe enough to result in a 3ms head acceleration clip that was greater than 80g. There were three borderline cases, where seat back contact resulted in a peak resultant head acceleration of 80g or more but where the 3ms clip was between 74 and 80g. These cases included three rear facing infant seats and four infant/ child restraints. One of these infant/ child restraints was occupied by a dummy that was representative (in size) of a 3 year-old child (the only one in the test series). The peak resultant head acceleration results and corresponding 3ms clips are presented Appendix A, Table 1 as a function of test vehicle, test speed, seat type, attachment method and vehicle seat location.

These seven tests involved child/infant seat kinematics where the back of the child restraint, behind the dummy head, impacted the seat back. Seat back contacts that involved only the upper edge or rim of the child/infant restraint were generally glancing blows that resulted in lower head accelerations.

Child restraints that were installed in the third row behind a second row bench seat (positions 17/18/19), were associated with higher head accelerations more frequently than restraints installed behind the driver or right front passenger seats: 3/11 tests (27%) for third row seats compared to 5/96 tests (5%) for child restraints installed in the second row. It is not known whether this was due to the spacing variations between the seat rows or to the more rigid seat frames typically found in second row seats.

Freeze frames obtained from the crash videos are shown in Figure 4 to illustrate the different types of interactions that were observed during testing. In Figure 4a only the top edge of the infant seat, shown in the foreground, contacts the driver seat. The peak resultant head acceleration in this test was 55g compared to 119g for the dummy in the infant/ child restraint, shown in the background of the same image. In this latter case, the back of the infant/ child restraint strikes the right front passenger seat, resulting in an impact to the back of the dummy head.

Figure 4b is an example of an infant seat contacting the upper edge of a second row bench seat. This contact resulted in a peak resultant head acceleration of 110g and a 3ms clip of 97g. Though contact with the handle was also observed this was not a significant contributor to the head response in this instance.

a) **Contact with front passenger seat**

b) **Contact with second row bench seat**

Figure 4. Freeze frame images of child seat contact at impact.

Differences in child seats may influence the nature of the contact as well as the severity of the dummy head response in cases of contact. Table 4 presents the results of two paired comparisons conducted side by side, each pair in the same test vehicle. The vehicle seats located ahead of the restraints were identically placed, and the attachment methods for the child restraints were the same. Only the seat model differed.

Differences in the shape of the shell could influence the nature of the contact while the presence or absence of deformable energy absorbing material affected the head acceleration responses of the dummies. In the KIA Magentis test, the Safety 1st Intera 4 in 1 had a taller profile than the Britax Marathon. Where the top edge of Britax Marathon glanced off the driver seat back, as shown in the the top image of Figure 4, the Safety 1st struck the front passenger seat back full-on.

The infant dummy, occupying the Safety 1st child/infant seat, recorded a peak resultant head acceleration of 119g. This seat had no energy absorbing material lining the shell. The Britax seat installed in the adjacent seat location of the same test vehicle had energy absorbing material lining the head rest. The peak head acceleration recorded in this dummy was 55g.

Table 4.
Results of paired comparisons of CRS designs

Test	CRS	Location & Attach. Method	Peak R. Head Accel. (3ms clip)
Kia Magentis 47.8 km/h	**Safety 1st Intera 4 in 1** *No energy absorbing foam*	16 Latch	119g (109)
	Britax Marathon *Energy absorbing foam*	14 Latch	55g
FORD E350 40.7 km/h	**Cosco Scenera** *No energy absorbing foam*	18 Seat belt	83g (77)
	Evenflo Titan *Energy absorbing foam*	19 Seat belt	49g

In the Ford E350 15 passenger van, the two child restraints were installed side by side on the third row bench seat. The Cosco Scenera tipped forward striking a region just below the upper edge of the bench while the Evenflo Titan translated forward and struck the second row seat back in an upright orientation. Differences in the child seat bases and interface with the vehicle seat cushion motion likely contributed to the differences in kinematics.

The infant dummy placed in the Cosco seat installed in the third row inboard position (18) recorded a peak head resultant acceleration of 83g while the infant dummy seated in the Evenflo, in the adjacent seat position, recorded a peak resultant head acceleration of 49g. Figure 5 illustrates the differences in interior construction of the Cosco and Evenflo seats.

The plastic shell of the Cosco is not lined with any energy absorbing material while the Evenflo is lined with a layer of energy absorbing material or polystyrene foam. The second or top layer shown in the photo with the test number label attached is soft compressible foam likely intended to provide comfort to the child.

a) The Cosco Scerena contains no energy absorbing liner

b) The Evenflo seat contains energy absorbing liner (white)

Figure 5. Comparison of interior construction of two child restraint seat models.

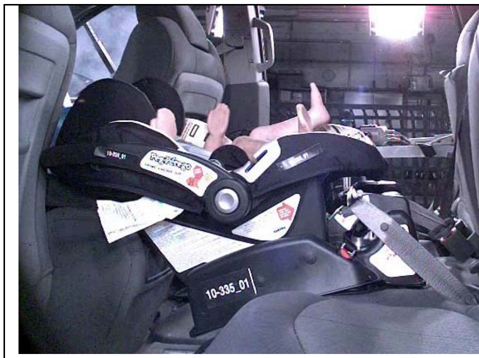
Contact of the Infant Seat with the Center Console

Elevated dummy head accelerations were observed in 10 of the 24 tests conducted with the infant seat installed in the center seating position of the second row (location 15). The elevated head accelerations were the result of interaction between the back of the infant seat and the center console and involved infant seats that had been secured with the seat belt of the vehicle.

Interaction with the center console leading to elevated head responses could be influenced by numerous factors including but not limited to: the physical dimensions of the console; the extent to which the console extended into the rear passenger compartment; the amount of forward excursion (of the infant seat); the placement of the front seats; the rigidity of the inboard aspect of the front seats; the dimensions of the infant seat and the position of the carry handle.

Contact with the center console was observed in small and large vehicles and at crash speeds as low as 40km/h. It was not possible to predict possible console interaction during installation of the infant seats as the motion of the infant seat during the impact combined with the influence of the factors noted above could not be anticipated.

A contact with the console that results in elevated head accelerations is best described as a blow to the back of the infant seat. Interactions that involved contact between the base of the infant seat or the carry handle did not result in elevated head accelerations. Examples of the strikes that were recorded during the crash tests are presented in the images shown in Figure 6.



a) Peak head resultant acceleration 117g

Chevrolet Traverse 48 km/h FFRB

Installed with base

b) Peak head resultant acceleration 77g

VW Passat 48 km/h FFRB

Installed with base

c) Peak head resultant acceleration 93g

VW Passat 48 km/h FFRB

Installed without base

Figure 6. Examples of infant seat strikes into the center console.

In all cases, as shown in Figure 6, forward excursion of the infant seat was great enough to cause a significant portion of the infant restraint to slide off the front edge of the vehicle seat.

The infant seats shown in figure 6b and c are examples of two different infant seats installed in the same vehicle model, and tested at the same crash severity. In Figure 6b the front seats were placed in the foremost seat track position while in 6c the front seats were placed further rearward in the mid-track position. Even though the seat placement in 6c reduced the amount of console exposure in the rear seat compartment, head accelerations were more elevated for the infant seat shown in 6c. Comparison of the seat designs for these two infant seats suggests that the presence of energy absorbing material may have influenced the amount of energy that was transmitted to the each of the crash dummy heads.

a) Britax Chaperone infant seat is lined with energy absorbing foam on the sides and in the head rest.

b) Peg Perego Primo Vaggio infant seat is lined with energy absorbing foam on the sides of the shell only.

c) The head rest is moulded plastic lined with polystyrene and compressible comfort foam.

d) The head rest is a moulded plastic covered in soft compressible comfort foam.

e) Cut away of head rest

f) Cut away of head rest

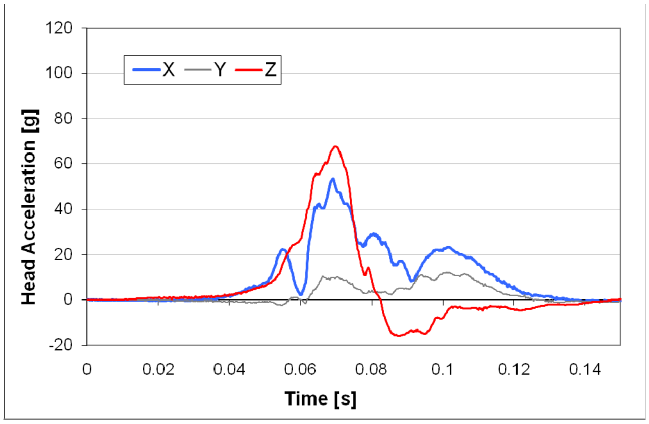
Figure 7. Comparison of the head protection padding in two infant seat designs.

Figure 7a is a photo of the Britax Chaperone seat with the upholstery removed. The energy absorbing system is made up of a shell within a shell. The outer shell (black) has polystyrene foam along the sides while the inner head rest is constructed of a plastic shell (black) and a polystyrene liner. The headrest portion is covered with compliant foam as shown in 7c and 7e.

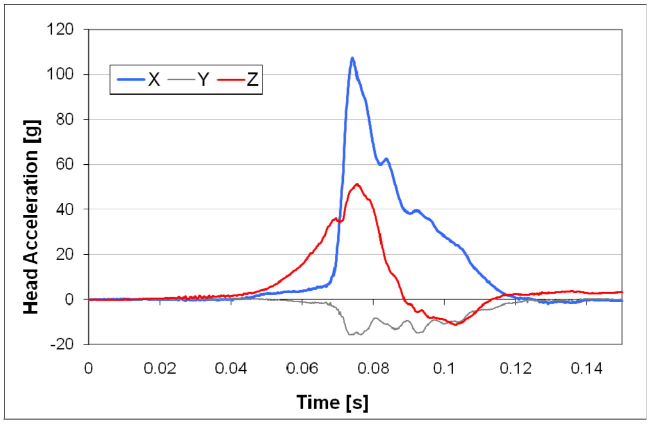
The Peg-Perego shown in Figure 7b has a similar construction in that there is a shell within a shell. The difference with this model is that there is no polystyrene foam behind the head in either the shell or the head rest. The moulded headrest is covered with soft compliant foam as illustrated in 7d and 7f.

Head Acceleration Responses as a Function of Contact

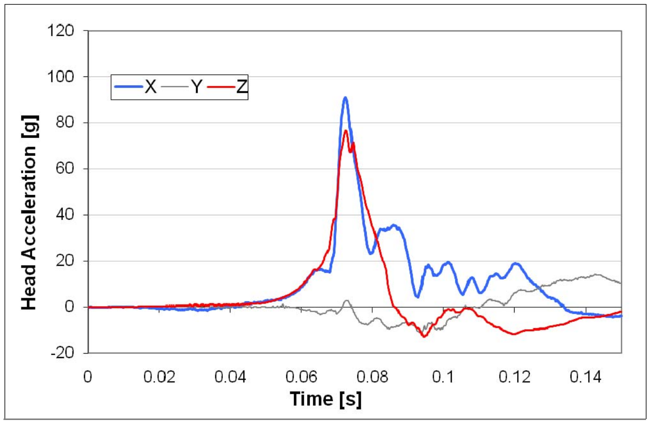
Sample head acceleration traces for the four types of contact are shown in Figure 8 for comparison. The X axis or translational component coming from the back of the dummy head is shown in blue while the Z axis or vertical component coming from the top of the head, is shown in red. The light grey line is the lateral acceleration. Forces caused by inertia or the forward motion of the dummy are principally in the Z axis. This is because the infant seat, installed at a 45^0 angle, tips down as it slides forward on the vehicle seat orienting the top of the head with the front of the vehicle.



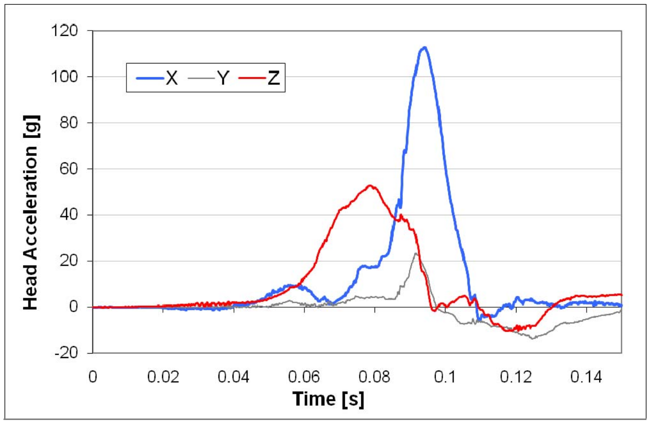
a) Head contact with seat back



b) Seat contact with seat back



c) Head contact with handle



d) Seat contact with console

Figure 8. Comparison of head acceleration responses for four types of contacts

The traces on the left display the head response in tests where there was direct contact between the head and the seat back (A) and the head and the carry handle (C). In both these conditions the timing and magnitude of the X and Z components suggest that the loading to the head is a combined loading, in other words, coming from the top and back of the head as the dummy reaches its maximum forward excursion.

In contrast, when the head region of the child seat strikes the seatback or strikes the console, the principal direction of force is from the back of the head. For example, in the two cases of seat contact and console contact, shown in Figure 8b and 8d respectively, the X component shown by the blue trace predominates.

Each of the two blue traces on the right is characterized by a sudden rise in the acceleration attaining a peak that is of the order of 110g. The peak in 8b occurs when the child seat strikes the seat back of the right front passenger seat. The timing of the red and blue traces suggests that contact occurred at the end of the excursion. A similar response is observed when the child seat strikes the center console 8d, except that now because the console is further forward than the seat back it is possible to clearly distinguish the two mechanisms of loading. The first peak occurs in the vertical acceleration component shown in red and is the result of inertial forces as the child seat and the dummy move forward towards the impact zone. The second, much more important peak of 110g occurs when the back of the child restraint impacts the center console. This peak is the result of the dummy getting struck in the back of the head.

To summarize, direct head impacts with the vehicle interior or the carry handle of the child seat are characterized by combined loading in X and Z involving the top of the head while seat or console impacts, result in high loads in X consistent with strikes to the back of the head.

DISCUSSION AND CONCLUSION

The study was conducted to investigate the interaction of rear facing child restraints with the occupant interior of motor vehicles during full frontal and offset barrier crash tests; and to investigate the effect that these interactions have on the head responses of crash test dummies restrained in the child restraints. The sample included 131 child restraints evaluated in 82 motor vehicle crash tests.

Four types of interactions, resulting in elevated head responses were observed:

1. Direct head contact with the seatback located forward of the infant seat (n=5);
2. Direct head contact with the carry handle of the infant seat (n=2);
3. Contact of the child seat with the seatback located forward of the infant seat (n=8);
4. Contact of the infant seat with the center console (n=10).

Direct head contact with the seat back or carry handle resulted in combined loading to the head that tended to be less severe than that observed in child seat contact with the vehicle interior. Nevertheless, since these contacts occurred at the top of the dummy head, a region that would correspond to the fontanels or soft spots in a child's skull, these contacts are a concern.

Each case of direct head contact was subsequent to interaction of the child restraint with the seat back located forward of the child seat. In the case of handle contact, the handle became wedged between the child seat and the seat back prior to the dummy head making contact. Current child seat regulations in the U.S. and Canada do not include a front row seat back hence these types of interactions and contacts cannot be detected in compliance testing.

The perception that greater clearance between the infant/child seat and the front row seats offers better protection to a rear facing child was not supported by the findings in this study. While the available distance between the infant seat and front row seats was not measured prior to the test, not one of the 15 infant/child seats that were initially touching the seat back at installation was found to result in a head acceleration of 80g or greater. It may be that the front seat acts to hold back the infant seat. This blocking effect prevents the seat from gaining the necessary speed to forcefully strike the seat back. It may also reduce exposure of the head by limiting the amount dummy occupant excursion towards the upper edge of the seat. A study by Sherwood et.al (2005) conducted 12 sled tests and developed computational models to investigate the effect of the location and structural properties of vehicle interior components on the performance of rear facing infant seats. The authors reported a potential for increased injury values in cases where a differential velocity was present between the front seat and the infant seat at the time of contact.

The more severe impacts, as defined by elevated head accelerations, were the result of child seat contact with either the seat back or the console. In one comparison the dimensions of the Britax and Safety 1st seats were quite different. Since this difference led to the child seats impacting the front seat backs in different orientations it was not possible to attribute the differences in recorded head responses to the presence or absence of energy attenuating material. However, it is likely that the energy imparted to the head of the dummy in the Safety 1st may have been lessened by the presence of energy attenuating material.

The magnitude and shape of the head acceleration traces suggest that some child restraints did not contain the appropriate type and/or quantity of material necessary to attenuate the energy imparted to the head during impact with the seat back or the console. Indeed, inspection of the child seats confirmed that several child restraints contained only soft compressible foam.

The protection of an infant should be based on the same principles that are used to guide helmet design for head protection. The shell serves to distribute or spread the load over a large surface and the energy absorbing foam, crushes or deforms on impact to absorb the energy of the impact. To be effective, and reduce the risk of head injury, the foam must deform instead of the skull. If the foam is too stiff (high density) it will require too much energy to crush and the skull will deform. If the foam is too soft (low density) then the foam will bottom out and fail to absorb enough energy to prevent head injury. An impact test carried out with an instrumented head form or dummy can evaluate the effectiveness of the shell and foam liner combination by providing a measure of the amount of energy that is transmitted to the head during an impact. Current child seat regulations in the U.S. and Canada do not include such an impact test.

It was not possible to foresee the potential for interaction with the console during the installation of the infant seats. Since many vehicle manufacturers do not permit the use of the universal anchorage systems (UAS) in the center seating position, installation with the three-point seat belt remains the only option. As was reported in the first internal report on infant seat testing (ASFB 2009-01), forward excursions of the infant seats are greater when infant/child seats are installed with the seat belt compared to the UAS. The size of the console, the extent to which the console intrudes into the rear passenger compartment and the placement of the front seats all appear to influence the likelihood of console strikes.

Since it is not possible to eliminate interactions between the infant/child seat and the vehicle interior during a collision, future child restraint regulations should include an impact test to ensure that the infant/child seats provide adequate protection to the head. A test apparatus that appropriately simulates a seat back could also be included to monitor the effect of infant/child seat interactions on dummy responses.

In the interim parents and caregivers should avoid installing rear facing infant seats in the center of the second row if the vehicle is equipped with a center front console. Installation with the universal anchorage system (lower anchors) in the outboard seating locations will provide good retention and reduce the risk of interaction with the front passenger or driver seat backs. Contact with the front seats during initial seat installation in the vehicle, should not reduce the level of protection provided that the infant/child seat can be installed at the recommended incline angle.

LIMITATIONS OF THE STUDY

The sample selection and test matrix were based on test vehicle and child restraint availability. It was not feasible to conduct a controlled study whereby a statistically representative number of seats could be repeatedly tested in the same test vehicle. As a result not all available child restraints could be evaluated and not all of the seats included in the sample were subjected to the same frequency or test configuration.

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DISCLAIMER

The contents of this paper reflect the views and interpretation of the author, who is responsible for the results, the information, and their accuracies herein. The contents do not necessarily represent, or otherwise reflect, the official opinion, position or policies of Transport Canada or the Government of Canada.

APPENDIX A

Table 1.
Tests where contact with a seat back resulted in elevated head accelerations

Test Vehicle	Test Speed Km/h	CRS	Position	Attachment Method	Peak Resultant Head Acceleration (3ms clip)
KIA MAGENTIS	47.8	Safety 1st Intera 4 in 1 infant/child	16	Latch	119 (109)
HYUNDAI ENTOURAGE	47.7	GRACO Myride65 infant/child	16	Latch	113[1] (103)
DODGE CARAVAN	47.7	PEG PEREGO Primo Viaggio infant	18	Latch	110 (97)
HONDA PILOT	47.6	Evenflo Embrace infant	16	Lap & Torso	88 (83)
FORD E350	40.7	COSCO Scenera infant/child	18	Lap & Torso	83 (77)
HONDA ODYSSEY	47.7	BRITAX Marathon infant/child	14	Lap & Torso	80 (76)
VOLKSWAGEN ROUTAN	47.7	CHICCO Keyfit infant	19	Lap & Torso	80 (74)

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