RELATIVE DEGRADATION OF SAFETY TO CHILDREN WHEN AUTOMOTIVE RESTRAINT SYSTEMS ARE MISUSED

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ABSTRACT

This paper describes the results of a series of forty-four dynamic sled tests simulating a 48 km/h frontal impact. Three convertible child restraints installed in the forward-facing mode were tested. The first used a 5-point harness system, the second a T-shield configuration, and the third an overhead shield system. The type of misuse was varied for each test and included: the amount of shoulder harness slack and/or twisting, seat belt and tether strap slack, seat belt routing, shoulder harness location, shoulder harness slot height, and chest clip use. An instrumented child anthropometric test dummy was installed in the restraints.

The results of the misuse testing showed that the most important degradation of safety resulted from pulling the test dummy's arms through the shoulder harness. The second most important degradation of safety resulted from adding 3" of slack to the shoulder harness, to the tether strap and to the seat belt.

INTRODUCTION

In Canada, approximately 15,000 children aged 14 years and under are killed or injured in motor vehicle collisions each year [1]. The proper use of a child restraint is an effective method of preventing these serious injuries and deaths. Studies have shown that if a child is properly secured in a restraint that is appropriate to the child's development, height and weight, the child is 87% less likely to die in the event of a collision [2].

Up to one third of child restraints are not properly installed [3]. Common misuses include: not tightly securing the child restraint to the vehicle, having too much slack in the shoulder harness designed to keep the child within the restraint, improperly or not attaching the chest clip used to keep the shoulder harness straps together, and placing a child that is not developmentally ready into a child restraint designed for an older child [3].

This paper describes and gives the results of a series of forty-four dynamic sled tests conducted to identify the relative degradation of safety resulting from the misuse of child restraints. Restraints sold in Canada must comply with design and performance regulations, including dynamic testing (described in the Canada Motor Vehicle Restraint Systems and Booster Cushions Safety Regulations (RSSR) [4]). The results of this testing will be used to improve the already high level of safety that the current regulations maintain.

BACKGROUND

Convertible Child Restraint Protection and Performance

There are three basic types of child restraints: infant restraints (birth to ~ 9-10 kg), convertible restraints (birth to ~ 18 kg), and booster seats (over 18 kg). This report focuses on the misuse of convertible child restraints.

Convertible restraints can be installed rear-facing for a younger child (from birth to approx. 9-10 kg), or forward-facing for an older child (from approx. 9-10 to 22 kg). In the case where a convertible restraint is installed in the forward-facing mode, loading is transferred to the harness, then to the shoulders as the child moves forward in a frontal crash. Therefore, it is important that children be developmentally ready before moving to a forward-facing restraint – if their bony structure is not sufficiently developed, it will not be able to withstand the forces applied by the harness in a crash.

Child restraints are very effective when used correctly. In Canada, child restraint overall effectiveness increased from 76% to 87% from 1984 to 1990 [2]. These figures were based on data collected from New Brunswick, Nova Scotia, Ontario and Prince Edward Island. Dalmotas and Krzyzewski [5] placed the overall effectiveness of restraints in preventing child fatalities in the range of 44% to 86%. These figures were based on children aged between 0 and 4 years of age and depended on the child's seating location and on certain restraint usage assumptions.

Misuse Data

There is considerable data which shows that child restraint misuse is the most likely cause of child restraint safety degradation. The type of misuse determines the potential reduction in child safety [2].

Through the use of observational surveys, data has been collected on child restraint misuse. In a survey of Canadian children (collected in shopping centre parking lots), it was found that the child restraint harness or shield was either not functional or not used in 36% of observed cases. The chest clip was incorrectly used, and was not functional or not used in 12% and 37% of observed cases, respectively [3]. A more recent observational study found that 42% of children (N=714) had 3" or more of shoulder harness slack while installed in a forward-facing convertible restraint [6]. The same study found that 2" of seat belt slack was present for 35% of children.

Technicians at child restraint clinics, where parents and caregivers learn how to properly install child restraints, collect data on how the restraint was installed when parents arrive at the clinic. However, this data is not recorded in a standardized manner by the different organizations that conduct the clinics (hospitals and fire stations, for example) and is not routinely collated.

Testing Objective

The objective of the project was to identify the relative degradation of safety resulting from the misuse of child restraint systems. The results of this testing will be used to improve the already high level of safety that the current regulations maintain.

With the large variety of child restraints on the market (at any one time, there are typically over sixty different child restraints available for sale on the Canadian market), the complexity of many designs, and the large number of different vehicle seats in which to install them in, misuse is common. This project studies the impact of misuse types similar to those described in the Canadian surveys described above [3], [6]. This project did not attempt to target gross misuse such as failing to secure the child restraint to the vehicle and not using the harness to secure the child in the restraint. In these cases the restraint provides no protection for the child.

TEST METHOD

Child Restraints

<u>Test Samples</u> Three convertible child restraints were used in testing (Figures 1 – 3). The three restraints were of similar design and were made by the same manufacturer. The major difference between the restraints was the way in which a child is secured. The first restraint had a five-point harness system (Figure 1), the second a T-shield configuration (Figure 2), and the third an overhead shield configuration (Figure 3). This make and model was chosen for testing because of its large market share in Canada, and because it was offered with three harness system types. All restraints were installed in the forward-facing mode for testing. In this mode, the restraint was designed for a child weighing between 9 and 18 kg.

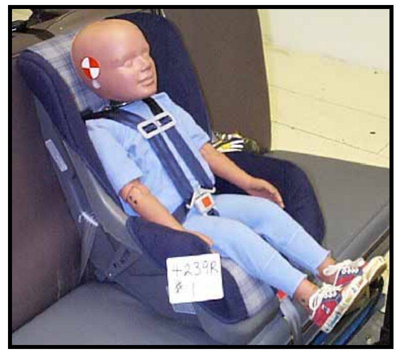

Figure 1. 5-point Restraint.

Figure 2. T-shield Restraint.

Figure 3. Overhead Shield Restraint.

<u>Features of Convertible Child Restraints</u> Figure 4 shows the main components of a convertible child restraint used forward-facing. The tether strap and hook anchor the top portion of the restraint to a tether anchorage inside the vehicle, and are designed to limit head excursion.

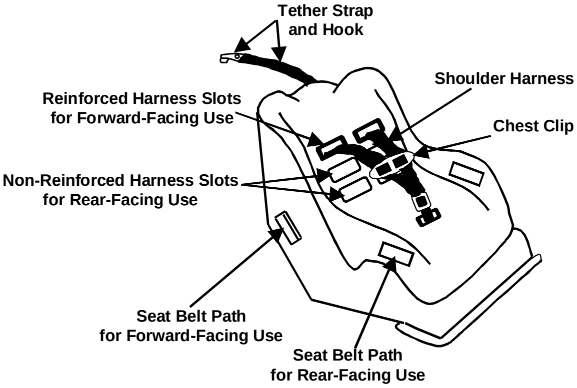

Figure 4. Convertible Child Restraint Components.

The shoulder harness secures the child to the restraint, and limits motion during a crash. In all restraints, it can be tightened and adjusted to provide a snug fit.

The chest clip holds the two portions of the shoulder harness together at the chest level and keeps the harness snugly on the shoulders during regular use. Good pre-impact harness strap position prevents the child's narrow shoulders from squeezing through the gap and potentially causing the child's ejection in a crash [7].

Convertible child restraints usually have two paths where the seat belt can be routed through: one for forward-facing use and one for rear-facing use. The belt path used is always closest to the belt anchorages to provide a secure fit.

Misuse Modes

The type of misuse was varied for each test and included: the amount of shoulder harness slack and/or twisting, seat belt and tether strap slack, seat belt routing, shoulder harness location, shoulder harness slot height, and chest clip use. Appendix A outlines the tested misuse modes. Imperial units (inches) were used in the field to measure the amount of slack in the harness, seat belt and tether strap [6]. For this reason, the misuse conditions were also measured in inches. In addition to the misuse conditions, each restraint was also tested in a baseline condition, i.e. correctly installed according to the manufacturer's instructions. To minimize variability within each test, there were strict procedures regarding the method by which the misuse was introduced. These procedures are included in Appendix A. In total, forty-four tests were conducted, including four tests to ensure that the tests were repeatable.

Test Dummies and Data Collection

The Hybrid III 3-year-old test dummy weighing approximately 15.5 kg was used in all tests. To quantitatively measure the relative degradation of safety resulting from misuse, all dummies were instrumented with load cells and accelerometers. Table 1 gives the active data channels for each test run. Due to the large number of data channels, only those ***highlighted*** are analyzed in detail in this report.

Table 1.
Active Data Channels

Location	Value	Direction(s)
Head	Max. Excursion	***X***
	Acceleration	x, z, ***RESULTANT***
Chest	Acceleration	x, z, ***RESULTANT***
Upper Neck	Loads	***X***, y, ***Z***, resultant
	Moments	x, ***Y***, z, resultant
Lower Neck	Loads	x, y, ***Z***, resultant
	Moments	x, ***Y***, z, resultant
Left Shoulder	Loads	x, z, ***RESULTANT***
Right Shoulder	Loads	x, z, ***RESULTANT***

Dynamic Crash Simulation

The testing was conducted on the HyGe Crash Simulation testing sled, located at the Defence and Civil Institute for Environmental Medicine in Toronto, Ontario. The sled test procedure, test pulse and equipment was identical to that used in RSSR compliance testing. The sled simulated a frontal impact of 48 km/h.

INJURY CRITERIA

The Motor Vehicle Restraint Systems and Booster Cushions Safety Regulations (RSSR) [4] require the use of a Hybrid II 3-year-old test dummy. Its head acceleration must not exceed 80g, its chest acceleration must not exceed 60g and its head must not move forward more than 720 mm during the test.

Previous research has established child injury criteria. The criteria of Planath, et al. [8], Trosseille and Tarriere [9], Janssen et al. [10], and Yoganandan et al. [11] are summarized in Table 2.

Table 2.
Acceptable Injury Tolerances and Sign Conventions

Source	Dummy Size	Head Ares (g)	Head Excur-sion (mm)	Chest Ares (g)	Upper Neck Fx (N)	Upper Neck Fz (N)	Upper Neck My (N-m)	Lower Neck Fz (N)	Lower Neck My (N-m)
RSSR [4]	3 year	< 80	< 720	< 60					
Planath, 1992 [8]	3 year				< 300	< 1000	> -30		
Trosseille, 1993 [9]	6 month				< 950	< 1200	> -41		
Janssen, 1993 [10]	9 month				< 800	< 850	> -41		
Yoganandan et al., 1999 [11]	3 year					>-2500, < 2500	> -30, < 100	>-2500, < 2500	> -30, < 100
Sign Convention for Positive Output (as per SAE J211)	*N/A*	*N/A*	*Head For-ward*	N/A	*Head Rear-ward Chest For-ward*	*Head Up-ward Chest Down-ward*	*Chin Toward Ster-num*	*Head Up-ward Chest Down-ward*	*Chin Toward Ster-num*

RESULTS

The following graphs give the results as a percent difference between the baseline condition and the misuse condition (1). Appendix A gives detailed descriptions of the baseline and misuse conditions.

$$\%diff = \left[\frac{|misuse| - |baseline|}{|baseline|}\right] \times 100\% \qquad (1).$$

Only the maximum value of each data channel for each run was used in this analysis. The %-difference was computed based on the absolute value of the data so as to avoid any misinterpretation caused by sign differences between the baseline and misuse conditions. Positive %-difference indicates that the dummy fared worse in the misuse condition than in the baseline/correct condition. Conversely, negative %-difference indicates that the dummy fared better in the misuse than in the baseline condition.

For example, if the upper neck My channel recorded 15 N-m (flexion) in the baseline condition and -16 N-m (i.e. 16 N-m extension), the %-difference would not be –207%. This would give the false impression that the misuse condition gave 200% better results than the baseline condition. Instead, the difference would be computed using the absolute value of the data, and the %-difference would be +6.7%.

Complete numerical results are given in Appendix B.

Figures 5, 6, and 7 show the effect of shoulder harness slack on the performance of the 5-point, T-shield, and overhead restraints, respectively.

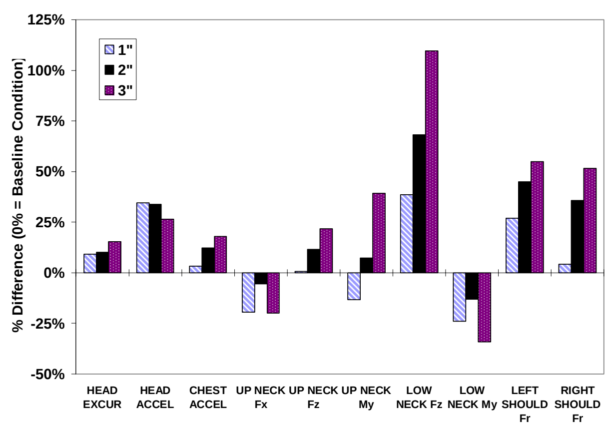

Figure 5. Effect of Shoulder Harness Slack, 5-point Harness, Baseline Condition: 0" Slack.

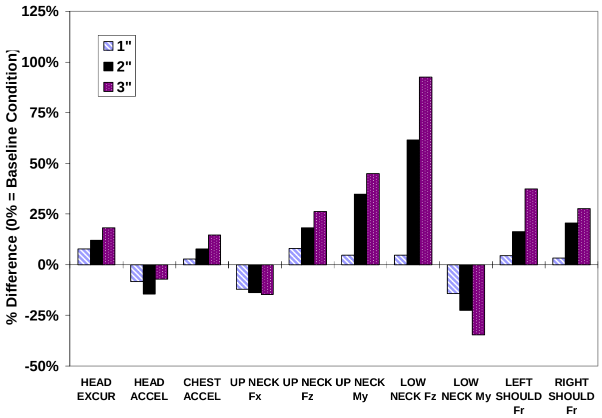

Figure 6. Effect of Shoulder Harness Slack, T-shield Harness, Baseline Condition: 0" Slack.

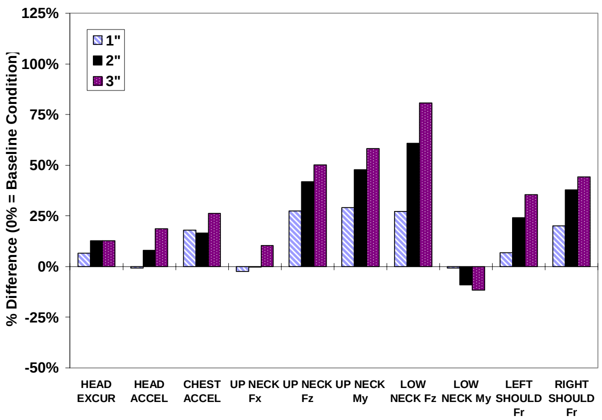

Figure 7. Effect of Shoulder Harness Slack, Overhead Harness, Baseline Condition: 0" Slack.

Figure 8 shows the effect of adding tether strap and seat belt slack to a 5-point restraint.

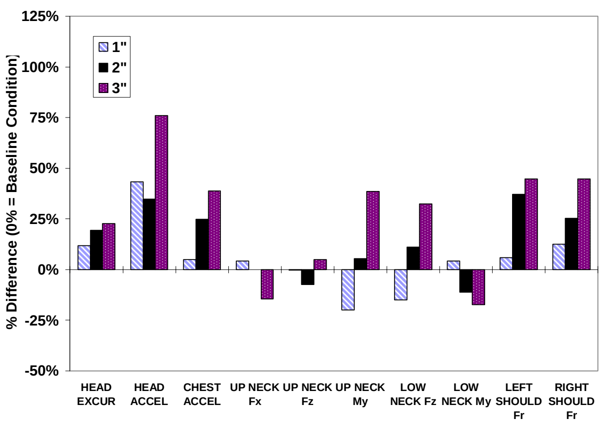

Figure 8. Effect of Tether Strap and Seat Belt Slack, 5-point Harness, Baseline Condition: 0" Slack.

Figure 9 shows the compounded effect of adding shoulder harness, tether strap, and seat belt slack to a 5-point harness.

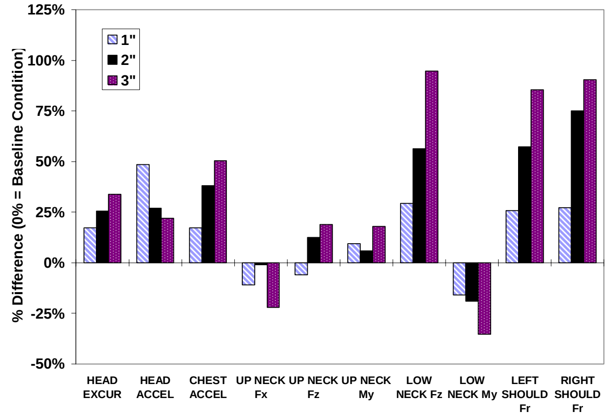

Figure 9. Effect of Shoulder Harness, Tether Strap and Seat Belt Slack, 5-point Harness, Baseline Condition: 0" Slack.

Figure 10 shows the effect of shoulder harness slack and twisting for a 5-point harness.

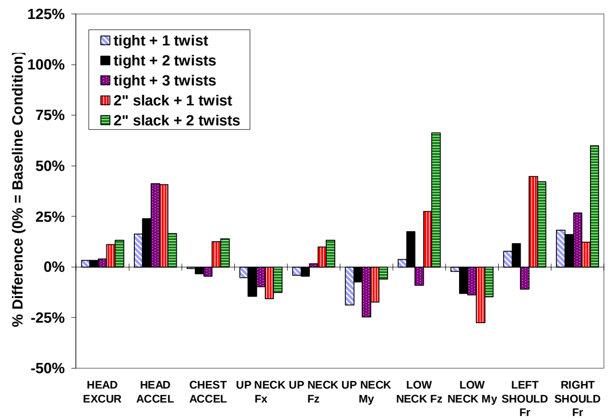

Figure 10. Effect of Shoulder Harness Slack and Twisting, 5-point Harness, Baseline Condition: 0" Slack + No Twisting.

Figure 11 gives the effect of shoulder harness location/placement for the 5-point, T-shield, and overhead restraints.

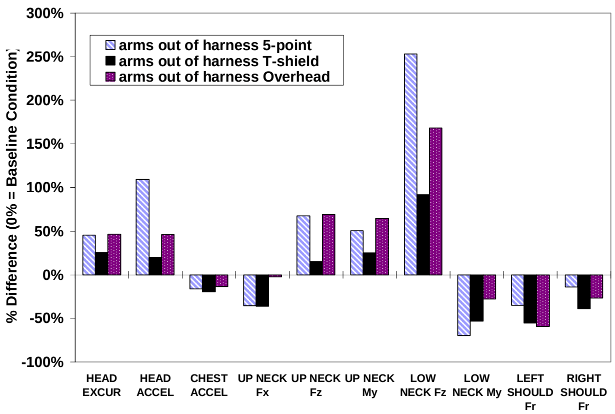

Figure 11. Effect of Shoulder Harness Location, 5-point, T-shield, and Overhead Harnesses, Baseline Condition: Shoulder Harness Straps Placed on Dummy's Shoulders.

Figure 12 shows the effect of shoulder harness slot height for the 5-point harness.

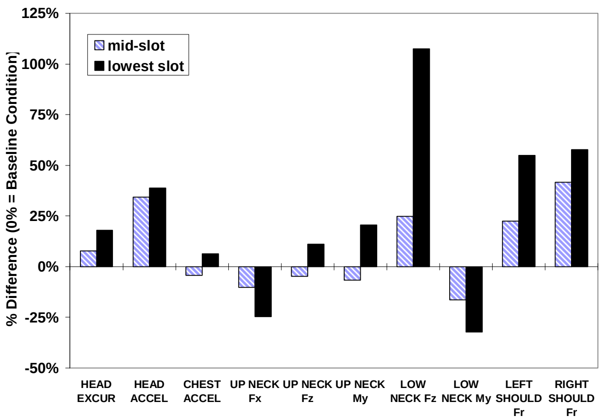

Figure 12. Effect of Shoulder Harness Slot Height, 5-point Harness, Baseline Condition: Shoulder Harness Routed Through Top Slots.

Figures 13, 14, and 15 show the effect of proper chest clip use with and without harness slack, for the 5-point, T-shield, and overhead restraints, respectively.

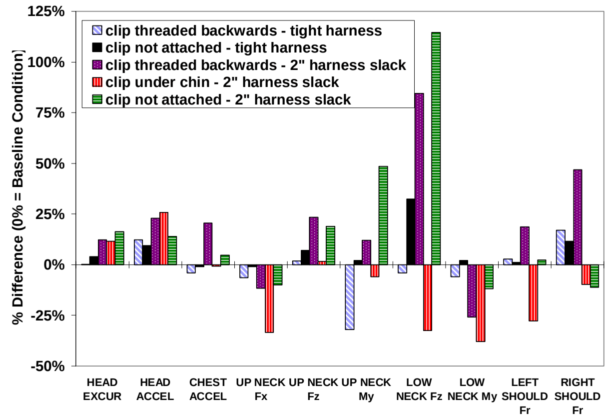

Figure 13. Effect of Chest Clip Use, 5-point Harness, Baseline Condition: Clip Threaded Correctly, At Armpit Level, 0" Harness Slack.

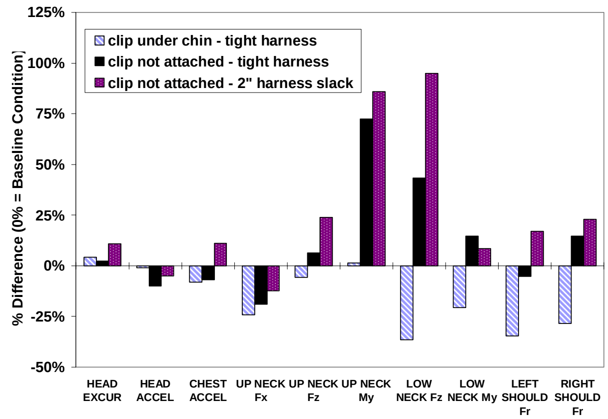

Figure 14. Effect of Chest Clip Use, T-shield Harness, Baseline Condition: Clip Threaded Correctly, At Armpit Level, 0" Harness Slack.

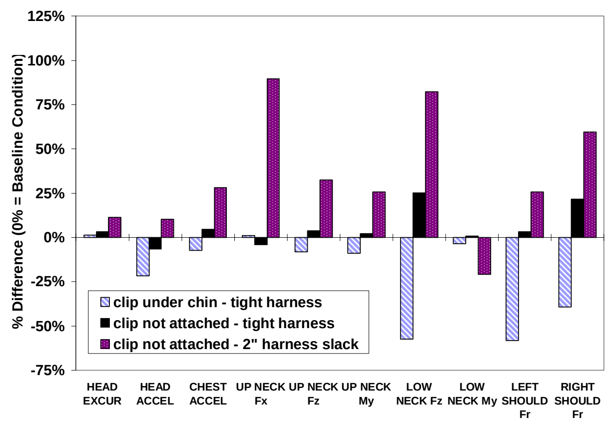

Figure 15. Effect of Chest Clip Use, Overhead Harness, Baseline Condition: Clip Threaded Correctly, At Armpit Level, 0" Harness Slack.

Figure 16 shows the effect of improperly routing the seat belt through the path for rear-facing use on the 5-point restraint.

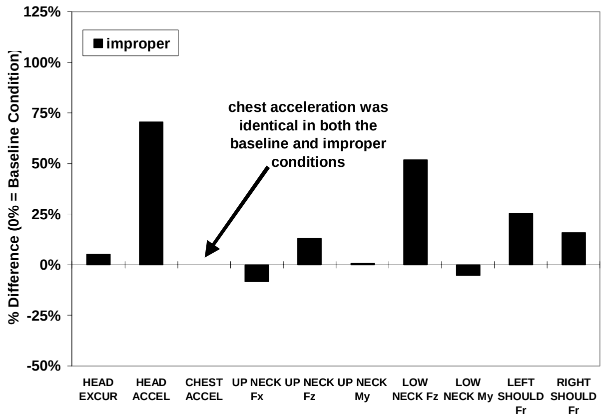

Figure 16. Effect of Seat Belt Routing, 5-point Harness, Baseline Condition: Belt Routed Through Slots for Forward-Facing Use.

Repeatability Analysis

To ensure the repeatability of the tests, four extra tests were conducted. These tests were paired to four of the original tests: one using each of the three restraint types with 2" of shoulder harness slack, plus the 5-point restraint with the chest clip placed under the test dummy's chin. The repeated tests were set up identically to the original tests, and the same data channels were active.

Aside from some sign inconsistencies caused by test dummy rebound, the repeated tests generally gave relative variabilities of approximately 25%. The only exception was shoulder loading, where up to 50% differences were recorded.

Test Equipment

Right and left shoulder loads did not correspond for many tests. Multiple noisy peaks in the right shoulder data (particularly Fx) were a result of a mechanical problem that required adjustment after each run. The peak Fx and Fz values were most likely not recorded, and therefore affected the resultant shoulder loading which was analyzed.

SUMMARY AND DISCUSSION OF PRIMARY FINDINGS

In the baseline condition, all data met the RSSR injury criteria.

Reduction in Safety Resulting from Misuse

The **effect of adding shoulder harness slack** was important (Figures 5, 6, and 7). For all three restraints, child restraint performance worsened as the amount of harness slack was increased. This was the case especially for lower neck forces in the Z-direction which increased to 80-100% with 3" of harness slack. Both shoulders experienced increases of up to 50% when harness slack was introduced. The three restraint types gave similar results, except in the case of head acceleration: while head acceleration increased with respect to the baseline condition for the 5-point and overhead restraints, the head acceleration decreased with respect to the baseline condition for the T-shield restraint. Shoulder harness slack might have caused an even more important effect on safety if the method used to introduce slack was less conservative. Amounts of 1", 2", and 3" of slack were chosen since these had been recorded in the field [6]. However, the method of measuring slack in the field was less precise than in testing. For example, 1" in the field may have been 1.5" using a stiff board.

The **effect of adding tether and seat belt slack** was also important (Figure 8). While adding harness slack had a more important effect on neck loading, tether and seat belt slack affected head and chest acceleration most. For 3" of slack, head acceleration increased by 76% over the baseline condition, while chest acceleration increased to 39%. The test dummy experienced shoulder loading that was similar to those experienced in the harness slack conditions. Only the 5-point restraint was tested in this condition.

As expected, adding both **shoulder harness and tether and seat belt slack** compounded the effects of each condition alone (Figure 9). The variables most affected were the the lower neck Fz, head excursion, head and chest acceleration. Head excursion increased to 34% in the 3" slack condition. Strangely, head acceleration was higher for 1" slack (49%) than for 2" and 3" of slack (27% and 22%, respectively). Shoulder loading increased to almost 90% in the 3" slack condition. Only the 5-point restraint was tested in this condition.

The **effect of shoulder harness slack and twisting** was moderate. The addition of 2" of slack with 2 twists gave the worst performance, followed by 2" of slack with 1 twist (Figure 10). The addition of slack to the harness seemed to have a worse effect on the restraint's performance than the addition of twisting while the harness was tight. Nonetheless, performance worsened as the number of twists increased for a tight shoulder harness. The effect of twisting on a loose (2" slack) harness is unclear. Low neck Fz, shoulder loading and head acceleration were most affected by harness slack and twisting. Notably, the low neck Fz showed a 66% increase from the baseline in the 2" slack + 2 twists condition. Only the 5-point restraint was tested in this condition.

The **effect of pulling the dummy's arms through the shoulder harness** was major for all three restraints (Figure 11). This misuse condition resulted in the partial ejection of the test dummy in the T-shield and overhead restraints. All measured variables increased significantly when the harness was placed incorrectly versus in the baseline condition, except for shoulder loading, chest acceleration and low neck My which decreased. The low shoulder loading reflects that when the dummy's arms are pulled through the harness, the straps are not pressing down on its shoulders. Head excursion increased by nearly 50% for the 5-point and overhead restraints, and by 25% for the T-shield restraint. The test dummy's head acceleration increased by 110% in the 5-point restraint. However, the most significant decrease in performance occurred for the lower neck Fz channel: it exceeded 250% in the 5-point restraint.

The **effect of threading the harness straps through the lower slots** was also important (Figure 12). In all cases, threading the harness straps through the lowest slots gave the worst results. Notable values included a 107%-difference for the low neck Fz in the lowest slot condition. Head acceleration increased by 34% and 39% for the middle and lowest slots, respectively. Shoulder loading also increased significantly (55% and 58% in the lowest slot condition for the left and right shoulders, respectively). When the slots were threaded through the middle and lowest slots, the harness was lower than the dummy's shoulders. Although these slots are not designed for forward-facing use, the restraint's plastic shell around the non-reinforced harness slots did not fracture. Only the 5-point restraint was tested in this condition.

The **effect of chest clip use (with and without harness slack)** was also important, especially with respect to neck injury (Figures 13, 14, and 15). When the shoulder harness was tightly adjusted, chest clip misuse did not significantly affect the performance of the 5-point restraint, except low neck Fz (clip not attached, 32%). Misuse of the chest clip was compounded when 2" of shoulder harness slack was added: 115% was recorded by the low neck Fz channel in the "clip not attached" condition, and 85% in the "clip threaded backwards" condition. Left and right shoulder loads did not correspond. When a tight shoulder harness was used in the T-shield and overhead restraints, placing the chest clip under the test dummy's chin generally gave a better performance than not using a chest clip altogether with respect to neck loading. Adding 2" of shoulder harness slack worsened both restraints' performance. Notable values included: up neck My in the T-shield restraint when the chest clip was not used (73% and 86% for a tight shoulder harness and with 2" of harness slack, respectively), and low neck Fz values for both the T-shield and overhead restraints in all chest clip misuse conditions. It should also be noted that shoulder loading in all three restraints decreased significantly when the chest clip was placed under the dummy's chin. This coincided with increased lower neck loading.

Routing the seat belt through the incorrect path also negatively affected the safety performance of the restraint (Figure 16). Head acceleration was most affected. It increased by 71% as compared with the baseline condition. The low neck Fz channel was also negatively affected (52%). Once again the left and right shoulder loads did not correspond. The tether strap was tightly installed for these tests and would likely have offset any moment created by routing the seat belt through the rear-facing path located further away from the seat back. This is most likely the reason why routing the seat belt incorrectly did not have a major effect on all of the measured data channels.

Test Equipment

The HyGe sled testing is non-destructive, repeatable and less costly than full-scale crash testing in which a vehicle is completely destroyed. However, the current test bench set-up is also limited. For example, it cannot account for the large number of different vehicle seat and seat belt assemblies. The sled's bench seat is made of soft, compressible foam, and does not have contours like those found in today's vehicles. Also, the seat belt buckle is mounted at the seat bight on the sled's seat, but in today's vehicles, the seat belt buckle is forward of the seat bight.

CONCLUSIONS

The most important degradation of safety resulted from pulling the test dummy's arms through the shoulder harness. The second most important degradation of safety resulted from adding 3" of slack to the shoulder harness, to the tether strap and to the seat belt.

As expected, the addition of slack to any misuse condition always worsened the performance of the child restraint. This was the case in the shoulder harness twisting and chest clip misuse conditions.

Although the lower shoulder harness slots were not reinforced and are not recommended for forward-facing use, the restraint's plastic shell did not fracture in the harness slot height misuse condition.

Incorrect seat belt routing also affected the safety performance of the restraint. If the tether strap had not been tightly installed for this condition, routing the seat belt incorrectly would likely have caused an even more pronounced degradation in safety.

The tests were repeatable to an acceptable tolerance, except in the case of shoulder loading. In some cases, the signs indicating the direction of loading may have been reversed.

RECOMMENDATIONS

Shoulder harness, tether strap and seat belt slack are common in the field and had an important detrimental effect on the safety performance of the child restraint. Therefore, it is recommended that design and testing criteria be added to the Motor Vehicle Restraint Systems and Booster Cushions Safety Regulations to ensure that misuse is minimized.

The measurement of child restraint misuse at child restraint installation clinics should be standardized and routinely collated. This would allow researchers to accurately assess actual child restraint misuse in the field by accessing a large sample of uniform data.

DISCLAIMER

The opinions expressed in this report are those of the authors and are not necessarily those of Transport Canada or of RONA Kinetics and Associates Ltd.

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APPENDIX A

Table A1.
Misuse Modes

Misuse Mode	Photo	Value	How Misuse Was Introduced for Testing	
Amount of shoulder harness slack	See Figures 1, 2 ,3	baseline	as per mfg's instructions: no more than a 1 finger gap between the child and the harness	
	Figure A1	1, 2, or 3 inches	by placing a 1-, 2- or 3-inch board behind the test dummy and removing before the test	
Amount of seat belt slack	See Figures 1, 2 ,3	baseline	as per mfg's instructions: very tight so as to allow less than 1-inch of child restraint movement	
	Figure A2	1, 2, or 3 inches	by placing a 1-, 2- or 3-inch board behind the child restraint and removing before the test	
Amount of tether slack	See Figures 1, 2 ,3	baseline	as per mfg's instructions: very tight so as to compress the vehicle seat's foam	
	Figure A2	1, 2, or 3 inches	by placing a 1-, 2- or 3-inch board behind the child restraint and removing before the test	
Seat belt routing	See Figures 1, 2 ,3	baseline	as per mfg's instructions: through the correct routing path for a forward-facing child restraint	
	Figure A3	improper	by routing belt through the path for rear-facing installation	
Shoulder harness slack and twisting	See Figures 1, 2 ,3	baseline	as per mfg's instructions: no twisting in shoulder harness	
	Figure A4	2" slack + 1 or 2 twists, tight + 1, 2, or 3 twists	slack:	by placing a 1-, 2- or 3-inch board behind the test dummy and removing before the test
			twisting:	by twisting the harness straps before buckling
Shoulder harness location	See Figures 1, 2 ,3	baseline	as per mfg's instructions: on the shoulders	
	Figure A5	arms out of harness	by pulling the test dummy's arms completely out of harness	
Shoulder harness slot height	See Figures 1, 2 ,3	baseline	as per mfg's instructions: at the highest slots since these are the only reinforced ones appropriate for forward-facing use	
	Figure A6	middle or lowest slots	by threading the harness straps through the middle or lowest slots (only appropriate for rear-facing use)	
Chest clip use	See Figures 1, 2 ,3	baseline	as per mfg's instructions: at armpit level and threaded correctly	
	Figure A7	not attached	by removing the chest clip completely	
	Figure A8	threaded backwards	by threading the harness straps backwards through the clip	
	Figure A9	under chin	by placing the clip high under the chin of the test dummy	

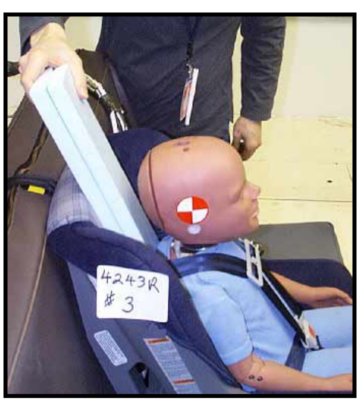

Figure A1.

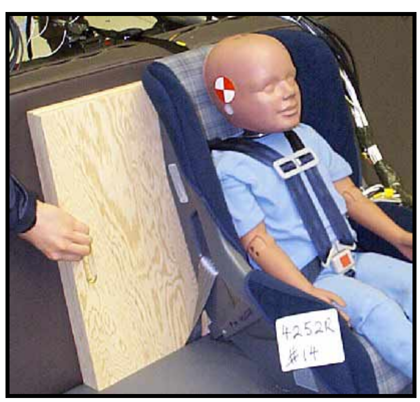

Figure A2.

Figure A3.

Figure A4.

Figure A5.

Figure A6.

Figure A7.

Figure A8.

Figure A9.

APPENDIX B

Table B1.
Test Results

Misuse Condition	Head Excursion (mm)	Head Acceleration (g)	Chest Acceleration (g)	Up Neck Fx (N)	Up Neck Fz (N)	Up Neck My (Nm)	Low Neck Fz (N)	Low Neck My (Nm)	Left Sh Fr (N)	Right Sh Fr (N)
Shoulder Harness Slack										
5-point										
tight (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
1"	749	66.1	41.4	674.7	1339	13.0	944	98.8	1061	762
2"	755	65.7	45.0	792	1484	16.1	1146	112.9	1212	992
3"	792	62.1	47.3	671	1618	20.9	1427	85.7	1296	1106
T-shield										
tight (baseline)	709	67.3	38.9	699	1353	14.9	824	105.3	1126	988
1"	765	61.7	40.0	615	1462	15.6	862	90.4	1177	1021
2"	795	57.5	41.9	603	1599	20.1	1331	81.6	1311	1193
3"	838	62.5	44.6	596	1708	21.6	1586	68.8	1548	1261
Overhead										
tight (baseline)	691	58.3	38.5	622	1251	14.4	845	108.0	1107	813
1"	737	57.9	45.4	607	1594	18.6	1075	107.2	1184	977
2"	780	63.0	44.9	620	1775	21.3	1360	98.3	1374	1120
3"	780	69.2	48.6	686	1880	22.8	1529	95.3	1500	1173

Test Results (Continued)

Misuse Condition		Head Excursion (mm)	Head Acceleration (g)	Chest Acceleration (g)	Up Neck Fx (N)	Up Neck Fz (N)	Up Neck My (Nm)	Low Neck Fz (N)	Low Neck My (Nm)	Left Sh Fr (N)	Right Sh Fr (N)
Tether Strap & Seat Belt Slack											
	5-point										
	tight (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
	1"	767	70.4	42.1	873	1326	12.0	580	135.5	886	821
	2"	820	66.2	50.1	837	1231	15.8	757	115.4	1147	915
	3"	841	86.4	55.7	715	1396	20.8	901	107.6	1210	1057
Shoulder Harness, Tether & Seat Belt Slack											
	5-point										
	tight (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
	1"	805	72.9	47.0	745	1250	16.4	881	109.2	1051	929
	2"	861	62.4	55.4	828	1498	15.9	1065	105.3	1315	1278
	3"	919	59.9	60.3	652	1583	17.7	1326	84.1	1552	1391
Seat Belt Routing											
	5-point										
	correct (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
	improper	721	83.7	40.1	768	1504	15.1	1034	123.2	1048	845
Shoulder Harness Slack & Twisting											
	5-point										
	tight (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
	tight + 1 twist	709	57.1	39.8	793	1277	12.2	706	127.3	901	863
	tight + 2 twists	709	60.9	38.8	716	1269	13.9	800	113.2	934	847
	tight + 3 twists	714	69.3	38.3	755	1352	11.3	619	112.1	746	925
	2" slack + 1 twist	762	69.1	45.1	705	1461	12.4	868	94.3	1211	821
	2" slack + 2 twists	777	57.2	45.7	732	1506	14.1	1132	110.8	1188	1167
Shoulder Harness Location											
	5-point										
	correct (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
	arms out of harness	998	102.9	33.6	541	2223	22.6	2405	39.5	542	628
	T-shield										
	correct (baseline)	709	67.3	38.9	699	1353	14.9	824	105.3	1126	988
	arms out of harness	889	80.9	31.3	447	1558	18.6	1578	49.3	501	605
	Overhead										
	correct (baseline)	691	58.3	38.5	622	1251	14.4	845	108.0	1107	813
	arms out of harness	1013	85.2	33.3	608	2115	23.7	2265	78.2	451	596
Shoulder Harness Slot Height											
	5-point										
	highest slot (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
	mid-slot	739	66.0	38.4	752	1266	14.0	850	108.6	1023	1034
	lowest slot	810	68.2	42.7	631	1477	18.1	1413	88.0	1296	1152

Test Results (Continued)

Misuse Condition	Head Excursion (mm)	Head Acceleration (g)	Chest Acceleration (g)	Up Neck Fx (N)	Up Neck Fz (N)	Up Neck My (Nm)	Low Neck Fz (N)	Low Neck My (Nm)	Left Sh Fr (N)	Right Sh Fr (N)
Chest Clip Use (w/o Shoulder Harness Slack)										
5-point										
as per mfg instructions (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
clip threaded backwards	688	55.1	38.5	784	1356	10.2	653	122.4	859	854
clip under chin	X	X	X	X	X	X	X	X	X	X
clip not attached	713	53.7	39.7	829	1424	15.3	902	132.7	845	815
T-shield										
as per mfg instructions (baseline)	709	67.3	38.9	699	1353	14.9	824	105.3	1126	988
clip threaded backwards	X	X	X	X	X	X	X	X	X	X
clip under chin	739	66.6	35.8	530	1278	15.1	523	83.5	737	706
clip not attached	726	60.6	36.2	567	1438	25.7	1181	120.7	1068	1134
Overhead										
as per mfg instructions (baseline)	691	58.3	38.5	622	1251	14.4	845	108.0	1107	813
clip threaded backwards	X	X	X	X	X	X	X	X	X	X
clip under chin	701	45.6	35.7	629	1150	13.1	361	104.1	462	493
clip not attached	713	54.5	40.3	596	1297	14.7	1058	108.9	1142	990
Chest Clip Use (with 2" Shoulder Harness Slack)										
5-point										
as per mfg instructions (baseline)	686	49.1	40.1	837	1330	15.0	681	130.0	836	730
clip threaded backwards	770	60.4	48.4	740	1641	16.8	1256	96.4	993	1073
clip under chin	765	61.8	39.8	558	1352	14.1	461	80.7	605	660
clip not attached	798	56.0	42.0	753	1581	22.3	1461	114.5	855	649
T-shield										
as per mfg instructions (baseline)	709	67.3	38.9	699	1353	14.9	824	105.3	1126	988
clip threaded backwards	X	X	X	X	X	X	X	X	X	X
clip under chin	X	X	X	X	X	X	X	X	X	X
clip not attached	787	64.0	43.2	612	1675	27.7	1607	114.2	1319	1214
Overhead										
as per mfg instructions (baseline)	691	58.3	38.5	622	1251	14.4	845	108.0	1107	813
clip threaded backwards	X	X	X	X	X	X	X	X	X	X
clip under chin	X	X	X	X	X	X	X	X	X	X
clip not attached	770	64.3	49.3	1180	1657	18.1	1541	85.5	1393	1296

Note: "X" indicates that this condition was not tested.