

**Testing of Passenger Airbags with
6-Year-Old Child Hybrid III Dummy to
Assess Injury Risk to Belted Children**

Michael R. Powell
David S. Zuby

September 1999

**INSURANCE INSTITUTE
FOR HIGHWAY SAFETY**

1005 N. GLEBE RD. ARLINGTON, VA 22201-4751

PHONE 703/247-1500 FAX 703/247-1678

website <http://www.highwaysafety.org>

BACKGROUND

More than 3.3 million driver airbags and more than 600,000 passenger airbags with people occupying right front seats have inflated in crashes in the United States. Experts agree that these airbag deployments have resulted in a net safety benefit. Deaths in frontal crashes are reduced about 26 percent among drivers using seat belts and about 32 percent among those not using belts. Similarly, deaths in frontal crashes are reduced about 14 percent among right-front passengers using belts and about 23 percent among those not using belts. The National Highway Traffic Safety Administration (NHTSA) estimates that the combination of an airbag plus a lap/shoulder belt reduces the risk of moderate and serious head injury by 81 percent, compared with a 60 percent reduction for belts alone. Despite this effectiveness, deaths are about 34 percent higher than expected among child passengers younger than age 10 (Insurance Institute for Highway Safety, 1999a).

Airbag injury risk to children would be essentially eliminated if all children were properly restrained in the rear seats of passenger vehicles. State legislatures have responded to concerns about airbags injuring children by considering laws that would require children to ride in rear seats. Delaware, Louisiana, and Rhode Island already have passed such laws (Insurance Institute for Highway Safety, 1999b). Massive public information campaigns, such as NHTSA's "Buckle Up America" and the National Safety Council's "Air Bag & Seat Belt Safety Campaign," have tried to encourage parents and others who transport children to put them in rear seats. A recent survey shows these campaigns have been effective and that fewer children were riding in the front seats of passenger airbag-equipped vehicles in 1997 than in 1996 (Cammisa and Ferguson, 1998). Still, the authors found that 44 percent of those surveyed in 1997 had sometimes transported children in front seats within the previous 6 months. According to the survey, children rode in front seats because they wanted to and not because of some necessity (e.g., not enough rear-seat capacity or so the child's health could be monitored by the driver). Parents' desires to let their children ride in front seats are reflected in the Delaware law, which would allow children to ride in the front seats of cars with passenger airbags designed to be safe for children.

The federal government has proposed safety regulations intended to mitigate airbag injury risk to children. These regulations involve tests with crash dummies that represent small children. The Insurance Institute for Highway Safety has conducted similar tests with dummies representing 6-year-old children and 12-month-old infants. This report describes the test methods and results using the 6-year-old child Hybrid III dummy restrained in the front passenger seat of various passenger vehicle models. Tests methods and results using the 12-month-old infant dummy are described in a separate report (Zuby and Powell, 1999).

This work was supported by the Insurance Institute for Highway Safety.

TEST CONDITIONS

Static (noncrash) in-vehicle airbag deployment tests were conducted using five different passenger vehicle models and the 6-year-old child Hybrid III dummy in three different seating positions.

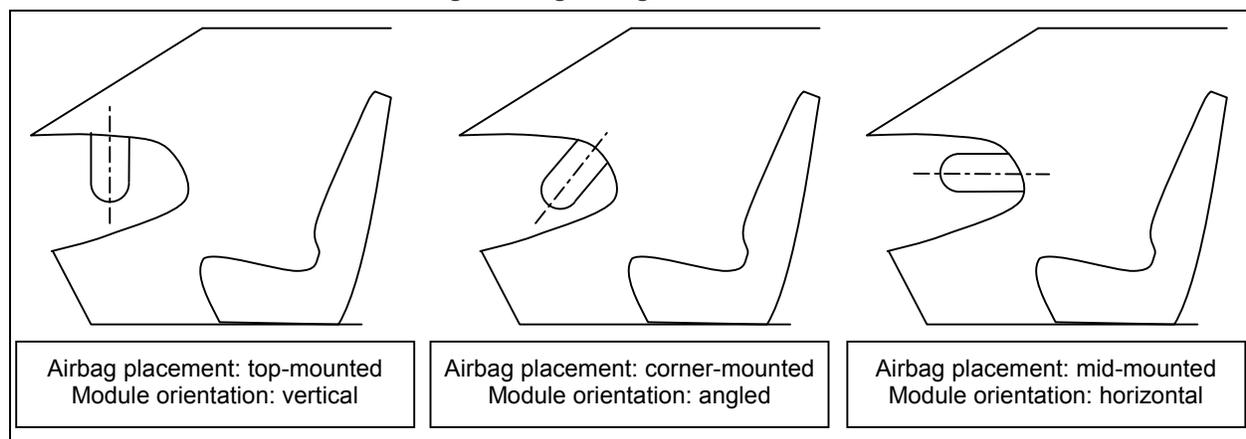
Vehicles/airbag configuration: The vehicle models tested were a 1990 Lincoln Town Car, 1996 Dodge Grand Caravan, 1996 Ford Taurus, 1996 Honda Accord, and 1996 Volvo 850. These vehicles were chosen in part because they have different passenger airbag configurations (see Table 1).

Table 1
Passenger Airbag Configurations

Vehicle	Type of Door	Airbag Placement	Module Orientation
1990 Lincoln Town Car	Dual-flap, soft plastic door	Mid-mounted	Horizontal
1996 Dodge Grand Caravan	Dual-flap door, thin steel backing	Mid-mounted	Horizontal
1996 Ford Taurus	Tethered, unhinged single-flap door, rigid steel backing	Top-mounted	Angled
1996 Honda Accord	Dual-flap, hard plastic door	Top-mounted	Vertical
1996 Volvo 850	Tethered, hinged, hard plastic single-flap door	Corner-mounted	Angled

Airbag placement was defined as *top-mounted* if most of the airbag deployment opening was part of the top horizontal (or nearly horizontal) surface of the instrument panel, *corner-mounted* if the opening was nearly equally positioned between the top horizontal and vertical surfaces of the instrument panel, or *mid-mounted* if most of the opening was part of a vertical (or nearly vertical) surface of the instrument panel. Module orientation was defined as *vertical* if the orientation of the airbag module housing was closer to vertical than 45 degrees, *angled* if the orientation was nearly halfway between vertical or horizontal (i.e., at a 45-degree angle), or *horizontal* if the orientation was closer to horizontal than 45 degrees. Figure 1 illustrates three possible airbag placement/module orientation configurations. It should be noted that module orientation is not synonymous with deployment direction, which is necessarily three dimensional in all cases.

Figure 1
Passenger Airbag Configuration Nomenclature



Dummy positioning: Three test series were conducted to place the 6-year-old child Hybrid III dummy, restrained by a lap/shoulder belt in the right front passenger seat, at different locations relative to the airbag. For each vehicle, the passenger seat was positioned according to manufacturer's compliance testing specifications for seat back angle, seat height, and seat pan angle.

The first test series was intended to represent a normal seating position. The seat was adjusted to its forwardmost longitudinal locking position in the seat track. The dummy was centered laterally in the seat and pushed back until its buttocks contacted the seat back and its back was against the seat back.

The second test series was intended to represent a mildly out-of-position condition. The seat was adjusted to its middle longitudinal position in the seat track. If the mid-track position was not a locking point in the seat's travel, the seat was pushed forward to the nearest lock. The dummy was seated upright and moved forward an amount such that the knees extended over the front edge of the seat cushion and the lower legs could extend downward freely over the front edge of the seat cushion. The dummy was moved inboard of the seat centerline just enough to allow the left hand to be placed on the vehicle's radio controls. If necessary, small amounts of masking tape were applied to lightly confine the hand to this position. For the third test series, the seat was adjusted to its rearmost longitudinal locking position in the seat track. The dummy was positioned normally in the seat with its buttock and back against the seat back.

Table 2 reports the pretest face-to-airbag and chest-to-airbag clearance measurements for the first test series (seat fully forward, dummy in normal position). The face-to-airbag measurement was made from the nasion point on the dummy's face to the point on the airbag cover that was in the center of the cover laterally and closest to the dummy longitudinally. The chest-to-airbag measurement was made from a point on the chest that was approximately the center of the sternum to the same point on the airbag cover used for the face-to-airbag measurement. Table 3 reports for the second test series (seat mid-track, dummy out of position) the pretest face-to-airbag and chest-to-airbag clearance measurements along with measurements of the dummy's inboard lateral offset from the longitudinal centerline of the passenger seat. Table 4 reports the pretest face-to-airbag and chest-to-airbag clearance measurements for the third test series (seat fully rearward, dummy in normal position).

Dummy instrumentation: The Hybrid III dummy used in these tests simulates the size and weight of a 50th percentile 6-year-old child and is similar in design to the 50th percentile adult male Hybrid III dummy in widespread use. For the tests, a subset of the dummy's instrumentation that was determined to be relevant to airbag testing was monitored. The monitored parameters consisted of three head accelerations (one along the anterior-posterior (A-P) axis, one along the lateral-medial (L-M) axis, and one along the inferior-superior (I-S) axis), six upper neck loads (A-P and L-M shear forces, axial force, A-P and L-M bending moments, and the twisting moment about the I-S axis), and four chest parameters (A-P, L-M, and I-S accelerations and A-P compression).

Table 2
Pretest Dummy Clearance Measurements – First Test Series
(Seat Fully Forward, Dummy in Normal Position)

Vehicle	Face-to-Airbag (cm)	Chest-to-Airbag (cm)
1990 Lincoln Town Car	48	42
1996 Dodge Grand Caravan	60	58
1996 Ford Taurus	44	44
1996 Honda Accord	69	69
1996 Volvo 850	52	48

Table 3
Pretest Dummy Clearance Measurements – Second Test Series
(Seat Mid-Track, Dummy Out of Position)

Vehicle	Face-to-Airbag (cm)	Chest-to-Airbag (cm)	Lateral Offset from Seat Centerline (cm)
1990 Lincoln Town Car	29	34	8
1996 Dodge Grand Caravan	24	36	10
1996 Ford Taurus	30	36	4
1996 Honda Accord	36	48	8
1996 Volvo 850	31	39	9

Table 4
Pretest Dummy Clearance Measurements – Third Test Series
(Seat Fully Rearward, Dummy in Normal Position)

Vehicle	Face-to-Airbag (cm)	Chest-to-Airbag (cm)
1990 Lincoln Town Car	62	61
1996 Dodge Grand Caravan	69	68
1996 Ford Taurus	65	68
1996 Honda Accord	87	89
1996 Volvo 850	74	75

Data were collected at 10,000 samples per second. Head accelerations and neck shear forces were filtered to Society of Automotive Engineers Channel Frequency Class (SAE CFC) 1000 (SAE, 1988). Neck bending moments were filtered to SAE CFC 600, and chest accelerations and compression were filtered to SAE CFC 60.

Neck flexion/extension bending moments were measured on the Hybrid III dummy at a point 17.88 mm above the location of the occipital condyle. The flexion/extension moments therefore were translated to the occipital condyle location by subtracting the moment (in Nm) induced by the A-P shear force (in N) as

$$\text{occipital } M_{A-P} = M_{A-P} - [0.01788(F_{A-P})].$$

Neck injury indices were calculated for four combinations of neck loading: tension-extension, tension-flexion, compression-extension, and compression-flexion. These indices were developed by NHTSA (Kleinberger et al., 1998) to evaluate the injury risk associated with axial loading and flexion/extension bending moments acting simultaneously on the neck.

Combined thoracic index (CTI), a normalized chest injury index also developed by NHTSA (Kleinberger et al., 1998), considers both chest acceleration and deflection in estimating injury risk and is calculated as

$$CTI = A_{\max}/A_{\text{int}} + D_{\max}/D_{\text{int}},$$

where A_{\max} is the maximum resultant chest acceleration (in m/s^2), D_{\max} is the maximum chest deflection, and A_{int} and D_{int} are intercept values for acceleration (85 g) and deflection (63 mm), respectively, for the 6-year-old child Hybrid III dummy. The chest injury assessment reference values (IARV) proposed by NHTSA require that the CTI be less than unity. The proposal also requires that chest deflection and resultant acceleration be less than their prescribed limits — 47 mm and 60 g, respectively — for the 6-year-old child Hybrid III dummy.

High-speed photography was used to record the airbag deployments. Two cameras, one at 2,000 frames per second and the other at 500 frames per second, were positioned perpendicular to the longitudinal axis of the vehicle and facing directly into the occupant compartment. A real-time camera at 24 frames per second also was used.

RESULTS

Dummy injury measures recorded during the third test series (seat fully rearward, dummy in normal position) were all extremely low. In most of these tests, the airbag made only slight contact with the dummy. Therefore, only results from the first (seat fully forward, dummy in normal position) and second (seat mid-track, dummy out of position) test series, in which the dummy's initial position was closer to the airbag, are presented.

Head injury measures: Tables 5a and 5b summarize the head injury measurements and respective IARVs (Kleinberger et al., 1998; NHTSA, 1996) for the first and second test series. Head accelerations generally reached their peak values early in the airbag interaction period as the airbag fabric first struck the dummy's head. Head accelerations exceeded the IARV of 80 g in both the normal- and out-of-position tests in the Dodge Grand Caravan and approached the IARV with a peak of 77 g in the out-of-position test in the Lincoln Town Car. The main acceleration pulses in these three tests were

of short duration, as evidenced by the large differences between the instantaneous maximum head acceleration and the 3 ms clip acceleration values. None of the tests exceeded 80 g for a duration exceeding 3 ms. Head injury criterion (HIC) results were low in all tests.

Table 5a
Head Injury Measurements – First Test Series
(Seat Fully Forward, Dummy in Normal Position)

	IARV	1990 Lincoln Town Car	1996 Dodge Grand Caravan	1996 Ford Taurus	1996 Honda Accord	1996 Volvo 850
Head acceleration (g)	80*	55	89	34	5	37
Head acceleration, 3 ms clip (g)	None	14	43	15	1	23
HIC – 36 ms interval (HIC-36)	1000**	105	136	19	0	36

Sources: *NHTSA, 1996; **Kleinberger et al., 1998

Table 5b
Head Injury Measurements – Second Test Series
(Seat Mid-Track, Dummy Out of Position)

	IARV	1990 Lincoln Town Car	1996 Dodge Grand Caravan	1996 Ford Taurus	1996 Honda Accord	1996 Volvo 850
Head acceleration (g)	80*	77	133	55	46	66
Head acceleration, 3 ms clip (g)	None	41	45	39	31	50
HIC – 36 ms interval (HIC-36)	1000**	82	287	173	48	335

Sources: *NHTSA, 1996; **Kleinberger et al., 1998

Neck injury measures: Tables 6a and 6b summarize the neck injury measurements and respective IARVs (Kleinberger et al., 1998) for the first and second test series. The only normal-position test to produce large neck loads was in the Lincoln Town Car. This car’s airbag induced an extension moment of 35 Nm, which caused the compression-extension index to exceed the IARV of 1.00. The high compression and extension loads in this test occurred as the airbag neared full inflation. At this time, the airbag was both on top of the dummy’s head, which may account for the high neck compression, and under the chin, which probably caused the 35 Nm extension moment. Neck loading was not severe in any other normal-position test.

Two out-of-position tests resulted in neck injury indices that exceeded the IARVs. In the Lincoln Town Car, a large extension moment (46 Nm) resulted in high tension-extension and compression-extension indices. In this test, the airbag appeared to force the dummy’s chin upward while the head was in contact with the seat back. In the Dodge Grand Caravan, axial forces and A-P moments were all high, resulting in tension-flexion and compression-extension indices that exceeded the IARVs. In this test, the timing of the neck loading peaks, combined with a review of the high-speed film, indicated the airbag first induced high flexion moments in the neck by loading the lower face. Further inflation of the airbag pushed the dummy’s face upward with the neck still in a flexed state, applying

Table 6a
Neck Injury Measurements – First Test Series
(Seat Fully Forward, Dummy in Normal Position)

	IARV	1990 Lincoln Town Car	1996 Dodge Grand Caravan	1996 Ford Taurus	1996 Honda Accord	1996 Volvo 850
Shear force (N)						
A-P direction	None	-377	717	285	15	356
L-M direction	None	-198	208	192	8	-157
Axial force (N)						
Tension	2900	435	133	676	29	930
Compression	2900	981	340	169	66	112
Bending moment (Nm)						
Flexion	125	5	40	37	1	46
Extension	40	35	2	4	1	14
Neck indices						
Tension-extension	1.00	0.92	0.14	0.23	0.02	0.44
Tension-flexion	1.00	0.15	0.36	0.38	0.01	0.68
Compression-extension	1.00	1.10	0.39	0.10	0.02	0.62
Compression-flexion	1.00	0.34	0.43	0.30	0.03	0.68
Neck twisting moment (Nm)	None	-6	-14	32	0	-16

Table 6b
Neck Injury Measurements – Second Test Series
(Seat Mid-Track, Dummy Out of Position)

	IARV	1990 Lincoln Town Car	1996 Dodge Grand Caravan	1996 Ford Taurus	1996 Honda Accord	1996 Volvo 850
Shear force (N)						
A-P direction	None	-516	750	-681	447	-1283
L-M direction	None	-149	747	310	-207	-597
Axial force (N)						
Tension	2900	320	1954	1671	664	1138
Compression	2900	1113	2100	1262	348	1680
Bending moment (Nm)						
Flexion	125	8	90	63	34	21
Extension	40	46	39	19	17	24
Neck indices						
Tension-extension	1.00	1.14	0.97	0.78	0.47	0.63
Tension-flexion	1.00	0.11	1.33	0.84	0.32	0.39
Compression-extension	1.00	1.44	1.27	0.47	0.42	0.63
Compression-flexion	1.00	0.38	0.88	0.87	0.27	0.68
Neck twisting moment (Nm)	None	-11	23	26	-11	27

significant tension forces to the neck. The dummy then was forced rearward and inboard until its back contacted the seat back, but its head traveled between the two front seats, causing an extension moment of 39 Nm (just less than the IARV of 40 Nm). Finally, the top of the dummy's head struck the side of the driver seat, causing significant neck compression. In the out-of-position test in the Honda Accord, neck indices were notably low, all less than 0.5.

Chest injury measures: Tables 7a and 7b summarize the chest injury measurements and respective IARVs (Kleinberger et al., 1998) for the first and second test series. None of these measurements indicates a serious risk of significant injury.

Table 7a
Chest Injury Measurements – First Test Series
(Seat Fully Forward, Dummy in Normal Position)

	IARV	1990 Lincoln Town Car	1996 Dodge Grand Caravan	1996 Ford Taurus	1996 Honda Accord	1996 Volvo 850
Chest acceleration, 3 ms clip (g)	60	9	25	7	1	14
Chest compression (mm)	47	5	32	1	0	2
Combined thoracic index (CTI)	1.00	0.19	0.80	0.10	0.01	0.20

Table 7b
Chest Injury Measurements – Second Test Series
(Seat Mid-Track, Dummy Out of Position)

	IARV	1990 Lincoln Town Car	1996 Dodge Grand Caravan	1996 Ford Taurus	1996 Honda Accord	1996 Volvo 850
Chest acceleration, 3 ms clip (g)	60	13	36	19	15	19
Chest compression (mm)	47	14	6	3	6	4
Combined thoracic index (CTI)	1.00	0.38	0.52	0.27	0.27	0.29

SUMMARY

Two Dodge Grand Caravan tests (normal and out-of-position) generated instantaneous head accelerations exceeding the IARV of 80 g. These acceleration pulses were of extremely short duration and may be indicative of relatively high fabric velocity imparting a *slapping*-type impulse to the head. The HICs were well below the IARV of 1000 in all tests, as would be expected from such short acceleration pulses.

Three tests resulted in neck indices exceeding the IARVs of 1.00. In the out-of-position test in the Lincoln Town Car, both the tension-extension and compression-extension IARVs were exceeded, as was the extension moment IARV of 40 Nm. In the out-of-position test in the Dodge Grand Caravan, both the tension-flexion and compression-extension IARVs were exceeded. This test produced high tension, compression, flexion, and extension loads, although none individually exceeded its IARV. The dummy was forced rearward and inboard until its back contacted the seat back, but its head traveled between the two front seats, causing a high extension moment. The top of the dummy's head then struck the side of the driver seat, causing significant neck compression. This test illustrates the possibility of significant injuries being caused by contact with interior structures as a result of the airbag propelling the child about the vehicle's interior. The only normal-position test to generate a neck index greater than its IARV was in the Lincoln Town Car, with a compression-

extension index of 1.10. Neck compression forces, which are not widely associated with real-world airbag-induced injuries to children, were higher than expected and, in many cases, were higher than tension forces in a given test.

None of the tests generated significant chest injury measurements. This result is consistent with real-world experience to date. Of 68 airbag injury and fatality cases involving forward-facing children under investigation by NHTSA, only 5 reportedly involve thoracic or abdominal injuries.

The dummy's position in the out-of-position tests was chosen as an example of an orientation that would not be uncommon for even a lap/shoulder-belted child. The high neck injury indices in the out-of-position tests in the Lincoln Town Car and Dodge Grand Caravan indicate that even a lap/shoulder-belted child in a front passenger seat can be endangered by the airbag if seated improperly. Moreover, it should be noted that the risk to a child in this position in a real crash is even greater due to the likelihood of preimpact braking, which could place the child even closer to the deploying airbag.

REFERENCES

Cammisa, M.X. and Ferguson, S.A. 1998. Survey of drivers' attitudes toward airbags and deactivation. *Journal of Traffic Medicine* 26:115-24.

Insurance Institute for Highway Safety. 1999a (updated 29 July). Safety facts: airbag statistics. Arlington, VA. Available: http://www.highwaysafety.org/safety_facts/airbags/stats.htm. Last accessed: 11 Sept. 1999.

Insurance Institute for Highway Safety. 1999b (updated 20 Aug.). State laws: child restraint, belt laws. Arlington, VA. Available: http://www.highwaysafety.org/safety_facts/state_laws/restrain.htm. Last accessed: 11 Sept. 1999.

Kleinberger, M.; Sun, E.; Eppinger, R.; Kuppa, S.; and Saul, R. 1998. Development of improved injury criteria for the assessment of advanced automotive restraint systems. Washington, DC: National Highway Traffic Safety Administration.

National Highway Traffic Safety Administration. 1982. Child restraint/passenger airbag interaction analysis, final report (DOT HS-808-004). Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. 1996. Techniques for developing dummy protection reference values, event report. Washington, DC: U.S. Department of Transportation.

Society of Automotive Engineers. 1988. Instrumentation for impact test – SAE recommended practice J211. Warrendale, PA.

Zuby, D.S. and Powell, M.R. 1999. Testing of passenger airbags with 12-month-old infant CRABI dummy to assess injury risk to restrained infants. Arlington, VA: Insurance Institute for Highway Safety.