Injury Risk and Seating Position for Fifth-Percentile Female Drivers — Crash Tests with 1990 and 1992 Lincoln Town Cars

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ABSTRACT

A series of 35 mi/h barrier crash tests were conducted to assess the head, neck, chest, and upper leg injury likelihood for fifth-percentile female drivers for both forward and rearward seating positions. One test was conducted with the dummy in a forward position with a driver airbag, two tests with the dummy in the same position and the airbags deactivated, and two tests with the dummy in a rearward seating position with airbags. Pedal extenders, which were installed in the rearward position tests, allowed the rearward position to be judged reasonable for driving by a person of similar stature.

Measurements from the dummy's head indicated head injury risk was low in all crashes, but a comparison of the force distribution offered by the airbags and unprotected steering wheels indicated that substantial facial fractures were likely without the airbags. The measured neck tension forces exceeded reference values in the forward position test with airbag and one of the forward position tests without airbag.

INTRODUCTION

There is concern that the driving positions chosen by some small stature drivers, especially women, put them so close to the steering wheels that they can be at risk of a significant injury from an inflating airbag. In a series of 35 mi/h barrier crash tests, the head, neck, chest, and upper leg injury likelihood for fifth-percentile female drivers was assessed for forward and rearward seating positions in vehicles with and without driver airbags.

METHODS

Five crash tests were conducted with an instrumented Hybrid III fifth-percentile dummy: three with the dummy in a forward seating position and two with the dummy in a rearward seating position. The airbags were active for one of the forward position tests but were deactivated for the other two tests. The airbags were active for the rearward position tests (Table 1).

Table 1
Test Series Matrix

	Airbag Active	Airbag Deactivated
Forward driver seat position	1	2
Rearward driver seat position (with pedal extenders)	2	None

For the airbag/forward position test, the dummy was positioned in the driver seat with the lap/shoulder belt fastened. The driver seat's longitudinal position was determined by allowing an adult female volunteer of similar height and weight as the dummy to position the seat to what she considered the closest "comfortable" driving position, though it was further forward than she would have chosen for driving. This position was 1 cm aft of the forwardmost seat position and 23 cm forward of the rearmost position, resulting in a chest-to-steering wheel clearance measurement of 17 cm for the dummy.

For both no airbag/forward position tests, the dummy was positioned in the driver seat with the lap/shoulder belt fastened. Both the driver and passenger airbags were deactivated by disconnecting the wires that supply power to the airbag modules. The driver seat was positioned according to the seat position determined for the airbag/forward position test.

For both airbag/rearward position tests, the dummy was positioned in the driver seat with the lap/shoulder belt fastened and both airbags active. The driver seat was positioned to its rearmost position, resulting in a chest-to-steering wheel clearance measurement that averaged 32 cm for both tests.

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Pedal extenders, manufactured by Easy Rider Pedal Extensions, were fitted to the vehicles' accelerator and brake pedals. These extensions moved the pedals' foot contact surfaces approximately 11 cm rearward of their normal positions, allowing the dummy's feet to easily contact the extended pedals. The same adult female volunteer found this seating position acceptable with the extended pedals. Two tests were conducted with this condition.

Late-model Lincoln Town Cars were used as test vehicles: 1992 model year cars were used for the first airbag/rearward and first no airbag/forward position tests, and 1990 model year cars were used for the second airbag/rearward, airbag/forward, and second no airbag/forward position tests. All driver and passenger doors were removed to facilitate filming of the dummy/airbag and dummy/steering wheel interactions. The weights of all test vehicles were equated by adding ballast to closely match the weight of the first vehicle tested (1,801 kg).

Target test speeds were nominally 56.3 km/h (35 mi/h). The actual impact speeds for the five tests are shown in Table 2. The impact barrier was rigid, and the vehicles impacted it perpendicularly with full engagement of their front ends.

Table 2
Test Vehicle Impact Speeds

Test Condition	Speed (km/h)
Airbag, forward position	56.2
No airbag, forward position (1)	56.0
No airbag, forward position (2)	56.0
Airbag, rearward position (1)	56.0
Airbag, rearward position (2)	56.2

RESULTS

Head: The head injury measurements recorded during the test series are shown in Table 3. The head injury criterion (HIC) was less than the injury reference values, whether calculated over 36 ms (HIC) or 15 ms (HIC-15), for all tests. However, both the HIC and the maximum head acceleration results were much lower for the airbag/forward position test. Although there was a spike of 86 g in the head acceleration data during this test, its short duration (less than 1 ms) suggested it most likely was caused by inadvertent looseness in the dummy's head/neck joint pivot. Consequently, it was disregarded from the evaluation of head injury risk for this test. Head injury results were highest for the first no airbag/forward position test.

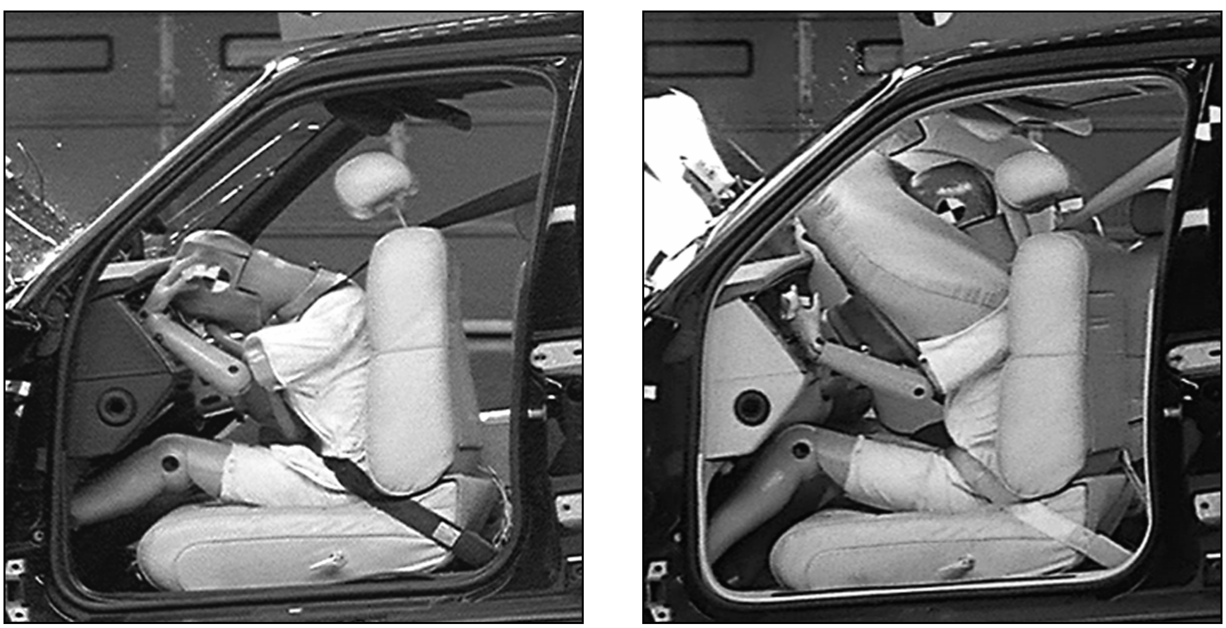
Table 3
Head Injury Data

	Reference Value	Test Conditions: Airbag, forward position	No airbag, forward position (1)	No airbag, forward position (2)	Airbag, rearward position (1)	Airbag, rearward position (2)
Maximum acceleration (g)	––	45	71	60	69	67
HIC	––	317	846	613	735	650
HIC-15	1113*	171	467	341	503	490
Maximum acceleration (3 ms clip, g)	––	43	69	56	67	66

Reference values for head injury data other than HIC-15 were not available.
*Nahum, A.M. and Melvin, J.W. (Eds.) 1993. *Accidental Injury: Biomechanics and Prevention*. New York, NY: Springer-Verlag.

Although the HIC did not exceed the reference values for significant head injury risk during any of the tests, the dummy's face contacted and bent the steering wheel rims during both no airbag/forward position tests (Figure 1). This concentration of load to more fragile facial bones, as opposed to distributed loading to the face and stronger skull bones provided by airbags, suggests a much different and higher face/head injury risk due to the absence of airbags. The potential increase in risk was estimated by calculating the forces acting on the dummy's face, with and without airbags, and comparing those calculated forces with values associated with facial fracture from the biomechanical literature.

Figure 1
First No Airbag/Forward Position Test and Airbag/Forward Position Test



An estimate of the force acting on the dummy's face by the steering wheel rim or airbag was made by subtracting the force applied by the neck from the total force acting on the head, which was estimated by multiplying the measured head acceleration by the mass of the dummy's head (3.7 kg). Only the longitudinal and vertical components of the dummy's head acceleration were considered because only those components of the neck force were recorded by the upper neck load cell. This two-dimensional analysis is reasonable for the full-frontal crash condition in which the lateral forces acting on the dummy are small compared with the forces acting in other directions. After subtracting the neck force from the respective components of the total head force, the resultant force was calculated. Table 4 shows the various force peaks that resulted from these calculations.

Table 4
Calculated Facial Forces

Test Condition/Contact Area	Time (ms)*	Calculated Force (N)
No airbag, forward position (1)		
Mandible/maxilla (first steering wheel contact)	79	1,363
Nasion/zygoma	111	1,563
No airbag, forward position (2)		
Mandible/maxilla (first steering wheel contact)	70	1,856
Maxilla	81	1,968
Airbag, forward position		
Entire face	55	1,818

*From onset of crash

Nahum et al. (1993) have associated fractures of the maxilla with forces as low as 778 N when struck by a 6 cm^2 impactor, and fractures of the zygoma were associated with forces as low as 890 N. Given the curvature of both the face and the steering wheel rim, the contact area appears comparable to the 6 cm^2 area of Nahum's impactor. However, even if the contact area were as much as 50 percent larger, it appears very probable that a human occupant would have sustained substantial facial fractures during the no airbag/forward position tests.

The injury mechanism described by this analysis is not merely hypothetical but has been observed in investigations of real-world crashes. A detailed study of 15 restrained drivers, fatally injured in frontal crashes with head injuries of Abbreviated Injury Scale (AIS) 4 or greater, found that steering wheels were the sources of head injuries for 9 of these drivers, and that 13 drivers suffered their head injuries from loading to the facial bones (Gloyns et al., 1993).

Similar calculations were performed using head acceleration data from the airbag/forward position test. As shown in Table 4, these calculations yielded force values similar to those from the no airbag/forward position tests, with a maximum value of 1,818 N at 55 ms. During the airbag/forward position test, however, the force was distributed over the entire face. To compare this force level with the observations of Nahum et al. (1993), the peak force was divided by the approximate frontal area of the dummy's face (125 cm^2) and multiplied by the 6 cm^2 area of the Nahum impactor. This yielded a peak force of 87 N for the airbag/forward position test, much lower than any of the fracture loads observed by Nahum et al.

Neck: The neck injury measurements recorded during the test series are shown in Table 4. During the airbag/forward position test, the head/neck joint problem also affected the neck axial tension data. An anomalous spike of very short duration (less than 1 ms) with a magnitude of 2,478 N was recorded at exactly the same time as the anomalous spike in the head acceleration data (51 ms). The neck tension spike also was disregarded since it was most likely the result of the same problem that affected the head acceleration data. The resulting peak axial tension force of 1,490 N was the lowest of all tests. During both this test and the first no airbag/forward position test, neck extension moments exceeded the reference value of 31 Nm. However, the neck did not appear hyperextended during the times these high moments were recorded. Thus, the measurements did not represent a hyperextension injury risk and were disregarded.

Table 4
Neck Injury Data

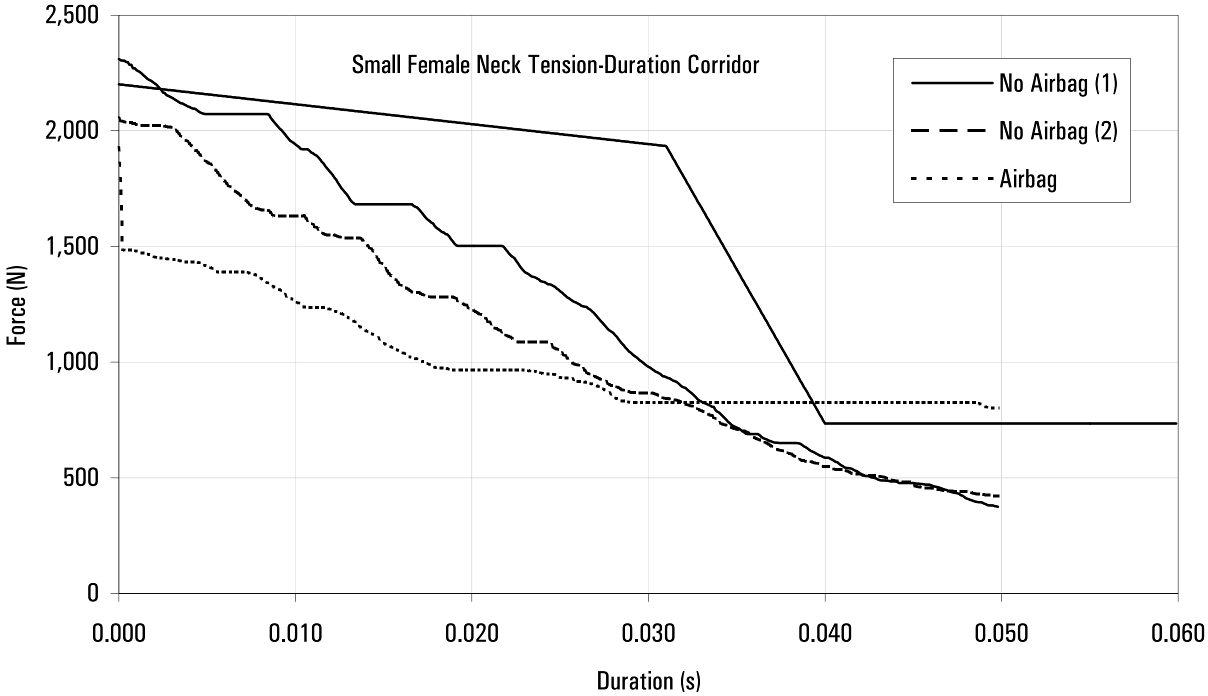
		Test Conditions				
	Reference Value	Airbag, forward position	No airbag, forward position (1)	No airbag, forward position (2)	Airbag, rearward position (1)	Airbag, rearward position (2)
Maximum axial tension (N)	2,200	**1,490***	**2,312**	2,063	1,995	1,645
Maximum axial compression (N)	2,700	617	36	517	434	583
Maximum negative A-P shear force (N)	−2,100	−179	−105	−294	−144	−200
Maximum positive A-P shear force (N)	2,100	520	657	398	269	290
Maximum flexion moment (Nm)	104	13	28	39	10	17
Maximum extension moment (Nm)	31	34**	32*	25	18	18

*Force-duration corridor was exceeded

**The neck was not hyperextended when this measurement was recorded; hence, this result may not indicate the risk of a hyperextension injury.

The only reliable indication of neck injury risk for the fifth-percentile female occurred during two of the forward position tests, when the neck tension force-duration corridor was exceeded. During the airbag/forward position test, an axial tension of approximately 827 N was sustained for more than 40 ms (Figure 2). During the first no airbag/forward position test, the axial tension reference was exceeded by an even greater amount than during the airbag/forward position test. The second no airbag/forward position test produced a neck tension which remained within the recommended force-duration corridor. All other neck injury measurements recorded during the second no airbag/forward and two airbag/rearward position tests were quite low and represented little risk of significant neck injury.

Figure 2
Neck Tension Load-Duration Data
Forward Seating Position Tests



Chest: The chest injury measurements recorded during the test series are shown in Table 5. All chest measurements were low and represented little risk of significant injury.

Table 5
Chest Injury Data

	Reference Value	Test Conditions: Airbag, forward position	No airbag, forward position(1)	No airbag, forward position (2)	Airbag, rearward position (1)	Airbag, rearward position (2)
Rib compression (mm)	50	32	31	34	30	30
Peak vector resultant spine acceleration — (3 ms clip, g)	60	44	46	48	51	47
Viscous criterion (m/s)	1.0	0.2	0.2	0.3	0.1	0.2

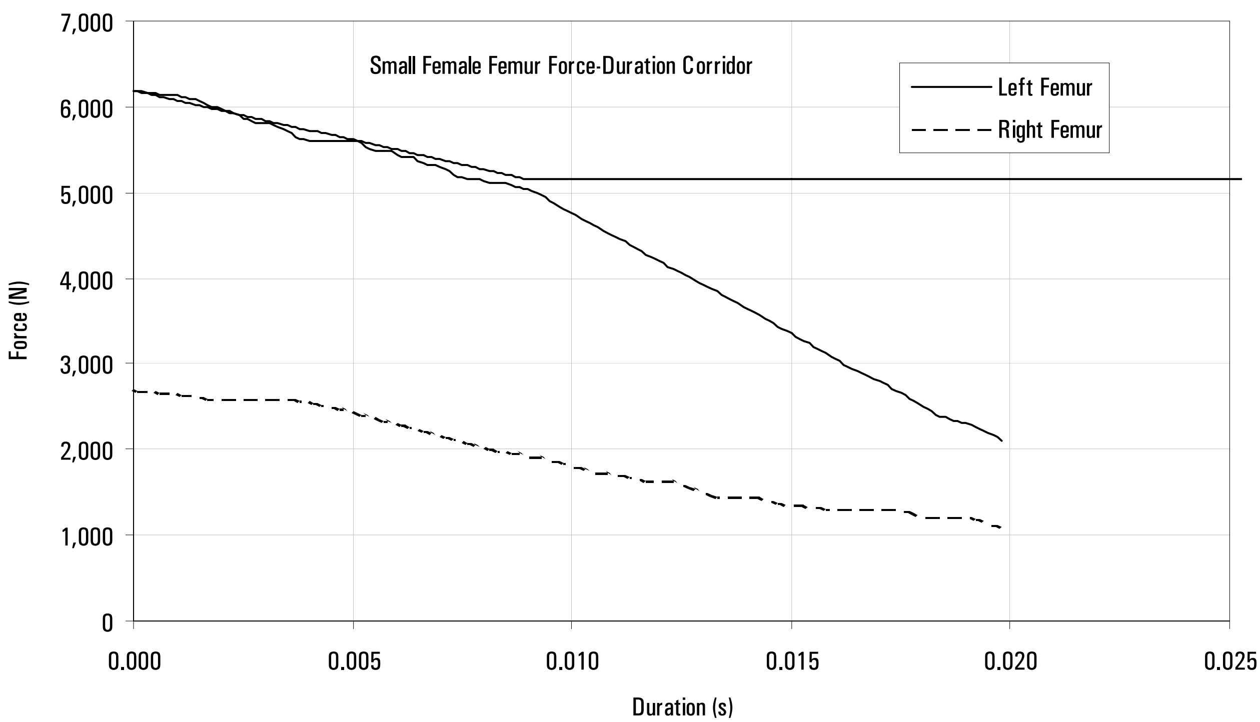
Legs: The leg injury measurements recorded during the test series are shown in Table 6. Only the second airbag/rearward position test indicated any likelihood of significant leg injury as the left femur axial force slightly exceeded the recommended force-duration corridor (Figure 3). Comparison of the second airbag/rearward position test film with the airbag/forward and no airbag/forward position test films indicated the increased clearance between the dummy's knees and the vehicles' knee bolsters may have allowed the knees to reach greater velocity relative to the knee bolsters prior to contact. This could account for the higher left femur forces recorded during the second airbag/rearward position test than during the airbag/forward and no airbag/forward position tests. The left femur forces were higher for the rearward position tests than for any of the forward position tests.

Table 6
Leg Injury Data

		Test Conditions				
	Reference Value	Airbag, forward position	No airbag, forward position (1)	No airbag, forward position (2)	Airbag, rearward position (1)	Airbag, rearward position (2)
Left femur maximum axial force (N)	6,200	5,508	4,163	4,349	5,839	**6,189***
Right femur maximum axial force (N)	6,200	3,746	5,231	2,939	2,353	2,700

*Force-duration corridor was exceeded

Figure 3
Femur Force-Duration Data
Second Rearward Seating Position Test



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