FIELD DATA ON HEAD INJURIES IN SIDE AIRBAG VEHICLES IN LATERAL IMPACT

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ABSTRACT

Field data on side airbag deployments in lateral crashes and head injuries have largely remained anecdotal. Consequently, the purpose of this research was to report head injuries in lateral motor vehicle impacts. Data from the National Automotive Sampling System files were extracted from side impacts associated with side airbag deployments. Matched pairs with similar vehicle characteristics but without side airbags were also extracted. All data were limited to the United States Federal Motor vehicle Safety Standards FMVSS 214 compliant vehicles so that the information may be more effectively used in the future. In this study, some fundamental analyses are presented regarding occupant- and vehicle-related parameters.

THE UNITED STATES Lateral Impact New Car Assessment Program (LINCAP) and Federal Motor Vehicle Safety Standards (FMVSS) 214 compliance tests focus on the torso and pelvic regions through thoracic trauma index (TTI) and pelvic acceleration injury criteria. TTI values of 85 and 90 g for four- and two-door vehicles and pelvic accelerations of 130 g are cutoffs. In contrast, no metric is currently specified for head injury, although the widely adopted head injury criteria (HIC) is used in frontal impact standards. This is due to the lack of countermeasures at the time of promulgation of 214 standards. The National Highway Safety Administration (NHTSA) gathers head accelerations from LINCAP tests using the SID-H3 dummy, although it is not directly used in the star-rating system. Table 1 includes a description of the star-rating system, focused on chest injuries and based on the thoracic trauma index. The index is computed using accelerations of the upper and lower ribs and spine. Pelvic accelerations of 85 g for four- and 90 g for two-door vehicles are thresholds, although stars are not associated with this biomechanical variable. Since April 2002, NHTSA has noted safety concerns and one of those is specific to head injuries in LINCAP crash test. A remark informs the consumer about the potential for head injury in tests with HIC greater than 1000 (Figure 1).

Table 1: Star-rating system in US NCAP test

Rating	Description
1-star	Less than 5% chance of serious torso injury
2-stars	6 to 10% chance of serious torso injury
3-stars	11 to 20% chance of serious torso injury
4-stars	21 to 25% chance of serious torso injury
5-stars	Greater than 10% chance of serious torso injury

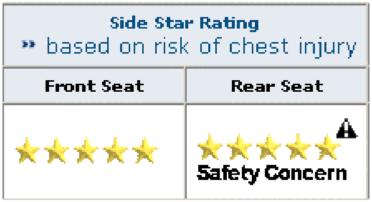

Figure 1: Scheme used in LINCAP tests indicating a higher likelihood of head injury if the test results in HIC > 1000.

Motor vehicle manufacturers have developed and are using side or head curtains or a combination of torso-head bags as a countermeasure for head injury protection. Inflatable tubular structures are included in the side curtain category. Like the frontal airbags in the 1990s, these systems are gaining popularity in the United States; escalated public awareness is also a factor. Despite increasing availability and awareness issues, real-world side impact studies in vehicles with side airbag deployments are limited (Bauer et al., 2000, Dalmotas et al., 2001, Kirk and Morris, 2003, Langwieder et al., 1998). Head injury studies are even more anecdotal. National databases are valuable as they include broad-based information. The present study used NASS files to analyze head injuries in lateral impacts.

A recent study using National Automotive Sampling System (NASS) concluded that front seat occupants of vehicles with side airbags had a risk of injury similar to occupants of vehicles without side airbags (McGwin, Metzger et al. 2003). In the cited study, it was assumed that all vehicles with side airbags as optional equipment are equipped with side airbags. Validity of this assumption was not discussed. In addition, the study did not refer to the different types of airbags. Such information will be valuable to the biomechanics community. The objective of the present research is therefore, to focus on head injuries and side airbags in lateral impacts, and, from the largest and most widely used database, provide occupant- and vehicle-based information to the automotive community.

METHODS

The study was conducted in two phases. Cases were selected from 1994-2004 NASS files. Only cases with head injury were used, and although no constraints were placed on occupant position, and as described later in the results, all were near side occupants. The case selection criteria were such that the occupant should be involved in a side impact collision, and the primary impact should be in the lateral direction resulting in the deployment of a side airbag, irrespective of the type, i.e., torso alone, side or head curtain or inflatable tubular structure, or a combination of torso and side curtain. In addition, the vehicle involved in the crash must be compliant according to 214 standards. For left side impacts, the principal direction of force (PDOF) was between 230 and 310 degrees, and for right side impacts, it was between 50 and 130 degrees. Other selection criteria included passenger cars, light trucks, and vans. Outboard front seat occupants, driver and passenger, were included. Rollovers and full ejection events were excluded. No limitation was placed on the age of the occupant. AIS 1990 scoring scheme used in the analysis was limited to severity level two plus. In addition, the source of injury and confidence in injury assignments were extracted on a case-by-case basis. Occupant demographics such as age, height, weight, gender, and body mass index were obtained. Results are presented on raw data analyses because of the focus of the study. In the second phase of the study, as a parallel effort, cases were extracted from lateral impact crashes involving the same make, model, and year of the vehicle but without side airbags. This phase was intended to serve as a matched pair comparison with data obtained in the previous phase. As in phase one, only cases with head injuries were extracted. Other selection and inclusion criteria were identical to the previous phase.

RESULTS

In the first phase, out of the 61 raw cases with side airbag deployments, 23 cases had head injuries. The mean age, height, and weight were: 46 years, 174 cm, and 82 kg. Of the 23 cases, four were right side and 19 were left side impacts. The principal direction of force ranged from 250 to 310 for left side and 60 to 90 degrees for right-side impacts. The mean change in velocity was 31.5 km/h, and body mass index was 27.2 kg/m^2 for the entire group. Table 2 provides a summary of data. Mean data for left-side impacts were age 47 years, height 173 cm, weight 78 kg, change in velocity 31.8 km/h, and body mass index 26.2 kg/m^2.

When data were split based on gender, there were nine male and 14 female occupants in the group. The mean age, height, and weight data were 47 years, 169 cm, and 61 kg, for females. For males, these data were: 45 years, 176 cm, and 96 kg. The principal direction of force ranged from 280 to 300 for impacts involving females, and 60 to 300 degrees for impacts involving males. The mean change in velocity was 37.3 km/h and body mass index was 21.4 kg/m^2 for females; these data were 27.4 km/h and 30.8 kg/m^2 for males. Table 3 provides a detailed summary of these data. Out of the 23 occupants, 10 were male drivers, nine were female drivers, and four were male occupants on the right front outboard passenger seat. Tables 4 and 5 provide data on an individual basis.

Table 2: Summary of side airbag deployment cases as a function of position. SD denotes standard deviation.

Parameter	Mean	SD	Minimum	Maximum
Age (years)	46.1	23.7	14	93
Driver	47.1	23.2	16	93
Passenger	41.3	28.9	14	79
Height (cm)	173.5	6.5	160	188
Driver	172.8	5.7	160	180
Passenger	176.5	9.5	165	188
Weight (kg)	82.4	29.1	48	159
Driver	78.5	27.5	48	159
Passenger	99.0	34.0	52	133
Body mass index (kg/m^2)	27.2	9.0	15.8	51.9
Driver	26.2	8.8	15.8	51.9
Passenger	31.4	10.2	19.1	43.4
Change in velocity (km/h)	31.5	12.5	12	70
Driver	31.8	12.9	12	70
Passenger	30.0	13.1	15	39
PDOF	250.0	85.8	60	310
Driver	287.9	15.5	250	310
Passenger	70.0	14.1	60	90

Extending the analysis and using the type of side airbag as a denominator, there were 12 torso bags and 11 combination bags out of which nine were torso-head, one was a torso-inflatable tubular structure, and the other was classified as a torso-side curtain airbag. All right front seat passengers were wearing a lap and shoulder belt, and three of the 19 drivers were unbelted (Table 4). There were ten (44%) AIS 2, six (26%) AIS 3, four (17%) AIS 4, and one (4%) case each AIS 5 and 6, and the remaining was of unknown severity head injury. Twenty-six percent (six cases) had only head injuries. Of these cases, one-third (two cases) had AIS 4 injuries, cerebrum concussion and cerebrum diffuse axonal injury with intra-ventricular and subarachnoid hemorrhages, and two-thirds (four cases) had AIS 2 injuries, amnesia and dizziness/vomiting subsequent to impact. Left B-pillar was identified as the responsible injury source for AIS 4 trauma. Noncontact was identified as the injury source in three-quarter of cases with amnesia or dizziness, and in the remaining, right B-pillar was the cause.

Table 3: Summary of side airbag deployment cases as a function of gender.

Parameter	Mean	SD	Minimum	Maximum
Age (years)	46.1	23.7	14	93
Female	47.1	24.9	16	93
Male	45.4	23.8	14	79
Height (cm)	173.5	6.5	160	188
Female	169.4	6.0	160	178
Male	176.0	5.5	165	188
Weight (kg)	82.4	29.1	48	159
Female	61.1	14.9	48	91
Male	95.5	28.2	52	159
BMI (kg/m^2)	27.2	9.0	15.8	51.9
Female	21.4	5.6	15.8	32.2
Male	30.8	9.0	19.1	51.9
Change in velocity (km/h)	31.5	12.5	12	70
Female	37.3	14.9	25	70
Male	27.4	9.2	12	39
PDOF	250.0	85.8	60	310
Female	292.2	13.9	280	310
Male	222.9	101.5	60	300

In right side impacts, sources responsible for trauma were right interior surface three cases and right B-pillar in the remaining case. In these impacts, injury source confidence assignments were equally divided between certain and probable categories. Multiple sources were identified in left side impacts. Noncontact sources accounted for 32% (six cases) and left B-pillar accounted for 21% of trauma (four cases). The hood of the bullet vehicle was the source in another 21% of the cases. Specific case-by-case descriptions are shown in table 5. Injury source identifications were assigned certain or probable in 90% (17 cases) of the cases by the investigating team, reflecting the confidence in the assignments.

Table 4: Summary of side airbag deployment cases.

ID	Curb wt	Model	PDOF	CDC	DV	Gender	Age	Height	Weight	Airbag	Airbag	Belt use
	(kg)	Year			km/h		(years)	(cm)	(kg)	Location	Type	
1	1,821	2000	270	89LPAW4		Male	17	173	68	seatback	Torso/head	None
2	1,819	1997	280	09LYAW3		Female	45	160	57	door	Torso	Lap+shoulder
3	1,158	2000	290	90LPAW6		Male	41	178	95	seatback	Torso/head	Lap+shoulder
4	1,618	2000	300	10LYEW3	32	Male	62	175	159	seatback	Torso	Lap+shoulder
5	1,230	1999	280	09LYEW3	31	Female	20	175	54	seatback	Torso	Lap+shoulder
6	1,500	2002	250	08LPEW2	12	Male	78	180	93	seatback	Torso/head	Lap+shoulder
7	1,393	2000	310	10LYEW4	37	Female	43	178	50	seatback	Torso/head	Lap+shoulder
8	1,158	2000	290	10LDAW3	70	Female	49	170	66	seatback	Torso/head	Lap+shoulder
9	1,308	2000	280	89LYAW4	30	Male	16	178	75	seatback	Torso	Lap+shoulder
10	1,791	1999	280	09LYEW3		Female	32			seatback	Torso/head	None
11	1,815	2003	290	10LYAW3	27	Male	76	170	98	seatback	Torso	Lap+shoulder
12	1,098	2003	310	10LYEW2	25	Female	49	168	73	seatback	Torso	Lap+shoulder
13	1,095	1998	270	09LDHW3	37	Male	36			seatback	Torso	Lap+shoulder
14	2,430	2001	300	10LYEW4	21	Male	65	175	104	seatback	Torso/head	Lap+shoulder
15	1,760	1997	280	09LYEW3	30	Female	77	168	91	seatback	Torso	Lap+shoulder
16	1,293	2000	290	10LPAW4	35	Male	28	180	75	seatback	Torso/head	Lap+shoulder
17	1,651	2000	300	10LPEW3	25	Male	52	173	79	seatback	Torso	Lap+shoulder
18	1,730	2001	290	10LYAW4	33	Female	93	163	50	seatback	Torso	None
19	1,470	2002	310	10LPAW3	35	Female	16	173	48	door/side rail	Torso-ITS	Lap+shoulder
20	1,618	2000	70	02RPEW3	36	Male	79	178	109	Seatback	Torso	Lap+shoulder
21	1,431	2001	90	03RZAW4		Male	48	188	102	seatback	Torso/head	Lap+shoulder
22	1,462	2002	60	02RYEW3	39	Male	24	175	133	seatback/side rail	Torso-curtain	Lap+shoulder
23	1,966	2002	60	02RZEW2	15	Male	14	165	52	seatback	Torso	Lap+shoulder

Table 5: Head Injury summary of side airbag deployment cases.

No	Injury description	MAIS	Injury source	Confidence
1	Scalp contusion, and minor superficial laceration, LOC, length unknown	2	Other vehicle or object	Probable
2	Basiliar skull fracture	3	Hood edge	Certain
3	Cerebrum, epidural hematoma and subdural hematoma, vault skull fx, LOC, Scalp lacerations	4	Left B-pillar	Probable
4	LOC, length unknown	2	Other noncontact source	Certain
5	Scalp abrasion and superficial minor laceration, lethargic on admission; No prior LOC	2	Left side interior surface	Possible
6	LOC, length unknown	2	Other noncontact source	Certain
7	Closed head injury died with out further evaluation	7	Unknown	Unknown
8	LOC less than one hour, scalp contusion	2	Roof left side rail	Probable
9	No LOC, but dizzy/vomiting	2	Other noncontact source	Probable
10	Cerebrum, SAH and small multiple contusions, same side	3	Left B-pillar	Probable
11	Cerebrum, SAHs, and single contusion NFS	3	Hood	Probable
12	No LOC but dizzy/vomiting	2	Other noncontact source	Probable
13	Cerebrum, DAI, Cerebrum, SAH and intraventricular hemorrhages, scalp abrasion, and laceration	4	Belt restraint B-pillar/door frame	Probable
14	Cerebrum, concussion	2	Other noncontact source	Probable
15	Brainstem contusion with hemorrhage, Cerebellum contusion, SDH, SAH, scalp contusion*	5	Left B-pillar	Probable
16	Cerebrum, intracerebral hemorrhage	4	Other vehicle or object	Probable
17	LOC, length unknown	2	Other noncontact source	Probable
18	Cerebrum, subarachnoid hemorrhage, scalp contusion and superficial minor laceration	3	Hood	Certain
19	Cerebrum, small subdural hemorrhage, subarachnoid hemorrhage	4	Hood edge	Probable
20	Cerebellum SAH	3	Right side interior surface	Probable
21	Brainstem laceration, Cerebrum contusions, at least one on each side	6	Right side interior surface	Probable
22	Cerebrum subarachnoid hemorrhages	3	Right side interior surface	Certain
23	Amnesia, awake on admission	2	Right B-pillar	Certain

*: *Injury source: seat back support, confidence: possible

In the second phase of the study, seventeen cases without side airbag deployments matched with side airbag deployed cases; a summary of is given in table 6. One was a right side impact and the remaining were left side impacts. The mean age, height, weight, and BMI for the entire group were: 42 years, 170 cm, 76 kg, and 26.2 kg/m^2. The mean change in velocity was 23 km/h. The principal direction of force for left side impacts ranged from 260 to 310 deg. Data as a function of gender along with standard deviations are shown in table 6. With the exception of one occupant, all were wearing lap and shoulder belts. Table 7 provides case-by-case details. It should be noted that numbers in the first columns of tables 7 and 8 refer to numbers in cases with side airbag deployments, shown in tables 4 and 5.

Table 6: Summary of cases without side airbag deployment.

Parameter	Mean	SD	Minimum	Maximum
Age (years)	42.1	19.9	16	82
Female	40.8	22.2	16	82
Male	44.5	16.5	32	77
Height (cm)	170.3	7.7	160	188
Female	167.0	6.8	160	178
Male	175.3	6.4	170	188
Weight (kg)	75.5	20.3	45	127
Female	64.9	11.1	45	77
Male	91.3	21.4	68	127
PDOF	277.1	47.4	100	310
Female	270.0	58.1	100	310
Male	290.0	11.0	280	310
BMI (kg/m^2)	26.2	6.0	16.9	42.4
Female	23.7	4.3	16.9	29.0
Male	29.6	6.7	23.5	42.4
Change in velocity (km/h)	23.0	9.4	14	41
Female	26.0	9.9	14	41
Male	18.0	6.1	14	30

Table 7: Summary of cases without side airbag deployment.

ID	Curb Weight (kg)	PDOF	CDC	DV (km/h)	Gender	Age (yrs)	Ht (cm)	Wt (kg)
5	1,256	290	70LYEW3	17	M	46	173	127
6	1,537	280	09LPEW2	16	F	20	163	50
7	1,393	290	10LFEW4	18	M	32	175	91
7	1,331	270	09LYAW3		F	20	178	
9	1,339	290	70LFEW4	19	F	43	165	70
10	1,761	280	10LYEW2	15	M	37	173	79
11	1629	310	10LYEW2	20	M	77	170	69
12	1,375	300	10L99999	28	F	61	163	77
12	1,175	280	09LDEW3	30	F	17	163	75
13	1,117	290	10LDAW3	35	F	29	170	72
13	1,095	290	10LPAW4	41	F	82		
14	1,761	290	10LYEW2	14	M	37	173	79
16	1,371	280	09LDEW2	30	M	38	188	104
16	1,304	260	09LYEW4	38	F	50	178	70
19	1,430	310	10L99999	24	F	16	163	45
22	1,435	100	03RYEW2	14	F	63	160	61
23	1,910	300	10LYEW2	15	F	48		64

Lap and shoulder belt used in all cases (exception #16 weight 1,304 kg). ID corresponds to the numbers in the first column in tables 3 and 4.

Head injury sources in the matched cases were attributed to other vehicle or object in one and left side pillar (A, B, roof rail) in a majority of cases; table 8 includes a summary of injuries, sources, AIS and confidence levels. In all but two cases, certain or probable confidence levels were determined for injury source assignments. Twenty four injuries were identified: 46% (11) with AIS 1, 12.5% (3) each with AIS 4 and 3, 25% (6) with AIS 2, and 4% (1) with AIS 5 trauma.

DISCUSSION

Field studies of side airbag deployed cases have largely remained anecdotal. Langwieder et al., described a side impact in a vehicle with thorax airbag and inflatable tubular structure, and the nearside front seat occupant injury was contusion and sprain to the arm (Langwieder, Hummel et al. 1998). From case reviews Kirk and Morris concluded that “further studies of airbag deployments are essential” (Kirk and Morris 2003). Dalmotas et al., stated “additional field collision data on side airbag systems are needed” (Dalmotas, German et al. 2001). Bauer et al., analyzed four side airbag cases and stated “a proper statistical sampling

Table 8: Head injury summary of non side airbag deployment cases.

No	MAIS	Description	Injury Source	Confidence
5	1	Awake post resuscitation on admission/Initial observation at scene	Other noncontact injury source	Probable
7	1	Awake post resuscitation on admission/ Initial observation at scene, scalp contusion	Left side window glass	Probable
7	2	Awake post resuscitation on admission with neuro deficit	Other noncontact injury source	Probable
9	2	Awake post resuscitation on admission with neuro deficit, scalp contusion	Left A-pillar	Possible
10	1	Awake post resuscitation on admission/ Initial observation at scene	Belt/B-pillar/door frame attachment	Probable
11	2	Awake post resuscitation on admission with neuro deficit	Other noncontact injury source	Probable
12	1	Scalp laceration minor, scalp contusion	Left side window glass	Probable
12	2	Awake post resuscitation on admission with neuro deficit	Roof left side rail	Certain
	1	Scalp contusion/subgaleal hematoma	Roof left side rail	Certain
13	2	Awake post resuscitation on admission with neuro deficit	Left B-pillar	Probable
13	5	LOC greater than 24 hours, facial laceration	Other vehicle or object	Possible
	4	Cerebrum hematoma/hemorrhage intracerebral	Other vehicle or object	Probable
	3	Basilar skull fracture, cerebellum contusion	Other vehicle or object	Possible
14	1	Headache or dizziness	Belt/ B-pillar/door frame attachment	Probable
16	1	Scalp contusion/subgaleal hematoma,	Steering wheel rim	Probable
16	4	Cerebrum hematoma/hemorrhage subdural small	Windshield	Possible
	2	Lethargic, stuporous, obtunded post resuscitation, upper skin extremity contusion	Left B-pillar	Probable
22	4	Cerebrum hematoma/hemorrhage subdural small	Belt/B-pillar/door frame attachment	Probable
	3	Cerebrum subarachnoid hemorrhage	Belt/B-pillar/door frame attachment	Probable
	1	Scalp laceration	Belt/B-pillar/door frame attachment	Probable

could not be achieved at this time," reflecting the anecdotal nature of field data (Bauer, Lange et al. 2000). The present study was conducted because these studies indicated a clear need to explore other databases.

In the present study, one case was associated with separate torso and curtain airbags, and another was associated with separate torso and inflatable tubular system. Combined torso and head airbags were involved in 39% (9) while torso alone was involved in 52% (12) of the cases (Table 3). One torso airbag was door-mounted. This system is phased out because of its aggressive nature and the potential for injuries to out-of-position occupants including children (Pintar, Yoganandan et al. 1999). The production or mitigation of head injuries in the combined torso/head airbag systems may be overrepresented in the present data because of its current availability in the fleet, a trend expected to shift towards separate torso and head (curtain or inflatable tubular structure) systems. The current study however, serves as a first step in the analysis of field performance of all types of side airbags in side impact crashes. The belted nature of the majority of occupants in this group reflects seatbelt use in the general population, and this trend will also likely continue.

Limitations include considerations of only outboard front seat occupants, and difficulty in determining position of the occupant at impact. The sample size of paired data limits statistical analysis aimed at determining the efficacy of side airbags (Tables 4-5 and 7-8). Caution must be exercised while generalizing the current results. An initial evaluation of data indicates that with increasing velocity, AIS levels increase, as expected. Torso and torso/head bags do not clearly decrease severity of head injuries. However, the separate system of torso and curtain appears to offer improved protection. These preliminary findings should be reinforced with additional data in the future.

As indicated earlier in the Introduction, McGwin et al., analyzed 1997-2000 nearside impact data and concluded that front seat occupants of vehicles with side airbags had a risk of injury similar to occupants of vehicles without side airbags; these results were found to be true even when data were adjusted for potentially confounding variables such as occupant demographics, belt use, seating position, and vehicle parameters (McGwin, Metzger et al. 2003).

However, it must be noted that, because of lack of information in the database, the authors of this paper assumed all vehicles with side airbags as standard/optional equipment to be equipped with the technology, and no distinctions were made between different types of airbags systems. This may dampen confidence of the conclusions from this previous study. In contrast, while not completely amenable to detailed statistical analyses to determine the efficacy due various factors discussed earlier, data from the current study, from a widely used national database, will supplement existing anecdotal information. It must be noted that, to the best knowledge of the authors, the present study provides the largest data on side airbag deployments in side impacts and compares with similar conclusions in vehicles without side airbags.

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