Appendix A: NASS-CDS data

NASS-CDS: is the National Automotive Sampling System, Crashworthiness Data System (www.nhtsa.dot.gov). It is a stratified multiphase, unequal selection probability sample of motor vehicle crashes that are prospectively selected for in-depth investigation. Most of the vehicles were towed from the scene because of damage. NASS-CDS data for calendar years 1994-2015 was evaluated for light vehicles with 1994+ model year (MY).

Rear Crashes: Rear impacts were defined with GAD1 ='B' and rollover (rollover ≤ 0) variables:

Analyzed variables: The following variables were assessed by crash severity:

- Crash severity was identified using delta V (DVTOTAL). The data was grouped by 0-<16, 16-<24, 24-<32, 32-<40, 40-<48, 48-<56, 56-<64 and 64+ km/h.
- Front seat occupants were determined as 15+ year old (15<=AGE<=110) non-ejected (EJECTION = 0) drivers (SEATPOS =11) and/or right-front passengers (SEATPOS =13).
- Belt use was identified using variables MANUSE (manual belt use) and ABELTUSE (automatic belt use).
    - Unbelted was defined as MANUSE ≤1 and ABELTUSE <1 or =2 for calendar years less than 2010 and as MANUSE = 0 or 1 for calendar years greater than 2009.
    - Belted was defined as MANUSE=4.
- Gender was identified using the SEX variable:
    - Male: SEX = 1.
    - Female: 1<SEX<7.
- Height and weight were identified using HEIGHT and WEIGHT variables
- BMI was assessed using the WEIGHT and HEIGHT variables. It equaled (weight (kg) /(height (cm)*height (cm))*10000. The following lower and upper limits were used:
    - HEIGHT taller than 115 cm and shorter than 221cm.
    - WEIGHT greater than 35 kg and lower than 115 kg.

Maximum injury severity: was assessed using the Maximum Abbreviated Injury Scale (MAIS), "TREATMNT" and "INJSEV" variables were analyzed. MAIS ranges from 0 to 6 and 9, where MAIS 9 is an injury with unknown severity. Fatality was recorded if the occupant died within 30 days of the crash. Fatality (F) was defined by:

- TREATMNT = 1 since it means that the occupant was fatally injured and not transported to the hospital.
- Police injury severity: INJSEV = 4 represents a fatality from police rating.

Exposed occupants were defined as those with known MAIS (MAIS 0-6) or with a fatality. The shorthand notation is MAIS 0+F. Seriously injured occupants were defined as those with MAIS 3-6 or fatality, because fatalities can occur at any MAIS level. The shorthand notation is MAIS 3+F.

Injuries were classified as:

- AIS 3+ neck spinal injuries were classified as serious (AIS 3–6) injuries to the neck (region90 = 3) or spine (region90 = 6).
- AIS 3+ head/face injuries were classified as serious (AIS 3–6) injuries to the head (region90 = 1) or face (region90 = 2).
- AIS 3+ thorax injuries were classified as serious (AIS 3–6) injuries to the thorax (region90 = 4).

Analysis:

- Occupant Rate: The rate that an occupant experienced a serious injury was determined by dividing the number of occupants with serious injury (MAIS 3+F) by the number of occupants with known injury status, MAIS 0-6 or F (MAIS 0+F).
- Injury Rate: The rate of a serious injury was assessed by dividing the number serious injuries (AIS 3-6) by the number of occupants with known injury status, MAIS 0-6 or F (MAIS 0+F).

Occupant and injury rates are provided with ± one standard error.

Means: PROC SURVEYMEANS was used to query complex surveys such as NASS-CDS and calculate the mean data and standard errors for the age, weight, height and BMI variables.

Weighted data: National estimates for the number of crashes and occupant injuries were made using the inflation ratio (RATWGT) variable in the NASS-CDS. All calculations were based on weighted values. Cases with a RATWGT equal to 0 or with a negative RATWGT were excluded from the analysis.

The analysis presented in this paper is based on weighted data. The unweighted data is provided in the Appendices. Some numbers in the tables are highlighted in grey. The highlight was used to identify weighted numbers that were based on an unweighted sample ≤ 10. While these samples are small and there should be caution, the numbers provided represent the best national estimates from the NASS-CDS.

Table A1: Incidence and distribution of MAIS 0+F front seat occupants in rear crashes by delta V based on 22 years of data (1994-2015 NASS-CDS).

	Crash severity (delta V, km/h) in rear crashes										
Front seat occupants	**<16**	**16-24**	**24-32**	**32-40**	**40-48**	**48-56**	**56-64**	**64+**	**All w/o unknown**	**All**	**other**
MAIS 0+F incidence											
unwgt	801	1,179	729	366	169	78	48	49	3,419	5,026	1,607
wgt	538,396	727,947	315,025	121,774	61,842	11,066	4,876	6,983	1,787,909	2,494,677	706,768
se	137,311	145,401	43,626	17,518	13,914	4,234	940	3,225	312,125	392,131	89,522
Distribution (%)											
MAIS 0+F	30.11	40.72	17.62	6.81	3.46	0.62	0.27	0.39			
se	2.87	2.27	2.55	0.95	0.98	0.21	0.09	0.19			
5%	24.31	36.13	12.47	4.89	1.49	0.20	0.09	0.00			
95%	35.91	45.30	22.77	8.73	5.43	1.04	0.46	0.78			
Gender											
Male	45.49	43.69	39.40	37.17	39.50	25.14	25.14	21.90	44.73	44.46	
se	6.08	2.70	4.28	7.79	14.95	15.39	15.39	10.49	1.82	1.89	
Female	54.51	56.09	60.58	62.83	60.50	74.86	74.86	78.10	55.23	55.52	
se	6.08	2.68	4.27	7.79	14.95	15.39	15.39	10.49	1.83	1.89	
Belt use											
Lap-shoulder	88.33	92.08	87.20	89.80	86.02	90.57	89.01	86.86	89.69	89.40	
se	2.54	1.71	2.36	3.36	7.64	4.14	8.99	4.10	1.00	0.81	
None	6.89	4.16	8.09	8.05	9.07	9.43	10.99	8.29	6.17	6.47	
se	1.49	1.32	2.38	2.30	5.40	4.14	8.99	5.19	0.70	0.69	
Other/Unk	4.78	3.76	4.72	2.16	4.91	0.00	0.00	4.85	4.14	4.13	
se	2.03	1.25	2.56	1.37	2.87	0.00	0.00	2.30	0.72	0.79	
Age											
mean	39.1	37.4	39.1	34.1	36.3	38.7	31.4	30.6	37.9	38.6	
mean se	1.4	1.9	1.1	1.6	2.5	3.5	2.0	2.0	1.1	0.65	
var	2.1	3.5	1.1	2.6	6.3	12.6	3.9	4.1	1.2	0.43	
10%	19.3	18.9	19.9	17.6	18.7	24.1	20.4	22.0	19.1	19.2	
25%	26.8	23.2	19.9	22.0	24.0	24.8	25.4	25.1	23.9	24.3	
median 50%	32.3	30.9	34.9	27.0	32.1	30.7	27.5	25.7	32.0	33.5	
75%	53.0	47.4	50.5	44.6	52.2	53.5	37.3	31.7	49.0	50.6	
90%	63.4	65.9	64.2	55.1	56.4	63.5	41.8	45.3	63.5	62.7	
Weight (kg)											
mean	77.5	77.2	77.4	73.8	76.2	78.5	74.0	83.8	77.1	77.7	
mean se	1.2	1.4	1.3	1.8	2.9	4.7	2.7	9.1	0.93	0.71	
var	2.1	2.0	1.8	2.6	8.1	22.5	7.1	83.1	0.86	0.51	
10%	57.6	53.6	56.1	56.1	53.4	56.5	54.6	51.9	53.9	53.9	
25%	62.9	63.6	61.0	64.6	63.3	64.1	58.1	59.3	63.2	63.4	
median 50%	76.9	74.2	76.1	73.0	76.1	79.4	77.0	93.3	75.0	76.0	
75%	90.1	85.9	90.2	81.4	82.7	91.8	77.9	101.5	87.6	87.7	
90%	94.4	99.8	99.4	94.4	94.5	97.7	100.2	102.5	99.3	99.7	
Height (cm)											
mean	169.8	171.0	170.9	169.4	171.8	171.2	166.5	166.8	170.5	170.5	
mean se	0.53	0.56	0.47	0.94	1.3	3.9	3.2	5.0	0.41	0.26	
var	0.28	0.32	0.22	0.88	1.6	15.5	10.4	24.6	0.17	0.07	
10%	156.2	158.4	157.5	158.1	158.8	158.5	152.2	142.0	157.6	157.3	
25%	161.9	164.1	162.5	160.2	163.2	159.5	155.4	156.6	162.8	162.8	
median 50%	168.7	168.9	169.2	168.2	168.7	163.8	168.2	170.9	168.8	169.3	
75%	175.9	175.4	176.7	176.5	180.0	181.0	169.9	172.5	176.6	177.4	
90%	180.0	184.7	182.9	182.7	184.8	189.0	180.1	180.1	182.8	182.9	
BMI (kg/m2)											
mean	26.9	26.3	26.4	25.7	25.5	26.7	26.6	29.7	26.4	26.6	
mean se	0.33	0.31	0.41	0.57	0.80	1.26	1.45	1.90	0.22	0.22	
var	0.11	0.10	0.17	0.33	0.64	1.58	2.11	3.61	0.05	0.05	
10%	20.9	20.2	20.3	20.3	19.9	21.6	20.3	21.5	20.4	20.3	
25%	22.0	22.2	22.1	22.2	21.7	22.6	24.0	26.6	22.2	22.3	
median 50%	26.5	24.8	25.1	25.6	24.5	25.8	25.2	30.2	25.7	25.7	
75%	29.8	29.0	29.8	27.3	28.3	30.4	26.9	33.2	29.2	29.4	
90%	34.1	32.5	33.4	32.5	30.8	32.0	37.3	34.0	33.5	33.7	

Table A2: Incidence and distribution of MAIS 3+F injury in rear crashes by delta V based on 22 years of data (1994-2015 NASS-CDS).

	Crash severity (delta V, km/h) in rear crashes										
Front seat occupants	**<16**	**16-24**	**24-32**	**32-40**	**40-48**	**48-56**	**56-64**	**64+**	**All w/o unknown**	**All**	**other**
MAIS 3+F incidence											
unwgt	4	13	13	10	15	16	16	19	106	204	98
Rear	233	1,736	1,245	492	1,107	511	408	992	6,724	11,094	4,370
se	121	800	552	296	632	267	212	272	1,403	2,329	1,146
Distribution (%)											
MAIS 3+F	3.46	25.82	18.52	7.32	16.46	7.60	6.08	14.75			
se	2.02	10.18	6.38	4.13	9.09	3.74	3.04	2.43			
5%	0.00	5.26	5.64	0.00	0.00	0.04	0.00	9.85			
95%	7.53	46.38	31.40	15.66	34.82	15.16	12.22	19.65			
Gender											
Female	18.09	69.35	55.45	27.52	41.93	67.71	63.42	68.73	56.85	51.93	
se	17.24	13.56	22.40	19.05	10.10	9.08	13.27	20.70	5.51	4.89	
Male	81.91	30.65	44.55	72.48	58.07	32.29	36.58	31.27	43.15	48.07	
se	17.24	13.56	22.40	19.05	10.10	9.08	13.27	20.70	5.51	4.89	
Belt use											
Lap-shoulder	78.47	81.35	33.59	30.45	77.03	76.94	89.32	78.18	67.65	69.18	
	19.72	7.08	19.39	20.07	16.27	7.02	7.99	8.78	6.80	6.29	
None	21.53	18.65	66.41	62.95	13.82	23.06	10.68	16.28	29.54	27.13	
	19.72	7.08	19.39	24.12	12.40	7.02	7.99	8.29	7.31	6.71	
her/Unknown	0	0	0	6.60	9.15	0	0	5.54	2.80	3.70	
	0	0	0	7.01	9.35	0	0	4.40	1.61	1.29	
Age											
mean	52.9	58.4	64.1	62.9	36.8	43.2	32.9	38.7	50.4	48.5	
mean se	2.3	6.7	8.7	7.7	2.3	5.5	2.0	9.2	4.6	2.5	
var	5.2	45.2	76.5	59.7	5.4	30.5	3.9	85.2	21.1	6.1	
10%	45.0	31.6	31.5	32.9	28.1	26.6	19.0	18.7	25.7	22.2	
25%	46.3	38.2	48.3	42.9	33.2	30.5	23.3	22.3	34.4	33.0	
median 50%	52.6	58.0	70.1	60.8	34.6	37.1	28.3	27.5	49.4	47.9	
75%	53.9	69.0	78.9	68.7	36.1	49.4	37.4	54.2	66.6	61.9	
90%	56.9	81.7	79.6	73.4	38.8	66.0	40.9	58.9	79.3	77.8	
Weight (kg)											
mean	84.7	82.7	97.7	80.5	97.4	85.0	78.4	75.7	86.3	86.9	
mean se	3.7	11.3	5.4	3.1	5.4	11.0	8.0	5.0	3.6	3.5	
var	13.9	127.8	29.5	9.4	29.7	120.1	64.3	24.8	12.9	12.6	
10%	77.0	58.0	79.6	64.1	68.4	54.0	54.1	53.9	59.9	60.1	
25%	77.3	60.3	82.9	67.2	70.6	66.1	57.3	63.4	70.0	71.3	
median 50%	79.6	70.9	88.5	72.3	77.9	78.8	63.8	72.0	80.0	83.8	
75%	81.9	85.0	98.6	78.7	109.9	103.9	84.0	81.5	94.2	99.1	
90%	91.3	120.5	120.4	82.7	125.6	109.8	113.8	91.2	132.2	121.0	
Height (cm)											
mean	169.8	161.9	163.3	175.2	183.0	170.5	172.7	166.5	168.7	169.8	
mean se	1.9	3.8	4.7	2.4	2.2	2.3	2.0	5.5	3.4	2.6	
var	3.8	14.8	22.5	5.7	4.7	5.5	4.1	30.0	11.5	6.7	
10%	165.0	142.0	146.6	163.2	167.4	158.0	158.8	157.0	155.4	155.7	
25%	165.0	147.0	149.7	172.4	171.3	160.9	163.4	157.0	158.3	160.1	
median 50%	166.4	160.7	154.8	176.6	177.0	166.4	171.7	162.7	167.3	167.9	
75%	169.7	166.8	172.3	177.5	194.4	177.0	178.2	175.9	176.6	177.9	
90%	171.7	173.9	175.6	178.5	196.5	183.6	181.1	177.8	182.0	184.5	
BMI (kg/m2)											
mean	29.4	32.2	36.8	25.7	28.3	29.0	26.0	27.2	30.5	30.1	
mean se	1.11	4.6	1.8	1.1	1.0	3.1	2.1	1.0	1.4	1.2	
var	1.23	21.2	3.1	1.2	1.1	9.6	4.4	1.1	2.0	1.3	
10%	27.4	23.6	29.5	22.5	23.2	19.7	19.1	21.4	20.4	22.2	
25%	27.4	23.7	33.3	22.9	24.3	22.0	21.5	22.9	22.2	24.3	
median 50%	27.9	26.6	34.9	23.7	25.6	28.6	22.7	26.9	25.7	27.7	
75%	30.0	34.9	36.5	24.8	34.4	32.3	28.1	30.1	29.2	34.6	
90%	31.6	37.3	39.1	27.5	34.6	35.4	35.9	30.3	33.5	37.8	
	1	2	3	4	5	6	7	8			
	Rate (%) MAIS 3+F by crash severity (delta V, km/h) in rear crashes										
	<16	**16-24**	**24-32**	**32-40**	**40-48**	**48-56**	**56-64**	**64+**	**All w/o unknown**	**All**	
All	0.043	0.24	0.40	0.40	1.79	4.62	8.38	14.20	0.38	0.44	
se	0.021	0.11	0.17	0.24	1.02	2.43	5.04	8.39	0.067	0.065	
5%	0	0.010	0.023	0	0	0	0	0.0	0.24	0.31	
95%	0.089	0.47	0.77	0.92	4.0	9.8	19.1	32.1	0.51	0.58	

Gray cells highlight unweighted sample < 10

Table A3: Incidence and distribution of MAIS 0+F front seat occupants in rear crashes by delta V based on 22 years of data (1994-2015 NASS-CDS).

	Crash severity (delta V, km/h) in rear crashes					
Front seat occupants	**<24**	**24-<48**	**48+**	**All w/o unknown**	**All**	**other**
MAIS 0+F incidence						
unwgt	1,980	1,264	175	3,419	5,026	1,607
wgt	1,266,343	498,641	22,925	1,787,908	2,494,677	706,768
se	278,377	64,340	2,912	312,125	392,131	89,522
Distribution (%)						
MAIS 0+F	70.83	27.89	1.28			
se	4.13	4.05	0.20			
5%	62.50	19.71	0.87			
95%	79.16	36.07	1.69			
Gender						
Male	46.1	41.8	31.1	44.7	44.5	
se	2.7	2.4	7.2	1.82	1.89	
Female	53.9	58.0	68.9	55.2	55.5	
se	2.7	2.4	7.2	1.83	1.89	
Belt use						
Lap-shoulder	90.5	87.7	89.1	89.7	89.4	
se	1.1	1.6	2.7	1.0	0.81	
None	5.3	8.2	9.4	6.2	6.5	
se	1.0	1.6	2.9	0.7	0.69	
Other/Unk	0.0	4.1	1.5	4.1	4.1	
se		1.7	1.3	0.7	0.79	
Age						
mean	38.1	37.5	34.7	37.9	38.6	
mean se	1.5	0.9	2.6	1.1	0.7	
var	2.2	0.9	6.5	1.2	0.4	
10%	19.1	19.0	22.1	19.1	19.2	
25%	23.8	23.4	25.1	23.9	24.3	
median 50%	31.3	32.9	27.2	32.0	33.5	
75%	49.4	48.4	38.7	49.0	50.6	
90%	64.6	60.4	62.5	63.5	62.7	
Weight (kg)						
mean	77.3	76.4	79.1	77.1	77.7	
mean se	1.1	0.8	5.0	0.9	0.7	
var	1.3	0.6	25.5	0.9	0.5	
10%	52.7	53.6	-	53.9	53.9	
25%	61.7	60.1	50.3	63.2	63.4	
median 50%	69.8	71.6	60.9	75.0	76.0	
75%	84.2	83.1	-	87.6	87.7	
90%	97.0	95.4	-	99.3	99.7	
Height (cm)						
mean	170.5	170.6	168.8	170.5	170.5	
mean se	0.47	0.4	2.5	0.41	0.3	
var	0.22	0.2	6.0	0.17	0.1	
10%	157.7	157.8	154.2	157.6	157.3	
25%	162.9	162.1	159.2	162.8	162.8	
median 50%	168.8	168.8	168.2	168.8	169.3	
75%	175.7	177.0	175.5	176.6	177.4	
90%	182.6	182.9	186.6	182.8	182.9	
BMI (kg/m2)						
mean	26.5	26.1	27.6	26.4	26.6	
mean se	0.25	0.25	1.67	0.22	0.22	
var	0.06	0.06	2.79	0.05	0.05	
10%	20.4	20.3	21.6	20.4	20.3	
25%	22.2	22.2	24.3	22.2	22.3	
median 50%	25.8	25.1	26.7	25.7	25.7	
75%	29.2	28.9	32.0	29.2	29.4	
90%	34.1	33.1	34.4	33.5	33.7	

Table A4: Incidence and distribution of MAIS 3+F injury in rear crashes by delta V based on 22 years of data (1994-2015 NASS-CDS).

Crash severity (delta V, km/h) in rear crashes					
Front seat occupants	**<24**	**24-<48**	**48+**	**All w/o unknown**	**All**
MAIS 3+F incidence					
unwgt	17	38	51	106	204
Rear	1,969	2,844	1,911	6,724	11,094
se	765	877	488	1,403	2,329
Distribution (%)					
MAIS 3+F	29.3	42.3	28.4		
se	9.7	9.0	4.8		
5%	9.7	24.0	18.8		
95%	48.8	60.6	38.1		
Gender					
Female	63.3	45.4	67.3	56.9	51.9
se	12.3	11.1	12.1	5.5	4.9
Male	36.7	54.6	32.7	43.1	48.1
se	12.3	11.1	12.1	5.5	4.9
Belt use					
Lap-shoulder	81.01	49.95	80.23	67.65	69.18
	7.05	17.71	4.67	6.80	6.29
None	18.99	45.35	16.90	29.54	27.13
	7.05	17.65	4.47	7.31	6.71
Other/		4.70	2.87	2.80	3.70
Unknown		4.25	2.33	1.61	1.29
Age					
mean	57.7	53.3	38.6	50.4	48.5
mean se	5.9	7.2	4.6	4.6	2.5
var	34.4	51.7	21.5	21.1	6.1
10%	32.1	29.5	19.6	25.7	22.2
25%	45.9	34.7	25.2	34.4	33.0
median 50%	53.6	45.8	31.9	49.4	47.9
75%	66.5	75.0	53.1	66.6	61.9
90%	81.1	79.0	61.3	79.3	77.8
Weight (kg)					
mean	82.9	94.2	78.8	86.3	86.9
mean se	10.1	3.9	4.5	3.6	3.5
var	101.8	15.3	19.9	12.9	12.6
10%	58.2	70.3	56.4	59.9	60.1
25%	60.8	76.0	63.5	70.0	71.3
median 50%	72.2	88.1	72.4	80.0	83.8
75%	84.9	99.9	93.3	94.2	99.1
90%	118.4	125.4	104.9	132.2	121.0
Height (cm)					
mean	162.9	172.9	169.1	168.7	169.8
mean se	3.7	5.4	3.0	3.4	2.6
var	13.9	29.5	9.1	11.5	6.7
10%	142.0	155.4	157.0	155.4	155.7
25%	149.3	156.6	158.2	158.3	160.1
median 50%	161.8	172.3	165.9	167.3	167.9
75%	167.6	177.6	176.6	176.6	177.9
90%	174.8	194.0	181.3	182.0	184.5
BMI (kg/m2)					
mean	31.9	31.6	27.4	30.5	30.1
mean se	3.98	2.0	1.4	1.4	1.2
var	15.87	3.9	1.9	2.0	1.3
10%	23.6	23.2	20.3	20.4	22.2
25%	23.8	24.4	22.2	22.2	24.3
median 50%	27.3	33.3	27.3	25.7	27.7
75%	34.3	35.5	30.4	29.2	34.6
90%	42.2	36.8	33.0	33.5	37.8

Rate (%) MAIS 3+F by crash severity (delta V, km/h) in rear crashes					
	<24	**24-<48**	**48+**	**All w/o unknown**	**All**
All	0.156	0.57	8.34	0.38	0.44
se	0.063	0.18	1.87	0.067	0.065
5%	0.021	0.19	4.34	0.24	0.31
95%	0.290	0.95	12.33	0.51	0.58

Table A5: Incidence and proportion of AIS 3+ injury by body regions and delta V.

	Crash severity (delta V, km/h) in rear crashes										
Front seat occupants	**<16**	**16-24**	**24-32**	**32-40**	**40-48**	**48-56**	**56-64**	**64+**	**All w/o unknown**	**All**	**other**
AIS 3+ (region90)											
unwgt	2	14	17	11	10	23	31	40	148	278	130
Head/face (1,2)	100	598	4954	486	1157	740	701	1807	10544	14649	4105
se	100	330	4475	307	904	330	376	801		5841	1439
unwgt	1	5	1	7	9	11	16	19	69	163	94
Chest (4)	42	560	128	150	322	369	311	879	2762	5966	3205
se	42	372	128	80	228	270	173	427		1695	1037
unwgt	1	7	4	5	1	3	3	6	30	63	33
Neck/Spine (3,6)	55	514	52	135	9	94	72	245	1177	3031	1854
se	55	288	42	82	9	56	53	184		887	699
Rate AIS 3+ (region90) per MAIS 0+F											
Head/face (1,2)	0.019%	0.082%	1.6%	0.40%	1.87%	6.7%	14.4%	25.9%	0.59%	0.59%	0.58%
Chest (4)	0.0078%	0.077%	0.041%	0.12%	0.52%	3.3%	6.4%	12.6%	0.15%	0.24%	0.45%
Neck/Spine (3,6)	0.010%	0.071%	0.017%	0.11%	0.015%	0.85%	1.5%	3.5%	0.066%	0.12%	0.26%

Individual case review: To better understand injury risks in 64+km/h delta V, individual cases were downloaded and reviewed. Table A6 summarizes individual cases involving MAIS 3+F front-outboard occupants in 64+ km/h rear crashes.

Table A6: Summary of rear cases with 64+ km/h delta V.

					Vehicle					Occupant			
#	ratwgt	Year	PSU	Caseid	Vehicle	CDC	Delta-V (km/h)	Intrusion (cm) Max	Intrusion (cm) 2nd row @ occ loc	Loc	Age	Gender	Seatback rotation
1	5	1998	82	122J	1997 Honda Civic	06BDEW6	65	19	16	D	26	M	Rwd
2	51	1999	11	154A	1996 Chevrolet Cavalier	06BDEW8 99RDAW2 12FYEW2	72 Unk Unk	35	29	D	28	F	Same
3	80	1999	45	78K	1994 Saturn SL	06BDEW7	68	30	12	RF	25	F	Rwd (broken prior)
4	88	2000	8	185A	1999 Hyundai Elantra	06BDEW6 12FDEW1	80 14	26	14	D	26	F	Unk
5	88	2000	8	185A	1999 Hyundai Elantra	06BDEW6 12FDEW1	80 14	26	16	RF	54	F	Unk
6	8	2003	74	130B	1998 Mercury Mystique	06BDEW6	65	22	22	D	44	M	Fwd
7	254	2004	48	102K	1998 Mitsubishi Mirage	06BDEW6	74	18	18	D	62	F	Same
8	45	2004	73	201K	1995 Pontiac Grand Prix	06BDAW7	72	39	39	D	18	F	Fwrd
9	7	2005	50	116B	1995 Saturn SL	06BYAW07 01FRMS03	83 Minor	91	91	D	26	M	Fwrd
10	8	2007	49	156K	2003 Kia Optima	06BDAW07 99RPA999	51 minor	65	36	D	27	M	Unk
11	163	2008	43	249D	2002 Honda Accord	06BDEW07	47	54	54	D	20	M	Rwd
12	38	2008	49	2K	1998 Chevrolet Malibu	06BDEW07 06BDEW07	70 28	47	38	D	22	M	Rwd
13	10	2008	49	232B	1999 Ford Contour	06BDAW08 12FLEW01	92 12	74	53	D	53	M	Rwd
14	23	2008	73	125K	1997 Huyndai Accent	01FDEW02 06BDEW07	29 96	>61	>61	D	27	M	Unk
15	23	2008	73	125K	1997 Huyndai Accent	01FDEW02 06BDEW07	29 96	>61	>61	RF	43	M	Unk
16	42	2011	11	159K	2005 Mazda 3	66BDAW07 07LFEW03	84 9	54	28	D	34	M	Unk
17	48	2012	11	137K	2008 Ford Escape	06BDAW04 12FZEW01	74 11	20	20	D	52	M	Rwd
18	22	2013	9	5J	2012 Honda Civic	06BDEW05 12FYEW01 01F99999 01R99999	78 26 Unk Unk	15-30	15-30	D	45	F	Unk
19	5	2014	49	2B	2006 Jeep Liberty	46BDEW04 12FDEW01 99LDEW02	72 24 Mod	3-8	3-8	D	24	M	Unk
20	5	2014	49	2B	2006 Jeep Liberty	46BDEW04 12FDEW01 99LDEW02	72 24 Mod	3-8	Unk	RF	24	M	Unk

Appendix B: Sled test data

Fifty-two (52) sled tests were analyzed and grouped by sled delta V, ATD size, initial position and head restraint design.

ATD initial position

Out-of-position (OOP): Twelve tests were conducted with OOP ATD to represent a range of real-world seating positions reflecting the possible orientation of occupants loading into the seatback in rear impacts. The positions included leaning forward to represent a pre-impact braking scenario for example and leaning forward and inboard to represent someone changing the radio.

Various out-of-position (OOP) scenarios were considered in the analyzed tests reflecting the possible orientation of occupants loading into the seatback in rear impacts. Being out-of-position prior to a rear crash can occur in various scenarios as documented in Viano et al. (2009). These include: 1) oblique or offset rear impacts that cause the vehicle to displace forward at an angle and yaw, 2) over-ride by the striking vehicle that pushes the rear of the vehicle and seat down with respect to the occupant inducing ramping (Parenteau et al. 2020) and 3) sitting out-of-position or moving away from the seatback prior to crash, such as to control the radio or heater causing the occupant to lean forward and inboard.

Head restraint: Head restraint configuration was grouped into two categories:

- above head center of gravity (cg)
- below head center of gravity (cg).

Head cg was determined as 6 cm below the top of head using set-up photos. The 6 cm corresponds to the vertical distance limit for IIHS "GOOD" geometric rating (IIHS 2016).

Matches

Matched tests were identified with ABTS and conventional seats involving the same test set-up. The data was also grouped by head restraint design. In the matched test analysis, the head restraint location was assessed relative to the head cg of the ATD. The conventional seat for Match # 10 was a 1996 Ford Explorer. The test was conducted with a 5^{th} female HIII and the top of the head restraint was above the head cg of the ATD. It should be noted that the head restraint would have been below with a 50^{th} HIII.

The sled test data was grouped into 13 matched test categories based on same test velocity, head restraint design, ATD size and its initial position. Table B1 summarizes the test set-up and data.

Table B1: List of matched sled tests.

#	Seat	Head Restraint	Delt V (km/h)	ATD	Position	Test loc	Seats	Stiffness (lb/in) (Padmanaban et al. 2016)	Reference
	16 km/h tests								
1	Conv	Above	16	BioRID2	IP	IIHS	2006 F-150	45.9	Viano et al. 2011
2	Conv	Above	16	BioRID2	IP	IIHS	2008 Sebring	--	Viano et al. 2011
3	Conv	Above	16	BioRID2	IP	IIHS	2007 Saab 9-3	--	Viano et al. 2011
4	Conv	Above	16	BioRID2	IP	IIHS	2006 BMW 3 series	--	Viano et al. 2011
5	Conv	Above	16	BioRID2	IP	IIHS	2010 Sebring AHR	--	
5	ABTS	Above	16	BioRID2	IP	IIHS	2006 F-150 (2)	--	Viano et al. 2011
4	ABTS	Above	16	BioRID2	IP	IIHS	2008 Sebring (2)	293.8	Viano et al. 2011
6	ABTS	Above	16	BioRID2	IP	IIHS	2007 Saab 9-3	--	Viano et al. 2011
7	ABTS	Above	16	BioRID2	IP	IIHS	2007 BMW 3 series	--	Viano et al. 2011
10	ABTS	Above	16	BioRID2	IP	IIHS	2010 Sebring AHR	--	
							Ratio	6.4	
	16-<24 km/h tests								
11	Conv	Above	19	BioRID	IP	Exponent	2001-2003Taurus	107.3	Welch et al. 2010
12	ABTS	Above	19	BioRID	IP	Exponent	2001 Sebring	293.8	Welch et al. 2010
							Ratio	2.7	
13	Conv	Above	19	50HIII	IP	Exponent	2001-2003 Taurus	107.3	Welch et al. 2010
14	ABTS	Above	19	50HIII	IP	Exponent	2001 Sebring	293.8	Welch et al. 2010
							Ratio	2.7	
	24-<32 km/h tests								
15	Conv	Above	24	50HIII	IP	Ford	2000 Taurus	107.3	Viano et al. 2013
16	ABTS	Above	24	50HIII	IP	Ford	2001 Sebring	293.8	Viano et al. 2013
							Ratio	2.7	
17	Conv	Below	24	95HIII -300 lb	IP	Ford	2002 Explorer	60.0	McGowan et al. 2010
18	Conv	Below	24	95HIII -300 lb	IP	Ford	2002 Explorer	60.0	McGowan et al. 2010
							Average	60.0	
19	ABTS	Below	24	95HIII -300 lb	IP	Ford	2002 Trailblazer	87.5	McGowan et al. 2010
20	ABTS	Below	24	95HIII -300 lb	IP	Ford	2002 LeSabre	144.9	McGowan et al. 2010
							Average	116.2	
							Ratio	1.9	
21	Conv	Below	26	50HIII	OOP-L	Ford	2005 Explorer	60.0	
22	ABTS	Below	26	50HIII	OOP-L	Ford	2002 LeSabre	144.9	
							Ratio	74.8	
23	Conv	Below	26	50HIII	OOP-R	Ford	2005 Explorer	60.0	
24	ABTS	Below	26	50HIII	OOP-R	Ford	2002 LeSabre	144.9	
							Ratio	1.9	
32-<40 km/h tests								1.9	
25	Conv	Above	32	50HIII	IP	Ford	2000 Taurus	107.3	Viano et al. 2013
26	ABTS	Above	32	50HIII	IP	Ford	2001 Sebring	293.82	Viano et al. 2013
							Ratio	2.7	

#	Seat	Head Restraint	Delt V (km/h)	ATD	Position	Test loc	Seats	Stiffness (lb/in) (Padmanaban et al. 2016)	Reference
27	Conv	Above	40	50HIII	IP	Ford	2005 Ford Freestyle	--	
28	Conv	Above	40	50HIII	IP	Ford	2006 Ford Expedition	--	Viano et al. 2018
29	Conv	Above	40	50HIII	IP	Ford	2008 Ford F-150	--	Viano et al. 2013,
30	Conv	Above	40	50HIII	IP	Ford	2008 Ford F-150	--	2018
31	Conv	Above	40	50HIII	IP	Ford	2009 Ford Expediton	--	
32	Conv	Above	40	50HIII	IP	Ford	2009 Toyota Sequoia	--	
33	Conv	Above	40	50HIII	IP	Ford	2009 Nissan Armada	--	
34	Conv	Above	40	50HIII	IP	Ford	2009 Chevrolet Tahoe	--	
35	Conv	Above	40	50HIII	IP	Ford	2012 Ford Escape	--	Viano et al. 2021
36	Conv	Above	40	50HIII	IP	Ford	2012 Ford Explorer	--	
37	Conv	Above	40	50HIII	IP	Ford	2014 Ford Edge	--	
38	Conv	Above	40	50HIII	IP	Ford	2015 Ford F-250	--	Viano et al. 2018
39	Conv	Above	40	50HIII	IP	Ford	2016 Ford Focus	--	
40	ABTS	Above	40	50HIII	IP	Ford	2008 Sebring	293.82	Viano et al. 2018
41	ABTS	Above	40	50HIII	IP	Ford	1998 Sebring	293.82	
42	ABTS	Above	40	50HIII	IP	Ford	ABTS*	--	Viano et al. 2021
43	Conv	Above	40	5HIII	OOP-R	Ford	1996 Explorer	64.79	Viano et al. 2009
44	ABTS	Above	40	5HIII	OOP-R	Ford	1996 Sebring	293.82	Viano et al. 2009
							Ratio	4.53	
45	Conv	Above	40	50HIII	OOP-L	Ford	2012 Escape	--	Viano et al. 2021
46	ABTS	Above	40	50HIII	OOP-L	Ford	2008 Sebring	293.82	Viano et al. 2018
47	ABTS	Above	40	50HIII	OOP-L	Ford	ABTS*	--	Viano et al. 2021
48	Conv	Below	40	50HIII	OOP-R	Ford	2002 Explorer	59.97	Viano et al. 2018
49	ABTS	Below	40	50HIII	OOP-R	Ford	2002 Trailblazer	87.54	Viano et al. 2018
50	ABTS	Below	40	50HIII	OOP-R	Ford	2002 LeSabre	144.91	Viano et al. 2018
							Average	116.2	
							Ratio	1.94	
	56-<64 km/h tests								
51	Conv	Above	56	5HIII	IP	Ford	2014 F-150	--	Viano et al. 2021
52	ABTS	Above	56	5HIII	IP	Ford	ABTS*	--	Viano et al. 2021

ABTS*: Non-production double-recliner Sebring ABTS

ATD responses

The ATD biomechanical responses included head resultant acceleration and HIC_{15}; upper neck compression, tension and shear force, flexion and extension moment; lower neck compression, tension and shear force, flexion and extension moment; thoracic spine compression, tension and shear force, flexion and extension moment; and chest with 3 ms acceleration. For tests conducted with the BioRID, the resultant T1 acceleration was assessed to represent chest response.

Ratio analysis of biomechanical responses: The ratio between biomechanical responses of the ATDs in the ABTS and conventional seats was calculated based on the same matched test conditions. If more than one test was conducted for the test condition, an average was taken. The average of the ratios was then calculated. Tables B2-B11 and Figures B1-B4, B6 and B8-B16 show biomechanical ratio responses.

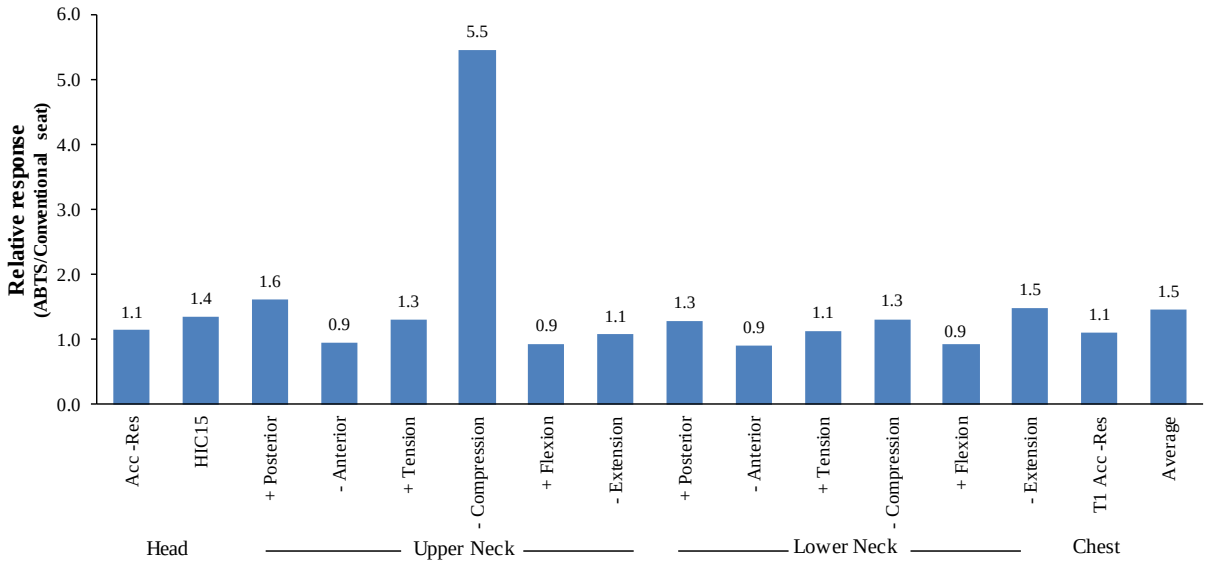
<10 mph (<16 km/h): Ten test were conducted at 16 km/h (10 mph) delta V. Table B2 summarizes the data. For 16 km/h, ten sled tests were conducted with a BioRID 2 and were downloaded from IIHS website (Match #1).

Table B2: Selected peak sled and biomechanical responses in IIHS rear sled tests.

(Adapted from Viano et al. 2011)

10 mph	Sample (n)		5	5	**Relative**	**IARV**	**% IARV**		**% Injury Risk**		**Relative**
	Seat		Conv	ABTS	**Response**		Conv	ABTS	Conv	ABTS	**Risk**
	HR		Above	Above	**ABTS/**						**ABTS/**
Occupant	ATD		BioRID2	BioRID2	**conv**						
	Location		D	D							
	Position		IP	IP							
Head	Acc (g)		21	24	1.1	180	12%	13%	0.017%	0.019%	1.11
	HIC_{15}		36	49	1.4	700	5%	7%	0.013%	0.057%	4.30
Upper Neck	Fx (lb)	+ Posterior	20	33	1.6	697	3%	5%	0.027%	0.030%	1.10
		- Anterior	-26	-25	0.9	-697	4%	4%	0.029%	0.028%	0.99
	Fz (lb)	+ Tension	127	166	1.3	937	14%	18%	0.000%	0.000%	1.17
		- Compression	-21	-115	5.5	-899	2%	13%	0.027%	0.047%	1.76
	My (inlb)	+ Flexion	21	20	0.9	1,682	1%	1%	0.025%	0.025%	1.00
		- Extension	-55	-59	1.1	-859	6%	7%	0.028%	0.029%	1.03
Lower Neck	Fx (lb)	+ Posterior	76	98	1.3	697	11%	14%	0.042%	0.050%	1.19
		- Anterior	-9	-8	0.9	-697	1%	1%	0.025%	0.025%	0.99
	Fz (lb)	+ Tension	67	76	1.1	937	7%	8%	0.000%	0.000%	1.17
		- Compression	-156	-205	1.3	-899	17%	23%	0.060%	0.081%	1.34
	My (inlb)	+ Flexion	21	20	0.9	3,363	1%	1%	0.024%	0.024%	1.00
		- Extension	-89	-132	1.5	-1,717	5%	8%	0.031%	0.036%	1.15
Chest	T1 acc (g)/ 3ms		12	13	1.1	60	20%	22%	0.028%	0.032%	1.14
D: Driver, IP: In-posiiton				**Average**	1.5						1.4

Max by body region			
Head	0.02%	0.06%	3.35
Spine	0.06%	0.08%	1.34
Chest	0.03%	0.03%	1.14
Max	0.06%	0.08%	1.34



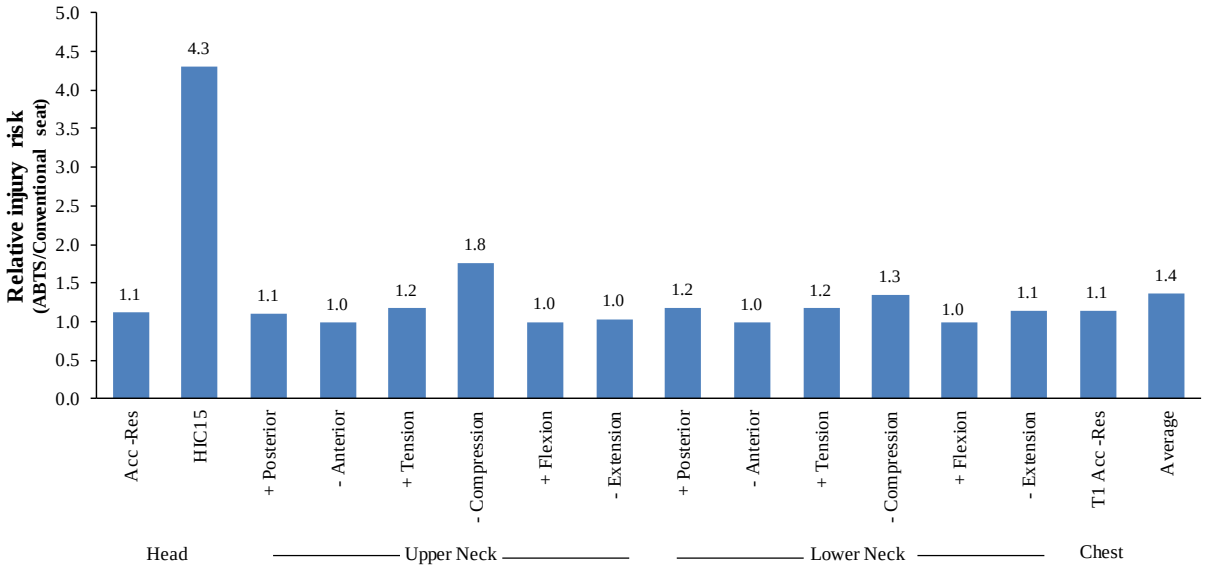


Figure B1: 10 mph rear sled test with a BioRID20 in-position (IP).
(updated from Viano et al. 2011)

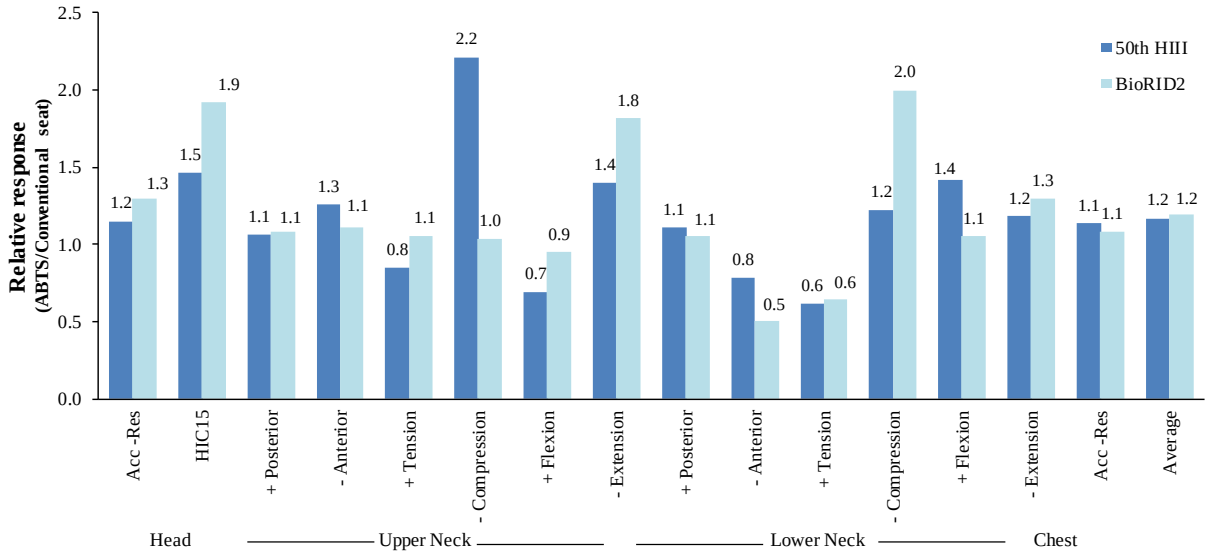
10-<15 mph (16-<24 km/h): Four tests were with a 19 km/h delta V from Welch et al. (2010). Two were with a BioRID 2 lap-shoulder belted on a conventional seat and on an ABTS (Match #2) and two were with a 50th Hybrid III on the same seat configuration (Match #3). Table B3 tabulates the data.

Table B3: Selected peak sled and biomechanical responses in 12 mph rear sled tests.

12 mph	Sample (n)		1	1	1	1														
	MY		2001-3	2002	2001	2001														
Seat	Make		Ford	Ford	Chrysler	Chrysler	**Relative**		**IARV**	**% IARV**				**% Injury Risk**				**Relative Risk**		
	Model		Taurus	Taurus	Sebring	Sebring	**Response**											**ABTS/ conv**		
	Seat		Conv	Conv	ABTS	ABTS	**ABTS/conv**			Conv	Conv	ABTS	ABTS	Conv	Conv	ABTS	ABTS			
	HR		Above	Above	Above	Above														
Occupant	ATD		BioRID2	50 HIII	BioRID2	50 HIII	BioRID2	50 HIII	50th HIII	BioRID2	50 HIII	BioRID2	50 HIII	BioRID2	50 HIII	BioRID2	50 HIII	BioRID2	50 HIII	
	Location		D	D	D	D														
	Position		IP	IP	IP	IP														
Head	Acc (g)		26	24	30	31	1.15	1.30	180	15%	13%	17%	17%	0.021%	0.019%	0.024%	0.025%	1.16	1.30	
	HIC_{15}		44	37	65	70	1.47	1.92	700	6%	5%	9%	10%	0.037%	0.014%	0.154%	0.194%	4.21	13.81	
Upper Neck	Fx (lb)	+ Posterior	93	74	99	81	1.06	1.08	697	13%	11%	14%	12%	0.048%	0.042%	0.050%	0.044%	1.05	1.05	
		- Anterior	-45	-46	-56	-51	1.26	1.11	-697	6%	7%	8%	7%	0.033%	0.033%	0.036%	0.035%	1.09	1.04	
	Fz (lb)	+ Tension	213	164	180	173	0.85	1.06	937	23%	17%	19%	18%	0.000%	0.000%	0.000%	0.000%	0.88	1.04	
		- Compression	-11	-17	-25	-17	2.21	1.04	-899	1%	2%	3%	2%	0.025%	0.026%	0.027%	0.026%	1.09	1.00	
	My (inlb	+ Flexion	413	158	287	150	0.69	0.95	1,682	25%	9%	17%	9%	0.089%	0.039%	0.059%	0.038%	0.67	0.97	
		- Extension	-37	-66	-52	-119	1.40	1.82	-859	4%	8%	6%	14%	0.024%	0.030%	0.027%	0.047%	1.13	1.55	
Lower Neck	Fx (lb)	+ Posterior	123	124	136	131	1.11	1.05	697	18%	18%	20%	19%	0.061%	0.061%	0.068%	0.065%	1.11	1.05	
		- Anterior	-28	-49	-22	-25	0.78	0.51	-697	4%	7%	3%	4%	0.029%	0.034%	0.028%	0.028%	0.95	0.83	
	Fz (lb)	+ Tension	109	131	67	85	0.62	0.65	937	12%	14%	7%	9%	0.000%	0.000%	0.000%	0.000%	0.47	0.44	
		- Compression	-98	-13	-120	-26	1.22	2.00	-899	11%	1%	13%	3%	0.042%	0.025%	0.048%	0.027%	1.14	1.08	
	My (inlb	+ Flexion	156	469	221	493	1.41	1.05	3,363	5%	14%	7%	15%	0.030%	0.050%	0.033%	0.052%	1.11	1.04	
		- Extension	-242	-541	-286	-701	1.18	1.30	-1,717	14%	32%	17%	41%	0.050%	0.129%	0.058%	0.213%	1.15	1.65	
Chest	T1 acc (g)/ 3ms		15	14	17	15	1.14	1.09	60	24%	24%	28%	26%	0.039%	0.037%	0.048%	0.042%	1.24	1.14	
						Average	1.2	1.2										1.23	1.93	

D: Driver, IP: In-posiiton
(adapted from Welch et al. 2010)

Max by body region						
Head	0.04%	0.02%	0.15%	0.19%	4.21	10.20
Spine	0.09%	0.13%	0.07%	0.21%	0.76	1.65
Chest	0.04%	0.04%	0.05%	0.04%	1.24	1.14
Max	0.09%	0.13%	0.15%	0.21%	1.74	1.65



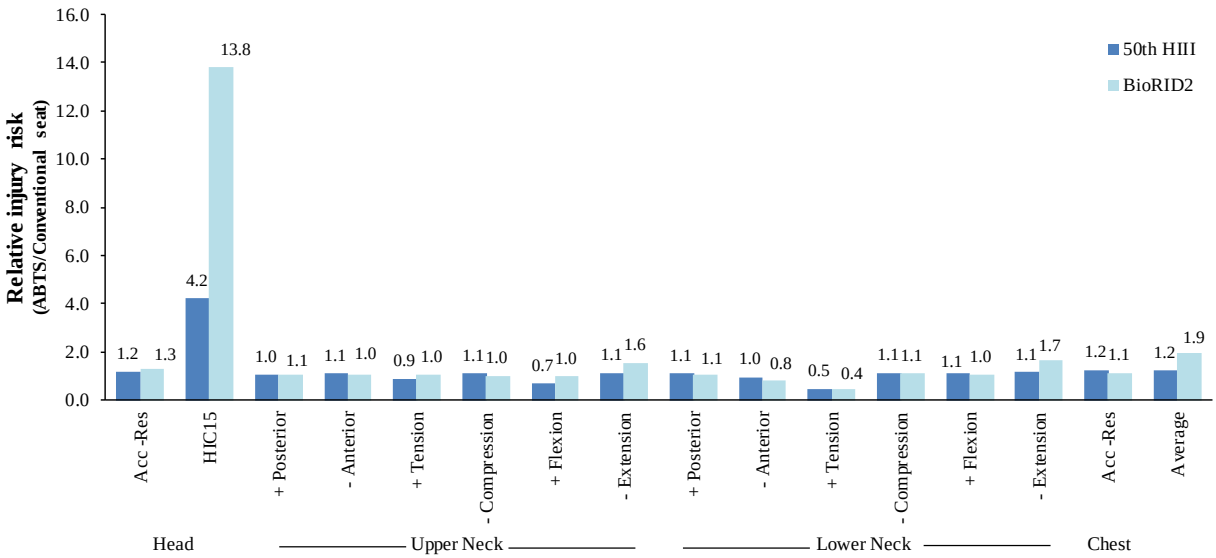


Figure B2: 12 mph rear sled test with a BioRID2 and 50III in-position (IP).
(Welch et al. 2010)

15-<20 mph (24-<32 km/h): Ten rear sled tests were conducted at 24-32 mph delta V and were part of 4 matches. Seven tests were conducted with a 24 km/h rear delta V. Two tests were with the 50th Hybrid III and were discussed in Viano et al. (2011). Table B4 tabulates the data (Match #4). Four tests were with a 136 kg (300 lb) 95th Hybrid III and were discussed in McGowan et al. (2010). Two were a conventional seat and two with an ABTS. Table B5 tabulates the data (Match #5). For 26 km/h, 4 tests were conducted with the 50th Hybrid III with a conventional seat and with an ABTS seat. Two out-of-positions were simulated, including leaning forward (OOP-L, Match # 6) and leaning forward and inboard to change the radio settings (OOP-R, Match # 7). Table B6 tabulates the data.

Table B4: Selected peak sled and biomechanical responses in 15 mph rear sled tests.

15 mph	Sample (n)		1	1							
Seat	MY		2000	2001	**Rel.**						**Rel.**
	Make		Ford	Chrysler	**Resp.**						**Risk**
	Model		Taurus	Sebring	**ABTS/**	**IARV**	**% IARV**		**% Injury Risk**		**ABTS/**
	Seat		Conv	ABTS	**conv**		Conv	ABTS	Conv	ABTS	**conv**
	HR		Above	Above	Above		Above	Above	Above	Above	Above
Occupant	ATD		50HIII	50HIII							
	Location		D	D							
	Position		IP	IP							
Head	Acc (g)		26	30	1.18	180	14%	17%	0.020%	0.024%	1.19
	HIC_{15}		45	67	1.49	700	6%	10%	0.040%	0.170%	4.30
Upper Neck	Fx (lb)	+ Posterior	81	65	0.81	697	12%	9%	0.044%	0.039%	0.89
		- Anterior	-34	-70	2.05	-697	5%	10%	0.031%	0.040%	1.32
	Fz (lb)	+ Tension	224	244	1.09	937	24%	26%	0.000%	0.000%	1.08
		- Compression	-18	-14	0.80	-899	2%	2%	0.026%	0.026%	0.98
	My (inlb)	+ Flexion	221	196	0.88	1,682	13%	12%	0.048%	0.044%	0.92
		- Extension	-53	-83	1.57	-859	6%	10%	0.027%	0.035%	1.28
Lower Neck	Fx (lb)	+ Posterior	191	233	1.22	697	27%	33%	0.103%	0.143%	1.39
		- Anterior	-37	-48	1.31	-697	5%	7%	0.031%	0.034%	1.09
	Fz (lb)	+ Tension	184	213	1.16	937	20%	23%	0.000%	0.000%	1.69
		- Compression	-31	-20	0.66	-899	3%	2%	0.028%	0.026%	0.94
	My (inlb)	+ Flexion	389	636	1.63	3,363	12%	19%	0.044%	0.065%	1.49
		- Extension	-363	-607	1.67	-1,717	21%	35%	0.074%	0.159%	2.16
Chest	3 ms		12	14	1.17	60	21%	24%	0.030%	0.038%	1.25
Thoracic spine	Fx (lb)	+ Posterior	37	10	0.28			**Max by body region**			
		- Anterior	-86	-224	2.60			Head	0.04%	0.17%	4.30
	Fz (lb)	+ Tension	235	108	0.46			Spine	0.10%	0.16%	1.54
		- Compression	-104	-86	0.83			Chest	0.03%	0.04%	1.25
	My (inlb)	+ Flexion	654	840	1.28			**Max**	0.10%	0.17%	1.65
		- Extension	-1071	-1332	1.24						
D: Driver, IP: In-position				**Average**	1.21						1.46

(adapted from Viano et al. 2013)

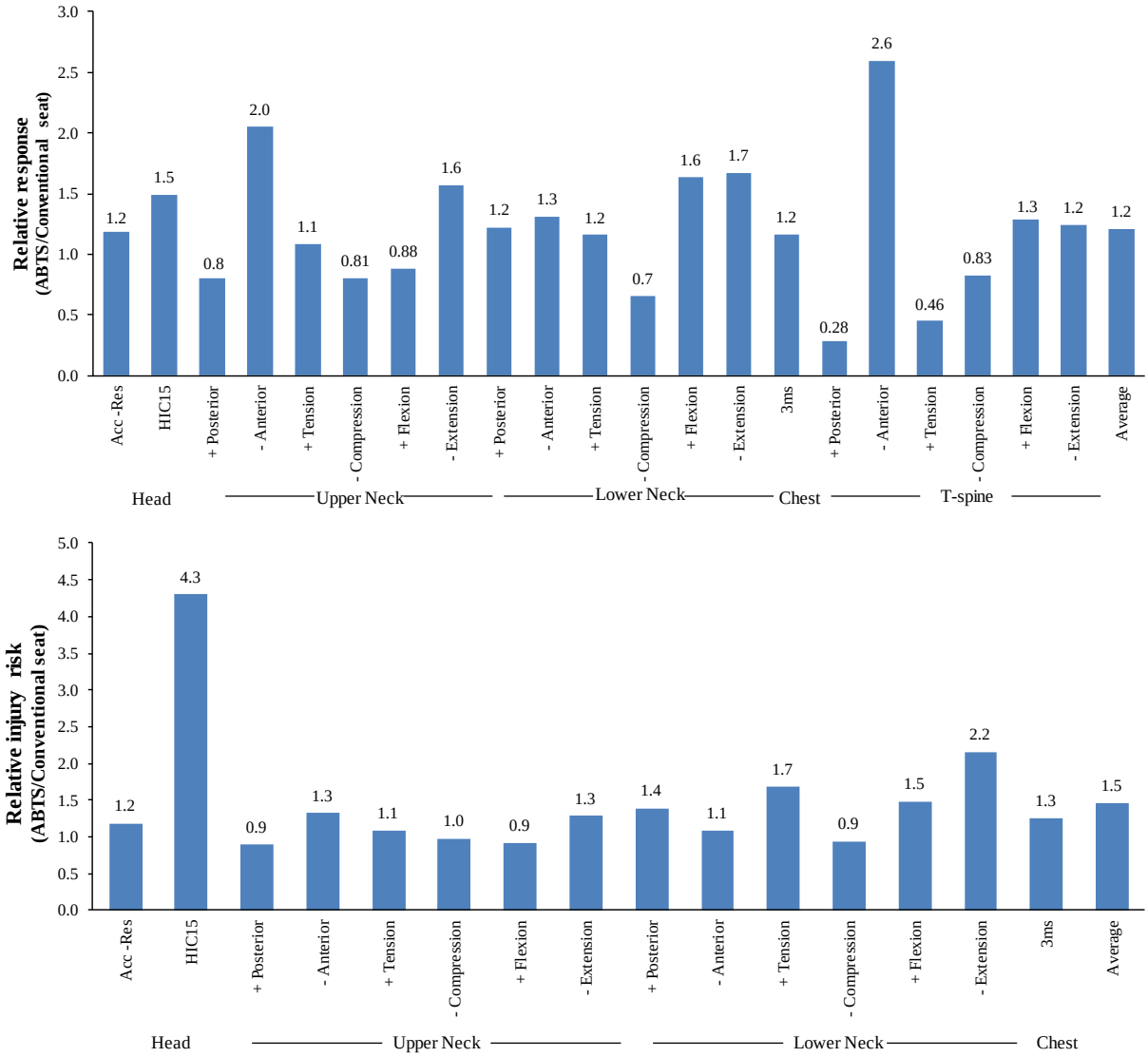
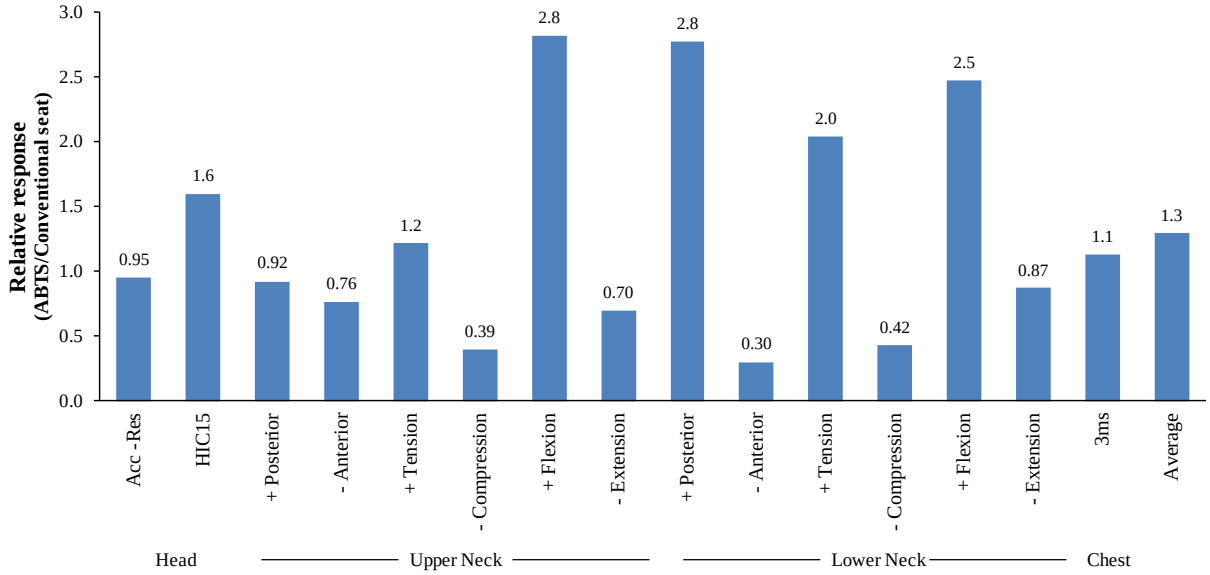


Figure B3: 15 mph rear sled test with a 50III in-position (IP).

Table B5: Selected peak sled and 95th Hybrid III (300 lb) biomechanical responses in 15 mph rear sled tests.
(Adapted from McGowan et al. 2010).

15 mph	Sample (n)		2	2							
Seat	MY		2002	2002							
	Model		Explorer	Traiblazer LeSabre	**Relative Response ABTS/ conv**	**IARV**	**% IARV** Conv Below	**% IARV** ABTS Below	**% Injury Risk** Conv Below	**% Injury Risk** ABTS Below	**Relative Risk ABTS/ conv**
	Seat		Conv	ABTS							
	HR		Below	Below							
Occupant	Location		D	D							
	ATD		95HIII	95HIII							
	Weight (lb)		300	300							
	Position	Sign	IP	IP							
Head	Acc (g)		34	32	0.95	175	19%	18%	0.027%	0.025%	0.94
	HIC_{15}		49	78	1.60	670	7%	12%	0.055%	0.255%	4.67
Upper Neck	Fx (lb)	+ Posterior	62	57	0.92	841	7%	7%	0.035%	0.034%	0.97
		- Anterior	-60	-46	0.76	-841	7%	5%	0.035%	0.032%	0.91
	Fz (lb)	+ Tension	346	420	1.21	1,131	31%	37%	0.001%	0.003%	2.99
		- Compression	-0.43	-0.17	0.39	-1,086	0%	0%	0.023%	0.023%	1.00
	My (inlb)	+ Flexion	65	181	2.81	2,230	3%	8%	0.027%	0.036%	1.33
		- Extension	-401	-280	0.70	-1,133	35%	25%	0.22%	0.101%	0.47
Lower Neck	Fx (lb)	+ Posterior	111	307	2.77	841	13%	37%	0.048%	0.169%	3.53
		- Anterior	-141	-42	0.30	-841	17%	5%	0.058%	0.031%	0.53
	Fz (lb)	+ Tension	131	267	2.04	1,131	12%	24%	0.000%	0.000%	7.48
		- Compression	-38	-16	0.42	-1,086	4%	1%	0.028%	0.025%	0.90
	My (inlb)	+ Flexion	190	469	2.46	4,461	4%	11%	0.030%	0.041%	1.40
		- Extension	-1461	-1266	0.87	-2,266	64%	56%	0.764%	0.480%	0.63
Chest	3 ms		11	12	1.12	54	20%	22%	0.029%	0.034%	1.17
D: Driver, IP: In-position				**Average**	1.29						1.93

Max by body region			
Head	0.05%	0.25%	4.67
Spine	0.76%	0.48%	0.63
Chest	0.03%	0.03%	1.17
Max	0.76%	0.48%	0.63



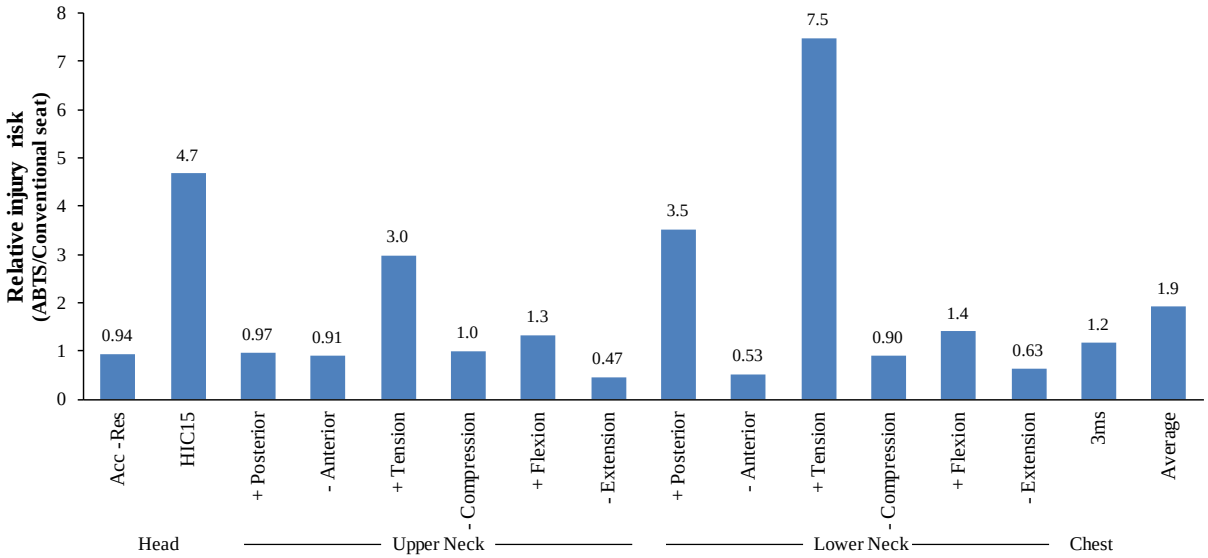


Figure B4: 15 mph rear sled test with a 300lb 95III in-position (IP).
(McGowan et al. 2010)

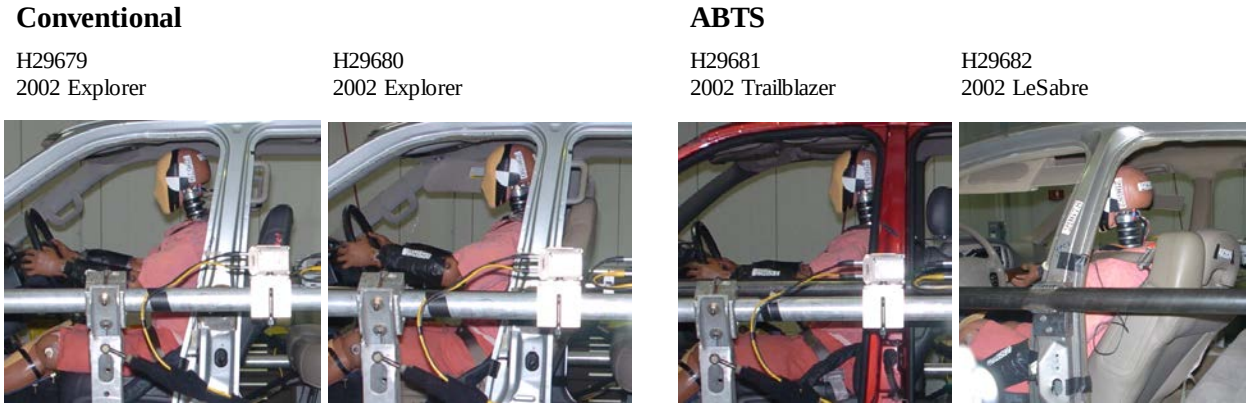


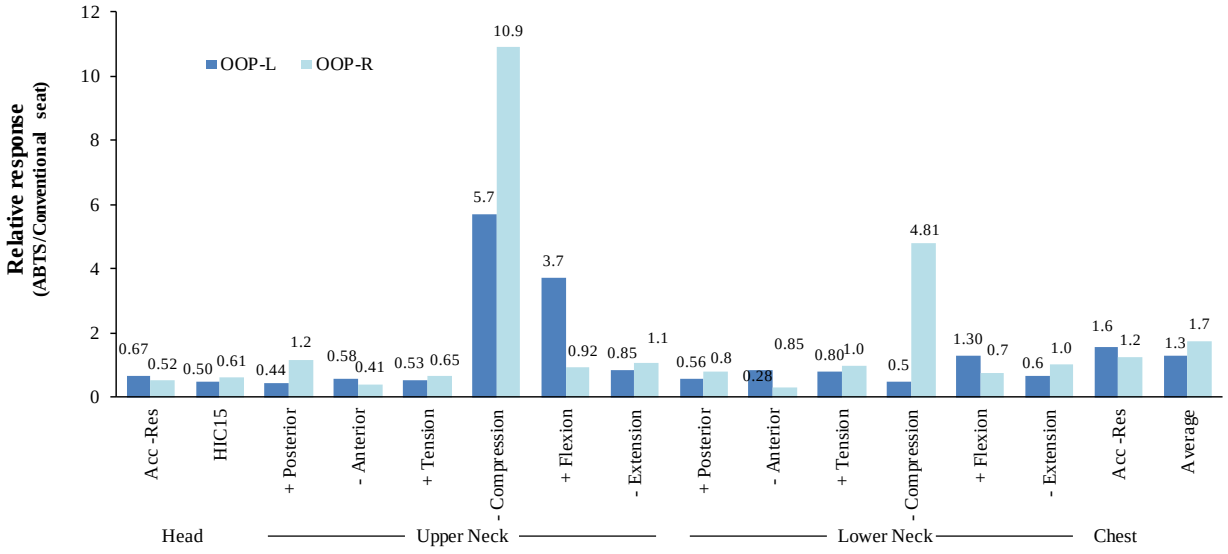
Figure B5: 15 mph rear sled test with a 300lb 95III in-position (IP).

Table B6: Selected peak sled and biomechanical responses in 16 mph rear sled tests.
(Adapted from McGowan et al. 2010).

16 mph	Sample (n)		1	1	1	1														
Sled	MY		2002	2002	2002	2002														
Seat	Make		Ford	Buick	Ford	Buick														
	Model		Explorer	LeSabre	Explorer	LeSabre														
	Seat		Conv	ABTS	Conv	ABTS	**Relative Response ABTS/conv**			Conv	ABTS	Conv	ABTS	Conv	ABTS	Conv	ABTS	**Relative Risk ABTS/ conv**	
	HR		Below	Below	Below	Below								Below	Below	Below	Below		
Occupant	Location		D	D	D	D			**IARV**	**% IARV**					**% Injury Risk**				
	ATD		50HIII	50HIII	50HIII	50HIII	50HIII	50HIII											
	Position	Sign	OOP L	OOP L	OOP-R	OOP-R	OOP L	OOP-R		OOP-L		OOP-R		OOP L	OOP L	OOP-R	OOP-R	OOP L	OOP-R
Head	Acc (g)		72	49	90	47	0.67	0.52	180	40%	27%	50%	26%	0.11%	0.05%	0.20%	0.04%	0.43	0.21
	HIC_{15}		341	170	289	175	0.50	0.61	700	49%	24%	41%	25%	1.76%	0.98%	1.48%	1.00%	0.56	0.68
Upper Neck	Fx (lb)	+ Posterior	177	78	50	59	0.44	1.18	697	25%	11%	7%	8%	0.09%	0.04%	0.03%	0.04%	0.47	1.07
		- Anterior	-163	-95	-171	-70	0.58	0.41	-697	23%	14%	25%	10%	0.08%	0.05%	0.09%	0.04%	0.59	0.46
	Fz (lb)	+ Tension	1005	534	710	458	0.53	0.65	937	107%	57%	76%	49%	0.00%	0.00%	0.00%	0.00%	0.15	0.36
		- Compression	-10	-56	-2	-26	5.70	10.89	-899	1%	6%	0%	3%	0.025%	0.033%	0.024%	0.027%	1.32	1.15
	My (inlb)	+ Flexion	111	410	236	217	3.71	0.92	1,682	7%	24%	14%	13%	0.03%	0.09%	0.05%	0.05%	2.62	0.94
		- Extension	-458	-389	-394	-421	0.85	1.07	-859	53%	45%	46%	49%	0.77%	0.44%	0.45%	0.57%	0.57	1.25
Lower Neck	Fx (lb)	+ Posterior	479	267	375	300	0.56	0.80	697	69%	38%	54%	43%	0.96%	0.19%	0.43%	0.24%	0.19	0.56
		- Anterior	-44	-37	-43	-12	0.85	0.28	-697	6%	5%	6%	2%	0.03%	0.03%	0.03%	0.03%	0.95	0.79
	Fz (lb)	+ Tension	535	426	299	293	0.80	0.98	937	57%	45%	32%	31%	0.08%	0.01%	0.00%	0.00%	0.14	0.90
		- Compression	-65	-31	-18	-84	0.47	4.81	-899	7%	3%	2%	9%	0.03%	0.03%	0.03%	0.04%	0.81	1.50
	My (inlb)	+ Flexion	343	445	544	406	1.30	0.75	3,363	10%	13%	16%	12%	0.04%	0.05%	0.06%	0.05%	1.18	0.80
		- Extension	-1482	-963	-2104	-2135	0.65	1.01	-1,717	86%	56%	123%	124%	2.45%	0.49%	15.14%	16.44%	0.20	1.09
Chest	3 ms		14	22	15	19	1.57	1.24	60	23%	36%	25%	31%	0.04%	0.08%	0.04%	0.06%	2.37	1.48
						Average	1.3	1.7										0.84	0.88

D: Driver, OOP: Out-of-position
Corrected My value unavailabel for OOP-L with Explorer

Max by body region						
Head	1.76%	0.98%	1.48%	1.00%	0.56	0.68
Spine	2.45%	0.49%	15.14%	16.44%	0.20	1.09
Chest	0.04%	0.08%	0.04%	0.06%	2.37	1.48
Max	2.45%	0.98%	15.14%	16.44%	0.40	1.09



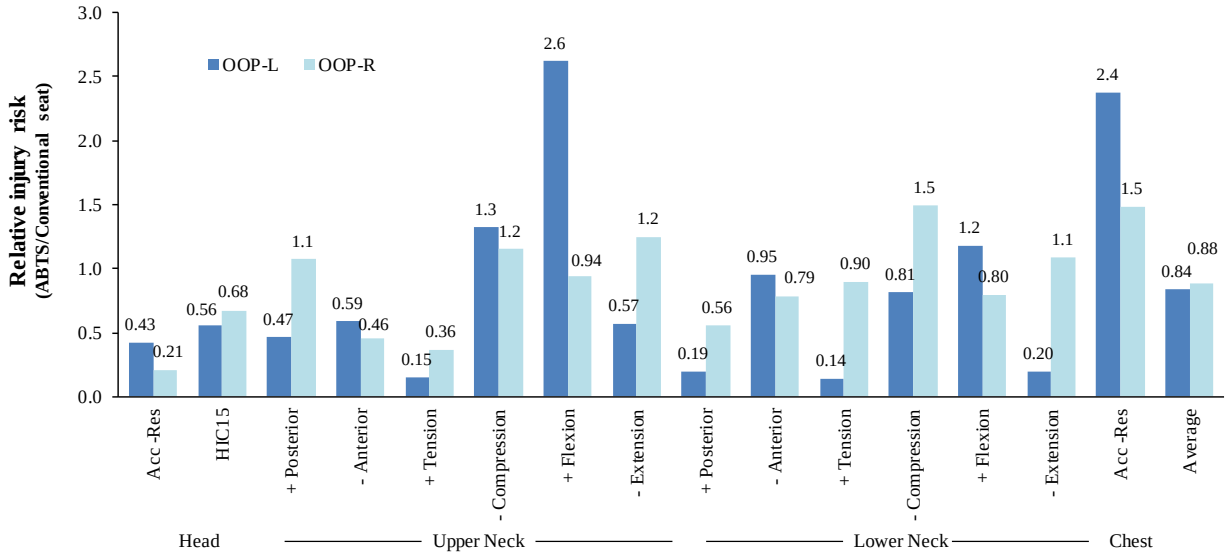


Figure B6: 16 mph rear sled test with a 50th Hybrid III out-position (OOP).

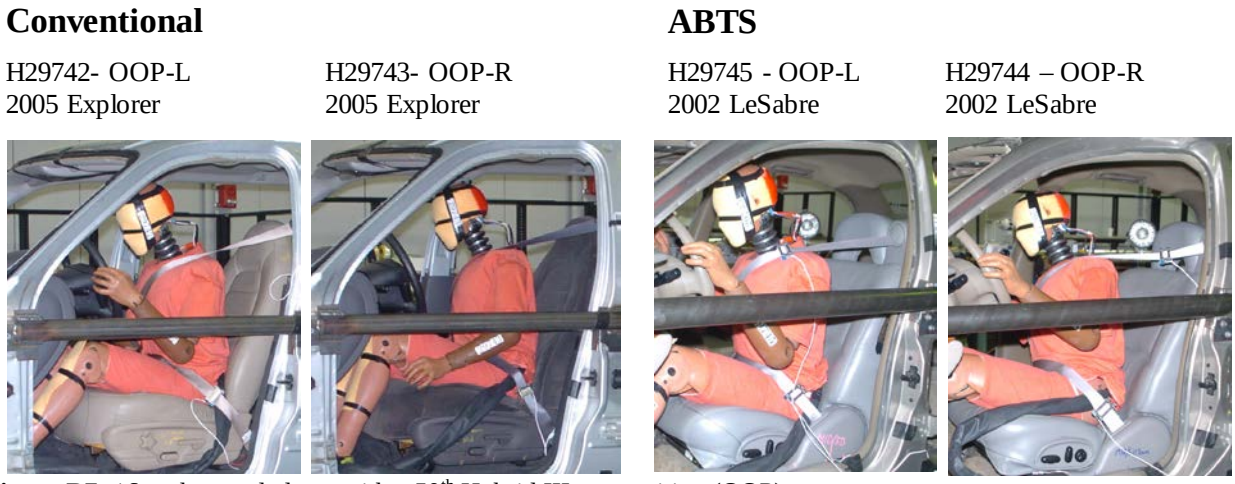


Figure B7: 16 mph rear sled test with a 50th Hybrid III out-position (OOP).

20-<25 mph (32-<40 km/h): For 32 km/h delta V tests, 2 were discussed in Viano et al. (2011). Table B7 tabulates the data (Match # 8).

Table B7: Selected peak sled and biomechanical responses in 20 mph rear sled tests.
(Adapted from Viano et al. 2013).

20 mph	Sample (n)		1	1							
Seat	MY		2000-2	2001							
	Make		Ford	Chrysler	**Rel. Resp. ABTS/ conv**	**IARV**	**% IARV**		**% Injury Risk**		**Rel. Risk ABTS / conv**
	Model		Taurus	Sebring							
	Seat		Conv	ABTS			Conv	ABTS	Conv	ABTS	
	HR		Above	Above	Above		Above	Above	Above	Above	
Occupant	ATD		50^{th} HIII	50^{th} HIII							
	Location		D	D							
	Position		IP	IP							
Head	Acc (g)		28	37	1.35	180	15%	21%	0.02%	0.03%	1.42
	HIC_{15}		35	117	3.34	700	5%	17%	0.62%	0.82%	1.33
Upper Neck	Fx (lb)	+ Posterior	61	80	1.30	697	9%	11%	0.04%	0.04%	1.15
		- Anterior	-27	-60	2.20	-697	4%	9%	0.03%	0.04%	1.29
	Fz (lb)	+ Tension	274	363	1.32	937	29%	39%	0.00%	0.00%	1.43
		- Compression	-28	-30	1.04	-899	3%	3%	0.03%	0.03%	1.01
	My (inlb)	+ Flexion	170	182	1.07	1,682	10%	11%	0.04%	0.04%	1.04
		- Extension	-170	-65	0.38	-859	20%	8%	0.07%	0.03%	0.42
Lower Neck	Fx (lb)	+ Posterior	171	332	1.94	697	25%	48%	0.09%	0.31%	3.48
		- Anterior	-37	-30	0.82	-697	5%	4%	0.03%	0.03%	0.95
	Fz (lb)	+ Tension	234	333	1.43	937	25%	36%	0.00%	0.00%	5.91
		- Compression	-46	-38	0.83	-899	5%	4%	0.03%	0.03%	0.95
	My (inlb)	+ Flexion	414	551	1.33	3,363	12%	16%	0.05%	0.06%	1.25
		- Extension	-395	-763	1.93	-1,717	23%	44%	0.08%	0.26%	3.18
Chest	3 ms		14	21	1.43	60	24%	34%	0.04%	0.07%	1.96
Thoracic spine	Fx (lb)	+ Posterior	49	6	0.12			**Max by body region**			
		- Anterior	-159	-327	2.05			Head	0.62%	0.82%	1.33
	Fz (lb)	+ Tension	333	185	0.55			Spine	0.09%	0.31%	3.48
		- Compression	-164	-194	1.18			Chest	0.04%	0.07%	1.96
	My (inlb)	+ Flexion	632	742	1.17			**Max**	0.62%	0.82%	1.33
		- Extension	-1527	-1732	1.13						
D: Driver, IP: In-position				**Average**	1.33						1.78
(adapted from Viano et al. 2013)											

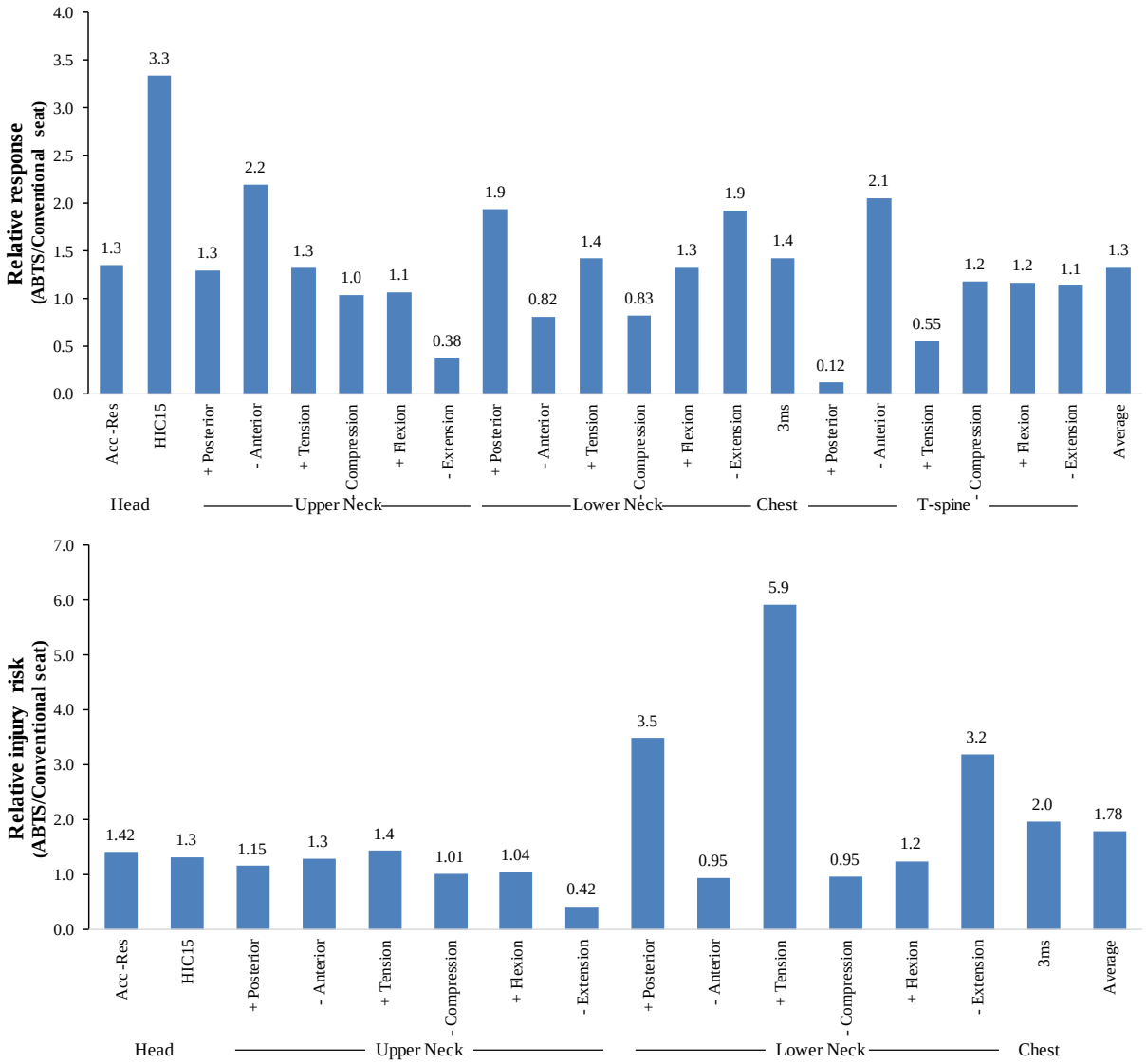


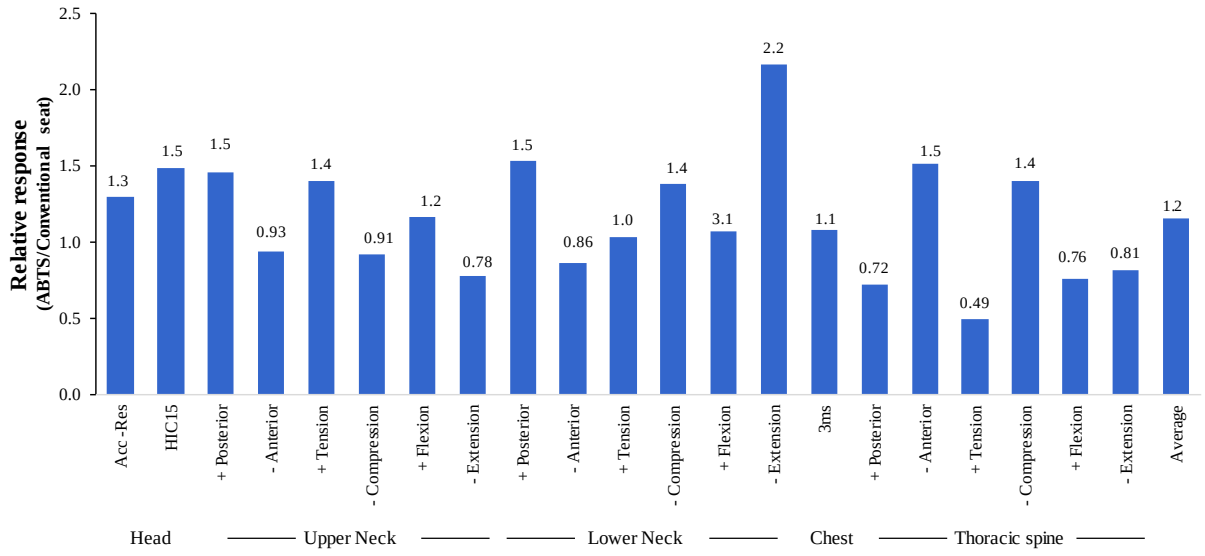
Figure B8: 20 mph rear sled test with a 50III in-position (IP).
(Viano et al. 2013)

40-<48 km/h: Twenty-four rear sled tests were run with a nominal 40+ km/h delta V. Tables B8-B11 summarizes the data. Three tests were conducted with a modified dual recliner ABTS (ABTS*). The ABTS* is a non-production seat. Its stiffness properties are unknown but was assumed to be similar or higher to some production ABTS seats. Appendix C provides additional info on the ABTS* seat designs.

Sixteen tests were with a 50th HIII in-position; 13 were with a conventional seat, 3 with an ABTS seat (Match #9). Five of the 13 tests with conventional seats and one test with an ABTS seat were discussed in Viano et al. (2018a). One test with a conventional seat and one with an ABTS*seat is discussed in Viano et al. (2021). Table B8 tabulates the average data.

Table B8: Selected peak sled and in-positioned 50 HIII biomechanical responses in 25 mph rear sled tests.
(Adapted from Viano et al. 2018a,b, 2021)

25 mph	Sample (n)		13	3	**Rel. Resp.**	**IARV**	**% IARV**		**% Injury Risk**		**Rel. Risk**
	Seat		**Conv**	**ABTS**	**ABTS/Conv**		**Conv**	**ABTS**	**Conv**	**ABTS**	**ABTS/Conv**
	HR		Above	Above	Above		Above	Above	Above	Above	Above
Occupant	ATD		50HIII	50HIII							
Head	Acc (g)		23	30	1.29	180	13%	17%	0.02%	0.02%	1.28
	HIC_{15}		39	57	1.48	700	6%	8%	0.62%	0.67%	1.07
Upper Neck	Fx (lb)	+ Posterior	40	58	1.45	697	6%	8%	0.03%	0.04%	1.15
		- Anterior	-49	-46	0.93	-697	7%	7%	0.03%	0.03%	0.98
	Fz (lb)	+ Tension	167	233	1.40	937	18%	25%	0.00%	0.00%	1.31
		- Compressior	-20	-18	0.91	-899	2%	2%	0.03%	0.03%	0.99
	My corr	+ Flexion	150	174	1.16	1,682	9%	10%	0.04%	0.04%	1.08
		- Extension	-152	-118	0.78	-859	18%	14%	0.06%	0.05%	0.76
Lower Neck	Fx (lb)	+ Posterior	164	250	1.53	697	23%	36%	0.08%	0.16%	1.95
		- Anterior	-41	-36	0.86	-697	6%	5%	0.03%	0.03%	0.96
	Fz (lb)	+ Tension	164	169	1.03	937	17%	18%	0.00%	0.00%	1.09
		- Compressior	-20	-28	1.38	-899	2%	3%	0.03%	0.03%	1.05
	My (inlb)	+ Flexion	393	419	1.07	3,363	12%	12%	0.04%	0.05%	1.04
		- Extension	-347	-750	2.16	-1,717	20%	44%	0.07%	0.25%	3.56
Chest	3ms		15	16	1.07	60	25%	26%	0.04%	0.04%	1.12
Thoracic spine	Fx (lb)	+ Posterior	41	30	0.72			**Max by body region**			
		- Anterior	-177	-268	1.51			Head	0.62%	0.67%	1.07
	Fz (lb)	+ Tension	202	99	0.49			Spine	0.08%	0.25%	2.98
		- Compressior	-139	-195	1.40			Chest	0.04%	0.04%	1.12
	My (inlb)	+ Flexion	779	588	0.76			**Max**	0.62%	0.67%	1.07
		- Extension	-1261	-1025	0.81						
Conv: Conventioal seat				**Average**	1.15						1.29



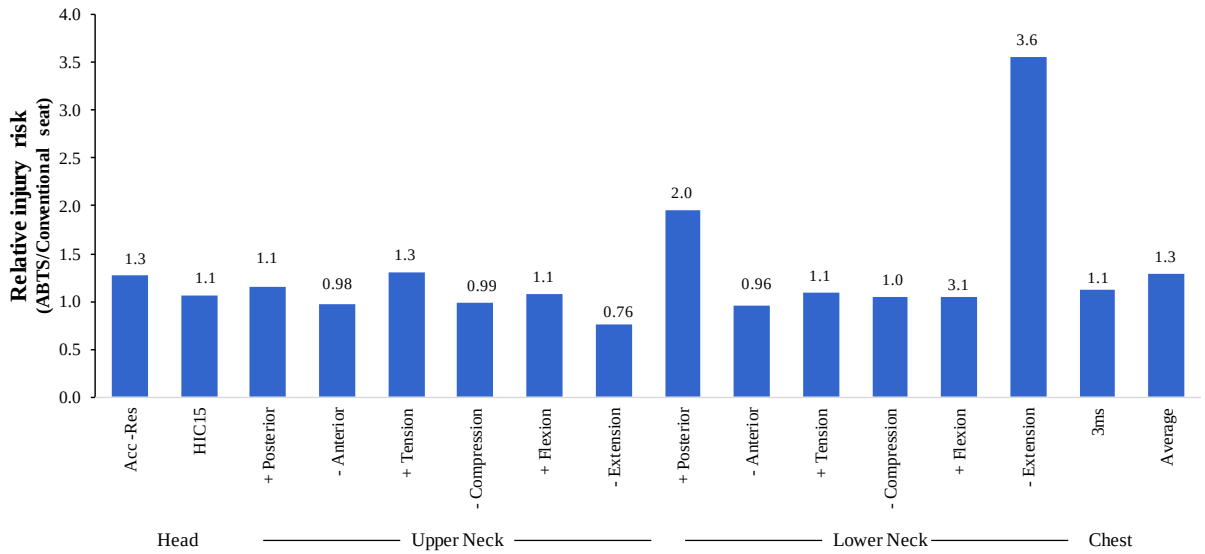


Figure B9: Relative biomechanical response and risk with a 50III in position (IP) ATD in ABTS v conventional seat at 25 mph rear sled test.

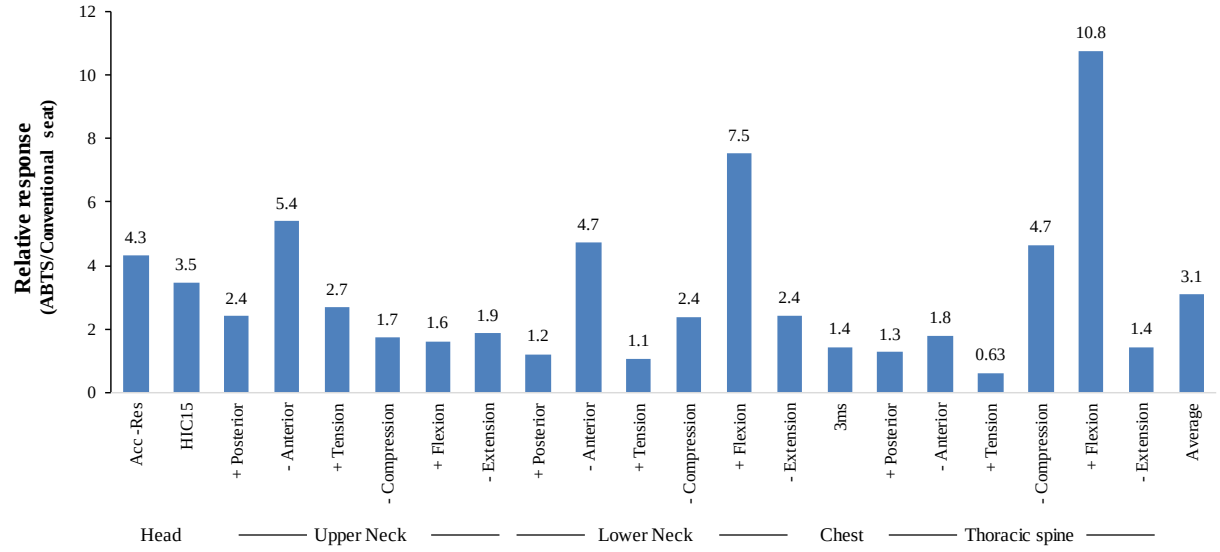
Eight tests were conducted with an out-of-position ATD. Two with a 5th HIII that were discussed in Viano et al. (2009) (Match #10) and are summarized in Table B9. Six tests were with a 50th HIII out-of-position. Three of the 6 tests were with a conventional seat, 3 with an ABTS seat and one with an ABTS*. Of the 6 tests with the 50th HIII OOP, 4 were discussed in Viano et al. (2018b) and 2 are included in Viano et al. (2021). The head, neck and chest responses were however not included in Viano et al. (2018b) and were analyzed herein. The six tests were grouped into OOP-L (Match #11) and OOP-R (Match #12). Tables B10 and B11 summarize the data.

Table B9: Selected peak sled and out-positioned (OOP) 5 HIII biomechanical responses in 25 mph rear sled tests.

	25 mph	Sample (n)		1	1							
				1996	1996							
	Seat	Make		Explorer	Sebring	**Relative**	**IARV**	**% IARV**		**% Injury Risk**		**Relative**
		Design		**Conv**	**ABTS**	**Response**		**Conv**	**ABTS**	**Conv**	**ABTS**	**Risk**
		HR		Above	Above	**ABTS/ Conv**		Above	Above	Above	Above	**ABTS/**
Head	**Occupant**	ATD		5HIII	5HIII		5HIII					**Conv**
		Location		D	D		(Mertz et al.					
		Position		OOP-R	OOP-R		2016)					
	Head	Acc (g)		32	139	4.3	193	17%	72%	0.03%	1.20%	47.1
		HIC_{15}		69	239	3.5	779	9%	31%	0.69%	1.24%	1.8
	Upper Neck	Fx (lb)	+ Posterior	9	21	2.4	438	2%	5%	0.03%	0.03%	1.2
			- Anterior	-36	-192	5.4	-438	8%	44%	0.04%	0.25%	6.9
		Fz (lb)	+ Tension	235.0	629.80	2.7	589	40%	107%	0.005%	76.61%	>50
			- Compression	-2	-3	1.7	-567	0%	1%	0.02%	0.02%	1.0
		My (inlb)	+ Flexion	7	12	1.6	841	1%	1%	0.02%	0.03%	1.0
			- Extension	-23	-43	1.9	-434	5%	10%	0.03%	0.04%	1.4
	Lower Neck	Fx (lb)	+ Posterior	167	202	1.2	438	38%	46%	0.18%	0.28%	1.5
			- Anterior	-10	-47	4.7	-438	2%	11%	0.03%	0.04%	1.6
		Fz (lb)	+ Tension	239	257	1.1	589	41%	44%	0.01%	0.01%	1.7
			- Compression	-2	-4	2.4	-567	0%	1%	0.02%	0.02%	1.0
		My (inlb)	+ Flexion	43	320	7.5	1,682	3%	19%	0.03%	0.07%	2.4
Thoracic			- Extension	-930	-2261	2.4	-867	107%	261%	7.21%	99.68%	13.8
spine	**Chest**	3 ms		13	19	1.4	73	18%	25%	0.03%	0.04%	1.6
	Thoracic spine	Fx (lb)	+ Posterior	37	47	1.3			**Max by body region**			
			- Anterior	-135	-243	1.8			Head	0.69%	1.24%	1.8
		Fz (lb)	+ Tension	157	99	0.63			Spine	7.21%	99.68%	13.8
			- Compression	-20	-94	4.7			Chest	0.025%	0.041%	1.6
Lumbar		My (inlb)	+ Flexion	34	369	10.8			**Max**	7.21%	99.68%	13.8
			- Extension	-1158	-1667	1.4						
	D: Driver, RFP: Right-front passenger, OOP: Out-of-position					**Average**	3.09					>50

Dark grey: > IARV

(adapted from Viano et al. 2009)



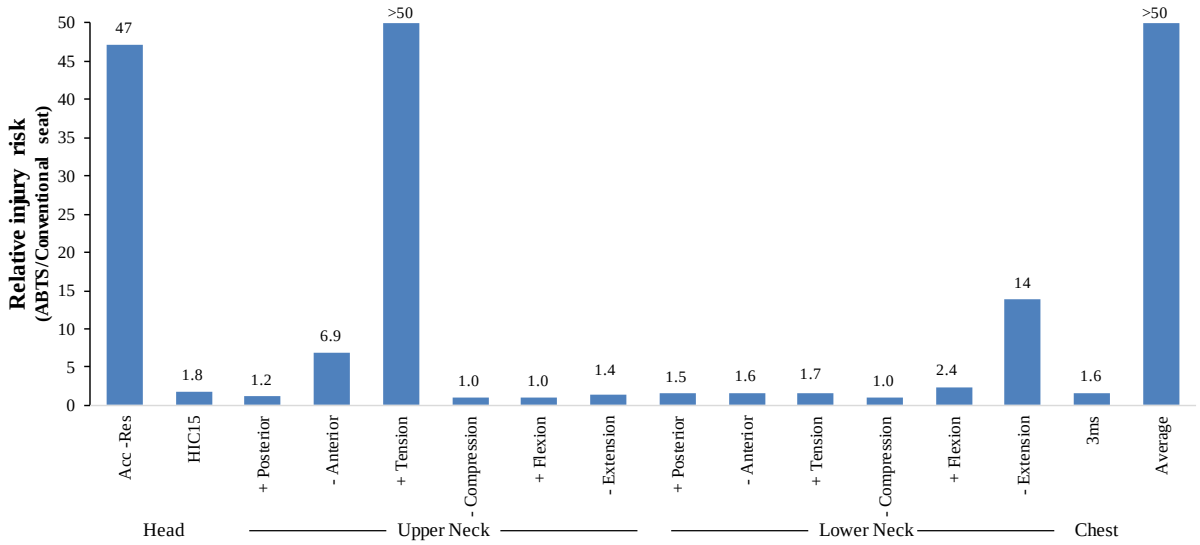


Figure B10: 25 mph rear sled test with a 5III in a leaning inboard position (OOP-R)

Table B10: Selected peak sled and out-of-positioned (leaning forward) 50 HIII biomechanical responses in 25 mph rear sled tests.
(Updated from Viano et al. 2018a,b, 2021)

25 mph	Sample (n)		1	2							
Seat	Seat		Conv	ABTS	**Rel.**	**IARV**	**% IARV**		**% Injury Risk**		**Rel.**
	HR		Above	Above	**Resp.**						**Risk**
Occupant	ATD		50HIII	50HIII	**ABTS/**						**ABTS**
	Location		RFP	D/RFP	**Conv**		Conv	ABTS	Conv	ABTS	**/Conv**
	Position		OOP-L	OOP-L							
Head	Acc (g)		50	61	1.2	180	28%	34%	0.05%	0.07%	1.48
	HIC_{15}		121	293	2.4	700	17%	42%	0.83%	1.50%	1.80
Upper Neck	Fx (lb)	+ Posterior	40	144	3.6	697	6%	21%	0.03%	0.07%	2.25
		- Anterior	-65	-66	1.0	-697	9%	9%	0.04%	0.04%	1.00
	Fz (lb)	+ Tension	546	620	1.1	937	58%	66%	0.00%	0.00%	1.34
		- Compression	-20	-127	6.3	-899	2%	14%	0.03%	0.05%	1.90
	My (inlb)	+ Flexion	183	548	3.0	1,682	11%	33%	0.04%	0.14%	3.24
		- Extension	-347	-318	0.9	-859	40%	37%	0.31%	0.24%	0.79
Lower Neck	Fx (lb)	+ Posterior	216	438	2.0	697	31%	63%	0.13%	0.70%	5.61
		- Anterior	-43	-61	1.4	-697	6%	9%	0.03%	0.04%	1.15
	Fz (lb)	+ Tension	536	529	1.0	937	57%	56%	0.08%	0.07%	0.87
		- Compression	-28	-131	4.6	-899	3%	15%	0.03%	0.05%	1.86
	My (inlb)	+ Flexion	445	684	1.5	3,363	13%	20%	0.05%	0.07%	1.47
		- Extension	-691	-1418	2.1	-1,717	40%	83%	0.21%	2.01%	9.71
Chest	3 ms		16	34	2.1	60	27%	57%	0.04%	0.32%	7.17
Thoracic spine	Fx (lb)	+ Posterior	94	214	2.3			**Max by body region**			
		- Anterior	-88	-298	3.4			Head	0.83%	1.50%	1.80
	Fz (lb)	+ Tension	301.1*	289	--			Spine	0.31%	2.01%	6.51
		- Compression	-80	-269	3.4			Chest	0.04%	0.32%	7.17
	My (inlb)	+ Flexion	441	632	1.4			**Max**	0.83%	2.01%	2.42
		- Extension	--	--	--						
Conv: Conventioal seat, OOP-L: Out-of-position lean					**Average**	2.36					2.8

* Saturated channel, Dark grey: > IARV

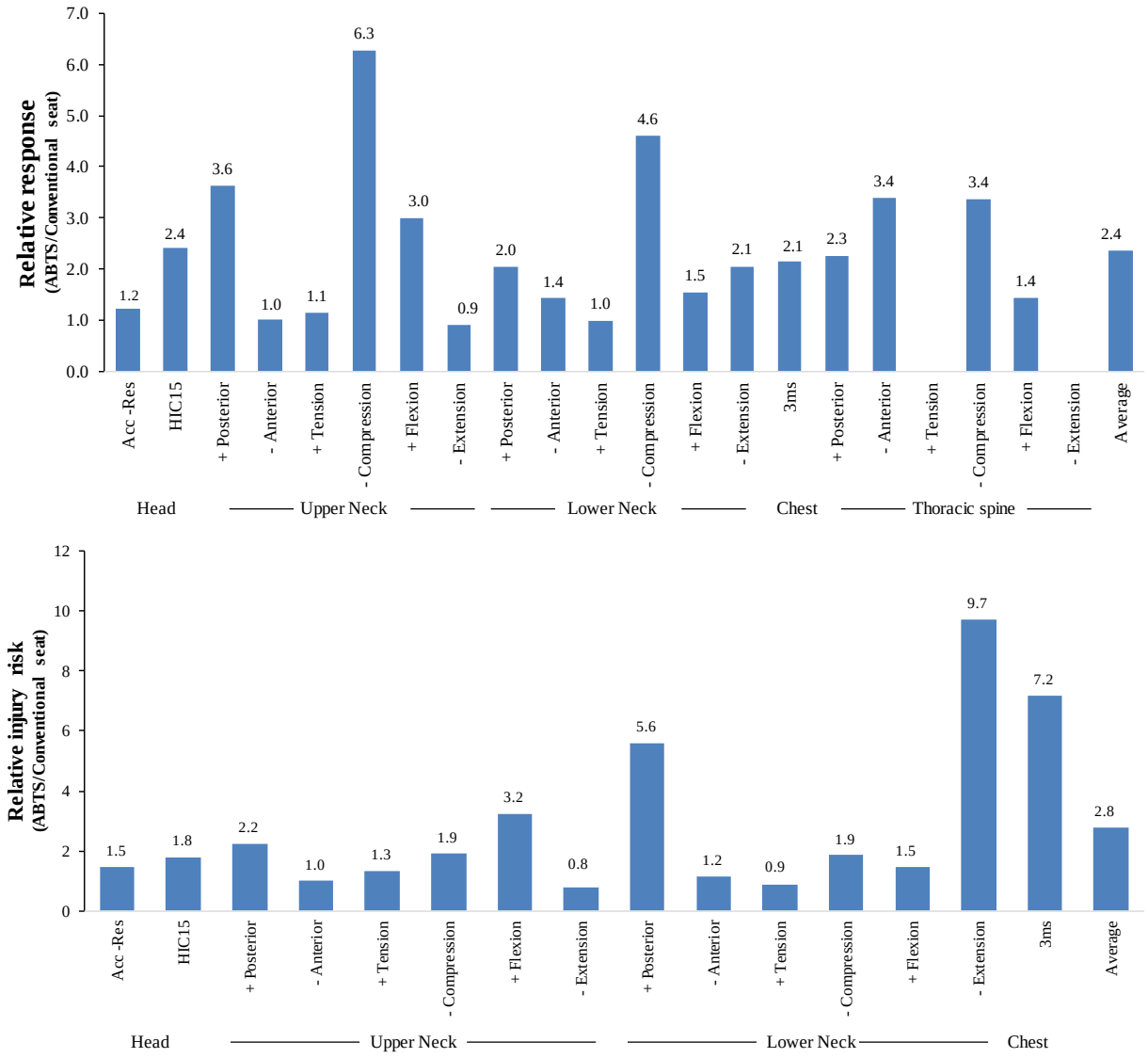


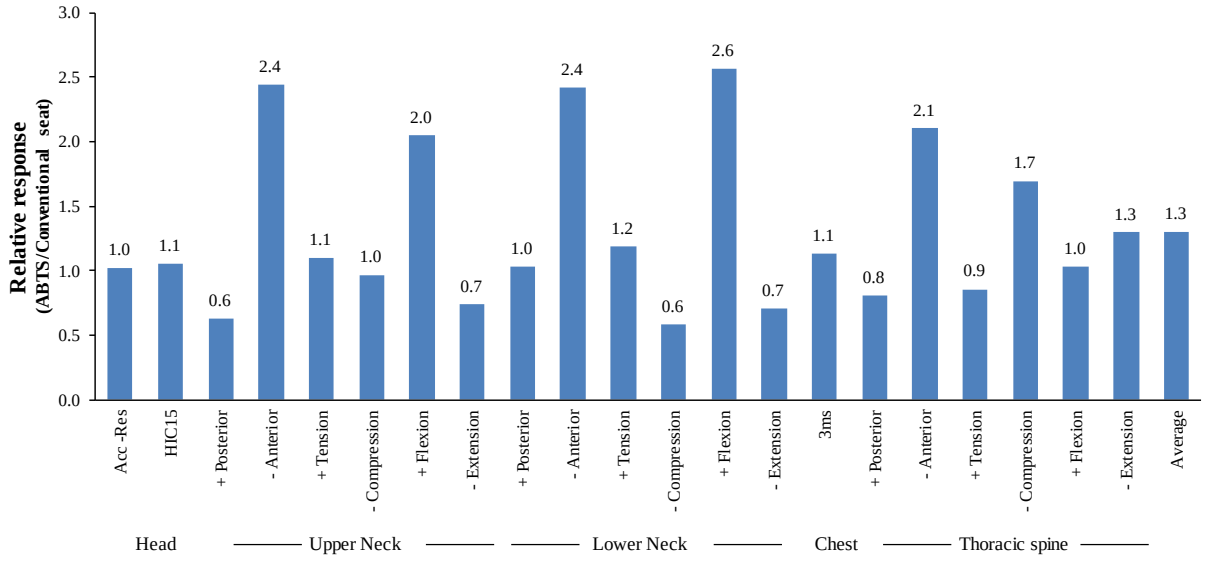
Figure B11: Relative biomechanical response and risk with an out-of-positioned 50III ATD in ABTS v conventional seat
OOP: Lean-forward position.

Table B11: Selected peak sled and out-positioned (OOP-R) 50 HIII biomechanical responses in 25 mph rear sled tests.

25 mph	Sample (n)		1	2							
Seat	MY		2002 Explorer	2002 LeSabre Trailblazer	**Relative Response**	**IARV**	**% IARV**		**% Injury Risk**		**Relative Risk**
	Design		**Conv**	**ABTS**	**ABTS/**	50HIII	**Conv**	**ABTS**	**Conv**	**ABTS**	**ABTS/**
	HR		Below	Below	**Conv**		Below	Below	Below	Below	**Conv**
Occupant	ATD		50HIII	50HIII							
	Location		D	D/RFP							
	Position		OOP	OOP							
Head	Acc (g)		38	38	1.0	180	21%	21%	0.03%	0.03%	1.0
	HIC_{15}		120	127	1.1	700	17%	18%	0.83%	0.85%	1.0
Upper Neck	Fx (lb)	+ Posterior	47	30	0.6	697	7%	4%	0.03%	0.03%	0.9
		- Anterior	-23	-57	2.4	-697	3%	8%	0.03%	0.04%	1.3
	Fz (lb)	+ Tension	376	415	1.1	937	40%	44%	0.00%	0.00%	1.2
		- Compression	-17	-16	1.0	-899	2%	2%	0.03%	0.03%	1.0
	My (inlb)	+ Flexion	106	217	2.0	1,682	6%	13%	0.03%	0.05%	1.4
		- Extension	-438	-324	0.7	-859	51%	38%	0.65%	0.25%	0.4
Lower Neck	Fx (lb)	+ Posterior	344	354	1.0	697	49%	51%	0.34%	0.37%	1.1
		- Anterior	-13	-31	2.4	-697	2%	5%	0.03%	0.03%	1.2
	Fz (lb)	+ Tension	278	330	1.2	937	30%	35%	0.00%	0.00%	2.5
		- Compression	-178	-104	0.6	-899	20%	12%	0.07%	0.04%	0.6
	My (inlb)	+ Flexion	215	550	2.6	3,363	6%	16%	0.03%	0.06%	1.7
		- Extension	-2170	-1528	0.7	-1,717	126%	89%	17.97%	2.82%	0.2
Chest	3 ms		14	15	1.1	60	23%	26%	0.04%	0.04%	1.2
Thoracic spine	Fx (lb)	+ Posterior	65	52	0.8			**Max by body region**			
		- Anterior	-155	-326	2.1			Head	0.83%	0.85%	1.02
	Fz (lb)	+ Tension	290	248	0.9			Spine	17.97%	2.82%	0.16
		- Compression	-37	-63	1.7			Chest	0.04%	0.04%	1.21
	My (inlb)	+ Flexion	241	249	1.0			**Max**	17.97%	2.82%	0.16
		- Extension	-2311	-2995	1.3						
D: Driver, RFP: Right-front passenger, OOP: Out-of-position					**Average**	1.30					1.1

Dark grey: > IARV

(adapted from Viano et al. 2018a,b)



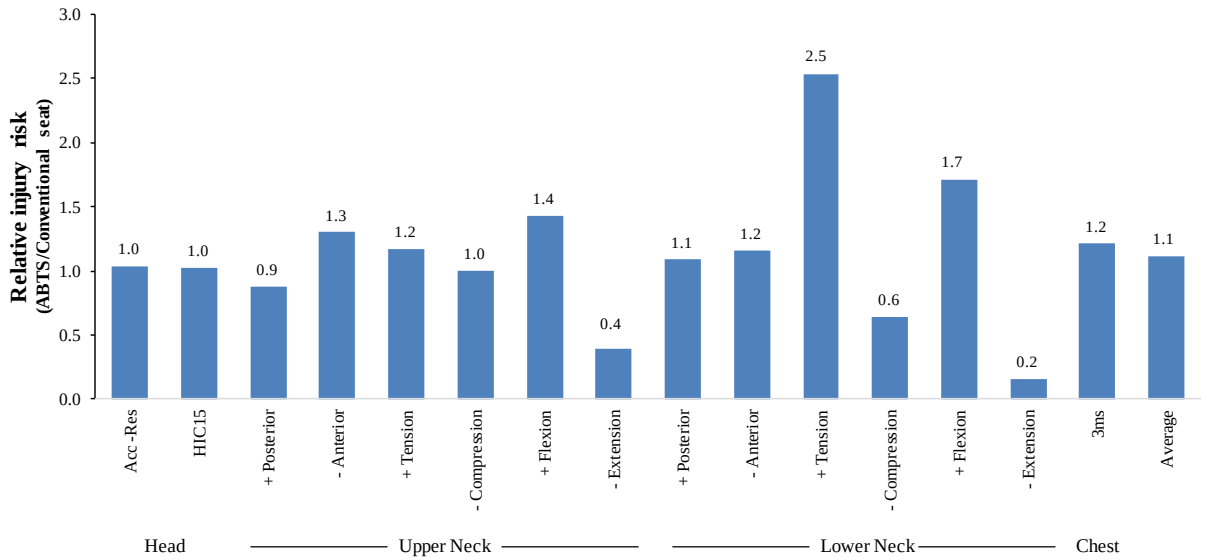


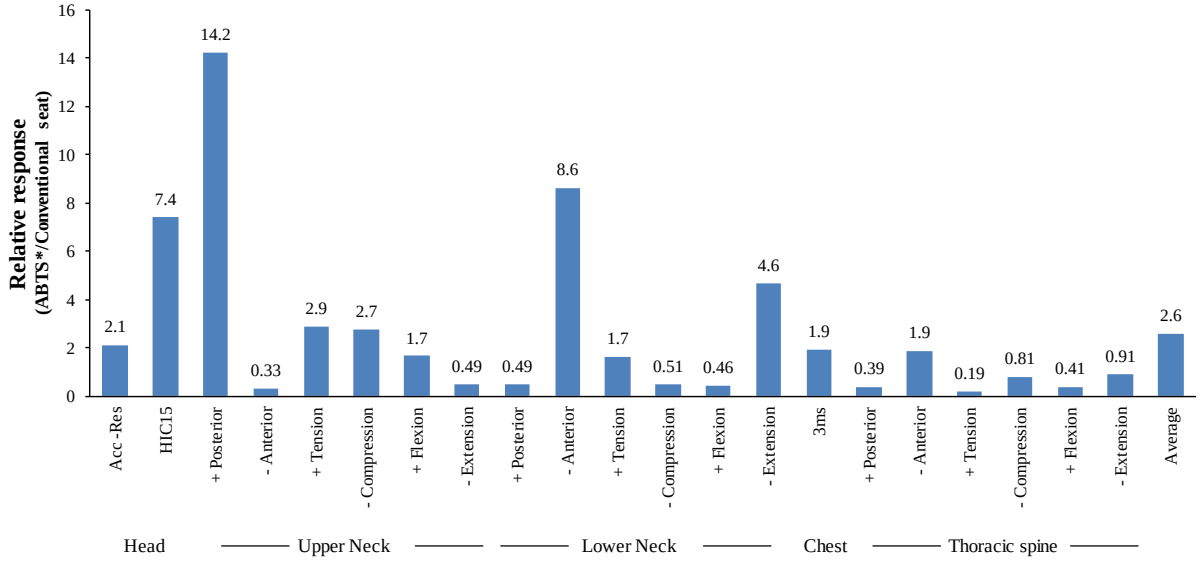
Figure B12: 25 mph rear sled test with a 50III in a radio position (OOP).
(adapted Viano et al. 2018b)

35-<40 mph (56-<64 km/h): For 56 km/h, two tests were conducted with an in-position 5th Hybrid III (Match #13). The tests are discussed in more details in Viano et al. (2021). One test was with a conventional seat and one with an ABTS*. Table B12 tabulates the data.

Table B12: Selected peak sled and 5 HIII biomechanical responses in 35 mph rear sled tests.

35 mph	Seat		**Conv**	**ABTS**	**Relative**	**IARV**	**Conv**	**ABTS**	**Conv**	**ABTS**	**Relative**
	HR		Above	Above	**Response**		Above	Above	Above	Above	**Risk**
Occupant	ATD		5HIII	5HIII	**ABTS/**	5HIII	**% IARV**		**% Injury Risk**		**ABTS/**
	Location		D	D	**Conv**	(Mertz et					**Conv**
	Position		IP	IP		al. 2016)					
Head	Acc (g)		41.3	88.1	2.13	193	21%	46%	0.04%	0.19%	5.4
	HIC_{15}		121.0	896.0	7.40	779	16%	115%	0.83%	10.95%	13.2
Upper Neck	Fx (lb)	+ Posterior	13.4	189.6	14.20	438	3%	43%	0.03%	0.24%	8.8
		- Anterior	-145.2	-47.9	0.33	-438	33%	11%	0.14%	0.04%	0.3
	Fz (lb)	+ Tension	250.0	717.0	2.87	589	42%	122%	0.01%	97.49%	>50
		- Compressio	-13.4	-36.7	2.74	-567	2%	6%	0.03%	0.03%	1.2
	My (inlb)	+ Flexion	288.7	480.4	1.66	841	34%	57%	0.15%	0.51%	3.4
		- Extension	-289.2	-142.0	0.49	-434	67%	33%	2.05%	0.18%	0.1
Lower Neck	Fx (lb)	+ Posterior	110.0	54.4	0.49	438	25%	12%	0.09%	0.05%	0.5
		- Anterior	-60.7	-523.5	8.63	-438	14%	119%	0.05%	13.09%	>50
	Fz (lb)	+ Tension	299.6	494.4	1.65	589	51%	84%	0.03%	6.58%	>50
		- Compressio	-131.9	-66.8	0.51	-567	23%	12%	0.08%	0.04%	0.5
	My (inlb)	+ Flexion	869.9	403.1	0.46	1,682	52%	24%	0.38%	0.09%	0.2
		- Extension	-438.4	-2037.7	4.65	-867	51%	235%	0.36%	98.74%	>50
Chest	3 ms		29.9	57.8	1.93	73	41%	79%	0.11%	1.35%	11.8
Thoracic	Fx (lb)	+ Posterior	123.1	48.1	0.39			**Max by body region**			
spine		- Anterior	-117.3	-222.6	1.90			Head	0.83%	10.95%	13.2
	Fz (lb)	+ Tension	371.4	72.3	0.19			Spine	2.05%	98.74%	48.2
		- Compressio	-307.8	-250.7	0.81			Chest	0.11%	1.35%	11.8
	My (inlb)	+ Flexion	1086.0	439.9	0.41			**Max**	2.05%	98.74%	48.2
		- Extension	-694.0	-633.6	0.91						
D: Driver, IP: In-position				**Average**	2.6						>50

Dark grey: > IARV
(adapted from Viano et al. 2021)



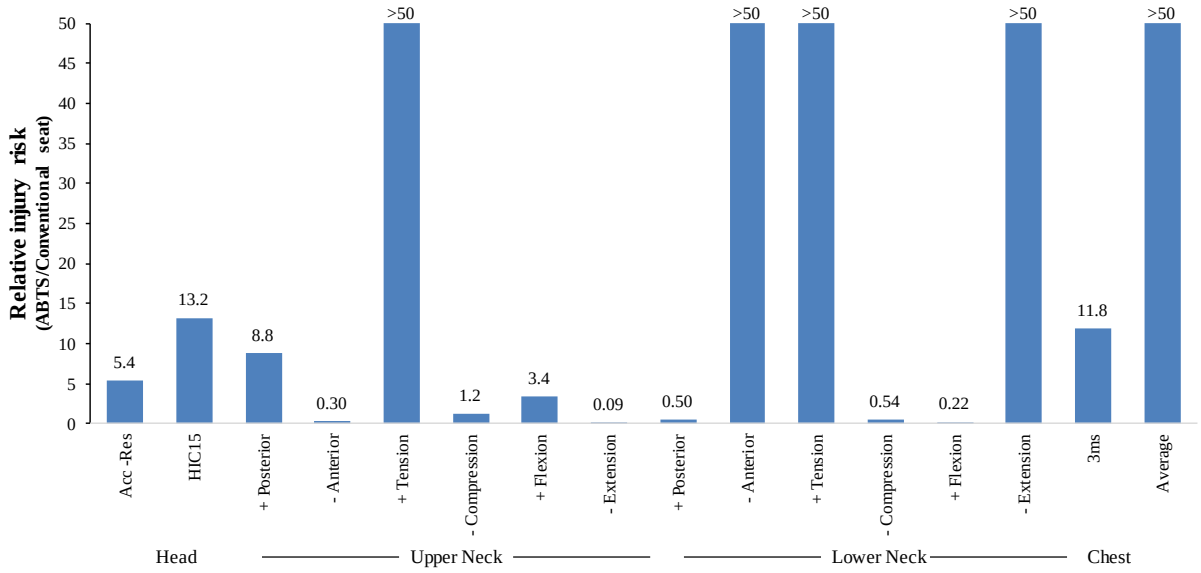


Figure B13: Selected peak sled and 5 HIII biomechanical responses in 35 mph rear sled tests.

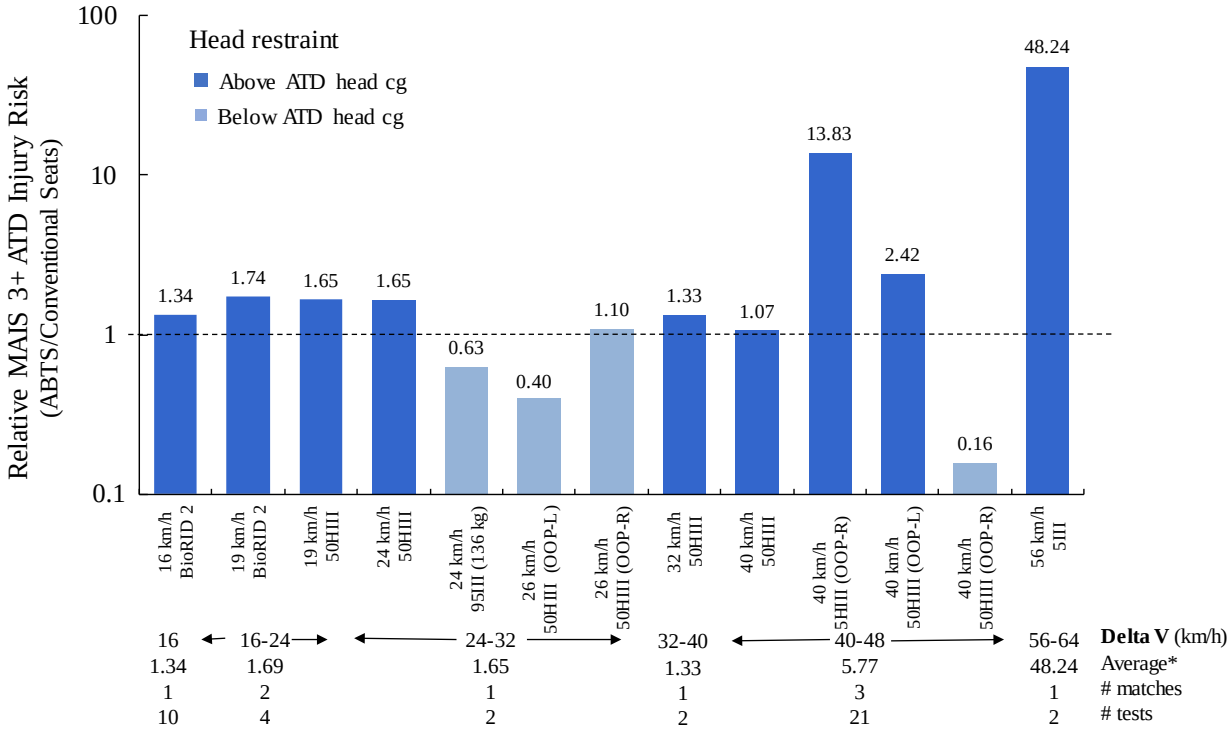


Figure B14: Relative maximum injury risk responses in ABTS v conventional seats by head restraint type, crash severity, ATD type and initial position.

The ATD biomechanical responses included head resultant acceleration and HIC_{15}, thoracic spine, upper and lower neck tension and posterior shear force and extension moment and chest 3 ms acceleration (or T1 acceleration for BioRID).

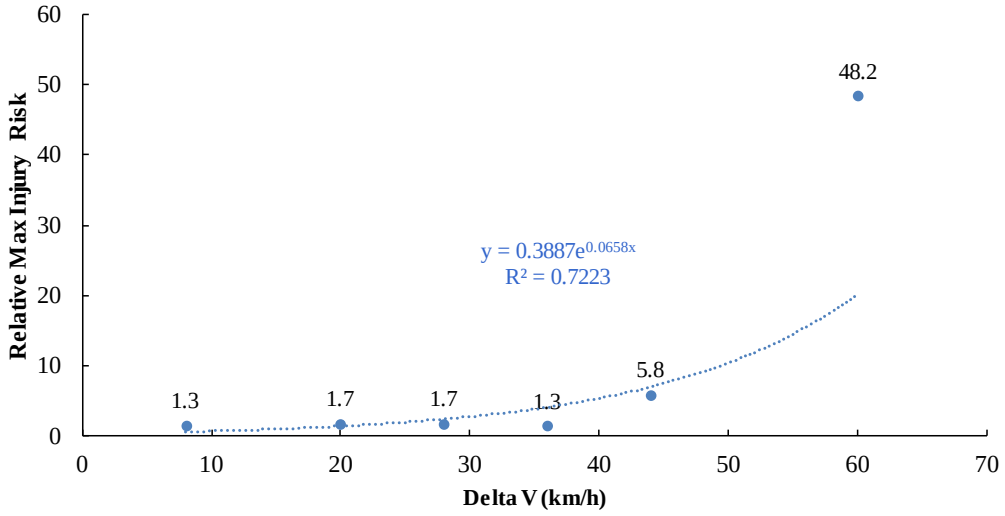
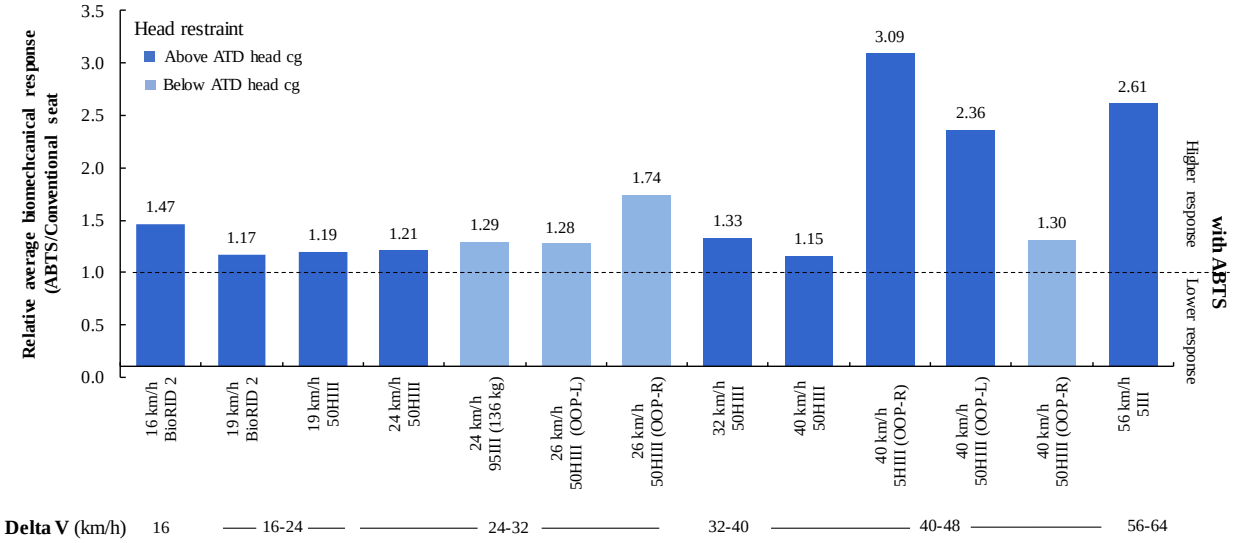
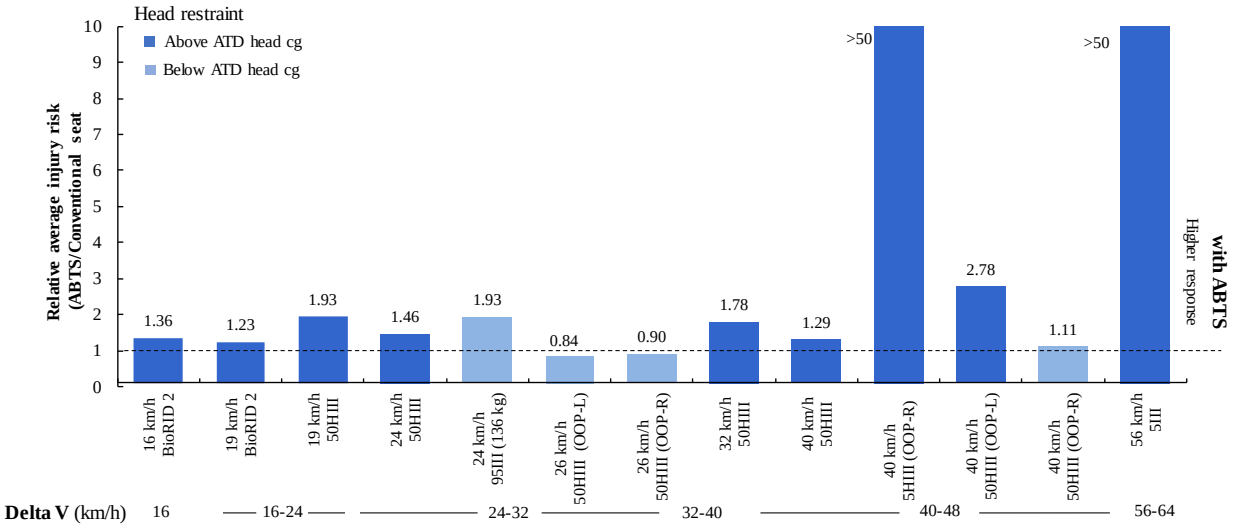


Figure B15: Curve-fit for relative maximum injury risk responses in ABTS v conventional seats by crash severity.



Data with various occupants including a 50HIII, BioRID 2, 5HIII and 95HIII
OOP-L: Leaning forward position, OOP-R: Radio position, ABTS*: Modified double-recliner ABTS



Data with various occupants including a 50HIII, BioRID 2, 5HIII and 95HIII
OOP-L: Leaning forward position, OOP-R: Radio position, ABTS*: Modified double-recliner ABTS

Figure B16: Relative average biomechanical and injury risk responses in ABTS v conventional seats by crash severity, by head restraint type, ATD type and initial position.

The ATD biomechanical responses included head resultant acceleration and HIC_{36}, thoracic spine, upper and lower neck tension and posterior shear force and extension moment and chest 3 ms acceleration (or T1 acceleration for BioRID).

Appendix C: Seat design info

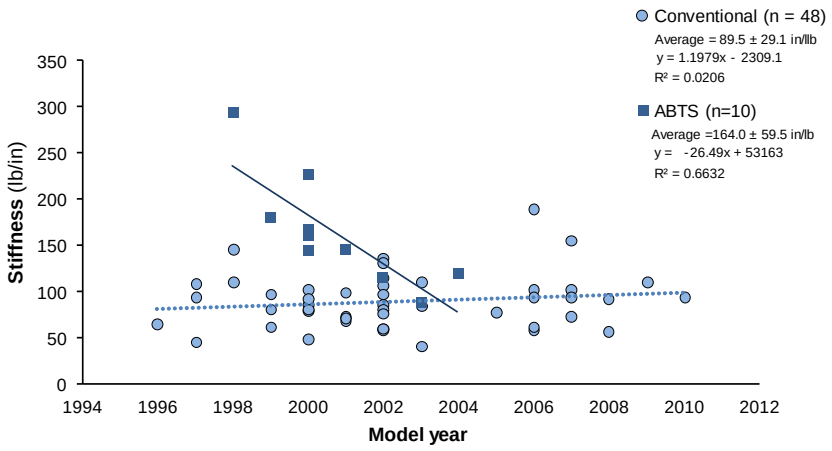


Figure C1: Seat stiffness summary (based on Appendix A in Pabmanaban et al. 2016)

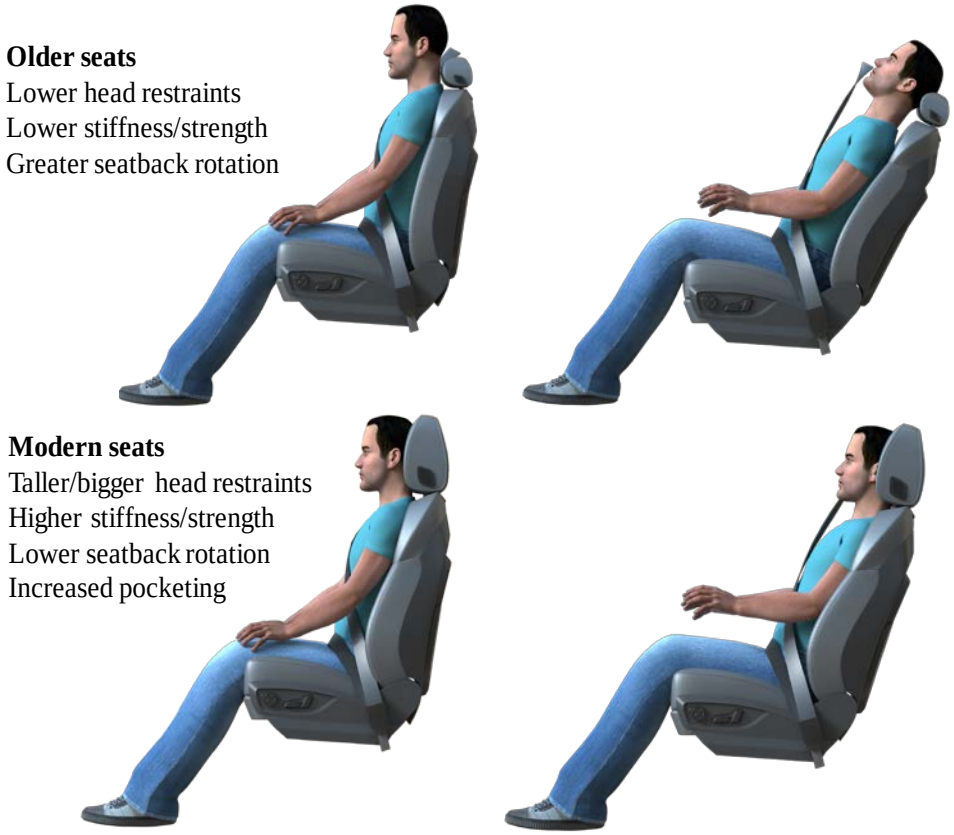


Figure C2: Seat design changes.

Double Recliner ABTS

- Combination of D & RFP outboard ABTS
  - Double recliners with own handle
  - Rigid frame with double stanchions
  - No seat track adjustment
- Stiff diagonal seatback bar
  - No pocketing
- Heavy reinforced floor attachments

Figure C3: Modified double recliner Sebring seat.

Appendix D: Injury Assessment Reference Value and Corresponding Sigmoidal Risk Data

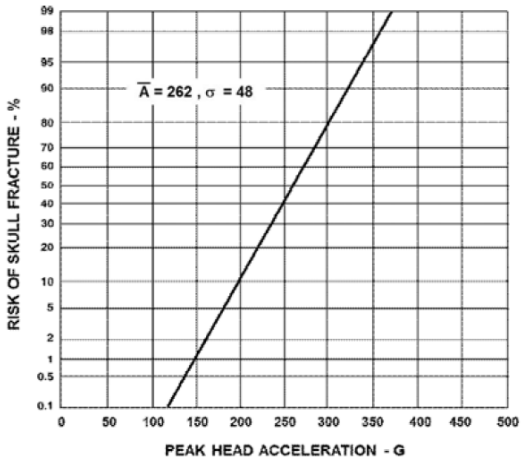
Table D1 summarizes the Injury Assessment Reference Values (IARV) from Mertz et al. (2016). The data is tabulated by ATD size. The corresponding estimated Alpha and Beta for sigmoidal risk is also listed.

Table D1: Injury Assessment Reference Value and Corresponding Sigmoidal Risk Data

		ATD	5 HIII			50 HIII			95 HIII		
			IARV	Sigmoidal risk		IARV	Sigmoidal risk		IARV	Sigmoidal risk	
				Alpha	Beta		Alpha	Beta		Alpha	Beta
Head	Acc (g)		193	9.441	0.036	180	9.441	0.036	175	9.441	0.036
	HIC15*		779	5.204	0.003	700	5.204	0.003	670	5.204	0.003
Upper neck	Fx (lb)	+ Posterior	438	8.358	0.012	697	8.358	0.008	841	8.358	0.006
		- Anterior	-438	8.358	0.012	-697	8.358	0.008	-841	8.358	0.006
	Fz (lb)	+ Tension	589	16.670	0.028	937	16.670	0.004	1,131	16.670	0.015
		- Compression	-567	8.358	0.010	-899	8.358	0.006	-1,086	8.358	0.005
	My (inlb)	+ Flexion	841	8.358	0.006	1,682	8.358	0.003	2,230	8.358	0.002
		- Extension	-434	8.640	0.017	-859	8.640	0.008	-1,133	8.640	0.006
Lower neck	Fx (lb)	+ Posterior	438	8.358	0.012	697	8.358	0.008	841	8.358	0.006
		- Anterior	-438	8.358	0.012	-697	8.358	0.008	-841	8.358	0.006
	Fz (lb)	+ Tension	589	16.670	0.028	937	16.670	0.018	1,131	16.670	0.015
		- Compression	-567	8.358	0.010	-899	8.358	0.006	-1,086	8.358	0.005
	My (inlb)	+ Flexion	1,682	8.358	0.003	3,363	8.358	0.002	4,461	8.358	0.001
		- Extension	-867	8.358	0.006	-1,717	8.358	0.003	-2,266	8.358	0.002
Chest	3ms		73	9.441	0.089	60	9.441	0.108	54	9.441	0.120

* If delta V> 15 mph

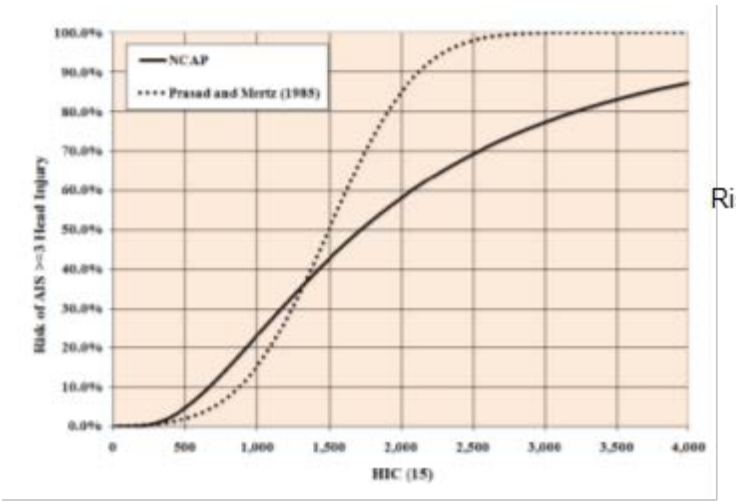
Head acceleration: Figure D1 shows the risk of skull fracture as a function of head acceleration (Mertz et al. 2016).



Risk = 1/(1+EXP(9.44053

Figure D1: Skull fracture risk curve based on head acceleration (Mertz et al. 2016).

HIC_{15}: Figure D2 shows the risk of serious head injury as a function of HIC15 for rear impact > 15 mph (Prasad et al. 2010, Prasad and Mertz 1985).



Risk = 1/(1+EXP(5.203803-0.003469*HIC15))

Figure D2: Skull fracture risk curve based on head acceleration (Prasad et al. 2010 based on Prasad and Mertz 1985).

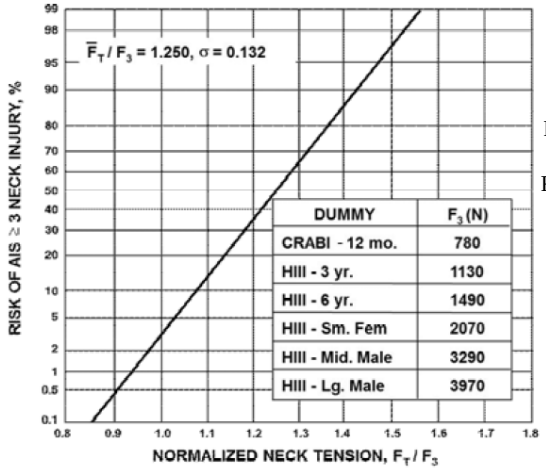
For rear crashes ≤ 15 mph, the MAIS 3 injury risk associated with HIC15 was obtained from NHTA (2011)

Risk= =1/(1+EXP((3.39+200/HIC15))-0.00372*HIC15)

Upper neck shear: A upper neck shear of 697 lb (3100 N) was assumed to represent a 0.05 risk of serious neck injury and a 1254 lb (5580 N) to represent a 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.357856-0.007768*Upper Neck Shear (lb)))
Or
Risk = 1/(1+EXP(8.357856-0.001746*Upper Neck Shear (N)))

Upper neck tension: A upper neck tension of 740 lb (3290 N) was assumed to represent a 0.03 risk of serious neck injury and a 1058 lb (4705 N) at 0.9 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:



Risk = 1/(1+EXP(16.66987-0.017839*Upper Neck Compression (lb)))

Risk = 1/(1+EXP(16.66987-0.00401*Upper Neck Compression (N)))

Figure D3: Risk of neck serious (AIS 3+) injury based on normalized tension in OOP testing (Mertz et al. 2016).

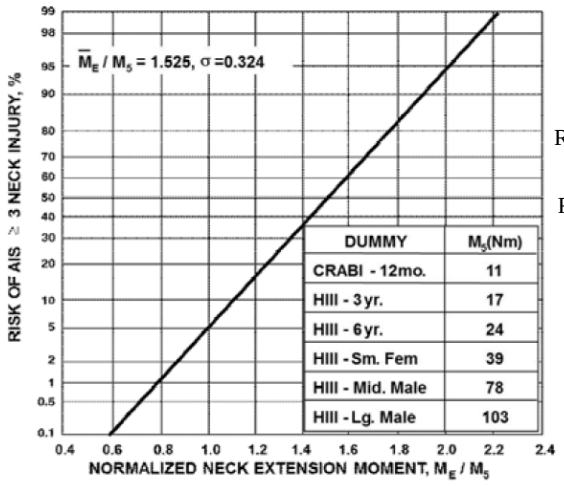
Upper neck compression: A upper neck tension of 899 lb (4000 N) was assumed to represent a 0.05 risk of serious neck injury and a 1619 lb (7200 N) at 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.3579-0.00602*Upper Neck Compression (lb)))
Or
Risk = 1/(1+EXP(8.3579-0.00135*Upper Neck Compression (N)))

Upper neck flexion: A upper neck tension of 1682 inlb (190 Nm) was assumed to represent a 0.05 risk of serious neck injury and a 3027 inlb (342 Nm) at 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.357856-0.0032190*Upper Neck Compression (inlb)))
Or
Risk = 1/(1+EXP(8.357856-0.028491667*Upper Neck Compression (Nm)))

Upper neck extension: A upper neck extension of 691 inlb (78 Nm) was assumed to represent a 0.05 risk of serious neck injury and a 1381 inlb (156 Nm) at 0.9 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:



Risk = 1/(1+EXP(8.640413-0.008251*Upper Neck Extension (inlb)))

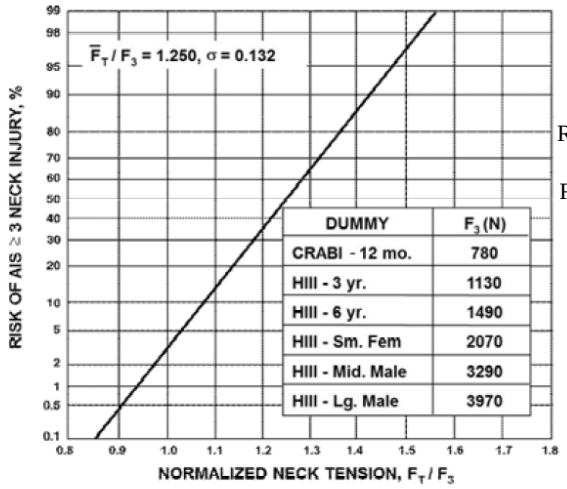
Risk = 1/(1+EXP(8.640413-0.073025*Upper Neck Extension Nm)))

Figure D4: AIS 3+ risk curve based on normalized neck extension for OOP testing without muscle tone (Mertz et al. 2016).

Lower neck shear: A lower neck shear of 697 lb (3100 N) was assumed to represent a 0.05 risk of serious neck injury and a 1254 lb (5580 N) to represent a 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.357856-0.007768*Upper Neck Shear (lb)))
Or
Risk = 1/(1+EXP(8.357856-0.001746*Upper Neck Shear (N)))

Lower neck tension: A upper neck tension of 740 lb (3290 N) was assumed to represent a 0.03 risk of serious neck injury and a 1058 lb (4705 N) at 0.9 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:



DUMMY	F_3 (N)
CRABI - 12 mo.	780
HIII - 3 yr.	1130
HIII - 6 yr.	1490
HIII - Sm. Fem	2070
HIII - Mid. Male	3290
HIII - Lg. Male	3970

Risk = 1/(1+EXP(16.66987-0.017839*Lower Neck Compression (lb))

Risk = 1/(1+EXP(16.66987-0.00401*Lower Neck Compression (N)))

Lower neck compression: A lower neck tension of 899 lb (4000 N) was assumed to represent a 0.05 risk of serious neck injury and a 1619 lb (7200 N) at 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.3579-0.00602*Upper Neck Compression (lb)))
Or
Risk = 1/(1+EXP(8.3579-0.00135*Upper Neck Compression (N)))

Lower neck flexion: A lower neck flexion of 3363 inlb (380 Nm) was assumed to represent a 0.05 risk of serious neck injury and a 6054 inlb (684 Nm) at 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.357855655- 0.00160951681800983* Lower Neck Flexion (inlb)))
Or
Risk = 1/(1+EXP(8.357855655-0.014245833356205* Lower Neck Flexion (Nm)))

Lower neck extension: A lower neck extension of 1717 inlb (194 Nm) was assumed to represent a 0.05 risk of serious neck injury and a 3091 inlb (349 Nm) at 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(8.35785565-0.00315266* Lower Neck Extension (inlb)))
Or
Risk = 1/(1+EXP(8.35785565-0.0279042097* Lower Neck Extension (Nm)))

Chest acceleration: A chest acceleration of 60g was assumed to represent a 0.05 risk of serious chest injury and a 100 g at 0.8 risk based on the biomechanical IARV data from Mertz et al. (2016). The sigmoidal risk function was then calculated to equal:

Risk = 1/(1+EXP(9.440539-0.108268* Chest Acceleration (g)))

Appendix E: Safety benefit calculation

Crash severity (delta V, km/h) in rear crashes										
<16	**16-24**	**24-32**	**32-40**	**40-48**	**48-56**	**56-64**	**64+**	**All w/o unknown**		**All**
Occupant MAIS 0+F										
538,396	727,947	315,025	121,774	61,842	11,066	4,876	6,983	1,787,909	706,768	2,494,677
Occupant MAIS 3+F										
233	1,736	1,245	492	1,107	511	408	992	6,724	4,370	11,094
Occupant rate MAIS 3+F										
0.043%	0.24%	0.40%	0.40%	1.8%	4.6%	8.4%	14.2%			0.44%
Relative maximum ATD injury risk in ABTS v conventional seat										
1.34	1.69	1.65	1.33	5.77	11.90	48.24	34.11			
New occupant rate MAIS 3+F (estimated)										
0.058%	0.40%	0.65%	0.54%	10.3%	55.0%	404.2%	484.4%			
Occupant MAIS 3+F estimated										
313	2,942	2,055	653	6,389	6,081	19,708	33,826	71,966	4,370	76,336
Change in occupant MAIS 3+F (estimated v orignal)										
1.34	1.69	1.65	1.33	5.77	11.90	48.24	34.11	10.70		**6.88**

Appendix F: References and Bibliography

1. Benson B, Smith G. Kent R, Monson C, Effect of Seat Stiffness in Out-of-Position Occupant Response in Rear-End Collisions, SAE 962434, Society of Automotive Engineers, Warrendale, PA, 1996.
2. Berton R. Whiplash: Tests of the Influential Variables. SAE 680080, Society of Automotive Engineers, Warrendale, PA, 1968.
3. Blaisdell DM, Levitt AE, Varat MS. Automotive seat design concepts for occupant protection. SAE 930340, Society of Automotive Engineers, Warrendale, PA, 1993.Brennan JE. Seat Frames. SAE 490047, Society of Automotive Engineers. New York, New York, 1949.
4. Burnett R, Carter J, Roberts V, Myers B. The influence of seatback characteristics on cervical injury risk in severe rear impacts. Accid Anal Prev. 36(4):591-601, 2004.
5. CDC Fryar CD, Gu Q, Ogden CL, Flegal KM. Anthropometric reference data for children and adults: United States, 2011–2014. National Center for Health Statistics. Vital Health Stat 3(39). 2016. https://www.cdc.gov/nchs/data/series/sr_03/sr03_039.pdf .
6. Anthropometric Reference Data for Children and Adults: United States, 2011–2014, Data from the National Health and Nutrition Examination Survey. 2016
7. Edwards M, Viano DC, Parenteau CS. Analysis of Front-Seat Occupant Injuries in Rear Impacts. Warrendale, PA: SAE International; 2009. Paper SAE 2009-01-1200.
8. Estep CR, Lund AK, Vann DT. Measurement and evaluation of head restraints in1995 vehicles. Arlington, VA: Insurance Institute for Highway Safety. 1995.
9. Hu AS, Bean SP, Zimerman RM. Response of belted dummy and cadaver to rear impact. SAE 770929, Society of Automotive Engineers, Warrendale, PA, 1977.
10. IIHS. Vehicle Seat/Head Restraint Evaluation Protocol Static Geometric Criteria (Version IV). https://www.iihs.org/media/dc027e6e-1e00-40e0-bfe9-df732360602e/ydLKGA/Ratings/Protocols/current/head_restraint_protocol_static.pdf, 2016
11. James MB, Strother CE, Warner CY, Decker RL, Perl TR. Occupant Protection in Rear-end Collisions: I. Safety Priorities and Seat Belt Effectiveness. SAE 912913, Society of Automotive Engineers, Warrendale, PA, 1991.
12. Malliaris AC.Malliaris AC, Digges DH, DeBlois JH. Relationships Between Crash Casualties and Crash Attributes. SAE 970393, Society of Automotive Engineers, Warrendale, PA, 1997.
13. McGowan JC, Levitt A, Corrigan C, Burnett R, Lucas S. Seatback Strength and Occupant Response in Rear Impact Crash: Observations with Respect to Large Occupant Size and Position. SAE 2010-01-1029, Society of Automotive Engineers, Warrendale PA. 2010.
14. Mertz HJ, Jarrett K, Moss S, Salloum M, Zhao Y. The Hybrid III 10-Year-Old Dummy. Warrendale, PA: SAE International; SAE 2001-22-0014. 2001.
15. Mertz HJ, Irwin A, Prasad P. Biomechanical and Scaling Basis for Frontal and Side Impact Injury Assessment Reference Values, Stapp Car Crash J. 60:625-657, 2016.
16. Mertz HJ, Prasad P, Dalmotas DJ. Irwin AL. Age-Specific Injury Risk Curves for Distributed, Anterior Thoracic Loading of Various Sizes of Adults Based on Sternal Deflections, Stapp Car Crash J. SE 2016-22-0001, 2016.
17. NHTSA. Federal Motor Vehicle Safety Standards; Head Restraints FMVSS 202, final rule. Vol. 69, No. 239 / Tuesday, December 14, 2004.
18. NHTSA. Federal Motor Vehicle Safety Standards; Head Restraints FMVSS 202, final rule. Vol. 75, No. 211 /Tuesday, November 2, 2010.
19. NHTSA. Injury risk curves and reference values, http://www.nhtsa.gov/cars/rules/rulings/80g/80gii.html, 2011.
20. Padmanaban J, Burnett R, Levitt AE. Relationship Between Seatback Stiffness/Strength and Risk of Serious/Fatal Injury in Rear-Impact Crashes. SAE 2009-01-1201, Warrendale, PA: SAE International;.2009.
21. Padmanaban J, Burnett R, Levitt A. Seatback Strength as a Predictor of Serious Injury Risk to Belted Drivers and Rear Seat Occupants in Rear-Impact Crashes, SAE 2016-01-1512, Society of Automotive Engineers, Warrendale, PA, 2016.
22. Parenteau CS, Viano DV. Spinal fracture-dislocations and spinal cord injuries in motor vehicle crashes. Traffic Inj Prev. 2014;15(7):694-700. doi: 10.1080/15389588.2013.867434.
23. Parenteau C, Caird M, Kohoyda-Inglis C, Holcombe S, Wang S. Characterization of Thoracic Spinal Development by Age and Gender and Possible Effect on Crash Occupants 2020-01-0520, Society of Automotive Engineers, Warrendale PA, 2020

24. Partyka SC. Seat damage and occupant injury in passenger car towaway crashes. Office of Vehicle Safety Standards, Rulemaking, National Highway Traffic Safety Administration, June 8, 1992.
25. Prasad P, Kim A, Weerappuli DVP, Roberts V, Schneider D. Relationships between passenger-car seatback strength and occupant injury severity in rear-end collisions: field and laboratory studies. SAE 973343, 41st Stapp Car Crash Conference, Society of Automotive Engineers, Warrendale, PA, 1997.
26. Prasad P, Mertz H. The Position of the United States Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment, SAE 851246,S ociety of Automotive Engineers, Warrendale, PA,1985.
27. Prasad P, Mertz HJ, Dalmotas DJ, Augenstein JS, Digges K. Evaluation of the Field Relevance of Several Injury Risk Functions, Stapp Car Crash Conference, SAE 2010-22-0004, Society of Automotive Engineers, Warrendale, PA, 2010
28. Saunders JW, Molino LN, McKoy FL. Performance of seating systems in a FMVSS No.301 rear impact crash test. Paper 248, 18th Enhanced Safety of Vehicles (ESV) conference, 2003.
29. Severy DM, Mathewson J, Bechtol O. Controlled Automobile rear-end collisions and investigation of related engineering and medical phenomena, Canadian Services Medical Journal, XI: 727 – 759, November, 1955.
30. Viano DC, Role of the seat in rear crash safety. SAE Book, ISBN 0-7680-0847-6, Society of Automotive Engineers, Warrendale, PA, SAE R-317:1-491, 2002.
31. Viano DC, Role of the Seat in Rear Crash Safety. SAE Book, ISBN 0-7680-0847-6, Society of Automotive Engineers, Warrendale, PA, SAE R-317:1-491, 2002.
32. Viano DC, Parenteau CS, Prasad P, Burnett R. Stiff versus yielding seats: Analysis of matched rear impact tests. SAE 2007-01-0708, Society of Automotive Engineers, Warrendale, PA, 2007.
33. Viano DC, Parenteau CS, Prasad P, Burnett R. Stiff versus Yielding Seats: Analysis of Matched Rear Impact Tests. SAE 2007-01-0708, Society of Automotive Engineers, Warrendale PA, 2007.
34. Viano DC, Parenteau CS. Serious Injury in Very-Low and Very-High Speed Rear Impacts. SAE 2008-01-1485, Society of Automotive Engineers, Warrendale PA, 2008
35. Viano DC. Seat design principles to reduce neck injuries in rear impacts. Traffic Injury Prevention 9(6): 552-560, 2008.
36. Viano DC, Parenteau CS, Edwards ML. Crash injury risks for obese occupants using a matched-pair analysis. Traffic Injury Prevention, 9:59–64, 2008.
37. Viano DC, Parenteau CS, Burnett, R, James M. Influence of Seating Position on Dummy Responses With ABTS Seats in Severe Rear Impacts. Warrendale, PA: SAE International; 2009. Paper SAE 2009-01-0250.
38. Viano DC, Parenteau CS. BioRID dummy responses in matched ABTS and conventional seat tests on the IIHS rear sled. In review Traffic Injury Prevention, 2011
39. Viano DC. Fracture-dislocation of the thoracic spine in extension with upright seats in severe rear crashes. SAE 2011-01-0274, Society of Automotive Engineers, Warrendale PA, 2011.
40. Viano DC, Parenteau CS, Burnett R. Rear Impact Tests of Starcraft-Type Seats With Out-of-Position and in-Position Dummies. Warrendale, PA: SAE International; 2011. Paper SAE 2011-01-0272.
41. Viano DC, Parenteau CS, Burnett R. Rebound After Rear Impacts. Traffic Injury Prevention, 14:181-87, 2013.
42. Viano DC, Parenteau CS. NASS-CDS Analysis of High Retention Seat Performance in Rear Impacts. Traffic Inj Prev. 2015 Jul 4;16(5):491-7.
43. Viano DC, White SD. Seat Strength in Rear Body Block Tests. Traffic Inj Prev. 2016 Jul 3;17(5):502-7.
44. Viano DC, Parenteau CS, Burnett R. Thoracic and Lumbar Spine Responses in High-Speed Rear Sled Tests. Traffic Inj Prev. 2018 Mar 1:1-22. (a)
45. Viano DC, Parenteau CS, Burnett R, Prasad P. Occupant responses in conventional and ABTS seats in high-speed rear sled tests. Traffic Inj Prev. 2018 Jan 2;19(1):54-59. (b)
46. Viano D, Parenteau C, White S. Influence of DISH, Ankylosis, Spondylosis and Osteophytes on Serious-to-Fatal Spinal Fractures and Cord Injury in Rear Impacts SAE 2019-01-1028, Society of Automotive Engineers, Warrendale PA, 2019.
47. Viano D, Burnett R, White S. FRED II Quasistatic Seat Testing Rearward: An Improved Method Based on the SAE H-point Manikin, SAE 2019-01-1032, Society of Automotive Engineers, Warrendale, PA, 2019.
48. Viano DC, Burnett RA, White SD, Stephens GD, Parenteau CS. Dual-Recliner ABTS Seats in Severe Rear Sled Tests with the 5th, 50th and 95th Hybrid III, SAE 2021 (TBD)
49. Yoganandan N, Ray G, Pintar FA, Myklebust JB. et al., Stiffness and Strain Energy Criteria to Evaluate the Threshold of Injury to an Intervertebral Joint, J Biomech. 22:135-142, 1989.
50. Welch T, Bridges A, Gates D, Heller M, Stillman D, Raasch C, Carhart C. An evaluation of the BioRID II and Hybrid III during low- and moderate-speed rear impact. SAE World Congress, 2010-01-1031 and

International Journal of Passenger Cars 2010; 3:704–733, Society of Automotive Engineers, Warrendale, PA, 2010.
51. White S, Viano D, Burnett R. Seat Performance and Occupant Moving Out of the Shoulder Belt in ABTS (All-Belts-to-Seat) in Rear Impacts, SAE 2019-01-1031, Society of Automotive Engineers, Warrendale, PA, 2019.