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NCAP Test Improvements with Pretensioners and Load Limiters

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16. Abstract

New Car Assessment Program (NCAP) test scores were analyzed in order to assess the benefits of equipping seat belt systems with pretensioners and load limiters. In NCAP tests, vehicles are crashed into a fixed barrier at 35 mph. Instruments measure the force of impact to the head, chest, and legs of anthropomorphic dummies secured in the vehicle by seat belts. NCAP data from model year 1998 through 2001 cars and light trucks were examined. The combination of pretensioners and load limiters is estimated to reduce Head Injury Criterion (HIC) by 232, chest acceleration by an average of 6.6 g's, and chest deflection (displacement) by 10.6 mm, for drivers and right front passengers. All of these reductions are statistically significant. When looked at individually, pretensioners are more effective in reducing HIC scores for both drivers and right front passengers, as well as chest acceleration and chest deflection scores for drivers. Load limiters show greater reductions in chest acceleration and chest deflection scores for right front passengers. By contrast, in make-models where neither load limiters nor pretensioners have been added, there is little change during 1998 to 2001 in HIC, chest acceleration, or chest deflection values in NCAP tests.

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The goal of this evaluation was to determine what effect, if any, pretensioners and load limiters have on injury prevention. As part of determining their effectiveness, results from frontal New Car Assessment Program (NCAP) tests just before the installation of one or both of these belt technologies were compared with those shortly after they were installed in the same make/model. The combination of pretensioners and load limiters is estimated to reduce Head Injury Criterion (HIC) by 232, chest acceleration by an average of 6.6 g's, and chest deflection (displacement) by 10.6 mm, for drivers and right front passengers. All of these reductions are statistically significant. When looked at individually, pretensioners are more effective in reducing HIC scores for both drivers and right front passengers, as well as chest acceleration and chest deflection scores for drivers. Load limiters show greater reductions in chest acceleration and chest deflection scores for right front passengers. By contrast, in make-models where neither load limiters nor pretensioners have been added, there is little change during 1998 to 2001 in HIC, chest acceleration, or chest deflection values in NCAP tests.

The initial step was to examine frontal NCAP scores for vehicles, both passenger cars and light trucks, which at one time did not have pretensioners and/or load limiters but later included them as standard equipment. To minimize the influence of air bag modifications on NCAP scores, only vehicles of model year 1998 and later were selected (i.e., all vehicles had depowered air bags). Note that air bag modifications continued after 1998. For example, some 1998-99 vehicles may have had "quick-reaction" depowering-type modifications, such as vent hole size increases or propellant reductions. The 2000-2001 vehicles started to introduce dual or multi-stage air bags. However, the most dramatic changes would result from pre-model year 1998 to those produced in 1998 and later.

NHTSA's "Buying a Safer Car" brochure was used to establish the status of these belt technologies on vehicles for model years 1998 through 2001. Seat belt pretensioners retract the seat belt almost instantly in a crash to remove excess slack. Energy management systems allow seat belts to yield in a crash, preventing the shoulder belt from directing too much energy on the chest of the occupant. Note that load limiters are the primary, but not only, energy management method used in seat belts. Other examples of energy management systems that have been used include tear stitching, and sheet metal tearing or torsion rod twisting within the retractor. The majority of vehicles included in the present analysis use load limiters as the energy management feature. Therefore, although the term 'load limiter' is used throughout, in a small number of cases a specific vehicle could possibly utilize another of the energy management systems.

Vehicles that had gone through a major redesign concurrently with adding pretensioners and/or load limiters were excluded from the analysis. Once the models of interest were determined, NCAP tests were searched in order to locate all test data that could be found for these vehicles. It was necessary that for any given model, NCAP tests were available for model years both with and without pretensioners and/or load limiters. For a number of vehicles, there were multiple NCAP tests available in the "with" and/or "without" belt technology (pretensioners or load limiters) period.

In addition, frontal NCAP tests on vehicles that did not add either pretensioners or load limiters were located, to serve as a "No Change" comparison group. Since there was no change in regard to pretensioners or load limiters occurring in these vehicles, only two model years were required for each vehicle. If additional model years had been obtained, it would be arbitrary whether they would be considered comparable to the "without" or "with" pretensioner groups.

Tests were restricted to standard frontal barrier NCAP tests using 50th percentile male Hybrid III dummies. In all, there were three vehicles that added pretensioners only from one available NCAP test to the next, and five that added load limiters only. Ten vehicles added both pretensioners and load limiters, and fourteen had no change.

Exhibit 1 presents the vehicles (and model years) that met all requirements. The model years listed are those for which NCAP tests were available and used in the analysis. For those vehicles adding load limiters and/or pretensioners, the "Before" column lists the model years without the noted technology, while the "After" column lists the years the technology was standard in the vehicle. For vehicles with no change, these columns note the earlier and later model year used.

All of the three vehicles that added pretensioners only were already equipped with load limiters, while none of the five vehicles adding load limiters had pretensioners before that time. Of the fourteen vehicles that had no change in either pretensioners or load limiters, one (Chevrolet Venture) had pretensioners in both model years used, four (Chevrolet Malibu, Chrysler LHS, Chevrolet S-10, and Dodge Dakota) had load limiters only in both model years, and four had both technologies for both model years used (Toyota Avalon, Camry, 4Runner, and Tacoma). The remaining five vehicles (Nissan Altima, Dodge Durango and Ram 1500, Ford Expedition and F150 Pickup) had neither belt technology in either model year used. Of course, those vehicles listed as adding both pretensioners and load limiters had neither technology in the "Before" years.

The Ford Taurus appears in the group that added load limiters only as well as the group that added pretensioners only. Load limiters were installed first in the Ford Taurus in model year 1999, while pretensioners were first installed in 2000. Thus, data from model year 1998 served as the "Before" for load limiters, while data for model year 1999 served as the after. For the pretensioner comparison, the model year 1999 data was the "Before" and from model year 2000 was the "After."

Six vehicles (Nissan Altima, Dodge Durango, Ford Expedition and F150 Pickup, and Toyota 4Runner and Tacoma) are listed in the "No Change" group as well as the "Added Both Pretensioners and Load Limiters" group. These are vehicles for which data were available for at least one model year before the technologies were installed and one model year with the technologies, which were used to examine the change due to adding the belt technologies. In addition, at least one addition model year of data was available, either with or without both technologies, to serve as a comparison year in the "No Change" group.

Exhibit 1: Available Frontal NCAP Test Data of Vehicles with and without Change in Pretensioners and/or Load Limiters

	Model Year(s) Before	Model Year(s) After
Vehicles that added Pretensioners only		
Dodge Stratus	1998	2001
Ford Taurus	1999	2000
Mazda Protégé	1999	2001
Vehicles that added Load Limiters only		
Ford Mustang	1998	2001
Ford Taurus	1998	1999
Dodge Caravan	1998	2000
Dodge Grand Caravan	1998	1999
Jeep Grand Cherokee	1998	1999
Vehicles that added both Pretensioners and Load Limiters		
Ford Crown Victoria	1998	2001
Honda Accord	2000	2001
Nissan Altima	1998,1999	2000
Nissan Sentra	1998	2001
Dodge Durango	1998,1999	2001
Ford Expedition	1998,1999	2001
Ford F150 Pickup	1998,1999	2001
Nissan Frontier	1998	2001
Toyota 4Runner	1998	1999,2001
Toyota Tacoma	1998	1999,2001
Vehicles with no change in Pretensioners or Load Limiters		
Chevrolet Malibu	1998	2001
Chrysler LHS	2000	2001
Nissan Altima	1998	1999
Toyota Avalon	1998	2001
Toyota Camry	1998	2000
Chevrolet S-10	1998	2000
Chevrolet Venture	1998	2001
Dodge Dakota	1998	2001
Dodge Durango	1998	1999
Dodge Ram1500	1998	2001
Ford Expedition	1998	1999
Ford F150 Pickup	1998	1999
Toyota 4Runner	1999	2001
Toyota Tacoma	1999	2001

Specifics on the presence of each belt technology, as well as the model year of data used in each of the four groups, are presented in Exhibit 2, titled "Individual Vehicle NCAP Scores." Presented in this table are the specific vehicles' data taken from NCAP tests. The table lists, for each vehicle used in the analysis, the driver and right front passenger HIC, chest acceleration, and chest deflection values for each NCAP test, as well as whether or not pretensioners were present in the vehicle, for each model year of data used in the analysis. These data show, time after time, that both scores are dramatically lower after pretensioners and/or load limiters were installed in vehicles. Note that no usable chest deflection data were obtained for the 1999 Ford Taurus test, for either the driver or right front passenger. In later tables, when difference scores are presented, no comparisons can be made to this year. In such cases, the entry n/a will appear, to indicate the data are unavailable.

Exhibit 3 (a-c) presents the average (mean) HIC, chest acceleration, and chest deflection values for those vehicles used in the analysis. When more than one NCAP test was performed on the same vehicle with the same pretensioner/load limiter status (present or not), the average was determined. Data in Exhibit 3a are averages for drivers and right front passengers combined. Drivers alone are shown in Exhibit 3b, and right front passengers alone in 3c. Columns labeled "Difference" show the change in score, subtracting the value for vehicles without the belt technology from those with them. For those vehicles with no change in pretensioner and load limiter (the fourth group), the difference is the earlier year subtracted from the later year. Thus, a negative number reflects a reduction in the HIC or chest acceleration score over time. For all but the last group, this reduction coincides with the addition of the belt technology. The table shows that the majority of vehicles experienced a reduction in both HIC and chest acceleration after pretensioners and/or load limiters were installed. Vehicles that did not have a change in belt technology show little change in either score.

Note in Exhibit 3a that every vehicle that added both pretensioners and load limiters experienced a reduction in HIC, chest acceleration, and chest deflection. In addition, in all cases where vehicles added only pretensioners or load limiters, every vehicle experienced a reduction in chest-g's, and only one in each group failed to receive a lower HIC score. Furthermore, one vehicle that added load limiters only did not obtain a lower chest deflection score. In vehicles with no change in either technology, only four of the fourteen saw a reduction in HIC. While more than half (eight of fourteen) of these vehicles did experience a reduction in chest acceleration, the decreases are much smaller than those seen in the other groups of vehicles. Similarly, eight of the fourteen received a lower chest deflection score. There was some, but not total, overlap with the eight obtaining lower chest acceleration score. Five vehicles reduced their scores for both chest acceleration and chest deflection. Six vehicles had a lower score for one, and higher for the other.

Exhibit 2: Individual Vehicle NCAP Scores

Make	Model	Mod Year	Pretensioner ?	Load Limiter ?	Driver			Right Front Passenger		
					HIC	Chest g	Chest Deflct	HIC	Chest g	Chest Deflct
Vehicles that added Pretensioners only										
DODGE	STRATUS	1998		L	873	54.4	38.5	641	53.7	34.5
DODGE	STRATUS	2001	P	L	463	54.1	25.5	408	50.3	24.4
DODGE	STRATUS	2001	P	L	441	43.4	31.2	328	41.9	23.4
FORD	TAURUS	1999		L	467	44.4	N/A	480	41.1	N/A
FORD	TAURUS	2000	P	L	345	40.8	26.0	370	37.5	26.0
MAZDA	PROTEGE	1999		L	445	55.3	28.0	534	50.3	23.4
MAZDA	PROTEGE	2001	P	L	392	44.7	24.6	615	52.3	21.7
Vehicles that added Load Limiters only										
FORD	MUSTANG	1998			436	41.3	29.0	364	46.9	38.1
FORD	MUSTANG	2001		L	279	41.5	36.6	250	44.4	35.4
FORD	TAURUS	1998			577	48.8	36.2	486	51.0	27.9
FORD	TAURUS	1999		L	467	44.4	N/A	480	41.1	N/A
DODGE	CARAVAN	1998			870	52.8	49.6	788	53.0	39.9
DODGE	CARAVAN	2000		L	771	48.8	43.8	792	48.8	27.6
DODGE	GRAND CARAVAN	1998			1026	54.3	46.0	994	60.0	36.0
DODGE	GRAND CARAVAN	1999		L	802	46.7	45.8	814	44.8	29.3
JEEP	GRAND CHEROKEE	1998			948	56.2	36.0	546	57.6	41.0
JEEP	GRAND CHEROKEE	1999		L	998	55.3	30.5	773	53.7	22.9

Exhibit 2 continued: Individual Vehicle NCAP Scores

Make	Model	Mod Year	Pretensioner ?	Load Limiter ?	Driver			Right Front Passenger		
					HIC	Chest g	Chest Deflct	HIC	Chest g	Chest Deflct
Vehicles that added both Pretensioners and Load Limiters										
FORD	CROWN VICTORIA	1998			602	39.0	35.6	335	40.5	28.8
FORD	CROWN VICTORIA	2001	P	L	361	33.2	30.4	288	34.2	20.2
HONDA	ACCORD	2000			605	55.4	40.4	487	50.9	40.9
HONDA	ACCORD	2001	P	L	280	37.7	23.4	722	46.6	25.8
HONDA	ACCORD	2001	P	L	256	44.4	26.4	413	43.8	24.7
NISSAN	ALTIMA	1998			887	51.1	35.0	1119	55.4	36.0
NISSAN	ALTIMA	1999			908	51.3	31.8	834	49.8	34.7
NISSAN	ALTIMA	2000	P	L	585	40.8	35.0	428	39.6	31.0
NISSAN	SENTRA	1998			898	48.8	40.5	797	49.5	44.2
NISSAN	SENTRA	2001	P	L	409	47.6	24.8	518	43.9	29.0
DODGE	DURANGO	1998			997	62.3	48.6	627	62.1	33.8
DODGE	DURANGO	1999			1008	60.8	41.0	592	54.2	36.3
DODGE	DURANGO	2001	P	L	690	48.0	26.5	607	48.6	27.9
FORD	EXPEDITION	1998			544	44.8	33.4	569	42.2	37.8
FORD	EXPEDITION	1999			583	46.7	31.3	680	43.7	32.7
FORD	EXPEDITION	2001	P	L	514	37.7	32.7	492	38.3	31.3
FORD	F150 PICKUP	1998			497	42.3	42.3	615	46.3	41.6
FORD	F150 PICKUP	1999			517	45.7	44.6	634	45.0	42.2
FORD	F150 PICKUP	2001	P	L	623	41.2	34.9	507	38.9	35.2
FORD	F150 PICKUP	2001	P	L	439	41.5	27.3	559	36.2	24.6

Exhibit 2 continued: Individual Vehicle NCAP Scores

Make	Model	Mod Year	Pretensioner ?	Load Limiter ?	Driver			Right Front Passenger		
					HIC	Chest g	Chest Deflct	HIC	Chest g	Chest Deflct
NISSAN	FRONTIER	1998			1000	46.5	46.5	521	54.0	30.0
NISSAN	FRONTIER	2001	P	L	560	56.6	37.6	355	41.9	23.6
TOYOTA	4RUNNER	1998			760	56.8	51.6	743	58.8	50.7
TOYOTA	4RUNNER	1999	P	L	693	44.6	37.0	438	43.3	40.2
TOYOTA	4RUNNER	2001	P	L	673	41.2	33.8	584	44.8	40.5
TOYOTA	TACOMA	1998			731	51.4	48.2	683	54.6	47.2
TOYOTA	TACOMA	1999	P	L	701	43.9	34.7	497	47.5	20.3
TOYOTA	TACOMA	2001	P	L	752	55.7	33.3	754	49.1	30.1
Vehicles with No Change in Pretensioners or Load Limiters										
CHEVROLET	MALIBU	1998		L	691	41.8	38.6	473	49.7	35.4
CHEVROLET	MALIBU	2001		L	725	51.0	28.1	500	45.4	29.0
CHRYSLER	LHS	2000		L	708	60.7	38.9	581	54.1	24.4
CHRYSLER	LHS	2001		L	907	55.6	40.4	657	52.9	25.5
NISSAN	ALTIMA	1998			887	51.1	35.0	1119	55.4	36.0
NISSAN	ALTIMA	1999			908	51.3	31.8	834	49.8	34.7
TOYOTA	AVALON	1998	P	L	504	50.4	21.2	577	36.7	28.4
TOYOTA	AVALON	2001	P	L	868	51.1	30.4	577	39.1	28.3
TOYOTA	CAMRY	1998	P	L	525	45.8	34.0	480	37.5	31.0
TOYOTA	CAMRY	2000	P	L	525	45.6	24.1	428	37.0	28.1

Exhibit 2 continued: Individual Vehicle NCAP Scores

Make	Model	Mod Year	Pretensioner ?	Load Limiter ?	Driver			Right Front Passenger		
					HIC	Chest g	Chest Deflct	HIC	Chest g	Chest Deflct
CHEVROLET	S-10	1998		L	634	54.7	46.0	450	56.1	28.6
CHEVROLET	S-10	2000		L	852	61.1	45.7	835	60.9	39.7
CHEVROLET	VENTURE	1998	P		538	43.0	29.1	962	48.0	30.1
CHEVROLET	VENTURE	2001	P		646	39.3	26.6	559	36.2	25.2
DODGE	DAKOTA	1998		L	550	50.9	29.5	570	49.5	37.8
DODGE	DAKOTA	2001		L	747	51.9	51.9	569	42.0	21.9
DODGE	DURANGO	1998			997	62.3	48.6	627	62.1	33.8
DODGE	DURANGO	1999			1008	60.8	41.0	592	54.2	36.3
DODGE	RAM1500	1998			691	47.2	27.5	330	49.4	26.9
DODGE	RAM1500	2001			352	36.0	36.9	410	44.4	33.8
FORD	EXPEDITION	1998			544	44.8	33.4	569	42.2	37.8
FORD	EXPEDITION	1999			583	46.7	31.3	680	43.7	32.7
FORD	F150 PICKUP	1998			497	42.3	42.3	615	46.3	41.6
FORD	F150 PICKUP	1999			517	45.7	44.6	634	45.0	42.4
TOYOTA	4RUNNER	1999	P	L	693	44.6	37.0	438	43.3	40.2
TOYOTA	4RUNNER	2001	P	L	673	41.2	33.8	584	44.8	40.5
TOYOTA	TACOMA	1999	P	L	701	43.9	34.7	497	47.5	20.3
TOYOTA	TACOMA	2001	P	L	752	55.7	33.3	754	49.1	30.1

Exhibit 3a: Means and Differences Before And After, Average of Drivers and Right Front Passengers

Make	Model	Mean HIC Without	Mean Hic With	Difference (HIC)	Mean Chest g Without	Mean Chest g With	Difference (Chest g)	Mean Chest Deflect Without	Mean Chest Deflect With	Difference (Chest Deflect)
Vehicles that added Pretensioners only										
Dodge	Stratus	757.0	410.0	-347.0	54.1	47.4	-6.6	36.5	26.2	-10.4
Ford	Taurus	473.5	357.5	-116.0	42.8	39.2	-3.6	N/A	26.0	N/A
Mazda	Protégé	489.5	503.5	14.0	52.8	48.5	-4.3	25.7	23.2	-2.6
Vehicles that added Load Limiters only										
Ford	Mustang	400.0	264.5	-135.5	44.1	43.0	-1.2	33.6	36.0	2.5
Ford	Taurus	531.5	473.5	-58.0	49.9	42.8	-7.2	32.1	N/A	N/A
Dodge	Caravan	829.0	781.5	-47.5	52.9	48.8	-4.1	44.8	35.7	-9.1
Dodge	Grand Caravan	1010.0	808.0	-202.0	57.2	45.8	-11.4	41.0	37.6	-3.5
Jeep	Grand Cherokee	747.0	885.5	138.5	56.9	54.5	-2.4	38.5	26.7	-11.8
Vehicles that added both Pretensioners and Load Limiters										
Ford	Crown Victoria	468.5	324.5	-144.0	39.8	33.7	-6.1	32.2	25.3	-6.9
Honda	Accord	546.0	417.8	-128.3	53.2	43.1	-10.0	40.7	25.1	-15.6
Nissan	Altima	937.0	506.5	-430.5	51.9	40.2	-11.7	34.4	33.0	-1.4
Nissan	Sentra	847.5	463.5	-384.0	49.2	45.8	-3.4	42.4	26.9	-15.5
Dodge	Durango	806.0	648.5	-157.5	59.9	48.3	-11.6	39.9	27.2	-12.8
Ford	Expedition	594.0	503.0	-91.0	44.4	38.0	-6.4	33.8	32.0	-1.8
Ford	F150 Pickup	565.8	532.0	-33.8	44.8	39.5	-5.4	42.7	30.5	-12.2
Nissan	Frontier	760.5	457.5	-303.0	50.3	49.3	-1.0	37.7	30.6	-7.1
Toyota	4Runner	751.5	597.0	-154.5	57.8	43.5	-14.3	51.2	37.9	-13.3
Toyota	Tacoma	707.0	676.0	-31.0	53.0	49.1	-4.0	47.7	29.6	-18.1

Exhibit 3a continued: Means and Differences Before And After, Average of Drivers and Right Front Passengers

Make	Model	Mean HIC Without	Mean Hic With	Difference (HIC)	Mean Chest g Without	Mean Chest g With	Difference (Chest g)	Mean Chest Deflect Without	Mean Chest Deflect With	Difference (Chest Deflect)
Vehicles with no change in Pretensioners or Load Limiters										
Chevrolet	Malibu	582.0	612.5	30.5	45.8	48.2	2.5	37.0	28.6	-8.5
Chrysler	LHS	644.5	782.0	137.5	57.4	54.3	-3.2	31.7	33.0	1.3
Nissan	Altima	1003.0	871.0	-132.0	53.3	50.6	-2.7	35.5	33.3	-2.3
Toyota	Avalon	540.5	722.5	182.0	43.6	45.1	1.6	24.8	29.4	4.6
Toyota	Camry	502.5	476.5	-26.0	41.7	41.3	-0.4	32.5	26.1	-6.4
Chevrolet	S-10	542.0	843.5	301.5	55.4	61.0	5.6	37.3	42.7	5.4
Chevrolet	Venture	750.0	602.5	-147.5	45.5	37.8	-7.8	29.6	25.9	-3.7
Dodge	Dakota	560.0	658.0	98.0	50.2	47.0	-3.3	33.7	38.9	5.3
Dodge	Durango	812.0	800.0	-12.0	62.2	57.5	-4.7	41.2	38.7	-2.6
Dodge	Ram1500	510.5	381.0	-129.5	48.3	40.2	-8.1	27.2	35.4	8.2
Ford	Expedition	556.5	631.5	75.0	43.5	45.2	1.7	35.6	32.0	-3.6
Ford	F150 Pickup	556.0	575.5	19.5	44.3	45.4	1.1	42.0	43.5	-1.6
Toyota	4Runner	565.5	628.5	63.0	44.0	43.0	-1.0	38.6	37.2	-1.5
Toyota	Tacoma	599.0	753.0	154.0	45.7	52.4	6.7	27.5	31.7	4.2

Exhibit 3b: Means and Differences Before And After, Drivers Only

Make	Model	Mean HIC Without	Mean Hic With	Difference (HIC)	Mean Chest g Without	Mean Chest g With	Difference (Chest g)	Mean Chest Deflect Without	Mean Chest Deflect With	Difference (Chest Deflect)
Vehicles that added Pretensioners only										
Dodge	Stratus	873.0	452.0	-421.0	54.4	48.8	-5.7	38.5	28.3	-10.2
Ford	Taurus	467.0	345.0	-122.0	44.4	40.8	-3.6	N/A	26.0	N/A
Mazda	Protege	445.0	392.0	-53.0	55.3	44.7	-10.6	28.0	24.6	-3.4
Vehicles that added Load Limiters only										
Ford	Mustang	436.0	279.0	-157.0	41.3	41.5	0.2	29.0	36.6	7.6
Ford	Taurus	577.0	467.0	-110.0	48.8	44.4	-4.4	36.2	N/A	N/A
Dodge	Caravan	870.0	771.0	-99.0	52.8	48.8	-4.0	49.6	43.8	-5.8
Dodge	Grand Caravan	1026.0	802.0	-224.0	54.3	46.7	-7.6	46.0	45.8	-0.2
Jeep	Grand Cherokee	948.0	998.0	50.0	56.2	55.3	-0.9	36.0	30.5	-5.5
Vehicles that added both Pretensioners and Load Limiters										
Ford	Crown Victoria	602.0	361.0	-241.0	39.0	33.2	-5.8	35.6	30.4	-5.2
Honda	Accord	605.0	268.0	-337.0	55.4	41.1	-14.4	40.4	24.9	-15.5
Nissan	Altima	897.5	585.0	-312.5	51.2	40.8	-10.4	33.4	35.0	1.6
Nissan	Sentra	898.0	409.0	-489.0	48.8	47.6	-1.2	40.5	24.8	-15.7
Dodge	Durango	1002.5	690.0	-312.5	61.6	48.0	-13.6	44.8	26.5	-18.3
Ford	Expedition	563.5	514.0	-49.5	45.8	37.7	-8.1	32.3	32.7	0.4
Ford	F150 Pickup	507.0	531.0	24.0	44.0	41.4	-2.7	43.5	31.1	-12.35
Nissan	Frontier	1000.0	560.0	-440.0	46.5	56.6	10.1	45.4	37.6	-7.8
Toyota	4Runner	760.0	683.0	-77.0	56.8	42.9	-13.9	51.6	35.4	-16.2
Toyota	Tacoma	731.0	726.5	-4.5	51.4	49.8	-1.6	48.2	34.0	-14.2

Exhibit 3b continued: Means and Differences Before And After, Drivers Only

Make	Model	Mean HIC Without	Mean Hic With	Difference (HIC)	Mean Chest g Without	Mean Chest g With	Difference (Chest g)	Mean Chest Deflect Without	Mean Chest Deflect With	Difference (Chest Deflect)
Vehicles with no change in Pretensioners or Load Limiters										
Chevrolet	Malibu	691.0	725.0	34.0	41.8	51.0	9.2	38.6	28.1	-10.5
Chrysler	LHS	708.0	907.0	199.0	60.7	55.6	-5.1	38.9	40.4	1.5
Nissan	Altima	887.0	908.0	21.0	51.1	51.3	0.2	35.0	31.8	-3.2
Toyota	Avalon	504.0	868.0	364.0	50.4	51.1	0.7	21.2	30.4	9.2
Toyota	Camry	525.0	525.0	0.0	45.8	45.6	-0.2	34.0	24.1	-9.9
Chevrolet	S-10	634.0	852.0	218.0	54.7	61.1	6.4	46.0	45.7	-0.3
Chevrolet	Venture	538.0	646.0	108.0	43.0	39.3	-3.7	29.1	26.6	-2.5
Dodge	Dakota	550.0	747.0	197.0	50.9	51.9	1.0	29.5	55.9	26.4
Dodge	Durango	997.0	1008.0	11.0	62.3	60.8	-1.5	48.6	41.0	-7.6
Dodge	Ram1500	691.0	352.0	-339.0	47.2	36.0	-11.2	27.5	36.9	9.4
Ford	Expedition	544.0	583.0	39.0	44.8	46.7	1.9	33.4	31.3	-2.1
Ford	F150 Pickup	497.0	517.0	20.0	42.3	45.7	3.4	42.3	44.6	2.3
Toyota	4Runner	693.0	673.0	-20.0	44.6	41.2	-3.4	37.0	33.8	-3.2
Toyota	Tacoma	701.0	752.0	51.0	43.9	55.7	11.8	34.7	33.3	-1.4

Exhibit 3c: Means and Differences Before And After, Right Front Passengers Only

Make	Model	Mean HIC Without	Mean Hic With	Difference (HIC)	Mean Chest g Without	Mean Chest g With	Difference (Chest g)	Mean Chest Deflect Without	Mean Chest Deflect With	Difference (Chest Deflect)
Vehicles that added Pretensioners only										
Dodge	Stratus	641.0	368.0	-273.0	53.7	46.1	-7.6	34.5	23.9	-10.6
Ford	Taurus	480.0	370.0	-110.0	41.1	37.5	-3.6	N/A	26.0	N/A
Mazda	Protege	534.0	615.0	81.0	50.3	52.3	2.0	23.4	21.7	-1.7
Vehicles that added Load Limiters only										
Ford	Mustang	364.0	250.0	-114.0	46.9	44.4	-2.5	38.1	35.4	-2.7
Ford	Taurus	486.0	480.0	-6.0	51.0	41.1	-9.9	27.9	N/A	N/A
Dodge	Caravan	788.0	792.0	4.0	53.0	48.8	-4.2	39.9	27.6	-12.3
Dodge	Grand Caravan	994.0	814.0	-180.0	60.0	44.8	-15.2	36.0	29.3	-6.7
Jeep	Grand Cherokee	546.0	773.0	227.0	57.6	53.7	-3.9	41.0	22.9	-18.1
Vehicles that added both Pretensioners and Load Limiters										
Ford	Crown Victoria	335.0	288.0	-47.0	40.5	34.2	-6.3	28.8	20.2	-8.6
Honda	Accord	487.0	567.0	80.0	50.9	45.2	-5.7	40.9	25.2	-15.7
Nissan	Altima	976.5	428.0	-548.5	52.6	39.6	-13.0	35.4	31.0	-4.4
Nissan	Sentra	797.0	518.0	-279.0	49.5	43.9	-5.6	44.2	29.0	-15.2
Dodge	Durango	609.5	607.0	-2.5	58.2	48.6	-9.6	35.1	27.9	-7.2
Ford	Expedition	624.5	492.0	-132.5	43.0	38.3	-4.7	35.3	31.3	-4.0
Ford	F150 Pickup	624.5	533.0	-91.5	45.7	37.6	-8.1	42.0	29.9	-12.1
Nissan	Frontier	521.0	355.0	-166.0	54.0	41.9	-12.1	30.0	23.6	-6.4
Toyota	4Runner	743.0	511.0	-232.0	58.8	44.1	-14.8	50.7	40.4	-10.4
Toyota	Tacoma	683.0	625.5	-57.5	54.6	48.3	-6.3	47.2	25.2	-22.0

Exhibit 3c continued: Means and Differences Before And After, Right Front Passengers Only

Make	Model	Mean HIC Without	Mean Hic With	Difference (HIC)	Mean Chest g Without	Mean Chest g With	Difference (Chest g)	Mean Chest Deflect Without	Mean Chest Deflect With	Difference (Chest Deflect)
Vehicles with no change in Pretensioners or Load Limiters										
Chevrolet	Malibu	473.0	500.0	27.0	49.7	45.4	-4.3	35.4	29.0	-6.4
Chrysler	LHS	581.0	657.0	76.0	54.1	52.9	-1.2	24.4	25.5	1.1
Nissan	Altima	1119.0	834.0	-285.0	55.4	49.8	-5.6	36.0	34.7	-1.3
Toyota	Avalon	577.0	577.0	0.0	36.7	39.1	2.4	28.4	28.3	-0.1
Toyota	Camry	480.0	428.0	-52.0	37.5	37.0	-0.5	31.0	28.1	-2.9
Chevrolet	S-10	450.0	835.0	385.0	56.1	60.9	4.8	28.6	39.7	11.1
Chevrolet	Venture	962.0	559.0	-403.0	48.0	36.2	-11.8	30.1	25.2	-4.9
Dodge	Dakota	570.0	569.0	-1.0	49.5	42.0	-7.5	37.8	21.9	-15.9
Dodge	Durango	627.0	592.0	-35.0	62.1	54.2	-7.9	33.8	36.3	2.5
Dodge	Ram1500	330.0	410.0	80.0	49.4	44.4	-5.0	26.9	33.8	6.9
Ford	Expedition	569.0	680.0	111.0	42.2	43.7	1.5	37.8	32.7	-5.1
Ford	F150 Pickup	615.0	634.0	19.0	46.3	45.0	-1.3	41.6	42.2	0.8
Toyota	4Runner	438.0	584.0	146.0	43.3	44.8	1.5	40.2	40.5	0.3
Toyota	Tacoma	497.0	754.0	257.0	47.5	49.1	1.6	20.3	30.2	9.8

While the overwhelming majority of vehicles that added pretensioners and/or load limiters experienced a reduction in HIC, chest acceleration, and chest deflection scores, there are some exceptions. In a small number of cases, scores increased from one test to the next. Most of these increases were relatively small, but the chest acceleration score for drivers in the Nissan Frontier increased by 10.1 g's. The earlier score (before pretensioners and load limiters were added) is not a particularly low "before" score. Rather, the increase is due to a relatively high "after" score for this vehicle. The Frontier is one of a number of pickups included in the analysis for which one NCAP test was performed on a regular cab, and the other on an extended cab. The decision was made to include such cases in the analysis, as the results of testing involved in frontal impacts should not be markedly affected by a longer cab. It was felt that the larger sample provided by including these vehicles would be worth this comparatively minor disparity.

In this case, the wheelbase was the same in both vehicles, although of course the extended cab was longer. In most, but not all, cases, having the same wheelbase implies that the vehicles are structurally identical. However, detailed examination of the NCAP test results shows somewhat different crash pulses for the two vehicles. Specifically, these indicate that the 2001 vehicle has a stiffer frame. However, there was no major redesign of Frontiers between the two model years. Although data for these particular vehicles were not in line with expectations, it was decided to include them in the analysis. If these cases were excluded because of the differing crash pulses, standardization would necessitate a detailed examination of the crash pulses of all vehicles in the study. In fact, although the driver's chest acceleration score increased by 10.1 g's, the right front passenger's score *decreased* by 12.1.

Mean differences of the above groups, with one-tailed significance test results, are presented in Exhibit 4 (HIC scores in Exhibit 4a, chest-g (chest acceleration) scores in Exhibit 4b, and chest deflection scores in 4c). Data are shown for drivers and right front passengers combined as well as individually. The number of different vehicles (make/models) tested for each type of belt technology addition (one or the other, both, neither) is shown in the top row. For data including both drivers and right front passengers, the number of data points would be double this number, as means were determined separately by seat position. Again, since no usable chest deflection data for the 1999 Ford Taurus were obtained, comparisons to that model year cannot be made.

Seven overlapping sets of data were examined. The first column presents information on vehicles that added pretensioners only, while the second column presents vehicles that added load limiters only. Recall that all vehicles that added only pretensioners already had load limiters by that time, and that vehicles that added only load limiters did not have pretensioners prior to that. The third column shows data for vehicles that added pretensioners (and may or may not have added load limiters at the same time). Similarly, the fourth column shows data for those vehicles that added load limiters (and possibly pretensioners at the same time). Note that the ten vehicles adding both load limiters and pretensioners in the same model year would contribute data to both of these groups. The fifth column presents data for those vehicles that added something – load limiters, pretensioners, or both. This group, obviously, has data in common with all other groups that add one technology or the other. In the sixth column are data for those vehicles that added both technologies at the same time. The final column shows data for those vehicles with no change in belt technologies. Recall that this could mean the vehicles had either, neither, or both technologies, but that neither was added between the first and second model year used. The number of vehicles in each of these groups is shown in the second row. Note that the first two and last two columns correspond to vehicle groupings in Exhibit 3.

Exhibit 4a - Mean Differences in NCAP HIC scores

	Added Pretensioners Only	Added Load Limiters Only	Added Pretensioners *	Added Load Limiters **	Added Something	Added Both	No Change
N of Make/Models	3	5	13	15	18	10	14
Drivers and Right Front Passengers							
Difference	-149.67	-60.90	-177.42	-144.13	-145.06	-185.75	43.86
Mean Score Before	573.33	703.50	669.53	700.08	678.96	698.38	623.14
Mean Score After	423.67	642.60	492.10	555.95	533.90	512.63	667.00
Std Error	71.58	42.05	34.56	31.80	28.64	40.28	33.46
T-value	-2.09	-1.45	-5.13	-4.53	-5.06	-4.61	1.31
Probability	**0.0454**	0.0907	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.8995
Drivers only							
Difference	-198.67	-108.00	-218.08	-185.27	-187.50	-223.90	64.5
Mean Score Before	595.00	771.40	719.35	761.57	733.81	756.65	654.29
Mean Score After	396.33	663.40	501.27	576.30	546.31	532.75	718.79
Std Error	112.94	45.22	49.70	43.26	39.19	58.44	42.80
T-value	-1.76	-2.39	-4.39	-4.28	-4.78	-3.83	1.51
Probability	0.1103	**0.0377**	**0.0005**	**0.0004**	**0.0001**	**0.0020**	0.9222
Right Front Passengers only							
Difference	-100.67	-13.80	-136.81	-103.00	-102.64	-147.60	23.21
Mean Score Before	551.67	635.6	619.69	638.60	624.11	640.10	592.00
Mean Score After	451.00	621.80	482.88	535.57	521.47	492.45	615.21
Std Error	102.30	69.29	47.23	45.56	40.37	55.79	52.48
T-value	-0.9841	-0.20	-2.90	-2.26	-2.54	-2.65	0.44
Probability	0.2144	0.4260	**0.0067**	**0.0201**	**0.0106**	**0.0134**	0.6673

* and, possibly, load limiters

** and, possibly, pretensioners

Probability or “p-values” shown here (and in later exhibits) in bold are statistically significant.

Exhibit 4b - Mean Differences in NCAP Chest Acceleration scores

	Added Pretensioners Only	Added Load Limiters Only	Added Pretensioners	Added Load Limiters	Added Something	Added Both	No Change
N of Make/Models	3	5	13	15	18	10	14
Drivers and Right Front Passengers							
Difference	-4.84	-5.24	-6.79	-6.66	-6.36	-7.37	-0.85
Mean Score Before	49.87	52.19	50.28	51.00	50.81	50.40	48.62
Mean Score After	45.03	46.95	43.49	44.34	44.45	43.03	47.77
Std Error	1.74	1.44	1.10	1.01	0.89	1.32	1.04
T-value	-2.78	-3.63	-6.15	-6.59	-7.15	-5.55	-0.82
Probability	**0.0196**	**0.0028**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.2097
Drivers only							
Difference	-6.62	-3.34	-6.25	-5.21	-5.44	-6.14	0.68
Mean Score Before	51.37	50.68	50.35	50.25	50.44	50.04	48.82
Mean Score After	44.75	47.34	44.10	45.05	45.00	43.90	49.50
Std Error	2.08	1.38	1.88	1.68	1.42	2.42	1.58
T-value	-3.18	-2.42	-3.32	-3.11	-3.82	-2.54	0.43
Probability	**0.0431**	**0.0365**	**0.0031**	**0.0039**	**0.0007**	**0.0158**	0.6628
Right Front Passengers only							
Difference	-3.07	-7.14	-7.33	-8.12	-7.28	-8.61	-2.38
Mean Score Before	48.37	53.70	50.21	51.74	51.18	50.77	48.41
Mean Score After	45.30	46.56	42.88	43.63	43.91	42.16	46.04
Std Error	2.78	2.38	1.22	1.06	1.06	1.13	1.27
T-value	-1.10	-3.00	-6.02	-7.68	-6.85	-7.64	-1.88
Probability	0.1928	**0.0200**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0417**

* and, possibly, load limiters
** and, possibly, pretensioners
Probability or "p-values" shown here (and in later exhibits) in bold are statistically significant.

Exhibit 4c - Mean Differences in NCAP Chest Deflection scores

	Added Pretensioners Only	Added Load Limiters Only	Added Pretensioners	Added Load Limiters	Added Something	Added Both	No Change
N of Make/Models	2	4	12	14	16	10	14
Drivers and Right Front Passengers							
Difference	-6.46	-5.46	-9.79	-9.03	-8.71	-10.45	0.14
Mean Score Before	31.10	39.48	38.74	40.04	38.93	40.27	33.87
Mean Score After	24.7	34.00	28.96	31.01	30.22	29.81	34.03
Std Error	2.29	2.72	1.26	1.32	1.19	1.41	1.55
T-value	-2.83	-2.01	-7.78	-6.85	-7.33	-7.40	0.09
Probability	**0.0332**	**0.0423**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.5365
Drivers only							
Difference	-6.78	-0.98	-9.74	-7.66	-7.55	-10.33	0.58
Mean Score Before	33.25	40.15	40.18	41.16	40.18	41.57	35.41
Mean Score After	26.45	39.18	30.44	33.51	32.63	31.24	35.99
Std Error	3.38	3.13	1.96	2.14	1.89	2.26	2.54
T-value	-2.01	-0.31	-4.98	-3.59	-4.00	-4.56	0.23
Probability	0.1471	0.3881	**0.0002**	**0.0017**	**0.0006**	**0.0007**	0.5884
Right Front Passengers only							
Difference	-6.15	-9.95	-9.84	-10.40	-9.87	-10.58	-0.29
Mean Score Before	28.95	38.75	37.29	38.90	37.66	38.96	32.31
Mean Score After	22.8	28.80	27.44	28.49	27.78	28.37	32.01
Std Error	4.45	3.35	1.67	1.54	1.45	1.81	1.86
T-value	-1.38	-2.97	-5.89	-6.75	-6.81	-5.83	-0.16
Probability	0.1994	**0.0297**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.4386

* and, possibly, load limiters
** and, possibly, pretensioners
Probability or “p-values” shown here (and in later exhibits) in bold are statistically significant.

NCAP scores for HIC, chest acceleration, and chest deflection vary by the model of a vehicle, due to a number of factors, such as vehicle size, structure, and safety equipment. Thus, a comparison of the NCAP scores across these groups of vehicles would not be appropriate. What is of interest here is comparing the change (or lack thereof) across groups, not the actual scores. However, there are some homogeneous groups (with regard to the presence or absence of the belt technologies) that can be compared across column groups in Exhibit 4. Since none of the three vehicles that added pretensioners only had load limiters prior to that, both these "Before" vehicles and the "Before" vehicles in the "Added Both" column had neither of the belt technologies. Similarly, since all of the vehicles that added pretensioners only already had load limiters, these "After" vehicles as well as the "After" vehicles in the "Added Both" group had both belt technologies. Finally, only load limiters (and not pretensioners) were "Before" vehicles in the "Added Pretensioners" group and "After" vehicles in the "Added Load Limiters" group. Indeed, some of these were the same vehicles using additional model years. Consistency of mean NCAP scores can be seen across these groups with the same belt technology.

The earlier and later mean HIC and chest acceleration scores are presented, as well as the difference between the two. Note that, without exception, all mean HIC, chest acceleration, and chest deflection scores decreased after a belt technology was introduced. For the majority of the cases these decreases are significant. When both load limiters and pretensioners were added, HIC scores for drivers and right front passengers combined were reduced by 185.75, chest acceleration scores were lowered by 7.37, and chest deflections scores were lowered by 10.45 - all significant reductions. When pretensioners only were added, chest acceleration scores significantly decreased by 4.84 g's, chest deflection scores decreased by a significant 6.46 mm, and HIC scores decreased by a significant 149.67, for drivers and right front passengers. Chest acceleration scores were reduced by 5.24 and chest deflection scores by 5.46, when load limiters only were added. These were both significant reductions. HIC scores show no significant decline for right front passengers alone or combined with drivers when load limiters only are added. Note that, for adding pretensioners or load limiters only, there are three or five vehicles in each group, a very small sample, and statistical significance was not obtained in several of these tests. It is likely that, with larger samples, the results could have been significant. All other cases show a significant reduction in HIC, chest acceleration, and chest deflection when there is any addition of either belt technology.

HIC scores tend to have a greater decrease when pretensioners were added (alone or in combination with load limiters). Both chest acceleration and chest deflection scores for drivers show greater improvement when pretensioners were added, while scores for right front passengers show slightly greater improvement with the addition of load limiters. This can be seen by comparing the first two columns, with the results noted above. This is also illustrated by the third and fourth columns, where HIC and driver chest acceleration and chest deflection reductions are larger for those vehicles that added pretensioners, while passenger reductions in chest acceleration and chest deflection are greater for those adding load limiters.

Note also that, when there was no addition of either belt technology, in most cases the NCAP score (HIC or chest acceleration) increased by a nonsignificant amount. In two cases (chest acceleration scores for right front passengers as well as both front occupants) the scores did

decrease. For right front passengers alone, this decrease was significant, although the difference was only 2.38 g's. This demonstrates that there was no general trend toward improved NCAP scores, other than the improvements in vehicles that added pretensioners or load limiters.

Regression analyses were performed to shed additional light on improvements due to the addition of load limiters and pretensioners, and how they compare to improvements that occurred only over time (such as the reduction in chest acceleration for right front passengers). The regression analyses were performed on the combined set of data, using both the vehicles that added pretensioners and/or load limiters as well as those vehicles with no change in belt technology, in order to sort out the effects of pretensioners and load limiters. Analyses were done with both difference scores (the change in NCAP scores after load limiters and/or pretensioners were added, or between the earlier and later NCAP scores in those vehicles with no change) as well as the actual HIC and chest acceleration values.
Looking at the regression model using difference scores for both drivers and right front passengers, with belt technology determined by what was added to the vehicle, the interaction of pretensioners and load limiters was not significant for HIC ($p=0.7480$, using the one-tailed test), chest acceleration ($p=0.7173$), or chest deflection ($p=0.7480$). Results from this analysis are presented in Exhibit 5. Had the interaction term been significant, it would have meant that the two technologies combined in a synergistic manner that could not be predicted by the presence of either one alone. Since it is not significant, it may be assumed that when pretensioners and/or load limiters are added to a vehicle, the improvement due to either one is not dependent on whether the other is added at the same time. Since this is the case, the interaction term was dropped from the model in order to simplify the analysis. For completeness sake, however, full results are presented. Similar results were obtained when NCAP scores were looked at separately by occupant position. For drivers, the interaction term for HIC difference scores had a one-tailed probability of 0.8522, for chest acceleration the probability was 0.8060 and for chest deflection, 0.4041. The interaction for difference scores for right front passengers had a probability of 0.4745 for HIC, 0.4193 for chest acceleration, and 0.7953 for chest deflection.

The next model examined the influence of adding pretensioners and/or load limiters on the difference score, without including the interaction term. Data are presented in the right-hand side of Exhibit 5, with significant probabilities bolded. Note that, for drivers and right front passengers combined as well as individually, HIC scores were significantly lower after the introduction of pretensioners. Similarly, chest acceleration and chest deflection scores for drivers alone were significantly lower when pretensioners were added. On the other hand, for right front passengers alone, and drivers and right front passengers combined, had significantly lower chest acceleration and chest deflection values after load limiters were installed in vehicles. Chest deflections scores were also significantly lower for drivers and right front passengers combined when pretensioners were added. Since the effects of adding load limiters and pretensioners do not combine interactively, their simple effects can be summed together. Looking at the combined effect of pretensioners and load limiters, HIC is reduced by a total of 232.39 (154.08 due to pretensioners + 78.31 due to load limiters). The total reduction in chest acceleration is 2.92 g's due to pretensioners plus 3.67 g's due to load limiters, for a total of 6.59 g's. For chest deflection scores, the total reduction is 5.6 mm due to pretensioners, and 5.04 mm due to load limiters, for a combined 10.64 mm reduction.

Exhibit 5: Results of Regression Analyses on Differences Scores, Specific Belt Technology added to Vehicles

	Analysis	Difference Scores w/ Interaction			Difference Scores without Interaction		
Drivers and RF Passengers		**HIC**	**Chest-g**	**Chest Deflect**	**HIC**	**Chest-g**	**Chest Deflect**
Pretensioners	**Estimate**	-193.52	-3.99	-6.61	-154.08	-2.92	-5.60
	T-value	-2.50	-1.64	-1.68	-2.74	-1.70	-2.24
	P	0.0076	0.0534	0.0496	**0.0052**	0.0501	**0.0168**
Load Limiters	**Estimate**	-104.76	-4.39	-5.61	-78.31	-3.67	-5.04
	T-value	-1.65	-2.20	-1.90	-1.42	-2.17	-2.05
	P	0.0518	0.0159	0.0315	0.0838	**0.0193**	**0.0250**
P*LL Interaction	**Estimate**	68.67	1.86	1.62	-	-	-
	T-value	0.67	0.53	0.32	-	-	-
	P	0.7480	0.7173	0.7480	-	-	-
Drivers Only		**HIC**	**Chest-g**	**Chest Deflect**	**HIC**	**Chest-g**	**Chest Deflect**
Pretensioners	**Estimate**	-263.17	-7.29	-7.35	-178.59	-4.71	-8.59
	T-value	-2.51	-1.88	-1.18	-2.61	-1.87	-2.27
	P	0.0009	0.0354	0.1248	**0.0071**	**0.0360**	**0.0156**
Load Limiters	**Estimate**	-172.50	-4.02	-1.15	-115.78	-2.29	-2.25
	T-value	-2.01	-1.26	-0.33	-1.72	-0.92	-0.61
	P	0.0270	0.1084	0.3714	**0.0482**	0.1824	0.2747
P*LL Interaction	**Estimate**	147.27	4.49	-2.00	-	-	-
	T-value	1.07	0.88	-0.25	-	-	-
	P	0.8522	0.8060	0.4014	-	-	-
RF Passengers Only		**HIC**	**Chest-g**	**Chest Deflect**	**HIC**	**Chest-g**	**Chest Deflect**
Pretensioners	**Estimate**	-123.88	-0.69	-5.86	-129.58	-1.13	-2.61
	T-value	-1.06	-0.24	-1.19	-1.73	-0.62	-0.87
	P	0.1485	0.4059	0.1220	**0.0468**	0.2708	0.1997
Load Limiters	**Estimate**	-37.01	-4.76	-9.66	-40.83	-5.06	-7.83
	T-value	-0.39	-2.03	-2.62	-0.56	-2.80	-2.65
	P	0.3506	0.0259	0.0073	0.2916	**0.0045**	**0.0067**
P*LL Interaction	**Estimate**	-9.92	-0.77	5.23	-	-	-
	T-value	-0.06	-0.21	0.84	-	-	-
	P	0.4745	0.4193	0.7953	-	-	-

One final regression analysis was run on the difference data. In this model, data were coded based on whether either belt technology was added to the vehicle. That is, if either load limiters or pretensioners (or both) were added, the vehicle was considered as having technology added. Only those vehicles with no change in belt technology (over the span of model years included in the analysis) were considered as having no technology added. The results, presented in Exhibit 6, show that HIC, chest acceleration, and chest deflection scores, for both drivers and right front passengers (individually, as well as combined) are significantly reduced when load limiters and/or pretensioners are added to a vehicle.

Exhibit 6: Results of Regression Analyses on Differences Scores, Either Belt Technology added to Vehicles ("Added Something")

		HIC	Chest-g	Chest Deflect
Drivers and RF Passengers	**Estimate**	-188.91	-5.51	-8.85
	T-value	-3.82	-3.72	-4.37
	P	**0.0003**	**0.0004**	**0.0001**
Drivers Only	**Estimate**	-252.00	-6.12	-8.13
	T-value	-4.32	-2.87	-2.61
	P	**0.0001**	**0.0038**	**0.0072**
RF Passengers Only	**Estimate**	-125.83	-4.90	-9.57
	T-value	-1.93	-2.98	-4.12
	P	**0.0313**	**0.0029**	**0.0002**

As a check on the preceding analyses, additional regression analyses were run using raw data rather than difference scores. Vehicles were coded for either the presence or absence of each belt technology individually. Thus, data were examined based on whether load limiters and/or pretensioners were *present* in the vehicle, and not whether they were *added*. Recall that, in previous analyses, there were several cases in which the same vehicles were used in different groups. For example, the Ford Taurus had neither belt technology in model year 1998, added pretensioners in 1999, and load limiters in model year 2000. Therefore, the difference in HIC and chest acceleration scores from 1998 to 1999 were considered part of the "pretensioner added" group, while differences between 1999 and 2000 were part of the "added load limiters" group. In this analysis, vehicles were not grouped, since the presence (or absence) of pretensioners and/or load limiters was coded for each individual model year. Each vehicle model year was included only once. Also included in the model were occupant location (driver or right front passenger), type of vehicle (passenger car or light truck), vehicle make/model and model year. These were used as predictors for HIC and chest acceleration NCAP scores. Results from this analysis are presented in Exhibit 7.

No estimate is shown for make/model since there are several values for each of these variables. The regression analysis compares each of them to one (arbitrarily chosen) of the group. For this analysis, F-values (rather than t-values) are reported, which is the significance of the named variable, rather than any particular level of it. There are 23 degrees of freedom (df) for the make/model variable, and one df for each of the other degrees of freedom (df) for the

make/model variable, and one df for each of the other variables. There are no separate analyses for drivers and right front passengers, since occupant position is used as a variable.

For pretensioners and load limiters there are only two possible levels (present or not), so the significance test shows the impact of the belt technology being present. Similarly, there are only two levels of occupant position (driver or right front passenger). In the analysis as presented, the value shown reflects the influence the driver position has. For vehicle type, the value reflects the influence of the vehicle being a truck rather than a car. So, for example, the estimate for "Occupant Position (Driver)" in the HIC column is 68.83. This means that HIC scores for drivers were, on average, 68.83 higher than for right front passengers, regardless of the status of load limiters and/or pretensioners. Model year is treated as a linear variable.

Exhibit 7: Results of Regression Analysis on Raw Data

		HIC	Chest-g	Chest Deflect
Pretensioners	**Estimate**	-150.31	-3.59	-2.42
	F-value	7.17	4.57	5.85
	P	**0.0044**	**0.0176**	**0.0088**
Load Limiters	**Estimate**	-46.61	-4.05	-6.13
	F-value	0.79	6.64	4.49
	P	0.1885	**0.0058**	**0.0185**
Occupant Position (Driver)	**Estimate**	68.83	0.93	3.74
	F-value	7.99	1.64	13.33
	P	**0.0058**	0.2035	**0.0004**
Vehicle Type (Truck)	**Estimate**	287.49	-2.53	-0.85
	F-value	13.39	2.55	7.63
	P	**0.0004**	0.1140	**0.0070**
Model Year	**Estimate**	7.45	-0.16	0.43
	F-value	0.25	0.13	0.19
	P	0.6183	0.7233	0.6668
Make/Model (23 df)	**F-value**	4.32	6.89	2.00
	P	**0.0001**	**0.0001**	**0.0112**

It was hypothesized that adding load limiters and/or pretensioners to vehicles would lower HIC and chest acceleration scores, so one-tailed tests have been used for significance testing throughout. However, no such assumption is made for the other variables present in this model, so two-tailed probabilities are presented for the remaining factors.

The presence of pretensioners was associated with a HIC reduction of 150.31 (F=7.17, p=0.0044), a chest acceleration score reduction of 3.59 (F=4.57, p=0.0176), and a reduction in chest deflection scores of 2.42 (F=5385, p=0.0088), all of which are significant. The presence of load limiters was associated with a non-significant HIC reduction of 46.61 (F=0.79, p=0.1885), a significantly lower chest acceleration reduction of 4.05 (F=6.64, p=0.0058) as well as a significantly lower chest deflection reduction of 6.13 (F=4.49, p=0.0185). Thus, the effect of adding both pretensioners and load limiters is a HIC reduction of 196.92, a chest acceleration

reduction of 7.64 g, and a chest deflection reduction of 8.55 mm. That is quite consistent with the regression on difference scores (HIC reduction of 232.39, chest acceleration reduction of 6.59 g and chest deflection reduction of 10.64).

In both regression models that separate out the effects of pretensions and load limiters, for drivers and right front passengers combined, the reduction in chest acceleration due to load limiters is greater than that due to pretensioners, and the HIC reduction is much greater for pretensioners than load limiters. Chest deflection shows a greater reduction for load limiters in one statistical model, and nearly equal reductions in the other. In addition, the regression analysis on difference scores when either pretensioners or load limiters were added ("added something") is similar to the combined effects found for pretensioners and load limiters in the other two regressions analyses where each technology was examined individually. In sum, all the analyses consistently show similar effects for pretensioners and load limiters on HIC, chest acceleration, and chest deflection scores in NCAP tests.

Note also that, for HIC scores shown in Exhibit 7, both occupant position ($F=7.99$, $p=0.0058$) and type of vehicle ($F=13.39$, $p=0.0004$) had significant effects. Both of these variables were also significant for the chest deflection scores. Not surprisingly, vehicle make and model significantly impacted HIC, chest acceleration, and chest deflection scores. The NCAP tests are performed on a variety of makes and models of vehicles to assess compliance with NHTSA requirements. Variation in vehicles would be expected, thus the need for the NCAP program. Also, as discussed previously, several factors other than belt technology influence NCAP scores. Another important fact is the model year did not have a significant influence on HIC, chest acceleration, or chest deflection scores. In other words, there was no trend to lower scores in more recent model years (other than for those vehicles that added load limiters or pretensioners). This strengthens the belief that it is pretensioners and load limiters that are reducing the test scores.

This evaluation found that equipping vehicles with load limiters and pretensioners reduces HIC, chest acceleration, and chest deflection scores in NCAP tests. T-tests of mean differences between vehicles with and without pretensioners and/or load limiters showed that, in most cases, adding either or both of these technologies significantly reduces HIC, chest acceleration, and chest deflection scores. Regression analyses on difference scores gave similar results. The addition of pretensioners significantly lowered HIC at both seating positions. The addition of pretensioners was also associated with lower chest acceleration and chest deflection scores for drivers. Adding load limiters significantly lowered chest acceleration and chest deflection difference scores for right front passengers alone as well as when combined with drivers. When data were examined in regard to whether either technology was added, both seating positions (each individually as well as combined) experienced significantly lower HIC, chest acceleration, and chest deflection difference scores. Regression analyses on individual data points (raw scores rather than difference scores) show similar significant reductions.

More specifically, overall results suggest that pretensioners are especially valuable in lowering HIC scores overall and chest acceleration and chest deflection scores for drivers. Load limiters appear to have more of an influence lowering chest acceleration and chest deflection scores, particularly for right front passengers. Additionally, when neither load limiters nor pretensioners

have been added, at best there is little change during 1998 to 2001 in either HIC or chest acceleration values in NCAP tests. The improvements seen when one or both technologies are added can thus confidently be attributed to the addition, and not to other safety features added during this time or to a change in NCAP testing or instrumentation.

Currently not enough real-world crash data exist to permit an analysis of the effects of adding pretensioners and/or load limiters to passenger vehicles. Approximately 63 percent of the model year 2002 fleet of vehicles was equipped with pretensioners, and approximately 84 percent was equipped with load limiters or other energy management features for safety belts. When enough data are available, a follow-up report will use NHTSA's injury and fatality crash data files to determine the effect these belt technologies have in actual crashes, as well as updating NCAP test information.