SELECTION OF TEST PARAMETERS FOR A CONSUMER INFORMATION CRASH TEST PROGRAM TO EVALUATE THE SAFETY OF REAR-SEAT OCCUPANTS

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ABSTRACT

Regulatory and consumer information frontal crash testing programs in the United States have historically focused on the front seat occupants. The result has been significant safety improvements for people in those seating positions but not necessarily for rear-seat occupants. The objective of this research was to select a crash configuration, anthropomorphic test device (ATD), and seat position for a crash test program to evaluate and incentivize rear-seat safety improvements in frontal crashes.

Twelve full-scale vehicle crash tests were conducted with two different crash configurations (25% and 40% offset deformable barrier tests at 64.4 km/h) and four different ATDs (H3-50th male, H3-5th female, H3 10-year-old, and THOR 5th female) seated in the left and right rear outboard positions. Vehicles with rear-seat pretensioners and load limiters were compared with their previous generation counterparts without advanced belt technology in test conditions matched by crash configuration, ATD, and seating position.

The H3-5th female dummy represents an average stature for rear-seat passengers in frontal crashes, and the study showed that a 40% offset deformable barrier with an H3-5th female dummy positioned in the second-row seat behind the driver best reproduces common injury mechanisms documented in the field data and best discriminates between restraint system performance. The 40% offset deformable barrier test was more severe than the 25% offset test, which resulted in higher head and neck injury values and higher incidence of submarining in the 40% offset test. For all ATDs except the H3-50M, the left rear seating position was more challenging than the right, producing higher head and neck injury numbers, similar or higher chest injury numbers, and increased incidence of submarining. All ATDs tested showed reduced injury risks for vehicles equipped with pretensioners and load limiters. However, the ATDs also showed potential tradeoffs for occupants of different sizes. The smallest dummy (H3 10-year-old) had the highest incidence of submarining, while the largest dummy (H3-50th male) had the largest head excursions and the only cases in which the dummy's head made contact with the interior of the vehicle. The shoulder belt remained on the ATD shoulder in all cases except in one instance with a THOR 5th female ATD seated in the right seating position.

INTRODUCTION

Regulatory and consumer information frontal crash test programs in the United States have led to improvements in front seat safety due, in part, to optimized restraint systems that include improved airbag designs and seat belt technologies such as load limiters and pretensioners [1,2]. However, none of the U.S. frontal crash test programs to date include a rear-seat occupant and, as a result, rear-seat restraint systems have not kept pace with improvements in the front. This is evident in the field data, where multiple studies have shown rear-seat occupants in newer vehicles are at increased risk compared with front seat occupants [3,4,5]. In 2020, more than 1,600 people were killed in rear rows of passenger vehicles, accounting for nearly 7% of all passenger vehicle occupant deaths in the United States during that year [6].

The restraint environment in the rear differs from the front, and, as a result, the injury patterns differ as well. Kuppa et al. (2005) analyzed data from NASS-CDS (National Automotive Sampling System Crashworthiness Data System) and FARS (Fatality Analysis Reporting System) and identified the seat belt as a major source of injury in restrained rear-seat occupants [3]. Jermakian et al. (2019) also studied belt-restrained rear-seat occupants who sustained serious or fatal injuries and found that the most commonly documented injured body regions were the head, chest, and abdomen [7]. The authors found that the most common causes of injuries were shoulder belt loading, head impacts with the vehicle interior, and lap belt loading due to submarining.

Seat belt technologies such as pretensioners and load limiters may help mitigate these injuries and offer improved protection, particularly for older rear-seat occupants [3]. While these features are standard equipment in the front seats of modern vehicles, they are less common in the rear seat. In 2020, Consumer Reports found that fewer than 40% of U.S. vehicles were equipped with pretensioners and load limiters in the rear seat [8]. The European new car assessment program (Euro NCAP) and other consumer ratings programs around the world have introduced safety ratings for rear-seat occupants and seen rapid introduction of improved rear-seat restraint systems. Before the introduction of rear-seat safety ratings in Euro NCAP in 2015, only 10% of vehicles sold in Europe had standard pretensioners and load limiters. By 2020, nearly all European vehicles were equipped with these belt technologies [8]. The addition of these belt technologies may help reduce injuries when adapted appropriately for the rear-seat environment.

The objective of this research was to select a crash configuration, seat position, and ATD for a crash test program that can evaluate and incentivize improvements to rear-seat safety in frontal crashes. The test program should replicate injury mechanisms and kinematics observed in the field data and be able to demonstrate the potential benefits of robust restraint systems with pretensioners and load limiters adapted for the rear-seat environment which have proven to be effective in the front seat.

METHODS

Twelve full-scale vehicle crash tests were conducted in a test matrix (Table 1) that varied test mode, anthropomorphic test device (ATD) size and type, and second-row seat position. Two crash configurations were tested in which the test vehicle traveled at 64.4 km/h into an offset deformable, aluminum honeycomb barrier (ODB) with 25% and 40% overlap, as seen in Figure 1. Four different ATDs – Hybrid III 50th male (H3-50M), Hybrid III 5th female (H3-5F), Hybrid III 10-year-old (H3-10YO), and THOR 5th female (THOR-5F) – were seated in the left and right second row outboard positions (Figure 2) using the *IIHS dummy seating procedure for rear outboard positions Version 1* (April 2012). The H3-10YO dummy was positioned without a booster seat, and because of the short thigh length, the seating procedure was modified so the knees were bent and the calves were in contact with the seat cushion. The driver seat was positioned using the IIHS procedure, *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version V)* (IIHS, 2004). This study focuses only on the rear-seat occupants.

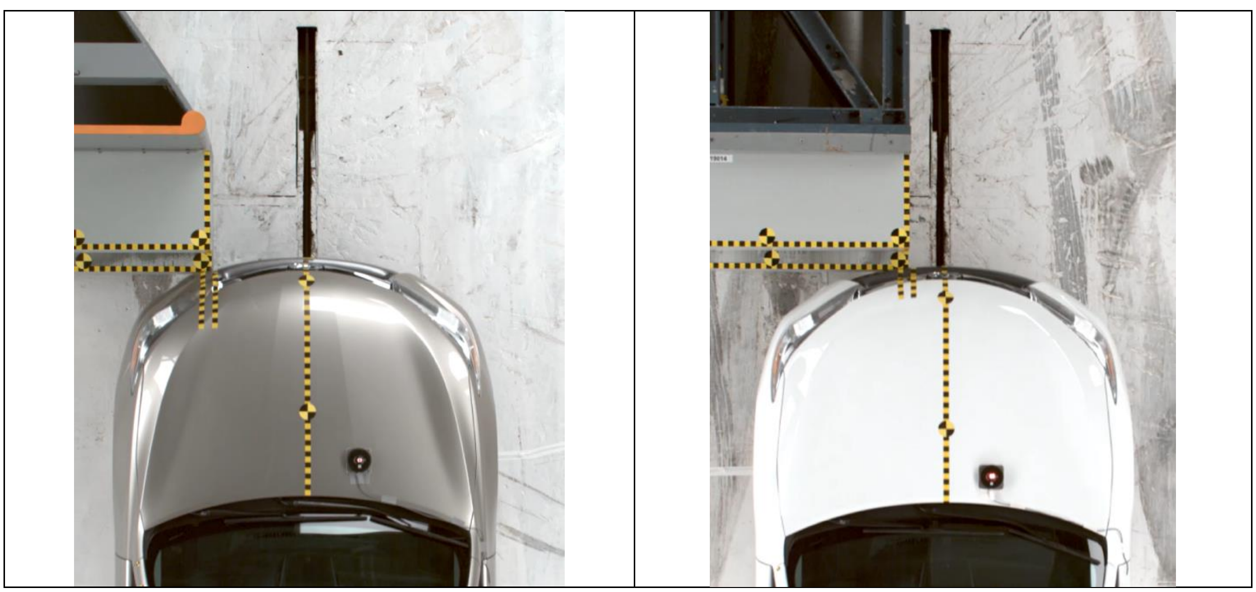

Figure 1. 25% ODB (left) and 40% ODB (right) test configuration at impact.

Figure 2. ATDs seated in left rear seating position, H3-50M (top left), H3-5F (top right), H3-10YO (bottom left), THOR-5F (bottom right).

Toyota Camry models equipped with pretensioners and load limiters in the rear seat were compared with their previous generation counterparts with standard belts in test conditions matched by crash configuration, ATD, and seating position. Test mode comparisons were made with H3-50M and H3-5F ATDs in two Toyota Camry models, one with and one without pretensioners and load limiters, in the 25% and 40% ODB configurations. Seating position and ATD comparisons were made with all four ATDs tested in the two Camrys in the 40% ODB test.

Table 1.
*Test Matrix (*PT+LL: Pretensioner + Load limiter)*

Test No.	Test mode	Vehicle	Vehicle category	Dummy		Rear seat belt technology
				Left rear seating position	Right rear seating position	
1	25% ODB	2018 Toyota Camry	Midsize car	H3-50M	H3-5F	PT+LL*
2		2016 Toyota Camry	Midsize car	H3-50M	H3-5F	Standard
3		2019 Toyota Camry	Midsize car	H3-5F	H3-50M	PT+LL
4		2017 Toyota Camry	Midsize car	H3-5F	H3-50M	Standard
5	40% ODB	2016 Toyota Camry	Midsize car	THOR-5F	H3-10YO	Standard
6		2018 Toyota Camry	Midsize car	THOR-5F	H3-10YO	PT+LL
7		2016 Toyota Camry	Midsize car	H3-10YO	THOR-5F	Standard
8		2018 Toyota Camry	Midsize car	H3-10YO	THOR-5F	PT+LL
9		2016 Toyota Camry	Midsize car	H3-50M	H3-5F	Standard
10		2019 Toyota Camry	Midsize car	H3-50M	H3-5F	PT+LL
11		2016 Toyota Camry	Midsize car	H3-5F	H3-50M	Standard
12		2018 Toyota Camry	Midsize car	H3-5F	H3-50M	PT+LL

The ATDs were instrumented according to table A1 (Appendix). A three-axis accelerometer was mounted on the vehicle to measure vehicle acceleration in all tests, and an angular rate sensor was mounted in tests 5–12 to measure vehicle rotation. Load cells were mounted on the outboard lap side and upper shoulder side of the belt restraint to measure belt loads in the respective regions. All data was processed and filtered using SAEJ211. Crash tests were recorded for analysis using on-board and off-board high speed video cameras.

For the H3 family of ATDs, the following body regions and injury measures were considered: head (HIC15, resultant acceleration 3ms clip), neck (tension, compression, Nij), chest (resultant acceleration 3ms clip, sternum deflection, viscous criterion, deflection rate), and lap/shoulder belt loads. These metrics were normalized according to the appropriate Injury Assessment Reference Values (IARV) or the thresholds in the appendix (table A2-A4) for comparison across ATDs. Comparisons of test metrics between crash configurations and seat position are described in terms of the average difference in each metric as a percent of the relevant IARV/threshold.

For the THOR-5F, the body regions and metrics considered were head (HIC15, resultant acceleration 3ms clip), neck (tension, compression), chest (maximum IRTACC deflection), and lap/shoulder belt loads. Since IARVs are under development for THOR-5F, the comparisons for this ATD are presented separately as the percent increase or decrease of a given metric.

In addition to injury measures, dummy kinematics were compared and analyzed through review of high-speed video to assess submarining and head excursion.

RESULTS

Twelve full-scale crash tests were conducted with minimal data loss. The shoulder belt load cell in test 11 and lap belt load cell in test 3 did not record meaningful data and were excluded. For the THOR-5F, data from multiple IRTRACC channels were lost in tests 7 and 8. Summary data for all tests is included in the Appendix, grouped by ATD.

Test mode

For the test mode comparison, four tests using the 25% ODB configuration and four others using the 40% ODB configuration were matched by vehicle generation, ATD (H3-50M/H3-5F), and test position and then analyzed. The 40% ODB test had a higher delta V and peak longitudinal acceleration (average of 69 km/h, 40 g) than the 25%

ODB test (average of 62 km/h, 31 g) (Figure 3). The 25% ODB test had higher z-axis vehicle rotations after impact than the 40% ODB.

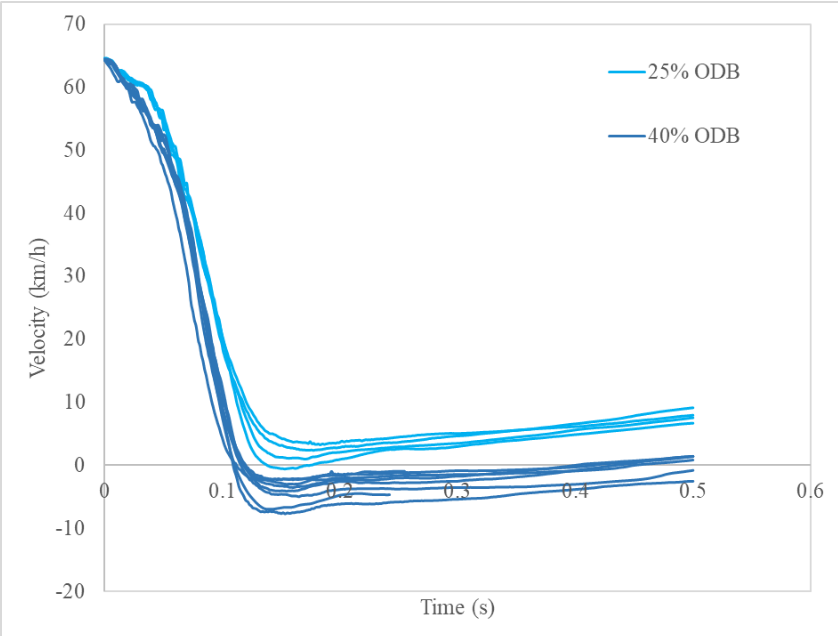

Figure 3. Vehicle velocity (km/h) vs. time (s) for the 25% and 40% ODB test configurations.

Figure 4 shows the average measures for the 25% and 40% ODB tests for H3-5F and H3-50M when normalized according to IARVs/threshold (Appendix table A2-A4). On average, both the H3-50M and H3-5F showed higher risk of injury in the 40% ODB test than in the 25% ODB test, although all injury metrics were below established IARVs except neck tension in the H3-5F in the 40% ODB. The average lap and shoulder belt loads were lower than the selected threshold (6000 N) for the H3-5F and higher than the threshold for the H3-50M.

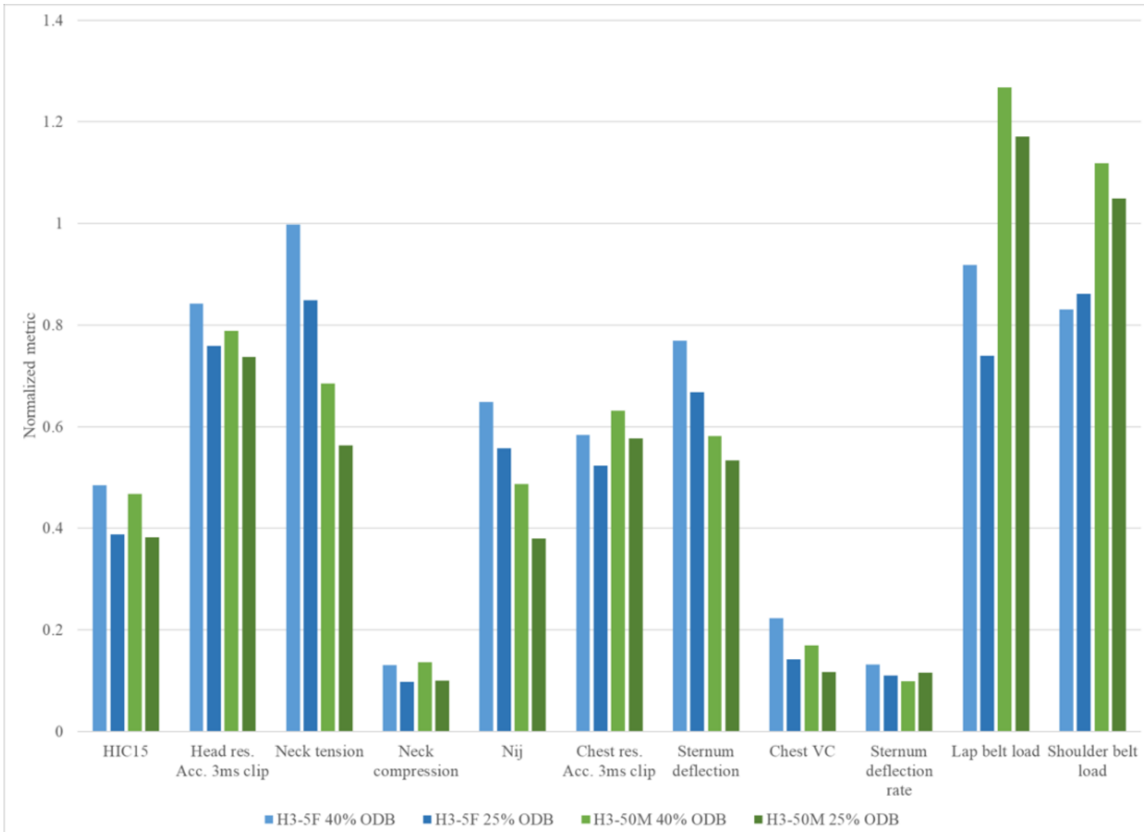

Figure 4. Comparison of 40% ODB and 25% ODB tests (normalized average measures) for H3-5F and H3-50M.

Table 2 shows the average change in each metric as a percent of IARV/threshold for the H3-5F and H3-50M in the 40% ODB test compared with the 25% ODB test. With regard to head-injury metrics, average HIC15 values for H3-50M and H3-5F dummies in the 40% ODB test were higher by 59 (8% of IARV) and 74 (10% of IARV), respectively. For the neck region, tension showed the largest difference between test modes and was higher in the 40% ODB test by an average of 309 N (15% of IARV) for H3-5F and 401 N (12% of IARV) for the H3-50M. For the chest region, the difference in the normalized injury values between the test modes was the smallest among all body areas for the H3-50M dummy. Average chest-injury metrics differed by no more than ±5% of IARV in 40% ODB test and the 25% ODB test. However, the differences in chest-injury metrics between test modes was wider for the H3-5F dummy. For this ATD, the average sternum deflection was higher by 4 mm (10% of IARV) in 40% ODB test than 25% ODB test. Differences in belt load were also evident. Average lap belt load in 40% ODB mode was higher by 1069 N (18% of threshold) and 580 N (10% of threshold) for H3-5F and H3-50M, respectively. The average shoulder belt load for the H3-5F was slightly lower by 180 N (3% of threshold) in 40% ODB test mode. However, for the H3-50M it showed an average increase of 418 N (7% of threshold) in the 40% ODB test mode.

Table 2.
Average change in test metric as a percent of IARV/threshold for H3-5F and H3-50M in the 40% ODB compared with the 25% ODB test. Positive values indicate average measures for 40% ODB test were higher.

Metric	H3-5F	H3-50M
HIC15	10%	8%
Head res. Acc. 3ms clip	8%	5%
Neck tension	15%	12%
Neck compression	3%	4%
Nij	9%	11%
Chest res. Acc. 3ms clip	6%	5%
Sternum deflection	10%	5%
Chest VC	8%	5%
Sternum deflection rate	2%	-2%
Lap belt load	18%	10%
Shoulder belt load	-3%	7%

The normalized average reduction in test metrics resulting from the addition of pretensioners and load limiters for vehicles matched on ATD and seating position was greater for both the 40% ODB test and the 25% ODB test (Figure 5). For the H3-5F, the addition of pretensioners and load limiters reduced injury metrics for 40% ODB tests across all body regions (reduction of 14%-55% of IARV/threshold in 40% ODB as opposed to reduction of 3%-42% in 25% ODB tests) (Appendix table A6). For the H3-50M, the addition of pretensioners and load limiters showed a greater reduction in head injury metrics for the 40% ODB test, while the reductions in neck and chest metrics were similar for both test configurations (Appendix table A7). In the 40% ODB test, the H3-50M neck compression was the only metric that increased with the addition of pretensioners and load limiters.

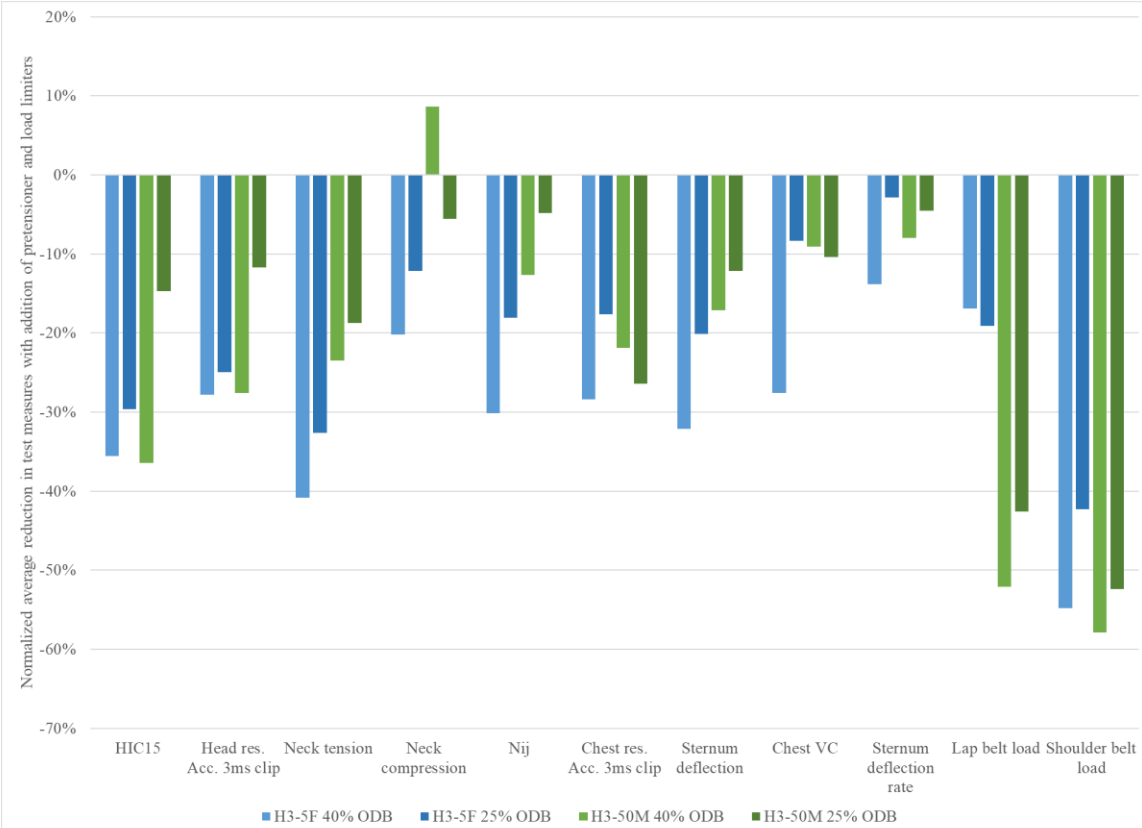

Figure 5. Comparison of 40% ODB and 25% ODB tests (normalized average reduction with addition of pretensioners and load limiters) for H3-5F and H3-50M ATDs. Negative values indicate average measures for vehicles with pretensioners and load limiters were lower.

Seating position

For the seating position comparison, eight 40% ODB tests matched by vehicle generation, ATD, and test position were analyzed. Figure 6 compares the normalized metrics for the left and right seating positions for the H3 family of ATDs. Overall, dummies seated in the left rear position showed higher injury values than those positioned on the right.

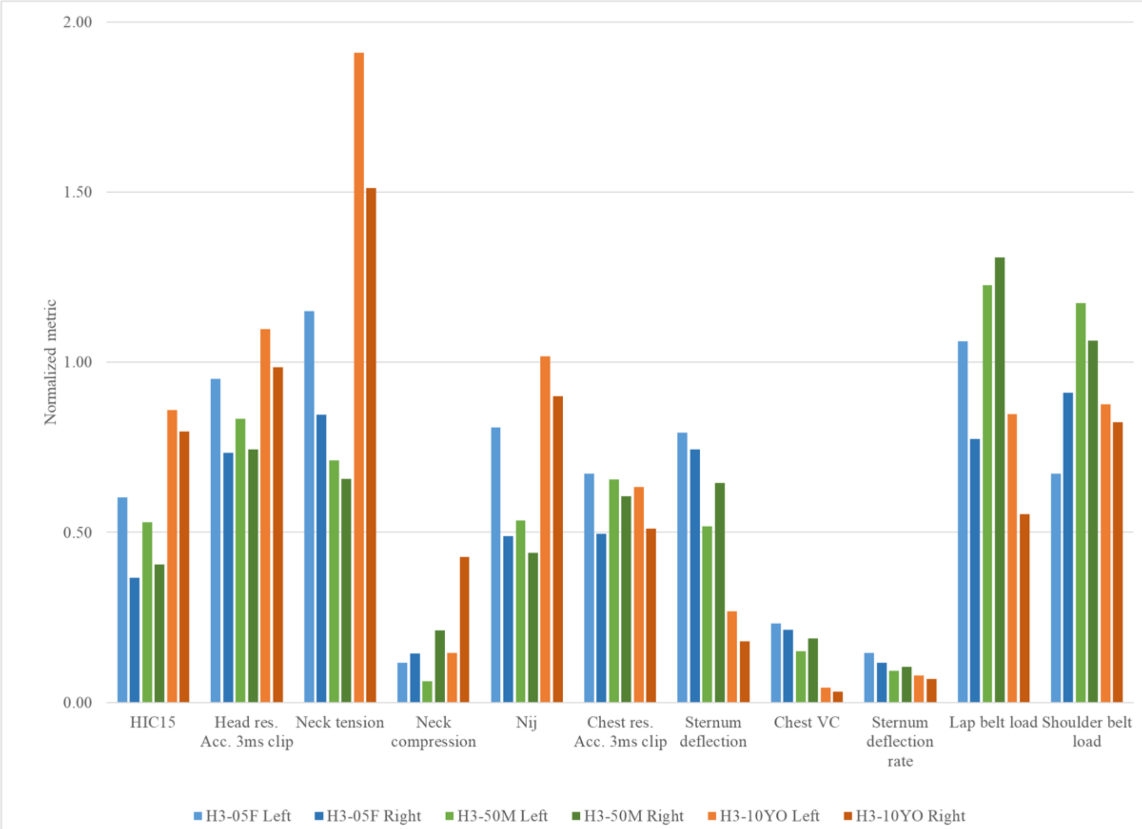

Figure 6. Comparison of left and right seating position (normalized average measures) for H3-5F, H3-50M and H3-10YO.

Table 3 shows difference in metrics between the left and right seating positions as a percent of the IARV/threshold. For the H3-5F, most metrics were 2–32% of IARV/threshold higher for the left versus right seating position, but average shoulder belt loads and neck compressions were higher for the right position. The higher average shoulder belt loads on the right may be due to loss of shoulder belt load cell data in one of the left seating position tests. For the H3-10YO, most metrics were 1–40% of IARV/threshold higher for the left versus right seating position, but neck compressions were higher for the right.

For the H3-50M, the differences in metrics between seating positions were much smaller. The average measures between seating positions did not differ more than 15% of IARV (or threshold) and were not consistently higher in one seat position or the other.

Table 3.
Average change in test metric as percent of IARV/threshold for H3-5F, H3-50M and H3-10YO for the left seating position compared with the right seating position. Positive values indicate average measures for the left seating position were higher.

Metric	H3-5F	H3-50M	H3-10YO
HIC15	23%	12%	6%
Head res. Acc. 3ms clip	22%	9%	11%
Neck tension	30%	5%	40%
Neck compression	-3%	-15%	-28%
Nij	32%	10%	12%
Chest res. Acc. 3ms clip	18%	5%	12%
Sternum deflection	5%	-13%	9%
Chest VC	2%	-4%	1%
Sternum deflection rate	3%	-1%	1%
Lap belt load	29%	-8%	29%
Shoulder belt load	-24%	11%	5%

Table 4 shows the average percentage difference in metrics between the left and right seating position for the THOR-5F dummy. The head and neck injury metrics were 6–59% higher in the left versus right seating position, while the chest deflection and belt load metrics were 2–12% higher for the right position than the left.

Table 4.
Average percentage difference between left and right seating position for THOR-5F dummy. Positive values indicate the left seating position values are higher.

Metric	THOR-5F
HIC15	24%
Head res. Acc. 3ms clip	10%
Neck tension	6%
Neck compression	59%
Max deflection IRTACC	-11%
Lap belt load	-12%
Shoulder belt load	-2%

The shoulder belt remained on the ATD shoulder in all cases except in one instance with the THOR-5F seated in the right position in test 12. For all H3 ATDs, both seating positions showed similar reductions in metrics with the addition of pretensioners and load limiters (Appendix tables A8, A9, A10). For THOR-5F, the addition of pretensioners and load limiters resulted in a greater reduction in head, neck, and chest injury numbers for the left seating position as well as a greater reduction in shoulder and lap belt loads for the right seating position (Appendix table A11).

ATDs
For the ATD comparison, eight 40% ODB tests matched by vehicle generation, ATD and test position were analyzed. All ATDs showed lower injury metrics for vehicles equipped with pretensioners and load limiters than those without, except for neck compression metric for the H3-50M. Addition of these belt technologies reduced average measures with respect to IARV/threshold by 14–55% for the H3-5F, 8–58% for the H3-50M and 2–101% for the H3-10YO (Table 5).

Table 5.
Change in test metric as a percent of IARV/threshold with addition of pretensioners and load limiters for H3-5F. H3-50M and H3-10YO. Positive values indicate lower measures for vehicles with pretensioners and load limiters.

Metric	H3-5F	H3-50M	H3-10YO
HIC15	36%	36%	85%
Head res. Acc. 3ms clip	28%	28%	47%
Neck tension	41%	23%	101%
Neck compression	20%	-9%	18%
Nij	30%	13%	44%
Chest res. Acc. 3ms clip	28%	22%	23%
Sternum deflection	32%	17%	9%
Chest VC	28%	9%	2%
Sternum deflection rate	14%	8%	4%
Lap belt load	17%	52%	26%
Shoulder belt load	55%	58%	40%

The THOR-5F had lower metrics for vehicles with pretensioners and load limiters with an average reduction of 1–114% as compared with standard belt vehicles (Table 6). There was little difference in the average max IRTRACC deflection metric, which may be due to loss of multiple IRTRACC data in tests.

Table 6.
Percent change in injury measures with addition of pretensioners and load limiters for THOR-5F. Positive values indicate lower measures for vehicles with advanced belt technology.

Metric	THOR-5F
HIC15	114%
Head res. Acc. 3ms clip	40%
Neck tension	33%
Neck compression	95%
Max deflection IRTACC	1%
Lap belt load	28%
Shoulder belt load	61%

Submarining

In submarining, the occupant's (or dummy's) pelvis slides forward beneath the lap belt, causing the lap belt to move from the ideal position over the iliac wings onto the abdomen, increasing the risk of abdominal injuries. In this test series, submarining occurred with each ATD type in at least one test, but the frequency of submarining differed between ATDs. The H3-50M submarined in 1 of 8 tests, the H3-5F in 4 of 8 tests, the H3-10YO in 4 of 4 tests, and the THOR-5F in 3 of 4 tests. In the one test in which the THOR-5F did not submarine, the shoulder belt slipped off the shoulder, which may have affected the dummy kinematics. Submarining occurred in vehicles with standard belts and belts with pretensioners and load limiters. Figure 7 shows submarining examples with each ATD.

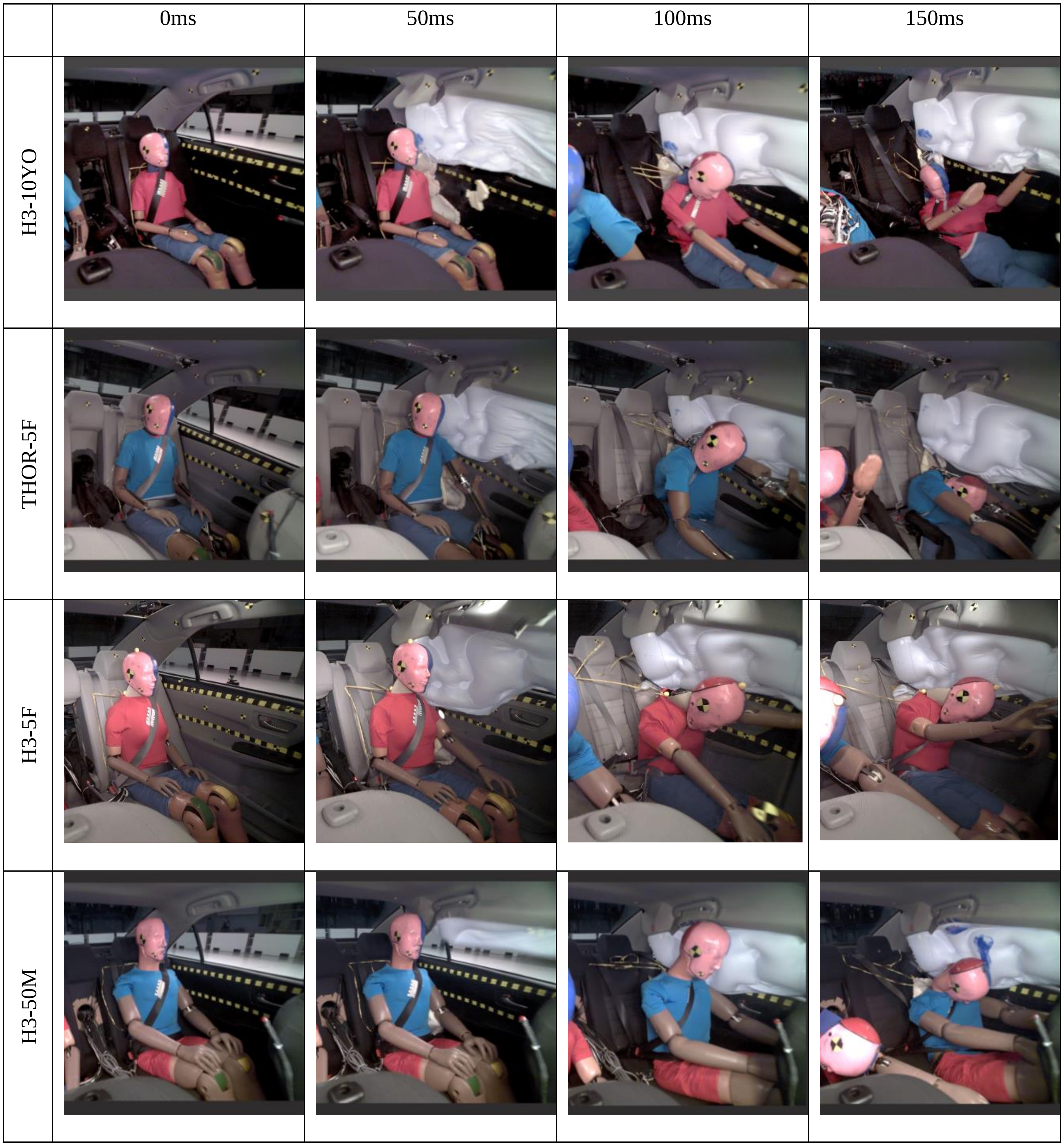

Figure 7. Submarining example with each ATD.

Excursion:
Head excursion was monitored in all tests. Head contact with the front seatback occurred in two tests, both with the H3-50M seated in right seating position in vehicles with a pretensioner and load limiter. Contact was confirmed with high-speed video, acceleration time history data, and dummy paint transfer to the front seatback. Both contacts resulted in peak resultant head accelerations of approximately 43 g.

0 ms	100 ms	150 ms	200 ms

Figure 8. H3-50M head excursion contact with front seatback.

DISCUSSION

Full-scale crash tests were conducted and analyzed with the objective of selecting a test mode, ATD, and second-row seat position for a rear-seat evaluation program that will incentivize improvements to rear-seat safety in frontal crashes. Field data show belted rear occupants sustain injuries due to belt loading to the chest, head impacts, and submarining [3,7]. That makes it important to select test parameters that can distinguish performance with respect to these outcomes and also discern the presence of countermeasures such as load limiters and pretensioners.

Test mode
In the current study, the 40% ODB test produced higher delta V and longitudinal acceleration than the 25% ODB test and resulted in less subsequent vehicle rotation. While field data show severe injuries and fatalities in the rear seat can occur at or below crash severities of either test mode [5], the 40% ODB test represents a larger proportion of towaway crashes. Nearly 70% of the frontal crashes represented in 2000-2013 NASS CDS cases were moderate or full overlap type crashes [9].

Real world studies have documented the head and chest as the most commonly injured body regions for restrained rear-seat occupants in frontal crashes across all occupant ages [3,5,7]. For the H3-50M and H3-5F used to compare test modes, the 40% ODB test mode was more severe, resulting in dummy injury measures representing higher head and neck injury risks, similar or slightly higher chest injury risks and shoulder belt loads, and higher lap belt loads than the 25% ODB mode. The H3-50M submarined only once; the H3-5F, however, submarined in three of four 40% ODB tests and one of four 25% ODB tests. Head contact with the front seat was observed with the H3-50M once in each test mode, both in the right seating position in a vehicle equipped with pretensioners and load limiters.

In short, the 40% ODB test aligns a greater percentage of the frontal crashes in the field data than the 25% ODB test, resulted in higher risks of most common injuries, and showed larger reductions in injury measures with the addition of pretensioners and load limiters.

Seating position
Nearly 85% of rear-seat occupants in all crashes are distributed in rear outboard seats, with 38% of the fatal cases in left rear seat and 45% of the fatal cases in right rear seating position [5]. Arbogast et al. showed that the risk of injury for restrained rear-seat occupants is higher when the impact is on the near side than on the far side for small overlap crashes [10]. For all of the ATDs except H3-50M, the left rear seating position, which is the near side for both test modes, resulted in higher head and neck injury risk and higher or similar chest injury risk. Submarining was also more common in the left rear seating position than the right. The only cases where head contact with the front seatback was observed were with the H3-50M in the right seating position of vehicles equipped with pretensioners and load limiters. Limiting excessive head excursion to prevent head contact injuries is important, especially when belts are equipped with load limiters that may increase belt payout. In the right seating position, which is on the far-side of the impact, there is a concern about the belt slipping off the occupant's shoulder. In this

test series, the shoulder belt remained on the far-side ATD's shoulder in all tests but one. The shoulder belt slipped off the shoulder in one test with the THOR-5F.

Together, those results suggest that the left rear seating position is most appropriate for a 40% ODB test in which the left side of the vehicle hits the barrier. It is a common seating position for rear-seat occupants in real world crashes, and the ATDs seated in the left seating position in this test series indicated higher risk of injury and increased incidence of submarining compared with the right position. The benefit associated with belts with pretensioners and load limiters was similar for both seating positions.

ATDs

ATD selection is challenging for a rear-seat evaluation because of the wide age and size ranges of people who sit in the rear, as restraint systems optimized for one size occupant might not work well for others who are larger or smaller. All ATDs tested in this study pointed to the need for restraint system improvements and showed lower injury measures for vehicles with pretensioners and load limiters. However, the ATDs showed differences in kinematics and evidence of potential tradeoffs for different size occupants. Submarining was most common for the smallest dummy (H3-10YO) (four out of four tests). The largest dummy (H3-50M) rarely submarined but had the largest head excursions and the only head contacts. Because the large H3-50M dummy creates higher shoulder belt loads, using it in a crash test program would likely promote higher-threshold load limiters to limit high belt payout. But these high-threshold load limiters would reduce the benefit of load limiting for smaller size occupants. On the other hand, an ATD such as the H3-10YO that represents a smaller sized occupant would focus attention on problems that occur because the restraint system is ill-fitting, but it would not address the majority of serious injuries and fatalities among rear-seat occupants, which occur in occupants ages 13 or older [5]. The H3-5F approximately represents the average stature of rear-seat occupants in frontal crashes [11]. It also exhibited submarining behavior and helped researchers discriminate between vehicles with and without pretensioners and load limiters. The THOR-5F is potentially more biofidelic [12] and has more complex thoracic and abdomen injury evaluation tools than the H3-5F. However, its continuing development and absence of established IARVs limits the use of THOR-5F at this time.

In addition to representing the average stature of rear-seat occupants, the H3-5F ATD showed a range of injury and kinematic measures across tested vehicles. It highlighted differences between vehicles with and without pretensioners and load limiters, indicating higher injury measures in vehicles with standard belts. This combination of factors suggests the H3-5F will promote restraint designs that will protect a broad range of rear-seated occupants.

CONCLUSIONS

Multiple test variables (crash configuration, ATDs, seating position) were studied to develop a crash test program that will incentivize improvement of rear-seat safety in frontal crashes. Based on the results, IIHS has updated its moderate overlap crash test to include a H3-5F ATD in the left rear seating position in a 40% ODB test. This evaluation aligns with common challenging scenarios documented in the field data and uses an ATD that is capable of discriminating restraint system performance for an occupant of average size in the rear-seat environment.

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APPENDIX

Table A1.
ATD sensors

Region	H3-10YO	H3-5F	H3-50M	THOR-5F
Head	Ax, Ay, Az Accelerations	Ax, Ay, Az Accelerations	Ax, Ay, Az Accelerations	Ax, Ay, Az Accelerations
		Avx , Avy, Avz Angular velocity	Avx , Avy, Avz Angular velocity	Avx , Avy, Avz Angular velocity
Upper Neck	Fx, Fy, Fz forces	Fx, Fz forces	Fx, Fz forces	Fx, Fy, Fz forces
	Mx, My, Mz moment	My moment	My moment	Mx, My, Mz moment
Lower Neck		Fx, Fz forces		Fx, Fy, Fz forces
		My moment		Mx, My, Mz moment
Chest	Ax, Ay, Az Accelerations	Ax, Ay, Az Accelerations	Ax, Ay, Az Accelerations	Ax acceleartion sternum
		Avy Angular velocity	Avy Angular velocity	
	Dx displacement: Mid-sternum	Dx displacement: Mid-sternum	Dx displacement: Mid-sternum	IRTRACC upper and lower L/R Dxyz
Clavicle				Clavicle L/R (2x) Fx, (2x) Fz
Abdomen				Abdominal pressure sensors APTS 2
Thoracic spine		Fx, Fz forces		Fx, Fy, Fz forces
		My moment		Mx, My, Mz moment
Lumbar spine	Fx, Fy, Fz forces	Fx, Fz forces	Fx, Fz forces	
	Mx, My, Mz moment	My moment	My moment	
Pelvis	Ax, Az Accelerations	Ax, Az Accelerations	Ax, Az Accelerations	Ax, Ay, Az Accelerations
	Avy Angular velocity	Avy Angular velocity	Avy Angular velocity	Mx, My, Mz moment
	Upper Iliac Fx force (left, right)	Iliac Fx force (left, right)		Iliac Fx force (left, right)
	Lower Iliac Fx force (left, right)	Iliac My moment (left, right)		Iliac My moment (left, right)

Table A2.
Summary data for H3-5F tests

			40% ODB				25% ODB			
		Seating position	Left	Left	Right	Right	Left	Left	Right	Right
		Rear seatbelt technology	Standard	PT & LL	Standard	PT & LL	Standard	PT & LL	Standard	PT & LL
		Vehicle	2016 Toyota Camry	2018 Toyota Camry	2016 Toyota Camry	2018 Toyota Camry	2017 Toyota Camry	2019 Toyota Camry	2017 Toyota Camry	2019 Toyota Camry
Group name	Parameter	IARV# (threshold)/ Test ID	CF19018	CF19019	CF19020	CF19021	CF19006	CF19011	CF19004	CF19003
Head	HIC15	779	644	294	388	184	387	199	449	175
	Clip_3_ms (g)	(70)	78	55	59	44	59	45	65	44
Neck	Neck Tension (N)	2070	2945	1815	2029	1470	1869	1464	2318	1372
	Neck Compression (N)	-2520	-474	-117	-694	-32	-295	-57	-501	-126
	Nij	1	1.0	0.6	0.6	0.4	0.6	0.5	0.7	0.4
Chest	Clip_3_ms (g)	73	64	35	42	30	52	37	38	27
	Sternum deflection (mm)	-41	-37	-28	-39	-22	-33	-26	-30	-20
	VC	(1)	0.3	0.1	0.4	0.1	0.2	0.1	0.2	0.1
	Deflection rate (m/s)	-8.3	-1.8	-0.6	-1.5	-0.4	-1.2	-1.0	-0.9	-0.6
Belt loads	Lap (N)	(6000)	7260	5483	4771	4523	5230	NA	4618	3471
	Shoulder (N)	(6000)	NA	4035	7102	3815	6710	3878	6158	3915
Submarining	Yes/No		Yes	Yes	Yes	No	No	Yes	No	No

#Reference [13]

Table A3.
Summary data for H3-50M tests

			40% ODB				25% ODB			
		Seating position	Left	Left	Right	Right	Left	Left	Right	Right
		Rear seatbelt technology	Standard	PT & LL	Standard	PT & LL	Standard	PT & LL	Standard	PT & LL
		Vehicle	2016 Toyota Camry	2018 Toyota Camry	2016 Toyota Camry	2018 Toyota Camry	2017 Toyota Camry	2019 Toyota Camry	2017 Toyota Camry	2019 Toyota Camry
Group name	Parameter	IARV[#] (threshold) /Test ID	CF19020	CF19021	CF19018	CF19019	CF19004	CF19003	CF19006	CF19011
Head	HIC15	700	487	254	422	145	339	277	299	155
	Clip_3_ms (g)	(70)	66	50	63	41	57	53	54	42
Neck	Neck Tension (N)	3290	2697	1988	2582	1746	2163	1296	2158	1792
	Neck Compression (N)	-4000	-410	-84	-337	-1353	-790	-448	-233	-132
	Nij	1	0.6	0.5	0.5	0.3	0.4	0.4	0.4	0.3
Chest	Clip_3_ms (g)	60	44	34	45	28	45	29	40	24
	Sternum deflection (mm)	-60	-32	-30	-48	-30	-33	-28	-38	-29
	VC	(1)	0.1	0.2	0.3	0.1	0.2	0.1	0.2	0.1
	Deflection rate (m/s)	-8.3	-1.0	-0.6	-1.3	-0.4	-1.3	-0.6	-1.0	-0.9
Belt loads	Lap (N)	(6000)	9359	5361	8979	6725	9414	5470	7191	6028
	Shoulder (N)	(6000)	8491	5593	8402	4352	8036	4254	7688	5185
Submarining	Yes/No		No	No	No	No	Yes	No	No	No
Head contact	Yes/No		No	No	No	Yes	No	No	No	Yes

[#]Reference [13]

Table A4.
Summary data for H3-10YO tests

			40% ODB			
		Seating position	Left	Left	Right	Right
		Rear seatbelt technology	Standard	PT&LL	Standard	PT&LL
		Vehicle	2016 Toyota Camry	2018 Toyota Camry	2016 Toyota Camry	2018 Toyota Camry
Group name	Parameter	IARV# (threshold) /Test ID	CF19016	CF19017	CF19014	CF19015
Head	HIC15	741	928	345	926	255
	Clip_3_ms (g)	(70)	94	60	85	53
Neck	Neck Tension (N)	1800	4363	2515	3625	1820
	Neck Compression (N)	-2200	-534	-108	-1123	-756
	Nij	1	1.3	0.8	1.1	0.7
Chest	Clip_3_ms (g)	82	63	41	50	34
	Sternum deflection (mm)	-36	-12	-7	-7	-6
	VC	(1)	0.1	0.0	0.0	0.0
	Deflection rate (m/s)	-8.4	-0.8	-0.5	-0.8	-0.4
Belt loads	Lap (N)	(6000)	6278	3891	3711	2935
	Shoulder (N)	(6000)	6717	3804	5876	4015
Submarinin g	Yes/No		Yes	Yes	Yes	Yes

#Reference [13]

Table A5.
Summary data for THOR-5F tests

		40% ODB			
	Seating position	Left	Left	Right	Right
	Rear seatbelt technology	Standard	PT&LL	Standard	PT&LL
	Vehicle	2016 Toyota Camry	2018 Toyota Camry	2016 Toyota Camry	2018 Toyota Camry
Group name	Parameter/Test ID	CF19014	CF19015	CF19016	CF19017
Head	HIC15	810	331	561	306
	Clip_3_ms (g)	85	54	70	56
Neck	Neck Tension (N)	2727	1853	2334	1973
	Neck Compression (N)	-1048	-357	-282	-292
Chest	Max deflection IRTACC (mm)	63	53	58	70
Abdomen	Abdominal pressure sensor left (Pa)	204,366	191,936	113,935	222,772
	Abdominal pressure sensor right (Pa)	224,959	243,597	84,813	232,610
Belt loads	Lap (N)	4705	4504	6205	4116
	Shoulder (N)	6308	3995	6522	3993
Submarining	Yes/No	Yes	Yes	No	Yes
Shoulder belt retention	Yes, if belt slipped off shoulder	No	No	Yes	No

Table A6.

Average reduction for H3-5F metrics in percent of IARV/threshold with addition of pretensioner and load limiters in 40% and 25% ODB tests.

Metric H3-5F	40% ODB	25% ODB
HIC15	-36%	-30%
Head res. Acc. 3ms clip	-28%	-25%
Neck tension	-41%	-33%
Neck compression	-20%	-12%
Nij	-30%	-18%
Chest res. Acc. 3ms clip	-28%	-18%
Sternum deflection	-32%	-20%
Chest VC	-28%	-8%
Sternum deflection rate	-14%	-3%
Lap belt load	-17%	-19%
Shoulder belt load	-55%	-42%

Table A7.

Average reduction for H3-50M metrics in percent of IARV/threshold with addition of pretensioner and load limiters in 40% and 25% ODB tests.

Metric H3-50M	40% ODB	25% ODB
HIC15	-36%	-15%
Head res. Acc. 3ms clip	-28%	-12%
Neck tension	-23%	-19%
Neck compression	9%	-6%
Nij	-13%	-5%
Chest res. Acc. 3ms clip	-22%	-26%
Sternum deflection	-17%	-12%
Chest VC	-9%	-10%
Sternum deflection rate	-8%	-5%
Lap belt load	-52%	-43%
Shoulder belt load	-58%	-52%

Table A8.

Average reduction for H3-5F metrics in percent of IARV/threshold with addition of pretensioner and load limiters for the left and right seating positions.

Metric H3-5F	Left	Right
HIC15	-35%	-31%
Head res. Acc. 3ms clip	-27%	-26%
Neck tension	-37%	-36%
Neck compression	-12%	-21%
Nij	-23%	-26%
Chest res. Acc. 3ms clip	-30%	-16%
Sternum deflection	-19%	-33%
Chest VC	-15%	-21%
Sternum deflection rate	-9%	-8%
Lap belt load	0%	-12%
Shoulder belt load	0%	-46%

Table A9.
Average reduction for H3-50M metrics in percent of IARV/threshold with addition of pretensioner and load limiters for the left and right seating positions.

Metric H3-50M	Left	Right
HIC15	-21%	-30%
Head res. Acc. 3ms clip	-12%	-25%
Neck tension	-19%	-18%
Neck compression	-10%	11%
Nij	-2%	-17%
Chest res. Acc. 3ms clip	-19%	-27%
Sternum deflection	-6%	-22%
Chest VC	-4%	-15%
Sternum deflection rate	-4%	-6%
Lap belt load	-59%	-28%
Shoulder belt load	-47%	-55%

Table A10.
Average reduction for H3-10YO metrics in percent of IARV/threshold with addition of pretensioner and load limiters for the left and right seating positions.

Metric H3-10YO	Left	Right
HIC15	-79%	-91%
Head res. Acc. 3ms clip	-49%	-45%
Neck tension	-103%	-100%
Neck compression	-19%	-17%
Nij	-47%	-41%
Chest res. Acc. 3ms clip	-27%	-19%
Sternum deflection	-14%	-4%
Chest VC	-3%	-2%
Sternum deflection rate	-3%	-5%
Lap belt load	-40%	-13%
Shoulder belt load	-49%	-31%

Table A11.
Average percent reduction in THOR-5F metrics with addition of pretensioner and load limiters for the left and right seating positions. Negative indicates higher reduction in the left seating position than the right seating position.

Metric THOR-5F	Left vs Right
HIC15	-47%
Head res. Acc. 3ms clip	-54%
Neck tension	-59%
Neck compression	-101%
Max deflection IRTACC	-219%
Lap belt load	940%
Shoulder belt load	9%