REPEATABILITY OF IIHS SMALL OVERLAP FRONTAL CRASH TESTS

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ABSTRACT

This paper examines the repeatability of the Insurance Institute for Highway Safety's small overlap frontal crash test, based on repeated tests of six midsize vehicle models. Vehicle accelerations, structural measures, restraint system performance, dummy kinematics, and dummy injury measures were compared. Vehicle longitudinal acceleration pulses were similar in repeated tests of the same vehicle. The test-to-test differences of the least repeatable vehicle structural intrusion measurement targets ranged from 4 to 8 cm, with the vehicle models having higher levels of structural intrusion showing the most variation. Restraint system deployments were not always repeatable because many vehicle restraint systems were not yet tuned for this crash mode. In vehicles where restraint systems performed consistently, similar dummy kinematics was observed. Head, neck, chest, leg, and foot injury measures were similar in repeated tests for these vehicles. In the vehicle where the restraint system did not perform consistently, different dummy kinematics was observed. This resulted in large variations in femur, knee, and tibia injury measures.

None of these vehicles would have received different component or overall ratings whether the ratings were based on the results from the original or repeat test. The largest variations observed in this study were unimportant to the overall assessment of the vehicle, as measures from either test would promote the same design changes. Higher levels of variability likely reflect the fact that many of the vehicle structures and restraint systems were not specifically designed for this load case. Repeatability can be expected to improve as vehicles are redesigned to take the small overlap crash into account.

BACKGROUND

Crash tests are conducted for a variety of reasons including satisfying safety regulations, re-creating real-world crashes to better understand injury mechanisms, and comparing crashworthiness of vehicles in consumer evaluation tests. Consumer evaluation tests must be both representative of real-world crashes and designed to produce repeatable results leading to meaningful comparison of vehicle models. Due to time and monetary constraints, typically a single test of each vehicle model is conducted to obtain a rating; therefore, ensuring that results from a single test are representative of the vehicle's performance in similar configurations is important.

Previous studies have examined the crash test repeatability for full and moderate overlap frontal configurations. The National Highway Traffic Safety Administration (NHTSA) evaluated the repeatability and reproducibility of the 56 km/h (35 mi/h) full overlap New Car Assessment Program (NCAP) test through a series of twelve tests of the 1982 Chevrolet Citation (Machey and Gauthier, 1984). The recorded driver dummy head injury criterion (HIC) values varied up to 459 due to significant variation in head impact locations and dummy kinematics. Kinematics also was affected by variations in occupant compartment intrusion, steering wheel deformation, and inconsistent routing of the dummy's shoulder belt. The large variation in HIC values would have resulted in a different vehicle rating for two of the tests. These findings may be less relevant when considering modern vehicle construction methods, advanced restraint systems and lessons learned about crash test procedures since this research was conducted.

The European Experimental Vehicle Committee (EEVC) Working Group 11 collected data evaluating the repeatability of a 56 km (35 mi/h) moderate overlap deformable barrier (ODB) test, showing that the ODB configuration was a more structurally repeatable crash mode than NCAP-style rigid barrier impacts. (Hobbs and Williams, 1994). Three tests of a midsize car were conducted, showing good repeatability in vehicle responses and dummy sensor measurements. The difference between highest and lowest test measurements was 53 for driver HIC values and 5kN for peak femur forces. Variations in femur loading were attributed to different interactions with the knee bolster. None of the variations in sensors resulted in a different evaluation of the dummy.

Additional studies showing good repeatability of the ODB test mode were submitted to the EEVC Working Group 11 by Bundesanstalt für Straßenwesen (BASt, 1994; Lowne, 1996) and Japanese Automo-

bile Standards Internationalization Center (JASIC) (Oki, 1995). BASt tested three midsize hatchback cars, and JASIC tested four midsize cars. These studies compared measurements between tests using the coefficient of variation (standard deviation as a percentage of the mean measured value). Both studies found that dummy head and chest sensors had good repeatability, with coefficients of variation below 10%. Leg sensor measures were less repeatable, with coefficients of variation up to 185%, mainly due to different leg interactions with the knee bolster. The majority of intrusion measures were repeatable, with only a localized area of the occupant compartment showing high levels of variation. Both studies found high coefficients of variation, up to 320%, for the steering column.

The Insurance Institute for Highway Safety (IIHS) evaluated the repeatability of the 64.4 km/h (40 mi/h) moderate overlap deformable barrier crash test based on seven pairs of vehicles across a range of classes (Meyerson et al., 1998). Peak vehicle accelerations were within 8 g between paired vehicles. The least repeatable structural intrusion measures exhibited test-to-test differences that ranged 3-11 cm across the seven vehicle models. Only one vehicle model received a different structural rating due to variations of 5-8 cm at every location. Restraint system performance, including airbag deployment and seat belt spoolout, were reasonably repeatable. Frontal airbag deployment times were within 4 ms within each pair except one, where deployment varied by 12 ms. This vehicle also had the largest difference in peak vehicle acceleration. Total seat belt spoolout varied up to 2 cm. Differences in steering column deformation were only significant for the evaluation of two vehicles, which had high levels of intrusion. Differences in dummy kinematics were limited to different rebound impacts; none of which would have resulted in a different assessment of head injury.

Driver dummy head, chest, femur, knee, and foot injury measures were reasonably repeatable. Differences between repeated tests ranged 17-73 for HIC, 3-6 mm for chest deflection, 0.1-0.8 kN for femur forces, 1-3 mm for knee displacements, and 3-33 g for foot acceleration. None of these measures resulted in a different evaluation of injury risk for a given sensor. The largest difference between repeated measures of the tibia index was 0.8, and two of the vehicles received a different evaluation of injury risk for the tibia. Only one vehicle model would have received a different overall evaluation due to different ratings of both structure and dummy leg sensors.

This study examines the repeatability of six midsize vehicle models tested in the IIHS small overlap crash mode based on comparisons of vehicle accelerations, structural measures, restraint system performance, dummy kinematics, and dummy injury measures.

METHODS

IIHS conducted repeat tests on pairs of the 2012 Volvo S60, 2009 Mitsubishi Galant, 2012 Audi A4, 2012 Acura TSX, and 2012 Acura TL, as well as three tests of the 2009 Ford Fusion at a nominal speed of 64.4 km/h (40 mi/h) and a nominal 25% overlap with the IIHS small overlap barrier. All tests and measurements followed the IIHS (2012a) small overlap test protocol. Table 1 lists the vehicle test weights, impact speeds and measured overlaps. The largest differences between repeated tests were 63 kg for weight, 0.2 km/h for impact speed, and 2 percentage points for overlap with the barrier.

Vehicle Response Measures

Longitudinal and lateral acceleration histories were obtained from a triaxial accelerometer array mounted in the rear floorpan of the vehicles. In some vehicles, acceleration measures could not be used as an indicator of overall vehicle motion because deformation near the sensor's mounting occurring late in the crash event changed its orientation from the vehicle's frame of reference; therefore, analysis of the high-speed video footage was used to determine longitudinal delta-V, in the laboratory reference frame.

Table 1.
Repeated small overlap frontal crash tests

Vehicle	Test	Test weight (kg)	Impact speed (km/h)	Percent overlap (%)
Ford Fusion	A	1,619	64.3	25
	B	1,679	64.3	24
	C	1,616	64.4	25
Mitsubishi Galant	A	1,662	64.1	25
	B	1,656	64.3	27
Volvo S60	A	1,729	64.2	25
	B	1,766	64.2	25
Audi A4	A	1,753	64.4	25
	B	1762	64.3	25
Acura TL	A	1,840	64.2	25
	B	1,863	64.2	25
Acura TSX	A	1,733	64.2	25
	B	1,748	64.2	25

Occupant Compartment Intrusion

Occupant compartment intrusion was characterized by pre- and post-crash measurements of nine intrusion targets in two zones, the lower occupant compartment (lower hinge pillar, footrest, left toepan, brake pedal, and rocker panel) and upper occupant compartment (steering column, upper hinge pillar, upper dash, and left instrument panel), shown in Figures 1-2. Locations of these intrusion targets are defined in the IIHS (2012a) small overlap test protocol. In several vehicles (Fusion tests A, B and C; Galant tests A and B; S60 test A), the upper and lower hinge pillar, rocker panel, and upper dash locations were similar to but not exactly the same as the locations defined in the protocol.

Restraint System Response

Restraint system responses were compared for the S60, TL, and TSX pairs. For the Galant and Fusion tests, different sized dummies were used in each test. In one of the A4 tests, the airbags did not deploy because the airbag control module shut down after being powered for too long without vehicle motion. Seat belt tensioner firing and airbag deployment times (frontal, side curtain, and side torso airbags) were compared using high speed video footage. An additional optical belt spoolout sensor was installed in the TL and TSX pairs to compare dynamic seat belt movement. Steering wheel stability in vertical and lateral directions was assessed using pre- and post-crash measurements of the steering column intrusion target.

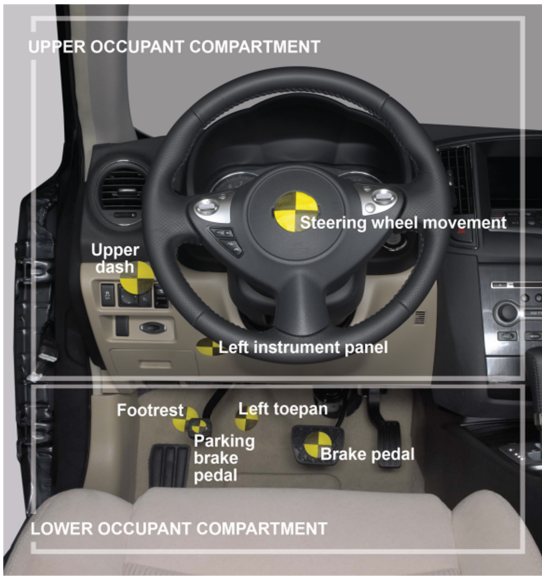

Figure 1. Driver seat view of occupant compartment intrusion targets

Dummy Response

An instrumented Hybrid III midsize male dummy was installed in the driver seat for all tests except two of the Fusion tests in which different dummies were used. All dummies were seated according to the University of Michigan Transportation Research Institute seating procedure (IIHS, 2004), and grease paint was applied to the dummy head to determine head contact locations, according to the IIHS (2012a) small overlap test protocol. Dummy kinematics and sensor measurements could only be compared for the S60, TL, and TSX pairs. Dummy instrumentation included sensors in the head, neck, chest, and lower extremities. Dummy kinematics was compared using high-speed video footage and contact evidence from paint transfer.

RESULTS

Vehicle Response Measures

Vehicle acceleration and velocity responses are compared in Table 2. The largest difference in peak longitudinal acceleration between repeated tests was 6 g for the Acura TSX pair. The corresponding longitudinal and lateral histories are shown in Figures 3 and 4. The acceleration curves were similar until the front wheel interacts with the barrier at 44 ms. In test A, the wheel is driven rearward for 16 ms before rotating outboard and detaching from the vehicle, whereas in test B, the wheel begins rotating at first contact with the barrier and remains attached to the vehicle throughout the crash.

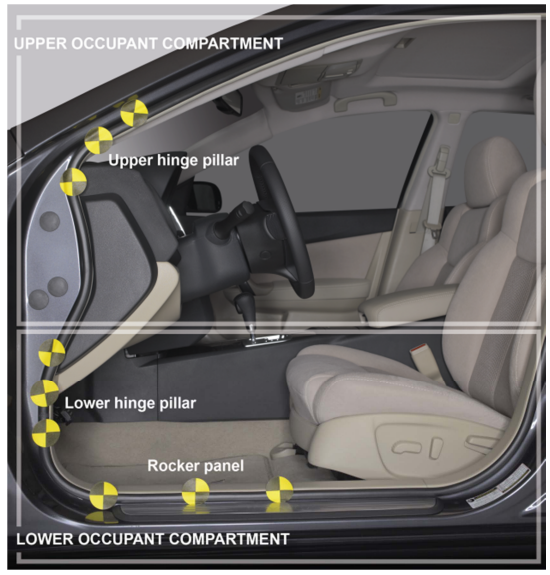

Figure 2. Door frame view of occupant compartment intrusion targets

Table 2.
Vehicle response

Vehicle	Test	Peak longitudinal acceleration (g)	Longitudinal delta-V (km/h)
Ford Fusion	A	-25	39.6
	B	-25	41.4
	C	-26	45.0
Mitsubishi Galant	A	-27	57.6
	B	-24	57.6
Volvo S60	A	-24	47.7
	B	-27	50.4
Audi A4	A	-22	54.0
	B	-22	54.9
Acura TL	A	-22	37.8
	B	-25	39.6
Acura TSX	A	-27	49.5
	B	-33	52.2

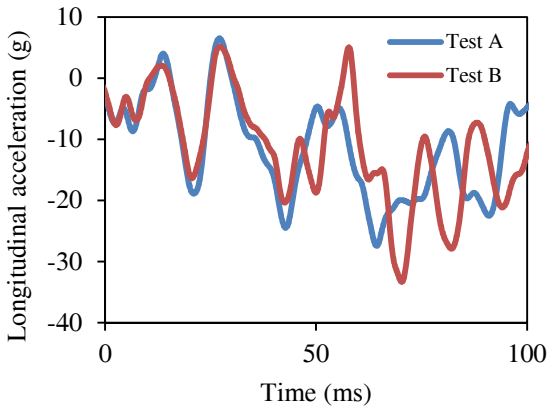

Figure 3. Acura TSX vehicle longitudinal acceleration.

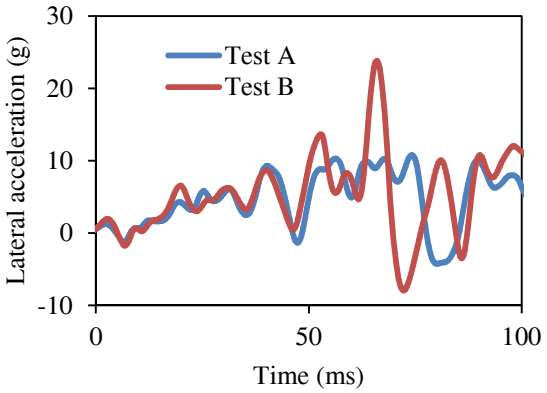

Figure 4. Acura TSX vehicle lateral acceleration

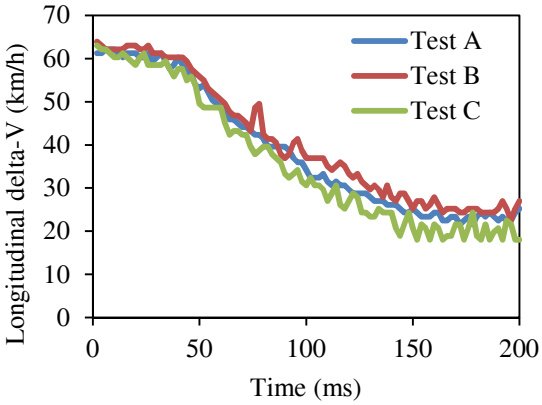

Figure 5. Ford Fusion vehicle longitudinal delta-V

The greatest variation in longitudinal delta-V of 5 km/h was observed in the Ford Fusion tests, shown in Figure 5. This variation mainly is attributed to differences in wheel interaction with the barrier starting at 140 ms.

Occupant Compartment Intrusion

Occupant compartment intrusion measurements for all vehicle sets are listed in Appendix A. The average intrusion, difference between tests at the most variable intrusion target, and coefficient of variation at the most variable target (standard deviation as a percentage of the mean measured value) are listed for all vehicles in Table 3. Vehicles with higher overall levels of intrusion tended to have the most variation. The maximum coefficients of variation for the Fusion, S60, and TSX occurred at the steering wheel, while the rocker had the greatest variation for the TL. At these locations, intrusions measures were all below 6 cm.

Table 3.
Variation in occupant compartment intrusion measures

Vehicle	Average intrusion (cm)	Maximum variation (cm)	Maximum coefficient of variation (%)
Ford Fusion	15	6	143
Mitsubishi Galant	14	4	40
Volvo S60	4	4	108
Audi A4	20	8	30
Acura TL	8	5	86
Acura TSX	11	4	86

The largest and smallest differences between repeated tests for each structural intrusion target location are shown relative to that location's good boundary in Figure 6. Six of the nine smallest test-to-test differences did not have variation; the remaining three locations varied between 1-3 cm. The Fusion accounted for six of the nine largest test-to-test differences and had levels of intrusion that exceeded the good boundary at three locations. The A4 accounted for the largest variation of 8 cm at the left instrument panel, where measures from either test were more than twice the good boundary.

A vehicle structure rating is determined based on the guidelines for rating occupant compartment intrusion in the IIHS (2012b) small overlap rating protocol. The lower occupant compartment and upper occupant compartment each receive a subrating and the structural component rating is the worse of the two subratings. A comparison of subratings for the upper and lower occupant compartment and structural rating is shown in Table 4. The upper and lower occupant compartments received the same ratings for each vehicle except for the TSX pair. In the TSX pair, the lower occupant compartment received different ratings between tests because the lower hinge pillar intrusion was 4 cm greater in test A, resulting in a marginal rating for that target compared with an acceptable rating in test B. The different lower occupant compartment subrating did not affect the structural component rating of the TSX because the worse of the two subratings was from the vehicle's upper occupant compartment.

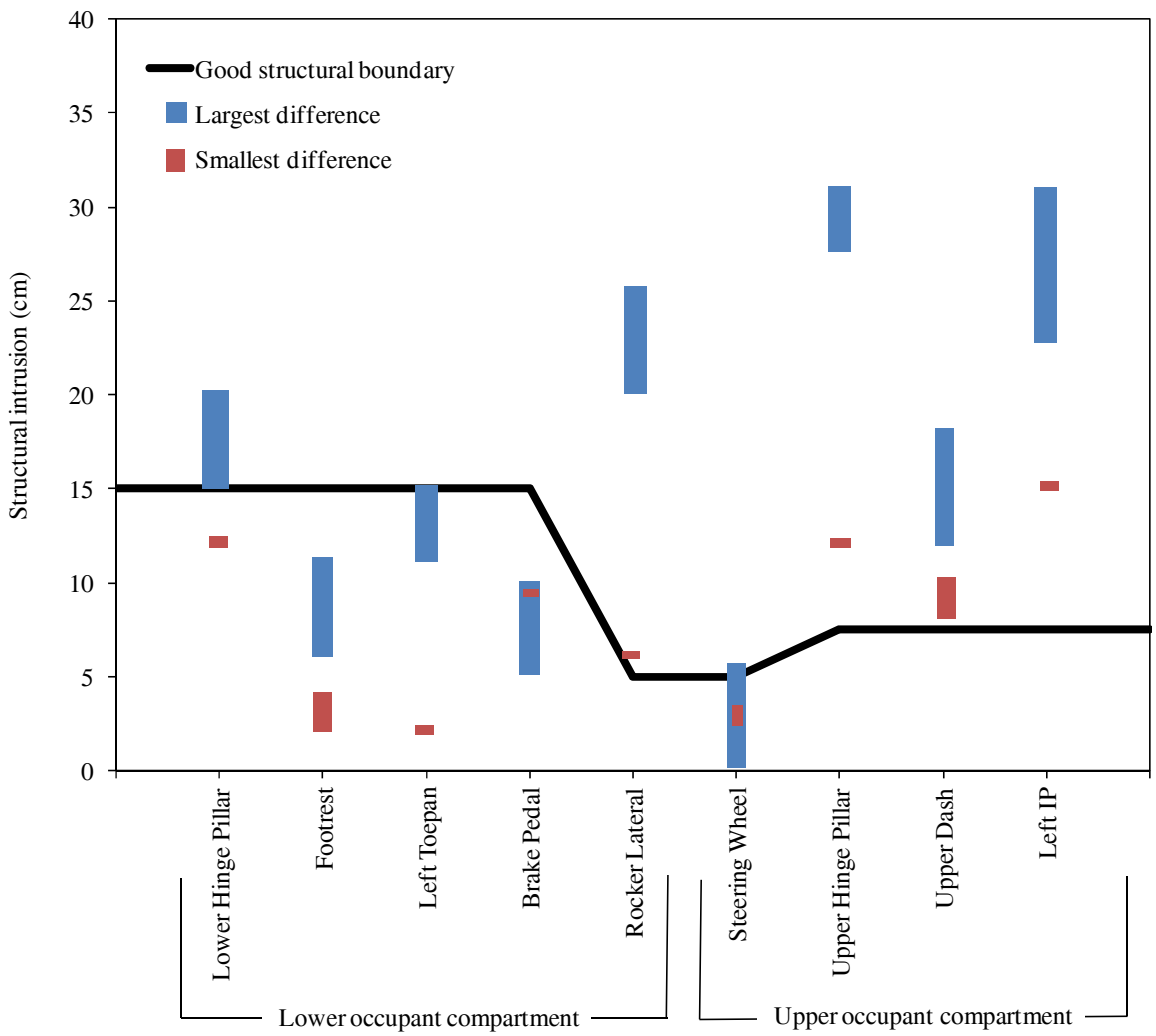

Figure 6. Variability in occupant compartment intrusion targets

Table 4.
Vehicle structural ratings

Vehicle	Test	Occupant compartment Lower	Occupant compartment Upper	Overall
Ford Fusion	A	Marginal	Poor	Poor
	B	Marginal	Poor	Poor
	C	Marginal	Poor	Poor
Mitsubishi Galant	A	Marginal	Marginal	Marginal
	B	Marginal	Marginal	Marginal
Volvo S60	A	Good	Good	Good
	B	Good	Good	Good
Audi A4	A	Acceptable	Poor	Poor
	B	Acceptable	Poor	Poor
Acura TL	A	Good	Acceptable	Acceptable
	B	Good	Acceptable	Acceptable
Acura TSX	A	Acceptable	Marginal	Marginal
	B	Good	Marginal	Marginal

Restraint System Response

Restraint system timings for the S60, TL, and TSX pairs are shown in Table 4. For the S60, all deployment times of the seat belts and airbags were within 4 ms of the original test. For the TL, the frontal airbag and seat belt deployments were consistent in timing, but the side curtain and thorax airbags varied by 8 and 10 ms, respectively. For the TSX, only the belt pretensioner deployed consistently. In test A, the frontal airbag deployed 18 ms earlier than in test B. The side curtain and side thorax airbags deployed during test A but not during test B. Data provided by the manufacturer suggested that lateral acceleration in test A was just above the threshold to deploy the side airbag system, whereas lateral acceleration in test B was just below the threshold. This variation in lateral acceleration occurring around 36 ms was not discernible in the lateral acceleration history shown in Figure 4.

Table 5
Restraint system deployment timing

Vehicle	Test	Pre-tensioner (ms)	Deployment of airbag: Frontal (ms)	Deployment of airbag: Side curtain (ms)	Deployment of airbag: Side thorax (ms)
Volvo S60	A	14	34	34	94
	B	12	34	36	98
Acura TL	A	26	34	40	44
	B	26	34	32	34
Acura TSX	A	26	32	36	38
	B	26	50	n/a	n/a

Deformation of the steering column is listed in Table 6. Deformation in both the vertical and lateral directions was within 4 cm between paired vehicles. Based on contact evidence and video footage, variation in steering wheel deformation may have contributed to differences observed in the dummy's interaction with the frontal airbag, as described in the Dummy Kinematics section.

Table 6.
Steering column deformation

Vehicle	Test	Vertical (cm)	Lateral (cm)
Volvo S60	A	2	0
	B	4	0
Acura TL	A	6	5
	B	10	4
Acura TSX	A	9	13
	B	8	9

Seat belt displacement for the TL and TSX pairs is shown in Figure 7. For the TL pair, seat belt displacement was similar throughout the duration of the crash. For the TSX pair, test A allowed 2 cm greater belt spoolout than test B. This difference in spoolout may be explained by variation in the occupant interaction with the frontal airbag, as described in the Dummy Kinematics section.

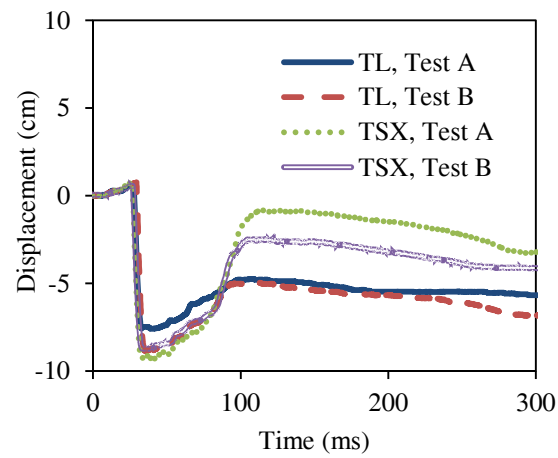

Figure 7. Acura TL and TSX seat belt displacements

Dummy Kinematics

In the S60, TL, and TSX vehicles, the dummy heads contacted the front and side curtain airbags. No hard contacts with vehicle structures were observed. A summary of contact times with these airbags is listed in Table 7. In the S60 and TL pairs, the head contact

times with both airbags were within 5 ms. In the TSX tests, the contact times varied by 6 ms.

Table 7
Dummy head contact timing

Vehicle	Test	Contact with frontal airbag (ms)	Contact with curtain airbag (ms)
Volvo S60	A	85	65
	B	80	66
Acura TL	A	72	50
	B	72	48
Acura TSX	A	70	100
	B	76	n/a

In the S60 and TL tests, dummy contact evidence on the frontal airbag showed similar paint transfer on comparable locations of the frontal airbag. Figure 8 shows the different dummy contact evidence on the frontal airbag in the TSX tests. In test A, the right-most edge of the dummy's face contacted the airbag 6 cm farther outboard than test B. Only the right side of the head was loaded by the airbag in test A, whereas both sides of the head were loaded in test B. This may be partially due to the differences in steering wheel lateral deformation between tests. The non-deployment of the curtain airbag in test B did not appear to result in additional lateral movement of the dummy. The off-center airbag interaction observed in test A may have placed additional loading on the belt system, resulting in more shoulder belt spoolout evidenced by the seat belt displacement sensor. Rebound kinematics was similar for all pairs.

In the S60 and TL tests, dummy leg contact evidence on the knee bolster showed similar paint transfer on comparable locations of the knee bolster. Different lower extremity kinematics was observed in the TSX pair. In test A, primarily, the lower part of the leg interacted with the knee bolster, whereas in test B, the knee and upper leg also had significant interaction with the knee bolster. The differences in seat belt loading and dummy head and torso kinematics contributed to these variations.

Figure 8. Post-crash paint evidence on front airbag in Acura TSX test A (left) and test B (right). Left side of head is pink; right side of head is blue.

Dummy Sensor Measurements

Injury measures for the S60, TL, and TSX pairs are listed in Appendix B. The largest and smallest differences between repeated tests of each injury measure were shown as a percentage of each sensor's injury assessment reference value (IARV) and are compared in Figure 9. The smallest test-to-test differences showed no variation for nine sensors. The remaining six sensors showed variation ranging 2-10% of the sensor's IARV, with the largest variation occurring at the left lower tibia index, where either measure resulted exceeded the IARV. The largest test-to-test differences showed variations of 2-75% of the sensor's IARV. Notable differences in dummy leg kinematics for the TSX pair contributed to the large differences in left tibia forces, left knee displacement, and right femur forces, although the latter did not contribute to a significant assessment of injury risk according to the knee-thigh-hip criteria (Kirk and Kuppa, 2009). The left upper tibia force and left knee displacement sensors would have received different evaluations of injury risk. These differences did not affect the leg injury evaluation, as the rating was based on the left lower tibia force sensor which received a poor rating for both tests.

Vehicle Ratings

A summary of component and overall evaluation ratings for the S60, TL, and TSX is shown in Table 8. Overall ratings were calculated using the weighting principles outlined in the IIHS (2012b) small overlap rating protocol. For each vehicle, repeat tests resulted in identical component and overall ratings.

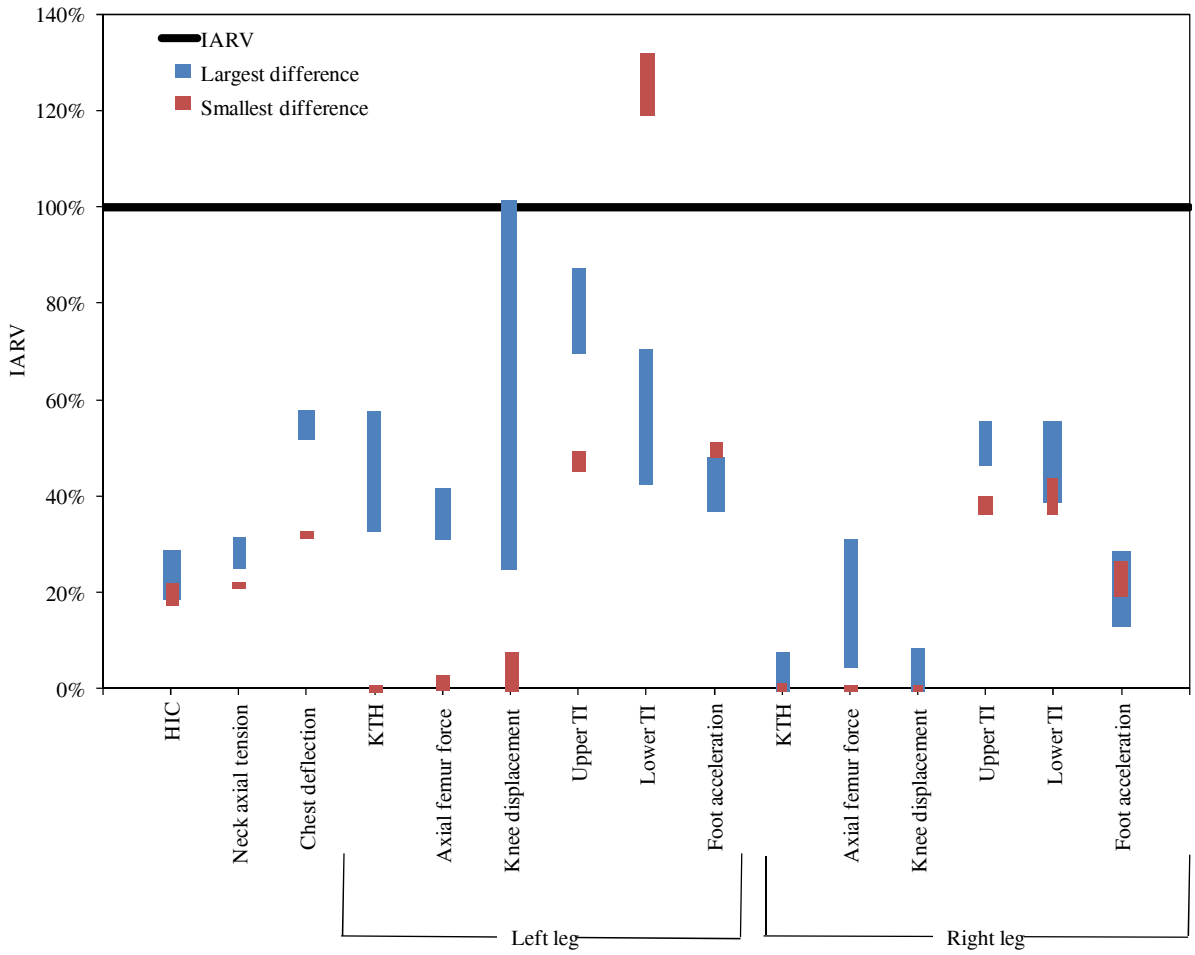

Figure 9. Variability in dummy sensor measurements

Table 8
Component and overall ratings

	Test	Structure	Restraints and kinematics	Dummy injury measures				Overall
				Head/neck	Chest	Thigh/hip	Leg/foot	
Volvo S60	A	Good	Acceptable	Good	Good	Good	Good	Good
	B	Good	Acceptable	Good	Good	Good	Good	Good
Acura TL	A	Acceptable	Good	Good	Good	Good	Good	Good
	B	Acceptable	Good	Good	Good	Good	Good	Good
Acura TSX	A	Marginal	Acceptable	Good	Good	Good	Poor	Marginal
	B	Marginal	Acceptable	Good	Good	Good	Poor	Marginal

DISCUSSION

The current study found similar or lower levels of test-to-test variation in small overlap tests compared with full and moderate overlap tests when considering vehicle accelerations, structural measures, restraint system performance, dummy kinematics, and dummy injury measures. Vehicle acceleration was more repeatable than observed in the moderate overlap test (Meyerson et al., 1998). Structural intrusion also was more repeatable than observed in studies of the moderate overlap test. Three of the seven vehicle models examined in the moderate overlap study (Meyerson et al., 1998) had maximum variations of intrusion greater than observed for all models in the current study. In the moderate overlap study, one vehicle model had high levels of variation at every intrusion location and would have been assigned a different rating between paired vehicles. In the current study, the highest levels of variation occurred at localized areas in the occupant compartment, and none of the vehicle models would have been assigned a different rating between paired vehicles. The largest coefficients of variation for structure were lower than reported by BASt (1994) and Oki (1995). These coefficients of variation were observed at the rocker panel and steering column, where all intrusion measure were below 6 cm and variations did not affect the rating of the individual intrusion target.

Restraint system and dummy kinematic repeatability were similar to those observed in moderate overlap tests. Variation in timing of the airbags and belt tensioners, overall belt spoolout, and steering column deformation were similar to those observed in the moderate overlap tests (Meyerson et al., 1998). Dummy head and torso kinematics were more repeatable than observed in the moderate overlap test because no significant variation in rebound kinematics was observed. In both small and moderate overlap evaluations, the greatest differences reported for dummy kinematics involved the lower extremities due to different interactions with the knee bolster.

Repeatability of the dummy sensors compared with those in full and moderate overlap tests was mixed. Dummy head and chest measures were significantly more repeatable than those observed in full and moderate overlap tests. These sensors also indicated a lower risk of injury than those observed in the other crash modes. Dummy leg sensor measures showed a similar range of repeatability as those observed in the moderate overlap studies by Lowne (1996), BASt (1994), Oki (1995), and Meyerson et al. (1998), with little variation for some vehicle models and significant variation in others. The S60 and TL pairs showed similar leg sensor measures and all indicated a low risk of injury, whereas the TSX pair showed large variations, leading to different assessments of injury risk for the knee and upper tibia index. These differences did not affect the component rating of the leg, as measures from the lower tibia index received a poor rating in both tests. All variations in foot acceleration were significantly less than those observed in the moderate overlap tests.

The small overlap test-to-test variation observed in this study of six midsize cars produced reasonably repeatable vehicle evaluations. Although variations observed in full and moderate overlap tests sometimes resulted in an overall change in rating for a vehicle, all vehicles in this study would have received the same component and overall ratings whether the evaluation was based on the original or repeated test.

Designing vehicles to exhibit low injury measures on dummies and low levels of occupant compartment intrusion has led to significant safety improvements in the modern fleet. Studies have found that vehicles receiving a higher rating in both NHTSA and IIHS crash test programs correlate to a reduced injury risk. Kahane et al. (1994) found that occupants of vehicles receiving a good NCAP rating have a 15-25% lower risk of fatal injury in a frontal crash compared with vehicles receiving lower scores. Similarly, Farmer (2005) found that occupants of vehicles receiving a good IIHS moderate overlap rating have a 74% lower risk of fatal injury in a head-on crash than vehicles receiving a poor rating.

The evaluation of repeatability was limited to a study of six midsize car models. Repeatability was assessed on pairs and triples of midsize cars based on availability, and the small number of repeat tests do not represent a comprehensive study of repeatability. Dummy kinematics and sensor measurements could be compared for a limited number of the test pairs. Results for the midsize cars may not reflect the variability observed in other sizes or types of vehicles.

CONCLUSIONS

Some vehicle structure measures, restraint system performance, and dummy injury measures were less repeatable than others. The large variations observed were mainly in locations where the proportionally large variations are unimportant to the overall assessment of the vehicle, as measures from either test would promote the same design changes. Variations in airbag deployments and resulting dummy kinematics will be resolved as restraint systems are specifically tuned for this load condition.

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APPENDIX A.
OCCUPANT COMPARTMENT INTRUSION MEASUREMENTS

Table A1.
Occupant compartment intrusion measurements

Vehicle	Test	Lower hinge pillar (cm)	Footrest (cm)	Left toepan (cm)	Brake pedal (cm)	Rocker lateral (cm)	Steering wheel (cm)	Upper hinge pillar (cm)	Upper dash (cm)	Left instrument panel (cm)
Ford Fusion	A	9	13	11	5	21	0	30	12	19
	B	13	17	14	8	25	2	31	18	20
	C	10	16	15	9	24	5	28	16	21
Mitsubishi Galant	A	12	18	11	8	23	2	12	16	15
	B	12	22	14	12	22	3	12	18	15
Volvo S60	A	6	3	3	3	5	1	6	3	3
	B	8	5	4	5	3	3	7	6	5
Audi A4	A	27	29	20	10	4	16	26	30	31
	B	24	26	18	10	3	13	24	26	23
Acura TL	A	15	11	2	4	5	2	9	9	10
	B	20	6	2	5	2	3	12	11	10
Acura TSX	A	25	13	4	6	5	2	12	14	18
	B	21	11	6	9	5	5	15	16	15

APPENDIX B
DUMMY SENSOR MEASUREMENTS

Table B1.
Dummy head, chest, and lower extremity sensor measurements

		Volvo S60		Acura TL		Acura TSX	
Measurement		**A**	**B**	**A**	**B**	**A**	**B**
HIC		148	136	68	98	145	193
Axial tension (N)		1	0.9	0.7	0.7	1.1	1.1
Flexion moment (Nm)		34	48	12	27	28	31
Chest deflection (mm)		-16	-16	-25	-27	-27	-28
KTH (%)	Left	0	0	1.7	2.8	0.9	0.4
	Right	0	0	0	0	0	0.3
KTH location	Left	Femur/knee	Femur/knee	Femur/knee	Femur/knee	Femur/knee	Femur/knee
	Right	Femur/knee	Femur/knee	Femur/knee	Femur/knee	Femur/knee	Femur/knee
Axial femur force (kN)	Left	-0.3	-0.16	-4.28	-4.89	-3.66	-3.01
	Right	0	0	-0.16	-0.13	-0.55	-2.7
Knee displacement (mm)	Left	0	-1	-10	-5	-4	-15
	Right	0	0	0	0	1	0
Upper tibia index	Left	0.54	0.45	0.48	0.47	0.72	0.86
	Right	0.48	0.54	0.42	0.48	0.38	0.37
Lower tibia index	Left	0.69	0.44	0.51	0.37	1.31	1.21
	Right	0.4	0.54	0.32	0.44	0.38	0.43
Foot acceleration (g)	Left	31	42	75	73	71	58
	Right	32	39	40	23	55	60