FRONTAL OFFSET CRASH TEST STUDY USING 50TH PERCENTILE MALE AND 5TH PERCENTILE FEMALE DUMMIES

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ABSTRACT

In September of 1996, United States Congress directed the National Highway Traffic Safety Administration (NHTSA) to conduct a feasibility study toward establishing a Federal Motor Vehicle Safety Standard (FMVSS) for frontal offset crash testing. Congress stated that these activities should reflect ongoing efforts to enhance international harmonization of safety standards. The offset crash test work described herein is part of NHTSA's undertaking in response to the Congressional directive. This paper presents NHTSA's initial results of offset testing where the test vehicle moves at a speed of 60 kmph into a fixed deformable barrier that overlaps 40 percent of the front of the vehicle. This test procedure essentially replicates that required by the European Union's (EU) Directive 96/79 EC, "On the Protection of Occupants of Motor Vehicles in the Event of a Frontal Impact and Amending Directive 70/156/EEC," which was adopted in December of 1996.

Previous testing with this particular frontal offset procedure has suggested that the lower legs of the dummies show loads that exceed possible injury limits. One goal of this testing activity is to determine if the offset test at 60 kmph provides additional benefits beyond the FMVSS No. 208 full frontal barrier test at 48 kmph. In addition, the agency has been petitioned to use smaller size dummies in its testing to look for aspects of safety that are not evaluated by the traditional 50th percentile male Hybrid III dummy.

To facilitate the potential for adding the 5th percentile to frontal testing and to evaluate the offset test with the 50th and 5th percentile dummies, a series of eight crash tests was performed. In the eight crash tests, all the dummies were restrained with the safety belt systems. The three cars used in the crash testing were the Dodge Neon, Toyota Camry, and Ford Taurus.

Background

Safety experts have noted that lower extremity trauma is strongly associated with disability. Luchter found that — in police reported tow away motor vehicles crashes in the USA — lower extremity injuries resulted in 41 percent of life-years lost to injury and 17 percent of total societal costs. [1] Miller et al. estimated that lower limb injuries are the second largest component of nonfatal highway crash costs. They determined that, for drivers and right front seat passengers in frontal collisions with no rollover or ejection, lower limb injuries cost \$8.2 billion per year. [2]

Pletchen et al. studied the trauma of 143 belted drivers of Mercedes-Benz passenger cars and found that the trauma of the lower extremities was ranked second highest in injury costs. [3] Morgan et al. examined the 1979 - 1986 National Automotive Sampling System (NASS) file for frontal crashes and determined that lower extremity trauma covers about 26 percent of the total moderate or greater injuries (AIS $\geq$ 2 count) for both belted and unbelted occupants. [4] Stucki et al. studied the NASS crash data files for the years 1988 - 1993 and again found that, in frontal crashes, approximately 25 percent of AIS $\geq$ 2 injuries are to the lower extremities. [5]

Grosch et al., of Daimler-Benz, studied passenger car intrusion in frontal crashes. For a passenger car to withstand vehicle intrusion, they believed that a passenger compartment must be sufficiently stiff. They suggested that, to minimize injury related to vehicle intrusion, it is essential to conduct appropriate crash tests such as offset collisions with an overlap of less than 40%. [6] Planath-Skogsmo et al., of Volvo, studied the differences in various types of frontal crash tests. From their study, they found that to assess the vehicle structural properties, either a severe partial overlap collision or Offset Deformable Barrier (ODB) tests can be used to complement the existing full frontal barrier test. [7] Also, in the United Kingdom, the Transport and Road Research laboratory conducted an investigation based on real world crashes. They indicated that, despite the use of seat belts, frontal impacts pose the greatest threat to car occupants due to vehicle intrusion. In that study, they suggested that there is a need for a test in which the barrier is offset and a deformable impact face is used. [8] In the U.S., beginning in 1995, the Insurance Institute for Highway Safety (IIHS) initiated a program using a frontal offset test to rate safety in cars. This ongoing frontal offset testing program evaluates the crashworthiness of new model vehicles crashed at 64 kmph (40 mph) into a deformable barrier. Based on their experience, they indicated that a full-width test and a frontal offset test complement each other; a full-width test is especially demanding of restraints, while the offset test is demanding of the structural integrity of a vehicle. [9]

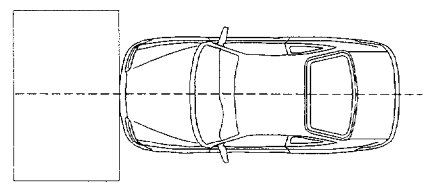
In 1996, Australia studied the benefits of a frontal offset regulation. In their study, they found that adding the EEVC frontal offset requirement to the Australia's Federal Office of Road Safety (FORS) dynamic full frontal crash standard (ADR 69, similar to FMVSS No. 208), would be highly beneficial and cost effective. [10]

NHTSA's Frontal Offset Harmonization Study

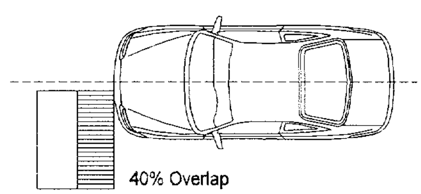
In September of 1996, Congress directed NHTSA to conduct a feasibility study toward establishing a Federal motor vehicle safety standard for frontal offset crash testing. In that directive, Congress stated, "...such a standard will enhance automobile safety for all consumers. Further, these activities should reflect ongoing efforts to enhance international harmonization of safety standards...." The offset test program described herein is part of NHTSA's undertaking to form standards that provide benefits and reflect efforts to strengthen world wide harmonization. [11]

In December of 1996, the European Parliament adopted Directive 96/79 EC, "On the Protection of Occupants of Motor Vehicles in the Event of a Frontal Impact and Amending Directive 70/156/EEC." Directive 96/79/EC requires a 40% frontal offset test of a vehicle into a deformable barrier at 56 kmph, with a restrained 50^{th} percentile adult Hybrid III anthropomorphic dummy. Also, in Australia, the Federal Office of Road Safety (FORS) is considering adopting Australian Design Rule (ADR) 73/00 Offset Frontal Impact Occupant Protection, which is identical to the Directive 96/79 EC. Furthermore, in Japan, since April 1993, the Ministry of Transport (MOT) has been researching a frontal offset test procedure similar to Directive 96/79 EC.

In Figure 1, the configurations of the FMVSS No. 208 test and the European Parliament adopted Directive 96/79 EC frontal 40% offset test are shown. The test conditions and injury criteria prescribed in the FMVSS No. 208 standard and the EU Directive 96/79/EC differ considerably. The differences are listed in Table A1 of Appendix A.



FMVSS No. 208



EU 96/79

Figure 1. Test configurations of FMVSS No. 208 and the EU-offset Deformable Barrier tests.

In 1997, the Canadian Government carried out a test program to validate the 40% offset crash test procedure designated in the Directive 96/79 EC. Four separate passenger cars were crashed at the speed of 56 kmph and at a higher speed of 60 kmph. In that study, at the impact speed of 60 kmph, the lower leg readings exceeded the allowed tibia criteria of the EU (European Union) Directive three times out of eight.[12] Based of that study, the European Parliament and Australian FORS are considering increasing the impact speed to 60 kmph.

5^{th} Percentile Female Hybrid III Dummy

In September of 1996, the American Automobile Manufacturers Association (AAMA) petitioned NHTSA to change the FMVSS No. 208 testing specifications. [13] Among other items, the petition requested the use of the 5th percentile adult female Hybrid III dummy in FMVSS No. 208. Subsequently, the NHTSA received a second petition to incorporate the 5th percentile female Hybrid III dummy into FMVSS No. 208. [14] The size of the occupant may be important in determining the safety value of different frontal crash procedures. Previous research into frontal crash protection has suggested that trauma risk levels differ by occupant size. [5] The general description and relative seating configuration of various adult dummy sizes are included in Table A2 and Figure A1 of Appendix A.

To use the 5th percentile female Hybrid III dummy in vehicle testing, a common seating procedure needs to be established. In July of 1997, a special task force of the SAE Dummy Test Equipment Subcommittee met at East Liberty, Ohio, to draft a seating procedure for the 5th percentile adult female Hybrid III dummy to use in passenger cars. Representatives from Chrysler, Ford, General Motors (GM), IIHS, KARCO, NHTSA, Toyota, Transportation Research Center, Transport Canada, and the University of Michigan were present. Existing seating procedures were studied and all parties agreed on a procedure, which is being finalized by the SAE subcommittee.

With the development of the 5th percentile female dummy seating procedure, NHTSA began frontal offset testing. The objectives of this testing are to (1) evaluate potential benefits of adopting the frontal offset test as a supplement to FMVSS No. 208 and (2) to evaluate the use of the 5th percentile female dummy in both the FMVSS No. 208, restrained test condition and in the offset test condition.

Crash Test Matrix

The agency crashed eight cars to understand the EU frontal offset and the response of the 5th percentile female dummy. Tests were conducted with three model year 1996 passenger cars — Dodge Neon, Toyota Camry, and Ford Taurus — using two dummies, the 50th percentile male Hybrid III dummy and the 5th percentile female Hybrid III dummy. The tests were conducted using all available restraints The conditions of the eight tests are shown in Table 1.

Vehicle selection was based on choosing vehicles for which (1) frontal impact test data already exist, (2) there are a large number of these cars sold in the U.S., and (3) there is a sales presence of these cars throughout the world. Of the three vehicles chosen, the Dodge Neon was one of the passenger cars tested by Transport Canada.[12] The Ford Taurus and the Toyota Camry are two passenger cars that have been tested extensively by NHTSA and IIHS.

All testing used the full instrumentation package available for the Hybrid III dummies. In this study, one of the primary interests is evaluating the lower extremity. A typical instrumented lower leg is configured with load cells at the upper and lower tibia with a 45 degree dorsiflexion angle foot with a rubber stopper. In this test series, the configurations of the instrumented legs used for the two dummy sizes are slightly different. The difference is that the 50th percentile male dummy configured with a single axis load cell (measures moments about the y-axis) whereas the 5th percentile female dummy configured with dual axes load cells (measures moments about x and y axes).

Table 1.
Test Matrix for the 1997 NHTSA's EU-offset feasibility study

Frontal Test	Dodge Neon	Toyota Camry	Ford Taurus
Full @ 48 kph with 5th% female dummy	1	2	3
40% Offset @ 60 kph with 50th% male dummy, restrained	✔	4	5
40% offset @ 60 kmph with 5th% female dummy	6	7	8

✔ = *data already exists for this test condition and make model combination* [12]

In each test of their car, engineers from Chrysler, Ford, and Toyota assisted the NHTSA with seating the 5th percentile female dummy. For most of the tests, the manufacturer's representatives actively participated in the test setup. All the test results have been compiled into reports, films and videos and are available through the NHTSA's public dockets (*Docket number*: NHTSA 98-3332).

RESULTS AND DISCUSSION

All of the dummy responses from the tests are tabulated in Tables A3 and A4 of Appendix A, for the driver and right front passenger, respectively. In the following analyses, the difference dummy responses are compared in terms of values that have been normalized to the preliminary injury criteria and Injury Assessment Reference Values (IARV) that are given in Table A5 of Appendix A. As the notes in this table indicate, many of the reference values are preliminary and subject to change, particularly those associated with the 5th percentile female dummy.

Head, Chest, and Femurs

In Figures 2, 3, and 4, the head and chest responses of the 5th percentile female Hybrid III are compared for the FMVSS No. 208 frontal test and the EU-offset test at 60 kmph. Note that the normalized responses are used in the figures. In general, the readings from the FMVSS No. 208 tests are either about the same or higher than those from EU-offset tests. Exceptions are that the chest displacement responses for the driver and right front passenger for the Neon are considerably higher in the EU test.

The comparisons of the femur loads are shown in Figures 5 and 6. In the EU-offset test, the femoral loading is higher in the driver's left leg than in the right. For the passenger, the femoral loading is generally higher in the FMVSS No. 208 test. However, in each of five comparisons, none of the readings exceeded the allowable injury criteria. In fact, most of the readings are far below the allowable limit.

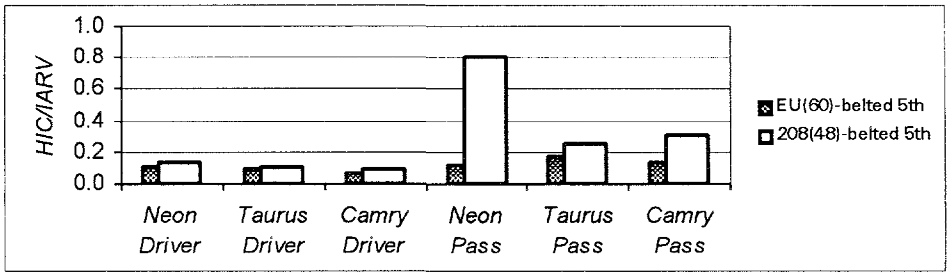


Figure 2. Head Injury Criterion (HIC) comparison.

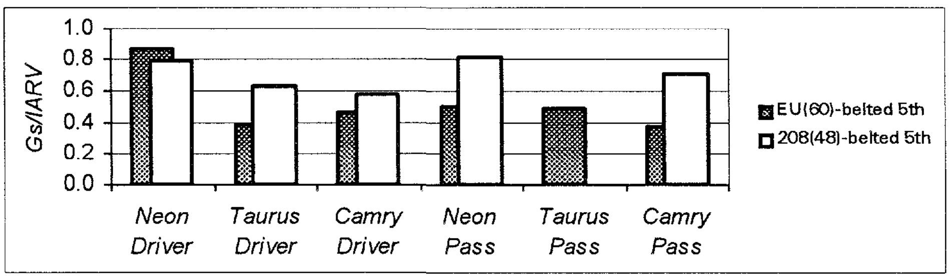


Figure 3. Chest acceleration (3ms clip) comparison

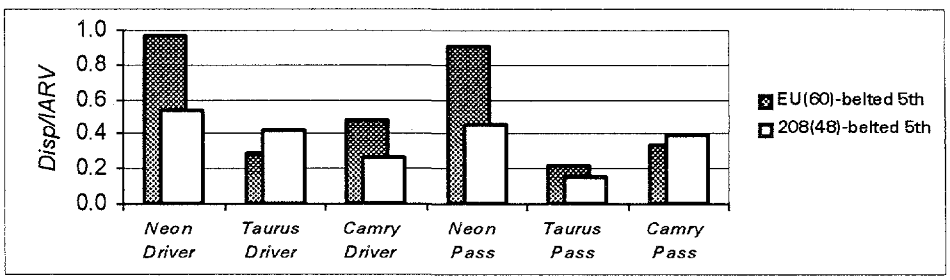


Figure 4. Chest displacement comparison

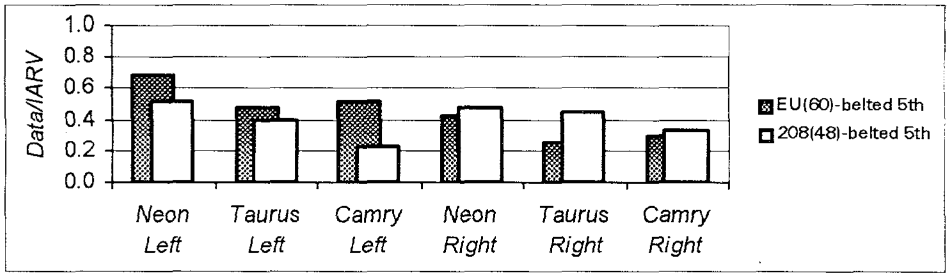


Figure 5. Driver femur comparison.

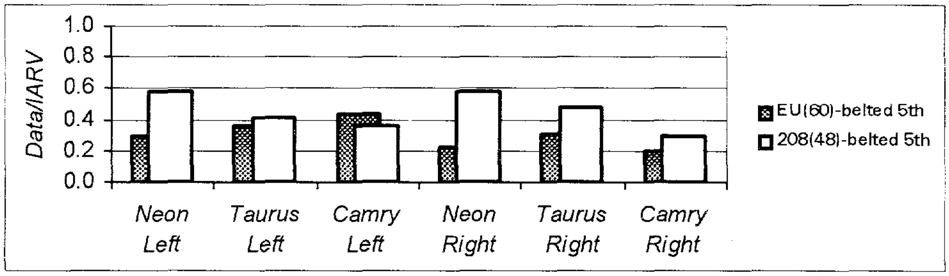


Figure 6. Right front passenger femur comparison.

Lower Extremity

Does the EU-offset test demonstrate that the loads to the lower extremities are greater than those in the FMVSS No. 208 test? How do the lower extremity loads differ between the two dummy types — the 50^{th} percentile male and the 5^{th} percentile female? In this test series, the lower extremity data for the driver and right front passenger are collected for all tests. However, because of the benign responses exhibited from the right front passenger dummy in the offset tests, the following discussion will be limited to the driver dummy. The right front passenger dummy readings are in Table A4 of Appendix A for the interested readers.

Two types of lower limb analyses are made: a comparison between test types given both used the 5^{th} percentile female dummy and a comparison of the 5^{th} percentile female and the 50^{th} percentile male dummies given both were exposed to EU-offset test conditions. For this lower extremity comparison, the injury criteria for the upper and lower tibia moments and foot/ankle axial loading forces are examined. For the tibia bending moment comparisons, resultant bending moments are used except for the lower leg data for the 50^{th} percentile male dummy — only the bending moments about y-axis were available.

First, the lower limbs of the 5^{th} percentile female dummy were examined between the two test types. In Figures 7 and 8, the comparisons of left and right legs are shown. In the Taurus, all values are below the reference values and are similar for both test types.

In the Camry, all values except the lower tibia moment are below the reference values. The right lower tibia moment in the EU-offset test is considerably higher than that observed in the FMVSS No. 208 test. When the difference is calculated for the right lower tibia moment, the reading for the EU-offset test is greater by 103%.

In the Neon, higher tibia forces and moments occurred in both test types than for the Taurus and Camry. The axial force reference value is exceeded in the FMVSS No. 208 test and the upper and lower tibia moment reference values are exceeded in both test types. Of the four tibia moment comparisons for the Neon, between the two test types, the readings of the 5^{th} percentile female exceed the allowable criteria in six out of the eight responses. When the percent difference is calculated between the two test types, the readings for the EU-offset test for Neon at the left and right lower tibia bending moments are higher by 137% and 101%, respectively. By contrast, the left upper tibia moment for the Neon in the FMVSS No. 208 test exceeds the response from the EU test by 75%.

Second, does the 5^{th} percentile female dummy exhibit any difference in loadings to the lower limbs as compared to the 50^{th} percentile male dummy under the EU-offset test condition? The lower limb comparisons between the 5^{th}

percentile female and the 50th percentile male dummies for the EU-offset tests are shown in Figures 9 and 10. For the Taurus, little difference is noted between the responses of the two dummy types with all responses meeting the reference values.

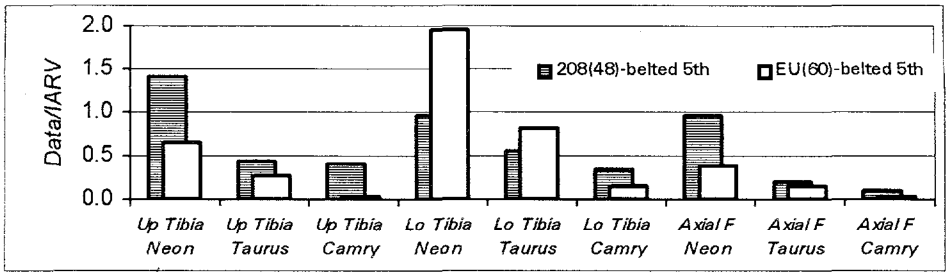


Figure 7. Driver left leg tibia comparison of the 5th percentile female dummy between the EU-offset and the FMVSS No. 208 tests.

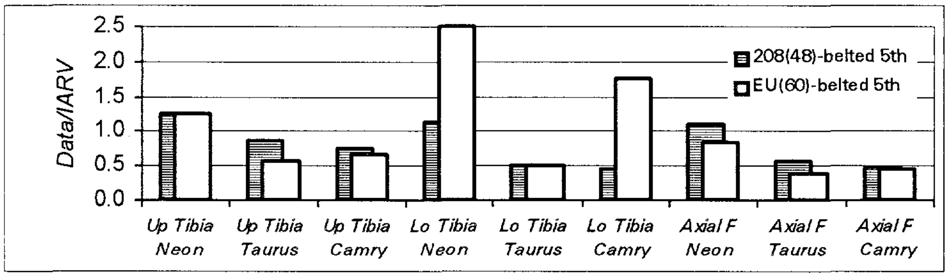


Figure 8. Driver right leg tibia comparison of the 5th percentile female dummy between the EU-offset and the FMVSS No. 208 tests.

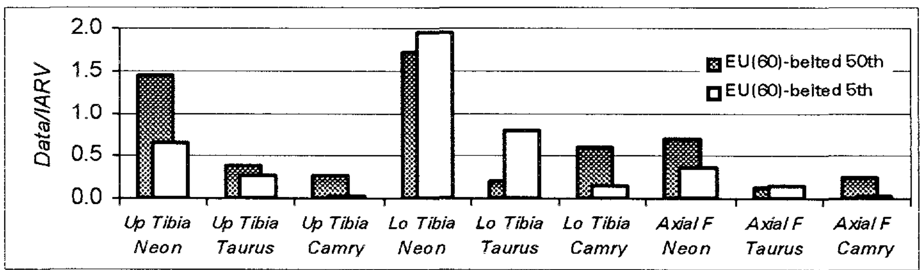


Figure 9. Driver left leg tibia comparison between the two dummy types in the EU-offset test.

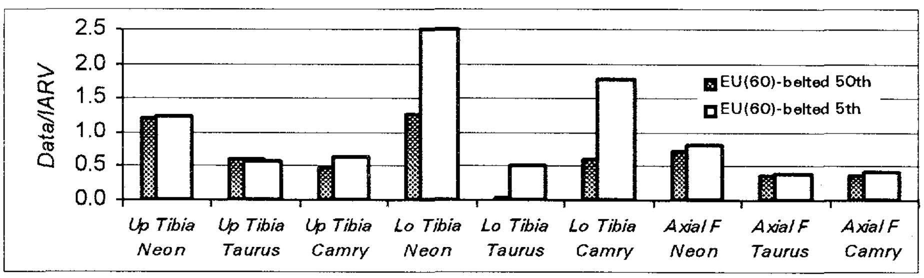


Figure 10. Driver right leg tibia comparison between the two dummy types in the EU-offset test.

For the Camry, again, most responses are similar for the two dummies except for the right lower tibia moment. When the difference is calculated, at the right lower tibia for Camry, the reading for the 5th percentile dummy is greater by 115% than for the 50th percentile male dummy. The reading for the 5th percentile female exceeds the reference value whereas the 50th percentile male does not.

For the Neon, the right tibia moment of the 5th percentile female is greater by 124% than the 50th percentile male dummy — both readings exceed the reference value. By contrast, for the left upper tibia moment, the reading of the 50th percentile male dummy is greater by 80%.

In general, the comparisons in Figures 7 and 8 suggest that the higher dummy readings above the preliminary reference values for lower tibia bending moment are exhibited in the EU-offset test than the FMVSS No. 208 test. In addition, the comparisons in Figures 9 and 10 suggest that when the readings for the two dummies are compared for the EU-offset test, the result shows that the 5th percentile generally shows greater loads in the lower limbs than the 50th percentile male dummy in the EU-offset test.

As discussed in the foregoing analysis, greater lower limb readings may be expected from the EU-offset test. It is also found, as expected, that generally greater intrusion occurs in the EU tests than in the FMVSS No. 208 tests. In Table A6 of Appendix A, the intrusion measurements of toepan collected from the test series are tabulated. From these intrusion data, it is noted that the Neon, which exhibited the higher lower leg responses, had the most intrusion (about twice as much as the other two vehicles).

Neck Response

Because of its different anthropometric properties, the small female may be exposed to different injury risks in frontal crashes than the mid-size male. In the previous sections, risks to the legs were explored. In this section, the potential for neck injury will be examined. For the neck evaluation, five injury criteria are examined: fore-and-aft shear, axial compression, axial tension, bending in flexion, and bending in extension. In reviewing the dummy readings, the outcome reveals that no significant neck readings are found for the criteria of shear, compression, tension or flexion. However, the neck extension readings are consistently high (exceed the preliminary reference neck extension criterion of 31 Nm found in Table A5) in the neck of the 5th percentile female dummy.

To further evaluate the neck extension criterion, two types of analyses are made: the comparison of the 5th percentile female and the 50th percentile male dummies in EU-offset test conditions and the 5th percentile female dummy comparison between the test types. In each comparison, the neck responses for both driver and right front passenger are included.

First, the driver neck extensions for the two dummies tested under EU-offset test are compared and shown in Figure 11. For the 5th percentile female dummy, all readings exceed the allowable limit by 1.61, 1.23, and 1.57 times for Neon, Taurus, and Camry, respectively. Whereas, for the 50th percentile male dummy, the reading for Camry exceeds the preliminary reference neck extension criterion of 31 Nm, a pertinent neck criterion by 1.1 times.

Figure 12 shows the neck extension comparison for the right front passenger between the two dummy types tested for EU-offset. In that comparison, the 5th percentile female dummy for Camry exhibits neck loading that exceeds the preliminary reference value by 2.9 times (89 Nm). In this particular event, the maximum neck extension occurred at 85 msec. Based on the high speed film analysis, the dummy's neck is being hyper-extended corresponding to the time that the neck load cells reads this maximum value.

Second, the neck extension readings for the driver 5th percentile female dummy are compared between the two test types and the comparison is shown in Figure 13. Between the two test types, the readings exceed the preliminary reference value five times out of six. Of the five high responses, the two highest readings are from the FMVSS No. 208 test for Taurus and Camry where the readings exceed the preliminary reference value by 2.4 and 2.1 times, respectively. Moreover, when the difference in readings is calculated, the readings for the FMVSS No. 208 are greater by 116% and 49% for Taurus and Camry, respectively. For the right front passenger dummy, Figure 14 shows neck extension comparison between the two test types. As can be seen, neither the Neon nor Taurus exceeds the preliminary reference value. However, the reading of the FMVSS No. 208 test for the Camry exhibits 5.6 times the preliminary reference value (172 Nm). When the difference is calculated, the reading for the FMVSS No. 208 test is greater by 270% than the EU-offset test. When the high speed film analysis is made, it shows that the dummy's neck is being hyper-extended at 73 msec.

Therefore, based on the neck analysis, between the driver and right front passenger, the readings for the driver 5th percentile female dummy exceed the preliminary reference value four times out of six. In addition, when the neck extension for the 5th percentile female dummy is compared between the two test types, for both driver and right front passenger dummies, the readings from the FMVSS No. 208 test are higher than those from the EU-offset test.

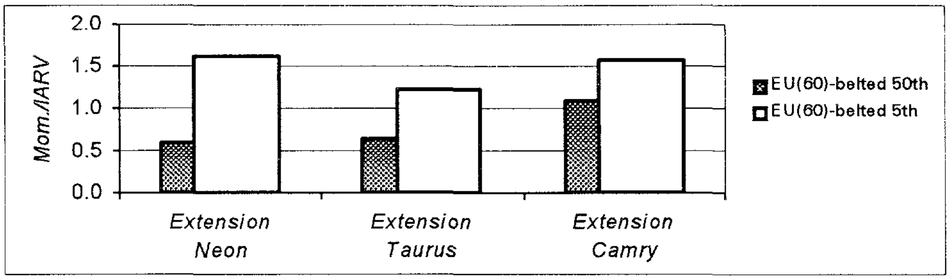


Figure 11. Driver neck bending moment comparison between the two dummy types in EU-offset test.

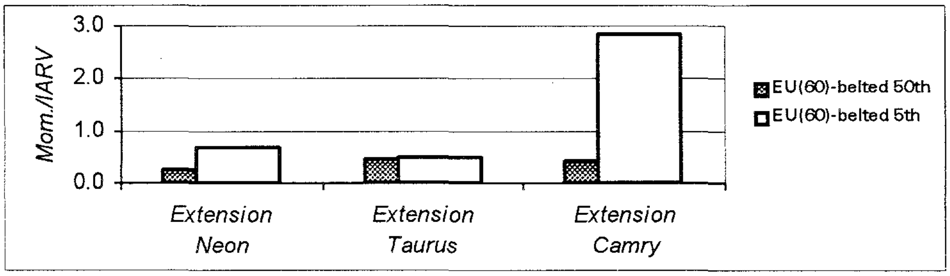


Figure 12. Passenger neck bending moment comparison between the two dummy types in EU-offset test.

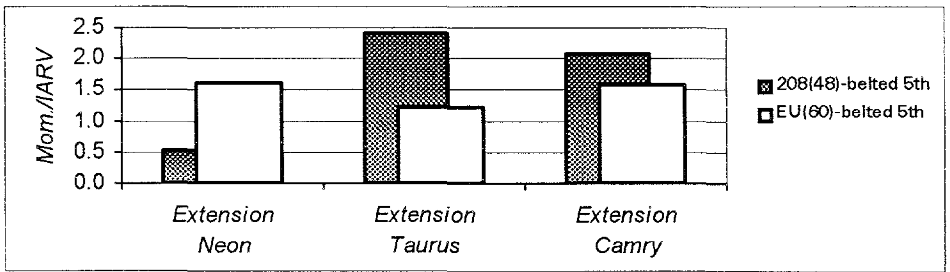


Figure 13. Driver neck bending moment comparison of the 5th percentile female Hybrid III between the two test types.

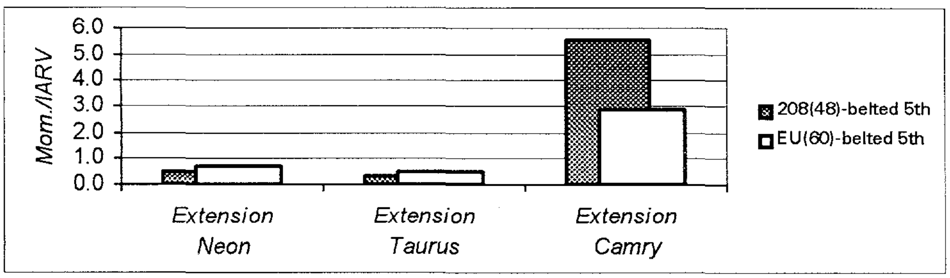


Figure 14. Right front passenger neck bending moment comparison of the 5th percentile female Hybrid III between the two test types.

CONCLUSIONS

The U.S. Congress directed NHTSA to investigate a frontal offset test procedure required by the EU Directive 96/79 EC. The NHTSA also took this opportunity to investigate the potential for adding the 5th percentile female dummy to a frontal flat barrier test and a frontal offset test. A series of eight crash tests was performed. In these tests, all dummies were restrained. The three cars used in the testing were the Dodge Neon, Ford Taurus, and Toyota Camry.

When the results for the 5th percentile female dummy are compared between the belted EU-offset test and the belted FMVSS No. 208 test, it is found that the responses for head, chest and femur from the FMVSS No. 208 test are about the same or slightly greater. By contrast, for the lower limb and neck criteria, considerable differences are found.

First, in the lower limb comparisons, when the readings are compared between the FMVSS No. 208 and EU-offset tests, the result suggests that the higher readings are exhibited more in the EU-offset test. For instance, in two occasions, the tibia readings for the EU-offset test exceed the preliminary reference values considerably whereas for the FMVSS No. 208 test these criteria are satisfied. In addition, when the lower limb readings for the two dummy sizes are compared in the EU-offset test, the results show that the 5th percentile female exhibits considerably greater loads than the 50th percentile male. In that comparison, in one occasion, the 5th percentile female dummy exceeds the preliminary reference values whereas the 50th percentile male does not.

Therefore, the result suggests that for the 5th percentile female dummy, the EU-offset test provides an additional benefit in assessing trauma in the lower limbs beyond that of the FMVSS No. 208 test. Furthermore, it reveals that in the EU-offset test condition, the 5th percentile female dummy would likely produce higher lower limb readings than the 50th percentile male dummy.

Second, the neck criteria for the 5th percentile female and the 50th percentile male dummies are evaluated. The results show that all of the neck criteria are satisfied except for the neck extension criterion. When the neck extension readings for the 5th percentile female are compared to the 50th percentile male dummy for the EU-offset test, between the driver and right front passenger dummies, the 5th percentile female exceeds the preliminary reference values four times by factors of 1.61, 1.23, 1.57 and 2.9 — none of the 50th percentile male dummy responses exceeds the preliminary reference values.

Furthermore, when the readings for the 5th percentile female are compared, between the two test types, the driver 5th percentile female dummy exceeds the preliminary reference values five times out of six by factors of 1.23 to 2.39. In addition, for the right front passenger, between the two test types, the 5th percentile female dummy exceeds the preliminary reference values two times out of six, by factors of 2.9 and 5.6. Of the seven highest neck readings mentioned, the three highest readings are exhibited from the FMVSS No. 208 test using the smaller dummy.

REFERENCES

(1) Luchter, S., "Long Term Consequences of Lower Extremity Injuries," International Conference on Pelvic and Lower Extremity Injuries Proceedings, National Highway Traffic Safety Administration, U.S. Department of Transportation, December 1995.

(2) Miller, T. R., Martin, P. G., and Crandall, J. R., "Cost of Lower Limb injuries in Highway Crashes," International Conference on Pelvic and Lower Extremity Injuries Proceedings, National Highway Traffic Safety Administration, U.S. Department of Transportation, December 1995.

(3) Pletschen, B., Schunert, D., Deubert, M., Herrmann, R., and Zeidler, F., "Application of the Injury Cost Scale (ICS) to Mercedes-Benz Accident Data," Thirty-fourth Stapp Car Crash Conference Proceedings, November 1990.

(4) Morgan, R. M., Eppinger, R. H., and Hennessey, B. C., "Ankle Joint Injury Mechanisms for Adults in Frontal Automotive Impact," Thirty-fifth Stapp Car Crash Conference Proceedings, November 1994.

(5) Stucki, S.L., Ragland, C., Hennessey, B., and Hollowell, W.T., "NHTSA's Improved Frontal Protection Research Program," Society of Automotive Engineers, Paper No. 950497, 1995.

(6) Grosch, L., Baumann, K, Holtze, H, and Schwede, W., "Safety Performance of Passenger Cars Desinged to Accommodate Frontal Impacts with Partial Barrier Overlap," Automotive Frontal Impacts, Society of Automotive engineers, Paper No. SP-782, 1989.

(7) Planath-Skogasmo, I., Nilsson, R., "Frontal Crash

Test -A Comparison of Methods," Thirty-eighth Stapp Car Crash Conference Proceedings, Paper No. 942228, November 1994.

(8) Hobbs, A. C., "The Need for Improved Structural Integrity in Frontal Car Impacts," Thirteenth International Technical Conference on Experimental Safety Vehicles, Paper No. S9-O-12, November 1991.

(9) O'Neil, B., Lund, A., Zuby, D., Estep, C.,"New Vehicle Crashworthiness Evaluations By the Insurance Institute for Highway Safety.", Fifteenth Intenational Technical Conference on the Enhance Safety of Vehicles. May 1996.

(10) Fildes, B., Digges, K., Dyte, D., Gantzer, S., Seyer, K.,"Benefits of a Frontal Offset Regulation", Federal Office of Road Safety Document., Report No. CR165., 1996.

(11) House Conference Report No. 104-785 to accompany HR 3675, H10409, September 16, 1996.

(12) Welbourne, E.R., "Offset Frontal Crash Tests: Summary Results of a Programme to Validate the Proposed Test Protocol of EEVC Working Group 11," Technical Memorandum, Vehicle Systems Division, Transport Canada Road Safety, September 1996.

(13) American Automotive Manufacturers Association, "Petition for Rulemaking, FMVSS 208," submitted to the National Highway Traffic Safety Administration, August 23, 1996.

(14) Lindsey, A. G., "Petition Seeking to Change the Size of the Dummy in FMVSS No. 208," submitted to NHTSA on September 1, 1996.

(15) Zuby, D., and Farmer, C., "Lower Extremity Loads in Offset Frontal Crashes," The 15^{th} International Technical Conference on the Enhanced Safety of Vehicles, May 1996.

(16) Federal Motor Vehicle Safety Standards; Occupant Crash Protection. [Docket No. 74-14; Notice 114] ., Federal Register Volume 62, No. 53, pg. 12960, 19 March 1997.

(17) Advisory Group for Aerospace Research and Development., "Athropomorphic for Crash and Escape System Testing." AGARD Advisory Report 330, July 1996.

Appendix A.

Table A1.
General summary of the test requirements for the FMVSS No. 208 and EU Directive 96/79/EC used for this study.

	FMVSS No. 208	EU Directive 96/79/EC
Impact Speed	48 kmph (30 mph)	56 kmph (35 mph)
Impact Object	fixed rigid barrier	fixed deformable barrier
Vehicle Frontal Overlap With Barrier	full frontal	40% overlap of the vehicle width directly in line with the barrier face
Dummy Type and Conditions	belt restrained 50th percentile Hybrid III male	belt restrained, 50 percentile Hybrid III male
Injury Criteria	includes threshold criteria for the head, chest deceleration, chest deflection, femur, and neck (only under the optional sled test)	includes the same threshold criteria, and in addition, viscous criteria (V*C), the neck, the knee, tibia index (inner lower leg), foot/ankle compression and compartmental intrusion

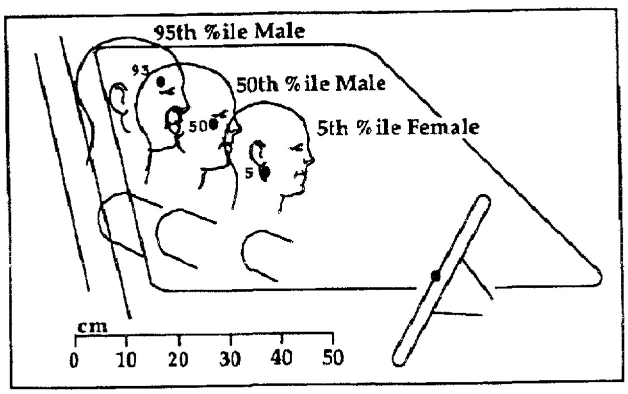


Figure A1. Relative driver dummy sitting position
(Parkin, S., Mackay, G. M., and Cooper, A., "How Drivers Sit in Cars," Accident Analysis & Prevention, Institute of Transportation Studies, University of California, Irvine, Pergamon Press, Vol.27, No. 6, December 1995.)

Table A2.
Hybrid III dummy weights and heights
For detail information, refer to reference No. 17

Dummy Type	Standing Height (cm)	Sitting Height (cm)	Weight (kg)
5th % Female Hybrid III	149.9	78.7	49.3
50th % Male Hybrid III	174.5	88.4	77.8

Table A3.

Dummy readings for driver. These results are from the offset test series except for the Neon EU-offset test data for 50th percentile male (from Transport Canada)

HIC, Chest 3ms Clip, & Chest Displacement - Driver Side

	HIC			Chest 3ms clip (G)			Chest Displacement (mm)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	583.0	343.0	407.0	40.0	30.0	33.7	30.0	29.5	21.5
EU(60)-belted 5th	111.5	86.0	70.5	52.4	23.0	28.0	50.8	16.0	25.3
208(48)-belted 5th	137.0	104.0	96.2	47.0	38.0	34.8	29.0	22.2	13.8

Neck Force - Driver Side

	Shear (N)			Compression (N)			Tension (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	167.5	732.1	549.5	777.6	611.0	1589.3	1974.1	1445.2	1037.9
EU(60)-belted 5th	546.0	455.0	733.0	283.0	109.0	108.0	1532.0	1783.0	1228.0
208(48)-belted 5th	301.0	1054.0	1093.4	456.0	547.0	414.0	1757.0	2389.0	2254.9

Neck Bending Moment - Driver Side

	Flexion (Nm)			Extension (Nm)		
	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	37.0	36.0	23.3	33.6	36.9	62.8
EU(60)-belted 5th	12.0	5.0	6.1	50.0	38.0	48.7
208(48)-belted 5th	17.0	6.0	12.9	16.0	74.0	63.8

Lower Extremity in Left Leg - Driver Side

	Upper Tibia Bending (Nm)			Lower Tibia Bending (Nm)			Axial Force (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	326.6	88.2	57.1	383.4	41.2	138.0	5667.7	962.0	1915.9
EU(60)-belted 5th	74.5	31.4	3.8	224.8	92.4	17.1	1891.0	731.0	97.8
208(48)-belted 5th	161.2	48.8	46.0	108.9	63.8	39.4	4875.0	1023.0	492.4

Lower Extremity in Right Leg - Driver Side

	Upper Tibia Bending (Nm)			Lower Tibia Bending (Nm)			Axial Force (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	272.6	138.5	111.7	282.1	8.6	138.1	5868.1	2810.0	2781.0
EU(60)-belted 5th	143.0	64.9	74.5	286.4	58.4	202.8	4201.0	1967.0	2210.0
208(48)-belted 5th	143.4	99.6	86.0	129.5	58.1	52.4	5602.0	2894.0	2439.7

Femur Force -Driver Side

	Left Leg (N)			Right Leg (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	6896.9	2577.0	2276.0	4902.1	3493.0	2958.0
EU(60)-belted 5th	4273.0	2928.0	3147.0	2571.0	1535.0	1830.0
208(48)-belted 5th	3161.0	2453.0	1344.5	2963.0	2729.0	2011.8

Table A4.

Dummy readings for right front passenger. These results are from the offset test series except for the Neon EU-offset test for the 50th percentile male (from Transport Canada)

HIC, Chest 3ms Clip, & Chest Displacement - Right Front Side									
	HIC			Chest 3ms clip (G)			Chest Displacement (mm)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	246.0	252.0	236.0		31.7	29.3	21.9	30.0	31.5
EU(60)-belted 5th	116.0	165.0	130.6	29.7	29.0	22.0	48.8	11.1	17.9
208(48)-belted 5th	806.0	255.0	303.0	49.0		42.5	24.0	8.4	20.6
Neck Force - Right Front Side									
	Shear (N)			Compression (N)			Tension (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th	675.1	470.1	499.5	361.8	130.3	245.6	1086.0	928.8	1086.0
EU(60)-belted 5th	694.0	1063.0	1385.0	208.0	1667.0	239.0	719.0	658.0	1579.0
208(48)-belted 5th	503.0	1284.0	2907.9	304.0	869.0	154.6	1437.0	988.0	1993.1
Neck Bending Moment - Right Front Side									
	Flexion (Nm)			Extension (Nm)					
	Neon	Taurus	Camry	Neon	Taurus	Camry			
EU(60)-belted 50th	38.1	30.7	32.0	14.4	25.8	22.3			
EU(60)-belted 5th	48.0	93.0	22.7	21.0	15.0	88.7			
208(48)-belted 5th	29.0	104.0	15.7	15.0	9.0	172.3			
Lower Extremity in Left Leg - Right Front Side									
	Upper Tibia Bending (Nm)			Lower Tibia Bending (Nm)			Axial Force (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th									
EU(60)-belted 5th	60.4	105.0	43.9	19.8		14.8	1157.0	1744.0	1639.0
208(48)-belted 5th	106.8	42.7	48.1	51.7	37.0	22.0	3067.0	2332.0	3525.0
Lower Extremity in Right Leg - Right Front Side									
	Upper Tibia Bending (Nm)			Lower Tibia Bending (Nm)			Axial Force (N)		
	Neon	Taurus	Camry	Neon	Taurus	Camry	Neon	Taurus	Camry
EU(60)-belted 50th									
EU(60)-belted 5th	60.9	35.5	24.0	0.6	0.4	0.4	42.0	26.0	26.0
208(48)-belted 5th	89.6	47.3	57.0		0.3			44.0	
Femur Force - Right Front Side									
	Left Leg (N)			Right Leg (N)					
	Neon	Taurus	Camry	Neon	Taurus	Camry			
EU(60)-belted 50th		3728.0	2806.0		1993.0	834.0			
EU(60)-belted 5th	1830.0	2238.0	2715.0	1344.0	1857.0	1253.0			
208(48)-belted 5th	3605.0	2527.0	2218.1	3620.0	2944.0	1813.3			

Table A5.
Preliminary Injury Assessment Reference Values. These values are currently being reviewed by the agency and are subject to change

Dummy/Body Region	**Hybrid III 5%**	**Hybrid III 50%**
Head-HIC (36ms)	1000	1000 (2)
Neck Flexion Bend. Mom. - Nm	104 (1)	190 (1)(2)
Neck Extens.Bend. Mom. -Nm	31 (1)	57 (1)(2)
Neck Axial Tension - N	2201-8.6*(T1-T2); 1934-52.2*(T1-T2) for ΔT>31ms (1)	3300-11.4*(T1-T2); 2900-72*(T1-T2) for ΔT>35ms (1)
Neck Axial Compression - N	2668-71.6*(T1-T2); 734 for ΔT>27ms (1)	4000-96.7*(T1-T2) 1100 for ΔT>30ms (1)
Neck Fore-and-Aft Shear - N	2068-53.4*(T1-T2) 1000 for ΔT 20-29ms 734=>ΔT37ms (1)	3100-64*(T1-T2) 1500 for ΔT 25-35ms 1100=>45ms (1)
Chest Acceleration - G (3ms cut-off)	60	60 (2)
Chest Deflection - mm	53 (1)	65 (1)
Femur - Axial Compr - N	6186	10,000(2)
Ankle/foot - Axial Compr. - N	5104	8000
Mc-Crit. Bend Mom.- Nm	115	225

(1) "Anthropomorphic Dummies for Crash and Escape Systems" , AGARD Conf. Proceedings, July 1996, AGARD-AR-330,
(2) FMVSS No. 208

Table A6.
Intrusion of upper (Level 1) and lower (Level 2) toeboard. These are based on pre and post test measurement done by hand

		40 % Offset 60 kph[1]		FMVSS 208 48 kph				40 % Offset 60 kph[1]		FMVSS 208 48 kph	
		Level 1 (mm)	Level 2 (mm)	Level 1 (mm)	Level 2 (mm)			Level 1 (mm)	Level 2 (mm)	Level 1 (mm)	Level 2 (mm)
Camry 1	Left	135	40	30	0	Camry 2	Left	145	75		
	Center	125	40	50	10		Center	165	100		
	Right	85	40	0	0		Right	160	65		
Taurus 1	Left	150	120	35	20	Taurus 2	Left	70	25		
	Center	145	135	37	20		Center	75	22		
	Right	130	100	40	22		Right	0	20		
Neon 1	Left	180	60	120	0	Neon 2	Left	296	219		
	Center	175	50	110	0		Center	282	215		
	Right	0	0	50	10		Right	212	148		