AN NCAP RATING FOR FEMALES

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ABSTRACT

This paper defines NCAP rating factors that would be useful to improve the safety of females in frontal crashes. The study is based on an analysis crash tests available on the NHTSA website and analysis of CISS and CRSS data.

Analysis of NHTSA databases of Crash Tests and Accident Data suggest that a Female NCAP should focus on encouraging crash safety countermeasures in three priority areas – reducing chest injuries, reducing lower limb injuries (especially foot and ankle injuries) and reducing the crash severity in lower speed crashes.

Based on the available literature and the additional data analysis, proposals are offered for a Female NCAP to address the three principal issues. These include better controls of belt and foot positioning, measuring chest and foot/ankle injury risk more accurately, limiting brake pedal motion and limiting the initial frontal stiffness of vehicles.

INTRODUCTION

In their 2019 paper in Traffic Injury Prevention, researchers from the University of Virginia analyzed NASS-CDS 1998-2015 and found that, in frontal crashes, belted females were at a higher risk than belted males of being injured at the AIS 2+ and AIS 3+ level (Foreman, 2019). They also found that risk reduction of thorax injuries has lagged the safety improvements for other body regions, resulting in an increasing prevalence among skeletal thorax injuries in newer model year vehicles.

Several studies have shown that the frontal stiffness as measured in frontal NCAP tests has increased with vehicle model year (Samaha, 2010, Sahraei 2009, 2013). Based on regression analysis, Sahraei found that passenger car stiffness had increased by 119% and large platform vehicle stiffness had increased by 128% over a 28 year period. The study also found that increases in vehicle stiffness also increased chest injury measurements on rear seat dummies. Samaha (2010) found that overall, the advances in restraint technologies, specifically seat belt load limiters, seemed to permit the higher vehicle acceleration resulting from increased stiffness to be accommodated in the NCAP test conditions. The increased stiffness has allowed the bumper-to firewall distance to be shortened. Brumbelow (2020b) concluded that vehicle bumper-to-firewall distance was a better predictor of thoracic injury outcomes than measurements by the Hybrid III dummy.

A further issue with the NCAP test conditions has been the lack of integrity for the chest deflection measurement, as documented in several papers (Haight, 2013, Digges, 2017). Failure to control the shoulder belt position relative to the single point chest deflection gage on Hybrid III dummies, has permitted lower chest injury measurements than would be obtained with a properly positioned belt. Brumblow (2020a) estimated that properly positioned shoulder belts in NCAP tests would increase the medium sternum deflection measured on Hybrid III by 49%. Rib-eye chest gages incorporated into the chest of the 5% Female Hybrid III dummy have been shown to improve the chest deflection measurements (Digges 2019). This failure in test protocol, along with the increase in vehicle frontal stiffness may have contributed to lag in skeletal thoracic injury reduction found in on-the-road injury data by Foreman.

A separate ESV paper by Dalmotas controlled CISS and CRSS data for additional crash factors and showed that, in frontal crashes, females are more likely than males to be driving smaller cars (Dalmotas, 2023). Males are more likely to be driving heavier vehicles, especially pickup trucks and larger vans. Consequently, a gender difference in crash exposure could account for some of the increased injury risk experienced by females as reported by Foreman.

The disparity of crash severity in cars vs pickups and vans has been documented by numerous studies (Joksch 1998, Gabler 1998, ESV and SAE). Jojksch examined front-to-front collisions in FARS and found there were 5 driver fatalities in cars for each driver fatality in vans or SUV's. For pickups the ratio was 3 to 1. Gabler (1998) found that the car to van fatality ratio for full size vans was 6 to 1 and for full size pickups was 5.3 to 1. The female preference for lighter vehicles increases their fatality risk in frontal collisions with heavier vehicle that are more likely to be driven by a male.

Morgan (1991) conducted an in-depth study of 480 occupants with AIS 2+ foot/ankle injuries. For 57% of the driver ankle injuries, the foot was on a pedal. Contact with the foot controls accounted for 43% of foot/ankle injuries; the floor contact accounted for 24% and pocketing between the floor and instrument panel accounted for 12%. The authors concluded that foot/ankle injuries were most frequent in lighter weight vehicles.

Others have reported differences in male and female injury risks by body region. Rudd (2009) found that females, especially those less than 164 cm in height were more likely to sustain foot/ankle injuries than males and the foot/ankle injury risk had increased in vehicles later than MY 2001. Brunbelow (2021) and Jermakian (2022) found that the overall injury risk for males and females was not statistically different in NASS-CDS 1998-2015, if extremity injuries were excluded from the comparison. They also attributed some of the female increased injury risk to a gender difference in crash exposure. Foreman (2022) found that the higher frequency of AIS 2+ ankle injuries to females in frontal crashes accounted for much of the overall male-female injury risk difference. Female AIS 2+ injuries tended to occur at lower delta-V than for males with the median at 25 kph.

METHODOLOGY

The gender preference for vehicle type was analyzed using data from the Collision Reporting Sampling System (CRSS). Both Single Vehicle and Two-Vehicle collisions were examined. For Well Defined Single Vehicle Crashes, the following constraints were applied: CRSS Calendar Years: 2016 – 2020; Selected Light Duty Vehicles (Cars & LTVs) / 1994-on MY Vehicles; VIN (B10) Available and Decoded; Vehicle Class (VIN) : CAR, CUV, PUT, SUV, VAN; Gender & Age of All LDV Occupants Known; Seating Position of All LDV Occupants Known; All Involved Occupants 15 Years of Age or Older. For Well Defined Two-Vehicle Crashes, the same constraints were applied plus the VIN (B10) Available and Decoded for Both Vehicles.

The Single Vehicle Sample was comprised of 34,780 (4,864,877 Weighted) Occupants, Drivers, Vehicles and Collisions. The Two-Vehicle Sample contained 183,810 (25,208,458 Weighted) Occupants, Drivers, Vehicles and 91,905 (12,604,229 Weighted) Collisions.

To explore injury mechanisms of injured females, cases from Crash Investigation Sampling System (CISS) 2017-2020 were examined statistically. The CISS cases were restricted to belt restrained outboard front seat occupants of light duty vehicles (LDV) in Well-defined Frontal Planar Crashes with known injuries MAIS 0-6 and known VIN. The cases were limited to adults at least 16 years of age with known gender and age and protected by safety belts and airbags. The injury data set was examined for body region, gender, age, and classes of vehicles involved. To study crash severity, an added restriction was that DeltaV had to be known. To study braking, the EDR data had to be known.

For the Well-defined Frontal Planar Crashes, the resulting occupant sample for the injured body regions study was 3,797 (3,834,943 Weighted). Of this population there were 1,938 (2,700,766 Weighted) uninjured occupants and 1,859 (1,134,177 Weighted) injured occupants (MAIS:1 – 6). These injured occupants had 8,656 (3,481,470) individual AIS 1-9 injuries. The analysis to follow will include 1,168 (405,613) AIS 2-9 injuries. The number of

AIS 2-9 body region injuries was 291 (121,252) for the chest and 332 (73,987) for the lower extremities. This data set was labeled Well-defined Frontal Planar Crashes. Females accounted for 61% of the AIS 1+ injuries and 54% of the AIS 2+ injuries. For the crash severity study, the unweighted sample of AIS 2+ injuries was 1168 (258,394 Weighted).

In examining the environment that may influence ankle injuries, we analyzed the influence of braking on driver ankle and foot injuries. If the EDR data indicated that braking was present during any interval of the recording braking was assumed to be associated with a right lower extremity injury. The braking analysis involved Lower Extremity AIS 2+ injured drivers in 2017-2020 CISS Single Event Frontal Crashes with Pre-Crash EDR Data. The data controls were as follows: Single Event Frontal (SEF) with Full CDC; Pre-Crash Data Available; Driver Belted (Lap/Shoulder Belt); Gender and Age of Driver Known; Vehicle Brake Engagement Information Provided. The Driver Sample was 1,114 Drivers. Of these Drivers 525 were uninjured at AIS 1+ and 589 were injured. The Number of Female Driver AIS 2+ Lower Extremity AIS 2+ injuries was 48.

Using data from NCAP like crash tests reported by Summers (2021), injury measures from the 50% male THOR dummy in the driver position and the 5% Female HII as the right front passenger were analyzed with special examination of the videos showing the toepan area and the lower limb motion.

Further analysis involved a series of tests to evaluate THOR under the offset/oblique test conditions that NHTSA has been evaluating. In these tests, a stationary target vehicle was impacted by a 2519 Kg moving deformable barrier traveling at 90 kph. The impact angle was 15 degrees and the overlap 35% (Saunders, 2012, 2015, 2018).

The study also examined data from the load cells on barriers in NCAP tests. Plots of barrier force distribution at peak loading were downloaded from the NHTSA website. Plots and tables of vehicle Average Height of Force/Moment and Test Mass were based on the vehicle test data from the NHTSA website. Average Height of Force and stiffness metrics have been defined in earlier papers (Digges, 1999, 2000, 2001, 2003). A methodology to control vehicle frontal stiffness has been previously proposed by Prasad (2008).

RESULTS

A 2023 ESV paper by Dalmotas shows that a major factor in male/female injury risk difference results from differences in their crash exposure. The female representation in well-defined two-vehicle collisions as a function of vehicle type/size classification is displayed in Figure 1 (Dalmotas, 2023). Because females are overrepresented in the smaller vehicles and underrepresented in the larger vehicles, their crash exposure differs from males. Males are more likely than females to be exposed to crashes while in heavier vans and pickup trucks. Females are more likely to be in smaller cars, and subjected to higher crash forces when a collision occurs with a heavier vehicle.

Figure 2 shows the distribution of AIS 2+ HARM by body region. The distributions in Figure 2 are for 2017-2020 CISS cases of belt restrained outboard occupants of passenger cars or LTV's in Well-Defined Frontal planar crashes with injuries AIS 1 to 9. The HARM factors are based on US costs of injuries as determined by Miller and shown in Table A1 (Miller, 1990), The female injury data is in Table A2. The HARM calculation uses the procedure developed by Mallaris (1982) and applied in a 1998 SAE Paper (Digges, 1998). The cost of an AIS 9 injury was assumed to equal an AIS 2 Injury.

It may be noted from Figure 2 that Lower Extremities are the greatest sources of AIS 2+ HARM to females and the largest male to female difference is the lower extremities. A further analysis of lower limb injuries is in the discussion section of this paper. In addition, chest injuries merit further analysis because they are a large source of HARM that is not being adequately addressed in current NCAP, as discussed in the introduction to this paper.

Figures 3a and 3b provide AIS 2-6 injury distributions of chest injuries in Well-Defined Frontal Planar Crashes by gender, occupant age and crash severity. Figure 3c provides female AIS 2-6 injury distribution for two occupant age ranges and two crash severity ranges. Figures 4a, 4b and 4c provide similar plots for lower limb injury data. The distribution of female AIS 2+ injuries by body region is shown in Tables A3. Table A4 shows AIS 2+ Thorax and Lower Extremity injuries by age and gender for two DeltaV groups.

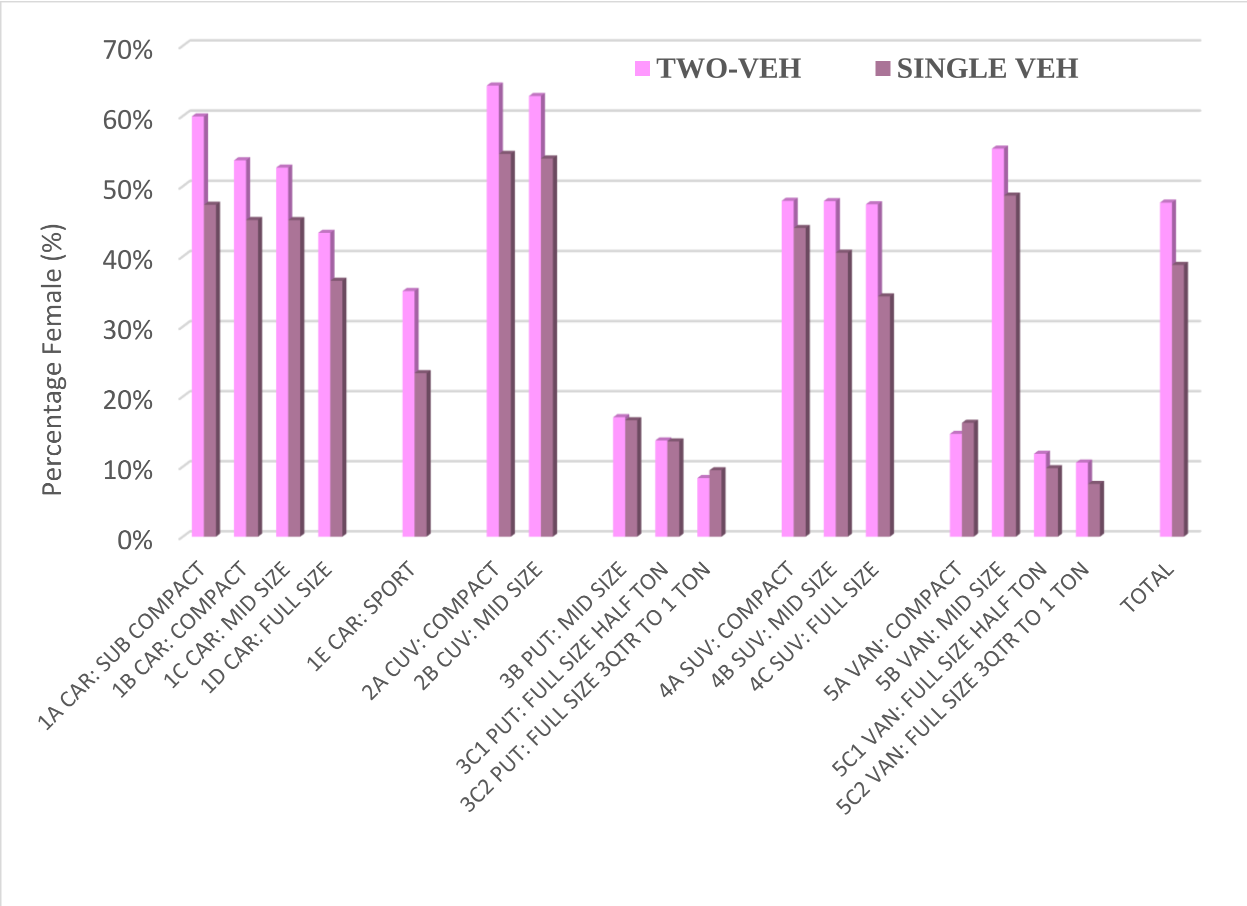


Figure 1. Female Representation in Well-Defined Collisions as a Function of Vehicle Type/Size Classification

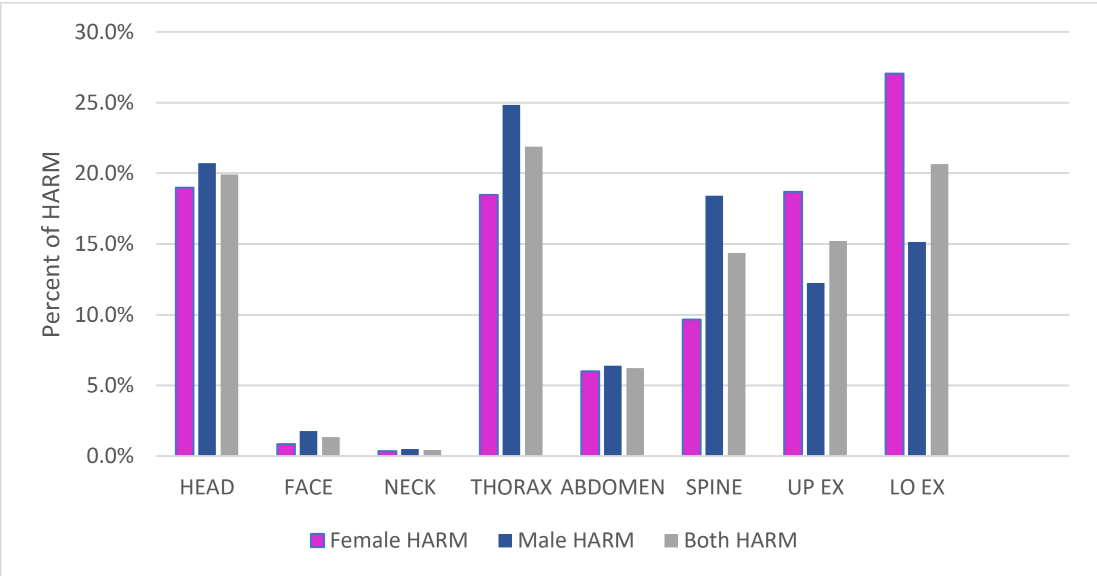


Figure 2. Occupant Injury Inventory, Distribution of AIS 2+ HARM by Body Region and Gender

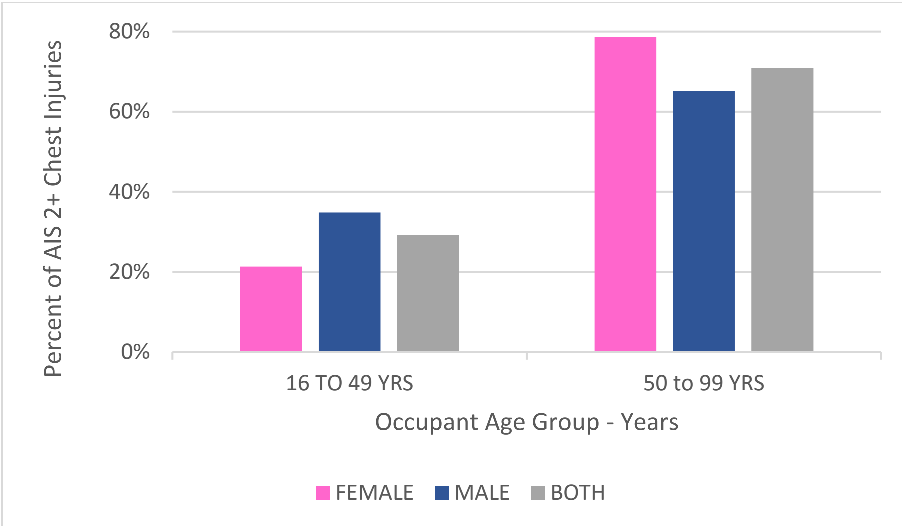


Figure 3a. AIS 2-6 Chest injuries in Well-defined Frontal Crashes by Gender and Age

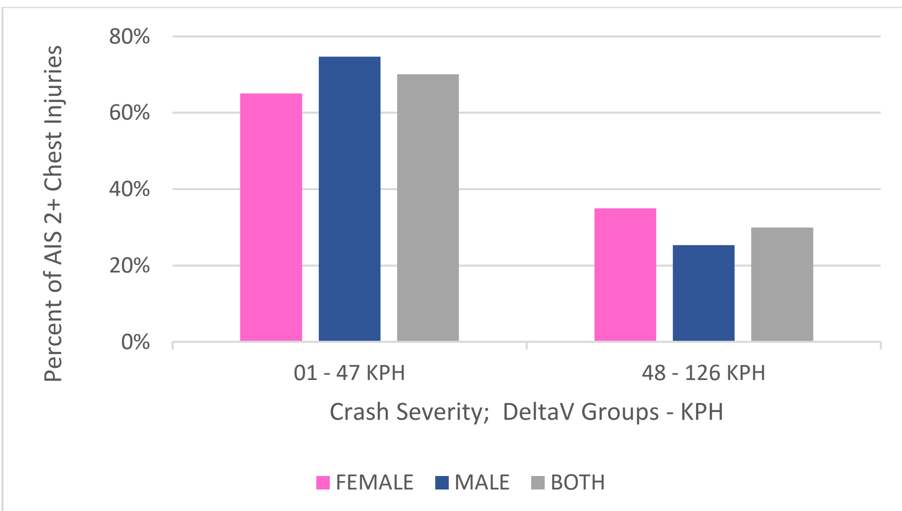


Figure 3b. AIS 2-6 Chest injuries in Well-defined Frontal Crashes by Gender and Crash Severity

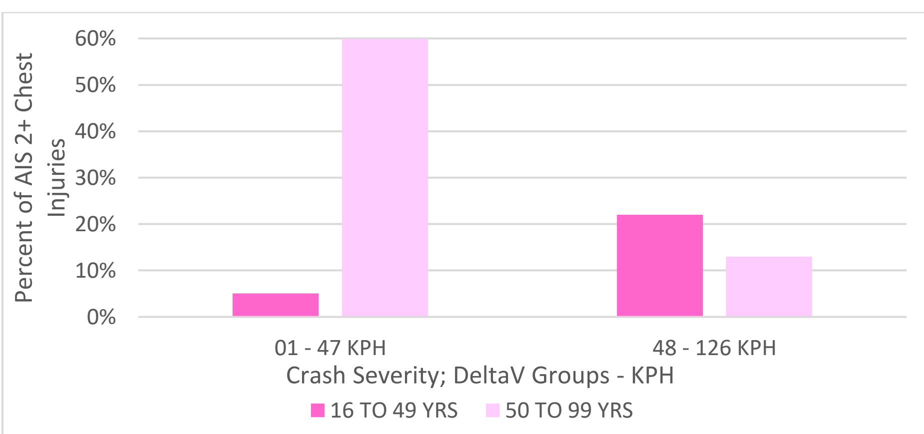


Figure 3c. AIS 2-6 FEMALE Chest injuries in Frontal Crashes by Age and Crash Severity

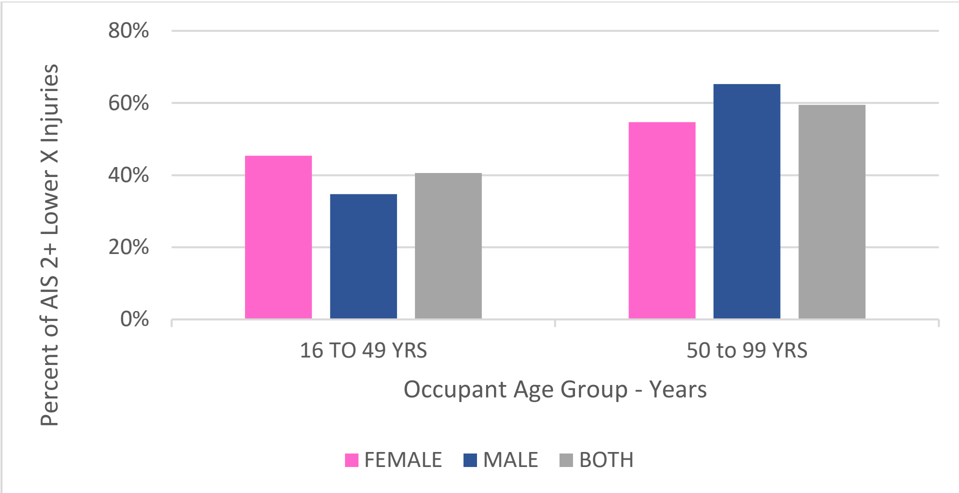


Figure 4a. AIS 2-6 Lower X Injuries in Well-defined Frontal Crashes by Gender and Age

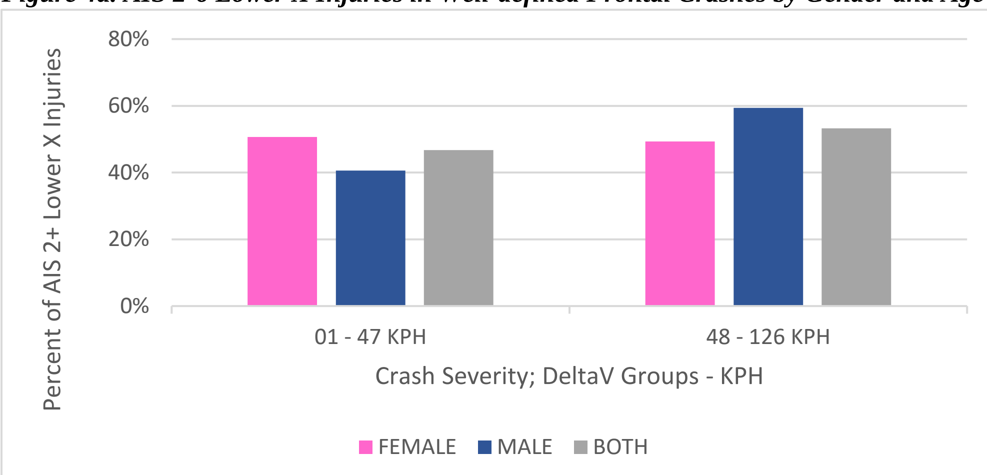


Figure 4b. AIS 2-6 Lower X Injuries in Well-defined Frontal Crashes by Gender and Crash Severity

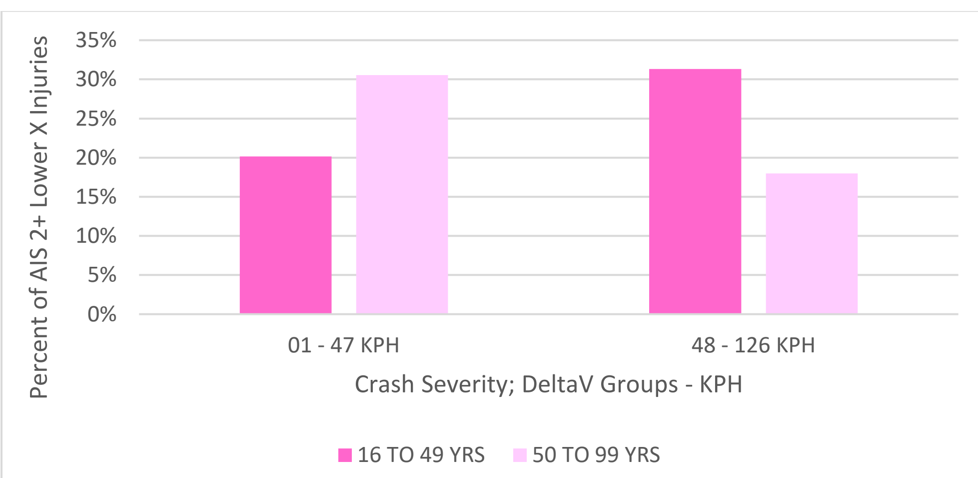


Figure 4c. AIS 2-6 FEMALE Lower X Injuries in Frontal Crashes by Age and Crash Severity

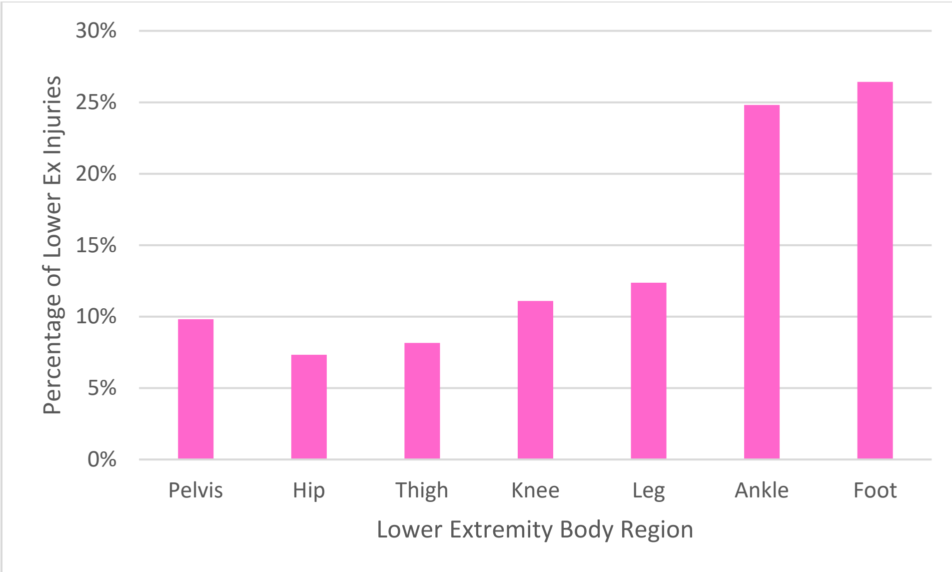


Figure 5. Distribution of Pelvic and Lower Extremity AIS 2-4 Injuries to Females in CISS 2017-2020 Well-Defined Frontal Crashes

The distribution of CISS Lower Extremity AIS 2+ injuries sustained by females in Well-Defined Frontal crashes is shown in Figure 5. A further disaggregation of foot and ankle injury data by left and right lower extremity is contained in Table 1. Table 1 shows the unweighted and weighted injury counts and percentage distributions for the foot and ankle injuries.

Table 1
Number and Distribution of Unweighted and Weighted AIS 2-3 Foot and Ankle Injuries to Front Seat Females in CISS 2017-2020 Well-defined Frontal Crashes

Body Region	Unweighted Number	Weighted Number	Unweighted Distribution	Weighted Distribution
Ankle Left	36	6,789	24%	33%
Ankle Right	38	3,291	25%	16%
Foot Left	19	2,990	13%	14%
Foot Right	59	7,749	39%	37%
Total	152	20,819	100%	100%

An examination of the Event Data Recorder data for the Single Vehicle Well-Defined Frontal cases found that braking was present when 79% of the 48 AIS 2+ injuries to the lower limbs. The body regions included in this Lower Limb category were foot, ankle, leg and knee. Table 2 shows the number of female driver foot and ankle AIS2+ injuries that occurred when the driver was braking. The table shows that the right foot injuries were predominately to the foot (66.6%) rather than the ankle. Braking was indicated by the EDR data for 79% of the female lower limb injuries and 88% of the foot/ankle injuries. The percentage of female all AIS 2+ foot/ankle injuries that occurred to the right foot/ankle was 64% unweighted and 53% weighted. During braking, the percentage was 70% (unweighted), as shown in Table 2.

Table 2.
CISS Documented Injuries to the Foot and Ankle During Braking

FEMALE BRAKING	Foot/Ankle	Foot/Ankle	Percent
Lower Limb Region	AIS 2-6	Percent	On Brake
Foot Left	5	17%	
Ankle Left	4	13%	
Foot Right	14	47%	
Ankle Right	7	23%	70%
All	30	100%	

.0 Sec .06 Sec .15 Sec

Figure 6a. Brake Pedal Motion in Test 9335; 5 mm Recorded Brake Pedal Intrusion

.0 Sec .06 Sec .15 Sec

Figure 6b. Brake Pedal Motion in Test 9336 – 110 mm Recorded Brake Pedal Intrusion

In their vehicle database, NHTSA has a series of NCAP like frontal crash tests with the 50% Male THOR Dummy in the Driver position. These tests also positioned a camera to record the motion of the brake pedal. Figures 6a and 6b show comparative motion from two different tests. The ankle inversion/eversion angles for the Figures 6a and 6b images are plotted in Figure 7.

Analysis of NHTSA crash test database provides insights into injury mechanisms and possible countermeasures for lower limb injuries. Figure 8 shows a comparison of Driver and Right Front Passenger Foot Accelerations that is typical of the NCAP like frontal tests conducted by NHTSA to evaluate the 50% male THOR Dummy in the driver position. The right front passenger was a 5% Female HIII dummy. Since the foot position 5% Female HIII is further away from the toepan than the 50% Male THOR, a more severe impact occurs and a higher acceleration results.

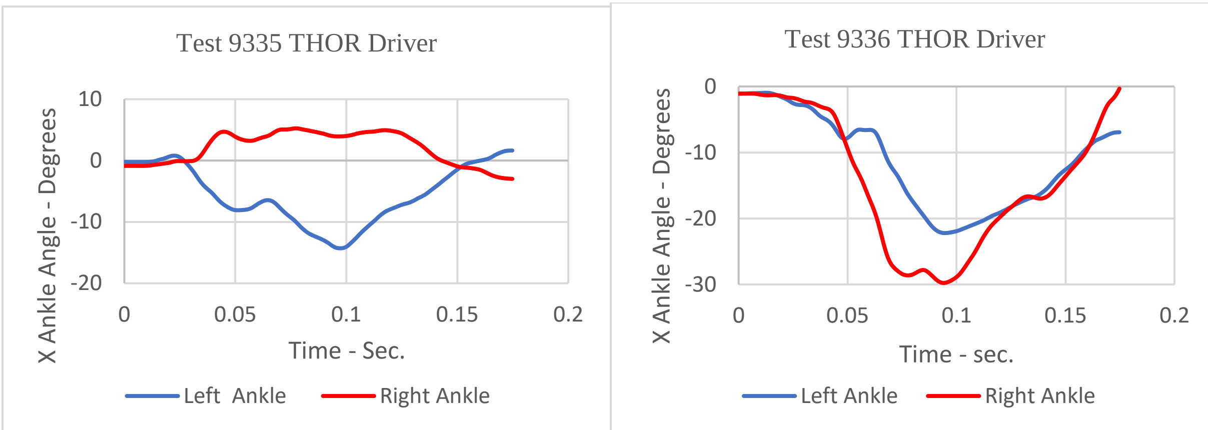


Figure 7. Ankle Inversion/Eversion Angle of 50% Male THOR Driver in NCAP Like Frontal Tests 9335 and 9336

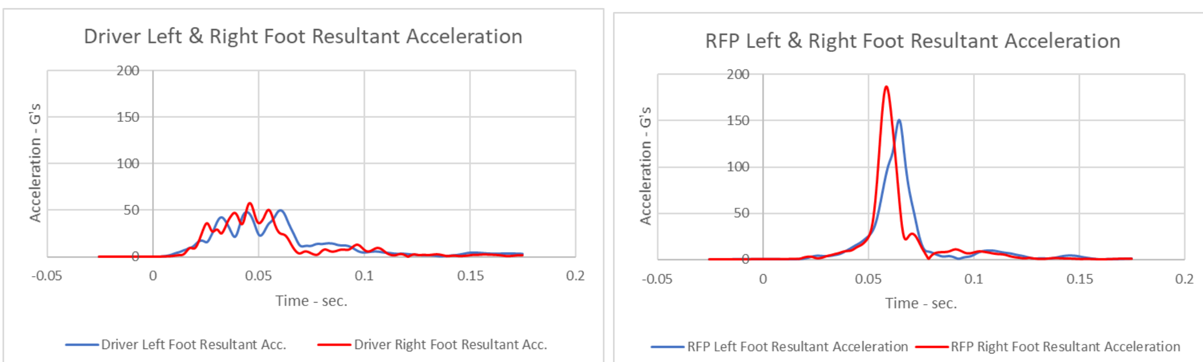


Figure 8. Foot Accelerations of 50% Male THOR Driver and 5% Female HIII in NCAP Like Frontal Test 9336

NHTSA's research testing of the Moving Deformable Barrier Evaluation of Small Overlap/Oblique Crashes clearly demonstrate a crash environment conducive to ankle eversion/inversion injuries (Saunders, 2012, 2015, 2021; Hu, 2019). The test condition was an impact by a moving deformable barrier traveling at 90 kph at an angle of 15 degrees and 35% offset. Ankle motion typical of this test mode is shown in Figure 9. Figure 9 shows the actual ankle position at three time periods. Figure 10 shows the plot of the THOR ankle eversion/inversion angles. The left ankle undergoes eversion and the right inversion. Note that the sign convention for eversion/inversion reverses from left to right foot. The longitudinal and lateral accelerations for the tested vehicle are shown in Figure 11.

.0 Sec .05 Sec .07 Sec

Figure 9. Foot and Ankle Motion Test 9500

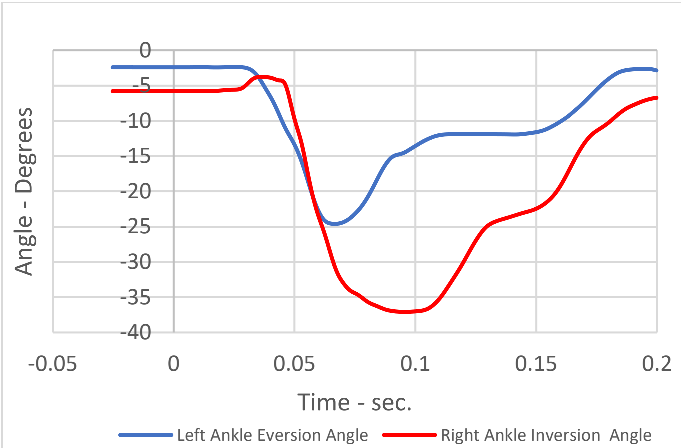


Figure 10. Foot and Ankle Eversion/Inversion Angle Test 9500

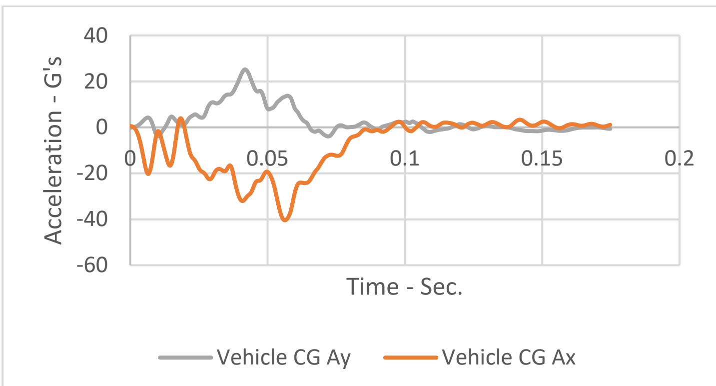


Figure 11. Vehicle Longitudinal and Lateral Accelerations in NHTSA Oblique/Offset Test 9500 (2015 Mazda CX5)

NHTSA's frontal NCAP tests include the force measurements from 176 load cells mounted in a 1375 mm by 2000 mm array on the test barrier. Analysis of the barrier load cells permits the measurement of stiffness and force distribution for each vehicle tested. This test data allows an assessment of the stiffness and geometric compatibility of various vehicles.

Figure 12 shows a comparison of the force vs. displacement for the Ford Focus subcompact car and the Ford F 150 pickup. Based on the barrier results, a frontal deformation of 120 mm on the F 150 would produce 350 mm of deformation on the Focus in a head-on collision. These results are typical of stiffness differences that currently exist in the NCAP test database.

Additional compatibility tests of the Ford Focus crashed head-on into more aggressive vehicles can be found on-line in the NHTSA vehicle test database. The following test numbers in the NHTSA database are of the 2002 Ford Focus vs other more aggressive vehicles: Test 5448 – 2003 Chevrolet Silverado pickup; Test 5686 – 2006 Honda Ridgeline pickup; Test 5685 2005 Honda Odyssey MPV; Test 5642 – 2005 Chrysler Town and Country MPV. These tests illustrate the vulnerability of small car occupants in frontal collisions with more aggressive vehicles.

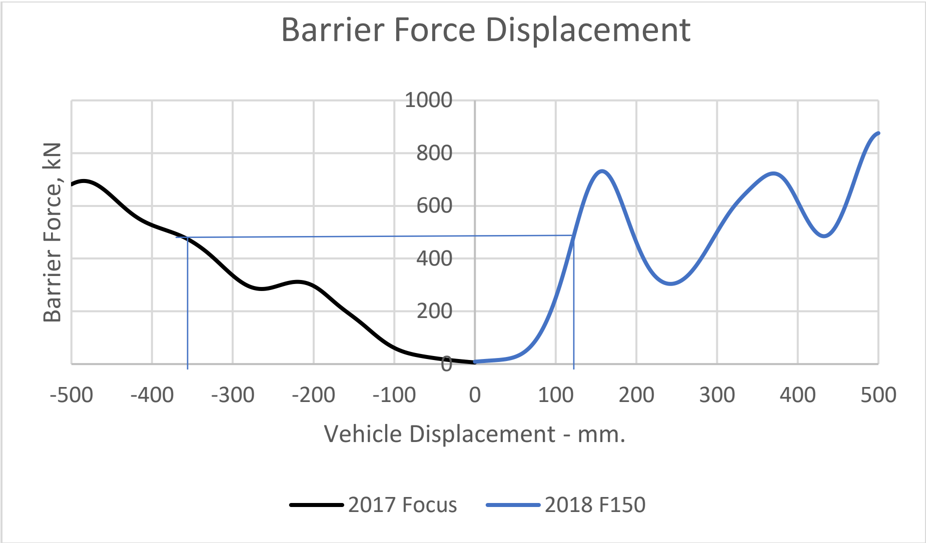


Figure 12. Stiffness comparison of the Focus vs F 150

In view of the expected increase in the population of electric vehicles in the fleet, it is essential to anticipate their influence on gender inequality. Like pickup trucks, electric vehicles have a weight advantage over most cars. Figure 13 and 14 show comparisons of the stiffness and weight of the F 150, the Tesla X, Polestar 2 and the Focus.

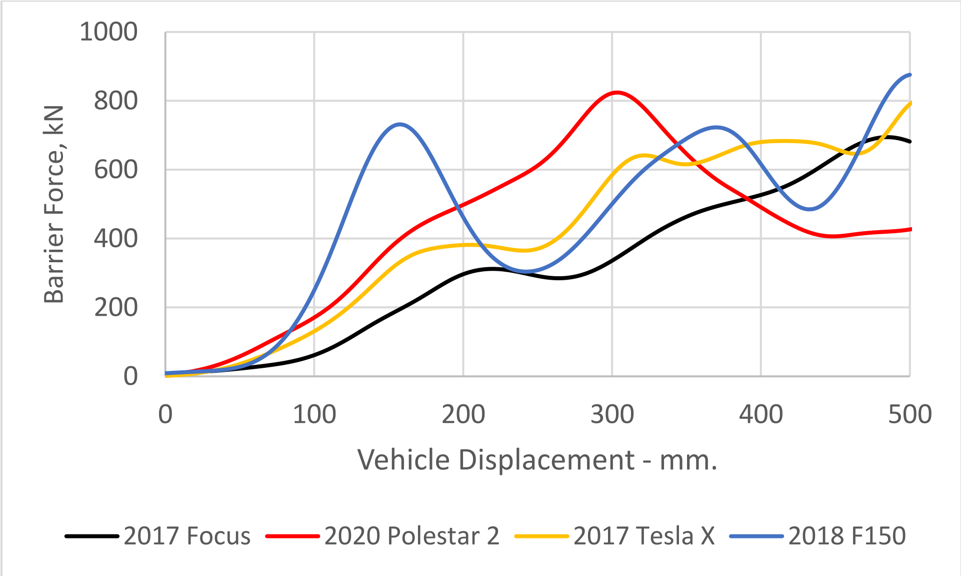


Figure 13. Frontal Stiffness of the F 150, Tesla X, Polestar 2, and Focus

The combination of weight and stiffness incompatibility makes it essential to encourage compatibility countermeasures to reduce the crash severity experienced by occupants of lighter vehicles that are more likely to have female occupants.

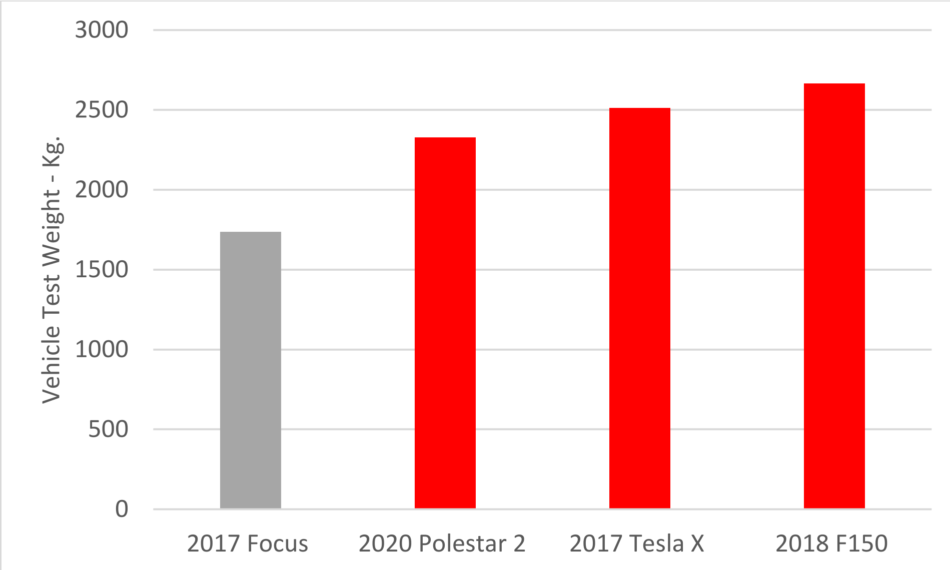


Figure 14. Vehicle NCAP Test Weight of 2017 Focus and Three Heavier Vehicles

Analysis of barrier force distribution has been reported in several papers (Digges, 1999, 2000, 2001, 2002). In a study for NHTSA, Digges, Eigen and Harrison analyzed barrier data to asses vehicle compatibility issues (Digges, 1999). They produced comparative barrier force distribution patterns for different classes of vehicles and proposed a geometric compatibility metric based on the Height of the Center of Force required to produce a restoring moment to the barrier forces. This metric, subsequently named the Average Height of Force (AHOF), was further applied in a paper that examined the aggressiveness of light trucks (Digges 2001). Figure 15 shows the AHOF for four vehicles.

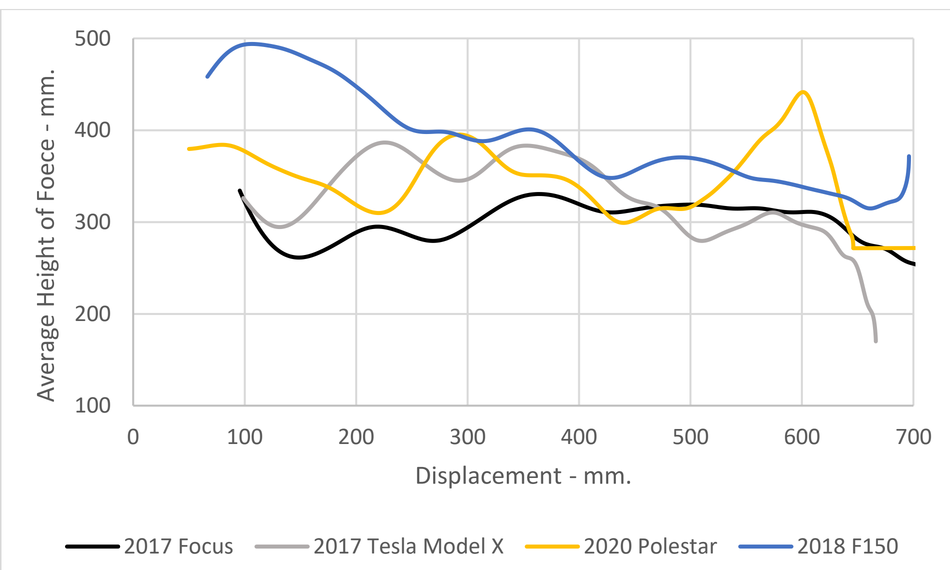


Figure 15. Average Height of Force Vs. Displacement for Focus, Polestar 2, Tesla X and F 150

Figure 16 shows the barrier force distribution for the Ford Focus, Tesla X and the Ford F 150 taken from NCAP test data on NHTSA website.

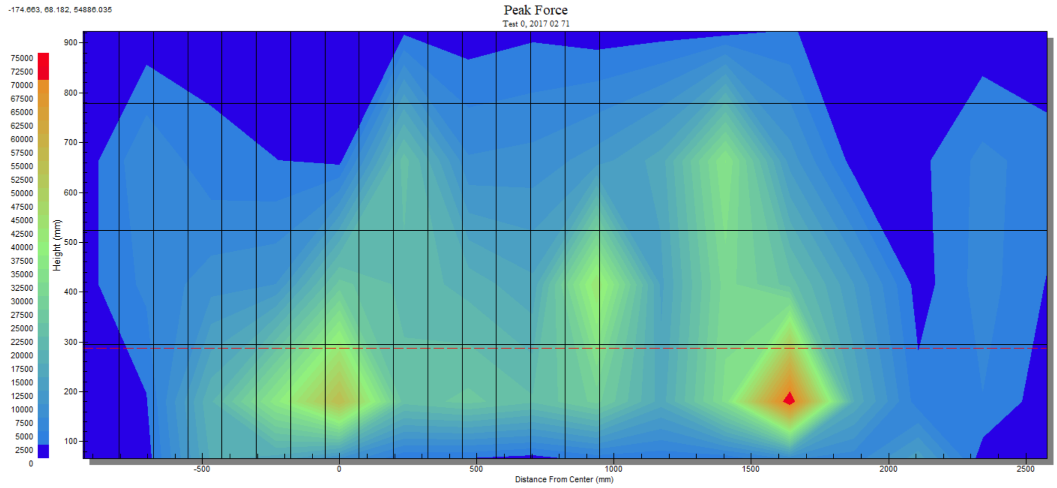


Figure 16a. 2017 Focus 10068 Barrier Force Distribution

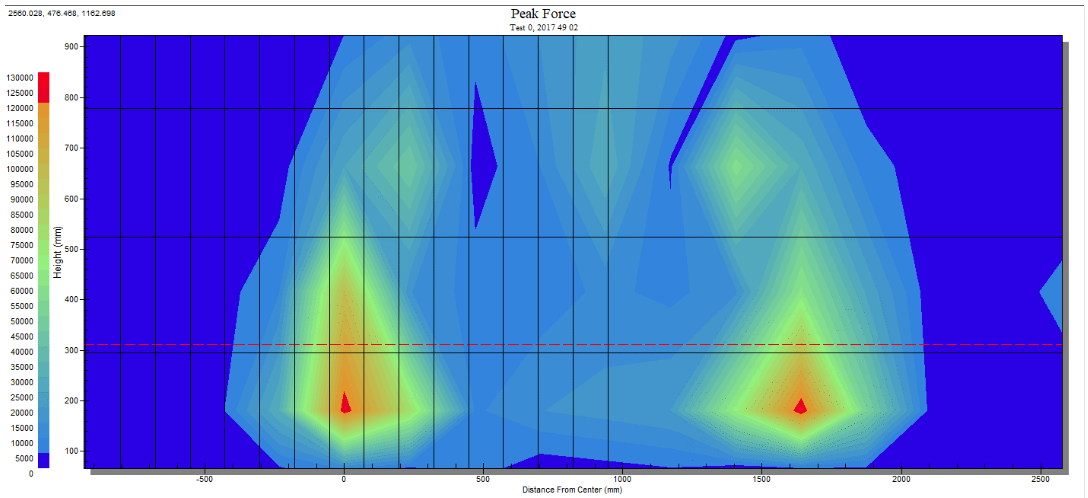


Figure 16b. 2017 Tesla X 10076 Barrier Force Distribution

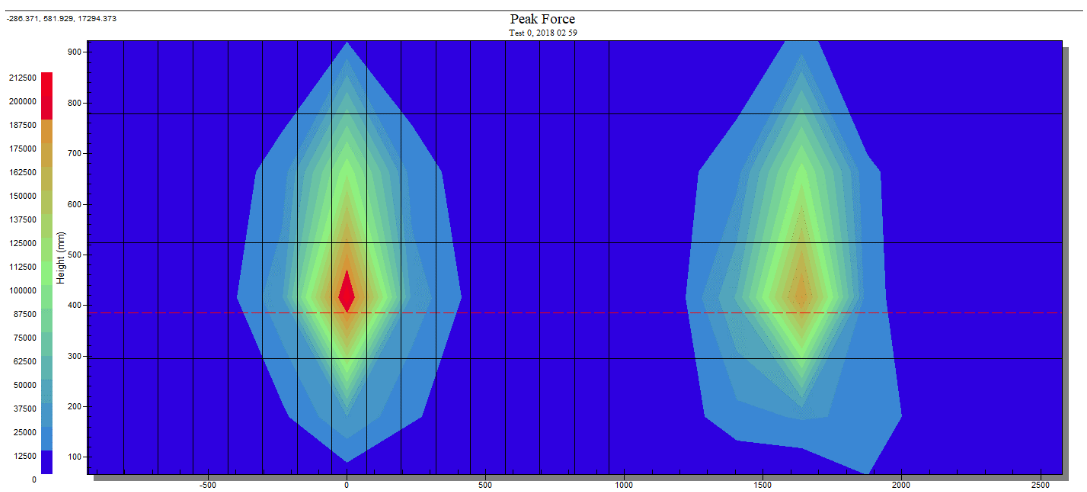


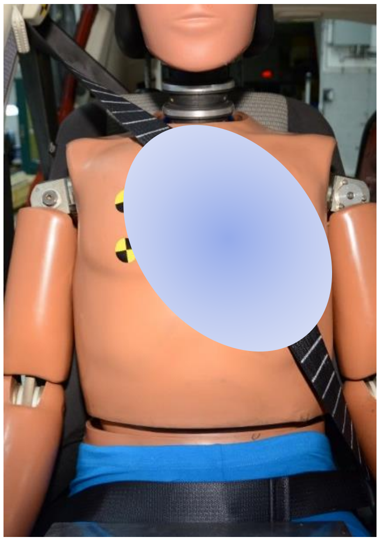
Figure 16c. 2018 Ford F 150 10310 Barrier Force Distribution

DISCUSSION: CHEST INJURIES

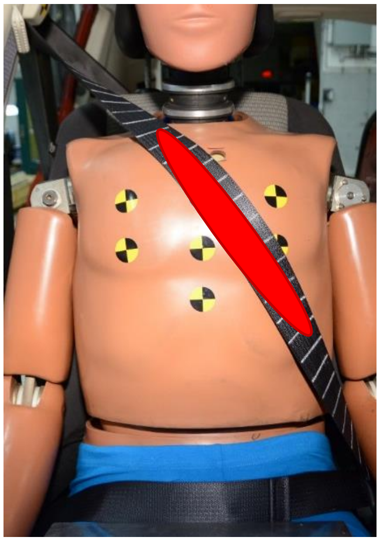
The 2019 research by the University of Virginia showed that the post 2009 cars very little change in the percentage of occupants with thorax injuries at the AIS 2+ severity (Foreman, 2019) The thorax injury reduction at the AIS 3+ level was small in comparison with the reductions in other body regions. This lack of improvement has occurred in spite of advances in safety belt pre-tensioning and force limiting.

To enhance thorax protection, improved chest measurements that better distinguish the injury risks of different restraint systems should be introduced in NCAP. Past research has shown that the lack of control of belt routing as permitted in current testing practices, makes the chest deflection measurements almost meaningless (Digges, 2019, 2017). In view of the preponderance of older females with chest injuries in lower severity crashes (Figures 3a and 3c), it is essential that older female chest injury risk curves be applied to NCAP injury measurements (Figure A1). To further address female chest injuries, audit crash tests should be performed on selected NCAP vehicles to ensure that the injury risks measured at 56 kph are lower at 40 kph, where most female injuries occur.

Improvements in safety belt technology including inflatable belts should be encouraged to reduce chest injury risks. Extensive research that documents the benefits of inflatable belts has been reported in the literature. An earlier paper by Digges and Morris summarizes extensive inflatable belt testing conducted by NHTSA (Digges, 1991) This research included human volunteers, cadavers and ATD tests that involved both sled tests and vehicle crash tests (Digges, 1991). One of the findings of the research was that ATD's of that period did not adequately measure the chest injury reduction benefits provided to the human subjects by the inflatable belt. More recent tests of inflatable belts have been reported by Foreman (2010) and Edwards (2017). Figure 17 illustrates the difference in pressure distribution across the chest of an inflatable belt vs a conventional belt (Gato, 2020). Improved chest injury measurements is a requirement to encourage improved countermeasures to reduce safety belt induced chest injuries.



Inflatable Belt Pressure Distribution



Conventional Belt Pressure Distribution

Figure 17. Typical Difference in Pressure Distribution Inflatable Belt vs Conventional Belt (After Goto, 2020)

A recent study indicates that the THOR may not adequately distinguish injury risk differences between concentrated pressure from the shoulder belt and distributed pressure from an inflatable belt (Goto,2020). Further improvements in chest injury measurement accuracy, including the use of contact pressure measurements, as being used in current IIHS Moderate Frontal Overlap Tests (IIHS 2022), should be researched and incorporated in order to further reduce shoulder belt loading of the chest.

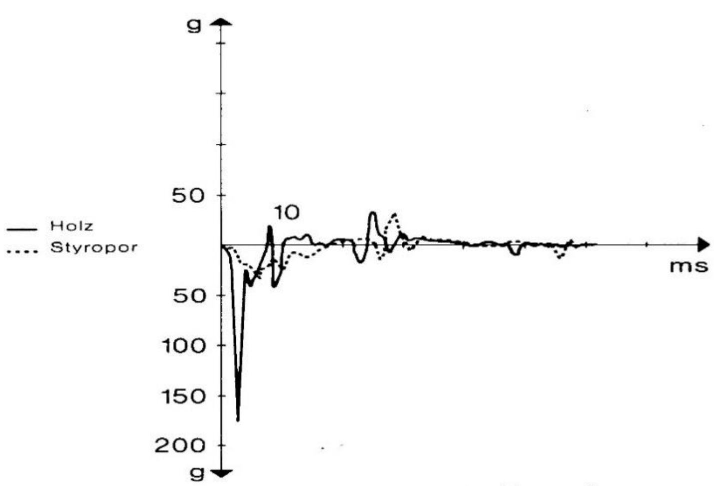
It may be observed from Figure 3b that the female chest injury frequency is highest (66%) in the crash severity range of 0 to 47 kph. Figure 3a shows that the 50 to 99 age range of females have the highest frequency (79%) of chest injuries. As shown in Figure 3c, the largest opportunity for chest injury reduction is in the older population at the lower speed range. These observations suggest a Female NCAP should encourage a reduction of chest injuries for older occupants at lower crash severities. It may be noted from Figure 4 that this addition to NCAP could benefit men more than women. Ensuring chest ratings are based on more accurate chest measurement would greatly enhance the utility of NCAP in terms of improving chest protection. Both genders could benefit from this improvement.

In recent model year vehicles, inflatable belts have been offered by Ford and Mercedes to improve the crash protection for rear seat occupants. It is time for NCAP to encourage the use of this countermeasure to reduce the chest injuries sustained by all occupants. This can be done simply by improving the belt routing and penalizing the high contact pressure that is characteristic of existing shoulder belts.

DISCUSSION: LOWER LIMB INJURIES

An examination of the CISS data for lower limb injuries shows that younger women are slightly more frequently injured (52%) than older women (Figure 4a) and that lower extremity injuries are about equally distributed in the two speed ranges (Figure 4b). Figure 4c indicates that more older women are injured at the lower speeds and more younger women are injured at the higher speeds. Figure 5 shows that the foot and ankle exhibit the largest fraction of AIS 2+ Lower Extremity injuries – exceeding 50%. Figure 8 shows that foot impact with the toepan in NCAP like crashes can cause foot acceleration spikes of 187 G's. for the 5% female dummy right front passenger. This compares with 52 G's for the 50% male dummy driver. The higher acceleration was caused by the gap between the foot and the toeboard that resulted in a foot impact. Shorter occupants seated in the right front position would be especially vulnerable to this kind of loading. Control of foot acceleration to encourage energy absorbing toepans would be useful to reduce talus and calcaneus injuries. The placement of the foot relative to the toepan for the RFP should also be controlled so that toepan impacts typical of female seating positions can be simulated in the Female NCAP Test. The test procedure should require a minimum distance between the foot and the toeboard for the right front passenger 5% Female Dummy.

Mercedes Benz has published research findings that show energy absorbing materials in the footwell can reduce the foot acceleration (Kallina, 1995). The foot accelerations before and after a countermeasure was applied are shown in Figure 18. Kallina reported that the accident data had shown a reduction of foot injuries after the introduction of the countermeasure in the Mercedes fleet.



After Kallina, 1995

Figure 18. Mercedes Crash Test Foot Acceleration With (Styropor) and Without (Holz) Countermeasure

Figures 9 and 10 illustrate how the lateral acceleration in a crash (Figure 11) can induce extensive ankle inversion/eversion under small overlap/oblique test conditions being researched by NHTSA. Earlier studies indicate that even non-oblique crashes can induce lateral accelerations in vehicles. Ishikawa (1996) analyzed crash pulses of car-to-car aligned frontal crashes with 40% and 60% offset. The authors found that the peak lateral acceleration (+y) was often as high as the peak longitudinal acceleration (-x). Bedewi (1998) and Digges (1997) reported on finite element computer modeling of the lower limb that showed a relationship between vehicle lateral acceleration and ankle inversion/eversion angles. The authors found that the lateral acceleration pulse in car-to-car offset crashes could be a source of ankle inversion/eversion injuries, especially when no intrusion occurs. The authors found that the offset barrier tests did not produce similar lateral accelerations. Consequently, a different type of crash test may be required to simulate the crash environment that produces most ankle eversion/inversion injuries. Countermeasures to mitigate for ankle eversion/inversion injuries may need additional research. However, the inclusion of energy absorbing material in the toepan as demonstrated by Mercedes could be beneficial to the ankle as well as the foot, and should be encouraged by incentivizing lower foot acceleration in the Female NCAP test. The test should require a minimum distance between the toepan and the feet of the 5% Female right front passenger.

Yoganandan (1996) published a compilation of dynamic impact tests to the feet of human specimens that produced foot and ankle injuries. Based on the test results, he produced injury risk curves and an injury risk formula that included age of the injured subject. A dynamic axial force of 3.7 kN produced a 10% injury risk. A 20% injury risk occurred at 4.7 kN. However, for a 65 year old specimen, the 4.7 kN force resulted in a 30% injury risk.

Foot/ankle injury assessment could be made by attaching force measurement instrumentation to the shoes of the dummy or by translating the force measurements to foot acceleration and setting limits on the latter. This translation may require testing the dummy lower limbs in a similar mode to the human specimen tests that produced the injury risk curves. This improvement should be incorporated in existing NCAP for during the near term. For a longer-term objective, tests and countermeasures for ankle inversion/eversion injuries should be developed.

The testing summarized by Yogenandan involved only axial loading. As noted by Ishikawa (1996) and as observed in NHTSA research tests (Figures 9, 10 and 11) lateral acceleration is present in vehicle-to-vehicle offset crashes. A comparison of the NCAP frontal tests (Figures 6a, 6b and 7) NHTSA oblique/overlap tests (Figures 9 and 10) clearly show that the lateral acceleration increases the extent of ankle inversion/eversion. Consequently, the final Female NCAP should include a test condition that induced lateral acceleration that is typical of on-the-road offset crashes. Ishikawa found that the offset deformable barrier test in common use did not satisfy that condition.

Begeman has conducted several studies that involve human specimen tests to determine ankle injury tolerance (Begeman 1993,1994 and 1996). In his study of inversion/eversion, he found that 50 degrees produced a 10% risk of ankle injury (Begeman, 1993). The ankle of the dummy would need to be correlated with the ankle of tested specimens in order to base a Female NCAP rating on this injury risk metric

Based on the CISS field injury data (Figure 5), a reduction of foot/ankle injuries should be a goal of Female NCAP. Some reduction should occur from controlling the dynamic force transmitted to the foot by the toeboard. That capability should be immediately incorporated in NCAP by measuring the foot dynamic force or the acceleration. Limiting the dynamic force to less than 10% injury risk should be a goal. Possible countermeasures include energy absorbing toepans (Figure 21) and seat cushion air bags, as are present in some Toyota vehicles.

Figure 6a shows a brake pedal that was relatively stable during the crash. The position is almost the same at each of three time periods, and the measured static intrusion was + 5 mm. Figure 6b shows a brake pedal that intrudes rapidly during the initial .06 seconds of the crash. The measured static intrusion was -110 mm. However, the position of the brake pedal when the static intrusion was measured post-crash does not capture the extent of brake pedal motion or its velocity.

In view of the high percentage (62%) of female driver foot and ankle injuries in CISS that occur during braking, it is evident that some safety features of the brake pedal should be included in a Female NCAP. The variability of brake pedal motion as displayed in the series of frontal crash tests with the 50% male THOR positioned as the driver clearly demonstrate that differences exist in brake pedal performance across vehicle models (Figure 6). As a minimum, a Female NCAP should limit brake pedal displacement and velocity during the NCAP test. EuroNCAP 2023 has discouraged pedal intrusion by penalizing a pedal blocked with a 200N force when its intrusion exceeds 50 mm. (EuroNCAP, 2022). Adoption of the EuroNCAP criteria in a Female NCAP could offer incentives for an immediate improvement in brake pedal stability and an associated reduction in dynamic loading of the right foot.

DISCUSSION: COMPATIBILITY

Figure 1 shows that females are more likely to be in lighter cars and males in heavier vans and pickups. This observation suggests the need to better control the aggressivity of pickups and other heavy vehicles in order to reduce their crash severity, especially at lower speeds where most injuries occur (See Figures 3c, 4c and Table A3). While females in lighter vehicles are expected to be the largest benefactors, even heavier vehicle occupants could benefit during collisions with fixed objects and other heavier vehicles. In addition, the occupants of vehicles involved in side impacts would benefit from bullet vehicles with more compatible front structures.

Figure 13 compares the stiffness of a compact car with a pickup and two electric vehicles. The initial stiffness of the electric Tesla X is a closer match to the small car than the electric Polestar 2. However, after the initial 350 mm the Tesla X is stiffer than Polestar 2. The higher stiffness of the heavier vehicles suggests that making electric vehicles stiffness compatible is not a design priority. Requiring stiffness compatibility in a Female NCAP would incentivize this compatibility improvement.

It may be noted in Figure 16 that the location of the maximum force for the Tesla X electric vehicle is close to the height of the max force of the Focus. The pickup tends to exert the max force at a higher level on the barrier. Figure 15 shows how the Average Height of Force varies with displacement for the three vehicles. The difference in Average Height of Force suggest that the pickup would tend to override the smaller vehicle more than the electric vehicles. The better alignment of electric vehicle crash forces should result in added structural engagement and increase the benefit to be expected from control of the stiffness of the heavier electric vehicles.

In order to improve stiffness compatibility, it would be desirable to design all vehicles so that their initial frontal stiffness is limited. Figure 19 shows the stiffness plot for a fixed barrier crash of a concept vehicle designed for stiffness compatibility. Either vehicle acceleration or barrier force are candidates for use in controlling initial vehicle stiffness. For an initial 400 mm of vehicle crush, there is a structural force or acceleration plateau that provides for structural stiffness compatibility. This structural force plateau will limit the force transmitted to both vehicles in lower severity vehicle-to-vehicle collisions. Consequently, occupants of both vehicles would benefit from the lower vehicle accelerations. Lower accelerations would also benefit compatible vehicle occupants in low severity single vehicle collisions with fixed objects.

Two different acceleration plateaus are shown in Figure 19 – the lower one for compatibility and the higher one for self-protection. The optimum vehicle crush and acceleration levels for these plateaus will require added research and analysis to determine.

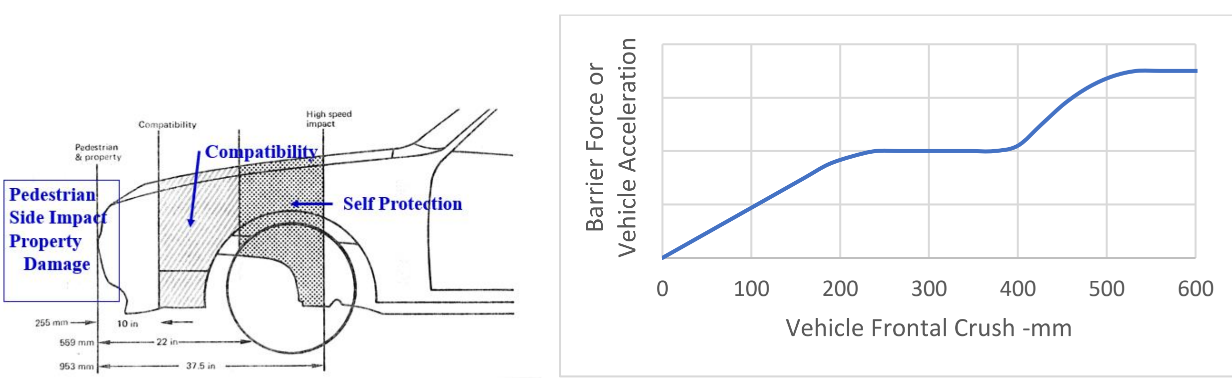


Figure 19. Vehicle Frontal Stiffness Compatibility Concept

CONCLUSIONS

The research presented here supports a Female NCAP that encourages safety improvements in three areas: (1) Chest injury reduction, (2) Lower Limb injury reduction and (3) Improved Vehicle Stiffness Compatibility. Improved Compatibility will reduce the crash severity in lower speed two-vehicle collisions where females are most frequently injured. There are near term improvements that can be introduced in the current test protocols and that do not require a new 50% female dummy.

An earlier study found that risk reduction of thorax injuries has lagged the safety improvements for other body regions, resulting in an increasing prevalence among skeletal thorax injuries in newer model year vehicles (Foreman 2019). Samaha, 2010, Sahraei 2009, 2013 found that increasing frontal stiffness had increased chest injury measurements for rear seat occupants and that improvements in safety belt technology had permitted front seat dummies to accommodate increased vehicle stiffness in NCAP crash tests. As shown in Figure 2, chest injuries are a large source of HARM for both male and female belted front seat occupants. The female AIS 2+ chest injuries occur mostly (70% Figure 3b) at the lower 0 to 47 kph speed range. Since the existing NCAP has not adequately encouraged chest injury reductions in the vehicle fleet, changes should be incorporated by way of a Female NCAP.

An immediate change should be an improvement of chest injury measurement via a better control of the shoulder belt position so that it engages the chest deflection gauge on the dummy chest. (See Digges 2017 for a detailed evaluation.) In the near term, the accuracy of chest injury measurements on the right front passenger should be improved by incorporating rib-rye gauges in the 5% Female Hybrid III dummy chest (See Digges 2019 for detailed analysis and discussion.). In addition, older female injury risk criteria should be applied to the 50% Male HIII (Figure A1) and the risk curves should be scaled by a factor of .817 when applied to the 5% female (Mertz 1997). Finally, audit testing at lower speeds should be conducted to ensure that injury risks are reduced at the deltaV's where most injuries occur.

Because females have increased presence in lighter vehicles (Figure1) they are more frequently exposed to crashes with heavier vehicles and could benefit most from improved front structure compatibility. Figure 14 shows the mass difference between a small car, a pickup and two electric vehicles. The higher mass of the electric vehicles and the increasing presence of these vehicles in the fleet suggest an urgent need to limit the stiffness aggressiveness of these vehicles. Research by Sahraei (2013) and Samaha (2010) indicates that much of the benefits of force-limited and pretensioned belts has been offset by the increased stiffness of vehicle front structures. This increase in stiffness increases the vehicle acceleration for each added increment of vehicle deformation during collisions, thereby increasing the crash severity. Figure 12 illustrates the structure deformation difference between two current on-the-road vehicles. Small deformation increments of the heavier vehicle structure cause much larger deformation increments in the lighter vehicle. This relationship contributes to the high fatality rates when car drivers collide with heavier vehicles as has been reported by Gabler (1998) and Joksch (1998).

Figure 13 shows that stiffness incompatibility exists not only in pickups, but also in some electric vehicles such as Tesla X and Polestar 2. It may be observed in Figures 15 and 16 that the geometric compatibility of the Tesla electric vehicle is a closer match with the small car than the pickup. This geometric match of the structures will tend to increase the vehicle acceleration for a given deltaV. In view of the large number of heavier electric vehicles expected to enter the fleet, it is imperative that Female NCAP address the resulting stiffness incompatibility issue that could result.

In order to encourage the added technology of inflatable belts, further improvements in chest injury measurement may be required. The research by Goto (2020) indicates that the THOR dummy gages may not adequately measure the beneficial pressure distribution of inflatable belts as compared to the conventional belts. This is because the conventional belt may not engage the existing chest deflection gages. The application of a pressure sensing vest may be required to encourage inflatable belts for a mid-term Female NCAP. It may be noted that a pressure sensing garment is being used on the dummies in the new IIHS protocol for the Frontal Offset Test (IIHS 2022).

Figure 4 shows the Female Lower Extremity injuries are about equally divided between the two speed ranges and age groups. However, more older females are injured in the lower speed range. Figure 5 shows that over half the

Female Lower Extremity injuries are foot/ankle injuries. This suggests the need to immediately address foot/ankle injuries in the existing frontal NCAP test. This could be done by penalizing vehicles with foot accelerations that produce greater than 10% injury risk. According to Yoganandan (1996) a dynamic force of 3.7 kN would cause a 10% injury risk to the foot/ankle body region. The test should require a minimum distance between the toeboard and the feet of the 5% female right front passenger. This near-term addition to NCAP is expected to encourage known improvements such as energy absorbing toe-pans (Figure 18) and innovative new technology such as seat cushion air bags.

The issue of ankle inversion/eversion injuries in crashes with lateral acceleration should be the subject of continuing research to determine appropriate countermeasures and associated test conditions and injury criteria. However, based on Yoganandan (1996) criteria, limiting the force transmitted to the foot in an NCAP frontal crash could be initiated in the near term and should provide benefits.

As shown in Figure 6, there is a large vehicle to vehicle difference in the brake pedal motion during an NCAP like frontal test. For CISS Well Defined Frontal Single Vehicle Crashes with EDR data, 79% of the Female Lower Limb injuries occurred with braking was indicated as present. For female foot/ankle injuries with braking, 70% were to the right foot. This data suggests an opportunity to reduce foot/ankle exposure to injuries induced by brake pedal motion by controlling the pedal intrusion. EuroNCAP (2022) proposes a method of brake pedal penalties that should be immediately incorporated in a Female NCAP.

These studies confirm earlier research that shows the chest and lower limbs as priority body regions for improved female protection. Females are generally exposed to crashes at lower severity than males. For Female AIS 2+ injuries, the percentage that occur in the 0 to 47 kph range are: Head/neck – 90%; Thorax – 65%; Spine – 71% and Upper Extremity – 83%. This suggests the need to ensure that the improved protection at crash speeds below the NCAP frontal test. A lower speed NCAP crash test may be necessary to address the majority of female injuries.

REFERENCES

Bedewi, P. G., The Biomechanics of Human Lower Extremity Injury in the Automotive Crash Environment, (May 1998) Doctoral Dissertation, The George Washington University, Washington, D.C., 1998.

Begeman, P. and K. Aekbote. Axial load strength and some ligament properties of the ankle joint. in Injury Prevention Through Biomechanics Symposium, Detroit, MI, 1996

Begeman, P. D., and Prasad, P., "Human Ankle Impact Response in Dorsiflexion," Proceedings of the 34th Stapp Car Crash Conference, (November 1990) SAE Technical Paper No. 902308. Reprinted in Hybrid III: The First Human-Like Crash Test Dummy, SAE PT-44, 1994.

Begeman, P., Balakrishnan, P., Levine, R., and King, A., "Dynamic Human Ankle Response to Inversion and Eversion," Proceedings of the 37th Stapp Car Crash Conference, (November 1993) SAE Technical Paper No. 933115, 1993.

Brumbelow, M.,and Jermakian, J,. "Injury Risks and Crashworthiness Benefits for Females and Males, "Which Differences are Physiological?" Traffic Injury Prevention, 2021.

Brumbelow, M., "Adjusting for the Effect of Shoulder Belt Placement on Hybrid III Sternum Deflection," Paper IRC-20-61, IRCOBI Conference, 2020a.

Brumbalow, M., "Can Front Crash Rating Programs Using Hybrid III Predict Real World Thoracis Injuries?," Paper IRC -20-79, IRCOBI Conference 2020b.

Dalmotas, D., Digges, K., and Prasad, P., "How Gender Preferences for Vehicle Size/Class Influence Fatality Outcomes," ESV Paper 23-0337, May 2023

Digges K., Dalmotas D., Prasad P., and Mueller B.; "The Need to Control Belt Routing for Silver NCAP Ratings," Proceedings of the 25th ESV Conference, Paper Number 17-0403, June 2017

Digges,K., and Bahouth, G., "Stiffness and Geometric Incompatibility in Collisions Between Cars and Light Trucks," SAE 2003 01-0907, March 2003.

Digges, K., and Eigen., A., "Examination of Car to Light Truck Compatibility in Frontal Crashes," SAE 2001-01-1165, March, 2001a.

Digges K., and Eigen, A., "Measurements of Vehicle Compatibility in Front-to-Side Crashes," IRCOBI Conference, October, 2001.

Digges, K., and Eigen, A., "Analysis of Load Cell Barrier Data to Assess Vehicle Compatibility," Safety Test Methodologies, SP –1516, SAE 2000-01-0051, March 2000.

Digges, K., Eigen, A., and Harrison, J., "Application of Load Cell Barrier Data to Assess Vehicle Crash Performance and Compatibility," SAE, 1999-01-0720, March, 1999.

Digges, K, and Malliaris, A., "Crashworthiness Safety Features in Rollover Crashes," SAE982296, September, 1998.

Digges, K., Bedewi, P., and Ishikawa, H., "Ankle Injury Mechanisms in Offset Crashes",1997 International Conference on the Biomechanics of Impact", p.87-98, September 1997.

Digges, K., and Others, "Determination and Modeling of Ankle Injury Causation," NHTSA International Conference on Pelvic and Lower Extremity Injuries, p. 317-326, December, 1995

Digges, K. and Morris, J., "Opportunities for Frontal Crash Protection at Speeds Greater than 35 MPH," Paper 910807, Frontal Crash Safety Technologies for the 90's, SAE Publication SP-852, p. 51-62, February, 1991.

Edwards, M., and Nash, C., "Inflatable Shoulder Belts and Inboard Anchor Shoulder-belt Geometry in Far-side Oblique Impacts," Paper IRC -17-56, IRCOBI Conference, 2017.

EuroNCAP, "Assessment Protocol – Adult Occupant Protection," Implementation 2023, Version 9.2.1, Section 3.2.1.6 Foot and Ankle, Pedal Page 12, November 14, 2022.

Forman, J., "Field Data Observations on Injury Occurrence across the Population," Presentation, IIHS Meeting on Protection of a Diverse Population, October 20, 2022

Foreman, J., Poplin, G., Shaw, G., McMurry, L., Schmidt, K., Ash, J and Sunnevang, C., "Automobile Injury Trends in The Contemporary Fleet: Belted Occupants in Frontal Collisions," Traffic Injury Prevention, 2019

Forman, J., Lopez-Valdes, F., Dennis, N., Kent, R., Tanji, H., and Higuchi, K., "An Inflatable Belt System in the Rear Seat Occupant Environment: Investigating Feasibility and Benefit in Frontal Impact Sled Tests with a 50th Percentile Male ATD," Traffic Injury Prevention, 2010.

Gabler, H., and Hollowell, W., "NHTSA.s Aggressivity and Compatibility Research Program," Proceedings of the 16th ESV Conference, Paper Number 98-S3-O-01, 1998a.

Gabler, H., and Hollowell, W., "The Aggressivity of Light Trucks and Vans in Traffic Crashes", SAE 980908, 1998b.

Goto, M., Kitagawa, Y., Schießler, M., Eggers, A., "Comparison of Chest Responses between THOR 50th Percentile Dummy and THUMS AM50 Version 4 in Frontal Oblique Impact with Inflatable Seatbelt," Paper IRC-20-23, International Research Conference on Biomechanics of Injury, 2020.

Haight, S, Biss, D. and Samaha, R.; Analysis of seat belt positioning in recent NCAP crash tests; SAE Technical Paper No. 2013-01-0460, 2013, Hu, J., Fischer, K., Schroeder, A., Boyle, K., Adler, A., & Reed, M., "Development of Oblique Restraint Countermeasures," (Report No. DOT HS 812 814). Washington, DC: National Highway Traffic Safety Administration, October 2019.

IIHS, "Moderate Overlap Frontal Crashworthiness Evaluation 2.0 Crash Test Protocol," Version I, December 2022.

Ishikawa, H., Digges, K., Ennis, J., "Vehicle Collision Force in Offset Barrier and Car to Car Offset Tests," 1996 International Conference on the Biomechanics of Impact", p. 189-200, September 1996.

Ishikawa, H., Digges, K., Ennis. J., "Impact Force Vector on Offset Frontal Collision", Transactions of Japanese Society of Automotive Engineers, October (in Japanese), 1996b.

Jermakian, J., "Are Vehicle Crashworthiness Improvements Benefiting Men More than Women," Keynote Presentation, IIHS Meeting on Protection of a Diverse Population, October 20, 2022

Joksch, H., Massie, D., and Pichler, R., "Vehicle Agressivity: Fleet Characterization Using Traffic Collision Data," DOT HS 808 679, February, 1998.

Kallina, I., Scheunert, D., Scheerer, J., Breitner, R., and Ziedler, F., "Injuries to the Lower Leg," Proceedings of International Conference on Pelvic and Lower Extremity Injuries, p. 211-218, NHTSA Sponsored, Washington DC, December 4-6, 1995.

Mallaris, A., Hedlund, J, and Hitchcock, R., "A Search for Priorities in Crash Protection," SAE 820242, 1982.

Miller T., Pindus N., Leon T., & Douglass J., "Motor Vehicle Injury Costs by Body Region and Severity," Proceedings of the 34th Annual Conference of the Association for the Advancement of Automotive Medicine, Scottsdale, AZ, 1990.

Mertz, H., Prasad, P. and Irwin, A., "Injury Risk Curves for Children and Adults in Frontal and Rear Collisions," SAE973318, 41st Stapp Car Crash Conference, 1997.

Morgan, R., Eppinger, R., and Hennessey, B., "Ankle Joint Injury Mechanism for Adults in Frontal Automotive Impact," 35th Stapp Car Crash Conference. 1991.

Prasad, P., "Motivations, Studies, and Actions Regarding Vehicle Crash Pulse Control," Briefing to NHTSA Washington DC, Feb 19, 2008

Prasad, P., Laituri, T., and Sullivan, "Estimation of AIS3+ Thoracic Injury Risks of Belted Drivers in NASS Frontal Crashes," Paper D15603, Special Issue I Mech E p.591-609, 2004.

Rudd, R. "Updated Analysis of Lower Extremity Injury Risk in Frontal Crashes in the United States," 21st International Technical Conference on the Enhanced Safety of Vehicles Conference (ESV), Stuttgart, Germany, June 15-19, 2009.

Sahraei, E., Digges, K., and Marzougui, D., "Effects of Vehicle Front-End Stiffness on Rear Seat Dummies in NCAP and FMVSS208 Tests," Traffic Injury Prevention, Vol. 14, Issue 6, 2013.

Sahraei, E., and Digges, K., "Trend of Rear Occupant Protection in Frontal Crashes Over Model Years of Vehicles," SAE 2009 -01- 0377, 2009

Samaha R, Digges K, Fesich T, Authaler M, "Frontal Crash Testing and Vehicle Safety Designs: A Historical Perspective Based on Crash Test Studies," SAE Paper 2010 01-1024, 2010.

Saunders, J., and Parent, D., "Repeatability and Reproducibility of Oblique Moving Deformable Barrier Test Procedure," SAE Paper 1018-01-1055, 2018.

Saunders, J., Parent, D., and Adams, E., "NHTSA Oblique Crash Test Results: Vehicle Performance and Occupant Injury Risk Assessment in Vehicles with Small Overlap Countermeasures," Paper 15-0108, ESV Conference, 2015

Saunders, J., Craig, M., and Parent, D., "Moving Deformable Barrier Test Procedure for Evaluation Small Overlap/Oblique Crashes," SAE International Journal for Commercial Vehicles, p. 171-195, 2012.

Summers, S., Hall, I., Parent, D., and Koen, T., "Occupant Response Evaluation in Flat, Full-Frontal Rigid Barrier Impact Testing," NHTSA Report DOT HS 813 014, June 2021.

Yoganandan, N., Pintar, F., Boynton, M., Brgeman, P., Prasad, P., Kuppa, S., Morgan, M., and Eppinger, R., "Dynamic Axial Tolerance of the Human Foot-Ankle Complex," SAE 962426, 1996

Viano, D., and Prasad, P., "Physics of Car Crashes: Design Concepts for Safer Cars," Encyclopedia of Automotive Engineering (print edition) ISBN: 978-0-470-97402-5, 2014

APPENDIX A

Table A1

Average Cost of Injury in US$ 000s (1988 prices) from Miller, et al (1990).

	INJURY SEVERITY					
BODY	Minor	Moderate	Serious	Severe	Critical	Maximum
REGION	(AIS = 1)	(AIS = 2)	(AIS =3)	(AIS = 4)	(AIS = 5)	(AIS = 6)
EXTERNAL	*3*	*16*	*45*	*73*	*106*	*644*
HEAD	4	19	78	180	636	644
FACE	4	19	78	103	211	644
NECK	4	19	78	103	211	644
CHEST	3	16	45	73	106	644
ABDOM/PELVIC	3	16	45	73	106	644
SPINE	3	16	105	905	1082	644
UPPER X	4	28	66			
LOWER X	3	28	84	124	*211*	

Table A2

AIS 2-6 Injuries to FEMALES in Well-defined Frontal Crashes by Body Region and Age Groups

BODY REGION	16 TO 49 YRS	50 TO 99 YRS	ALL	16 TO 49 YRS	50 TO 99 YRS	% of Body Regions
HEAD/NECK	26,354	14,055	40,410	65%	35%	18%
FACE	2,943	269	3,212	92%	8%	1%
THORAX	10,923	40,283	51,206	21%	79%	23%
ABDOMEN	8,614	7,513	16,127	53%	47%	7%
SPINE	6,490	16,317	22,808	28%	72%	10%
UPPER X	29,004	16,355	45,359	64%	36%	21%
LOWER X	18,417	22,210	40,627	45%	55%	18%
ALL	102,745	117,003	219,748	47%	53%	100%

Table A3

AIS 2-6 Injuries to FEMALES in Well-defined Frontal Crashes by Body Region and DeltaV Groups

BODY REGION	01 - 47 KPH	48 - 126 KPH
HEAD/NECK	90%	10%
FACE	43%	57%
THORAX	65%	35%
ABDOMEN	32%	68%
SPINE	71%	29%
UPPER X	83%	17%
LOWER X	51%	49%
ALL	69%	31%

Table A4

AIS 2-5 Weighted Thorax and Lower Extremity Injuries in CISS 2017-2020 Well-defined Frontal Crashes by Age, Gender and Crash Severity

	AGE / GENDER			
01 - 47 KPH	16 TO 49 YRS		50 TO 99 YRS	
REGION_DESC	FEMALE	MALE	FEMALE	MALE
THORAX	1,989	14,902	23,588	16,894
LOWER EXTREMITY	5,741	4,612	8,704	2,797
	AGE / GENDER			
48 - 126 KPH	16 TO 49 YRS		50 TO 99 YRS	
REGION_DESC	FEMALE	MALE	FEMALE	MALE
THORAX	8,655	4,249	5,103	6,519
LOWER EXTREMITY	8,926	3,807	5,119	7,012

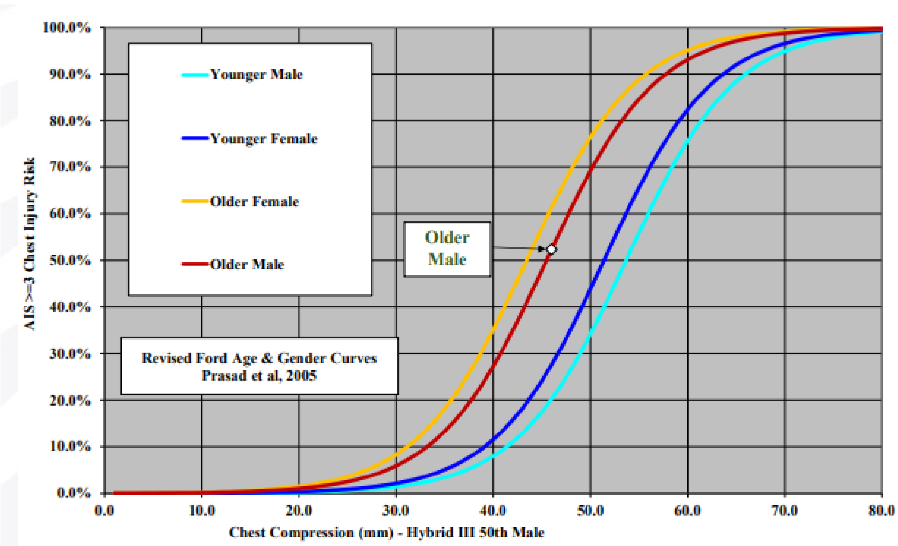


Figure A1. Risk of AIS 3+ Chest Injury Based on HIII 50% Male Dummy Measurements