COMPARISON OF THE HARMONIZED HYBRID III 5TH FEMALE DUMMY CHEST RESPONSE TO THE FTSS AND DENTON DUMMIES

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ABSTRACT

This paper will present a study comparing the chest response of the Humanetics Innovative Solutions Incorporated (HIS) Hybrid III 5th Percentile harmonized dummy with that of the Denton ATD (DN) and First Technology Safety Systems (FTSS) 5th percentile dummies. This study focuses specifically on the differences in the chest jacket designs, comparing the harmonized chest jacket used on the HIS dummy developed through the SAE technical working group in 2009 that was formed to address differences between the chest jackets of the two dummy brands at the time; Denton and FTSS chest jackets. The authors will present data from chest impact tests conducted in accordance with Part 572.134 Thorax impact. Additionally data will be presented for chest impacts conducted in accordance with SAE J2878. This test method produces chest deflections which are more inline with the deflection amounts typically seen in full scale vehicle testing conducted in the US New Car Assessment Program (NCAP). Additionally, controlled sled testing was conducted to compare the response observed in the chest impact testing to the chest deflections generated during seatbelt loading. For the sled test a 8 g ½ sine wave pulse with a duration of 175 msec. was selected, again, because it generated chest deflection amounts typically seen in the U.S. NCAP 35 mph frontal barrier test (15~20mm). Additionally, three belt positions were used to study the chest response for the three chest jackets depending on belt placement; a nominal position as well the shoulder belt position shifted 50 mm inboard and 50 mm outboard. All three dummies fell within the corridors of the Part 572.134 chest impacts required for FMVSS 208 with harmonized dummy having slightly less deflection 50 mm versus 51 and 52 mm for the FTSS and Denton dummies respectively. Chest impacts conducted per SAE J2878 showed the same tendency as Part 572.134 chest impacts with the harmonized dummy again showing slightly lower deflections than the FTSS and Denton dummies. Sled testing results showed the same tendencies as the chest impact tests with the HIS dummy with the harmonized chest jacket showing ~2mm lower chest deflection than the FTSS and DN dummies. It was also noted that the deflection amounts for all three dummies tend to be very sensitive to belt placement. Specifically, the deflection tended to be less if the belt remains on one of the dummy's breasts for the duration of the test; compared to cases where belt slips off the breast during the loading.

BACKGROUND

Before Denton ATD Inc. (DN) and First Technology Safety Systems (FTSS) merged to form Humanetics Innovative Solutions Inc. (HIS) in 2009, DN and FTSS were each making a version of the 5th percentile small female Hybrid III dummy. Differences in the physical characteristics between the two versions of the dummy were evident despite the dummy design and calibration requirements being formally documented in regulation (49 CFR Part 572 Subpart O). Most notably for the current study were differences in the design and construction of the dummy's chest jacket. Furthermore, neither the FTSS or DN chest jackets fully complied with the drawing requirements in Part 572.

The Hybrid III 5th Percentile chest jacket consists of a simulated flesh material and breast anthropmentry which covers the thorax of the dummy. The chest jackets produced by DN and FTSS differed in terms of material stiffness and breast location, geometry, and composition. These differences were thought to result in performance and calibration differences between dummies using either of the jackets, and previous studies attempted to quantify those effects. In particular, Tylko et. al. identified potential for differences in measured chest deflection between the two dummy brands particularly with respect to how the seatbelt interacted with the differences in the dummy's chest jacket geometry [1]. As such NHTSA currently allows manufacturers to select which dummy brand to use for testing under applicable Federal Motor Safety Standards (FMVSS) compliance testing as well as frontal testing under the New Car Assessment Program (NCAP).

Due to these differences, an effort was launched by the SAE Human Biomechanics and Simulations Standards Committee Hybrid III Task Force to develop a hamonized chest jacket design. The redesign was ultimately completed by Humanetics and documented in SAE Standard J2921 (Jan2013) "HIII5F Chest Jacket Harmonization." Figure 1 shows the three different variations of the Hybrid III 5th percentile female chest jacket.

Figure 1.
Comparison of Harmonized (HIS) Chest Jacket to the DN and FTSS brand for the Hybrid III 5th Percentile Female Dummy [2]

The purpose of this study was to build on the the previous work, providing a comparison of the chest stiffness of the Hybird III 5th percentile dummy with the HIS harmonized chest jacket to the DN and FTSS brand dummies. This investigation was accomplished using two different chest impact test procedures and a belted sled test. During the sled tests, three belt positions were used to evaluate the impact of belt positioning on chest response as well as potential differences in how the belt interacted with the geometry of the three chest jackets.

METHODS

The purpose of this research study was to study the differences in the chest response of the harmonized chest jacket of the HIS dummy compared to the DN and FTSS 5th percentile dummies. To accomplish this, the study was divided into three portions.

1. High Speed Chest Impacts: Conducted in accordance with Part 572.134 Thorax impact
2. Low Speed Chest Impacts: Conducted in accordance with SAE J2878
3. Controlled Sled Testing

High Speed Chest Impacts

The high speed chest impact tests were conducted in accordance with the Code of Federal Regulations (Part 572.134 Thorax Impact). This testing was conducted to ensure that each dummy's chest response is within the regulatory limits. A total of four dummies were used; two HIS dummies, one DN, and one FTSS. Each dummy was soaked in an environment with a relative humidity ranging from 10%-70% until the dummy's ribs reached a stable temperature between the range of 69°F to 72°F. The dummy was then seated on a flat steel surface without back and arm support. The pelvic angle was set to 13° via standard FMVSS 208 protocol. The test probe was aligned relative to the dummy's rib (See Figure 2). A test probe within the regulatory specifications was used; 14.19 kg and diameter of 152.37 mm. A 6.7 m/s probe velocity was used. Each dummy included a potentiometer installed inside the sternum which was used to measure the horizontal deflection of the sternum relative to the thoracic spine. [3]

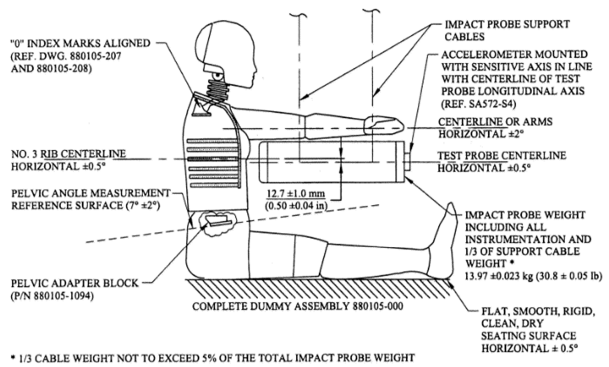

Figure 2.
High speed thorax impact test set-up specifications [3]

Low Speed Chest Impacts

The low speed chest impact was conducted to study chest responses similar to that typically seen in full scale vehicle testing under NHTSA's New Car Assessment Program (NCAP) of 15-20 mm. Tests were conducted in accordance with SAE J2878. A total of four dummies were used; two HIS dummies, one DN, and one FTSS (same dummies as the high speed chest impacts). Each dummy was dressed in standard t-shirt and pants. The chest flesh was removed for each dummy. The dummies were then soaked in an environment with a temperature ranging from 69°F to 72°F, for at least four hours, until the dummy's ribs reached a stable temperature between 69°F to 72°F. For each trial, the dummy was seated onto a fixture that consisted of a smooth, clean, and dry steel surface. The neck bracket upper and lower index locations were set to the zero position (Figure 3). Reference measurements were collected once the dummy was seated into position. The chest flesh and t-shirt was re-installed onto the dummy. The dummy would sometimes need to be repositioned correctly after the chest flesh was re-installed. Therefore, the reference points measured prior to chest jacket installation were used to adjust the dummy as needed.

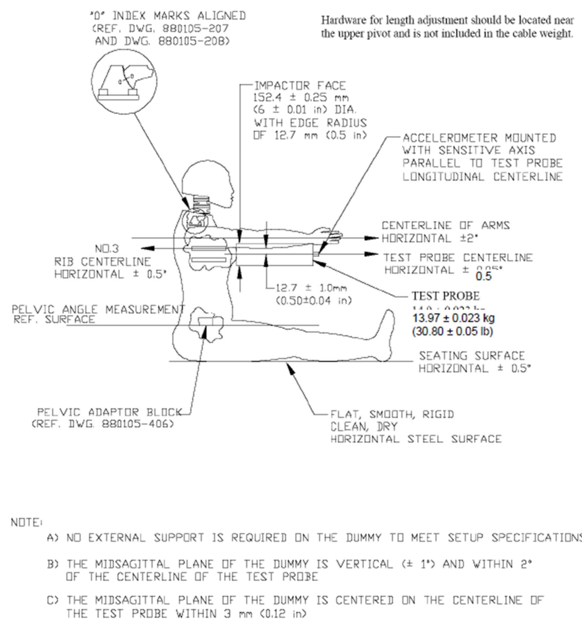

Figure 3.
Low speed thorax impact test set-up specifications [4]

The same test probe that was used for the high speed chest impacts was also used for this testing (152.37 mm diameter rigid cylinder with a total mass of 14.19 kg). The alignment of the probe with the dummy chest is shown in Figure 3. The probe's velocity upon impact was 3.00 m/s. Each dummy was tested for n=5 trials. [4]

Controlled Sled Testing

The test matrix shown in Table 1 was used for the controlled sled testing portion of this research study. This matrix was created with the purpose of comparing chest responses when mimicking belted seating positions. Also, different belt positions were utilized to study any potential influence the differences in the chest jacket geometry has on how the seatbelt interacted with the chest and thus influenced the chest response.

Belt Positions	ATD	Left Side Runs	Total Runs
Nominal	HIS #5159	2	
	HIS #1154	2	
	FTSS #494	1	
	DN #081	1	
			6
Neck ↖50 mm offset	HIS #5159	2	
	HIS #1154	2	
	FTSS #494	1	
	DN #081	1	
			6
Off shoulder ↘50 mm offset	HIS #5159	2	
	HIS #1154	2	
	FTSS #494	1	
	DN #081	1	
			6
			18

Table 1.
Controlled sled testing matrix

Sled Set-up: Dummies were seated on a rigid bench seat fixture. The seatbelt assemblies were standard vehicle 3-point ELR (emergency locking retractor) seatbelts without load limiters or pretensioners to minimize any potential testing variation. Figure 4 shows the sled test setup used. The nominal belt position was set to match a typical belt path (the belt layout of a mid-size SUV was used as a surrogate). Three belt postions were used as shown in Figure 5. The nominal belt position was centered on the shoulder with the belt passing between the breasts of the dummy. The off-shoulder position was shifted 50mm outboard placing it on the most distal portion of the shoulder skin and passed over the outer most breast. The neck collar position was shifted 50mm inboard flush with the edge of the neck skin. In this position the belt passed over the inner most breast. A portable coordinate measuring machine (CMM) was used to position the dummies and set the seatbelt to ensure repeatable results. [1]

Figure 4.
Controlled sled test set-up

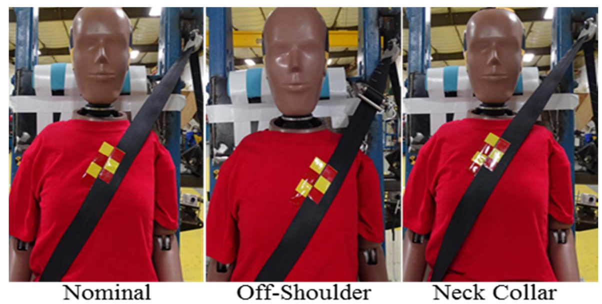

Figure 5.
Controlled sled testing belt positions

Sled Pulse: An 8 g ½ sine wave sled pulse with a 20 mph velocity change was used because this pulse achieved chest deflections of that seen in full scale vehicle NCAP testing (~15-20 mm). The resulting pulse shape and repeatability is illustrated in Figure 6.

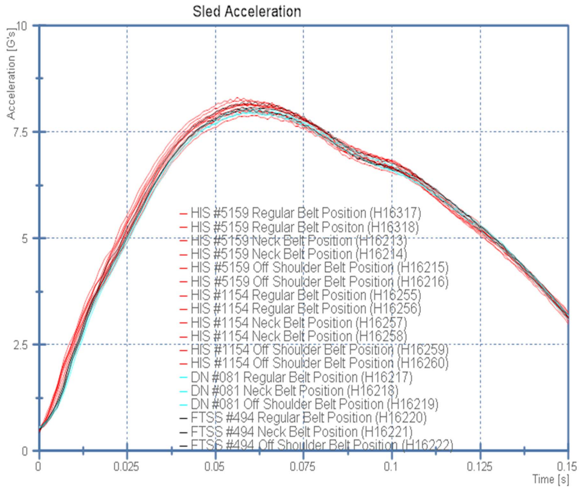

Figure 6.
Sled pulse overlay from simulation target of 8 g

Instrumentation: High-speed video cameras were installed for each test; Front onboard, Left rear onboard, left off board, right off board, and overhead. Data collection and filtering was conducted in accordance with SAEJ211. The dummies were instrumented as shown below:

1. Head tri-axial accelerometers x, y, z
2. Chest deflection x
3. Chest triaxial accelerometers x, y, z
4. Pelvis triaxial accelerometers x, y, z
5. Lap belt load
6. Shoulder belt load

RESULTS AND DISCUSSION

The HIS dummies had slightly lower chest deflections for all types of testing conducted (high speed and low speed chest impacts, and sled testing). In general, dummies showed a similar chest response effect of lower chest deflections when the belt placement was shifted away from the nominal chest position. Shifting the seatbelt away from the nominal position also resulted in more variation in results due to differences in breast-belt interaction during chest loading.

High Speed Chest Impacts

Dummy peak deflection, and internal hysteresis were examined. All tested dummies fell within the corridors of Part 572.134 chest impacts required for FMVSS 208. The probe speed during each test was within the regulatory corridor of 6.59 m/s to 6.83 m/s. The peak force for each test fell within the regulatory corridor of 3,900 N to 4,400 N (See Figure 7). The HIS dummies experienced lower resistive forces by at least 125 N compared to the FTSS and DN dummies but were still within the corridor.

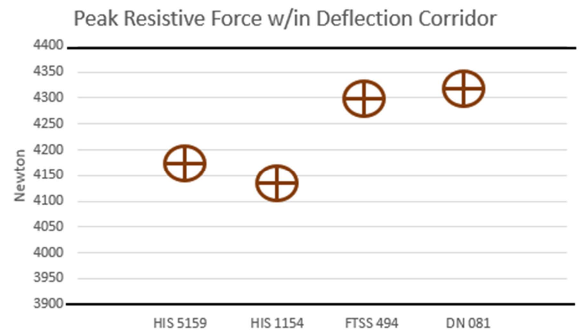

Figure 7.
High speed testing dummy peak resistive force during deflection corridor

Peak chest deflections ranged from 50 mm to 52 mm which fell within the regulatory corridor of 50 mm to 58 mm, with the HIS dummies showing slightly stiffer response. Specifically, both of the tested HIS dummies showed chest deflections of 50 mm while the FTSS and DN dummies had chest deflections of 51 mm and 52 mm respectively (See Figure 8).

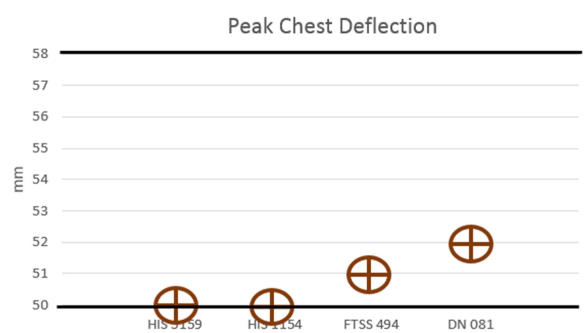

Figure 8.
High speed testing dummy peak chest deflection

The internal hysteresis was calculated for each test by taking the ratio of the loading area versus unloading area of the chest deflection versus resistive force graph (See Figure 9).

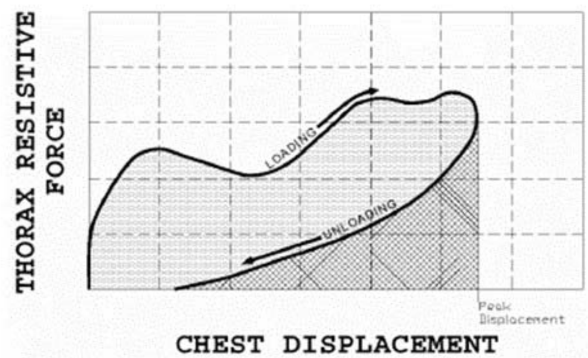

Figure 9.
High speed testing hysteresis calculation definition

The calculated hysteresis ranged from 73% to 76%; the HIS dummies showing slightly higher hysteresis (76% for both dummies) compared with the FTSS and DN dummies (73% for both). However, all dummies were within the regulatory corridor of 69% to 85% (See Figure 10).

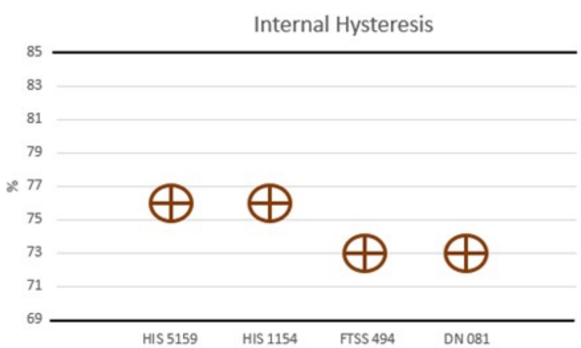

Figure 10.
High speed testing dummy internal hysteresis

Low Speed Chest Impacts

Dummy chest deflection, peak chest force, and hysteresis were examined. Similar to the high speed chest impacts, the HIS dummies consistently showed slightly lower deflection but still fell within the corridor of 17.4 mm to 21.8 mm, Figure 11 shows the chest deflection versus time for all tests.

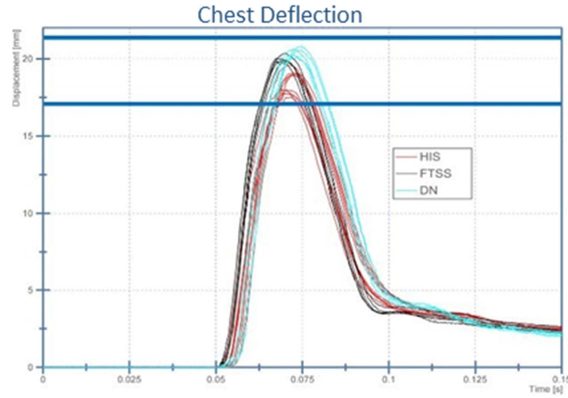

Figure 11.
Low speed testing, deflection vs. time

Box-and-whiskers plots were used to analyze each result. Again, the chest deflection of all dummies fell within the specified corridor. The HIS dummies showed more variation, however, this is likely due to the fact that the test samples of the HIS data was collected using two dummies (5 samples of each dummy) compared with one dummy of the DN and FTSS. All tests fell within the SAE J2878 chest deflection and peak chest force corridors, however, the chest deflection for the HIS dummies was stiffer compared to the FTSS and DN dummies (See Figure 12). This is as expected given the slightly lower chest deflections (See Figure 13).

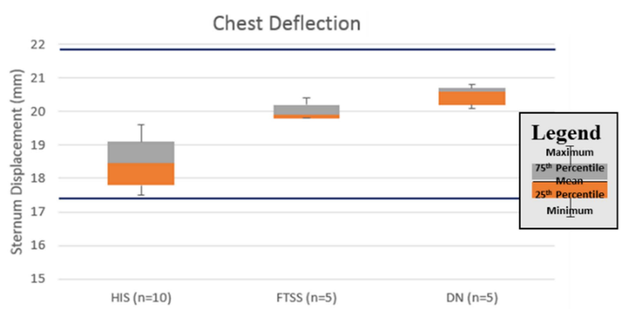

Figure 12.
Low speed testing dummy chest deflection

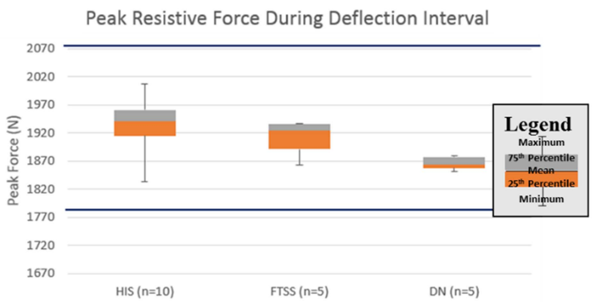

Figure 13.
Low speed testing dummy peak force during chest deflection interval

All HIS dummy trials fell outside of the hysteresis corridor. The DN and FTSS dummies generally fell within the corridor except for one trial of the FTSS dummy. (See Figure 14).

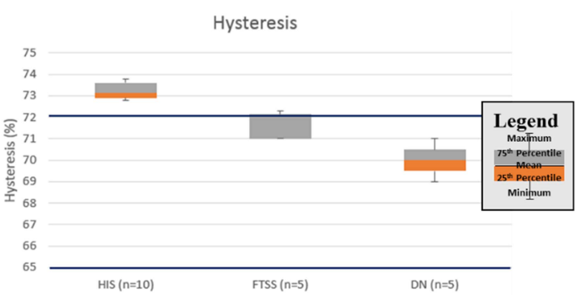

Figure 14.
Low speed testing dummy hysteresis

Figure 15 shows the chest deflection versus chest resistive force from which the hysteresis is calculated (the worst-case sample of each dummy is shown). While the FTSS and DN dummies showed very similar response, with each dummy's chest resistive force plateauing at 1,400~1,600 N for the first 10 mm of chest deflection; then ramping up to 1,846 N and 1,879 N respectively until the peak deflection was achieved. The HIS dummies showed a slightly different shape where the resistive force continues to ramp up until the peak deflection is achieved. The slightly different loading characteristic in the low speed chest impacts results in slightly higher hysteresis results for the HIS dummies.

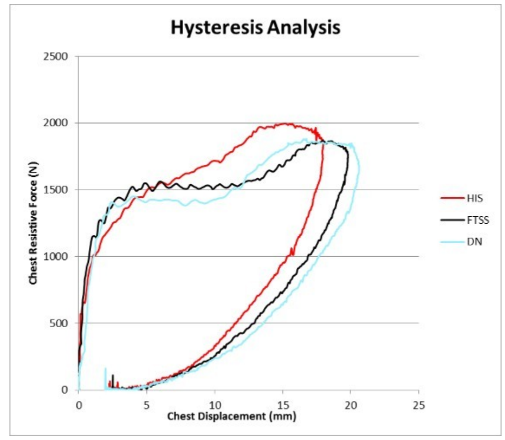

Figure 15.
Low speed testing dummy chest deflection versus resistive force

Controlled Sled Testing
Chest deflection and chest acceleration was analyzed for all three belt positions.

Nominal Belt Position: HIS had slightly lower chest deflections than that of the FTSS and DN dummies, which was consistent with the results of the chest impact tests. HIS dummies showed measured chest deflections between 17.1 mm to 18.3 mm while FTSS and DN both showed measured chest deflections of 19 mm (See Figure 16).

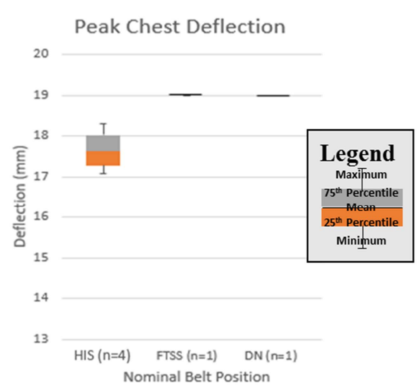

Figure 16.
Controlled sled testing chest deflection for the nominal belt position

The chest acceleration for the HIS dummies ranged from 19.5 g to 21.9 g and was comparable to the acceleration measured for the FTSS and DN dummies, 20.8 g and 21.5 g respectively (See Figure 17).

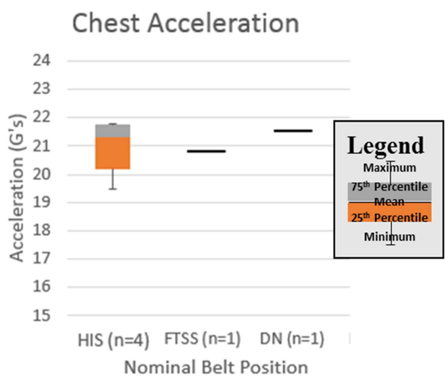

Figure 17.
Controlled sled testing chest acceleration for the nominal belt position

Neck Collar Belt Position (Belt over the inboard breast): Chest deflection measurements tended to be lower than the nominal belt position, ranging from 17.0 mm to 17.9 mm for the HIS dummies. Out of the four HIS trials, one trial was eliminated due to loss of data. Chest deflection also decreased for both FTSS and DN dummies compared to the nominal belt position (See Figure 18). In most cases, as the dummy loaded the belt, the belt tended to shift back to the nominal position between the breasts. However, in the test with the FTSS dummy the belt remained on the dummy breast, as opposed to shifting back to the nominal belt position (centered between the breasts), in this case the deflection was significantly lower compared with the HIS and DN dummies (See Figure 18 and 19). Given that the chest deflection appeared to decrease if the shoulder belt remained on the breast the authors studied which chest jacket had greater likelihood for the belt to shift back to the nominal position of the belt centered between the breasts. To do this the authors compared the time the belt began to shift back to centered between the breast for all three dummies, assuming that the earlier the belt began to shift back to nominal to more likely it is for the chest jacket geometry of the different dummies to encourage the belt to shift back to nominal (centered between the breasts). The HIS dummy's belt consistently began to shift back to nominal before the DN dummy (at least 8 msec.). This believed to be due to the different geometry of the breast jackets between the two dummies. Based on this limited data the HIS dummy chest jacket geometry tended to allow the belt to shift back to the nominal position more easily than the DN jacket and FTSS (which did not allow the belt to shift back). However, since only one sample of the FTSS and DN dummies were collected further testing is required to understand the potential differences caused by the differences in breast geometry between the three chest jackets in more detail.

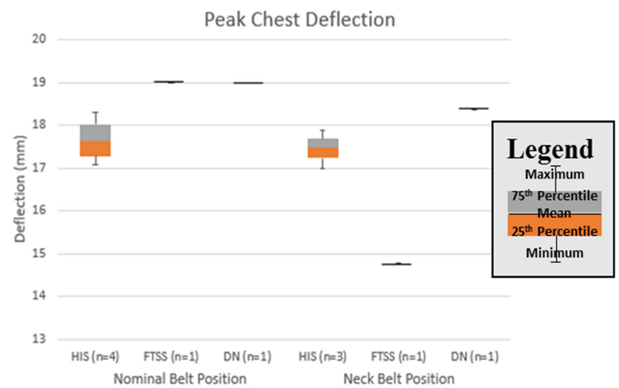

Figure 18.
Controlled sled testing chest deflection for the nominal and neck collar belt positions

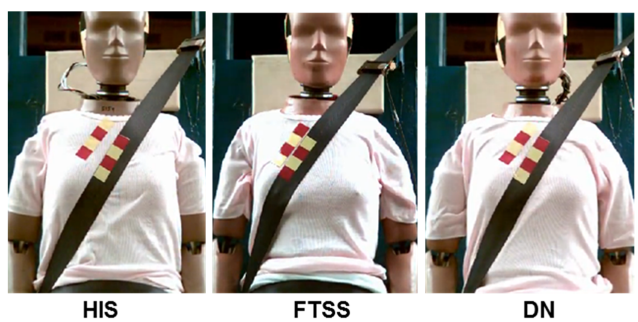

Figure 19.
Controlled sled testing neck collar belt position (video shot at 55 msec.)

The chest acceleration for the HIS dummies ranged from 20.4 g to 22.4 g compared to 23.0 g and 22.6 g for FTSS and DN respectively. In general, for all dummy types, chest acceleration slightly increased for the neck collar belt position as shown in Figure 20 and did not appear to be sensitive to if the belt shifted back to the nominal position as was the case for the chest deflection.

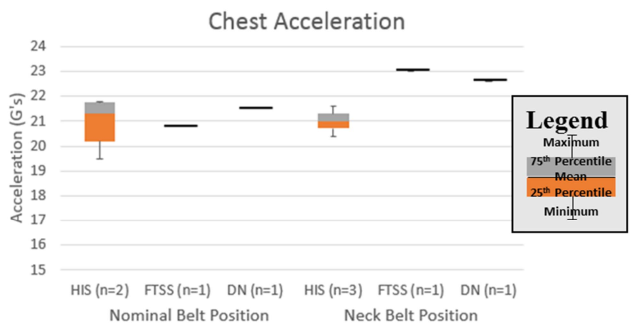

Figure 20.
Controlled sled testing chest acceleration for the nominal neck collar belt positions

Off-Shoulder Belt Position: Chest deflection measurements ranged from 16.1 mm to 18.3 mm for the HIS dummies. Chest deflections for FTSS and DN were 18.8 mm and 19.4 mm respectively (See Figure 21). As in the case with the neck collar belt position, the shoulder belt shifted back to the nominal belt position centered between the breast as the dummy began to load the belt. When comparing the timing the belt shifts back to the nominal belt positon (off of the breast), the DN dummy shifted back to nominal more than 15 ms earlier than the other two dummies. This could potentially be why the DN dummy experienced an increase in chest deflection as compared to the nominal belt position trial. However, further testing is required to understand the potential differences caused by the differences in breast geometry between the three chest jackets under this belt position.

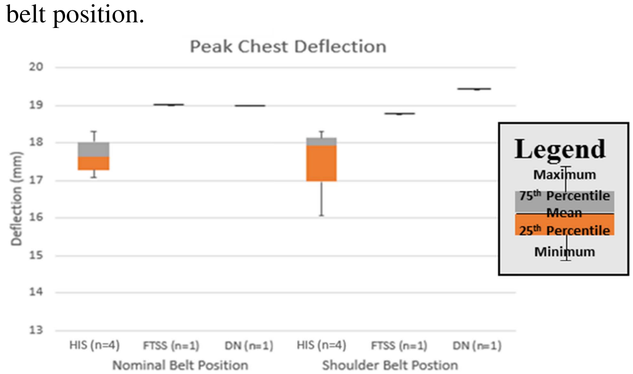

Figure 21.
Controlled sled testing chest deflection for the nominal and off-shoulder belt positions

The chest acceleration for the HIS was slightly lower (19.4 g to 20.5 g) than the FTSS and DN (20.7 g and 21.7 g) dummies respectively (See Figure 22) and again did not appear to be sensitive to the timing of when the belt shifted back to the nominal positon between the belts.

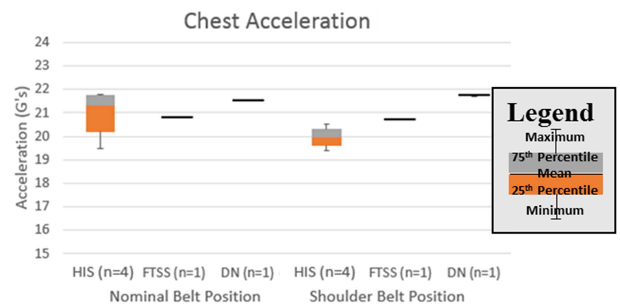

Figure 22.
Controlled sled testing chest acceleration for the nominal and off-shoulder belt positions

CONCLUSION

This study analyzed the differences in chest response between the HIS dummy with the harmonized chest jacket compared to the FTSS and DN dummies currently used in FMVSS 208 and the U.S. NCAP program.

High Speed Chest Impacts: All three dummies met the regulation corridors of Part 572.34 Thorax impacts. However, the HIS dummies with the harmonized chest jacket showed slightly lower chest deflections by 1-2 mm. Additionally the chest probe force was also slightly higher (~125N) as well as the hysteresis (3% higher) for the HIS dummies compared with the FTSS and DN dummies.

Low Speed Chest Impacts: While still falling within the corridor specified by SAE J2878, The HIS dummies showed slightly lower chest deflections than the DN and FTSS dummies, similar to differences seen during the high speed testing. As expected, the HIS dummies also had slightly higher probe peak forces than the other two types of dummies, but still falling within the SAE J2878 corridor. However, all HIS trials had higher hysteresis when compared to the FTSS and DN trials and were outside the corridor specified in SAE J2878. This was a function of slight differences in loading characteristics of the HIS dummies with the harmonized chest jacket in the low speed chest impacts.

Controlled Sled Testing: The HIS dummies showed the same tendency as the chest impacts where the HIS trials would generally showed lower chest deflection regardless of belt position than the FTSS and DN trials. When belt was positioned over the inboard breast the belt tended to shift back to the nominal positon between the breasts for the HIS and DN dummies as opposed to the FTSS dummy in which the belt remained on the breast for the duration of the test which was the only case where the FTSS chest deflection was less than the HIS dummies. Furthermore in the tests of the HIS dummies the belt shifted back to the nominal positon between the breasts sooner than the DN dummy (at least 8 msec. earlier) or the FTSS dummy (did not shift back to the nominal position). This is likely due to the differences in breast structure geometry and stiffness, however, more trials are needed since only one sample was conducted for the DN and FTSS dummies. As with the belt positioned at the neck collar, the off-shoulder belt position also showed the tendency for the belt to shift back to the nominal belt position. However, in this condition the DN dummy showed the shoulder belt shifting back to the nominal position 15 msec. earlier than the HIS and FTSS dummies (which showed similar timing). This yielded an increase in the chest deflection for the DN dummy compared to the nominal belt position where as the HIS and FTSS dummies showed deceases in the chest deflection compared with the nominal belt position. Again, this could be due to the unique breast structure geometry of the DN dummy but further trials need to be conducted to determine factors given only one sample was collected for the DN and FTSS dummies.

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REFERENCES

[1] Tylko/ Transport Canada, Suzanne, Kazuo Higuchi/ Takata, Schuyler St. Lawrence/ Takata, Alain Bussieres/ PMG Technologies, and Jean Marc Flore/ PMG Technologies. *A Comparison Of Hybrid III 5th Female Dummy Chest Responses In Controlled Sled Trials*. Tech. no. 2006-01-0455. Detroit: SAE World Congress, 2006. *SAE International*. Web. 09 Feb. 2016.

[2] The ATD Harmonization Task Group, comp. *The Brand Harmonization of the Hybrid III 5th Small Female Crash Test Dummy*. 880105-000. N.p.: Humanetics Innovative Solutions, Inc., 2012. Print.

[3] “Thorax Assembly and Test Procedure." 49 "CFR" 572.134. 2009.

[4] *Low Speed Thorax Impact Test Procedure for the HIII5F Dummy*. Tech. no. J2878. Warrendale: SAE International, 2010. Print. SURFACE VEHICLE RECOMMENDED PRACTICE.