BIOFIDELITY EVALUATION OF THE WORLDSID 5TH PERCENTILE FEMALE SIDE IMPACT ATD FITTED WITH A MODIFICATION KIT

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ABSTRACT

The purpose of this paper is to present findings from a biofidelity assessment of the WorldSID 5th percentile female side impact anthropomorphic test device with a modification kit (WorldSID 5F with mod kit). The modifications were proposed by the WorldSID 5th Technical Evaluation Group to reduce interference (bottoming out) in the neck, shoulder and pelvis areas to improve durability. The modification kit also included design changes to the neck and lumbar hardware to produce a posture that would position the head further forward to provide a broader range of head protection evaluations. The modification kits were supplied by Humanetics Innovative Solutions.

A subset of ISO/TR 9790:1999 pendulum, sled and drop tests were conducted to evaluate biofidelity of the neck, shoulder, thorax, abdomen and pelvis. The impact surfaces of the load plates and pendulums were scaled for use with a 5th percentile female. The sled test fixture was similar to those used by the University of Heidelberg and Wayne State University and consisted of a side-facing, rigid bench covered with Teflon™ and a rigid, segmented impact wall.

The biofidelity of the WorldSID 5F with mod kit did not meet the expected overall biofidelity rating of good. The neck, shoulder, thorax, abdomen, and pelvis have fair biofidelity. The overall biofidelity of the WorldSID 5F with mod kit is only fair.

The WorldSID 5F with mod kit was not durable in the rigid wall sled tests. Shoulder ribs deformed and in some cases new shoulder ribs fractured in their first test. Damage to wiring and instrumentation was also noted during the rigid wall sled tests. However, no damage was observed in the pendulum, drop or neck tests.

The WorldSID 5F with mod kit is less biofidelic than the reported good biofidelity of WorldSID 5F revision 1. However, when assessed in an identical subset of test conditions, the difference in biofidelity is insignificant. Furthermore, the WorldSID 5F with mod kit and the SID-IIs BLD have nearly identical overall biofidelity scores when they are assessed on the same subset of test conditions.

The WorldSID 5F with mod kit requires further design changes to improve its biofidelity and durability before it can be justified as an improvement over the SID-IIs BLD.

INTRODUCTION

The WorldSID Task Group was formed in 1997 to develop a world-harmonized, mid-size male, side impact dummy. Asia/Pacific, Europe, and North America contributed equally to the development costs and design decisions. Participants represented vehicle manufacturers, dummy and instrumentation manufacturers, research institutions and governments.

The WorldSID 5th percentile female (WorldSID 5F) was developed by the Advanced Protection Systems (APROSYS) European Commission Framework Program 6, beginning in 2004. Been et al. [1] published a biofidelity evaluation of the WorldSID 5F prototype. Biofidelity of the WorldSID 5F revision 1 (rev 1) was reported by Eggers et al. [2].

In 2011, the GRSP Working Group on Passive Safety formed the WorldSID 5th Technical Evaluation Group, an informal working group, to facilitate the evaluation and completion of the WorldSID 5F. Participants from around the world evaluated the WorldSID 5F rev 1. Humanetics Innovative Solutions designed and produced a modification kit to reduce interference, improve durability and change the seated posture. General Motors (GM) and Transport Canada volunteered to evaluate the biofidelity of the WorldSID 5F with the mod kit. A subset of ISO/TR 9790 [3] tests was conducted. This publication details the findings of the GM and Transport Canada biofidelity evaluations.

METHODS

WorldSID 5F with mod kit

The evaluations conducted at GM involved one WorldSID 5F with a modification kit. Contents of the mod kit are listed in Table 1. GM's WorldSID 5F was equipped with the standard content 2D IR-TRACCs in the thorax and abdomen.

Transport Canada conducted drop tests with a different WorldSID 5F with mod kit. The mod kit had a different build date, but the same parts as Table 1. In addition, it was instrumented with the RibEye™ instead of the 2D IR-TRACCs.

Table 1.
Modification kit parts list

Body Region	Description	Part No.
Head	Accel. mount	W5-00110
	ARS mount	W5-00204
	IES mount bracket	W5-00301
Neck	Lwr. neck load cell	W50-71001S5-M
	Lwr. neck bracket	W5-2030
	Upr. neck bracket	W5-2031
	Spacer, neck	W5-2134
	Plate, 4 deg. upr. neck	2110-4
Torso	String pot mount	W5-3157
	Shldr. accel. mount	W5-3158
	Shldr. mount plate	W5-3159
	Inner rib bracket	W5-3273
	String pot mount base	W5-3315
	Shldr. load cell guard	W5-7109
	Shldr. structural repl.	W5-3349
	Shldr. assy.	W5-3360
	Pot cover plate	3670-19
	IRTRACC pot brkt.	3670-20
	Spine box assy.	W5-3400
	Compl. thorax assy.	W5-3600
	Bushing lumbar side	W5-4034
	Interface brkt., left	W5-4210-1
	Interface brkt., right	W5-4210-2
	Lwr. lumbar mount	W5-4220
	Lumbar spine molded	W5-4225
	Lumbar load cell	W5-7112
	Instr. brkt. pelvis	W5-4230
	Clamp, lwr. lumbar	W5-4231
	Lumbar top bushing	W5-4234
	Clamp plate, pelvis	W5-4238
	Cable cover lumbar lc	W5-4239
	Pelvis flesh molded	W5-4240
	Lumbar mount wedge	W5-4241
	Clamp, upr. lumbar	W5-4242
	Instr. cover pad assy.	W5-4243
	Pubic buffer, mold.	W5-4250
	Pelvic bone, left	W5-4260-1
	Pelvic bone, right	W5-4260-2
	Hip socket assy.	W5-4262
	SI load cell	W5-7113
	Ring, inner hip joint	W5-4264
	Retainer, hip socket	W5-4265
Thigh	Femur ball	W5-5153
	Upr. leg flesh, left	W5-5010-1
	Upr. leg flesh, right	W5-5010-2

All results for the WorldSID 5F with mod kit presented in this report were conducted with the design intent 6 mm thorax pad.

Pendulum Tests

ISO/TR 9790 pendulum impacts to the shoulder, thorax and pelvis were conducted with pendulum masses and impact faces scaled to a 5th percentile female [3, 4, 5]. The pendulum for the shoulder and thorax tests had an impactor face diameter of 125 mm and a mass of 14 kg. The 10.14-kg pendulum for the pelvis test was 120 mm in diameter with an impactor face radius of curvature of 185 mm. Pendulum velocity was determined from laser speed traps.

The WorldSID 5F was positioned in an upright posture using the tilt sensors in the head, spine and pelvis. The WorldSID 5F was seated on two stacked sheets of Teflon™ which were on top of a flat surface. The shoulder, thorax and pelvis tests were conducted with the jacket on. The pelvis pendulum was centered on the greater trochanter.

Sled Tests

A HyGe™ system was used for all of the sled test evaluations. The sled test fixture consisted of a rigid bench covered with Teflon™ and was similar to the side impact test fixtures used with post mortem human subjects by the University of Heidelberg and Wayne State University (WSU).

For the ISO/TR 9790 neck tests, the WorldSID 5F was secured with straps around the shoulders, chest, hips and legs. Rigid wooden supports were used to constrain whole-body motion, without pre-loading the ribs. See Figure 1.

The University of Heidelberg and WSU tests used the same sled as the neck tests but without the constraints. See Figures 2 and 3, respectively. Table 2 gives the dimensions of the load wall plates that were used. The scaled load plates were aligned with the targeted body regions. Specifically, the thorax plate in the Heidelberg configuration was shifted downward to better align with the thorax ribs and the pelvis plate was shifted downward slightly to contact the greater trochanter and iliac wing, but not the lower abdomen rib. The spaces between the WSU plates were adjusted to better align with the WorldSID 5F geometry. The shoulder plate was centered on the shoulder socket. The thorax plate was positioned to cover as much of thorax ribs 1-3 as possible. The abdomen plate was positioned to contact abdomen ribs 1 and 2, but not the thorax ribs. Table 3 gives the dimensions of the gaps between the seat pan and various load plates.

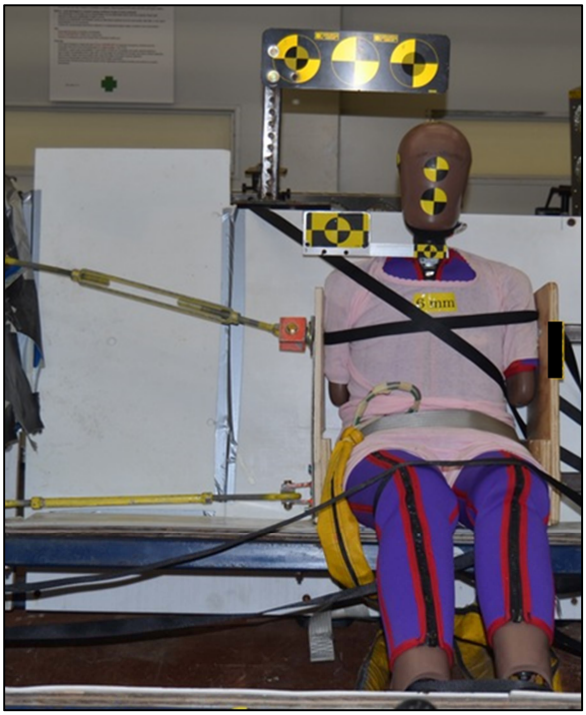

Figure 1. Neck test sled configuration.

For the Heidelberg tests, the thorax and pelvis load plates were each instrumented with four load cells and four accelerometers. For the Wayne State University tests, each load plate was instrumented with two load cells and two accelerometers.

A small sheet of Teflon under the WorldSID 5F and another sheet behind minimized friction, allowing the WorldSID 5F to maintain its pre-test posture. The WorldSID 5F and the smaller Teflon™ sheets slid across the Teflon™ sheets that were affixed to the bench surface. The sliding Teflon™ sheets were positioned such that they did not contact each other or the bight of the Teflon™ bench. They were tethered to prevent them from contacting the load wall during impact.

Figure 2. Heidelberg sled test configuration.

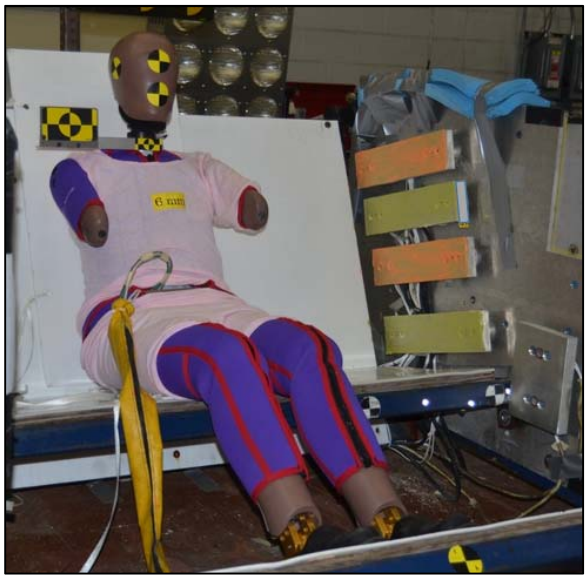

Figure 3. WSU sled test configuration.

Table 2.
Load wall plate dimensions

Test Condition	Plate	Height (mm)	Width (mm)
Heidelberg	Thorax	224	309
	Pelvis	179	309
Wayne State	Shoulder	91	359
	Thorax	91	359
	Abdomen	91	359
	Pelvis	91	359

Table 3.
Load wall plate spacing

Test Condition	Gap Location	Gap (mm)
Heidelberg	Pelvis to Thorax	45
	Seat Pan to Pelvis	15
Wayne State	Thorax to Shoulder	30
	Abdomen to Thorax	37
	Pelvis to Abdomen	78
	Seat Pan to Pelvis	34

The WorldSID 5F was placed on the bench at a distance from the load wall such that it would impact while the sled was travelling at a constant velocity. The pre-test shoulder-to-wall distance was calculated from the sled pulse. From test-to-test, the shoulder-to-load wall distance was maintained within ± 5 mm. The WorldSID 5F was positioned against the seatback in an upright posture using the tilt sensors in the head, spine and pelvis. The arms were positioned down along the side of the body for the Heidelberg tests and at a 15 degree angle down from horizontal for the WSU tests.

Drop Tests

The WorldSID 5F was suspended above the impact plates as shown in Figure 4. Nylon webbing restrained the ankles, knees and pelvis while webbing is secured to a bracket attached to the lower neck on the non-struck side. Each webbing harness was attached to electromagnets which were secured to a steel frame. To ensure greater control and stability the drop was carried out sequentially by first releasing the frame followed by the four electromagnets.

The impact plates and armrest height for the whole body drop tests were scaled to a 5th percentile female [4, 5]. Thorax plate dimensions were 305 mm x 305 mm and the pelvis plate was 406 mm x 305 mm. The armrest was 60 mm wide and 650 mm long. The offset between top of plates and the top of the armrest was 57 mm.

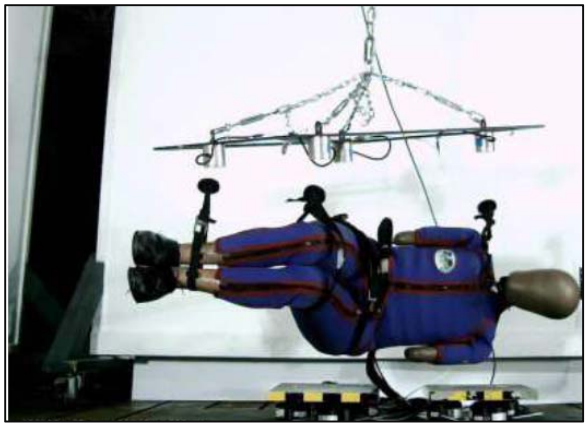

Figure 4. Drop test configuration.

Data Processing
All data were processed as described in ISO/TR 9790 [3], including the 100 Hz FIR filter for the thorax pendulum impacts and Heidelberg sled tests. All other tests were filtered according to SAE J211 [6]. Neither the pendulum, drop, nor sled test responses were scaled to correct for slight differences in velocity.

Load plate forces for the sled tests were compensated for inertia. This was accomplished by subtracting the product of plate mass and its acceleration from the sum of the loads for the plate, throughout the time history.

Time zero for the drop and rigid wall sled tests was determined similar to the SAE J2052 procedure for determining head contact [7]. Time zero for a test was determined by the earliest time that any load plate exceeded 5% of its peak load.

Biofidelity Assessment
Measurements from each test were evaluated against their respective scaled response corridor [4]. Those measurements within the corridor were given a score of 10. Those within one corridor width, either above or below the corridor, were given a score of 5. Corridors and corridor widths are given in Table A1. All other responses received a score of 0. Individual measurement scores from repeat tests were averaged. The weighting factors for individual measurement, test condition, and body regions given in ISO/TR 9790 [3] were used to calculate an overall biofidelity score. Table 4 categorizes the biofidelity scores into biofidelity ratings.

Table 4.
Biofidelity rating definitions

Biofidelity Score	Biofidelity Rating
$8.6 \leq B \leq 10$	Excellent
$6.5 \leq B < 8.6$	Good
$4.4 \leq B < 6.5$	Fair
$2.6 \leq B < 4.4$	Marginal
$0.0 \leq B < 2.6$	Unacceptable

RESULTS AND DISCUSSION

Biofidelity of WorldSID 5F with mod kit
Complete test results are given in Table A1.

Head Eggers et al. [2] reported excellent biofidelity of the WorldSID 5F rev 1 head in the 200 mm drop onto a rigid surface. Since the mod kit did not involve changes to the head, its biofidelity score of 10 was carried forward.

Neck The WorldSID 5F with mod kit had a score of 7.0 for Neck Test 1, the 7.2 G sled test. The peak flexion angle and peak vertical displacement of the head C.G. relative to T1 were 10 in all tests. The peak horizontal displacements of the head C.G. relative to T1 were within one corridor width below the corridor and scored 5 in all of the evaluations.

For Neck Test 2, the 6.7 G sled test, the score was only 2.3. The peak flexion angles were above the corridor, but within one corridor width above the upper bound. The peak bending moment about the A-P axis at the occipital condyles and peak shear force at occipital condyles were all well below their respective corridors.

In Neck Test 3, the 12.2 G sled test, the WorldSID 5F with mod kit scored 7.5. The peak flexion angle in Neck Test 3 scored all 10's. Peak lateral acceleration of the head C.G. values were below the corridor, but within one corridor width. Peak lateral acceleration of T1 values were within or just below the corridor. The neck biofidelity score for the WorldSID 5F with mod kit is 5.3.

Shoulder The WorldSID 5F with the mod kit had a biofidelity score of 7.1 in Shoulder Test 1, the 4.5 m/s pendulum impact. The pendulum force-time history, shown in Figure 5, is an example of a time-history response that was not within the corridor (solid boundary), but within one corridor width above the upper boundary (dashed boundary). The peak shoulder deflection was in the corridor.

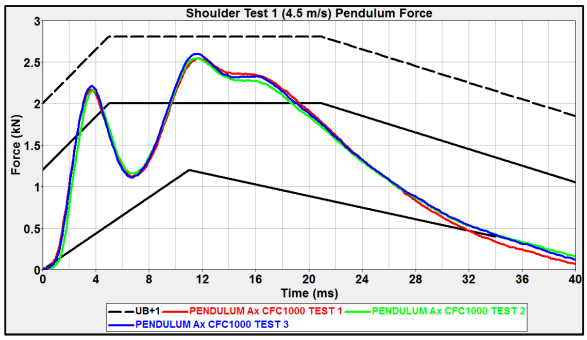

Figure 5. Pendulum force-time history from the 4.5 m/s shoulder pendulum test.

The biofidelity score in Shoulder Test 2, the 7.2 G neck sled test was only 2.5. The peak horizontal acceleration of T1 was within one corridor width below the lower boundary. The peak horizontal displacement of T1 was well above the upper boundary.

Shoulder Test 3, the 12.2 G neck sled test, had a biofidelity score of 6.7. Peak lateral acceleration of T1 was at the low end of the corridor or just below. Combining the results from Shoulder Tests 1, 2 and 3, the WorldSID 5F with mod kit shoulder has a biofidelity score of 5.4.

Thorax The pendulum force-time history and upper spine lateral acceleration-time histories from Thorax Test 1, the 4.3 m/s pendulum impact to the thorax of WorldSID 5F with mod kit, are shown in Figures 6 and 7, respectively. Figure 8 shows the pendulum force-time history from Thorax Test 2, the 6.7 m/s pendulum impact. The WorldSID 5F with mod kit received scores of 5.0 for both the 4.3 m/s and 6.7 m/s pendulum tests.

The WorldSID 5F with mod kit received a score of 6.6 in Thorax Test 3, the 1.0 m drop onto flat, rigid

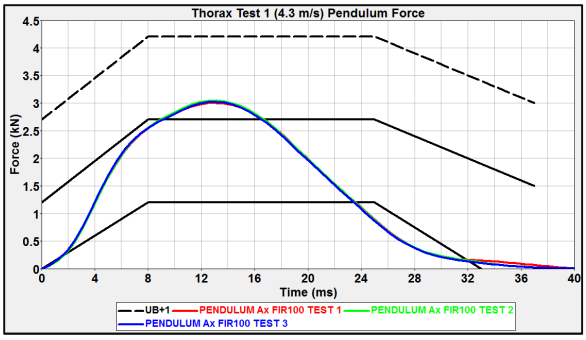

Figure 6. Pendulum force-time history from the 4.3 m/s thorax pendulum test.

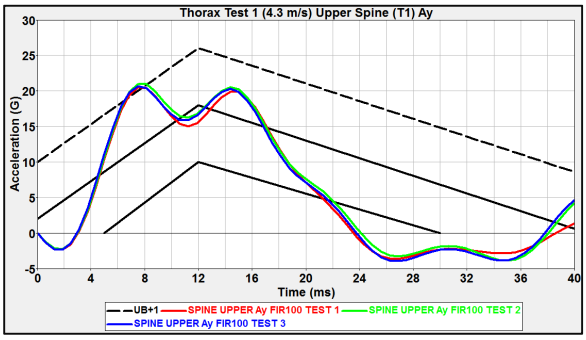

Figure 7. Upper spine lateral acceleration-time history from the 4.3 m/s thorax pendulum test.

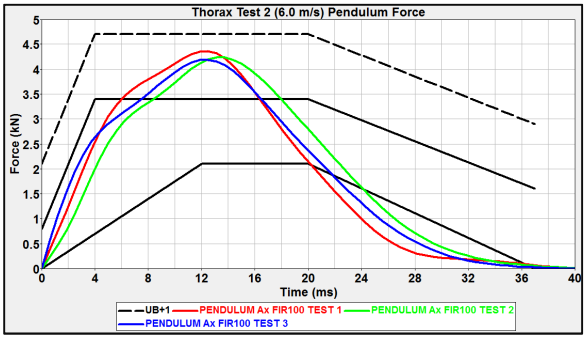

Figure 8. Pendulum force-time history from the 6.7 m/s thorax pendulum test.

surfaces. The thorax plate force was within or just under the lower corridor while peak deflection of impacted rib was near the upper boundary resulting in a mixture of 5's and 10's for both evaluations. Figure 9 shows the force time history for Thorax Test 3. The peaks after 30 ms were attributed to the WorldSID 5F head contacting the load plate.

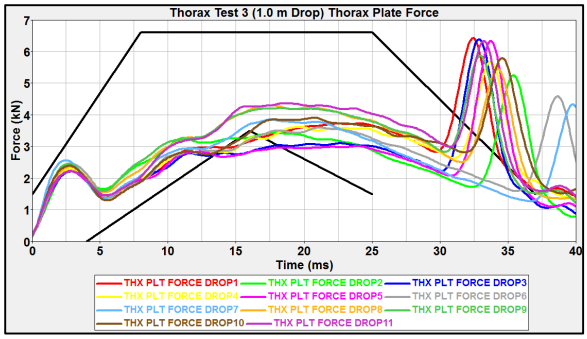

Figure 9. Thorax plate force-time history from the 1.0 m drop test.

The WorldSID 5F with mod kit received a score of 6.0 in Thorax Test 5, the 6.8 m/s rigid sled. The force-time histories of the thorax plate are within the corridor as shown in Figure 10. The peak lateral accelerations of T1 and T12 were both below the corridor. The peak lateral accelerations of the impacted rib (thorax rib 1) were one corridor width above the corridor. The WorldSID 5F with mod kit has a thorax biofidelity score of 5.5.

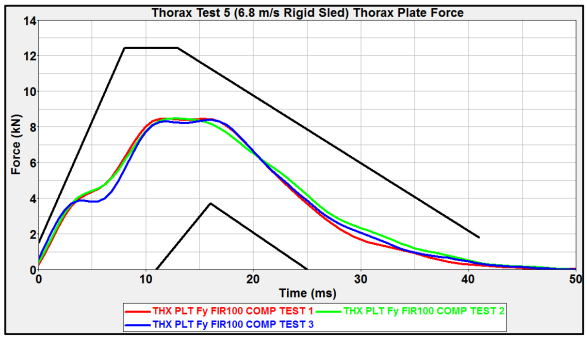

Figure 10. Thorax plate force-time history from the 6.8 m/s rigid sled test.

Abdomen The WorldSID 5F was evaluated in the 1.0-meter drop onto a rigid armrest and earned a score of 6.5. The armrest force results were slightly above the corridor resulting in scores of 5's. See Figure 11. The peak abdominal penetration values resulted in all 10's.

Results for the abdomen plate force in Abdomen Test 3 (6.8 m/s rigid sled) were just above the upper corridor. See Figure 12. The WorldSID 5F with mod kit has a biofidelity score of 6.1 for the abdomen.

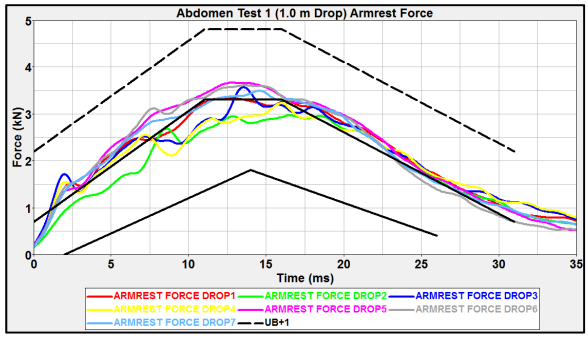

Figure 11. Armrest plate force-time history from the 1.0 m drop test.

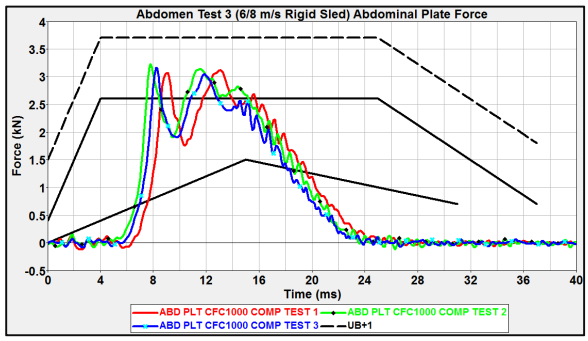

Figure 12. Abdomen plate force-time history from the 6.8 m/s rigid sled test.

Pelvis Pelvis Test 1, the 6.0 m/s pendulum impact, exhibited the best biofidelity of all evaluations of the pelvis. Figure 13 shows the peak pendulum force for three tests.

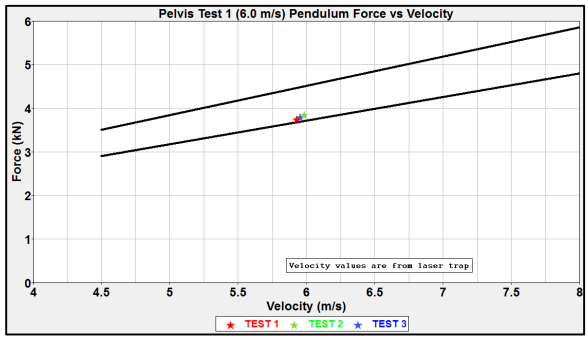

Figure 13. Pendulum velocity versus peak pendulum force from the 6.0 m/s pelvis pendulum impact.

For Pelvis Test 3, the 0.5 m drop onto rigid surfaces, and Pelvis Test 4, the 1.0 m drop onto rigid surfaces, the scores were 0.8 and 0.0 respectively.

Pelvis Test 7, the 6.8 m/s rigid sled test in the Heidelberg configuration, received a score of 4.4. The peak pelvis plate forces were well above the upper bound, while the peak pelvis accelerations were within the corridor.

Pelvis Test 10, the 6.8 m/s rigid sled in the WSU configuration, earned a score of 2.2. Figure 14 shows the pelvis plate force-time histories, which are well above the upper boundary of the corridor. The WorldSID 5F has a biofidelity score of 4.6 for the pelvis.

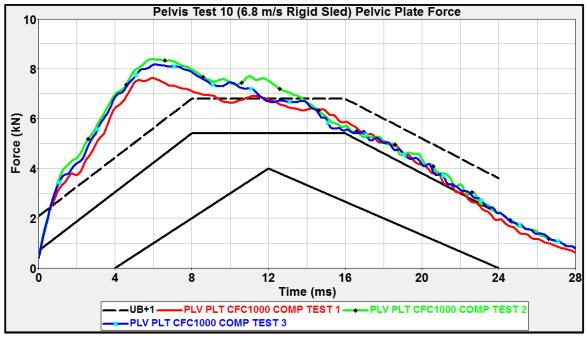

Figure 14. Pelvis plate force-time history from the 6.8 m/s rigid sled test.

Overall

All body regions that were evaluated had only fair biofidelity. The biofidelity of the head as reported by Eggers [2] was used in calculating the overall biofidelity of the WorldSID 5F with mod kit. The overall biofidelity score for the WorldSID 5F with mod kit is 6.1, which is only fair.

Durability

After seven tests in the WSU configuration, the inner and outer bands of the shoulder rib bent. See Figure 15. The third test in the Heidelberg configuration also bent the inner and outer bands of the shoulder rib

The final test in the WSU configuration fractured a new shoulder outer rib. The complete separation occurred near the posterior edge of the shoulder rib clamp. In the same test, components near thorax rib 1 were damaged. See Figure 16. It appears that the

Figure 15. Bent inner (top) and outer (bottom) shoulder ribs from WSU 6.8 m/s sled test.

inner rib was compressed all the way to the wire mounting block. The inner rib sheared the zip tie holding the wires to the mount. The outer covering of one wire was nicked.

Figure 16. Cut zip tie (left) and nicked wire (right) from direct contact by inner thorax rib 1.

After the second Heidelberg 6.8 m/s rigid sled test (Thorax Test 5/Pelvis Test 7) one of the accelerometers on the lower spine was dented. A spike in the acceleration data was noted and inspection revealed the dented accelerometer. No damage to the WorldSID 5F was observed during any of the pendulum, drop or neck/shoulder sled tests.

In several WSU sled tests, the Diversified Technical Systems G5 data acquisition module in the thigh lost data despite passing the pre-test system checks. Neither of the G5 modules in the thorax experienced data loss. After an extensive investigation, it was determined that static discharge from the Teflon™ seat surface through the WorldSID 5F thigh to the G5 Interposer casing caused the G5 to reset. An additional ground wire was added from the casing of the G5 Interposer to a common ground in the spine of the WorldSID 5F. It is expected that tests in a vehicle environment would not produce the same amount of static electricity as that generated by the Teflon™ sheets sliding across the Teflon™ covered bench seat.

Comparison of WorldSID 5F with mod kit to WorldSID 5F rev 1

Table 5 summarizes the biofidelity scores by body region for the WorldSID 5F with mod kit along with those for WorldSID 5F rev 1 from Eggers et al. [2]. The WorldSID 5F with mod kit has only fair biofidelity, while the WorldSID 5F rev 1 was reported to have good biofidelity. The flaw in this simple comparison is that the two versions of the WorldSID 5F were evaluated under different subsets of the tests in ISO/TR 9790 [3]. WorldSID 5F with mod kit was evaluated in all three neck test conditions, while WorldSID 5F rev 1 was not. Conversely, WorldSID 5F rev 1 was evaluated in padded sled tests, while WorldSID 5F with mod kit was not. Since some biofidelity test conditions are more challenging than others, this section attempts to reevaluate their biofidelity in an identical subset of tests to determine if the mod kit degraded the biofidelity of WorldSID 5F.

The mod kit did not include changes to the head. Head Test 1, the 200 mm head drop test, was not conducted with the WorldSID 5F with mod kit as it is assumed to have the same excellent biofidelity as WorldSID 5F rev 1.

Table 5.
Biofidelity scores of WorldSID 5F with mod kit and WorldSID 5F rev 1

Body Region	WorldSID 5F with mod kit	WorldSID 5F rev 1 [2]
Head	not tested	10
Neck	5.3	6.5
Shoulder	5.4	7.4
Thorax	5.5	6.9
Abdomen	6.1	8.5
Pelvis	4.6	6.5
Overall	6.1	7.6

When tested with the mod kit, the WorldSID 5F received a biofidelity score of 7.0 in Neck Test 1, the 7.2 G sled test. Although Eggers et al. [2] acknowledged that changes to the shoulder and arm may influence the response of the neck, they did not conduct any of the ISO/TR 9790 neck tests with the WorldSID 5F rev 1. Instead, they reassessed the results from WorldSID 5F prototype in Neck Test 1 from Been et al. [1] to corridors based on a "new scaling method" and reported a biofidelity score of 6.5.

Shoulder Test 1, the 4.5 m/s pendulum impact, was conducted with both versions of WorldSID 5F and both received a biofidelity score of 7.1. In Shoulder Test 2, the 7.2 G sled test, WorldSID 5F with mod kit had a score of 2.5. The WorldSID 5F rev 1 was not subjected to Shoulder Test 2, but Eggers et al. [2] carried over the score of 6.3 from the WorldSID 5F prototype despite changes made to the shoulder and arm for rev 1.

WorldSID 5F with mod kit received biofidelity scores of 5.0 for both Thorax Test 1, the 4.3 m/s impact, and Thorax Test 2, the 6.0 m/s impact. The thorax biofidelity scores of WorldSID 5F rev 1 given in Table 8 of Eggers et al. [2] are inconsistent with the pendulum force-time histories for Thorax Test 1 and Thorax Test 2, shown in Figures 6 and 7, respectively, of the same publication. Each figure shows the responses of three impacts. Based on the pendulum force-time histories for Thorax Test 1, the WorldSID 5F rev 1

should have received an average score of 5. For Thorax Test 2, it should have received an average score of either 1.7 or 3.3, depending on whether the scores for the individual tests are 0, 0, 5 or 0, 5, 5. For the thorax pendulum tests, both versions of WorldSID 5F have fair biofidelity.

For Thorax Test 5, the 6.8 m/s rigid sled test, the biofidelity scores of WorldSID 5F rev 1 and WorldSID 5F mod kit are identical, with only one exception. The thorax plate force-time history of one test with WorldSID 5F rev 1 was just outside the upper boundary. The other two tests of the WorldSID 5F rev 1 and all three test of the WorldSID 5F with mod kit were just within the upper boundary. For the 6.8 m/s rigid sled tests, both versions of WorldSID 5F have fair biofidelity.

Both versions of WorldSID 5F were evaluated in Abdomen Test 3, the 6.8 m/s rigid sled test. They received identical biofidelity scores of 5.0.

The WorldSID 5F with mod kit was evaluated in Pelvis Test 1, the 6.0 m/s pendulum impact, with the 10.1-kg, spherical-face impactor specified by Irwin et al. [5]. Tests with the WorldSID 5F rev 1 were conducted with a 14-kg impactor, but the geometry of the impactor face was not reported. Eggers et al. [2] scaled the results to estimate the responses of a 10.1-kg impactor. Both the WorldSID 5F rev 1 and WorldSID 5F with mod kit had excellent biofidelity in Pelvis Test 1.

Pelvis Test 7, the 6.8 m/s rigid sled test in the Heidelberg configuration, was conducted with both versions of WorldSID 5F. Differences in the test conditions and data processing make a direct comparison of the responses more difficult. The captions for Figures 22 and 23 of Eggers et al. [2] indicate a velocity of 7.6 m/s. The pelvis plate forces labeled "ISO normalized" are 33% to 35% higher than the data labeled "EEVC Normalized," despite the lower sled velocity specified in ISO/TR 9790. The data without normalization are not provided and neither the ISO normalization nor EEVC normalization are defined. Given the preceding caveats, it is not possible to confirm that the WorldSID 5F rev 1 with a score of 2.2 is actually less biofidelic than the WorldSID 5F with mod kit score of 4.4 for Pelvis Test 7.

In Pelvis Test 10, the 6.8 m/s rigid sled test in the WSU configuration, the width of the pelvis plate used with WorldSID 5F rev 1 was 264 mm [8] while that used with WorldSID 5F with mod kit was 359 mm wide. The figure caption indicates that the WorldSID 5F rev 1 pelvis plate force was "ISO normalized." Two of the three force-time histories have peak values greater than the upper boundary plus one corridor width, which would lower the score for WorldSID 5F rev 1 from 5.0 reported by Eggers et al. [2] to 3.1 for Pelvis Test 10. This compares to a score of 2.2 for WorldSID 5F with mod kit. Both versions of WorldSID 5F are rated unacceptable in Pelvis Test 10.

When considering only the biofidelity scores in Table 5, one could conclude that the WorldSID 5F with mod kit is less biofidelic than the WorldSID 5F rev 1. However, when the comparison is limited to those test conditions under which both were evaluated, there is little difference in biofidelity. See Table 6. It is difficult to differentiate the effects on the biofidelity score attributable to the mod kit versus those resulting from differences in test procedures and data processing.

Table 6.
Regional and overall biofidelity scores of WorldSID 5F with mod kit and WorldSID 5F rev 1 for equivalent tests

Body Region	WorldSID 5F with mod kit	WorldSID 5F rev 1 [2]
Head	not tested	10
Neck	5.3	not tested
Shoulder	7.1[a]	7.1[a]
Thorax	6.0[b]	5.5[b]
Abdomen	5.0	5.0
Pelvis	7.9[c]	8.1[c]

[a] Results from Shoulder Test 1 only
[b] Results from Thorax Test 5 only
[c] Results from Pelvis Tests 1 & 10 only

Comparison of WorldSID 5F with mod kit to SID-IIs BLD

SID-IIs went through several revisions and build level changes during its federalization into Part 572 [9]. Part 572, Subpart V defines the SID-IIs Build Level D (BLD), which was previously referred to as SID-IIs BLD+ by the Occupant Safety Research Partnership. Its overall biofidelity score was reported as 6.2, or fair. However, the evaluation included padded impact tests that could not be conducted with WorldSID 5F with mod kit. Table 7 compares the biofidelity of WorldSID 5F with mod kit and SID-IIs BLD over an identical subset of the test conditions. Although there were changes in some of the body region scores, the overall score remains the same. At this time, replacing SID-IIs BLD with WorldSID 5F cannot be justified on the basis of improved biofidelity.

Table 7.
Regional and overall biofidelity scores of WorldSID 5F with mod kit and SID-IIs BLD for equivalent tests

Body Region	WorldSID 5F with mod kit	SID-IIs BLD
Head	10	7.5
Neck	5.3	5.1
Shoulder	5.4	6.2
Thorax	5.5	7.0
Abdomen	6.1	6.8
Pelvis	4.6	4.5
Overall	6.1	6.2

Biofidelity improvement of WorldSID 5F

The WorldSID 5F Biofidelity Improvement Task Group was organized by Humanetics Innovative Solutions to propose changes to the WorldSID 5F to improve the biofidelity, making it significantly better than SID-IIs BLD. The task group will perform an engineering evaluation of the current WorldSID 5F. Proposed changes will be presented to the Technical Evaluation Group for approval.

CONCLUSIONS

The biofidelity for the WorldSID 5F with mod kit is fair, which is not as good as the published biofidelity of the WorldSID 5F rev 1. However, when the two versions are compared against an identical subset of ISO/TR 9790 tests there is little difference in their biofidelity scores.

The overall ISO/TR 9790 biofidelity score for WorldSID 5F with mod kit is nearly the same as the SID-IIs BLD. Before the WorldSID 5F is accepted for use, the durability should be improved and the biofidelity of each body region should be good or excellent.

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REFERENCES

[1] Been, B., Meijer, R., Bermond, F., Bortenschlager, K., Hynd, D., Martinez, L., and Ferichola, G. 2007. "WorldSID Small Female Side Impact Dummy Specifications and Prototype Evaluation." 20th International Technical Conference on the Enhanced Safety of Vehicles, Paper 07-0311

[2] Eggers, A., Schnottale, B., Been, B., Waagmeester, K., Hynd, D., Carroll, J., Martinez, L. 2009. "Biofidelity of the WorldSID Small Female Revison1 Dummy." 21st International Technical Conference on the Enhanced Safety of Vehicles, Paper 09-0420

[3] ISO/TR 9790. 1999. "Road Vehicles - Anthropomorphic Side Impact Dummy – Lateral Impact Response Requirements to Assess the Biofidelity of the Dummy." International Standards Organization, American National Standards Institute, NY, NY

[4] Irwin, A. L., Mertz, H. J., Elhagediab, A. M., and Moss, S. 2002. "Guidelines for Assessing the Biofidelity of Side Impact Dummies of Various Sizes and Ages." Stapp Car Crash Journal 46: 297-319

[5] Irwin, A. L., Mertz, H. J. 2010. “Rationale for and Dimensions of Impact Surfaces for Biofidelity Tests of Different Sizes of Frontal and Side Impact Dummies.” Stapp Car Crash Journal 54: 19-32

[6] Society of Automotive Engineers. 2014. “Surface Vehicle Recommended Practice J211-1 Instrumentation for Impact Test - Part 1 – Electronic Instrumentation.” Warrendale, PA

[7] Society of Automotive Engineers. 2011. “Surface Vehicle Information J2052 – Test Device Head Contact Duration Analysis.” Warrendale, PA

[8] Ferichola, G., Guerra, L.J., Garcia, A. 2007. “INSIA WSU Barrier Scaling to 5th Percentile.” APROSYS Technical Report AP SP52 0055

[9] NHTSA. 2006. Anthropometric Test Devices; “SID-IIs Side Impact Crash Test Dummy 5th Percentile Adult Female.” Final Rule, Federal Register, vol. 71, no. 240

Table A1.
ISO/TR 9790 measurements and scaled corridors used to assess the biofidelity of test results from WorldSID 5F with mod kit.

ISO/TR 9790 Tests	Measurement (Unit)	Corridor	Width	Test Results				
Neck 1 & Shoulder 2	Peak horiz displ head wrt T1 (mm)	121-151	30	115	112	120		
	Peak vert displ head wrt T1 (mm)	80-118	38	110	116	115		
	Time of peak head excursion (s)	0.161-0.177	0.016	0.169	0.168	0.170		
	Peak head lat accel Ay (G)	8-11	3	9.2	9.1	9.4		
	Peak head vert accel Az (G)	10-13	3	9.3	9.5	9.2		
	Peak flexion angle (degrees)	56-75	19	67	66	67		
	Peak twist angle (degrees)	-57 to -41	16	Could not calculate				
	Peak T1 lat accel Ay (G)	15-22	7	10.1	10.9	11.0		
	Peak horiz displ T1 wrt sled (mm)	38-51	13	72.6	73.6	75.5		
Neck 2	Peak flexion angle (degrees)	51-64	13	65	67	71		
	Peak moment Mx at O.C. (Nm)	34-43	9	18.9	19.1	19.5		
	Peak moment My at O.C. (Nm)	17-26	9	1.7	3.1	3.4		
	Peak moment Mz at O.C. (Nm)	10-13	3	3.9	3.8	4.2		
	Peak shear Fx at O.C. (N)	261-321	60	46	59	57		
	Peak shear Fy at O.C. (N)	602-682	80	329	325	316		
	Peak tension Fz at O.C. (N)	357-408	51	324	369	352		
	Peak resultant head accel (G)	18-24	6	13.5	13.5	12.8		
Neck 3	Peak head lat accel Ay (G)	25-47	22	10.2	10.4	10.6		
	Peak horiz displ head wrt sled (mm)	185-226		218	212	208		
	Peak flexion angle (degrees)	79-95	16	81	81	81		
	Peak twist angle (degrees)	79-95	16	Could not calculate				
Shoulder 1	Pendulum force (kN)		0.8	See Figure 5				
	Peak shoulder deflection (mm)	28-33	5	29.7	30.4	30.0		
Shoulder 3	Peak T1 lat accel Ay (G)	21-28	7	21.6	17.9	17.4		
Thorax 1	Pendulum force (kN)		1.5	See Figure 6				
	T1 lat accel Ay (G)		8	See Figure 7				
Thorax 2	Pendulum force (kN)		1.3	See Figure 8				
Thorax 3	Thorax plate force (kN)		-	See Figure 9				
	Peak deflection of impacted rib (mm)	21-31	10	36	30	33	35	34
				31	33	33	34	33
Thorax 5	Thorax plate force (kN)		-	See Figure 10				
	Peak T1 lat accel Ay (G)	100-149	49	59.9	45.2	57.3		
	Peak T12 lat accel Ay (G)	87-131	44	68.7	62.0	73.0		
	Peak thorax rib 1 lat accel Ay (G)	78-122	44	163	156	155		
Abdomen 1	Armrest force (kN)		1.5	See Figure 11				
	Peak lower spine lat accel Ay (G)	35-43	8	38	32	33	30	
				38	38	35	-	
	Peak lat accel of impacted rib (G)	122-153	31	329	326	365	441	
				307	292	340	-	
	Peak abdominal penetration (mm)	≥33	-	37	44	40	38	
				38	37	38	-	
Abdomen 3	Abdomen plate force (kN)		1.1	See Figure 12				

Table A1 (continued).
ISO/TR 9790 measurements and scaled corridors used to assess the biofidelity of test results from WorldSID 5F with mod kit.

ISO/TR 9790 Tests	Measurement (Unit)	Corridor	Width	Test Results				
Pelvis 1	Pendulum force (kN)		-	See Figure 13				
Pelvis 3	Peak lat accel Ay (G)	46-56	10	30		33		34
				36		32		33
	Peak lat accel Ay (G)	78-95	17	56	53	54	55	53
				53	54	60	58	58
Pelvis 7	Peak pelvis plate force (kN)	4.6-5.6	1.0	7.37		7.25		7.41
	Peak pelvis lat accel Ay (G)	78-95	17	91.0		92.1		91.3
Pelvis 10	Peak pelvis plate force (kN)		1.4	See Figure 14				
	Peak pelvis lat accel Ay (G)	105-142		86.2		90.6		90.4