

WORLDSID PRODUCTION DUMMY BIOMECHANICAL RESPONSES

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ABSTRACT

The results of biomechanical testing of the WorldSID production dummy are presented in this paper. The WorldSID dummy is a new, advanced **Worldwide Side Impact Dummy** that has the anthropometry of a mid-sized adult male. Based on previous testing the dummy design was frozen and developed into a production version of the WorldSID dummy. This dummy has been tested to determine that the biofidelity of the dummy has not degraded during its development and refinement.

The response corridors are defined in the International Organization of Standardization (ISO) Technical Report 9790. This dummy has been subjected to a rigorous program of testing to evaluate its biofidelity. The dummy's head, neck, thorax, abdomen and pelvis were evaluated against the ISO technical report requirements. Testing included drop tests, pendulum impacts, and sled tests. The biofidelity rating of the WorldSID was calculated using the weighted biomechanical test response procedure developed by ISO.

The WorldSID dummy has an overall ISO Biofidelity rating of 8.0, which corresponds to an ISO classification of "good". In addition the dummy shows good repeatability and good reproducibility. A comparison of the WorldSID dummy biofidelity compared to other existing side impact dummies biofidelity ratings will also be provided.

INTRODUCTION

In November 1997, the WorldSID Task Group was formed under the auspices of the International Organization for Standardization (ISO) TC22/SC12/WG5 - Anthropomorphic Test Devices Working Group [1]. The Task Group's purpose was to develop a unique, technologically advanced side impact dummy. This dummy is intended to be a more biofidelic side impact dummy and to replace

the current side impact dummies in regulation and other testing.

Currently, six mid-sized male side impact dummies were available for regulatory, consumer information and development use. They are the USDOT-SID dummy [2]; the EuroSID-1 dummy [3]; the ES-2 dummy which is regulated in a European standard [4]; the ES-2re which is utilized in the United States side impact protection regulation [5]; the SID/H3 dummy which is utilized in the United States side impact protection regulation FMVSS-201 [6]; and the BioSID dummy [7]. All six dummies have different levels of biofidelity and none of these dummies has a "good" rating on its biofidelity using the ISO rating scale (Table 1). The six dummies are structurally different, have different instrumentation and associated injury assessment criteria. Partially because of these reasons, and the differences in the test procedures, these dummies typically provide different design direction to the vehicle development engineer.

Table 1.
ISO Biofidelity Classifications

Excellent	> 8.6 to 10.0
Good	> 6.5 to 8.6
Fair	> 4.4 to 6.5
Marginal	> 2.6 to 4.4
Unacceptable	0 to 2.6

The vision of ISO was to develop a harmonized dummy that would have technological buy-in from biomechanics, dummy and regulatory experts from around the world. To accomplish this, the Task Group was charged with developing the dummy's specifications, its design, and finally with fabricating and evaluating the dummy. The results of years of hard work by the WorldSID Task Group and Design Team will be presented in this paper.

The completed WorldSID dummy is shown in Figure 1.



Figure 1. WorldSID production dummy.

BIOFIDELITY RATINGS

The biofidelity rating method published in the International Standards Organization (ISO) Technical Report (TR) 9790 [8] was used for determining the WorldSID biofidelity rating.

Equation 1 is used to determine the overall biofidelity of the dummy.

$$B = \frac{\sum_{i=1,2,\dots,6} U_i B_i}{\sum_{i=1,2,\dots,6} U_i} \quad (1)$$

where,

- B - overall biofidelity rating which has a value between 0 (poorest) and 10 (best)
- B_i - biofidelity rating for each of the body regions
- U_i - weighting factor for each body region
- i - subscript to represent each body region (i=1 Head, i=2 Neck, i=3 Shoulder, i=4 Thorax, i=5 Abdomen and i=6 Pelvis)

The equation used to calculate the biofidelity of a body region B_i is shown in Equation 2.

$$B_i = \frac{\sum_{j=1,2,\dots,m} V_{i,j} T_{i,j}}{\sum_{j=1,2,\dots,m} V_{i,j}} \quad (2)$$

where,

- V_{ij} - weighting factor for each test condition for a given body region

T_{ij} - test biofidelity for each test condition for a given body region

The equation used to calculate the test biofidelity is shown in Equation 3.

$$T_{i,j} = \frac{\sum_{k=1,2,\dots,n} W_{i,j,k} R_{i,j,k}}{\sum_{k=1,2,\dots,n} W_{i,j,k}} \quad (3)$$

where,

W_{ijk} - weighting factor for each response measurement for which a requirement is given

R_{ijk} - the rating of how well a given response meets its requirement

Values for the response rating, R_{ijk} , are as follows:

$R_{ijk} = 10$ if the response meets its requirements

$R_{ijk} = 5$ if the response is outside of its requirement, but lies within one corridor width of requirement

$R_{ijk} = 0$ if response is outside of requirement by more than one corridor width of the requirement

Repeat runs were performed on the majority of the tests and response ratings were assigned to each run. The five ISO classifications were used to indicate the degree of biofidelity for each response target, test, body region and the overall biofidelity rating of the dummy. Tests that were not conducted are not included in the biofidelity rating.

BIOMECHANICAL TESTING

The WorldSID was tested in accordance with the ISO TR 9790 requirements. The dummies responses were compared with the response corridors that are defined in ISO TR 9790 for a 50th percentile adult male.

For the WorldSID, all the ISO TR 9790 biomechanical tests were conducted, with the following exceptions. Tests requiring APR and Wayne State University (WSU) padding were not conducted because of the unavailability of the padding or an acceptable alternative. The 2.0 m abdominal drop and the 8.9 m/s rigid wall sled test were considered too severe, so they were not

performed.

Head Test 1

This test consists of dropping the head from a 200 mm height onto a rigid surface (Figure 2). Targets are given for the head resultant acceleration.



Figure 2. Head drop configuration.

The peak head acceleration for the left side impact was 140.8 g. The peak acceleration for the right side of the head was 129.2 g. The left and right side of the head were within the response target range of 100 - 150 g. The results are in Table A1, Appendix A.

The Head Drop Test 1 biofidelity rating is 10, which corresponds to an ISO classification of "excellent".

Overall head biofidelity

The overall head biofidelity rating is 10, which corresponds to an ISO classification of "excellent".

Neck Test 1

This test consists of restraining the torso and pelvis of the dummy, with the arms down (Figure 3). The mean sled velocity was 6.9 m/s and average sled deceleration was 7.2 g, described in ISO TR 9790. Boundaries were given for lateral acceleration and displacement at T1, lateral and vertical head centre of gravity (CG) displacement relative to T1, the time of peak head excursion, lateral and vertical peak head acceleration, the peak lateral flexion angle and the peak twist angle.

Neck Test 1 results are in Tables A2, Appendix A.

The Neck Test 1 biofidelity rating is 7.4, which corresponds to an ISO classification of "good".

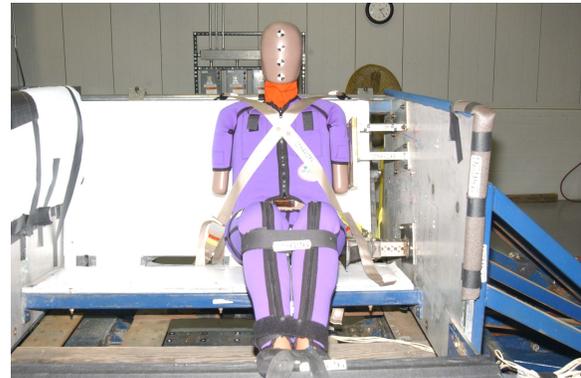


Figure 3. Neck Tests 1-3 configuration.

Neck Test 2

This test consists of restraining the torso and pelvis of the dummy, with the arms down (Figure 3). The sled velocity was 5.8 m/s and the constant deceleration level was 6.7 g. From this test, boundaries for peak flexion angle, peak forces and moments at the occipital condyles and peak head resultant acceleration were given.

Neck Test 2 results, are in Tables A3, Appendix A.

The Neck Test 2 biofidelity rating is 2.0, which corresponds to an ISO classification of "unacceptable".

Neck Test 3

This test consists of restraining the torso and pelvis of the dummy, with the arms down (Figure 3). An acceleration-type sled is accelerated to 12.2 g using the sled pulse described in ISO TR 9790. Boundaries are given for peak lateral T1 acceleration, peak lateral head CG acceleration, peak horizontal displacement of the head CG relative to the sled, peak flexion angle and peak twist angle.

Neck Test 3 results are in Table A4, Appendix A.

The Neck Test 3 biofidelity rating is 7.2, which corresponds to an ISO classification of "good".

Overall Neck Biofidelity

The overall neck biofidelity rating is 5.3, which corresponds to an ISO classification of "fair".

Shoulder Test 1

This test consists of impacting the shoulder, with the arm down, using a 23 kg, 150 mm diameter rigid pendulum impactor at 4.5 m/s. Targets are given for the pendulum force/time history and the maximum shoulder deflection.

The pendulum forces and peak shoulder deflections were within the response corridors. The peak shoulder deflections were 39, 37 and 40 mm, which are within the response target of 34-41 mm. The results are shown in Figure A1 and Table A5, Appendix A.

The Shoulder Test 1 biofidelity rating is 10, which corresponds to an ISO classification of "excellent".

Shoulder Test 2

This test consists of restraining the torso and pelvis of the dummy, with the arm down (Figure 3). The mean sled velocity was 6.9 m/s and average sled deceleration was 7.2 g, described in ISO TR 9790. Targets are given for peak horizontal T1 acceleration and peak horizontal T1 displacement.

The peak lateral T1 accelerations with respect to the sled were 16, 13, 13, 12, 12 and 12 g and the peak displacements with respect to the sled were 59.4, 53.6, 56.8, 53.9, 52.3 and 53.4 mm. These responses were within the response target corridors of 12-18 g and 46-63 mm, respectively. The results are in Tables A6, Appendix A.

The Shoulder Test 2 biofidelity rating is 10.0, which corresponds to an ISO classification of "excellent".

Shoulder Test 3

This test consists of restraining the torso and pelvis of the dummy, with the arms down (Figure 3). An acceleration-type sled is accelerated to 12.2 g using the sled pulse described in ISO TR 9790. Targets are given for T1 accelerations.

The peak T1 lateral accelerations with respect to the sled were 20.0, 17.9, 19.1, 17.2, 18.2 and 17.1 g. These responses were within the response target corridors of 17-23 g. The results are in Table A7, Appendix A.

The Shoulder Test 3 biofidelity rating is 10, which corresponds to an ISO classification of "excellent".

Overall Shoulder Biofidelity

The overall shoulder biofidelity rating is 10, which corresponds to an ISO classification of "excellent".

Thorax Test 1

This test consists of impacting the thoracic ribs, with the arm 90 degrees forward from vertical, using a 23.4 kg, 150 mm diameter rigid pendulum impactor at 4.3 m/s. Targets are given for the pendulum force and upper spine lateral acceleration.

The pendulum forces were within their respective response corridor and the upper spine lateral deflections were within one corridor width of their respective corridors. The results are shown in Figures A2-3 and Table A8, Appendix A.

The Thorax Test 1 biofidelity rating is 7.8, which corresponds to an ISO classification of "good".

Thorax Test 2

This test consists of impacting the thoracic ribs, with the arm 90 degrees forward from vertical, using a 23.4 kg, 150 mm diameter rigid pendulum impactor at 6.7 m/s. Targets are given for the pendulum force.

The pendulum forces were within the response corridor. The results are shown in Figure A4 and Table A9, Appendix A.

The Thorax Test 2 biofidelity rating is 10.0, which corresponds to an ISO classification of "excellent".

Thorax Test 3

This test consists of dropping the dummy laterally from a height of 1 m onto a continuous rigid plate, which spans the shoulder, thorax and abdomen regions with a separate plate for the pelvis region. The arm is rotated 20 degrees forward of the dummy's thoracic spine. Targets are given for the thoracic plate force and peak rib deflection.

All of the thoracic force plate loads were within the response corridors. The peak center thoracic rib displacements were 41, 42 and 30 mm. One of the rib displacements was within the response target corridor of 26-38 mm and two were within one corridor width. The results are shown in Figure A5 and Table A10, Appendix A.

The Thorax Test 3 biofidelity rating is 8.3, which

corresponds to an ISO classification of "good".

Thorax Test 5

This test requires a Heidelberg-type rigid wall sled impact at 6.8 m/s. Targets are given for the thorax plate force, peak lateral upper spine acceleration, peak lateral lower spine acceleration, and peak lateral acceleration of the impacted rib.

The thoracic region loading was within the thoracic force plate response corridors. One of the T1 accelerations was within one corridor width of the 82-122 g response target and twelve were greater than one corridor width. The peak T12 accelerations were within one corridor width of the response target of 71-107 g. The results are shown in Figure A6 and Table A11, Appendix A.

The Thorax Test 5 biofidelity rating is 6.4, which corresponds to an ISO classification of "fair".

Overall Thorax Biofidelity

The overall thorax biofidelity rating is 8.2, which corresponds to an ISO classification of "good".

Abdomen Test 1

This test consists of dropping the dummy laterally from a height of 1 m onto a simulated armrest, which protrudes 41 mm above a continuous rigid plate. The plate spans the shoulder, thorax and abdomen regions with a separate plate for the pelvis region. The arm is removed from the dummy to simulate the cadaver arm position. Targets are given for the armrest force, peak lower spine acceleration, peak impacted rib acceleration, and peak abdominal penetration.

The armrest force plate loads were within the response target corridor. The peak upper abdominal rib displacements were 50.9, 51.4 and 47.4 mm. The peak upper abdominal rib accelerations were 126.9, 130.9 and 193.3 g. The peak T12 accelerations were 32.0, 33.5 and 34.5 g. The abdominal rib displacements were within the response target of deflection greater than 41 mm. Two of the abdominal rib accelerations were within one corridor of the response corridor of 100-125 g and one was greater than one corridor width of the response corridor. All of the T12 accelerations were within the 29-35 g response corridor. The results are shown in Figure A7 and Table A12, Appendix A.

The Abdomen Test 1 biofidelity rating is 9.0, which

corresponds to an ISO classification of "excellent".

Abdomen Test 3

This test consists of a WSU-type rigid wall, deceleration sled (Figure 4) accelerated to 6.8 m/s. The dummy is seated on the sled with the arm at 45 degrees forward from vertical. A target is given for the abdominal plate force.

The abdomen force plate loads, except for local oscillations, were within the response corridor. The results are shown in Figure A8 and Table A13, Appendix A.

The Abdomen Test 3 biofidelity rating is 10, which corresponds to an ISO classification of "excellent".

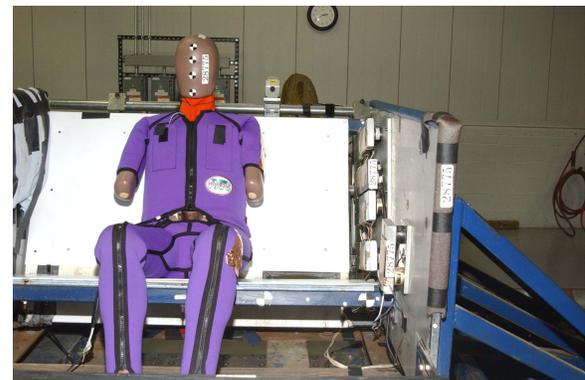


Figure 4. WSU-type sled test configuration.

Overall Abdomen Biofidelity

The overall abdomen biofidelity rating is 9.3, which corresponds to an ISO classification of "excellent".

Pelvis Test 1

This test consists of a rigid pendulum impact at 6 m/s. The impactor is defined as a 17.3 kg rigid impactor with a 600 mm radius of curvature and an outer diameter of 127 mm. A target is given for the pendulum force.

The peak forces were within the corresponding response corridors. The results are shown in Figure A9 and Table A14, Appendix A.

The Pelvis Test 1 biofidelity rating is 10.0, which corresponds to an ISO classification of "excellent".

Pelvis Test 2

This test consists of a rigid pendulum impact at 10 m/s. The impactor is defined as a 17.3 kg rigid impactor with a 600 mm radius of curvature and an outer diameter of 127 mm. A target is given for the pendulum force.

The peak force was within one corridor width of the corresponding response corridor. The results are shown in Figure A9 and Table A15, Appendix A.

The Pelvis Test 2 biofidelity rating is 5.0, which corresponds to an ISO classification of "fair".

Pelvis Test 3

This test consists of dropping the dummy laterally from a height of 0.5 m onto a continuous rigid plate, which spans the shoulder, thorax and abdomen regions with a separate plate for the pelvis region. The arm is rotated 20 degrees forward of the dummy's thoracic spine. A target is given for the peak pelvic acceleration.

The peak pelvic accelerations were 29.3, 31.2 and 30.2 g. All of the pelvic accelerations were within one corridor width of the 37-45 g response corridor. The results are shown in Table A16, Appendix A.

The Pelvis Test 3 biofidelity rating is 5.0, which corresponds to an ISO classification of "fair".

Pelvis Test 4

This test consists of dropping the dummy laterally from a height of 1 m onto a continuous rigid plate, which spans the shoulder, thorax and abdomen regions with a separate plate for the pelvis region. The arm is rotated 20 degrees forward of the dummy's thoracic spine. A target is given for the peak pelvic acceleration.

The peak pelvic accelerations were 45.6, 45.5 and 42.0 g. All of the peak pelvic accelerations were greater than one corridor width from the response corridor of 63-77 g. The results are shown in Table A17, Appendix D.

The Pelvis Test 4 biofidelity rating is 0, which corresponds to an ISO classification of "poor".

Pelvis Test 7

This test requires a Heidelberg-type rigid wall sled

impact at 6.8 m/s. Targets are given for the peak pelvic force and the peak pelvic acceleration.

All of the peak pelvis force responses were greater than one corridor width of the 6.4-7.8 kN response corridors. Ten of the peak pelvic accelerations were within the 63-77 g response corridor and three accelerations were within one corridor width of the response corridor. The results are shown in Table A18, Appendix A.

The Pelvis Test 7 biofidelity rating is 3.9, which corresponds to an ISO classification of "marginal".

Pelvis Test 10

This test requires a WSU-type rigid wall sled impact at 6.8 m/s (Figure 4). Targets are given for the pelvic plate force and the peak lateral pelvic acceleration.

Six of the pelvis forces were greater than one corridor width of the response corridors. Three of the pelvis forces were within one corridor width of the response corridor. The pelvic accelerations were all within one corridor width of the 85-115 g corridor. The results are shown in Figure A10 and Table A19, Appendix A.

The Pelvis Test 10 biofidelity rating is 3.1, which corresponds to an ISO classification of "unacceptable".

Overall Pelvis Biofidelity

The overall pelvis biofidelity rating is 5.1, which corresponds to an ISO classification of "fair".

REPEATABILITY AND REPRODUCIBILITY

A series of verification tests were performed for the purpose of assessing the repeatability of the WorldSID dummy. Tests were performed as per ISO 15830-2 and generally included a minimum sample of three trials. Analysis was performed using the coefficient of variation (CV) as a figure of merit. The CV is defined as the standard deviation of the samples divided by the sample mean, and is expressed as a percentage. Responses, which have a CV of 3% or less, are commonly considered as having an excellent level of repeatability whereas a value of 10% and above is considered to have a poor level of repeatability.

The WorldSID production dummy test results include a combination of repeat tests performed on the same

dummy (repeatability) and tests performed on different dummies (reproducibility). The CV values from these tests should be considered representative of the WorldSID repeatability and reproducibility. Results are presented by body region in Tables 2- 8.

**Table 2.
Head Repeatability and Reproducibility**

Response Measurements	CV (%)
Lateral drop peak resultant CG acceleration	5.6
Frontal drop peak resultant CG acceleration	4.3

**Table 3.
Neck Repeatability and Reproducibility**

Response Measurements	CV (%)
Peak flexion angle	4.1
Peak M_x	4.7

**Table 4.
Shoulder Repeatability and Reproducibility**

Response Measurements	CV (%)
Pendulum force	4.2
Peak shoulder deflection	4.9

**Table 5.
Thorax Repeatability and Reproducibility
(with arm)**

Response Measurements	CV (%)
Pendulum force	4.1
Upper spine T4 lateral acceleration	6.7
Lower spine T12 lateral acceleration	5.6
Thorax rib 1 deflection	7
Thorax rib 2 deflection	4.3
Thorax rib 3 deflection	4

**Table 6.
Thorax Repeatability and Reproducibility
(without arm)**

Response Measurements	CV (%)
Pendulum force	4.7
Upper spine T4 lateral acceleration	8.1
Lower spine T12 lateral acceleration	10.7
Thorax rib 1 deflection	6.4
Thorax rib 2 deflection	4.6
Thorax rib 3 deflection	5.5

**Table 7.
Abdomen Repeatability and Reproducibility**

Response Measurements	CV (%)
Pendulum force	3.9
Peak acceleration of the lower spine T12	6.3
Abdomen rib 1 deflection	3.9
Abdomen rib 2 deflection	4.4

**Table 8.
Pelvis Repeatability and Reproducibility**

Response Measurements	CV (%)
Pendulum force	5.5
Pelvis acceleration	6.5

SIDE IMPACT DUMMY BIOFIDELITY COMPARISON

The biofidelity rating of the WorldSID is compared to the USDOT-SID, ES-2re, Eurosid-1, ES-2, and BioSID in Table 9. It should be noted that not all tests were conducted for each dummy. As previously mentioned, tests that are not conducted are not

included in the biofidelity rating. This may influence the body region and overall biofidelity ratings.

The overall biofidelity rating of the WorldSID dummy is 8.0, which corresponds to an ISO classification of "good". The biofidelity ratings of the WorldSID body regions are shown in Appendix B.

Table 9.
Mid Male Side Impact Dummy Biofidelity Comparison

	Biofidelity rating						
	Head	Neck	Shoulder	Thorax	Abdomen	Pelvis	Overall
WorldSID production version	10	5.3	10	8.2	9.3	5.1	8
BioSID	6.7	6.7	7.3	6.3	3.8	4	5.7
ES-2	5	4.4	5.3	5.2	2.6	5.3	4.6
EuroSID-1	5	7.8	7.3	5.4	0.9	1.5	4.4
ES-2RE	5	4.2	4.5	4	4.1	3.2	4.2
USDOT-SID	0	2.5	0	3.1	4.4	2.5	2.3

CONCLUSIONS

This paper presents the results of a biofidelity, repeatability and reproducibility evaluation of the WorldSID production dummy conducted by the WorldSID Task Group.

Based on the results presented in this paper the following observations have been made:

- 1) The WorldSID dummy has the highest ISO biofidelity rating (8.0) of the existing mid male side impact dummies.
- 2) The WorldSID demonstrates good repeatability and reproducibility. The majority of the measurements compared have a CV of 6% or less.

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APPENDIX A

Table A1.
Head test 1 - 200 mm rigid lateral test results

Measure	Lower bound	Upper bound	Run	Rating
			#1	
Peak resultant acceleration (non-impacted side), left impact	100	150	141	10,0
Rating			10	
Peak resultant acceleration (non-impacted side), right impact	100	150	129	
Rating			10	

Table A2.
Neck test 1 – 7.2 g lateral sled test

Measure	Lower bound	Upper bound	Run							Rating
			#1	#2	#3	#4	#5	#6	Avg	
Horizontal acceleration of T1 (G) CFC180	12	18	16	13	13	12	12	12	13	7,4
Rating			10	10	10	10	10	10	10	
Horizontal displacement of T1 relative to sled (mm)	46	63	59	54	57	54	52	57	55,5	
Rating			10	10	10	10	10	10	10	
Horizontal displacement of head CG T1 (mm)	130	162	124	121	124	131	125	134	126,5	
Rating			5	5	5	10	5	10	6,7	
Vertical displacement of head CG relative to T1 (mm)	64	94	66	57	63	61	52	65	60,7	
Rating			10	5	5	5	5	10	6,7	
Time of peak head excursion (sec)	0,159	0,175	0,122	0,113	0,120	0,120	0,113	0,120	0,118	
Rating			0	0	0	0	0	0	0	
Lateral acceleration of head CG (G) CFC1000	8	11	11	12	12	11	11	12	11,5	
Rating			10	5	5	10	10	5	7,5	
Vertical acceleration of head CG (G) CFC1000	8	10	9	10	9	9	9	9	9,2	
Rating			10	10	10	10	10	10	10	
Head flexion angle (degrees)	44	59	51	50	51	47	44	48	48,5	
Rating			10	10	10	10	10	10	10	
Head twist angle (degrees)	32	45	22	21	23	22	22	22	22,0	
Rating			5	5	5	5	5	5	5	

Table A3.
Neck test 2 – 6.7 g lateral sled test

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Head flexion angle (degrees)	40	50	Nm	Nm	Nm		2,0
Rating			0	0	0	0	
Peak moment A-P axis at OC, M_x (Nm)	40	50	13	13	15	13,7	
Rating			0	0	0	0	
Peak moment R-L axis OC, M_y (Nm)	20	30	4	4	3	3,7	
Rating			0	0	0	0	
Peak twist moment, M_z (Nm)	15	20	8	9	9	8,7	
Rating			0	0	0	0	
Peak shear force OC, F_y (N)	750	850	427	428	428	427,7	
Rating			0	0	0	0,0	
Peak tension force OC, F_z (N)	350	400	384	363	397	381,3	
Rating			10	10	10	10	
Peak A-P shear force, F_x (N)	325	375	63	55	63	60,3	
Rating			0	0	0	0,0	
Peak resultant head acceleration (G)	18	24	14	15	15	14,7	
Rating			5	5	5	5,0	

Table A4.
Neck test 3 – 12.2 g lateral sled test

Measure	Lower bound	Upper bound	Run							Rating
			#1	#2	#3	#4	#5	#6	Avg	
Peak lateral acceleration of T1 (G)	17	23	20	18	19	17	18	17	18,2	7,2
Rating			10	10	10	10	10	10	10,0	
Peak lateral acceleration of head CG (G)	25	47	14	14	14	13	13	13	13,5	
Rating			5	5	5	5	5	5	5,0	
Peak horizontal displacement of head CG relative to sled (G)	185	226	213	202	207	211	214	210	209,5	
Rating			10	10	10	10	10	10	10,0	
Peak flexion angle (degrees)	62	75	64	63	64	58	59	58	61,0	
Rating			10	10	10	5	5	5	7,5	
Peak twist angle (degrees)	62	75	28	26	27	25	25	26	26,2	
Rating			0	0	0	0	0	0	0,0	

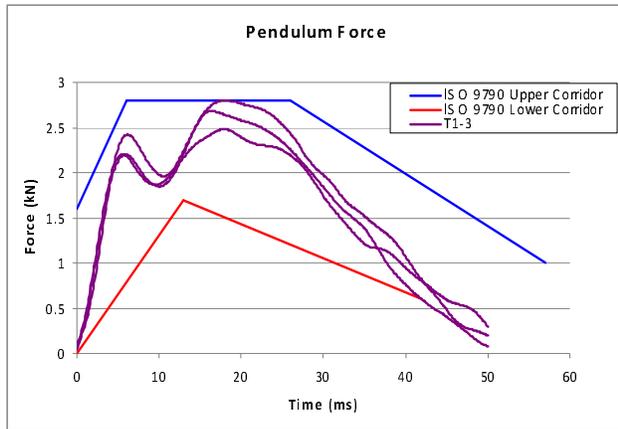


Figure A1 - Shoulder test 1 - pendulum force.

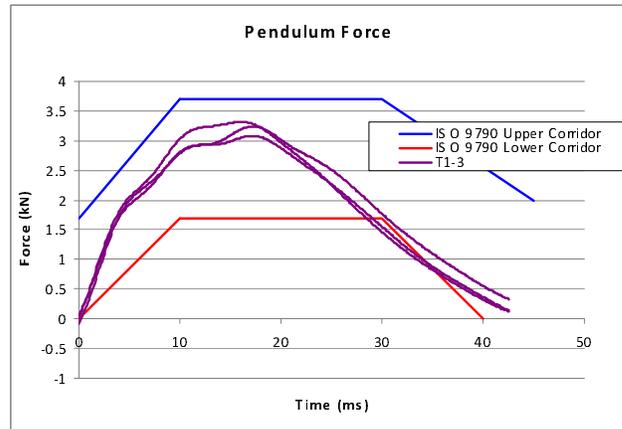


Figure A2 - Thorax test 1 - pendulum force.

Table A5.

Shoulder test 1 – 4.5 m/s pendulum test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Shoulder pendulum force (N)	Plot	Plot	Plot	Plot	Plot	Plot	10
Rating			10	10	10	10	
Peak shoulder deflection (mm)	34	41	39	37	40	39	
Rating			10	10	10	10,0	

Table A6.

Shoulder test 2 – 7.2 G sled test results

Measure	Lower bound	Upper bound	Run							Rating
			#1	#2	#3	#4	#5	#6	Avg	
Horizontal acceleration T1 (g)	12	18	16	13	13	12	12	12	13,0	10,0
Rating			10	10	10	10	10	10	10	
Horizontal displacement T1 relative to sled (mm)	46	63	59	54	57	54	52	53	54,8	
Rating			10	10	10	10	10	10	10	

Table A7.

Shoulder test D3 – 12,2 G sled test results

Measure	Lower bound	Upper bound	Run						Rating	
			#1	#2	#3	#4	#5	#6		Avg
Peak lateral acceleration T1 (G)	17	23	20	18	19	17	18	17	18,2	10,0
Rating			10	10	10	10	10	10	10,0	

Table A8.

Thorax test 1 - test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	7,8
Rating			10	10	10	10,0	
T1 lateral acceleration (G)	Plot	Plot	Plot	Plot	Plot	Plot	
Rating			5	5	5	5	

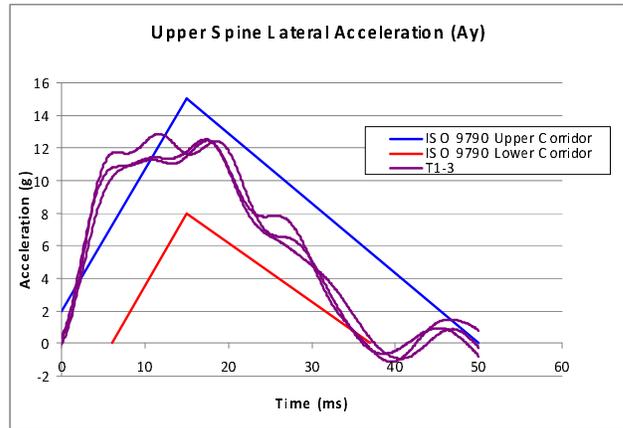


Figure A3 - Thorax test 1 - T1 lateral acceleration.

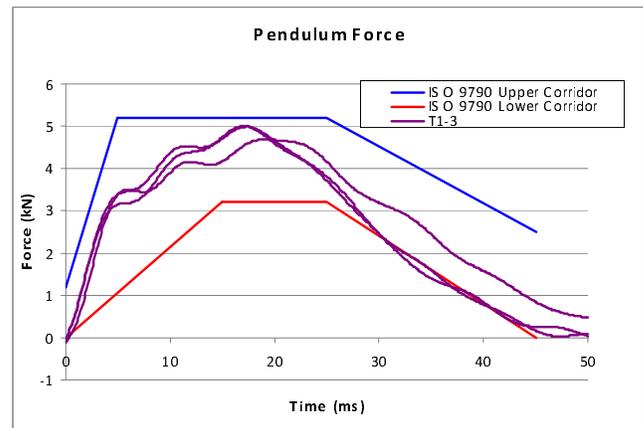


Figure A4 - Thorax test 2 - pendulum force.

Table A9.
Thorax test 2 – 6.7 m/s test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	10,0
Rating			10	10	10	10,0	

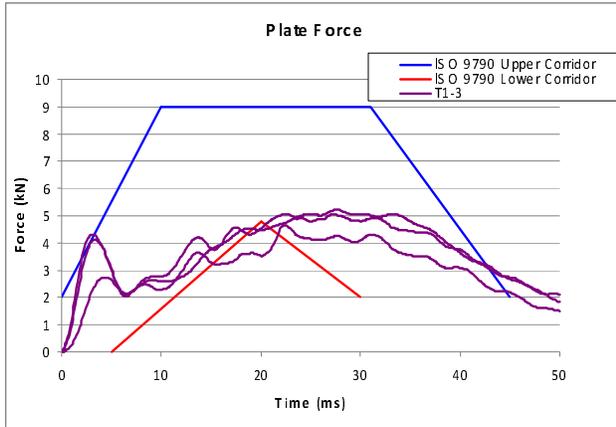


Figure A5 - Thorax test 3 - plate force.

Table A10.
Thorax test 3 – 1 m drop test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Thorax plate force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	8,3
Rating			10	10	10	10,0	
Peak deflection impacted rib (mm)	26	38	41	42	30	37	6,7
Rating			5	5	10	6,7	

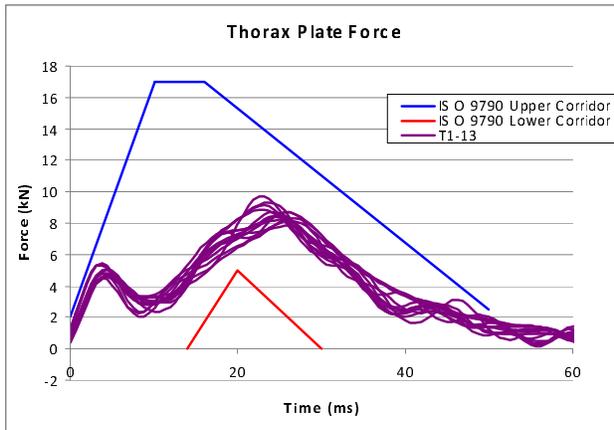


Figure A6 - Thorax test 5 – plate force.

Table A11.
Thorax test 5 – 6.8 m/s sled test results

Measure	Lower bound	Upper bound	Run		Rating
			1 to 13	Avg	
Thorax plate force (kN)	Plot	Plot	Plot	Plot	6,4
Rating			All tests 10	10,0	
Peak upper spine lateral acceleration (G)	82	122		39	0,8
Rating			2 tests 5, 11 tests 0		
Peak lower spine lateral acceleration (G)	71	107		52,0	5,0
Rating			All tests 5		
Peak lateral acceleration impacted rib (G)	64	100		86	10
Rating			All tests 10		

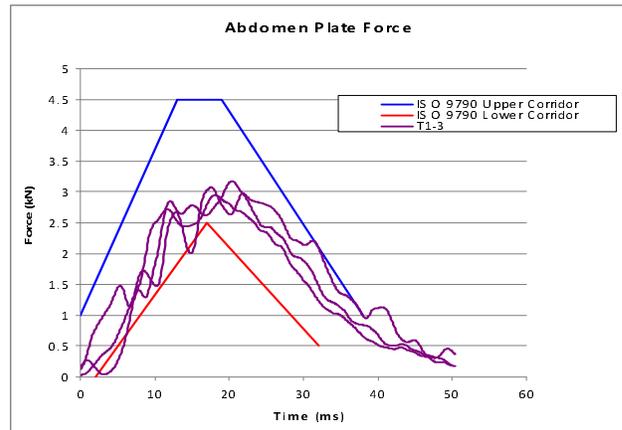


Figure A7 - Abdomen test 1 – armrest force.

Table A12.
Abdomen test 1 - 1 m rigid armrest test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Armrest force (kN)			See plot	See plot	See plot		9,0
Rating			10	10	10	10,0	
T12 lateral acceleration (G)	29	35	32	34	35	34	3,3
Rating			10	10	10	10,0	
Peak acceleration of impacted rib (mm)	100	125	127	193	130	150	50
Rating			5	0	5	3,3	
Abdomen penetration (mm)	41		51	51	47	50	10,0
Rating			10	10	10	10,0	

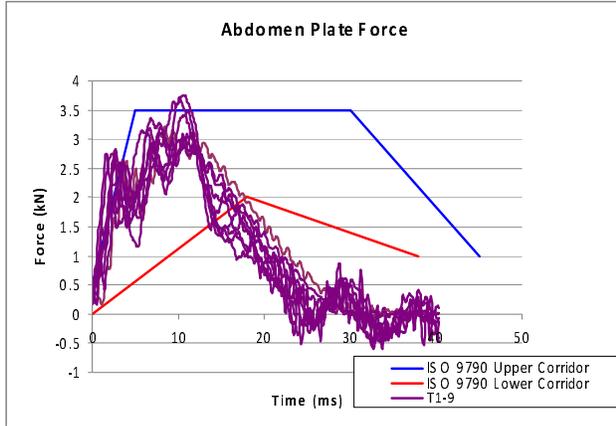


Figure A8 - Abdomen test 3 - plate force.

Table A13.
Abdomen test 3 – 6.8 m/s plate force sled test results

Measure	Lower bound	Upper bound	Run		Rating
			1 to 9	Avg	
Abdomen plate force (kN)			See plot		10,0
Rating			10	10,0	

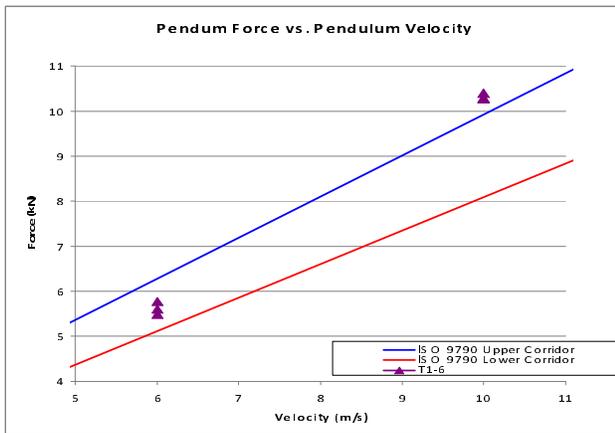


Figure A9 - Pelvis test 1 and 2 - pendulum force.

Table A14.
Pelvis test 1 – 6.0 m/s pendulum test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	10,0
Rating			10	10	10	10,0	

Table A15.
Pelvis test 2 – 10.0 m/s pendulum test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	5,0
Rating			5	5	5	5,0	

Table A16.
Pelvis test 3 – 0.5 m acceleration drop test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Peak pelvis acceleration (G)	37	45	30	31	30	30	5,0
Rating			5	5	5	5,0	

Table A17.
Pelvis test 4 – 1.0 m rigid drop test results

Measure	Lower bound	Upper bound	Run				Rating
			#1	#2	#3	Avg	
Peak pelvis acceleration (G)	63	77	46	45	42	44	0,0
Rating			0	0	0	0	

Table A18.
Pelvis test 7 – 6.8 m/s rigid sled test results

Measure	Lower bound	Upper bound	Run		Rating
			1 to 13	Avg	
Pelvis plate force (kN)	6,4	7,8		12,1	3,9
Rating			0 all tests	0,0	
Peak pelvis acceleration (G)	63	77		66,1	
Rating			5 three tests, 10 ten tests	8,4	

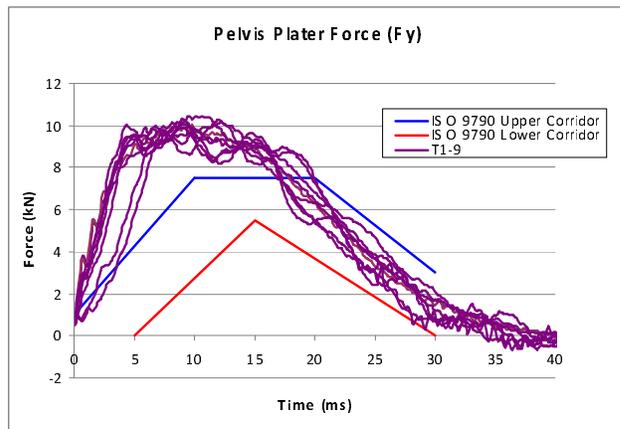


Figure A10 - Pelvis test 10 - pelvis plate force.

Table A19.
Pelvis test 10 – 6.8 m/s Wayne State rigid sled test
results

Measure	Lower bound	Upper bound	Run		Rating
			1 to 9	Avg	
Pelvis plate force (kN)	Plot	Plot	Plot	Plot	3,1
Rating			4 tests 5, 5 tests 0	1,7	
Peak pelvis acceleration (G)	85	115		50,0	
Rating			All tests 5	5,0	

APPENDIX B

Table B1.
WorldSID Biofidelity Ratings by Test and Body Region

Body Test No. & Test Description	Test Weighting, $V_{i,j}$	Test Biofidelity
Head Test 1 200 mm Rigid Drop	8	10.0
Head Test 2 1200 mm Padded Drop	4	N. M.
Head Biofidelity, B1		10.0
Neck Test 1 7.2 G Sled Impact	7	7.4
Neck Test 2 6.7 G Sled Impact	6	2.0
Neck Test 3 12.2 G Sled Impact	3	7.2
Neck Biofidelity, B2		5.3
Shoulder Test 1 4.5 m/s Pendulum	6	10.0
Shoulder Test 2 7.2 G Sled Impact	5	10.0
Shoulder Test 3 12.2 G Sled Impact	3	10.0
Shoulder Test 4 8.9 m/s Padded Sled	7	N. M.
Shoulder Biofidelity, B3		10.0
Thorax Test 1 4.3 m/s Pendulum	9	7.8
Thorax Test 2 6.7 m/s Pendulum	9	10.0
Thorax Test 3 1.0 m Rigid Drop	6	8.3
Thorax Test 4 2.0 m Padded Drop	5	N. M.
Thorax Test 5 6.8 m/s Rigid Sled	7	6.4
Thorax Test 6 8.9 m/s Padded Sled	7	N. M.
Thorax Biofidelity, B4		8.2
Abdomen Test 1 1.0 m Rigid Drop	7	9.0
Abdomen Test 2 2.0 m Rigid Drop	6	N. M.
Abdomen Test 3 6.8 m/s Rigid Sled	3	10.0
Abdomen Test 4 8.9 m/s Rigid Sled	3	N. M.
Abdomen Test 5 8.9 m/s Padded Sled	7	N. M.
Abdomen Biofidelity, B5		9.3
Pelvis Test 1 6.0 m/s Pendulum Impact	8	10.0
Pelvis Test 2 10.0 m/s Pendulum Impact	9	5.0
Pelvis Test 3 0.5 m Rigid Drop	4	5.0
Pelvis Test 4 1.0 m Rigid Drop	4	0.0
Pelvis Test 5 2.0 m Padded Drop	3	N. M.
Pelvis Test 6 3.0 m Padded Drop	5	N. M.
Pelvis Test 7 6.8 m/s Rigid Sled	8	3.9
Pelvis Test 8 8.9 m/s Rigid Sled	7	N. M.
Pelvis Test 9 8.9 m/s Padded Sled	8	N. M.
Pelvis Test 10 6.8 m/s Rigid Sled	3	3.1
Pelvis Test 11 8.9 m/s Rigid Sled	3	N. M.
Pelvis Test 12 8.9 m/s 15 psi Padded Sled	3	N. M.
Pelvis Test 13 8.9 m/s 23 psi Padded Sled	7	N. M.
Pelvis Biofidelity, B6		5.1
N.M. = Not Measured		
WorldSID With Blue Ribs Overall Biofidelity		8.0