1. Introduction

2. Background

2.1 General Background

The World Side Impact Dummy (WorldSID) Task Group has completed the design and development of the WorldSID. Developed under the direction of ISO/TC22/SC12/WG5 beginning in 1997, and funded by a worldwide consortium at a cost of about $16 million dollars, the WorldSID production design was completed on schedule in March 2004. The WorldSID heralds a significant improvement in the ability of crash dummies to predict a wide range of human injury potential and duplicate human motions and responses in side impact tests, which should lead to improved vehicle designs and occupant protection. In addition, WorldSID, which was developed by hundreds of engineers and scientists from over 45 organizations in Europe, Asia-Pacific and the Americas, represents a major breakthrough in worldwide cooperation in the design of crash test dummies.

One of the goals of this worldwide group was to achieve harmonization via the use of the same dummy in all worldwide markets. Humans are physically similar worldwide, so it is logical to have a single crash dummy to test vehicle safety. The WorldSID was developed to allow a single test device to be used for side impact testing in any regulation around the world. Such a worldwide-harmonized dummy could not have been developed without the international cooperation exhibited within the Task Group.

In addition, as a major benefit of harmonization, introduction of a single universal dummy into regulations and consumer testing in all regions would enable manufacturers to focus and coordinate resources to improve worldwide occupant safety, rather than engineering different safety designs for different dummies.

2.2 Technical Background

The WorldSID Design Team, consisting of FTSS, Denton Inc., Denton ATD Inc., DTS, and Endevco, under the direction of Phase I Program Managers Biokinetics and Associates Ltd., and Phase II Program Managers Dynamic Research, Inc., undertook to design and fabricate the WorldSID dummy to meet the design specifications detailed by the WorldSID Task Group in Task Group document TG N60 Rev2 (see attached for details).

The technical performance of the WorldSID design has been thoroughly tested and verified by extensive testing under a variety of conditions. The resulting production design is the result of three design, test, feedback, and re-design cycles. The original prototype dummy underwent nearly two years of biofidelity, vehicle, and component testing. Based on the prototype test results, a pre-production design was developed which resulted in the modification of nearly every part of the dummy in order to improve biofidelity, durability, usability, or other aspects of the dummy. Beginning in early 2003 eleven pre-production dummies were fabricated and delivered to each of the three world regions. The subsequent worldwide testing of the pre-production dummies resulted in a few final modifications, which were incorporated into the final production design. The production design is complete and the production dummy has been available for purchase and use since March 2004.

In total, testing has included nearly 1000 whole dummy biofidelity, vehicle, and component tests. This testing was conducted in sixteen different test labs and agencies in at least ten different countries including testing by governmental agencies in Canada, Japan, Australia, the United States and various organizations as part of a framework research program of the European Commission.

The excellent performance of the WorldSID design, as quantified in Section 3 below, is due in part to the use of new technologies and materials some of which were not available for use in older dummy designs. For example, the WorldSID ribs achieve humanlike deflection performance through the use of a superelastic nickel-titanium alloy. Also, the WorldSID anatomy is based on an extensive, diverse 50th percentile male driver data set, which resulted in a more humanlike seating position. In addition the WorldSID can utilize an optional in-dummy data acquisition system capable of recording up to 224 data channels, which for researchers can lead to a better understanding of the loads applied to car occupants during side impacts.

Specific technical requirements and WorldSID performance are detailed in Section 3 below.

3. Justification

3.1 Anthropometry

The WorldSID represents a mid-sized adult male vehicle occupant. Several anthropometry data sources were studied and compared with data from studies on anthropometry of different populations around the world. In

September 1999, the WorldSID Task Group decided to accept the AMVO dataset for a 50th percentile male (Robbins, D.H., et al.[1]) including later UMTRI corrections to the H-point definition. This dataset describes many anthropometry details of a mid-sized adult male in an automotive posture. Included are a 3D surface description, almost 150 anatomical reference points (including joint centres), definitions of segments (head, neck, etc.), and derivation of inertial properties of these segments. The automotive posture as represented by the AMVO dataset is defined as the design reference posture for the dummy.

FTSS created a 3D stickman diagram (lines connecting the joint centres) within the outer shell definition and anatomical landmarks. The Design Team used these as references for the WorldSID design. A detailed description of the anthropometry needs is given in Moss, S. et al.[2].

The resulting WorldSID 50th percentile adult male has a mass of 77,3 kg, a theoretical standing height of 1753 mm and a seated height of 911 mm. As detailed in WorldSID Task Group document N 396 (attached), the production dummy overall landmarks are a near perfect match to the AMVO design targets, the joint ranges of motion very closely match the design targets, and the individual WorldSID body segment dimensions and mass characteristics closely match the design targets with some small segment mass deviations which result because the dummy manufacturing segmentation is somewhat different than the underlying human anthropometry data base. In summary the anthropometry of the WorldSID is nearly an exact match to the mid-sized adult male vehicle occupant defined by the AMVO dataset.

3.2 Biofidelity

The WorldSID's biofidelity is the best of any side impact crash dummy to date and far exceeds that of its closest rival. ISO/TR 9790 specifies procedures for evaluating side impact dummy biofidelity performance using a series of 33 laboratory tests. Based on the ISO/TR9790 rating scale, the WorldSID rating is 7.6 ("Good" on a 10 point rating scale). A comparison of the WorldSID body region and overall rating is shown in comparison to other currently used side impact dummies in Table 1. Detailed WorldSID biofidelity test results including all data values and plots for all measures for all body segment tests are contained in WorldSID Task Group document N 398 (attached).

Table 1 — Biofidelity comparison of side impact dummies

	Biofidelity rating						
	Head	**Neck**	**Shoulder**	**Thorax**	**Abdomen**	**Pelvis**	**Overall**
WorldSID production version	10,0	5,6	7,1	8,3	7,8	6,1	7,6
BioSID	6,7	6,7	7,3	6,3	3,8	4,0	5,7
ES-2	5,0	4,4	5,3	5,2	2,6	5,3	4,6
EuroSID-1	5,0	7,8	7,3	5,4	0,9	1,5	4,4
USDOT-SID	0,0	2,5	0,0	3,1	4,4	2,5	2,3

In addition to the ISO/TR biofidelity testing, independently, the US/NHTSA (National Highway Traffic Safety Administration) evaluated the WorldSID prototype (unrevised version) together with two other side impact dummies, the ES-2 and the Hybrid III-SID to a newly developed biofidelity ranking system called Bio Rank System, as reported by Rhule, H., et al.[3]

This Bio Rank System quantifies the ability of a dummy to load a sled wall as a cadaver does (External Biofidelity) and the ability of a dummy to replicate those cadaver responses that best predict injury potential (Internal Biofidelity). The ranking is based on the ratio of the cumulative variance of the dummy response relative to the mean cadaver response and the cumulative variance of the mean cadaver response relative to the mean plus one standard deviation. That ratio expresses how well a dummy duplicates a cadaver response. Contrary to the ISO rating system, the lower the rating value the better the biofidelity.

Although still under development and not in use by the international community, the data presented by Rhule, et al., indicate that this assessment system also showed the WorldSID prototype to have the best ranking out of the three tested dummies.

In summary, compared with other, contemporary mid-sized adult male side impact dummies, the WorldSID overall ratings are better than all others. It achieves by far the best overall rating, and was the only side impact dummy as of March 2005 with an overall biofidelity rating of "good." The use of the WorldSID with its enhanced biofidelity should lead to safer vehicle designs, enhanced side impact protection, and reduce human injuries in side impacts.

3.3 Durability

The WorldSID durability performance targets specified that components were to remain functional after being subjected to at least 10 tests resulting in loads up to 150% of injury assessment values developed by Mertz[4]. Further details of the specific body region durability needs are contained in the WorldSID alpha Design Brief TG N100 Rev 100 (attached)

The actual durability of the WorldSID design was evaluated based on the results from laboratory sled, drop, and pendulum tests and numerous full-scale pole and MDB tests were carried out with WorldSID in the driver and/or rear passenger struck side position. Dummy responses ranged from below the injury assessment values to three times the injury values or the maximum measurement range. No damage was observed during visual inspections of the head, neck, thorax, pelvis or legs, indicating excellent durability. More specific information about WorldSID durability may be found in WorldSID Task Group document N 394 (attached)

3.4 Repeatability and Reproducibility

As detailed in WorldSID Task Group Document N395 (attached), when subjected to certification tests, the various body regions of the WorldSID demonstrated good repeatability and dummy to dummy reproducibility with resulting cumulative variance (CV) below 5% in many cases and below 10% in all measured cases.

3.5 Directional impact and other sensitivity issues

As required, in order to minimize sensitivities to small changes in impact locations and angles, the WorldSID production design consists of continuous surfaces including a neck shroud, integrated shoes and clothing, and a rib design which is not subject to binding when impacted at varying angles. The WorldSID was subjected to a wide variety of test types including oblique sled impacts up to 30 degrees from lateral and no binding of ribs or other flexible dummy components was observed. In addition, overall good repeatability in sled testing was observed indicating that the dummy is not overly sensitive to the small changes in impact angles which are a part of test to test set up variability. Overall the dummy is not overly sensitive to small changes in impact angles but the responses do change in response to gradually increasing changes in impact angles.

A temperature sensitivity study was conducted to assess the influence of temperature variations on the performance of the shoulder, thorax, abdomen and pelvis. The results indicated that the rib deflection measurements were insensitive to temperature in the temperature range from 20,6°C – 22,2°C thus, the use of the WorldSID in a temperature range from 20,6°C – 22,2°C is recommended.

3.6 Instrumentation

As described in WorldSID Task Group document N397 (attached) the WorldSID production design meets all of the original Task Group requirements. The extensive and widely distributed instrumentation forms an integral part of the WorldSID. It complies with recognized instrumentation standards such as SAE J211 and ISO 6487, is easy to use, can be implemented with either in dummy or off board recorders and will support injury risk, restraint system, and occupant behavior studies. A list of available sensors is found in Table 2.

Table 2 —Available WorldSID instrumentation

Component	Instrumentation	Channels	Subtotal
Head	Head CG linear acceleration ($a_{x,y,z}$)	3	8
	Rotational acceleration. ($\alpha_{x,y,z}$)	3	
	Head tilt ($\theta_{x,y}$)	2	
Neck	OC joint (upper neck) loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	12
	C7/T1 (lower neck) loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
Shoulders (each side)	Shoulder rib linear acceleration ($a_{x,y,z}$)	3	7 each side 14 total
	Shoulder rib displacement (δ_y)	1	
	Shoulder joint forces ($F_{x,y,z}$)	3	
Full Arm (each side)	Upper arm loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	21 each side 42 total
	Lower arm loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
	Elbow moments ($M_{x,y}$)	2	
	Elbow angular displacement (φ_y)	1	
	Elbow linear acceleration ($a_{x,y,z}$)	3	
	Wrist linear acceleration ($a_{x,y,z}$)	3	
Half Arm (each side)	None		0
Thorax (each side)	Upper thorax rib linear acceleration ($a_{x,y,z}$)	3	12 each side 24 total
	Upper thorax rib deflection (δ_y)	1	
	Middle thorax rib linear acceleration ($a_{x,y,z}$)	3	
	Middle thorax rib deflection (δ_y)	1	
	Lower thorax rib linear acceleration ($a_{x,y,z}$)	3	
	Lower thorax rib deflection (δ_y)	1	
Spine	T1 acc. ($a_{x,y,z}$)	3	13

Component	Instrumentation	Channels	Subtotal
	T4 (centre spine box) linear acceleration ($a_{x,y,z}$)	3	
	T12 (lower spine box) linear acceleration ($a_{x,y,z}$)	3	
	Thorax (spine box) rotational acceleration ($\alpha_{x,z}$)	2	
	Thorax tilt ($\theta_{x,y}$)	2	
Abdomen (each side)	Upper abdomen rib linear acceleration ($a_{x,y,z}$)	3	8 each side 16 total
	Upper abdomen rib deflection (δ_y)	1	
	Lower abdomen rib linear acceleration ($a_{x,y,z}$)	3	
	Lower abdomen rib deflection (δ_y)	1	
Lumbar Spine	Lower lumbar spine loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	6
Pelvis	Pelvis CG linear acceleration ($a_{x,y,z}$)	3	18
	Pubic Symphysis loads (F_y)	1	
	Sacro-iliac loads (left and right) ($F_{x,y,z}$, $M_{x,y,z}$)	12	
	Pelvis tilt ($\theta_{x,y}$)	2	
Upper Leg (each side)	Femur neck forces ($F_{x,y,z}$)	3	12 each side 24 total
	Mid femur loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
	Outboard knee force (F_y)	1	
	Inboard knee force (F_y)	1	
	Knee angular displacement (φ_y)	1	
Lower Leg (each side)	Upper tibia loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	15 each side 30 total
	Lower tibia loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
	Ankle angular displacement ($\varphi_{x,y,z}$)	3	

3.7 Vehicle performance testing

The WorldSID has been tested in at least 31 full scale vehicle tests conducted in Europe, the Americas, and Asia/Pacific using a variety of car makes, models and sizes. Test procedures have included

ECE-R-95 Moving deformable barrier (MDB)

EURO-NCAO MDB

FMVSS 201 90 Degree Pole

EURO-NCAO 90 Degree Pole

IHRA 75 Degree Oblique Pole

SINCAP

IIHS MDB at 50 km/h

FMVSS 214 MDB

Car to Car impact

AE-MDB

More specific information and results from these tests can be found in WorldSID Task Group document N368 (attached), a project summary presented at VRTC in May 2004, SIBER report G3RD-2000-00365, SIB-034 (attached), and a soon to be published ESV Paper 05-0256.

In general, the various test labs involved in the vehicle tests report that the WorldSID dummy was easy to handle and use, demonstrated good repeatability, acceptable durability and did not produce any artificial responses typically associated with the binding or grabbing of components.

3.8 Harmonization Capability and Benefits

The WorldSID Task Group's purpose was two fold; develop a unique, technologically advanced side impact dummy which would have greater biofidelity; and also produce a dummy which would replace the variety of side impact dummies used in world wide regulation and in other testing. It was with this double objective of developing an advanced and globally harmonized dummy that the WorldSID Task Group was formed.

As an international group, the WorldSID Task Group operated under the leadership of a Tri-Chair, consisting of one individual from the Americas, Asia Pacific, and European regions of the world. Each of the Tri-Chairs served as chairman of their respective regional Advisory Group and shared the chairmanship of the Task Group, which is made up of worldwide representatives of research facilities, manufacturers, government agencies, and dummy equipment manufacturers. Worldwide vehicle manufacturers and governmental bodies sponsored the WorldSID's development funding the design team, Program Manager and testing costs. The WorldSID project which involved hundreds of engineers and scientists from over 45 organizations in Europe, Asia-Pacific and the Americas, represents a major breakthrough in the worldwide harmonization of crash test dummies.

The need for a worldwide harmonized dummy is self evident when one considers that as of October 2003, five other mid-sized male side impact dummies were available for regulatory, consumer information and development use. They are the USDOT-SID dummy, which is utilized in the United States side impact protection regulation[5]; the EuroSID-1 dummy, which is regulated in a European standard[6]; the ES-2 dummy, which was being considered for European-Japan regulatory use under the UN/ECE 1958 Agreement; the Hybrid III-SID dummy which is utilized in the United States side impact protection regulation FMVSS-201; and the BioSID dummy, which is available for developmental purposes. The five dummies are structurally different, and have different instrumentation capabilities and associated injury assessment criteria. Because of these differences, as well as the differences in the associated test procedures, these dummies typically provide different design direction in the vehicle development process. This results in substantially different vehicle designs with regard to side impact protection in the different world regions, despite the similarity in occupant protection needs among the regions.

The existing dummies are less human-like, and cannot be instrumented for all the body regions of importance in side impact protection. This means that they have limited effectiveness as tools for improving occupant protection. In addition, the total costs to a vehicle manufacturer, and therefore to consumers, of developing different side protection systems for different regions is higher than a harmonized system.

Overall, with the existing diversity of dummies, the benefits in terms of occupant protection are lower, and the costs higher, than what would be the case if a more human-like side impact dummy was adopted on a worldwide basis.

A more human-like side impact dummy, accepted via consensus among the participating regions, along with harmonized vehicle side impact test procedures, will have significant benefits in terms of more realistic (and therefore more effective) occupant protection; as well as in reduced costs of side impact protection system development.

With regard to benefits, it is self-evident that a more advanced, human-like side impact dummy would result in vehicle side impact protection systems that would be more effective for human occupants, and would be less likely to produce harmful designs, which in principle can result from dummies that are either less human-like or unable to monitor for injuries to some body regions.

With regard to costs, it is also self-evident that vehicle manufacturers could eliminate the additional, wasteful efforts needed to develop vehicles to pass different regulatory tests, with different dummies, when they are to be sold in several markets. This process is costly for consumers and has no benefits for passive safety.

For these reasons, most of the major industrial nations, including members of the European Union, Canada, Japan and the United States, signed the *"Agreement concerning the establishing of global technical regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles,"* (1998) also referred to as the 1998 Global Agreement. This treaty implemented objectives and methods for proposing and developing within the forum of UN/ECE/TRANS/WP29 global technical regulations (GTR), which contracting nations or groups of nations would have the option to adopt as part of their domestic rulemaking processes. For similar reasons, to further support development of internationally harmonized test procedures and criteria, an International Harmonized Research Activity (IHRA) was established during the 15th International Technical Conference on the Enhanced Safety of Vehicles (ESV) held in Melbourne, Australia in 1996.

In summary, the harmonized use of the WorldSID would be expected to have substantial benefits for occupant protection, and would reduce total development costs.

3.9 Expansion of the WorldSID family

The WorldSID 50th percentile adult male which has a mass of 77,3 kg, a theoretical standing height of 1753 mm and a seated height of 911 mm is planned to be the basis for the future development of a harmonized side impact dummy family. The next dummy under development is a 5th percentile female, which is currently undergoing initial design.

4. Specifications

The WorldSID design is not patented or in any other way proprietary to any of the participating manufactures. The manufacturing specifications and the complete fabrication drawing package, including the three dimensional definitions of external contours on all parts are public domain information. The public availability of the design should facilitate the competitive production and availability of the dummy and its components.

In addition to the fabrication information, additional documentation including a complete User’s Manual, certification test requirements and procedures, dummy positioning procedures and Injury risk curves are publicly available as well.

4.1 User's Manual

WorldSID Task Group document N 393 (attached) contains a complete WorldSID user's manual including illustrated instructions for the assembly and disassembly of the dummy, and suggested wire routing for sensors.

4.2 Calibration

Detailed calibration requirements and test procedures, required for dummy manufacturers and useful for dummy users, for the head, neck, shoulder, thorax, abdomen and pelvis are included in the User's Manual, WorldSID Task Group document N393 (attached).

4.3 Positioning procedures

It has long been recognized that each individual dummy because of its different body segment dimensions, joint articulations, and posture necessitates an individualized set of seating procedures for the front driver position and the rear and front passenger positions. Detailed seating procedures for the WorldSID are included in the User's Manual, WorldSID Task Group document N393 (attached).

4.4 Instrumentation

Although designed to be compatible with data systems utilizing internal data recorders and those using external recorders, never the less, specific hardware compatible with the WorldSID production design was designed and fabricated and is available to dummy user's. Manufacture's information including model numbers and sensor specifications are found in WorldSID Task Group document N397 (attached). This document also includes general information related to sensor locations, and sign conventions.

4.5 Mechanical Design

WorldSID Task Group document N399 (attached) contains specific manufacturing requirements and a list of all WorldSID fabrication drawings including three dimensional data files detailing the external contours of all parts as needed. All drawings listed are available as electronic .pdf and .stp files as appropriate.

4.6 Injury Risk Curves

Under the direction of ISO/TC22/SC12/WG6, draft injury risk curves for the WorldSID have been prepared. The latest revisions are found in

WorldSID Task Group document N 401 (attached). Further investigations will continue.

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