DEVELOPMENT AND EVALUATION OF THE ES-2 SIDE IMPACT DUMMY

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ABSTRACT

The issue of the European Directive 96/27/EC: “Protection of Occupants of Motor Vehicles in the Event of a Side Impact” in 1998 marked an important step in improving vehicle safety in Europe, but also confronted car and restraint manufacturers with the difficulties of having to comply with different standards in the world. Subsequently, harmonisation of the side impact test procedures and test devices has become a key objective for industry and governments world-wide. The EEVC WG12 on Adult Crash Dummies has contributed to this objective by assessing the design of the existing European side impact dummy EUROSID-1. Updates to the design are proposed to make it acceptable for application in other standards in the world as an intermediate harmonisation solution until the WorldSID dummy becomes available.

This paper summarises the main design improvements and gives the results of the dummy evaluation program carried out on behalf of the working group. This evaluation has shown that the important shortcomings of the EUROSID-1 have been satisfactorily addressed with this new design, whilst biofidelity is maintained.

INTRODUCTION

The EUROSID-1 was developed in the 1980s’ to meet the needs of the European Commission, in terms of improving vehicle safety in side impact, through the activities of EEVC Working Group 9. The crash test dummy is now incorporated in ECE Regulation 95 and hence used as regulatory test device in two of the biggest automotive markets, Europe and Japan. Over the same time period another dummy, SID, was being developed in the USA by NHTSA. This dummy is now part of the US side impact standard FMVSS-214. Thus the current regulatory situation is that there are at least two different side impact test procedures using two different side impact dummies. There is a risk that similar tests with the two different dummies do not indicate a common result in terms of improving vehicle safety and thus trauma induced injury. Such diversity causes automotive industry serious concern, especially if they sell the same vehicle in different markets.

ISO has initiated the development of the new side impact dummy WorldSID to replace the existing dummies such that there will be a more advanced world single harmonized side impact test dummy. The realistic time frame for development and evaluation may be up to 10 years before this dummy can go into a legislative test procedure. Starting from an existing regulated dummy, interim harmonization could be reached much quicker.

There has always been pressure from Europe for the USA to accept the EUROSID-1 dummy in their side impact standard. This has been unsuccessful so far for a number of reasons, some of which have been technical. A new approach for interim harmonization has been made in terms of upgrading the EUROSID-1 dummy, addressing some of the technical issues that have so far prevented its adoption by NHTSA. At the same time, other issues have been addressed that origin from more than a decade of experience with the EUROSID-1 in Europe. Support for this development comes from NHTSA, Transport Canada, Japan, Australia and others.

EEVC Working Group 12 has the task of co-ordinating the development and evaluation of the upgraded EUROSID dummy world-wide. For this purpose, it has set up an international Task Group including governments and the automotive industry and a Steering Committee to oversee the process.

This paper reports on status of the development of the improved EUROSID dummy, ES-2. In particular, it summarizes the results from the ES-2 prototype evaluation in Europe, carried out on behalf of the EEVC Working Group 12 to explore the dummy's potential as regulatory test device.

DEVELOPMENT STATUS OF ES-2

The technical issues that have so far prohibited the EUROSID-1's adoption by NHTSA and US industry have been identified and documented by the EEVC WG12 [1]. Further issues that need to be addressed if an interim harmonized dummy is to be a reality have been identified through a questionnaire amongst users of the EUROSID-1 dummy world-wide [2]. The complete list of issues has formed the basis for the development of new parts, sensors and procedures for the EUROSID dummy [3]. The resulting dummy is called ES-2. It should be emphasized that there was no intention in this work to develop a 'new' advanced European side impact dummy or to 'improve' its biomechanical performance as these issues are dealt with in the WorldSID program. The development of ES-2 has been purely one of problem solving sufficient to meet the needs of legislative authorities world-wide. The following hardware improvements have been made and incorporated in the ES-2 dummy:

Head - Introduction of upper neck load cell for improved HIC and neck injury assessment;

Neck - Redesigned buffers and cavities to prevent buffer dislocation and improved locking of the spherical screw;

Shoulder - Coated low friction top and bottom plate and flexible clavicle;

Thorax - New 'needle bearing' rib module guide system to eliminate rib binding and re-designed back-plate (Figure 1).

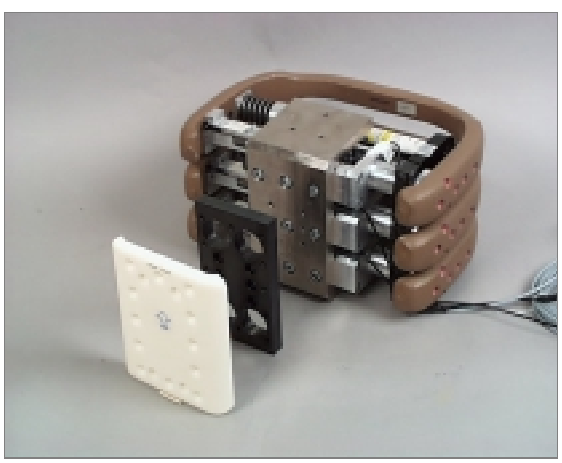


Figure 1. ES-2 needle bearing rib modules, new back-plate and load cell.

Abdomen/lumbar spine - Introduction of T12 load cell between thoracic spine and abdomen;

Pelvis - Abduction end stop buffer to prevent metal to metal contact and simplified and reduced-size pubic load cell attachment;

Extremities - Redesigned upper leg to prevent unrealistic loads going into the pelvis as a result of leg to leg contact.

New positioning tools (tilt angles and door-to-dummy distance measurement) have been developed to aid reproducible dummy positioning in the car prior to testing.

In addition to the hardware developments, updates are proposed of the certification procedures for neck, thorax, abdomen, lumbar spine and pelvis. More background on the modifications and proposed certification procedures can be found in [1] and [3].

EVALUATION

So far, ES-2 prototypes have been evaluated in Europe, the USA, Canada and Japan. The test programme has been carried out in three consecutive phases: design try-out, selection of the definite dummy configuration and assessment of the final dummy perfomance [3]. In the third and last phase, ES-2's superiority to EUROSID-1 as regulatory test device has been evaluated. This assessment includes biofidelity, sensitivity, repeatability, certification, handling, durability and full-scale car crash performance.

The final evaluation phase in Europe has been carried out by the partners in the EC SID-2000 project [4] on behalf of the European Enhanced Vehicle-safety Committee and by the Association of European Car Manufacturers ACEA [5]. The subjects covered in the evaluation of EEVC are biofidelity, certification, sensitivity, repeatability, handling and durability and full-scale test performance.

Biofidelity

A crash test dummy has to satisfy several types of requirements. One of the important requirements is that it exhibits a good degree of biofidelity. For the ES-2, the goal of the biofidelity assessment was to demonstrate that the changes introduced have not negatively affected the dummy's biofidelity with respect to the EUROSID-1. Hence, the tests have been focussed on those body regions that have altered significantly, i.e. the thorax and pelvis-femur. Unless mentioned otherwise, the test procedures and reference target corridors used are those established by the EEVC [6] and used for EUROSID-1. The biofidelity of the EUROSID-1 production version is reported previously [7].

Thorax - The thorax biofidelity has been assessed in two types of tests: full body pendulum tests and "Heidelberg" sled tests.

Full body pendulum tests

TNO Automotive in the Netherlands performed full body pendulum tests. The dummy thorax was impacted at 4.3 m/s and 6.7 m/s using the Part 572 23.4 kg mass impactor. The T1 lateral and pendulum acceleration results for both the ES-2 prototype and the EUROSID-1 are given in Figure 2. As EEVC does not give targets for 6.7 m/s, the responses at higher velocity are compared to the ISO TR9790 corridor given for pendulum acceleration only [8].

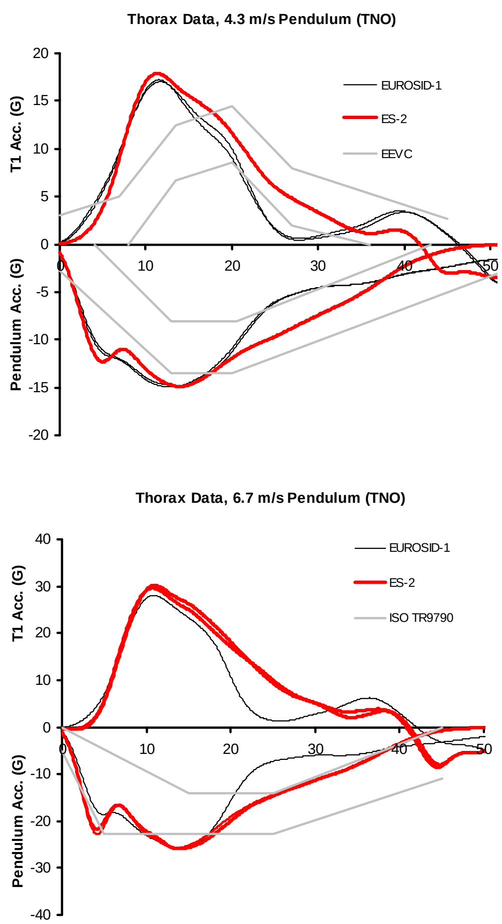


Figure 2. Thorax impactor and T1 lateral accelerations (4.3 and 6.7 m/s).

For the EUROSID-1, the results reproduce the test results published previously e.g. by Harigae, et al. [9] Both T1 and the pendulum signals show a dip in the unloading phase. At 6.7 m/s, the response is considerably below the lower boundary of the ISO corridor in the unloading phase.

For the ES-2 prototype, the results show a loading phase similar to that of EUROSID-1. The initial peak in the pendulum acceleration signals is somewhat more pronounced, probably due to the extra 100 gram moving mass in the needle bearing design. Unlike the EUROSID-1, the unloading signals fit well in the ISO corridor. Overall, the ES-2 prototype thorax shows improved biofidelity with respect to EUROSID-1 in the full body pendulum test, due to its better performance in the rebound phase.

"Heidelberg" sled tests

Full body sled tests were performed at the Transport Research Laboratory (TRL) in the UK (Figure 3). Three types of sled test against an instrumented wall are performed to collect the data necessary for comparison with the available corridors of impacts of 7.6 m/s against rigid wall, 10.3 m/s against rigid wall

Figure 3. ES-2 dummy in the "Heidelberg" padded wall sled test (TRL).

and 10.3 m/s against padded wall. The EUROSID-1 and the ES-2 prototype are subjected to the three test types. Tests were repeated two or three times. The results of these are given in Figure 4. According to the EEVC procedure, a shift in time is allowed to align the maximum of the signal with maximum of the corridor. This shift is not applied in the graphs.

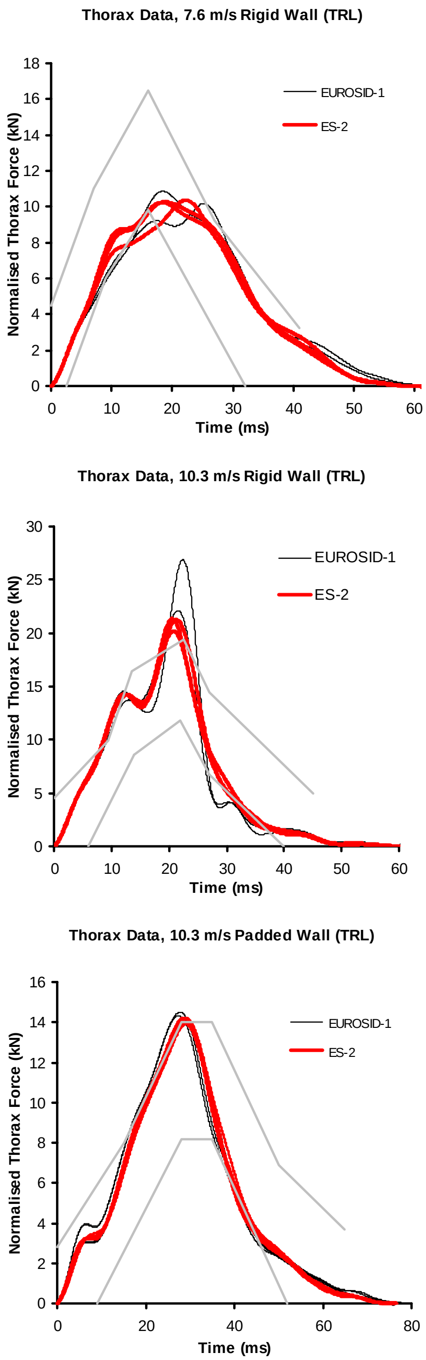


Figure 4. Thorax rigid and padded wall force (7.6 and 10.3 m/s).

In addition to the EEVC requirements, ISO gives target values for the lateral T1 and T12 acceleration responses. These data are given in Table 1 for both dummies.

Table 1.
Normalised dummy thorax accelerations, 7.6 m/s rigid wall

Dummy	T1 accel. (g)	T12 accel. (g)	Rib accel. (g)		
			Top	Mid	Bottom
EURO-	45.0	61.9	133.9	106.2	126.4
SID-1	37.6	72.0	146.2	115.5	127.8
ES-2	47.5	57.5	138.5	88.9	81.9
	40.7	55.3	134.9	93.6	98.3
	39.1	63.3	164.2	100.0	102.6

From these sled tests, it was observed that the ES-2 dummy and force plate measurements at the thorax are very similar to those for the EUROSID-1 dummy. Hence, no apparent change in the biofidelity of the dummy was found.

Pelvis - Linearly guided impactor and Heidelberg sled test responses have been used to assess the biofidelity of the pelvis.

Full body guided impactor tests
Linearly guided impactor tests have been performed at INRETS in France. Both the EUROSID-1 and the ES-2 prototype have been subjected to impacts between 3.3 and 10.6 m/s using a guided 23.4 kg impactor. The results of these tests are given in Figure 5. Comparison is made against two sets of requirements: those given by the EEVC [6] and those derived more recently by the EEVC, which are now considered by IHRA [10]. As the original biomechanical tests used a 17.3 kg impactor that was no longer availble, the EEVC corridors have been scaled to the 23.4 kg impactor mass.

In Table 2, the maximum pelvis accelerations obtained in the impactor tests are compared with the corridors specified in [10]. Both dummies meet the criteria at the 6.6 m/s condition, but are below the targets at 3.4 m/s. However, for both test conditions the ES-2 prototype responses are more close to the biofidelity targets than those of the EUROSID-1.

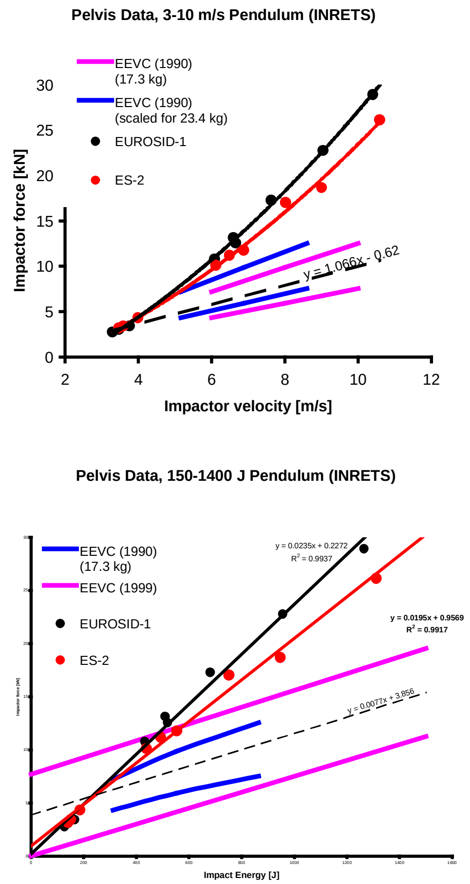


Figure 5. Pelvis impactor force/velocity and force/energy

Only for low energy levels (under 300 J) the dummy responses for EUROSID-1 and ES-2 are within the corridor. The ES-2 prototype is close to the EUROSID-1 but showing marginal improvement.

Table 2.
Maximum pelvis accelerations compared with the targets considered by IHRA

Test condition Target pelvis acceleration [10]	3.4 m/s impactor test (g) 25.5 - 42.5	6.6 m/s impactor test (g) 47.0 - 77.0
EUROSID-1	13.71 11.69	68.59 75.17
ES-2	15.5 15.84	70.82 64.59

"Heidelberg" Sled Tests

The results of the full body sled tests for the pelvis are given in Figure 6. Additionally, the normalised dummy pelvis acceleration data for all tests are shown in Table 3.

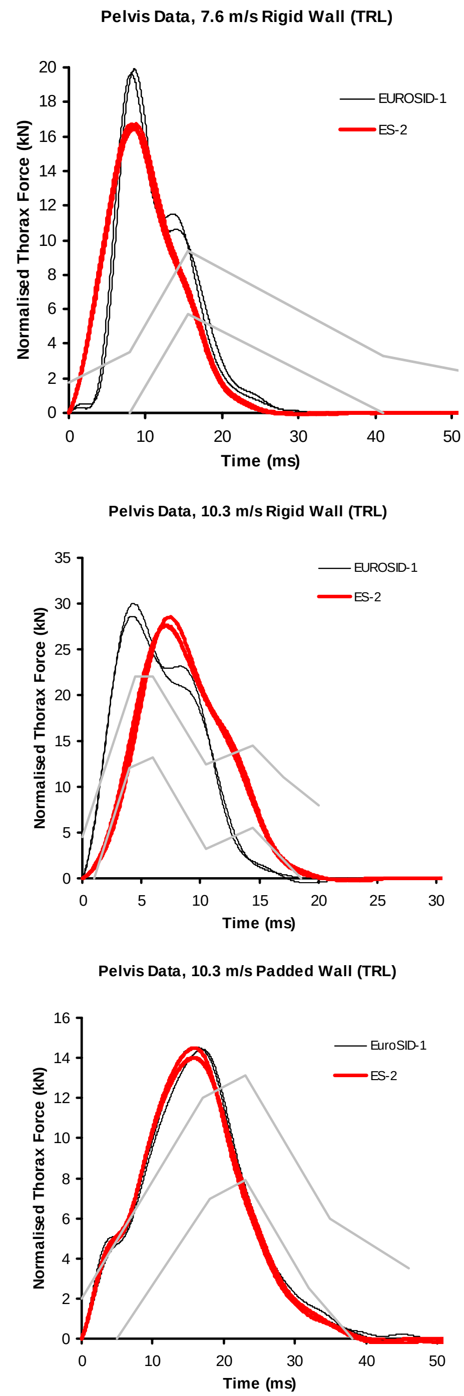


Figure 6. Pelvis rigid and padded wall force (7.6 and 10.3 m/s).

Table 3.
Maximum normalised pelvis accelerations

Test condition	7.6 m/s RW (g)	10.3 m/s RW (g)	10.3 m/s PW (g)
EEVC target acceleration	52.7- 87.9	79.5-132.5	65.8-109.7
EUROSID-1	166.4 158.1	277.1 277.8	99.1 99.3 105.0
ES-2	141.8 139.9 140.3	238.1 236.6 243.4	92.3 95.7 100.2

Both dummies meet the EEVC target acceleration criteria at the 10.3 m/s padded condition and give similar responses. The responses of both dummies at the rigid wall conditions are exceeding the EEVC targets. However, for all three conditions, the ES-2 prototype responses are slightly closer to the biofidelity targets than those of the EUROSID-1. The overall conclusion is that the ES-2 biofidelity measures are somewhat lower than for the EUROSID-1 dummy, but the change only represents a small improvement in biofidelity.

Other dummy requirements

Besides biofidelity, there are other requirements that are of almost equal importance and priority for a regulatory test device, like repeatability, reproducibility, sensitivity and durability. The WG12 has carried out an assessment of these characteristics of the ES-2 dummy with respect to the EUROSID-1.

Certification - The proposed certification procedures for the ES-2 dummy were assessed by BASt in Germany and by the manufacturer prior to release of the first prototype. In general, the ES-2 prototype met the specifications of the standard EUROSID-1 dummy. In addition, it fulfilled the new proposed certification requirements for the neck, lumbar spine, abdomen and pelvis. Some refinements for thorax and pelvis certification procedures may be required as explained below.

The thorax certification was changed on some details. The current EUROSID-1 certification procedure requires drop test tests on the rib only, damper only and full rib configuration. It was felt that this procedure contains redundancies, because only a correct performance of the complete rib is important for the dummy behaviour. Therefore it was proposed to skip the rib only and damper tests as long as the full rib modules comply with the certification test requirements [1,3]. In addition it was proposed to skip the full rib certification test at 1.0 m/s impact speed, because the energy and contact speed of this test is too far below those that can be expected in a full-scale car crash. The ribs fulfilled the specification, in some cases after application of the stiffest (19 N/mm) tuning spring. For the prototype, the majority of the results were close to the upper boundaries.

In conclusion, the ES-2 prototype rib meets the EUROSID-1 criteria, however, this is not easily achieved. The modified configuration of the rib guide system seems to have its effect on the corridors at the proposed three impact speeds. If after finalisation of the global evaluation programme this remains a concern, the corridors for the prototype rib performance may have to be re-adjusted.

For the pelvis, a revised procedure has been proposed at higher velocity of impact [1,3]. The proposed test was difficult to perform because at this higher speed the dummy tends to move extremely after the pendulum has hit the pelvis. In the end, the results were checked by a test according to the original EUROSID-1 specifications and all measurements were found to be within the specifications.

Both TRL and INRETS reported that in their tests the pendulum force was relative low in the corridor, whereas the pubic symphysis force was relative high. This effect is considered to be the direct result of the upper leg modification.

Sensitivity - The evaluation of the sensitivity of the ES-2 prototype potentially involves a wide range of aspects. The dummy should be sensitive to impact severity but less responsive to small changes in impact angle, temperature or such-alike parameters. The temperature sensitivity of ES-2 was assumed to be unchanged with respect to EUROSID-1. The work of WG12 focused primarily on impact direction sensitivity.

TRL performed 72 full body pendulum tests on the shoulder, thorax, abdomen, and pelvis. Five directions were tested per body part, e.g. forward of

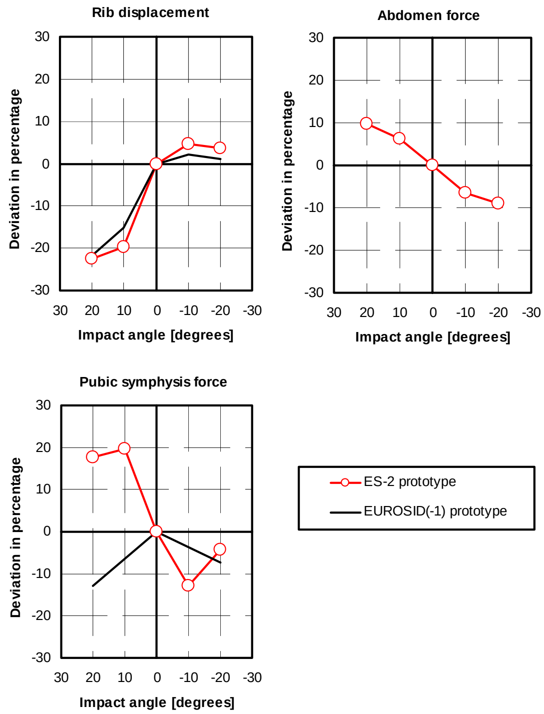


Figure 7. ES-2 prototype sensitivity to impact angle in full body pendulum tests.

lateral +20 and +10 degrees, lateral and rearward of lateral -10 and -20 degrees. The oblique tests were done three times and the pure lateral tests six times. Figure 8 illustrates the sensitivity of thorax, abdomen and pelvis criteria to the angle of impact. For comparison the available sensitivity data for the EUROSID prototype [11] is shown (not available for abdomen force).

The ES-2 rib deflection gave results below those for pure lateral impacts for the forward oblique condition, whilst rearward oblique tests gave slightly higher results. The effect was similar to that seen in tests with the prototype EUROSID [11]. The ES-2 abdomen was less responsive to changes in impact angle than the thorax. The ES-2 pelvis had a low sensitivity to changes in impact angle for the rearward oblique and pure lateral tests, tests in the frontal oblique condition resulted in a higher pubic force. The latter may be caused by interference of the modified upper leg with the impactor.

In general, the sensitivity of the parameters studied was found to be acceptable, and comparable for EUROSID-1 and the ES-2 prototype in the test conditions reviewed.

Repeatability - The peak responses of repeated tests are examined to assess the repeatability of the ES-2 dummy. For this, the results of the biofidelity sled tests and the sensitivity tests were used. The level of repeatability of dummy responses is expressed in the coefficient of variation. A coefficient of variation of 10% is generally considered to be acceptable. The purely lateral pendulum tests on the shoulder, thorax abdomen and pelvis at TRL were repeated six times, giving a firm base for a repeatability analysis. From the "Heidelberg" sled tests only a limited number of samples is available, however, comparable data are available from the tests performed on the first production EUROSID-1 in the 1991 [7]. In Table 4 and Table 5 the results are summarised.

The ES-2 prototype shows a good repeatability on the parameters assessed, showing CVs lower than 6% for all except the shoulder (10% on the impactor force). The repeatability of the ES-2 is equivalent or slightly better than the repeatability of EUROSID-1.

Table 4.
Coefficients of variation of not normalised peak values in lateral pendulum tests with ES-2

	Speed (m/s)	Mean (n=6)	SD	CV (%)
Shoulder				
Imp. Force, kN	4.3	9.58	0.96	10.0
Thorax				
Imp. Force, kN		15.49	0.61	4.0
Up rib dfl., mm		31.55	1.20	3.8
Mid rib dfl., mm	4.3	25.60	0.22	0.9
Low rib dfl., mm		27.52	0.73	2.7
Abdomen				
Imp. force, kN	4.0	4.22	0.09	2.2
Internal force, kN		2.53	0.05	2.1
Pelvis				
Imp. force, kN	6.3	10.09	0.42	4.2
Pubic force, kN		3.44	0.19	5.6

Handling and durability - The handling of the dummy with regards to dismounting and mounting has been extensively reviewed by BASt in Germany. In general, it was found easier to dismount and mount the prototype ES-2 than it was with the EUROSID-1. In particular, the (dis)assembly of the modified rib modules was found to be easy, unlike EUROSID-1.

Table 5.

Comparison of repeatability between EUROSID-1 and ES-2 in the Heidelberg sled tests (normalised peak values).

	Coefficient of Variation CV (%)	
	EUROSID-1[†]	ES-2
Thorax wall force		
7.6 m/s Rigid Wall	4.7 (1.2)	0.5
10.3 m/s Rigid Wall	14.0 (7.2)	3.1
10.3 m/s Padded Wall	1.3 (5.6)	1.0
Pelvis wall force		
7.6 m/s Rigid Wall	1.0 (1.0)	1.0
10.3 m/s Rigid Wall	3.4 (4.6)	1.9
10.3 m/s Padded Wall	1.0 (3.0)	2.1
Pelvis lateral acceleration		
7.6 m/s Rigid Wall	35.8 (4.5)	0.9
10.3 m/s Rigid Wall	0.2 (9.8)	1.5
10.3 m/s Padded Wall	26.8 (1.8)	4.1

[†] Values between brackets are for the first EUROSID-1 tested in 1991 [7].

Also, the H-point back plate has been modified and was easier to be (dis)mounted.

No major durability problems occurred during the EEVC WG12 test programme.

Full-scale performance - The final part of the test programme consisted of a full-scale evaluation. The main goal of this part was to investigate the effectiveness of the changes made in addressing the major concerns observed with the EUROSID-1 in full scale testing, in particular the “flat-top” rib issue, back-plate and pubic symphysis loading. Furthermore, by direct comparison of the responses between EUROSID-1 and ES-2 the level of similarity of the two dummies could be determined. Four tests were executed:

- ECE R95 test performed at Volvo Safety Centre, Sweden.
- EuroNCAP-type test, performed at TRL, UK.
- FMVSS 214 barrier test, performed at BMW, Germany.
- FMVSS 201 pole test, performed at BMW, Germany.

To further investigate the effect of the upper leg modification in deleting unrealistic pubic force loading, additional sled tests were done at BASt.

ECE R95 test

The test with the ES-2 prototype dummy and the reference test with the EUROSID-1 dummy were performed according to the ECE R95 test procedures. The study was focused on the chest, the torso back plate, the pelvis and the spine parts of the dummy. The car used in the test is the Volvo S80 that obtained a 100% score in the EuroNCAP side impact barrier test.

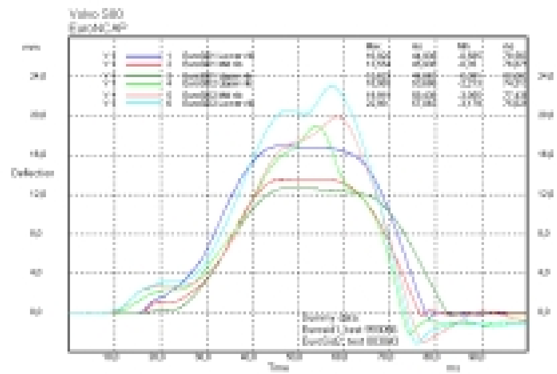


Figure 8. ES-2 prototype and EUROSID-1 rib responses in ECE R95 tests at Volvo.

The rib deflections found were higher in the ES-2 than in the reference test using the EUROSID-1. The characteristic of the rib deflection differed slightly, and was more rounded off in the ES-2. The “Flat Top” behaviour of EUROSID-1 was eliminated (Figure 8). A higher sensitivity of the new ribs in the ES-2 dummy was noted, specifically related to an earlier response from the onset of the side airbag. The lateral back plate force measured was lower in ES-2 than for EUROSID-1. No handling problems were encountered [5].

EuroNCAP-type test

The objective of this full-scale barrier test was to assess the effect changing the side impact dummy from EUROSID-1 to ES-2 might have on the European Directive side impact test incorporated in EuroNCAP. A mid-size family saloon was chosen to evaluate the performance of ES-2 because the performance of the EUROSID-1 seen in pervious EuroNCAP tests in the car was relatively close to the ECE R95 legislative limits in some areas.

Overall, the measurements obtained with the ES-2 prototype were found to be similar to those with EUROSID-1. Differences could be attributed to normal measurement spread, contact differences due to other position and measurement error due to loose of connection. No change in the full-scale performance from EUROSID-1 to ES-2 was indicated by this test.

FMVSS 214 barrier test

The crabbed side impact test was performed as described in FMVSS 214 (speed of 54.7 km/h). The main objective of this barrier test was to obtain data for comparison with data of the US-SID dummy, currently prescribed in FMVSS 214.

The measurements with EuroSID-2 mostly showed higher values than with US-SID. The ES-2 prototype seems to solve the EUROSID-1 problems like “Flat Topping” previously observed in this test condition. The rib accelerations, although similar to EUROSID-1, should be subject of more detailed investigation due to the presence of high frequency noise on the signals [5].

FMVSS 201 pole test

The car to pole test was performed as described in FMVSS 201, except for the test speed which was set to 32.2 km/h. The main objective of this test was to demonstrate the ES-2 prototype ability to assess the effectiveness and need for head protection systems in side impacts with fixed obstacles. Furthermore, the results were compared to those of EUROSID-1 in a similar test using the same vehicle.

The registered motion of the dummy in the test showed no noticeable differences to EUROSID-1. Like the EUROSID-1, the ES-2 prototype was able to show the need of head protection systems. The measurements with the ES-2 prototype mostly show higher values than with EUROSID-1which was expected. The ES-2 seems to solve the EUROSID-1 problems like “Flat Topping” and further support the finding in the FMVSS 214 test [5].

Pelvis and leg performance

A particular concern of EUROSID-1 is related to the pubic symphysis signal. In case of large upper leg abduction, metal-to-metal contact in the hip joint occurs resulting in a tension peak superimposed on the pubic symphysis compression load. On the other hand, knee-to-knee contact may result in a compression peak superimposed on the pubic symphysis compression load. Both effects are considered to be not humanlike.

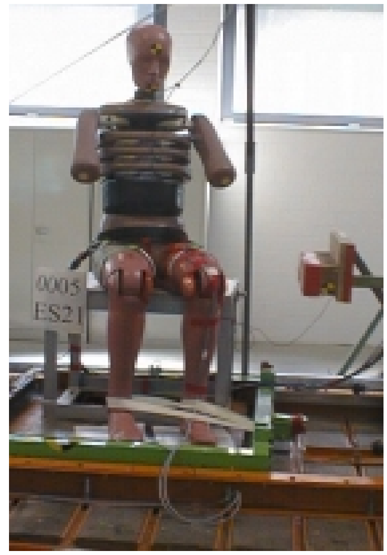
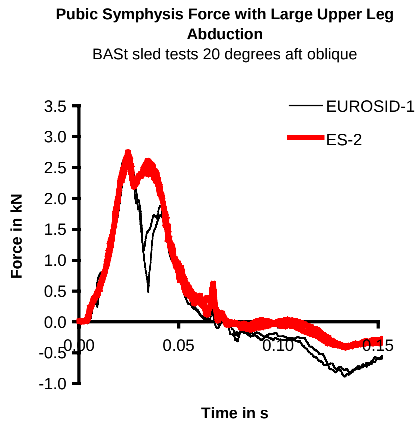


Figure 9. ES-2 prototype in sled tests at BASt, impact speed 20 km/h, 20 degrees forward (knee contact first) .

The modifications implemented in the ES-2 prototype have shown to be effective in the sled tests executed at BASt in Germany (Figure 9). In these tests, the ES-2 prototype pelvis shows considerable improved performance in case of large upper leg abduction. The metal-to-metal contact observed with EUROSID-1 is eliminated. More significantly, the ES-2 prototype legs exhibit more realistic behaviour in event of knee-to-knee contact. The shape interference peak in the pubic symphysis load signal is eliminated (Figure 10).

DISCUSSION AND CONCLUSIONS

The ES-2 dummy is a modified EUROSID-1 dummy with increased injury assessment capabilities, developed to meet the needs of legislative authorities world-wide. The test program carried out by the working group shows that dummy is indeed improved and addresses the main concerns of the EUROSID-1. The biofidelity of the dummy is maintained and even improved in some areas. The dummy met the EUROSID-1 and the new certification requirements. Repeatability, sensitivity durability and handling properties are improved compared to the EUROSID-1.



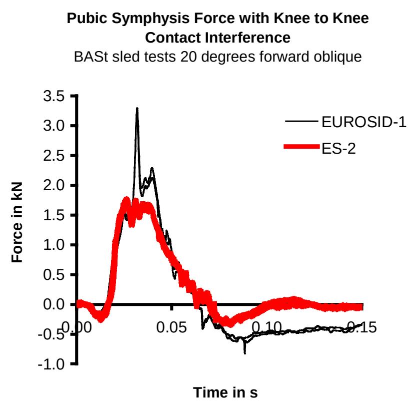


Figure 10. Pubic symphysis load signals from sled tests at BASt.

The full-scale tests carried out in this test program show that values for ES-2 are generally higher than EUROSID-1. This particularly holds for rib deflections and V*C. The number of full-scale tests carried out in this program was, however, limited. Further analysis is required once more data from the other test programs come available.

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