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Comparative Evaluation of EUROSID and SID Side Impact Dummies in Terms of Biofidelity

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ABSTRACT

The European Side Impact Dummy "EUROSID" and the Sid Impact Dummy "SID" were extensively tested in the frame of an experimental program conducted by the C.C.M.C. in EUROPE. The goal of this investigation was the evaluation of the biofidelity of both dummies according to impact response requirements selected by the ISO/TC22/SC12/WG5 experts and featuring in documents ISO/DTR 9790-1 through 9790-6. Each dummy section covered by these requirements was tested.

More than 40 impactor tests, 75 drop tests and 7 sled tests were carried out to assess the biofidelity of the head, neck, shoulder, thorax, abdomen and pelvis of EUROSID and SID. In this paper the performance of both dummies are compared with human response data proposed by ISO.

1 - INTRODUCTION

The biofidelity of a test tool such as an anthropomorphic test dummy is defined by its capacity to reproduce the responses of a human being as faithfully as possible, when this tool is subjected to the same forces. The quality of this reproduction of course depends on the dummy performances as a whole, and also on the performances of its subassemblies or segments. The nearer the response of these subassemblies to human references, the better the overall response of the dummy. Together with repeatability, sensitivity and reproducibility, biofidelity occupies a special part in the qualitative properties of an impact test dummy. While the first three properties are necessary, as for any test tool, biofidelity is of capital importance. The word "capital" is not excessive, since it is necessary to conceive a tool which can first of all -insofar as possible imitate the reactions of the occupant of an automobile during an accident precisely, to offer the best possible protection to the occupant.

To ensure and evaluate this essential characteristic of a dummy in the side impact mode, such biomechanical impact work has already been performed throughout the world.

This work consisted either of basic experiments with varied human substitutes, or was based on the inherent design of the dummy. One of the most important programs that can be mentioned was the "EEC Comparison Testing of Four Side Impact Dummies" program, which was performed between 1978 and 1982 by four European laboratories and which consisted in evaluation of biofidelity -but also other characteristics for four side impact dummies, the APROD 82, the DOT/SID, the MIRA and the ONSER 50 (1)*.

The conclusions of this program (2) have shown that none of the above-mentioned dummies, nor even their components, offered a sufficient degree of development to be usable for a test regulation procedure. In particular, one of the main conclusions concerned the reference data which were used for biofidelity evaluation for each dummy. The data were either insufficient, not updated, or difficult to exploit (1). This led to one of the main tasks of the ISO/TC22/SC12/WG5 group which, since 1983, has assembled, analysed and discussed available human data to enable evaluation of the biofidelity of a side impact dummy. This work resulted in a synthesis report drawn up by H. Mertz, President of WG5, which was initially approved by the group members, and then by subcommitte SC12, during its recent meeting in November 1987. The data contained in this report represent the best available and most up to date data for the evaluation of dummy segment biofidelity, i.e. the head, the neck, the thorax, the shoulder, the abdomen and the pelvis (3). These data are not the best in absolute since the violence of the tests selected might not be necessary representative of real-world accidents.

It was on the basis of these data, which were unanimously recognized by the ISO experts, that the Committe of Common Market Automobile Constructor (C.C.M.C.) decided, in March 1987, to conduct a comparative evaluation program, in Europe, on the two existing side impact dummies, the SID, or SIDE IMPACT DUMMY and the EUROSID, or the EUROPEAN SIDE IMPACT DUMMY respectively. The first dummy was developed by NHTSA (4, 5), and the second by European Reseach Laboratories, under the guidance of the EEVC (6, 7). This program is intended to contribute to discussions concerning future harmonization on the part of the U.S.A. and Europe, in the matter of regulations concerning side impact.

The EUROSID dummy used in this program corresponds to the first series, known as the production prototype, which became available in July 1987. Availability of the SID dummy, however, gave rise to delivery time problems. In fact, this dummy was not received until February 1988.

The goal of the investigation, reported here, has been to make a comparison between the EUROSID and US SID with the ISO requirements as the primary reference. During this work shortcomings of various kind in the dummies and the ISO requirements have been detected. It is outside the scope and ressources for this paper to present detailed accounts of these findings. They will, however, be mentioned, where appropriate in the text.

TEST MATRIX

The test matrix resuming the C.C.M.C. evaluation program is given in table 1. As can be seen from the table, all the body segments concerned by the ISO data as described in Documents ISO/DTR/ 9790-1 through 9790-6 are covered by this program.

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* Numbers in parentheses designate references at the end of the paper.

However, all tests required by ISO were not carried out. It can be noted that for segments, such as the neck, the thorax and the pelvis three different test configurations are respectively proposed. As far as the neck is concerned, the sled test described in the requirement No. 2 in Document DTR 9790-2 (8) was not selected since the test violence was considered similar to that defined in the requirement No. 1. Preference was then given to sled tests corresponding respectively to requirements No. 1 and No. 3, where the maximum input sled deceleration differs significantly, i.e. from 7 G to 13 G (see table 1). Sled tests proposed for the evaluation of the dummy thorax -which also relate to the pelvic segment- described in requirement No. 2 in Document DTR 9790-3 (9) were not performed so as not to overweight the contents of the test matrix. For each dummy, the same test in a given configuration was duplicated five times except, due to their complexity, for the lateral neck bending tests. The following tests, not including the pretests, were conducted with both dummies :

- 35 fall tests involving the head,
- 7 sled tests involving the neck,
- 10 fall tests and ten others with an impactor involving the thorax,
- 10 impactor tests involving the shoulder,
- 20 fall tests concerning the abdomen,
- and 20 impactor tests involving the pelvis.

It is the first time where both EUROSID and SID dummies are evaluated in terms of biofidelity on the basis of the same biomechanical reference. ISO requirements, as they are formulated, define limit ranges or corridors as a function of time to assess the dummy performance. For a given test configuration, involving a given dummy segment, the dummy response might be or not within the requirement. There is no doubt about the biofidelity of this dummy segment if its response is within the ISO requirement. On the contrary, and if the response is slightly higher or lesser, or slightly outside the requirement, a statement such as "not acceptable biofidelity" may appear in this case too severe. Therefore a qualitative ranking of the biofidelity of the dummy could be usefull, in order to avoid any too exclusive judgement. Three "classes of biofidelity" which will be used in the conclusions of this study, are proposed as follows :

- Class A : Excellent biofidelity of the considered segment : means that the dummy response is within the requirement.

- Class B : The biofidelity of the segment needs improvement. The dummy response is here slightly above or below the requirement.

- Class C : Not acceptable. The dummy response is far away from the requirement.

Whenever this proved necessary, the raw data for the dummy were normalized in accordance with the procedures described in reference (3). So as to enable the most complete evaluation possible of the biofidelity of both dummies, the various measurement configurations proper to each type of test, for the most part, comprised a higher number of recording channels than that required by ISO.

Table 1. Test Matrix

ISO Reference	Segment	Type of tests	Tests Performed with each dummy
DTR 9790-1 Req. No. 1	Head	Free fall	5
DTR 9790-1 Req. No. 2	Head	Free fall	15 (EUROSID), 10 (SID)
DTR 9790-2 Req. No. 1	Neck	Sled test	1 (EUROSID) 2 (SID)
DTR 9790-2 Req. No. 3	Neck	Sled test	2
DTR 9790-3 Req. No. 1	Thorax	Free fall	10
DTR 9790-3 Req. No. 3	Thorax	Impactor test	5
DTR 9790-4 Req. No. 1	Shoulder	Impactor test	5
DTR 9790-5 Req. No. 1	Abdomen	Free fall	10
DTR 9790-6 Req. No. 1	Pelvis	Impactor tests	10

2 - TEST SETUPS AND INSTRUMENTATION

General - The test setups described in the ISO documents were used. The instrumentation provided for each body segment evaluation was in accordance with that specified in these documents. High speed movies have been made of all tests. Dummy original data were filtered using the channel filter classes prescribed in the ISO documents.

Head tests - Requirements No. 1 and 2 : The dummy's head was suspended above the impacting surface, at a height of 200 mm, and 1200 mm respectively for specifications No. 1 and No. 2 (10). This height was defined by the distance between the surface to be impacted and the lowest point of the head. The head was oriented to an angle of 35° with respect to the horizontal, and 10° in the second. During the first specification tests, a 50 mm thick dry clean steel plate formed the rigid impact surface, while, for the second specification test, this plate was covered with a thin sheet of 5 mm thick padding. A quick-release mechanism was used to ensure the head drops. The instrumentation used comprised equipment for measurement of acceleration at the head c.g., in both evaluation cases. For the tests reproducing the requirement No. 2, the head was, in addition, equipped with a sensor for measurement of acceleration of a point of the head located opposite the impact point. All the measurement channels were class CFC 1000 filtered.
For tests corresponding to the requirement No. 2, we considered it interesting to compare the response of the dummy head when the latter was guided or not during the fall, or when a complete dummy was used.

Neck tests - Requirements No. 1 and 3 : The test set-up used here complies with the descriptions given in document ISO/DTR 9790-2 (8). The dummy, seated on a chair attached to the sled in the upright position, was restrained by a harness system at the thorax, and by a Vee-type belt at the pelvis. The shoulder and hip of the dummy were wedged against a vertical side wall. The anteroposterior axis of the head of the dummy was horizontal. Starting from this initial position, the dummy was submitted to a deceleration pulse applied to the sled. The object of both response characteristics is to evaluate the kinematic of the head and that of the base of the neck, with respect to the sled.
In measurement terms, the dummy was equipped with accelerometers, at the head, at T1, at T4 and at the pelvis. Two other sensors were provided for measurement of seat and sled decelerations. In particular, the head instrumentation consisted of a 15 accelerometric channel configuration developed by APR for calculation of dynamic reactions at the head-neck joint, i.e. at the occipital condyles. Photographic targets were used to evaluate head rotations and its movements -and those of T1. The filtering classes for the various measurements were as follows :

- head acceleration : CFC 1000,

- accelerations at T1, T4, pelvis, seat and sled : CFC 180,

- cinematographic data : these data, obtained from 5 high speed cameras, were processed at time intervals of 2 ms, between two points and according to a three-dimensional film analysis method.

Shoulder tests - Requirement No. 1 : The dummy was seated in an upright position on flat, rigid surface. The seating surface, with no back support, was clean. A linearly guided impactor with a mass of 23.4 kg, was used to strike the dummy shoulder. The impactor axis was perpendicular to the dummy's midsagittal plane. In EUROSID tests the impactor axis was aligned with the axis of the left upper arm joint. This dummy was used without its suit. In Sid tests, the dummy with its suit was positioned so that the impactor was centered on the foam block simulating the shoulder, without interference with the dummy rib cage. Measurements comprised, for both dummies, the acceleration respectively of the impactor and of the upper spine T1. These data were filtered according to class CFC 180. The required CFC 1000 filter (11), which was also used, showed high-frequency vibration responses. For both dummies the relative shoulder deflection was measured from high speed film.

Thorax tests - Requirements No. 1 and 3 :

Drop tests - Requirement No. 1 : The dummy was suspended above the impact surface with its median sagittal plane horizontal. Two dynamometric balances, respectively placed opposite the thorax and the pelvis, were provided for force measurements. For the EUROSID, the instrumentation comprised the deflections and accelerations for the three ribs, together with accelerations of the pelvis and T12. For the SID dummy, the same measurements were provided, but with a smaller number of channels. The accelerations, deflections and thoracic or pelvic forces were respectively CFC 180 and CFC 1000 filtered (9).

A quick release device was used to allow the dummy to drop freely. In EUROSID tests the dummy arms were rotated forward and upward in order to prevent any contact with the thoracic loading surface. The EUROSID was used without its rubber suit in order to obtain informations about its thoracic response from high speed movie. The SID dummy was used without its outer skin in order to allow a direct impact to the rib cage.

Impactor tests - Requirement No. 3 : The dummy was seated in an upright position on a flat and rigid surface without back support. The centerline of the impactor, perpendicular to the dummy's midsagittal plane, was centered on the middle rib in EUROSID tests and on the rib structure in SID tests.
Both dummies were used without their outer skins. The EUROSID dummy was used with the left arm raised so that its thorax was impacted directly. The same impactor was used as for shoulder impacts. The dummy instrumentation was similar to that mentioned above. In addition, the impactor and thoracic spine accelerations were measured at T1. In order to satisfy the filtering specifications recommended in the document (9), the accelerations were withdrawn using the FIR procedure available in a processing data program developed by Langdon (12). This also applied to the ribs and T12 accelerations. To enable comparison of the various thoracic lesion criteria, i.e. the T.T.I. or Thoracic Trauma Index, the V.C. or Viscous Criterion and C and thoracic deflection, a sufficient number of measurements was recorded.

Abdomen tests - Requirement No. 1 : The dummy was suspended above the impact surface with its median sagittal plane horizontal. The dummy was placed so that the armrest was centered on the abdominal region. For the EUROSID, which is specially equipped to measure side forces -conversaly to the SID- this armrest was centered along the central leafspring axis, forming what is known as the switch. For SID, the position of the armrest corresponded to the abdomen transverse plane of symmetry. This position of the armrest with relation to the dummy differed with respect to ISO recommendations, in which the impact also concerns the 9th rib (13). If an alignment such as this had been reproduced, a major part of the abdomen would not have been solicited in the case of the EUROSID. Moreover, this choice of armrest position was above all imposed by the anthropometry of the dummy's abdomen, which in terms of height, is much different than that of the human being. Measurements specified for both dummies comprised acceleration of the bottom rib and the thoracic column on T12, together with a dynamometric balance located under the armrest.
As far as the EUROSID is concerned, the abdominal switches were connected to determine if the lesion critical threshold -detectable by this dummy- had been exceeded or not. All the data recorded were filtered to class CFC 600, except for the signals obtained from the switches, which were not filtered. The test system was completed by a high-speed camera for measurement of abdominal intrusion.

Pelvis tests - Requirement No. 1 : The tests were conducted for each speed i.e. 7 and 8 m/s respectively and with each dummy with a spherical impactor of weight 23.4 kg, similar to that used by INRETS (14) with a diameter of 120 mm and a radius of curvature of 150 mm. It can be seen that these dimensions are different from those recommended by ISO (15) which, if these had been applied to the tests, would have led to an impactor of totally unusual dimensions, i.e. the impactor would have struck the dummy and the seat. The impactor was positioned so as to strike the center of the sorbothane block for EUROSID, and H point of the pelvis for SID.

The dummy was placed in an upright seating position on a rigid seat covered with two sheets of teflon. The choice of the pelvis-seat interface was not obvious. On the one hand, ISO does not mention the type of seat to be provided for this type of tests, and INRETS, in experiments implicating the pelvis with cadavers (14) used an ordinary seat. Therefore, we opted for a solution corresponding to the previous evaluations of pelvis biofidelity of the EUROSID (16) in which the pelvis-seat interface was, precisely, in teflon. The instrumentation for both dummies consisted of acceleration measurements for the sacrum and the impactor. In addition, the EUROSID instrumentation for measurement of the pubic symphis and iliac wing forces was used. The tests were filmed. The filtering frequency classes corresponded to CFC 180 for impactor acceleration and CFC 1000 for the other parameters.

Illustrations of the test setups, mentioned previously, are proposed in figures 1 through 6.

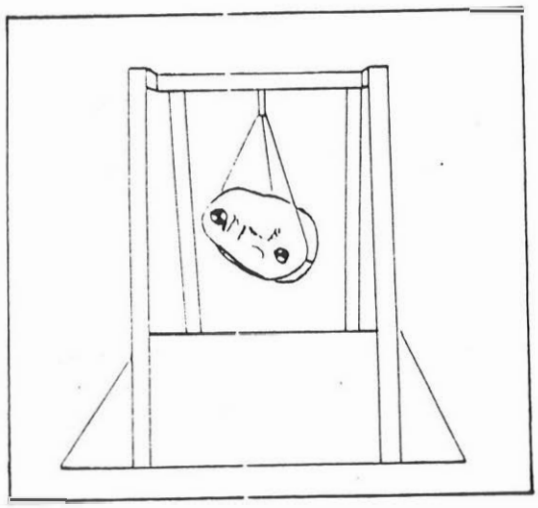

Figure 1. Test set-up used in free falls involving the head segment

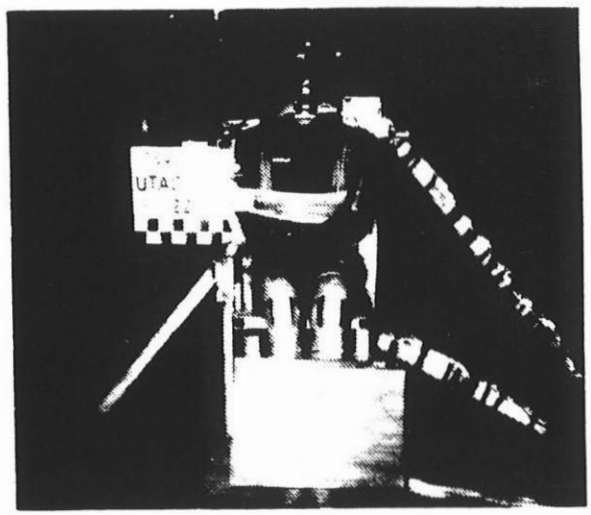

Figure 2. Test set-up used in sled tests involving the neck segment

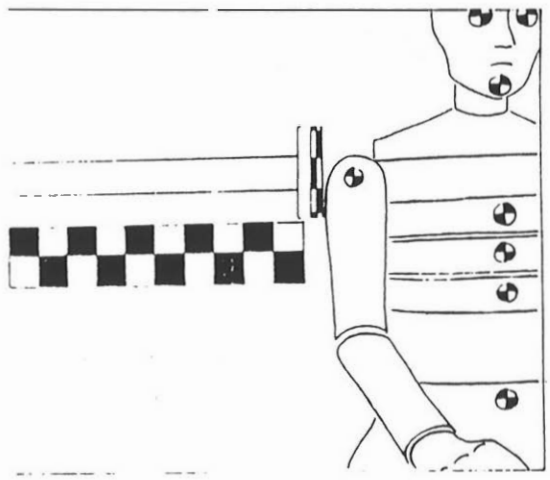

Figure 3. Test set-up used in impactor tests involving the shoulder segment

Figure 4. Test set-up used in drop tests involving the thorax segment

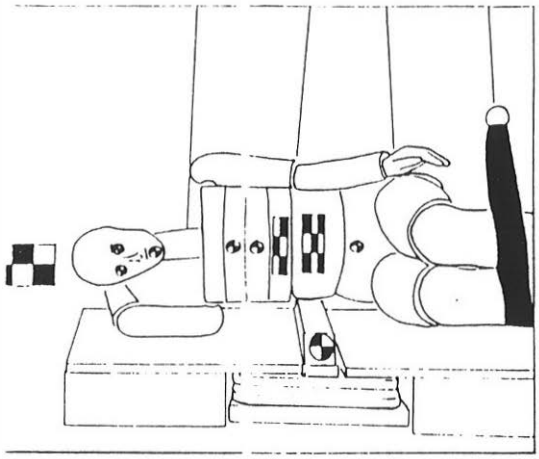

Figure 5. Test set-up used in drop tests involving the abdomen segment

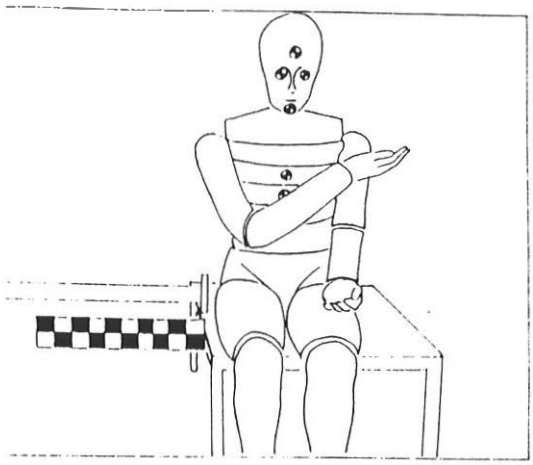

Figure 6. Test set-up used in impactor tests involving the pelvis segment

3 - RESULTS

Only those results dealing with dummy required responses are presented in this section, so as not to overweight the contents of the paper. Dummy performances are presented in the form of peak values or of response vs. time, depending on the type of the requirement prescribed by ISO. Detailed analysis of the results presented here feature in reference (17).

3 - 1. HEAD RESPONSES IN IMPACT TEST NO. 1

The results show that responses of EUROSID and SID heads are higher with respect to the upper limit of the cadaver corridor. As can be seen from figure 7, the EUROSID-cadaver difference is of 28 % for the maximum acceleration of the point of the non-impacted side. This difference appears, however, to be much higher in the case of the SID dummy, where a ratio of 2 between the cadaver upper limit and the SID can be observed.

3 - 2. HEAD RESPONSES IN IMPACT TEST NO. 2

For these padded drop tests, ISO requires that the maximum head c.g. acceleration should be between 217 G and 265 G. The EUROSID and SID responses are located beyond this interval. The acceleration of the EUROSID head is equal to 1.5 times the cadaver upper boundary, while that of the SID head shows a coefficient of 1.2, as shown in figure 7.

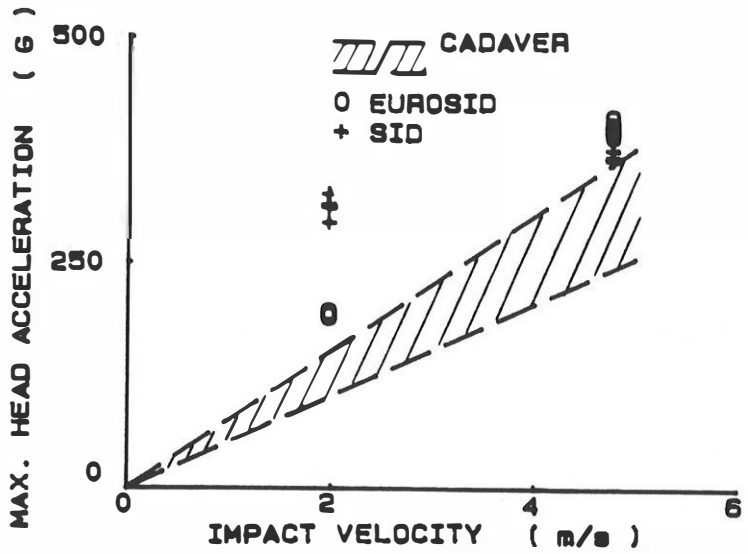

Figure 7. Max. head acceleration, as a function of impact velocity, obtained from respectively rigid and padded drop tests - EUROSID and SID responses compared with ISO requirements corridor

3 - 3. NECK RESPONSES IN SLED TESTS NO. 1

ISO requirements for the neck section consist, among others, of response boundaries defined for 3-D head kinematics relative to the upper spine T1. These requirements comprise also specifications for the lateral displacement of T1 and for accelerometric responses of the head and T1 (8). The sled deceleration vs. time is given in figure 8, where an adequate reproduction of the volunteer reference condition (18) can be noted. Only the most important parameters, dealing with responses vs. time of EUROSID and SID necks are here discussed, i.e. the lateral displacement of T1, the head c.g. trajectory and the head flexion angle (see respectively figures 9, 10, 11). It follows that :

- the EUROSID response in terms of T1 displacement is satisfactory, while that of the SID is much lesser than the requirement (figure 9).

- the EUROSID head c.g. trajectory appears to be closer to ISO data than that of SID, which is outside the volunteer envelope (figure 10),

- the maximum lateral flexion of the head of EUROSID is well within the response boundaries and that of the SID is outside these boundaries (figure 11).

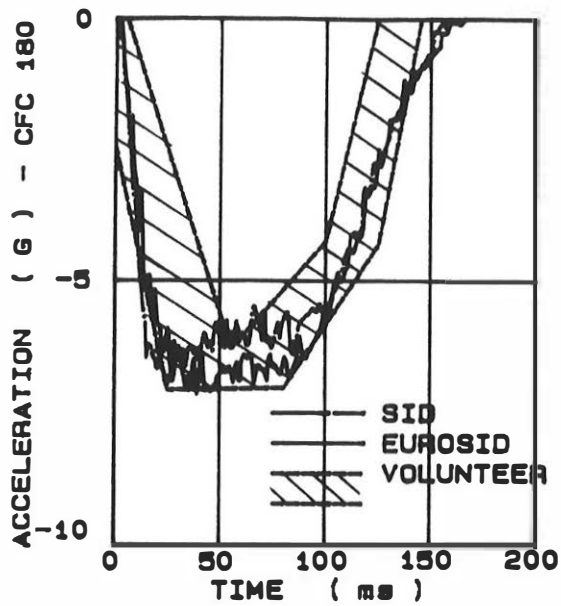

Figure 8. Sled deceleration time-history obtained from low G-level sled tests EUROSID and SID responses compared with ISO requirement corridor

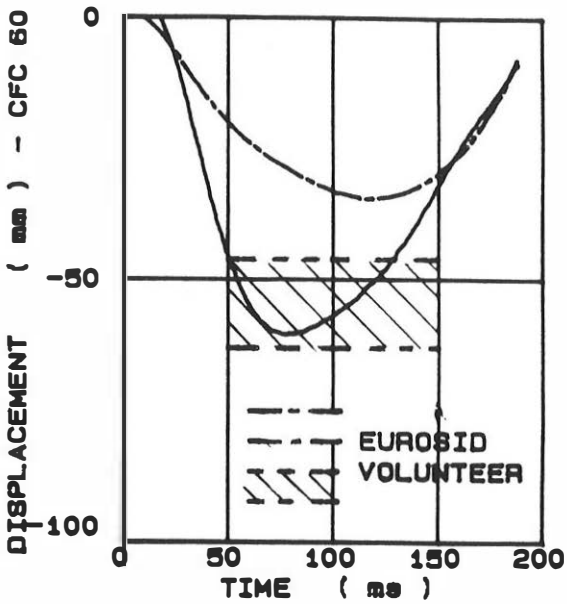

Figure 9. T1 lateral displacement relative to the sled obtained from low G-level sled tests - EUROSID and SID responses compared with ISO requirement

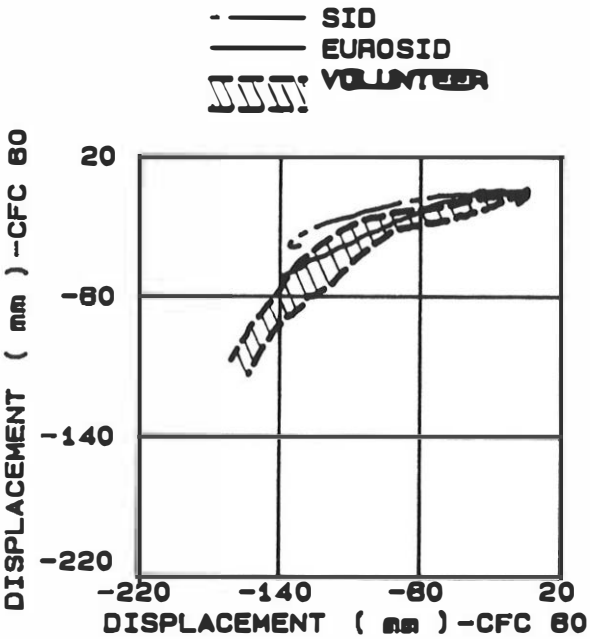

Figure 10. Trajectory of the head c.g. relative to T1 obtained from low G-level sled tests - EUROSID and SID responses compared with ISO requirements corridor

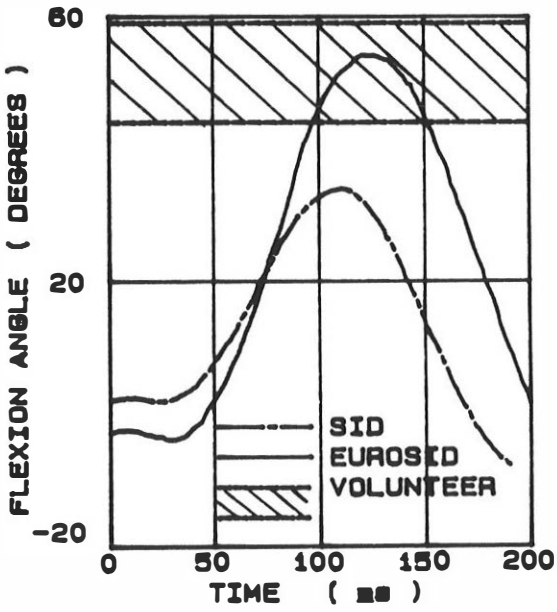

Figure 11. Head lateral flexion vs. time obtained from low G-level sled tests - EUROSID and SID responses compared with ISO requirement

3 - 4. NECK RESPONSES IN SLED TEST NO. 3

ISO requirements for sled tests No. 3 (8) are basically similar to those of test No. 1, except for head kinematics which is expressed relative to the sled. Figure 12 illustrates sled deceleration time-histories obtained from EUROSID and SID tests, where a higher sled deceleration than in the previous case, can be observed. EUROSID and SID neck responses are compared with ISO requirements in figures 13, 14 and 15 respectively for the lateral acceleration vs. time of T1, the head c.g. trajectory and the head flexion angle vs. time. It can be noted that :

- both dummies responses vs. time are slightly outside the T1 acceleration envelope of the cadaver (figure 13), but the EUROSID maximum response is closer to the boundaries,
- both dummies responses are close to the upper limit of the cadaver, in terms of head c.g. trajectory envelope (figure 14),
- the maximum head lateral flexion is, for both dummies, in agreement with response boundaries (figure 15).

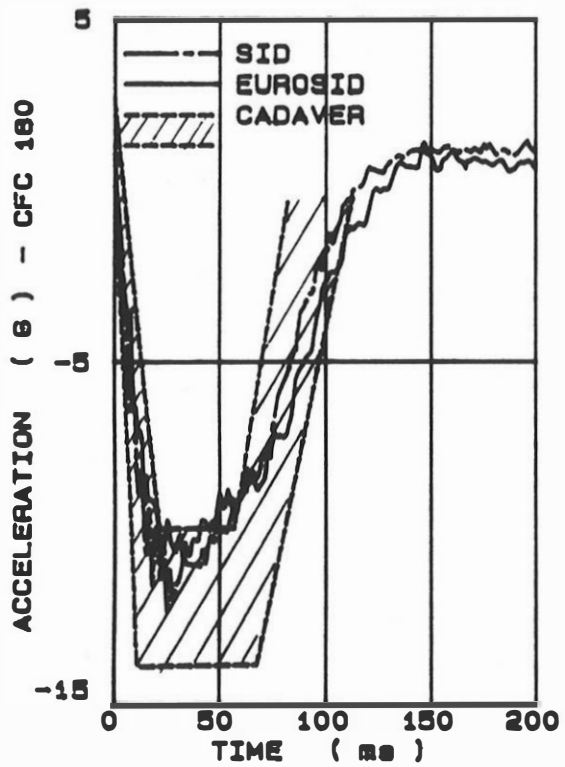

Figure 12. Sled deceleration time-history obtained from high G-level sled tests - EUROSID and SID responses compared with ISO requirement corridor

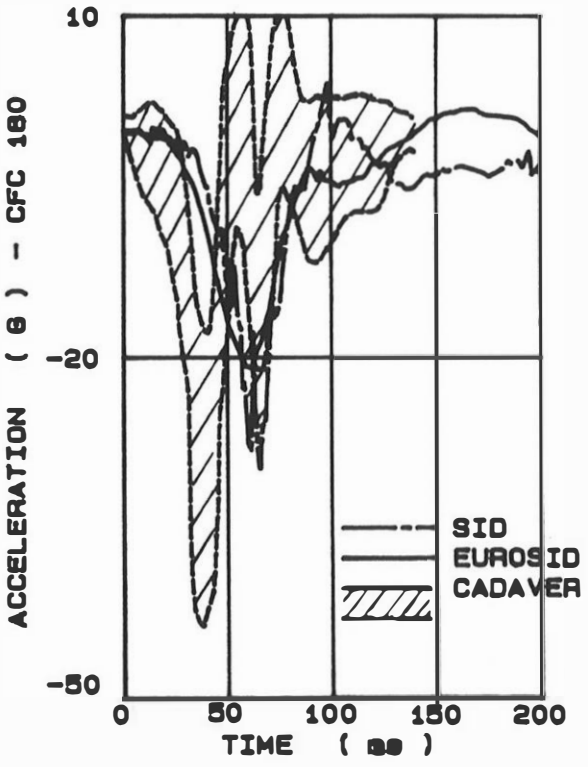

Figure 13. T1 acceleration time-history obtained from high G-level sled tests - EUROSID and SID responses compared with ISO requirement corridor

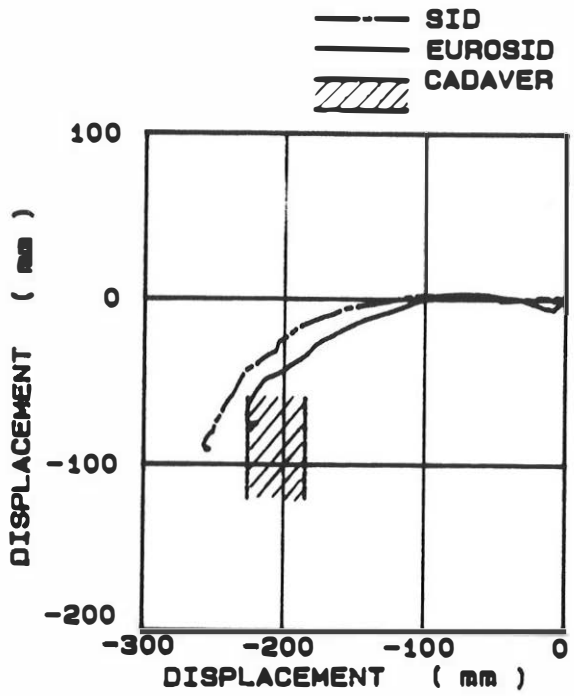

Figure 14. Trajectory of the head c.g. relative to the sled obtained from high G-level sled tests - EUROSID and SID responses compared with ISO requirement

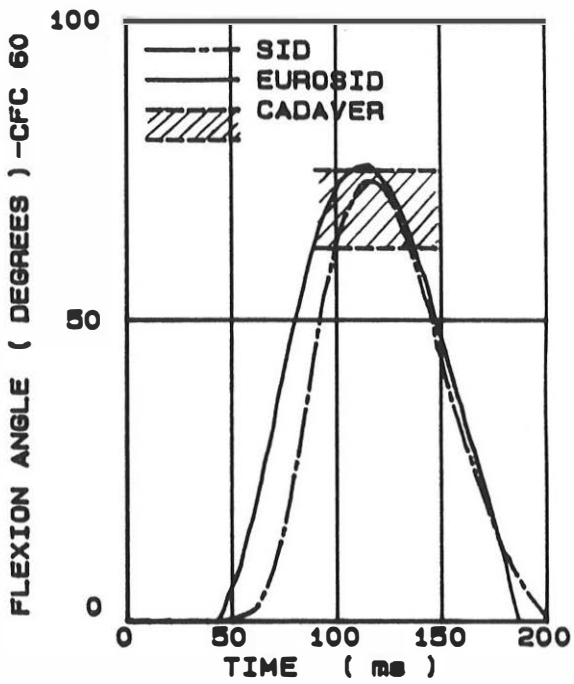

Figure 15. Head flexion angle vs. time obtained from high G-level sled tests - EUROSID and SID responses compared with ISO requirement

3 - 5. SHOULDER RESPONSES IN IMPACT TEST NO. 1

Two types of specifications are defined by ISO in Document DTR 9790-4 (11) for this segment. They are the normalized impactor force time-history and the normalized peak deflection of the shoulder. For such tests the normalization procedure seems to have a small effect when applied to dummy original data (17). In figure 16, the normalized impactor force is compared with the requirement corridor. The EUROSID response is well within the requirement, with peaks slightly exceeding the top boundary of the corridor. The SID response is completly outside this corridor. As far as the maximum shoulder deflection is concerned, the EUROSID response is two times higher and that of the SID is almost four times higher than the upper limit of the requirement, i.e. 41 mm.

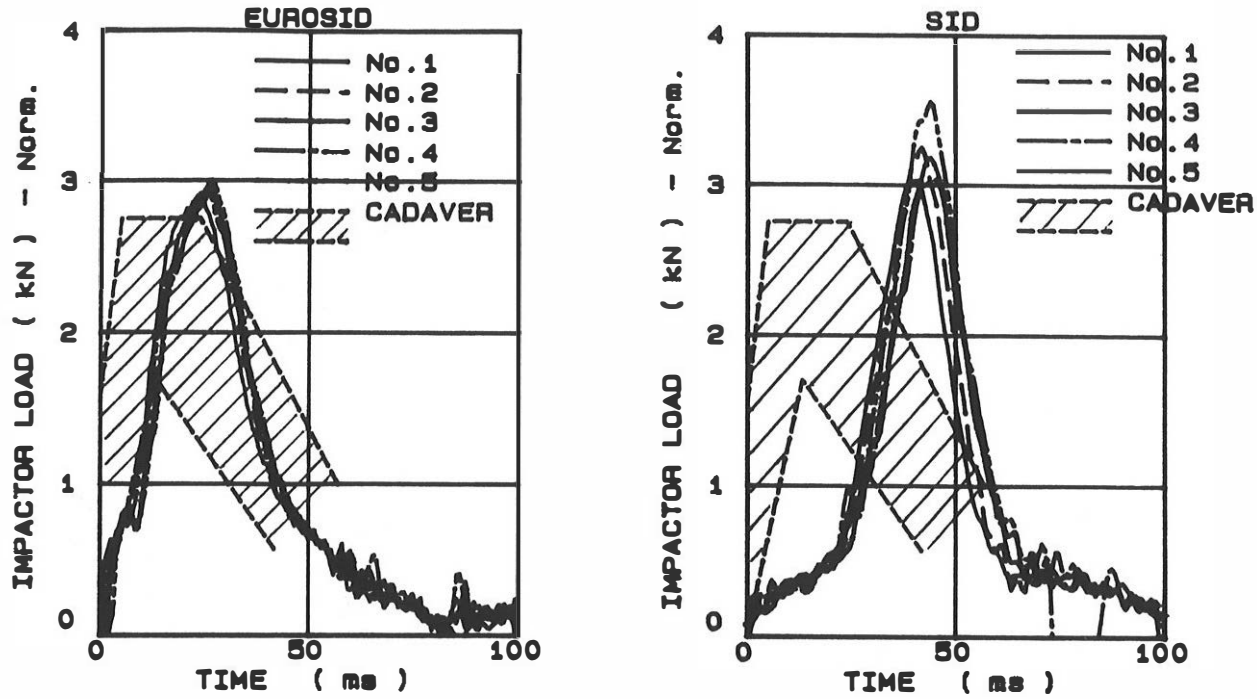

Figure 16. Normalized impactor load vs. time obtained from impactor tests. EUROSID and SID responses compared with the ISO requirement corridor

3 - 6. THORAX RESPONSES IN IMPACT TEST NO. 1

For evaluation of the biofidelity of this segment ISO has defined two response requirements (9), which are respectively the normalized thoracic load vs. time and the normalized peak rib deflection. Here again, the normalization procedure has a small effect on dummy original data, especially as far as the SID is concerned (17).

In figure 17, normalized thoracic load time-histories, obtained from 1 m rigid drop tests, are plotted. The EUROSID response is slightly outside the cadaver corridor and the magnitude of its thoracic load is in agreement with the corridor boundaries. The SID response shows much higher peaks when compared to the same corridor. Therefore, the EUROSID response is considered as closer to the requirement than that of the SID.

The normalized thoracic load obtained from 2 m padded drop tests is presented in figure 18. Dummy responses are here compared with the cadaver corridor required by ISO (9). It can be observed that the padding reduced considerably the differences between the dummy responses. The pulse duration of the thoracic load in SID test is close to that of the corridor ; this duration appears to be larger for the EUROSID. The responses of both dummies achieve their maximum approximately at the same time and are slightly outside the corridor. The brief peaks seen in the response of the SID in figure 18 are due to the impact of the dummy head, which took place later than the loading of the thorax.
The comparison of dummy responses, in terms of normalized rib deflection, with the requirement shows that the performance of the SID is better than that of the EUROSID. In 1 m drop tests, the SID normalized maximum deflection is slightly higher than the cadaver upper limit (12 %) while that of EUROSID is much higher than the limit. In 2 m drop tests, the SID dummy achieves a satisfactory response and the EUROSID rib deflection is close to the requirement (between 4 and 10 % higher than the cadaver upper boundary).

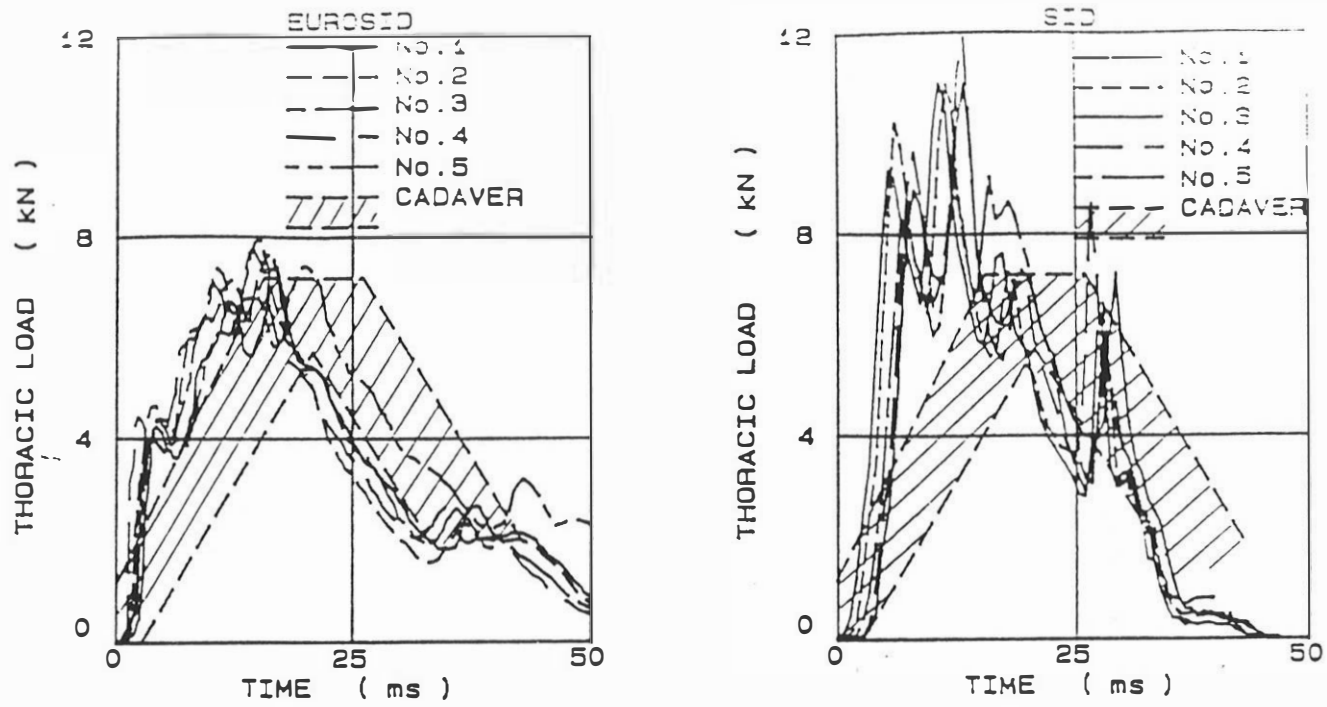

Figure 17. Normalized thoracic load vs. time obtained from 1 m rigid drop tests involving the thorax - EUROSID and SID responses compared with the ISO corridor requirement

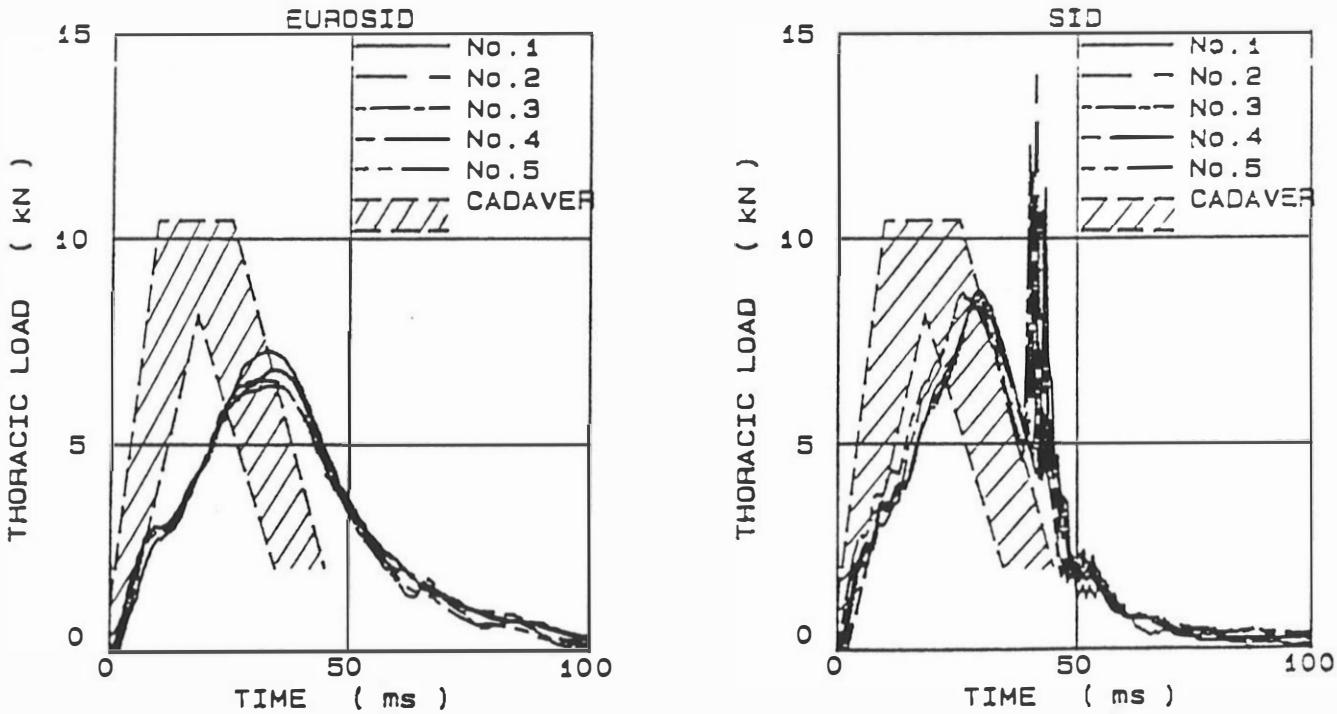

Figure 18. Normalized thoracic load vs. time obtained from 2 m padded drop tests involving the thorax - EUROSID and SID responses compared with the ISO corridor requirements

3 - 7. THORAX RESPONSES IN IMPACT TEST NO. 3

For these impactor tests, ISO requires that dummy original data have to be filtered using a FIR 100 Hz filter and then normalized (9). The impactor and spine accelerations vs. time were normalized for both dummies. The comparison of dummy responses with ISO requirements is illustrated in figures 19 and 20. It appears that both dummy responses exceed the limits of required corridors.

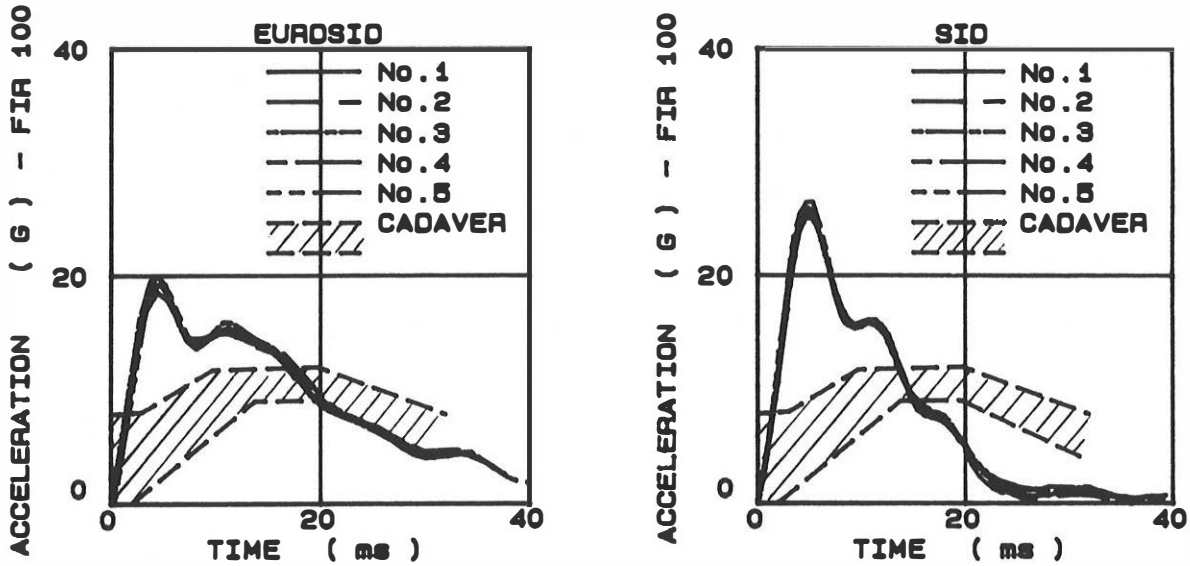

Figure 19. Normalized impactor acceleration vs. time obtained from impactor tests involving the thorax - EUROSID and SID responses compared with the ISO corridor requirement

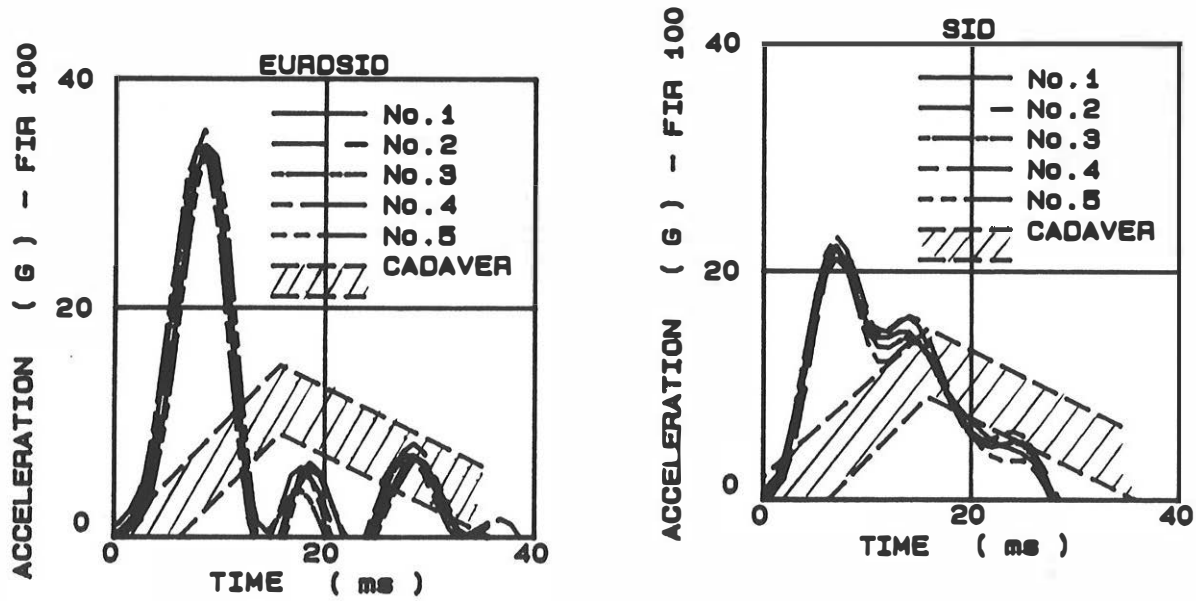

Figure 20. Normalized lateral T1 acceleration vs. time obtained from impactor tests involving the thorax - EUROSID and SID responses compared with the ISO corridor requirement

3 - 8. ABDOMEN RESPONSES IN IMPACT TEST NO. 1

EUROSID and SID test results were normalized according to the procedure described in (13), for drop tests conducted respectively at 1 m and 2 m heights. Results obtained before and after the normalization process are given respectively in tables 2 and 3, for two tests conducted with each dummy (17). A very small value of the effective mass Me, i.e. 0.9 kg, was obtained for SID dummy, whatever the drop height. This mass being so far from the 14.6 kg suggested by ISO (13), the normalizing factors, obtained for force and acceleration, show values which are not obvious, i.e. respectively 4.07 and 0.24 in a 2 m drop test for instance. Thus, SID data were reduced (rib and spine acceleration) or increased (abdominal force) about four times ! Therefore, the normalization procedure, when applied to such a dummy segment, is questionable. In figures 21 and 22, the EUROSID and SID normalized abdominal force vs. time is compared with requirement corridors. From data available in reference (17) and on the basis of results given in figures 21 and 22 (see also table 3), it follows that :

- whatever the drop heights, SID normalized responses appear to be much lesser than those required by ISO,

- the maximum spine and rib acceleration of EUROSID exceeds the cadaver responses in 1 and 2 m drop tests,

- the EUROSID response, in terms of normalized abdominal load, is considerably too high when compared with ISO corridors.

3 - 9. PELVIS RESPONSES IN IMPACT TEST NO. 1

For pelvic segment, ISO has defined in document DTR 9790-6 the normalized impactor force as a requirement for the dummy impact response (15). The impactor force was obtained from the product of the impactor mass (17.3 kg) and its acceleration.

As shown in figures 23 and 24, EUROSID and SID responses exceed the cadaver upper response respectively in 7 and 8 m/s impactor tests.

Table 2. Results obtained from respectively 1 and 2 m drop tests involving the abdomen

Test No.	EUROSID		SID	
	1	2	1	2
Drop height [m]	1	2	1	2
Max. Lateral Acceleration of the lower rib [G] - CFC 600	187	325	107	198
Max. Lateral Acceleration of the spine (T12) [G] - CFC 600	69	121	79	166
Max. Abdominal Impact force [kN] - CFC 600	7.46	13.86	0.52	1.06
Abdominal switch contact	No	Yes	-	-

Table 3. Normalized results obtained from respectively 1 and 2 m drop tests involving the abdomen

Test No.	EUROSID		SID	
	1	2	1	2
Effective Mass Me [kg]	13.12	12.05	0.89	0.99
Mass Ratio Rm	1.25	1.36	18.31	16.56
Normalizing factors - Rf = Rt	1.12	1.17	4.28	4.07
- Ra	0.84	0.85	0.23	0.24
Max. Normalized Lateral acceleration of the lower rib [G]	166	277	25	48
Max. Normalized Lateral acceleration of the spine [G]	60	103	18	40
Max. Normalized Abdominal Impact force [kN]	8.36	16.21	2.25	4.31

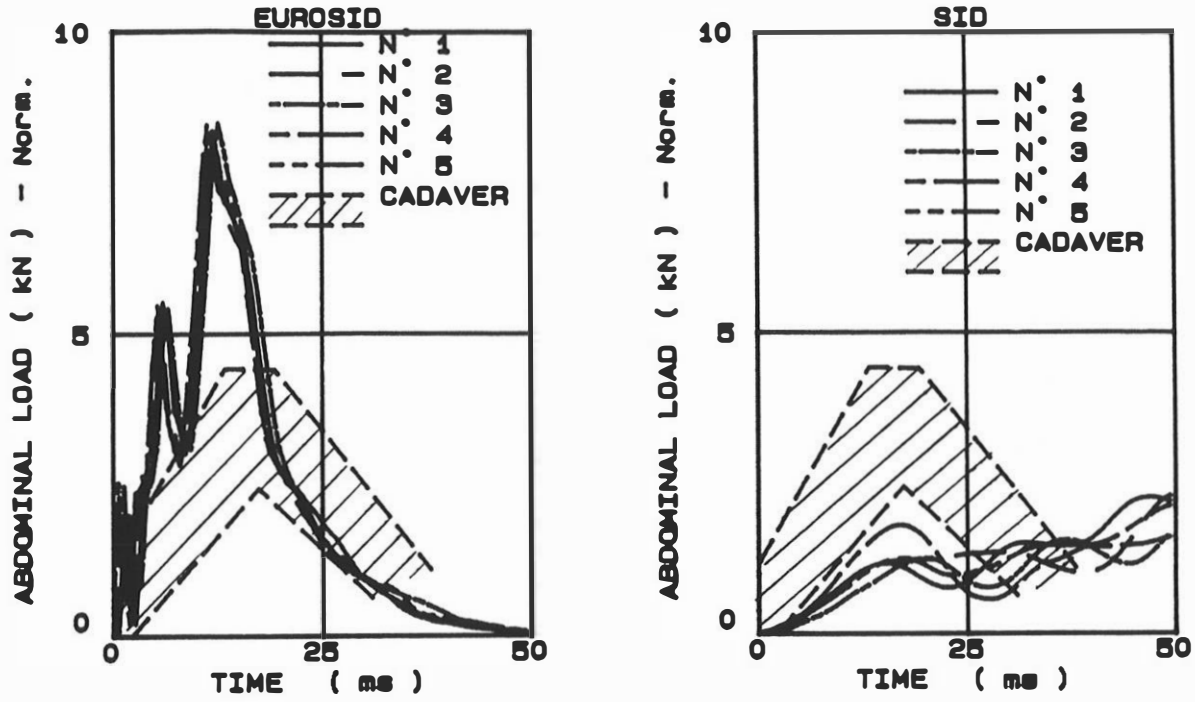

Figure 21. Normalized abdominal load vs. time obtained from 1 m drop tests - EUROSID and SID responses compared with the cadaver corridor

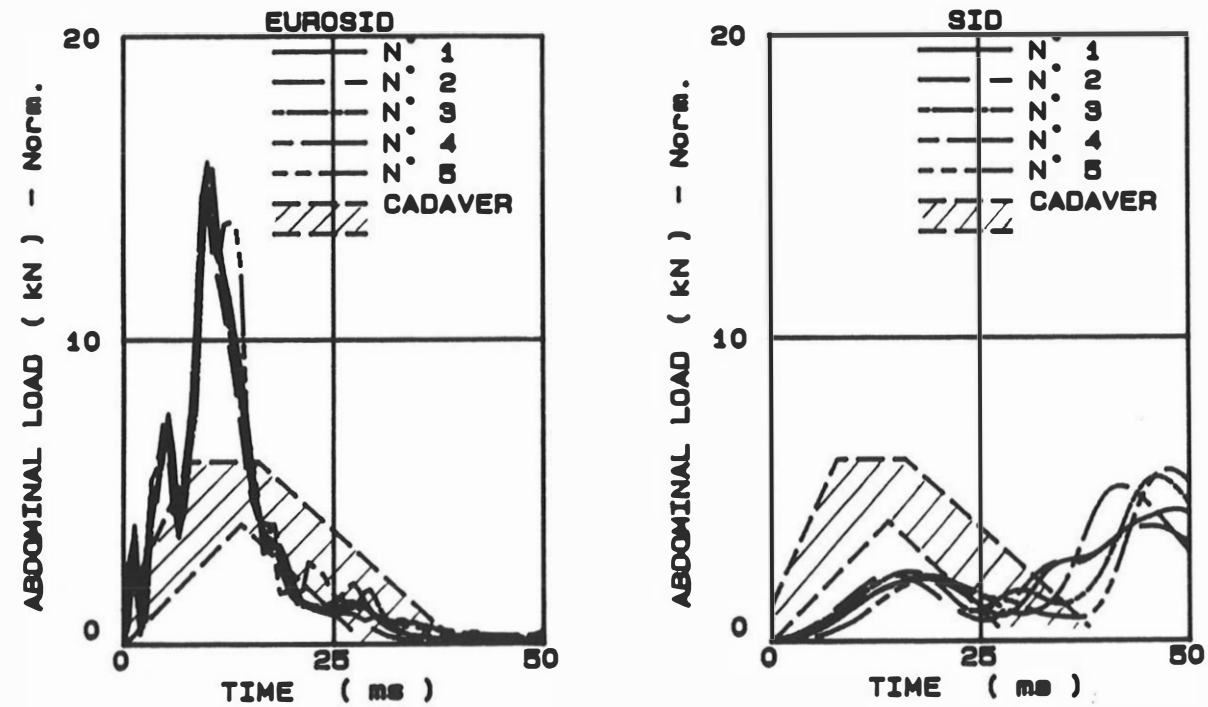

Figure 22. Normalized abdominal load vs. time obtained from 2 m drop tests - EUROSID and SID responses compared with the cadaver corridor

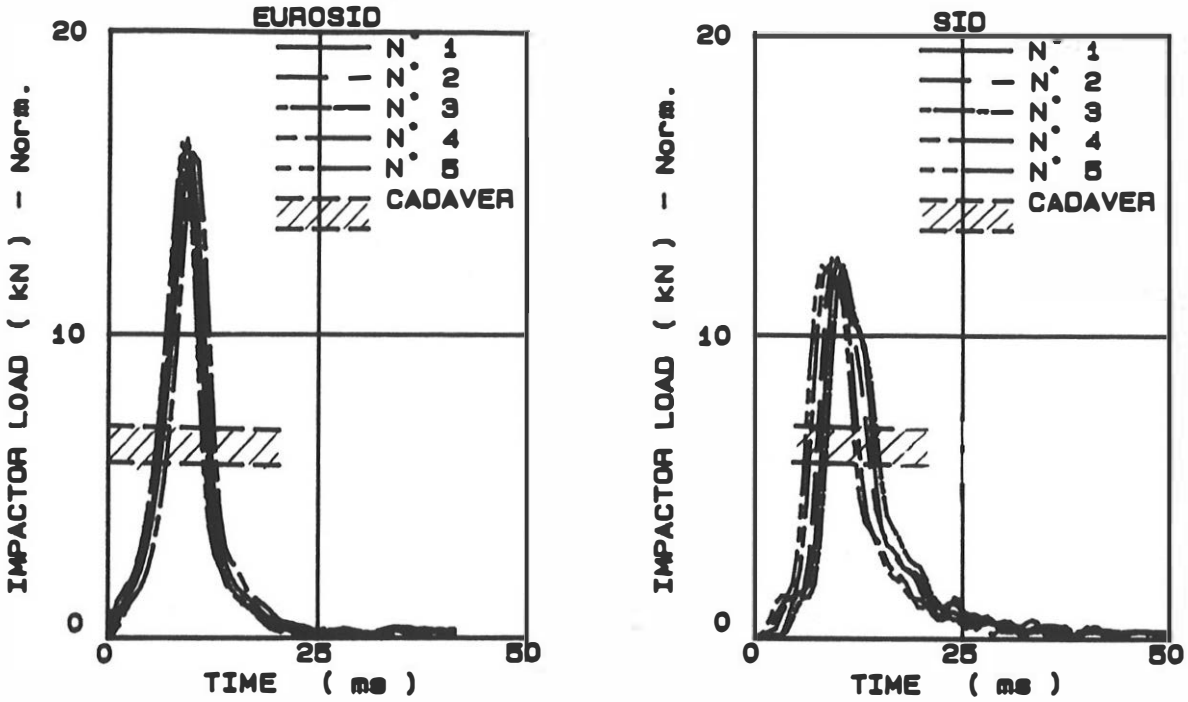

Figure 23. Normalized impactor load vs. time obtained from impactor tests involving the pelvis, performed at 7 m/s - EUROSID and SID responses compared with ISO requirement

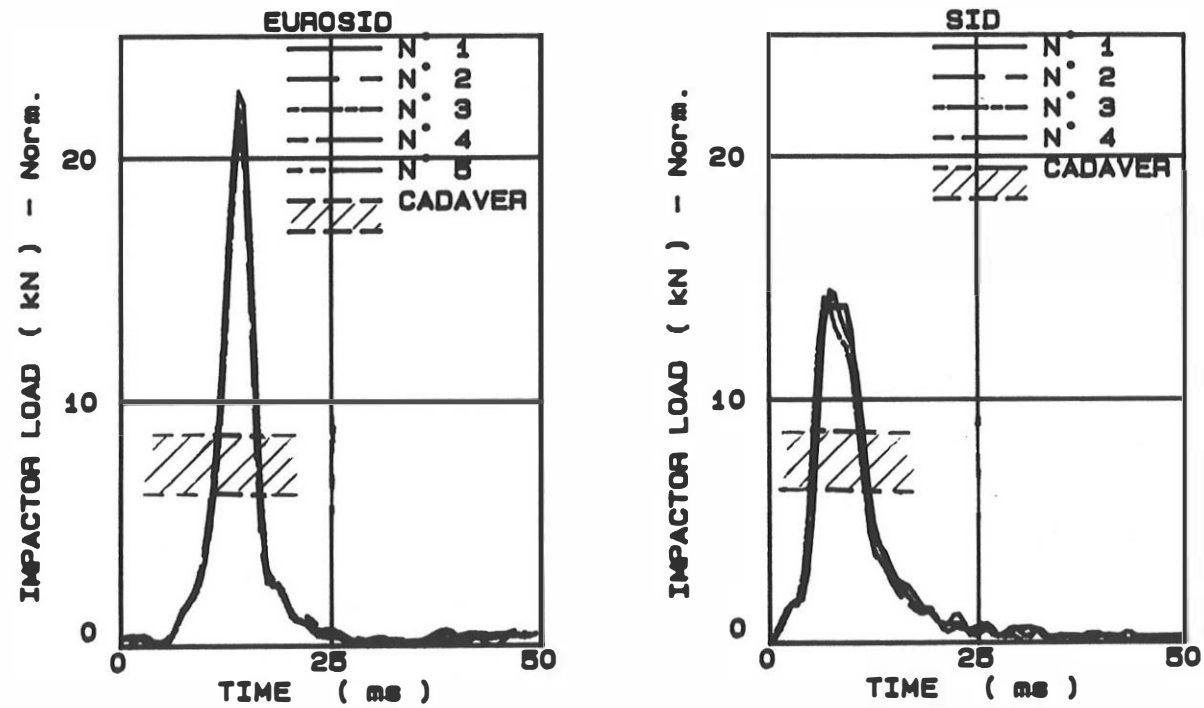

Figure 24. Normalized impactor load vs. time obtained from impactor tests involving the pelvis, performed at 8 m/s - EUROSID and SID responses compared with ISO requirement

4. DISCUSSION

The biofidelity of the two dummies, EUROSID and SID, was evaluated as part of a test program run by the C.C.M.C. in Europe. To obtain the fullest possible evaluation of this important dummy quality, the most recent and up-to-date evaluation data were employed as a human biomechanical reference. These data, selected and approved by the ISO experts, are set out in ISO documents DTR 9790-1 through 6 (3). Body segments such as head, neck, thorax, shoulder, abdomen and pelvis were tested in accordance with the test conditions recommended in said documents.

Duplication of these tests conditions posed some problems for certain segments (cf. Chapter 2). For the pelvis, for example (test No. 1), in which an impactor laterally impacts the pelvis, no requirement concerning the type of seat is specified in document DTR 9790-6. We therefore performed these data with a seat having a flat, smooth surface, without back support, and with two sheets of Teflon placed between the dummy's pelvis and the seat ; moreover, these conditions correspond to those used by INRETS (16) in evaluating the first EUROSID prototype. In addition, the dimensions of the impactor's surface, as recommended by ISO, are incorrect.

For the abdomen drop tests, ISO recommends (13) that the armrest be positioned in such a way that it is impacted by the lower rib of the dummy's thorax. If this position had been reproduced, for the EUROSID dummy a large part of the abdomen would not have been subjected to impact. Since this dummy was developed for the injury measurement criterion, the armrest was centered, in these tests, on the axis of the switches contacts designed precisely to allow such measurement (6).

For the head evaluation tests (drop test No. 2), we performed the recommended drop test (1.2 meters on a padding 5 mm thick), while varying the test conditions to obtain a head only drop, a guided head only drop, and, finally, the same drop with the whole dummy. The latter configuration, moreover, complies with the conditions of the cadaver tests performed by APR (19) (5). When comparing the head only drop and the guided drop, the differences between the head acceleration results are 1 %. These differences are as great as 9 % (EUROSID) and 13 % (SID) when comparing the free head drop and the whole dummy drop.

From the above remarks, it is clear that in the future it would be worth supplementing the ISO documents with a practical User's Manual of recommended test conditions.

The main purpose of the normalization procedure applied to the dummy data was to reduce the scatter between tests on an identical configuration. For the shoulder, thorax and abdomen, we observed that this procedure was capable of amplifying or attenuating the basic test data, but no fundamental change is observed (generally a variation of 5 % to 8 %). On the other hand, for drop tests with the SID abdomen, one notes that the normalization procedure amplifies (or attenuates) the original results to a far greater extent than what is observed for the other segments, namely, by a factor of 4. In this respect, the application of normalization to the SID abdomen poses a problem.

On the basis of the available results, the conclusions concerning the biofidelity performance of the two dummies can be presented as follows.

4.1. HEAD RESPONSES

For rigid impacts, the responses of both dummies are outside the required corridor, although the EUROSID response is closer to the corridor than the SID response. For damped impacts, the responses of both dummies are higher than the corridor's upper limit. For such impacts, padding attenuates the differences between the responses of the two heads.

4.2. NECK RESPONSES

For low-violence sled tests, both dummies appear to comply with the specification concerning the maximum lateral acceleration at T1, with the SID peak being closer to the stipulated limits.

Now, if the comparison between the two dummies is taken further with the time envelope (17) suggested by ISO reference DTR 9790-2, it can be seen that the EUROSID response matches the volunteer's response better than the SID. For lateral displacement of T1 (the neck base), the EUROSID response is within the required limits, while the SID response is well below the required limits. A comparison between the c.g. trajectories of the SID and EUROSID heads and the volunteer corridor showed that the SID response is outside the corridor's limits, while the EUROSID response is within them. In terms of the head lateral flexion angle, here again EUROSID seems in a better position than SID. From the mechanical viewpoint, the results achieved clearly show that the SID neck is stiffer than the EUROSID neck, for it simulates the volunteer's behavior less accurately. Moreover, neither dummy complies with the ISO specification concerning the head twist angle, giving values well below than required. For very violent tests, the responses of both dummies are close to the upper limits of the ISO corridors. It is surprising to observe that the SID neck has a greater head c.g. trajectory than the EUROSID. This can be explained by the fact that the T1 lateral displacement is approximatly 1.3 times higher for the SID.

4.3. SHOULDER RESPONSES

The normalized impactor force for EUROSID is located almost entirely in the ISO corridor. In terms of shoulder deflection, the EUROSID and SID responses are two and four times higher than the specification, respectively. The major deflection noted for SID can be explained by the very low stiffness of the foam block simulating the dummy's shoulder, which allows high deflection for a low force level. Moreover, a sharp deterioration was observed in the foam (problem of durability).

4.4. THORAX RESPONSES

For drops from a height of 1 meter onto a rigid surface, the dummies' responses in terms of normalized thoracic force are outside of the corridor. The time-history and the magnitude of EUROSID response are, however, much closer to the cadaver reference than those of the SID.

The maximum thoracic deflection for SID is closer to the stipulated limits. For 2-meter drops, the thoracic force time-history shows no large differences between the two dummies, and is for all tests slightly outside the corridor. The SID's thoracic deflection is in compliance with the specifications, while that of EUROSID is slightly higher than the cadaver upper limit. The good performance of the SID dummy for the thoracic deflection, in the drop tests, should be attenuated by the fact that the rib deflection has not the same physical sense for SID and EUROSID respectively, since the SID rib cage may deflect and rotate while that of the EUROSID can only deflect.

The EUROSID deflection rib data, given here, were obtained from three potentiometers, which equipped the dummy rib cage. The EUROSID special instrumentation for the measurement of rib deflection was used only during the first series of drop tests, since this showed errors (constant offsets in rib deflection time-histories).
For the impactor tests, the responses of both dummies in terms of normalized acceleration at T1 (FIR 100 Hz) are well outside the corridor. For impactor acceleration, the same trend is observed, but the dummy-corridor differences are slighter.

4.5. ABDOMEN-RESPONSES

Whatever the drop height in question (1 or 2m), the SID responses are well outside specifications. We saw in Chapter 3 that normalization had a major amplifying effect (for abdominal force) or attenuating effect (for rib acceleration) on the original SID results, by a factor close to 4. A direct comparison between the non-normalized SID data and the requirements in no way gives a better abdomen performance for this segment, except for acceleration of the lower rib, which comes nearer to the cadaver limits for the 1-meter tests. For EUROSID, the responses in terms of acceleration of the lower rib and spine exceed the required limits, but they are better for 2-meter drops. This dummy's abdomen shows very stiff behavior in terms of abdominal force and the levels obtained were far higher than the ISO corridor (coefficients of approximately 1.90 and 2.50 are noted for the 1- and 2-meter tests, respectively). Moreover, analysis of the film showed that the abdomen reached its maximum deflection in all tests.

4.6. PELVIS RESPONSE

The responses of both dummies are well above the required limits for normalized impactor force for both the impact speeds used, namely, 7 and 8 m/s.

5. CONCLUSIONS

For easy interpretation of the study results, the performance of each dummy response has been summarized in table 4. For each ISO requirement, there may be only a single required response for head requirement No. 1, for example, or up to nine required responses for neck requirement No. 1.
For each of the ISO requirements, the results have been classified by allocating a score for each required response. For this purpose, the results were classified in three categories, A, B and C.
For :
- A : the response is excellent, located within the required limits,
- B : the response is close to the required limits ; it must be improved,
- C : the response is very remote from the specifications and is regarded as unacceptable.

Table 4, shows as follows :

- 1 - The biofidelity of both dummies is rather bad by comparison with the ISO requirements as a whole. More "C"s are observed than "B"s or "A"s, and accordingly in most cases the responses are very poor (unacceptable). SID's score, with 23 "C"s, is even worse, as against 15 "C"s for EUROSID.

- 2 - EUROSID has a higher number of "B" scores than SID, with 12 "B"s as compared with 6, and especially a higher number of "A" scores (9, as compared with 7 for SID).

Table 4. Summary of EUROSID and SID performance according to ISO requirements DTR 9790-1 through 9790-6

Body Segment	ISO Reference DTR	Requirement n°	Dummy Score Per Required Response	
			EUROSID	SID
Head	9790-1	1	C	C
Head	9790-1	2	C	C
Neck	9790-2	1	AAACBBABA	CACCACACB
Neck	9790-2	3	ABCBBC	CBBBAC
Thorax	9790-3	1	BCBB	CBBA
Thorax	9790-3	3	CC	CC
Shoulder	9790-4	1	BC	CC
Shoulder	9790-2	1	A	C
Abdomen	9790-5	1	CCCABBCA	CCCACCCA
Pelvis	9790-6	1	CC	CC
TOTAL DUMMY SCORE			9 A + 12 B + 15 C	7 A + 6 B + 23 C

REFERENCES

(1) J. Maltha, E.G. Janssen,
"EEC Comparison Testing of Four Side Impact Dummies", Research Institute for Road Vehicles-TNO, EEC Biomechanics Programme Phase IV - Synthesis Report, Delft, March 1983.

(2) Commission of the European Communities,
"Biomechanics of Impacts in Road Accidents", Proceedings of the EEC Seminar, Brussels, 1983.

(3) ISO/TC22,
"Road Vehicles - Anthropometric Side Impact Dummy. Lateral Impact Response Requirements to Assess the Biofidelity of the Dummy", Documents No. DTR 9790-1 through 9790-6 - November 1987.

(4) US NHTSA 49 CFR PART 573 - Docket Nb 88-07, Notice 2,
"Side Impact Anthropometric Test Dummy", January 1988.

(5) R.M. Morgan and all.
"Side Impact - The Biofidelity of NHTSA's proposed ATD and Efficacy of TTI", SAE Paper Nb 861877, Proceedings of the Thirtieth STAPP Car Crash Conference, San Diego, California, October 1986.

(6) I.D. Neillson,
"The EUROSID Side Impact Dummy", Proceedings of the 10th ESV Conference, Oxford, 1985.

(7) R. Lowne and I. Neilson,
"The Development and Certification of EUROSID", Proceedings of the 11th ESV Conference, Washington, DC, May 1987.

(8) ISO/TC22,
"Road Vehicles - Anthropometric Side Impact Dummy. Lateral Neck Bending Response Requirement to Assess the Biofidelity of the Dummy", Document No. 9790-2.

(9) ISO/TC22,
"Road Vehicles - Anthropometric Side Impact Dummy - Lateral Thoracic Impact Response Requirements to Assess the Biofidelity of the Dummy", Document No. DTR 9790-3.

(10) ISO/TC22,
"Road Vehicles - Anthropometric Side Impact Dummy. Lateral Head Impact Response Requirements to Assess the Biofidelity of the Dummy", Document No. DTR 9790-1.

(11) ISO/TC22,
"Road Vehicles. Anthropometric Side Impact Dummy. Lateral Shoulder Impact Response Requirement to Assess the Biofidelity of the Dummy", Document No. DTR 9790-3.

(12) M.G. Langdon,
"Program to Analyse Chest Injury Data from EUROSID", TRRL, Vehicle Safety Division, Version written in June 1987.

(13) ISO/TC22,
"Road Vehicles - Anthropometric Side Impact Dummy - Lateral Abdominal Impact Response Requirements to Assess the Biofidelity of the Dummy", Document No. DTR 9790-5.

(14) D. Césari,, M. Ramet and P. Clair,
"Evaluation of Pelvic Fracture Tolerance in Side Impact", SAE 801306, 24th Stapp Car Crash Conference, October 1980.

(15) ISO/TC22,
"Road Vehicles - Anthropometric Side Impact Dummy - Lateral Pelvic Impact Response Requirements to Assess the Biofidelity of the Dummy", Document No. DTR 9790-6.

(16) D. Césari,
"Validation Programme for European Side Impact Dummy (EUROSID", INRETS-LCB, Report Nb. NNS 8601, September 1986.

(17) F. Bendjellal et al.
"Comparative Evaluation of the Biofidelity of EUROSID and SID Side Impact Dummies", 32nd Stapp Car Crash Conference, October 1987- Paper in preparation.

(18) C.L. Ewing, D.J. Thomas, L. Lustick, W.H. Muzzy, G.C. Willems and P. Majewski,
"Dynamic Response of Human Head and Neck to+Gy Impact Acceleration, Proceedings of the 21st Stapp Car Crash Conference, October 1977, New Orleans, Louisiana.

(19) "APR Lateral Cadaver Drop tests Involving the Head", ISO/TC22/SC12/WG5, Document No. 165, June 1986.