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2001-22-0010

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Reprinted From: Stapp Car Crash Journal, Vol. 45 (November 2001)
(P–375)

The Engineering Society
For Advancing Mobility
Land Sea Air and Space
INTERNATIONAL

45th Stapp Car Crash Conference
San Antonio, Texas
November 15-17, 2001

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A.   Tel: (724) 776-4841 Fax: (724) 776-5760

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Printed in USA

2001-22-0010

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Development and Evaluation of a New Rear-Impact Crash Dummy: The RID 2

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ABSTRACT – Low severity neck injuries due to vehicle accidents are a serious problem in our society. In 1997 the European Whiplash project started with the aim to develop passive safety methodologies to reduce the frequency of neck injuries in rear-end impacts. This project has resulted, among others, in a rear impact crash dummy, the so-called RID2. The objective of this paper is present the design of this dummy and to present its performance in comparison with human volunteer and post mortem human subject (PMHS) tests. Also a comparison is made with the Hybrid III dummy in similar test conditions.

In the comparison with human volunteers in a real car seat, both the RID2 and the Hybrid III showed realistic kinematics. Lower neck rotation as well as the typical S-shape in the neck were found in the RID2, but not in the Hybrid III dummy. Ramping up was not found in the Hybrid III, while the RID2 did show limited ramping up. The upper neck forces measured in both dummies were reasonably good in the regular car seat, but upper neck torques were not well predicted in either dummy. Compared to post mortem human subjects placed on a rigid seat without a head restraint, the Hybrid III was found to be less biofidelic than the RID2, as the kinematics of the human subjects were better approximated by the RID2 than by the Hybrid III, which was mainly attributed to the stiff spine and neck of the Hybrid III.

KEYWORDS – Rear Impact, RID2 dummy, Volunteer, PMHS

INTRODUCTION

Whiplash injuries resulting from car collisions cause human suffering and high social costs due to long-term impairment of the victims. NHTSA reports that in the USA the estimated amount of whiplash injuries each year is 740,000 (NHTSA 2001). Almost fifty percent of the neck injuries are associated with rear impacts (Temming and Zobel 1998). Similar figures have been reported for other countries, like Japan (Ono and Kanno 1993). The percentage of long-term impairments due to neck injuries account for nearly 50% of all long-term consequences resulting from traffic accidents (Koch et al. 1995).

It is assumed that the amount of whiplash associated disorders in rear-end collisions can be reduced significantly by design improvements of the vehicle seat and the head restraint system. In order to provide the necessary knowledge and tools for developing adequate protection by the seat and head restraint system, the European Whiplash project (Cappon et al. 2001) was initiated.

One of the objectives of the European Whiplash project was to develop a crash dummy, which accurately mimics the mechanical performance of a human body in rear-end collisions. The Hybrid III dummy, which was developed in the seventies primarily for use in frontal collisions, has been evaluated by several researchers in rear-end impacts. Most of these studies were conducted with human volunteers at relatively low impact severity levels (up to 10 km/hr and below 4g). The general conclusions from these studies was that the kinematic response of the Hybrid III dummy is quite different from human volunteer behaviour (Scott et al. 1993; Davidson et al. 1999a and 1999b). The human volunteer head-neck response was found to be more complex than the Hybrid III response and ramping-up observed in the volunteer tests was absent in the Hybrid III dummy.

For higher impact severity levels, Prasad et al. (1997) compared the Hybrid III to one human volunteer test and two PMHS tests performed by Mertz and Patrick (1967). He found realistic values for the peak head extension angle, the head acceleration and the neck torque in these test conditions, but for some of the time responses of these parameters significant deviations were reported.

Based on Davidsson's findings, a Swedish consortium developed the BioRID dummy (Davidsson, et al. 1999a and 1998). This dummy is designed with a detailed multi-segment spine allowing motion in the mid-sagittal plane. At the time the European Whiplash project started the BioRID dummy was not available, so within the European project a separate dummy development activity started using as much as possible components of the Hybrid III dummy. This dummy is referred to as Rear Impact Dummy (RID). Within the project two dummy versions have been developed: in the initial phase of the project the RID1 dummy, which was designed based on published tests with human subjects and in the second phase a more advanced dummy, the RID2-α prototype, based on new tests with human volunteers and PMHSs, conducted within this project.

The aim of this paper is to present the RID2 dummy, which is an updated commercially available version of the RID2-α prototype, and to compare the response of this dummy with human volunteer and PMHS tests conducted in the European Whiplash project and with similar tests conducted with the Hybrid III dummy.

THE RID2 DUMMY

Requirements

The RID dummy is intended to evaluate the protection offered to an adult car occupant seated in front and rear car seats during a rear-end collision. The main emphasis of the dummy is to get a realistic interaction with the seat and the headrest system during the initial loading phase of the seat and head-rest. A realistic response of the occupant in the rebound phase was not aimed for in this study. Accident studies (Temming and Zobel 1998) have shown that whiplash injuries most frequently occur in the range of 10-16 km/hr velocity change. So the dummy should show a realistic response within this velocity range.

It was decided to represent a 50th percentile adult male only. Other body sizes of interest initially were planned to be studied by a mathematical representation (i.e. scaled dummy models). In particular the 5th percentile female is of interest in this respect, since accident data show that the frequency of whiplash injuries among female car occupants is almost twice as high as for a male occupant (Temming and Zobel 2000).

The global dimensions (stature, mass and seating height) of the RID dummy were based on antropometric data generated by UMTRI (Schneider 1983), so that the dummy has the same size as the harmonised WorldSID dummy.

Biofidelity is the most important design requirement for a crash dummy. In the initial part of the project the requirements for the dummy were based on existing human subject response data in literature. Since, however, these data were found to be incomplete and sometimes also inaccurate, additional tests with human subjects have been conducted. These tests in particular were aimed to get detailed information on the upper torso-neck-head kinematics and kinetics. Two test series were performed:

1. Seven human volunteer sled tests presented earlier by Van den Kroonenberg et al. (1998). The volunteers were seated in a regular car seat with headrest and accelerated forward at ΔV 9 km/h at an average acceleration of 4.5 g. Tests were performed at the Allianz Zentrum für Technik in Ismaning, Germany under supervision of GDV. These tests will be further referred to as *soft seat tests*.
2. Six PMHS sled tests with three different subjects on a rigid seat and without headrest (see Bertholon et al. 2000 for details). Accident conditions were more severe due to a slightly higher impact velocity (10 km/hr), a higher g level (peak 12 g) and due to the usage of the rigid seat system. The subjects in these tests were strapped to the seat at leg, pelvis and thorax level in order to study the behaviour of the neck and head in particular. The tests were performed at the testing laboratory CEESAR. These tests will be further referred to as *rigid seat tests*.

The main aim of a rear-end impact dummy is the assessment of whiplash injury risk. In spite of the fact that quite some biomechanical studies have been conducted aimed to identify possible injury criteria for whiplash injuries, up to now no reliable and generally well accepted injury criteria for whiplash injuries have been established. In the European Whiplash project it was assumed that the risk of whiplash injuries will reduce if the loading in the neck is reduced. So for the dummy to be developed it was required to include load cells at different locations in the neck region. Additional instrumentation required for the dummy included: head angular and linear accelerations, lower neck accelerations, skull cap forces (head restraint induced) and upper lumbar accelerations and loads.

Additional design requirements for the RID dummy concerned the reproducibility, repeatability (coefficient of variation less than 5%), durability (durable in tests up to 10 g and 25 km/hr) and sensitivity. Furthermore the dummy should be easy to use and suitable for future testing standards. This paper mainly will focus on the biofidelity of the RID dummy.

Dummy design

The RID2 dummy is a combination of new parts and existing dummy parts. The initial dummy developed, i.e. the RID1 was completed in 1997 and many of its components were identical to the Hybrid III dummy. Most important differences were a new neck design, based on the TRID neck (Thunnissen et al. 1996), a new back shape and a skull cap load cell. Its neck motions were like for the BioRID dummy mainly restricted to the mid-sagittal plane (2-dimensional dummy). The biofidelic performance of this dummy in comparison to the two human subject test series conducted in the European Whiplash project, appeared not be sufficiently adequate yet.

Further developments resulted in the RID2-α prototype dummy, which was completed in March 2000. The dummy was tested extensively within the European Whiplash consortium and after that updated to a commercial version, simply called RID2. Like the RID1 dummy the RID2 dummy is based on the Hybrid III dummy. An important difference with the RID1 dummy is a more realistic torso design with larger spine flexibility. The ribcage of the THOR dummy was used and the lumbar spine of the EuroSID 1 dummy. The pelvis of the Hybrid III was modified to allow more flexion-extension movement of the femur and equipped with a bracket which allows adjustment of the pelvis angle. The neck design was changed in order to get more flexible and less stiff response and to be able to twist and to bend laterally. Furthermore there is a free range of motion of 15 degrees in the nodding joint, which allows the head to stay upright during the initial phase of the impact resulting in the S-shape in the neck. Figure 1 and Table 1 show an overview of the RID2 dummy parts and its instrumentation.

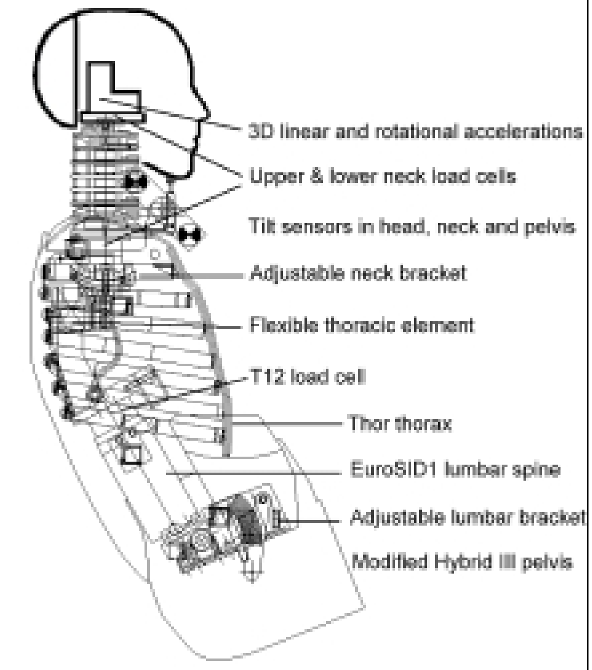

Figure 1: The RID2 dummy: basic design concept and instrumentation

Table 1: RID instrumentation

Position	Measurement	Axes
Head	Acceleration	x/y/z
Head	Rot. Acceleration	y
Skull Cap	Force	x/y/z
Skull Cap	Torque	x/y/z
Upper neck (C1)	Force	x/y/z
Upper neck (C1)	Torque	x/y/z
Lower neck (T1)	Acceleration	x/y/z
Lower neck (T1)	Force	x/y/z
Lower neck (T1)	Torque	x/y/z
Lower torso (T12)	Acceleration	x/y/z

Lower torso (T12)	Force	x/y/z
Lower torso (T12)	Torque	x/y/z
Pelvis	Acceleration	x/y/z

BIOFIDELITY EVALUATION

Two series of sled tests were performed to evaluate the biofidelity of the RID2 dummy. The Hybrid III was tested in similar conditions in order to make a valid comparison between both dummies.

Soft seat tests

Two rear impact tests at a ΔV level of 9 km/h were performed with the RID2 dummy at TNO Automotive and one with the Hybrid III according to the test conditions presented by Van den Kroonenberg et al. (1998) at Allianz Centrum für Technik in Germany. In these tests a regular car seat with a head restraint was used. The seat backrest was oriented at 25^{o} backward inclination and a regular 3-point belt was used. Clothing of the volunteers and dummies was not identical, as the effect of friction in these low severity tests was thought to be negligible. An overview of the setup is given in Figure 2 and the crash pulses of TNO and AZT are shown in Figure 3. The second peak in the RID2 pulse is induced by the brake of the sled during the rebound.

Figure 2: Overview of test set-up for RID 2 evaluation.

Kinematics of head and T1 were calculated using high-speed film recordings. The camera recorded the event from a lateral view with a frame rate of 1000 frames/sec for a duration of 300 ms. The positions of the targets on the head and T1 were obtained by digitising the film frames.

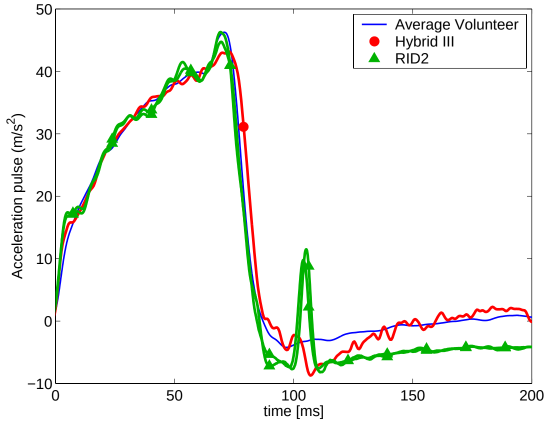

Figure 3: Sled pulse in soft seat testing

Rigid seat tests

A series of two sled tests was carried out at the Laboratory of Accidentology and Biomechanics (LAB) in France with both the RID2 dummy and the Hybrid III dummy according to the PMHS test conditions presented by Bertholon (2000). LAB and CEESAR use the same facility so conditions were similar for dummy and PMHS experiments. The pulses used are shown in Figure 4. Tests were conducted with rigid seat without a head restraint. Targets were used to monitor the head and T1 displacements on the RID2 dummy. In the tests with the Hybrid III dummy, the T1 location was not marked. The tests were filmed with a digital camera at 1000 frames/sec. Rotations and displacements were computed from video analysis. T1 displacements in the Hybrid III were derived from the accelerations measured.

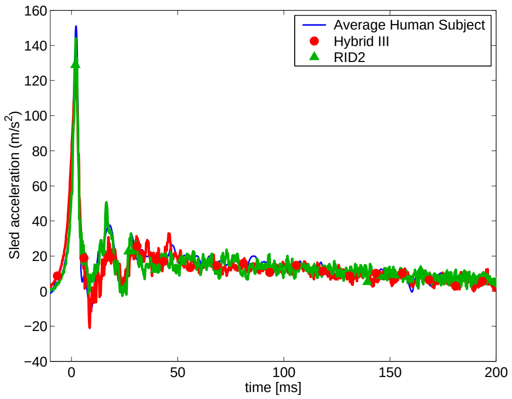

Figure 4: Sled pulses in rigid seat testing

Analysis

The following co-ordinate systems are used in the analysis:

- Sled co-ordinate system: x-axis pointing forward and z-axis upward.
- Head co-ordinate system: origin at the head centre of gravity, x-axis forward, z-axis upward. Both the x-axis and the y-axis are in the Frankfort plane.
- T1 co-ordinate system: origin at the anterior superior edge of the T1 vertebral body. The initial T1 orientation of the human subjects was not obtained, so the initial axes were taken parallel to the sled co-ordinate system.

For the human subject tests the shear force Fx, axial force Fy and bending torque Ty at the occipital condyles (OC) haven been calculated according the equations included in Appendix A. In the dummy tests these have been measured.

RESULTS

This section presents the results as obtained from the tests with the dummies compared with the human subject test results. A corridor covering the range of all the human subject responses is shown, as well as the average human subject response. (Note that the average response in time may be misleading, since human subjects are not reproducible and thus do not react in phase with each other. Signal peaks at different locations in time may therefore result in an average, which is lower than the average peak.) The dummy responses are shown as separate lines.

The following response parameters will be evaluated:

- T1 x- and z-displacement with respect to the sled versus time
- T1 rotation
- Head x- and z-displacement with respect to T1 versus time (in the sled co-ordinate system)
- Head rotation
- Head linear x- and z-accelerations versus time
- Head rotational y-accelerations versus time
- Upper neck x- and z- forces (shear and compression) versus time
- Upper neck y-torque versus time

Soft seat configuration

T1 Displacements - The T1 displacements in x- and z direction in the sled co-ordinate system are shown in Figure 5 and Figure 6. All responses are monitored with respect to their initial position.

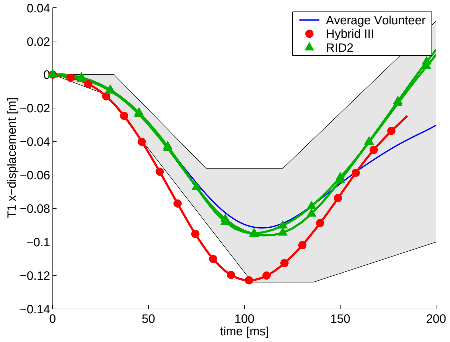

Figure 5: T1 x-displacement

The x-displacement of T1 in the RID2 is similar to the volunteer results, while the Hybrid III moves into the seat 10 to 20 ms earlier than both the RID2 and the volunteers. The ramping up which can be seen in the human volunteer tests influences the relative position of the head with regard to the headrest at the moment of impact. The z-displacement of the Hybrid III shows a downward motion of 0.012 m followed by a slight upward motion. The RID2 moves slightly downward initially and shows ramping up of 0.01 m after 100 ms. In the volunteers an overall upward motion of about 0.03 m is seen.

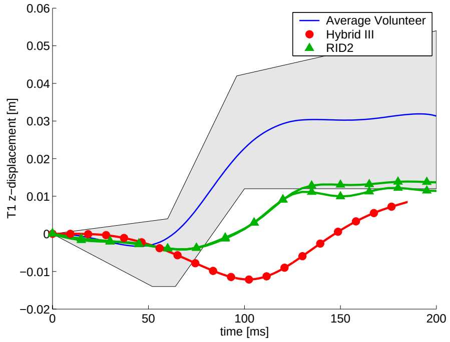

Figure 6: T1 z-displacement

OC Displacements - The displacements of the occipital condyle (OC) as determined in both the volunteer and dummy tests is shown in Figure 7 and Figure 8. These displacement are relative to the position of T1, yet in the steady sled co-ordinate system. As can be seen the both dummies show a good response within the corridor. The z-displacements are not consistent for the volunteer tests resulting in the wide corridor between -0.033 and 0.015 m. The Hybrid III shows a smaller z-displacement than the RID2 does.

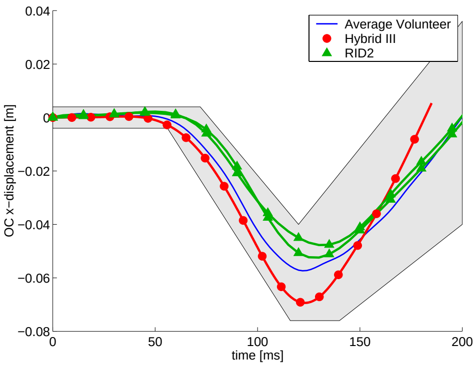

Figure 7: OC x-displacements

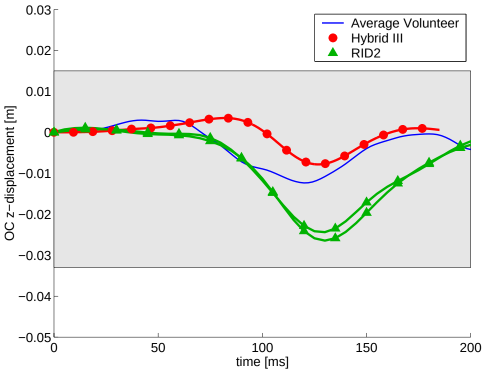

Figure 8: OC z-displacements

T1 and Head Angle - The rotation of T1 is shown Figure 9. It can be observed that almost no rotation occurs during the initial 50 ms, neither in the dummies nor the volunteers. Some of the volunteers show a slight forward flexion during this phase. The maximum extension angle for the RID2 occurs at the same time as in the volunteer tests, but is only half the magnitude. In the Hybrid III no T1 rotation was observed, resulting in the straight line shown.

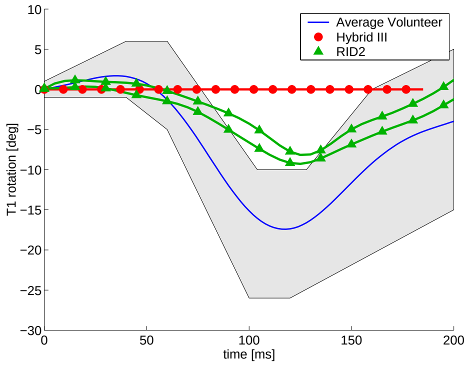

Figure 9: T1 angles

The head rotation of the RID2 with respect to the sled is 30% smaller than the average volunteer response (Figure 10), although there is less rebound, yet the RID2 response stays within the corridor. The Hybrid III shows 30% more head rotation than the average volunteer and the head starts rotating 30 ms too early.

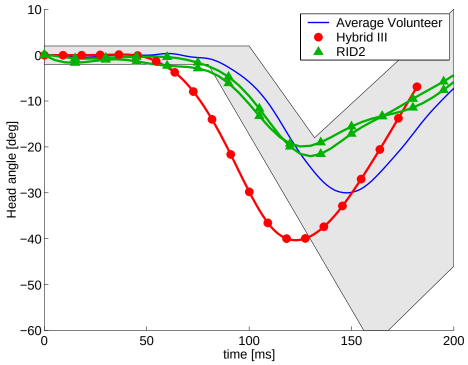

Figure 10: Head angle with respect to the sled

Accelerations - Linear and angular accelerations are shown in Figure 11 to Figure 13. The head x-acceleration of RID2 dummy reaches the upper corridor boundary, while the Hybrid III exceeds both the RID2 peak and corridor boundary by 15%. The sudden increase in accelerations after 90 ms is caused by the head restraint contact in all cases.

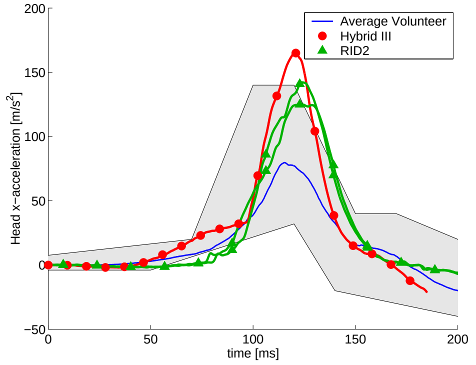

Figure 11: Head x-acceleration

The descent in head z-acceleration of the Hybrid III starts earlier than both the RID2 and the volunteers, however the maximum acceleration is closer to the average volunteer, compared to the RID2 response. The initial upward acceleration in the volunteers is caused by ramping up (the head is pushed upward), both dummies tend to sink deeper into the seat in this initial phase. The peaks after 100 ms are mainly caused by the head restraint contact.

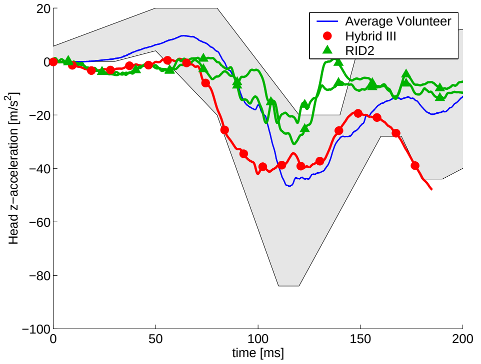

Figure 12: Head z-acceleration

The angular accelerations for the head show similar peak values compared to the volunteers. The shape of the signals of dummies and volunteers are also similar, although the Hybrid III is approximately 30 ms early with the initial response, while the RID2 has an overall response with a short duration.

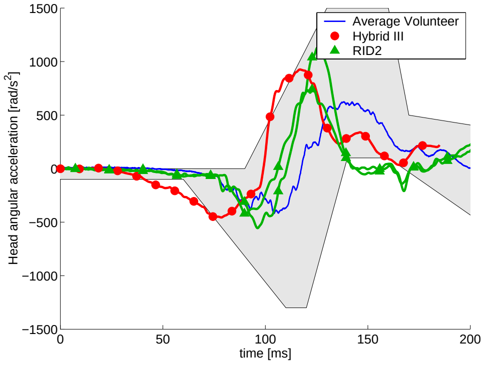

Figure 13: Head angular acceleration

Loads - The forces and bending moment are shown in Figure 14 to Figure 16. The shear forces in the dummies remain positive during the time interval evaluated. In the volunteer tests the shear force is positive for the first 100 to 125 ms and changes then to negative. The magnitude of the shear force of the volunteers is better estimated by the RID2, with 40 % peak deviation from the average, than by the Hybrid III, with more than 200% peak deviation. The RID2 response remains mainly within the defined corridor.

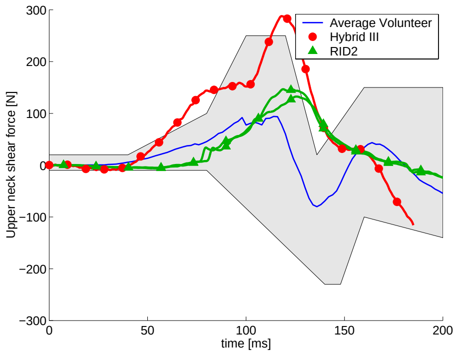

Figure 14: Upper neck shear forces

The overall axial force seems good for both dummies, even though the peak forces are twice as high as the average volunteer response. The Hybrid III response decreases earlier than the RID2 and average volunteer response, but both dummy reponses are mainly within the corridor. The initial difference between dummies and humans is caused by the weight of the head for which the load cell measurement is not corrected.

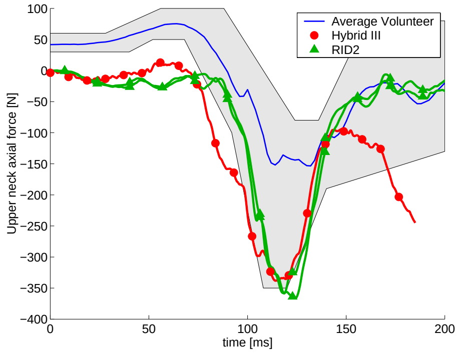

Figure 15: Upper neck axial forces

The RID2 dummy shows a consistent extension torque at OC until 160 ms, while the volunteers change from extension to flexion at about 130 ms, yet the RID2 response stays within the corridor presented.

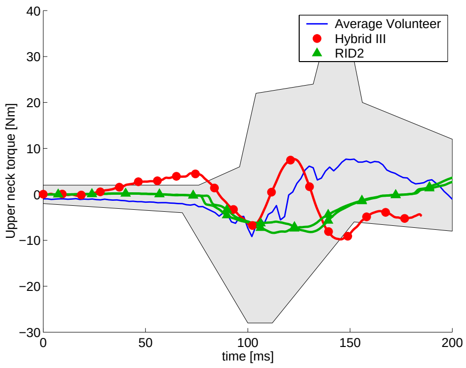

Figure 16: Upper neck torques

Rigid seat configuration

T1 Kinematics - The T1 longitudinal displacement is shown in Figure 17. The RID2 response is good compared to the human responses (moving backward). The Hybrid III response seems poor, due to the fast rebound of the dummy, but it must be noted that the Hybrid III displacements were not directly derived from digitised marker co-ordinates. They were based on sensor data and thus involved a double integration of the T1 accelerations, due to which they may become less accurate.

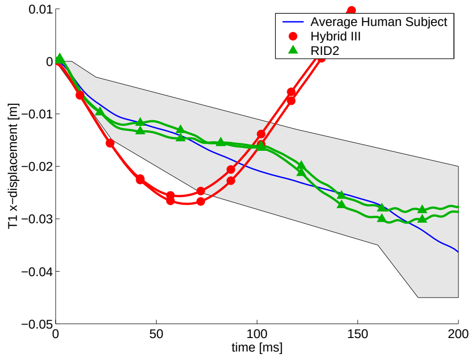

Figure 17: T1 x-displacement with respect to the sled

In the PMHS tests, the T1 z-displacement was highly dependent on the tested subject (due to inter-individual dispersion). The ramping-up motion is reproduced well by the RID2, although it occurs faster than in the PMHSs, while the Hybrid III moves further down into the seat, instead of showing ramping up.

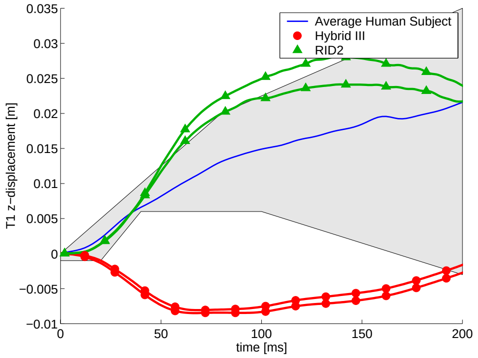

Figure 18: T1 z-displacement with respect to the sled

Head Kinematics - The rotation of the head in a sled co-ordinate system (rotation of the head in the laboratory reference frame) is illustrated in Figure 19. The head rotation of the RID2 corresponds well to the human responses, although the initial rate is higher, thus advancing the average PMHS by 20 ms. The Hybrid III rotation starts at least 30 ms too early, rebound occurs too fast and the head rotation is only half as large as the PMHSs.

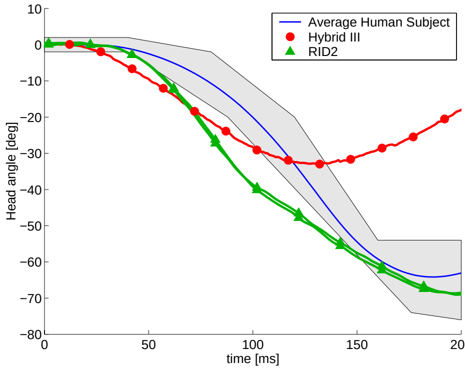

Figure 19: Head angle with respect to the sled

The x- and z-displacement of the head centre of gravity (CG) relative to T1 are shown in Figure 20 and Figure 21, respectively. It shows that the displacements of the RID2 correspond well to the PMHS tests, while the Hybrid III shows a quite different behaviour; too little head displacements in both x- and z-direction (deviations of 25% and 65% from the average PMHS response, respectively) and a fast rebound.

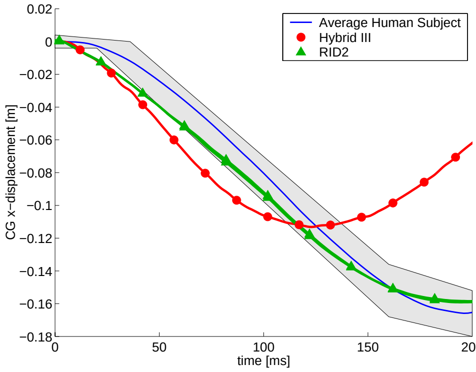

Figure 20: Head CG x-displacement

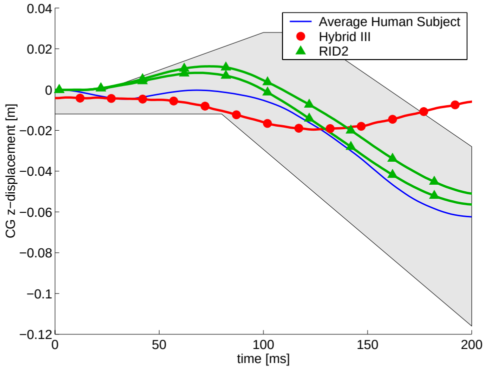

Figure 21: Head CG z-displacement

Head Accelerations - Figure 22 summarises the head x-accelerations. The results show that the shape of the head x-accelerations from dummies and human subjects are quite different. The RID2 approximates the corridor better than the Hybrid III does.

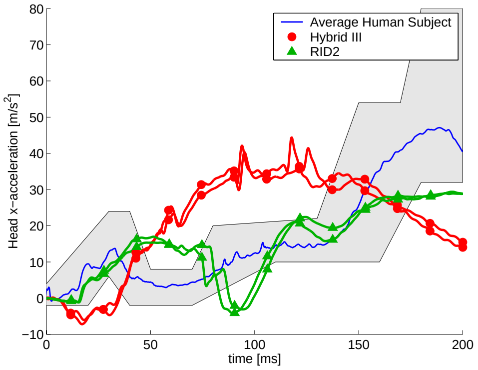

Figure 22: Head CG x-acceleration

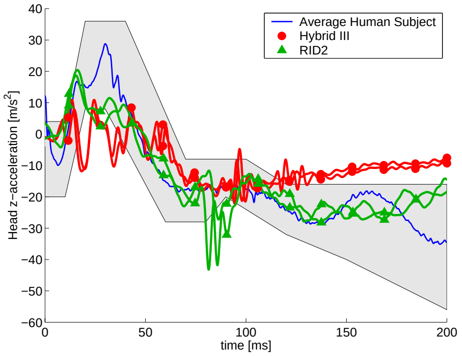

Figure 23: Head CG z-acceleration

As far as the head z-acceleration is concerned, Figure 23 shows the results for both the dummies and the PMHSs. The curves for the PMHSs and the RID2 are very comparable, the Hybrid III shows more deviation, especially after 125 ms. The spikes around 90 ms may be due to loosening of the hip joint, but has not been observed in other testing.

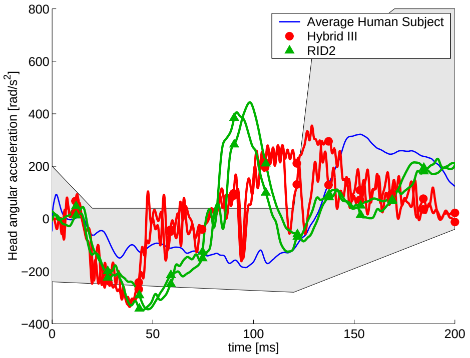

Figure 24: Head angular acceleration

The head angular acceleration is shown in Figure 24. In case of the PMHS tests, it was calculated using an angular rate sensor. The result is comparable for both dummy tests, even though the Hybrid III signals are quite noisy as a result of the derivation from the rate sensor.

Neck loads - During the tests carried out at LAB, the RID2 dummy was equipped with both lower and upper neck load cells. The neck forces measured in the Hybrid III dummy were not considered reliable due to instrumentation problems and therefore these responses are not presented here. The shear forces measured in the neck are presented in Figure 25. It shows that the RID2 response is initially within the corridor, but around 80 ms it deviates from the corridor.

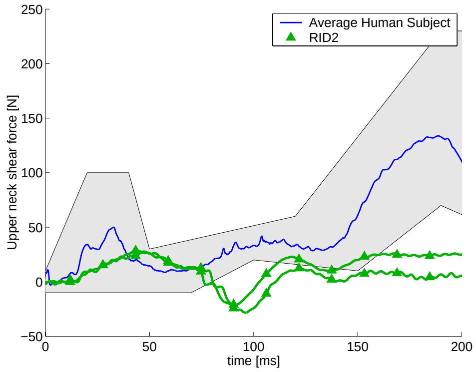

Figure 25: Shear forces in the upper neck

In Figure 26 the axial forces in the upper neck are shown. They correspond well to the experimental data and stay mainly within the corridor. The axial force is compressive in the initial phase (during ramping up) and becomes tensile as the head angle increases. Note that the offset caused by the head mass is initially set to zero. The spikes around 90 ms also occur in this signal as found earlier in the head z acceleration.

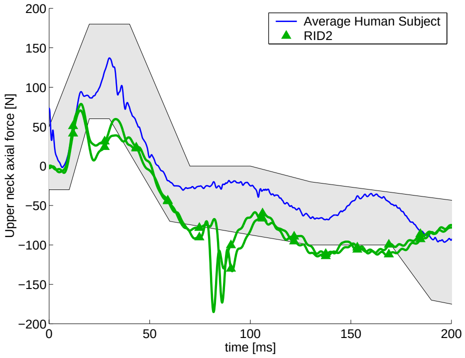

Figure 26: Axial forces in the upper neck

The torques measured at the level of the occipital condyles are given in Figure 27. The torques measured in the RID2 and the Hybrid III are in the same order of magnitude as the PMHS tests, although the shapes are different and the signals are partially outside the corridor.

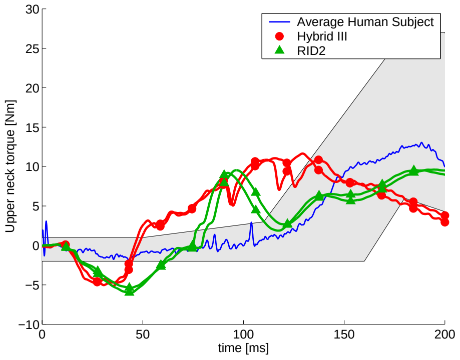

Figure 27: Torque in the upper neck

The final result which will be presented here, is a comparison of the torque-rotation characteristics resulting from the PMHS tests and the dummy tests relatively to the so-called Mertz biofidelity corridor for neck extension motion (Mertz and Patrick 1971) in Figure 28. Results of the human volunteer tests are not included due to the interaction with the head restraint system in these tests. This figure shows the Hybrid III response to the left, while both the PMHS and RID2 response are close together in the lower region of this corridor.

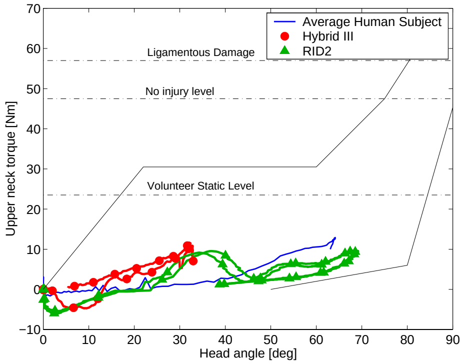

Figure 28: Mertz corridor

DISCUSSION

The RID2 dummy is a crash dummy intended to evaluate the protection offered to an adult car occupant in a rear-end collision. Its design is partly based on existing dummy components. Major difference with the Hybrid III dummy are: a more flexible spine and neck construction, a more realistic back shape and the application of the ribcage design of the THOR dummy. The dummy is intended to study the protection against whiplash injuries offered by the seat and head restraint system. The emphasis in the development of this dummy was on the accurate reproduction of the head-neck kinematics since a biofidelic response of the dummy in this body area is considered to be very important to get a realistic contact interaction with the seat and the head restraint system.

The main aim of this study was to evaluate the performance of the RID2 in low severity rear impact and to compare its response to the Hybrid III in similar conditions. The RID2 and the Hybrid III were therefore tested in the same conditions as a set of volunteer and PMHS experiments performed earlier. The human volunteer tests were conducted with a regular car seat provided with a head restraint system at an impact velocity of 9 km/hr. This impact velocity is just at the lower boundary of the range of delta v's, for which neck injuries occur most frequently. The Post Mortem subjects were tested at a higher impact severity on a rigid seat without a head restraint system.

The results of these human tests were not normalised in order to compare them with the dummy responses. The volunteers chosen were as close as possible to an average 50th percentile male. In the PMHS tests the subjects were below average male due to the age, thus these would be subject to normalisation. Normalisation would at least have to cover the head-neck system in order to be relevant for low severity rear impact. However, a way of normalising the head-neck system of different subjects has not been found in literature.

In the soft seat tests the RID2 showed comparable head and T1 displacements as the volunteers. The flexible thoracic spine and the flexible neck, allowing the characteristic S-shape (head lag), are the main contributors to this behavior. The ramping-up of the RID2, which is considered important for correct contact with the head restraint system, was still too small. The upper neck loads in the neck correlated reasonably well with the human volunteers. Although significant deviations for the average volunteer responses were found, the RID2 response mainly remained within the corridors defined.

In the comparison to the PMHS tests, the RID2 dummy showed realistic head and T1 kinematics (including ramping up). The head accelerations measured in the RID2 mainly fit within the corridors, but the shape of the x-acceleration was very different from the PMHS responses. The Hybrid III head accelerations slightly differed from the RID2 acceleration (in particular the angular acceleration) but all together they were within or close to the

PMHS envelopes. The RID2 upper neck loads showed the same trend as the accelerations, as can be expected. The responses met the corridor, but shapes deviated.

In both test series, the Hybrid III was found to react about 10-30 ms too early in most responses, probably caused by the fact that the Hybrid III torso and pelvis move as one rigid body into the seat, without allowing any spine flexibility. Ramping up appeared to be almost absent in the Hybrid III. The Hybrid III showed too small head rotation and too small horizontal centre of gravity displacements compared to the PMHS tests indicating the absence of the typical S-shape of the neck. The Hybrid III upper neck forces were not evaluated due to instrumentation problems. In the Hybrid III the kinematics and loads showed larger deviations from the human responses than the RID2.

The results for the torque- head rotation characteristics have been presented for both dummies and for the PMHS tests in the Mertz corridor for neck extension motion. All curves are within the corridor and the RID2 response is close to the average PMHS response. The location of the PMHS response, which is close to the lower boundary of the corridor, suggests that the Mertz corridor itself may be too wide in the upper region. The Hybrid III response is also in the lower region of the Mertz corridor, although the Hybrid III is meant to represent a human with active musculature in the neck. This supports the suggestion of the wide corridor.

The findings in this study for the Hybrid III are in general in agreement with the studies by Scott et al. (1993) and Davidsson (1999b). Major shortcoming of the Hybrid III for the test conditions considered are the absence of T1 rotation, too small head rotation (neck is too stiff), hardly no S-shape in the neck and no ramping-up motion. Due to this it can be expected that the interaction of the Hybrid III dummy with the seat-head restraint system will be different from a car occupant. On the other hand it can be noted that the observed deviations are less apparent in the accelerations and the neck loads. As far as the head rotation of the Hybrid III dummy is concerned it may be concluded that the findings from our study are different from the findings from Prasad et al. (1997) but it should be noted that Prasad considered higher impact velocity levels and that his conclusions were based only on a small set of human subject tests.

CONCLUSIONS AND RECOMMENDATIONS

In general the responses of the head-neck system of the RID2 in low severity rear impact evaluations correlate better to the human subject tests than the Hybrid III responses, in both the car seat tests and the rigid seat tests.

The RID2 dummy has been compared in this study with two sets of human subject data. It is strongly recommended to evaluate the dummy also in other test conditions for which recently data have become available. The world-wide testing of the dummy which is planned for 2001 and 2002 includes several of such evaluations and also includes comparison testing with alternative test devices like the THOR dummy and the BioRID dummy. Ideally the various human subject data which are available now should be integrated into one world-wide acceptable set of biofidelity requirements for a rear impact dummy. It is expected that ISO and or IHRA will develop such a set of data in view of the need of world-wide harmonisation.

A final and probably most important limitation for wide application of current test devices for rear-end impacts is the lack of reliable well accepted injury criteria and corresponding tolerance values for prevention of whiplash injuries. International research should clearly focus on fully understanding the basic injury mechanisms causing whiplash injuries as a basis for the development of such criteria.

ACKNOWLEDGMENTS

The authors would like to thank all partners of the European Whiplash project for their contribution in this extensive research. Furthermore we acknowlegde the Dutch Ministry of Transport and the European Commission for their financial support in this project.

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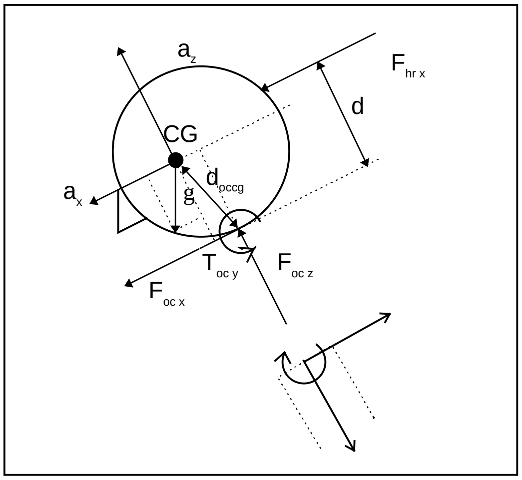
APPENDIX A - CALCULATION OF FORCES AND MOMENTS IN THE UPPER NECK

In the volunteer tests the loads in the neck were calculated. The shear force F_{ocx} , axial force F_{ocz} and torque T_{ocy} in the Occipital Condyle are calculated according to the following formulas. The figure below illustrates the data needed for this analysis.

$$F_{oc\,x} = m_h\,(a_x - g\sin(\varphi)) - F_{hr\,x}$$

$$F_{oc\,z} = m_h\,(a_z + g\cos(\varphi))$$

$$T_{ocy} = J_{cg\,y}\,\ddot{\varphi} - (d - d_{occgz)}F_{hr\,x} + d_{occgz}F_{ocx} - d_{occgx}F_{ocz}$$



$F_{oc\,x}$ = x component of force at the OC joint
applied by the neck to the head
$F_{oc\,z}$ = z component of force at the OC joint
applied by the neck to the head
$F_{hr\,x}$ = x component of impact force
applied by the head restraint to the head
$T_{oc\,y}$ = y component of torque at the OC joint
applied by the neck to the head
$J_{cg\,y}$ = moment of inertia of the head about the y-axis
m_h = head mass
a_x = x component of head acceleration
a_z = z component of head acceleration
φ = head angle with respect to sled frame
d_{occg} = distance between OC and head-CG
d = z-distance between OC and contact point of head restraint
g = gravity (9.81 m/s^2)