AN EVALUATION OF PROTOTYPE SEATS USING BIORID-P3 AND HYBRID III WITH TRID NECK

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ABSTRACT

There has been some discussion on whether Hybrid III can accurately evaluate the risk of low-severity neck injuries in rear impacts because it has been developed for the evaluation of frontal impacts. A new dummy with an articulated spine and a flexible torso has been developed. The newest prototype, BioRID-P3 has been compared with volunteer data at Delta V(DV)9km/h and it was found to respond with a good biofidelity.

The object of this study is to clarify the difference of response between the BioRID and the Hybrid III from tests using prototype seats at DV15km/h.

The characteristics of human kinematics which were confirmed in lower speed BioRID tests were also confirmed at DV15km/h. The upper neck shear forces and moments and NIC of the BioRID were significantly different from those of Hybrid III.

KEY WORDS
REAR IMPACTS, WHIPLASH, DUMMIES, SEATS, SLED TESTS

NECK INJURIES THAT OCCUR mainly in low speed rear impacts are the most frequent injuries in traffic accidents. These injuries are classified as AIS 1 and are not life threatening, but 10% of them lead to long term consequences. These injuries are very complex and the occurrence mechanism, which is not fully understood at present, is the subject of several ongoing research studies. Some manufacturers have used a currently available dummy (Hybrid III or Hybrid III equipped with a TRID neck (Thunnissen et al.,1996)) to evaluate new seats developed and introduced to reduce the risk of neck injuries. By the way there has been some discussion on whether Hybrid III can accurately evaluate the risk of low-severity neck injuries in rear impacts because it has been developed for the evaluation of frontal impacts. For example, its neck and torso are stiff and unlikely to interact with the seatback in the same compliant way as those of a human (Davidsson et al. 1998).

In these situations a new dummy with a good biofidelity is required to clarify the occurrence mechanism of neck injuries in rear impacts and develop the seats which can reduce the risk of neck injuries. Therefore a Swedish consortium began developing a dummy prototype with an articulated spine and a flexible torso and with human-like surface contours based on the work of Schneider et al. (1983). The newest prototype is called BioRID-P3, referred to as "BioRID" in this paper. The BioRID has been compared with volunteer data at DV9km/h and it was found to respond with a rather good biofidelity. (Davidsson et al. 1998)

However it has not been discussed enough that the BioRID could also be biofidelic at velocity changes higher than DV9km/h, which are often used in the evaluation of seat performance for neck injury risk in rear impacts. It is not clear whether the BioRID can properly evaluate the differences between seat structures. Furthermore the differences of response between the BioRID and the Hybrid III in the evaluation of seat performance has not been discussed. The objects of this study are; (1)To confirm that the BioRID shows human-like kinematics at DV 15 km/h, a higher velocity change thanDDV9km/h. (2)To clarify the differences of response between the BioRID and the Hybrid III from tests using prototype seats. (3)To identify the points which need attention and should be improved for the evaluation by each dummy.

MATERIALS AND METHODS

This section presents the test conditions and the seat specifications. A total of nine tests were conducted using both dummies, and their results were compared to each other. A prototype seat was mounted on a target sled. A dummy was seated in normal position without seat belt. A DV15km/h was chosen to represent a middle value from the velocity changes which are often used to evaluate seat performance for the risk of low-severity neck injuries in rear impacts. The five tests with the BioRID were conducted at Japan Automobile Research Institute (JARI) in cooperation with JARI and Chalmers University. The four tests with the Hybrid III with TRID neck were conducted at Mazda. Figure 1 shows the sled acceleration pulses used. All of the tests were conducted with the head restraint. In all tests the initial distances between the head and the head restraint are about 50mm and the seatback angles are the same (design angle). The BioRID was dressed in the special shirts and pants (made of Lycra) recommended by Chalmers University. The Hybrid III was dressed in normal cotton clothes.

Four kinds of prototype seats, whose structures were changed to affect the risk of neck injuries, were used. The test number and the specifications of the prototype seats are shown in Table 1. Seat1 is a production front seat of a small passenger car. The seat back stiffness of Seat2 is lower than that of Seat1. Seat3 has the same modifications as Seat2 and also has a stiffer recliner system. The head restraint of Seat4 was designed to move forward and upward by the occupant's inertial force. The stiffness of the seatback and the recliner of Seat4 are nearly same as those of Seat3.

The accelerations of the head, T1, T8 and pelvis were measured by the standard accelerometers. The upper neck load cell of the BioRID and the upper and lower neck load cells of the Hybrid III measured the neck loads. The dummy tests were recorded by high-speed video (500 frames/s) and each of the frames were digitized and smoothed. Figure 2 shows the test configuration and the positive direction of displacement, acceleration, angle and neck loads.

Table 1 - Test number and specification of prototype seats

Test No.	Name	Specification	Structure inside seatback frame	recliner	Dummy
1	Seatl	No modified	rigid wire	one side	BioRID
2	Seatl	No modified	rigid wire	one side	BioRID
3	Seat2	Soft seatback	spring	one side	BioRID
4	Seat3	Soft seatback & hard recliner	spring	both side	BioRID
5	Seat4	Movable head restraint	spring	both side	BioRID
6	Seatl	No modified	rigid wire	one side	Hybrid III
7	Seat2	Soft seatback	spring	one side	Hybrid III
8	Seat3	Soft seatback & hard recliner	spring	both side	Hybrid III
9	Seat4	Movable head restraint	spring	both side	Hybrid III

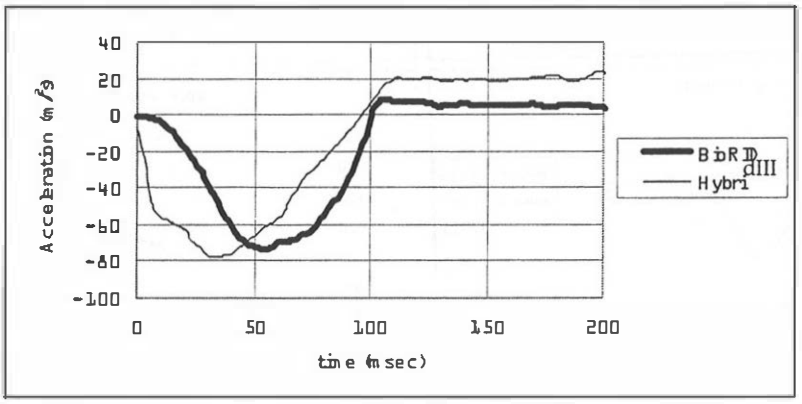

Fig.1 - Sled pulses for BioRID and Hybrid III

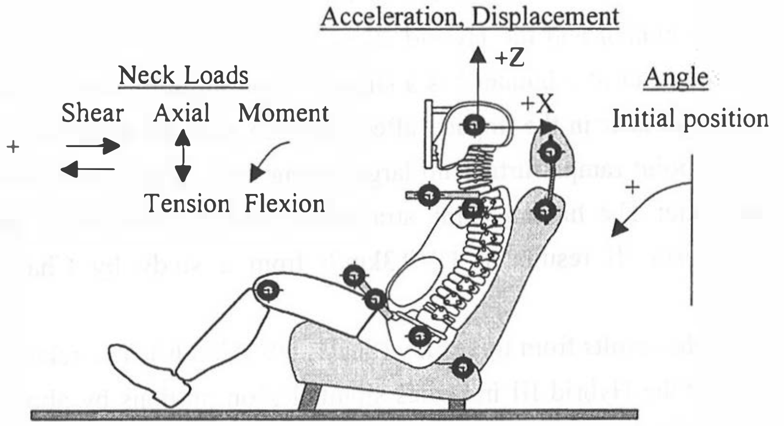

Fig.2 – Test configuration and the positive direction of measurements

RESULTS

REPEATABILITY OF BIORID: Two tests were conducted with Seatl at DV15km/h with the BioRID to confirm its repeatability. Figure 3 shows the test results. All the figures indicate that the two time-history curves of each response correspond almost exactly indicating the good repeatability of the BioRID. The video analysis, not shown in this paper, also confirms the good repeatability of the dummy.

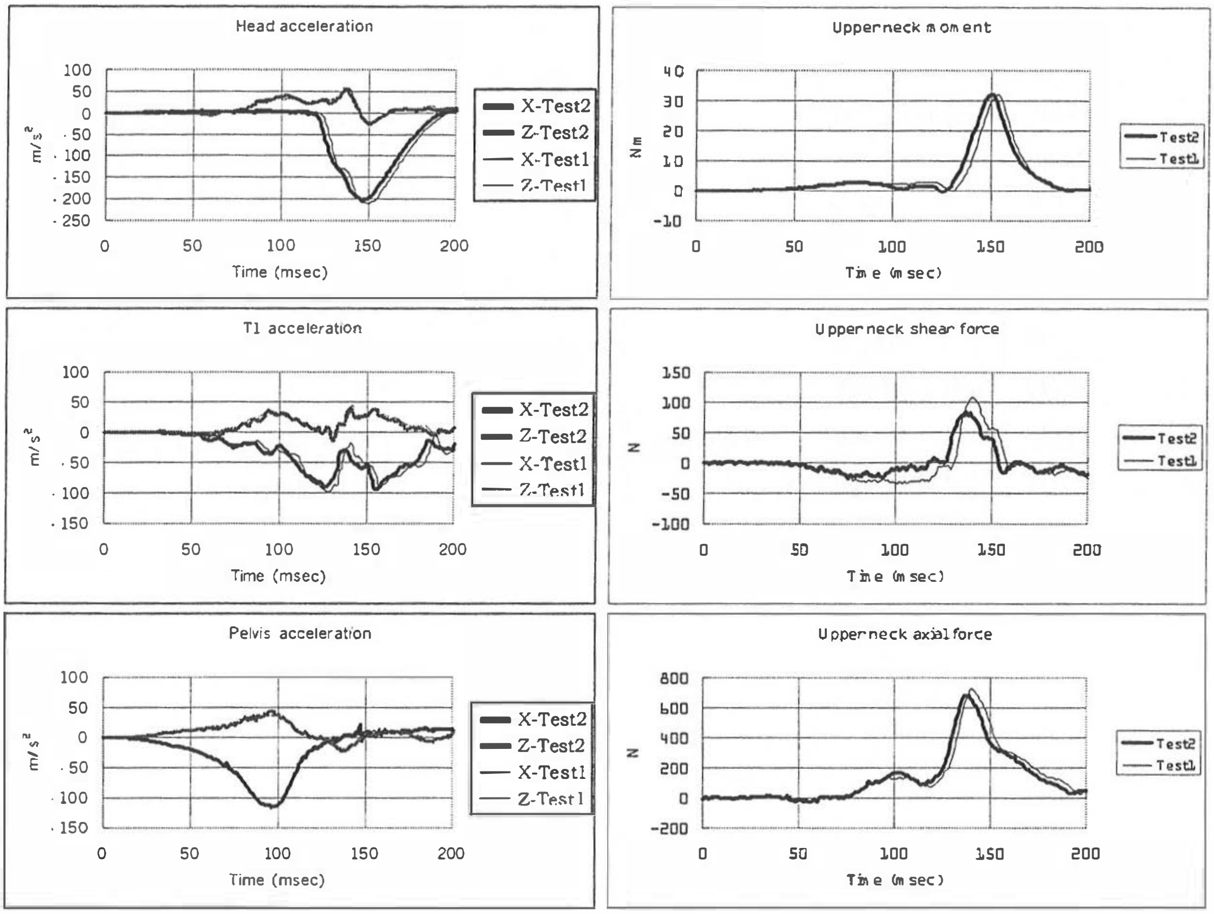

Fig.3 - Repeatability of BioRID

KINEMATICS COMPARISON OF BIORID/HYBRID III: It is said that the main differences between the kinematics of a human and the Hybrid III in low speed rear impacts are the following three items. I) Head lag: The head of a human has a slight flexion motion early in the impact and an extension motion which occurs later in the impact, after that seen with the head of Hybrid III. ii) Ramping-up: The human H-point ramps further up larger along the seatback than that of Hybrid III. iii) Straightening of the spine: The human spine straightens due to kyphosis. Figure 4 compares volunteer, BioRID and Hybrid III results at DV9.3km/h from a study by Chalmers University (Davidsson et al. 1999).

Figure 5 similarly shows the results from this study (Seat1, DV15km/h). The relative rotation angle between the head and T1 for the Hybrid III indicates slight flexion motions by about 70msec. After that, the Hybrid III trace indicates an abrupt extension motion, while the BioRID flexion motion continues until 200msec. This difference is similar to that at DV9 km/h. Though the BioRID results of the Chalmers study show an extension motion which occurs later than that of the Hybrid III, in this study the BioRID does not go into extension at any time during impact. The reason for this difference is that the seat used in the DV9 km/h test did not have a head restraint, while the seat for this study did and it supported the head throughout the impact.

Next the ramping-up results, which are expressed by the H-point upward displacement, are compared. The upward displacement at DV15km/h is larger than that at DV9 km/h. The displacement of the BioRID is larger than that of the Hybrid III. The difference between the dummies is similar to the results at DV9km/h. Finally the straightening of the spine which is calculated as the change in absolute distance between the H-point and T1 is compared. The distance change at DV15km/h for the BioRID is similar to that at DV9km/h. The change for the Hybrid III is not shown in Figure 6 because the spine of Hybrid III is not straightened as it is one rigid body. The above results are those of Seat1. Similar kinematics were seen with the other seat configurations.

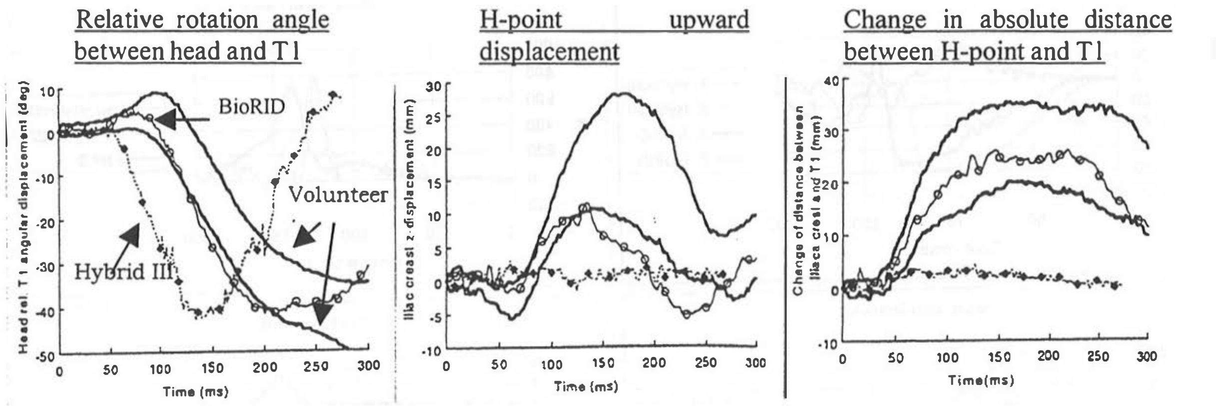

Fig.4 - Kinematics comparison at low speed (Rigid seat, DV9.3km/h, without head restraint)
Source: Johan Davidsson et al.: A Comparison between Volunteer, BioRID P3 and Hybrid III performance in Rear Impacts. IRCOBI Conference-Sitges(Spain), September 1999

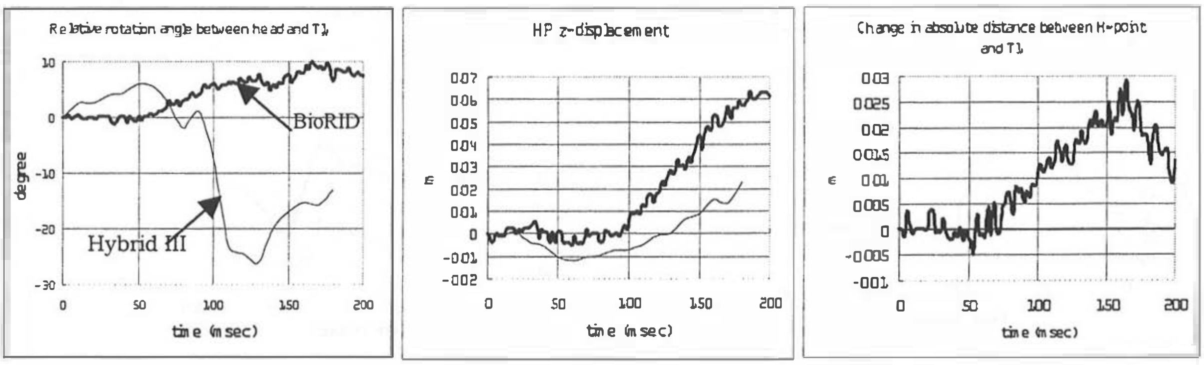

Fig.5 - Kinematics comparison at higher speed (Seat1, DV15km/h, with head restraint)

COMPARISON OF BIORID/ HYBRID III RESPONSES: The time history curves of the accelerations and neck loads of the BioRID and the Hybrid III are compared. Figure 6 shows the results of Seat1 at DV15km/h. The thick lines show the results of the BioRID and the thin lines show those of the Hybrid III. The lower neck loads of the Hybrid III are also shown in the same figures.

The left side of Figure 6 show the acceleration comparisons. The BioRID sled acceleration increases more slowly and peaks later than that of Hybrid III. Therefore all the accelerations of the BioRID also increase more slowly and peak later than those of the Hybrid III. Except for this phenomenon, no clear differences between the BioRID and the Hybrid III accelerations were seen. A similar thing can be said about the NIC. The NIC formula is shown below.

$NIC=(A_{T1}-A_{head})*0.2+(V_{T1}-V_{head})^2$

A_{T1}: T1 x-acceleration, A_{heat}: Head cg x-acceleration, 0.2: Length, V_{T1}: T1 x-velocity, V_{head}: Head cg x-velocity

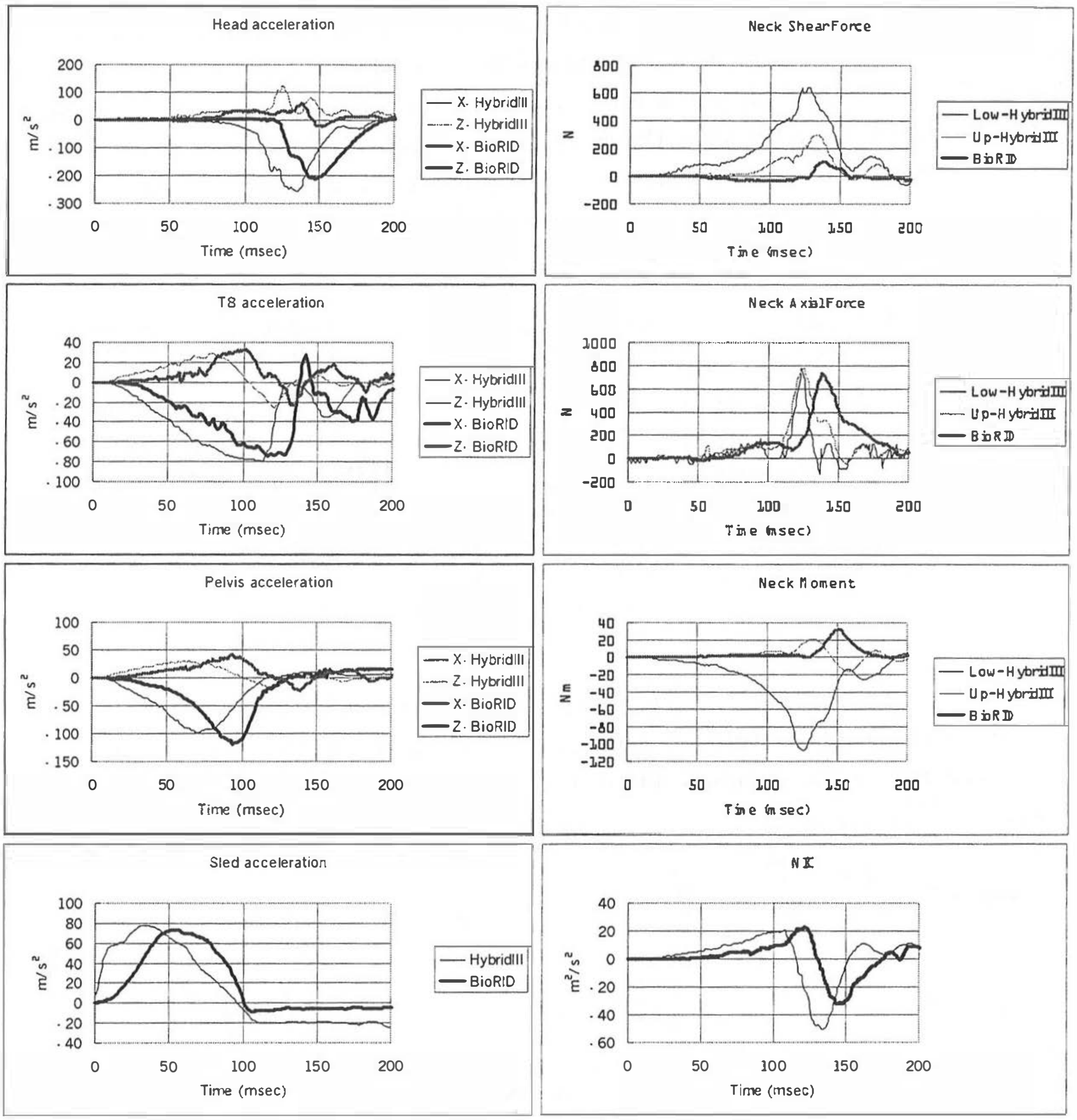

Fig.6 - Comparison of measurement results of BioRID/Hybrid III (Seat1, DV15km/h)

Next is a comparison of the neck loads. Two differences between the BioRID and the Hybrid III were found. One is that the peak value of the BioRID shear force is half or less than half of that of the Hybrid III. The other difference concerns the neck moments. After the initial flexion moment of the Hybrid III peaks at about 130msec, it changes to an extension moment which peaks at about 160msec. On the other hand, the moment of the BioRID indicates a flexion moment and does not change to an extension moment. The results of Seat1 were described here and similar results were found with the other seats.

Next the peak values of the accelerations and neck loads of the BioRID are compared with those of the Hybrid III in Figure 7. The horizontal axis shows the accelerations of head, chest and pelvis and neck loads and NIC. The vertical axis shows the ratio of the value of the BioRID to that of the Hybrid III (R_{BIO}). The values for the four different kinds of seats are shown for each item. The difference between the sled pulse of the BioRID and that of the Hybrid III is corrected by the ratio of the peak values of sled accelerations. The R_{BIO} formula is shown below.

$$R_{BIO} = \frac{G_{HYB}}{G_{BIO}} \bullet \frac{A_{BIO}}{A_{HYB}}$$

G_{BIO}: Peak value of sled acceleration for BioRID
G_{HYB}: Peak value of sled acceleration for Hybrid III
A_{BIO}: Peak value of BioRID
A_{HYB}: Peak value of Hybrid III

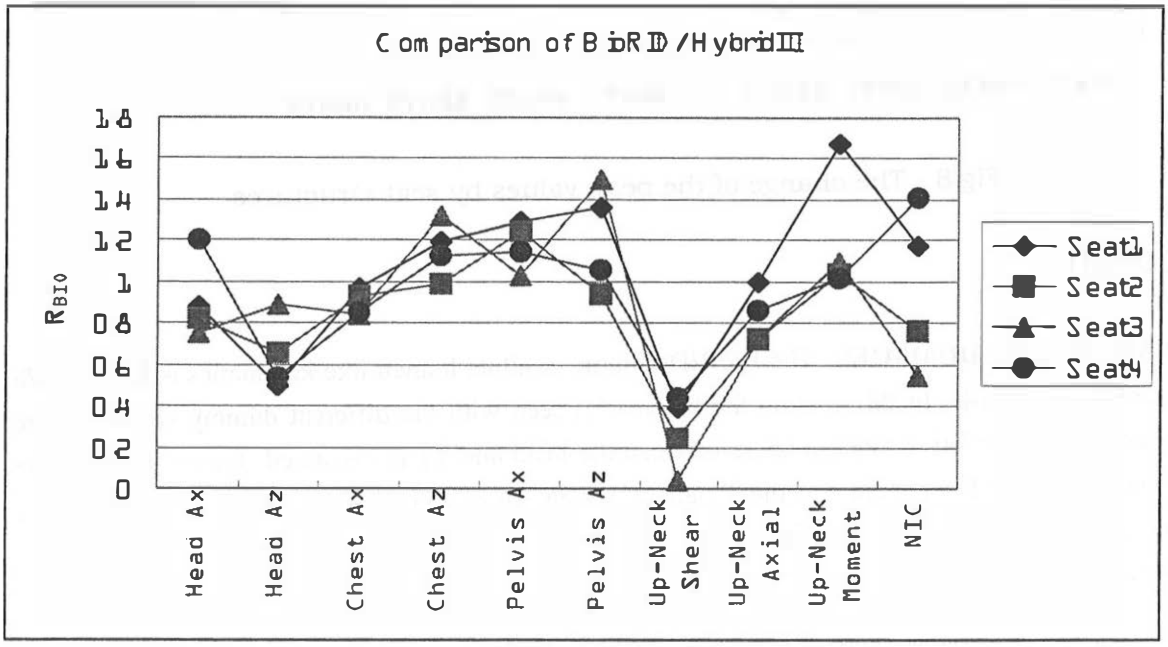

Fig.7 - Comparison of the peak values

Previously, it was mentioned that the peak value of the BioRID's shear force is half or less than half of that of the Hybrid III for Seat1. Figure 7 shows that for all four seats the shear forces are also half or less than half of those of the Hybrid III. Some of the other BioRID values (chest z-acceleration, pelvis x-acceleration and upper neck moment) are larger than those of the Hybrid III (1 or over) and some (head z-acceleration, chest x-acceleration, upper neck shear force and upper neck axial force) are smaller (1 or less). Looking at the NIC values, for two seats the BioRID peaks are larger than those of the Hybrid III, while those of the other seats are smaller. The order of the peak value ratios for each seat is not always the same.

Finally the change of each peak value due to the change of the seat structure is compared. The NIC and upper neck loads from the recorded responses are considered as primary indicators of neck injury risk. Figure 8 shows the results. The horizontal axis shows the seat type and the vertical axis shows the ratio of the peak values to those of the Seat1. The left graph shows the results of the BioRID and the right shows the Hybrid III. The lower neck moments of the Hybrid III are also shown in the right graph. Though the values tend to gradually decrease in the order of Seat1, Seat2, Seat3 and Seat4 for both dummies except for the upper neck moments of the Hybrid III, the degrees of change are different. The upper neck moments of the Hybrid III in this figure show the initial flexion moments to compare with those of the BioRID.

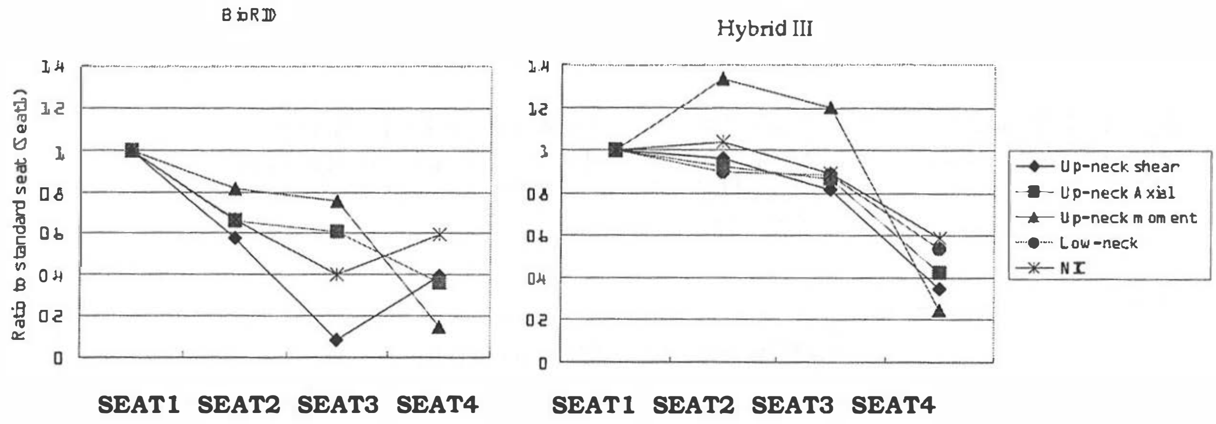

Fig.8 - The change of the peak values by seat structures

DISCUSSION

KINEMATICS OF DUMMIES: The BioRID dummy exhibits human like kinematics at DV15km/h as described previously. In this section the kinematics seen with the different dummy structures are discussed. First the relative rotation angle between the head and T1 is discussed. Figure 9 shows the time histories of the head angle and the T1 angle, which the relative rotation angle is calculated by. The left graph shows those of the BioRID and the right shows the Hybrid III. Each seatback angle is also shown in the same graph.

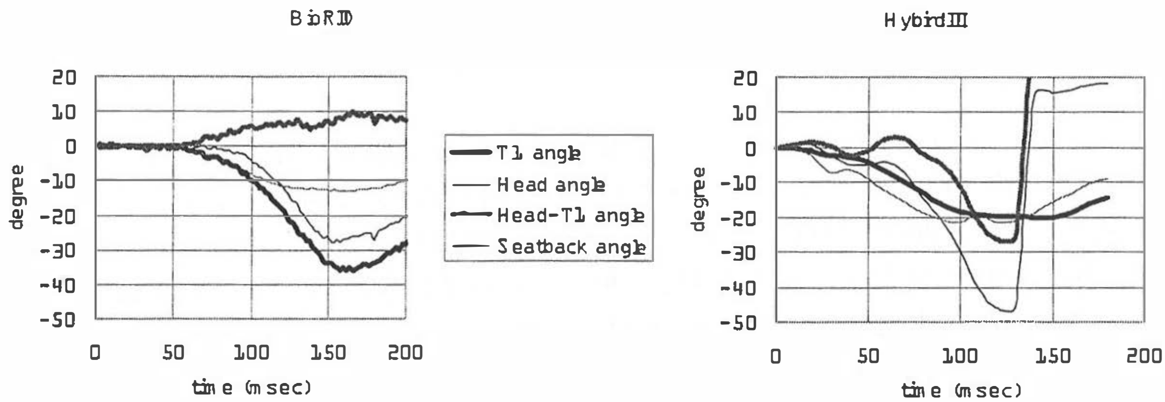

Fig.9 - The relative rotation angle between head and T1 and the angles of head, T1 and seatback

This figure indicates that the T1 rearward rotation of the Hybrid III ends at the same time (about 90msec) the rearward rotation of the seatback ends. The reason is considered to be that the T1 of the Hybrid III can not rotate past the rotation of the seatback because the thoracic spine of Hybrid III is a rigid body. The head, however, can continue to rotate rearward because it is attached to a deformable neck. Consequently the relative rotation angle between the head and T1 increases rapidly. On the other hand the T1 of the BioRID continues to rotate rearward after the seatback stops rotating. The reason is that the BioRID's thoracic spine consists of individual vertebrae, like a human's spine, which can move with respect to one another. This phenomenon results in a small change of the head relative to

T1 rearward rotation. The heads of both dummies contact the head restraint around 100msec (BioRID: about 120msec, Hybrid III: about 100msec) and the head angles begin to decrease at the time the X accelerations of the heads peak. (BioRID: about 150msec, Hybrid III: about 130msec) In this study, no significant difference in the kinematics between both dummies was found during the contact between the head and the head restraint. It is necessary to perform further analysis to explore any differences.

It is well known that the increase of the distance between the H-point and the T1 is due to the straightening of the spine kyphosis, which occurs by the contact force of the spine with the seatback. One of the reasons that the H-point upward displacement of the BioRID is larger than that of the Hybrid III seems to be due to the special shirts and pants for the BioRID which represents the movement between the skin and bones of a human. In this study the infłuence could no be clarified. It is necessary to investigate the influence including the difference of the spine structure also.

As mentioned above, the BioRID dummy succeeds in showing much closer kinematics to a human than that of the Hybrid III indicating a better level of biofidelity. From this point, the BioRID dummy seems to be an effective tool to evaluate neck injuries in rear impacts of these speeds.

COMPARISON OF BIORID/ HYBRID III RESPONSES: This section discusses the comparison results of the responses of the BioRID and the Hybrid III. First is the cause for the difference of the peak values of shear forces. Though the cause seems to be due to the difference of the neck structures (the neck of BioRID is softer than that of Hybrid III), we could not identify it in this study. Next is the cause for the difference of neck moments. It is due to the difference of the kinematics because the difference agrees with that of the relative rotation angles between the head and T1 that were described before. Further research is necessary because the upper neck loads of both dummies are very different from each other. From the video, it can be seen that the lower neck of the BioRID has an extension motion similar to the Hybrid III. It is desirable that the lower neck loads of the BioRID will be able to be measured and evaluated further because the lower neck loads also seem to be important for the evaluation of neck injury risk in rear impacts.

Next we would like to discuss the change of each peak value due to the change of the seat structure. If the relationship between one value of the BioRID and that of the Hybrid III is consistent, it is possible to evaluate the seat structure with either the BioRID or the Hybrid III. The relationship for each response however is not always the same, as shown in Figure 7 and 8. The differences between Seat3 and Seat4 are analyzed in more detail here. Though the NIC and upper neck shear force of the BioRID with Seat4 are larger than those with Seat3, those of the Hybrid III are smaller with Seat4 than those with Seat3. Since this phenomenon leads to opposite conclusions regarding seat performance with respect to risk of neck injuries, we should pay attention when we evaluate neck injuries using these dummies. The causes are discussed. The changes seen in the upper neck shear forces responses are similar to those seen in the NIC, therefore it is assumed that the causes for these changes are the same and only the NIC is discussed. The left side of Figure 10 shows the NIC time histories and the T1 and head accelerations of the Hybrid III which are used to calculate the NIC. This figure shows that the T1 accelerations seen with Seat3 and Seat4 increase gradually after 20msec and the initial difference due to the seats is small. Focusing on the head accelerations, it can be seen that the head restraint of Seat 4 starts supporting the head earlier than that of Seat 3, consequently reducing the NIC.

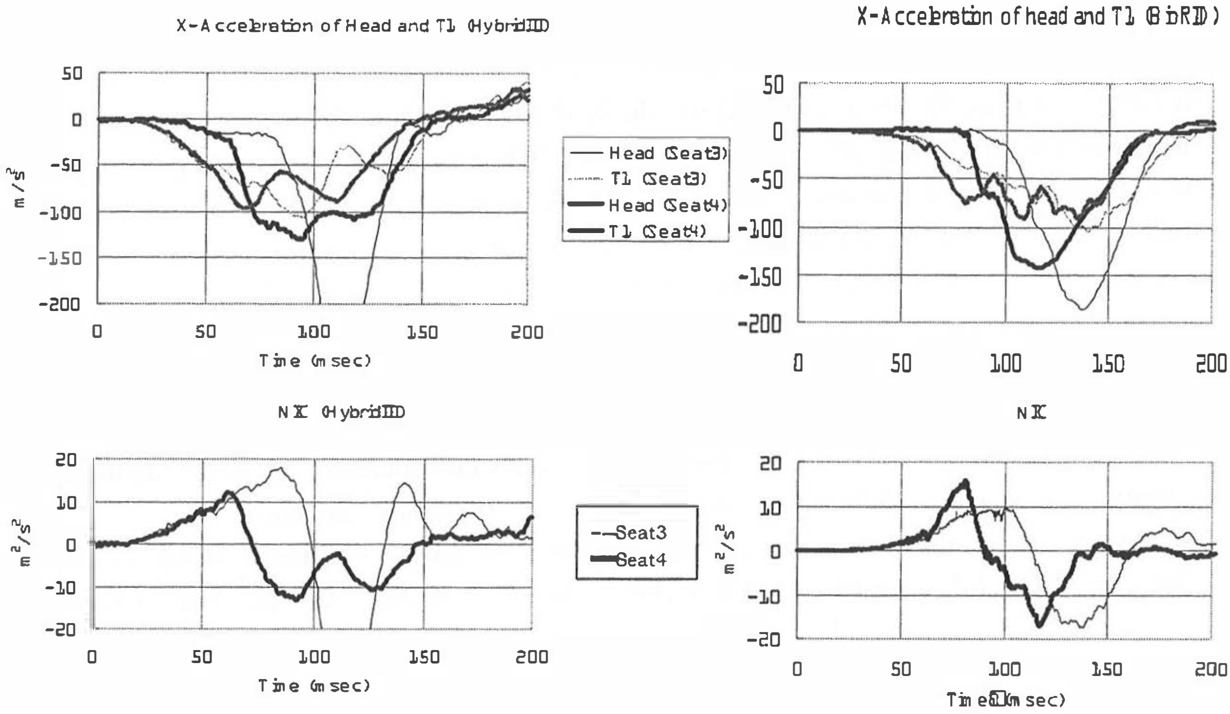

Fig.10 - Head acceleration, T1 acceleration and NIC

Similarly, the right side of Figure 10 shows the BioRID results. This figure indicates that the head is supported by the head restraint of Seat4 earlier than that of Seat3, similar to the Hybrid III. With Seat4 the T1 acceleration becomes larger than that of Seat3 after about 60msec. The increase is sharper than that of the Hybrid III. This sharp T1 acceleration increase results in an increase in the NIC response of Seat4. The cause for the sharp increase of T1 acceleration of the BioRID is further analyzed. Figure 11 shows the T8 acceleration of the BioRID, which represents the acceleration at the center of gravity of chest. The T8 acceleration does not increase sharply unlike that of the T1. The Hybrid III does not exhibit the same difference between the upper and the center of the thoracic spine because it is a rigid body. This seems to be one of the characteristics that is caused by the segmented spine of the BioRID. If this phenomenon also occurs with the human spine, which has a segmented structure like the BioRID's, the use of the NIC with the Hybrid III dummy for the evaluation of neck injury risk should be limited.

The reason that the T1 acceleration increases sharply when tested on Seat4 in this study is discussed next. It is due to the movement of Seat4. The upper part of the seatback of Seat4 moves slightly forward during impacts since the whole seatback moves to let the head restraint move forward and upward. (Figure 12) This movement results in the sharp increase of T1 acceleration seen with Seat4.

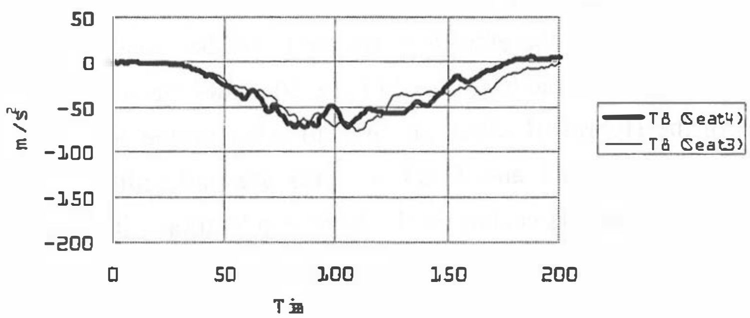

Fig.11 - T8 x-acceleration (BioRID)

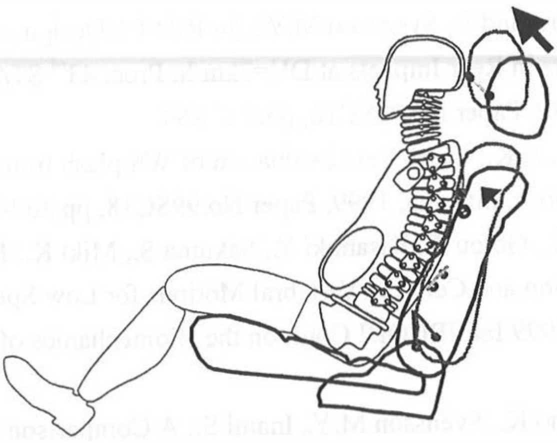

Fig.12 - The movement of seatback of Seat4

CONCLUSIONS

From what has been discussed above, we can conclude the following:

(1) The BioRID dummy shows good repeatability atDV15km/h.

(2) The characteristics of human kinematics (i. head lag, ii. H-point upward displacement, iii. Spine straightening) which were confirmed in lower speed (DV9km/h or less) BioRID tests were also confirmed at a higher speed (DV15km/h) of which is often used to evaluate the risk of neck injuries.

(3) The largest difference between the BioRID and the Hybrid III is that of the relative rotation angle between the head and T1, that of the BioRID does not exhibit an extension motion. The reason is that the T1 can rotate rearward after the seatback stops rotating due to the segmented spine structure of the BioRID.

(4) From the above three points, the BioRID dummy seems to be an effective tool to evaluate the risk of neck injuries in rear impacts of these speeds.

(5) Further research in the following areas is necessary in order to evaluate the risk of neck injuries; the cause of the difference between the upper neck loads of the BioRID and the Hybrid III, and the possibility of measuring lower neck loads with the BioRID.

(6) It was found that the NIC response of the BioRID responds differently than that of the Hybrid III when exposed to different seat structures. The reason is that T1 acceleration response of the BioRID is more sensitive to the change in seat structure than that of the Hybrid III because of the segmented spine of the BioRID.

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