A COMPARATIVE STUDY OF DUMMY SENSITIVITY TO SEAT DESIGN PARAMETERS

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ABSTRACT

Whiplash injuries and their associated cervical symptoms are a critical problem resulting from rear impact motor vehicle collisions. Although the exact injury mechanisms remain elusive, recent biomechanical research has suggested that relative motion between the head and torso, or more precisely between adjacent vertebrae of the neck, may be the primary cause for such injuries. Currently available test dummies have limited biofidelity and functionality in the assessment of head restraint performance. The challenge to the automotive safety community is to select a dummy that can discriminate between seat designs with varying levels of performance in terms of their whiplash injury mitigation. The objective of this study was to evaluate the responses of various 50th-percentile male dummies, namely the BioRID II, Hybrid III, RID III, and THOR, under rear impact conditions to determine their sensitivities to seat design parameters believed to be critical to the mitigation of whiplash injuries. Seat and head restraint design features studied included seatback recliner stiffness, head restraint height, and head restraint backset. A variety of biomechanical measurements related to whiplash injury risk were used in the comparison of dummy responses, including relative head-to-torso extension rotations, extension moments measured in the lower neck, and tension and shear forces measured in the upper neck. Results indicated significant differences between the dummy responses and their sensitivities to critical seat design features. Sensitivity was also found to vary greatly depending on the specific dummy and injury measure selected.

INTRODUCTION

Although typically classified as AIS 1, whiplash injuries can result in long-term and even permanent disabilities, with an annual societal cost in the US of approximately $2.7 billion associated with rear impacts as estimated by the National Highway Traffic Safety Administration (NHTSA) [1]. Although these injuries can occur in any crash direction, rear impact collisions produce a higher incidence rate than other types of crashes.

During a typical rear impact collision an occupant will initially move rearward with respect to the vehicle interior as the vehicle is accelerated forward. The occupant's head and torso will contact the head restraint and seatback, respectively, causing the seatback to rotate and deform rearward. The occupant will then rebound off the seatback and begin to move forward relative to the vehicle interior. For a belted occupant, the forward rebound motion is stopped by the force of the seatbelt acting across the torso and hips. Motion of the occupant depends on a number of parameters, including their height and weight, position and design of the head restraint, seatback recliner stiffness, seatbelt usage, and motion of the vehicle. The entire sequence of events typically takes less than 200 milliseconds, or two-tenths of a second.

Loading on the body during a rear impact collision is a complex, multi-directional event, even for an in-line bumper-to-bumper collision. As the seat moves forward and makes contact with the occupant's back, the normal kyphotic curve of the thoracic spine is straightened, resulting in a compressive load applied to the spine. This spinal compression was noted by Ono and Kaneoka [2,3] during their volunteer studies using high-speed x-ray imaging. Shear forces and localized flexion and extension bending moments are also sustained by the spine, resulting in a complex combination of forces and moments incurred at each level of the spine and on the head.

Although there is currently no consensus on cervical spine injury criteria, most researchers agree that whiplash injuries are related to the relative motion between the head and torso, and that the reduction of this relative motion will lead to a decrease in the incidence and severity of these injuries. Further, it has been shown that the relative motion between the head and torso is greatly affected by various seat design parameters, including the position of the head restraint relative to the head [4] and the seatback recliner stiffness [5]. Head restraint position is typically quantified using the height and backset (horizontal distance between the head and head restraint) as measured in accordance with the FMVSS 202a standard using the SAE J826 manikin and the ICBC Head Restraint Measuring Device (HRMD), respectively. Recliner stiffness is typically measured in accordance with the procedures established in the FMVSS 207 standard.

Injury Criteria

Several different injury criteria have been proposed by researchers in an attempt to predict the occurrence of whiplash injuries. Bostrom *et al* [6] proposed the Neck Injury Criterion (NIC), which is based on the Navier Stokes equations and the assumption that fluid flow within the spinal canal causes pressure gradients that are injurious to the nerve roots. Kleinberger *et al* [7] proposed the N_{ij} neck injury criteria, which combines the effects of forces and moments acting at the occipital condyles normalized by a set of critical threshold values. Schmitt *et al* [8] proposed a modified version of the Nij criteria, called the N_{km} Criteria, which combines the effects of shear force and flexion-extension moment acting in the upper cervical spine. Prasad *et al* [9] suggested using extension moments measured at the lower neck load cell because it was found to be more sensitive to seat design and crash severity. Viano *et al* [10] proposed a Neck Displacement Criterion (NDC), which is based on the relative displacement and rotation between the occipital condyles and the T1 vertebrae as compared with the natural range of motion. This criterion was proposed as a supplement to other existing criteria until the mechanisms of whiplash injury are better understood. More recently, Kuppa *et al* [11] proposed a relative head-to-torso extension rotation criterion, which has been adopted in the newly upgraded FMVSS 202a standard.

It is important to note that each of the proposed injury criteria mentioned above has been developed using a specific anthropomorphic test device (ATD). Application of these criteria to other ATDs would require the determination of a new set of critical values or thresholds, which would be a difficult task due to significant differences in dummy designs.

The objective of this study was to evaluate the relative performance of various ATDs currently being used to investigate occupant responses to rear impact. Dummy performance was compared using measures of the relative head-to-torso extension rotation, lower neck extension moment, upper neck tension force, and upper neck posterior shear force (head moving posteriorly relative to the neck) for various combinations of head restraint position and recliner stiffness.

EXPERIMENTAL METHODS

A production automotive seat (1999 Toyota Camry) was modified to allow the rotational recliner stiffness, head restraint height, and backset to be adjustable over a wide range. The normal recliner mechanism was replaced with a simple pin joint to provide free rotation at the hinge joint. Rotational stiffness was provided by two spring-damper assemblies externally mounted to the rear of the seatback. Stiffness was varied by changing the set of coil springs and/or their location relative to the hinge joint. To provide a repeatable test system and avoid any permanent deformation, the seatback frame was structurally reinforced with steel channels to provide attachment points for the spring assemblies. The head restraint supports were also modified to allow adjustment in both the horizontal and vertical directions. Figure 1 shows the modified seat with the attached spring-damper assemblies.

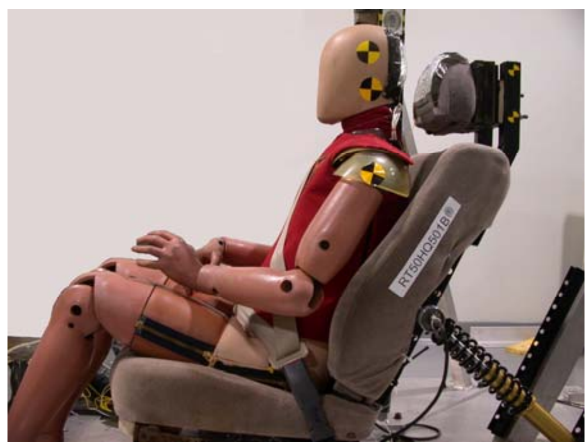

Figure 1. Modified seat providing adjustable recliner stiffness and head restraint position.

Rear impact tests were conducted on a Via Systems deceleration sled using four different mid-sized male ATDs, including the Hybrid III, BioRID2, THOR, and RID3. A sinusoidal sled pulse with a nominal impact speed of 17 kph was used that fit within the FMVSS 202a dynamic testing corridor. The nominal peak acceleration and duration of the pulse was 9.0 g's and 90 msec, respectively. Seatback angle was initially set at 25 degrees relative to vertical; head restraint height was set at either 750 mm or 800 mm;

and head restraint backset was set at either 50 mm or 75 mm. Head restraint height is the distance from the H-point to the top of the head restraint measured parallel to the torso line, as prescribed in FMVSS 202a. Backset is defined as the horizontal distance between the posterior aspect of the head and the front surface of the head restraint. This distance was measured using the ICBC's HRMD attachment to the SAE J826 manikin. Seatback recliner stiffness was set at either a baseline value of 35 Nm/deg or at 105 Nm/deg (300%). The baseline recliner stiffness value of 35 Nm/deg represents a relatively compliant single recliner automotive seat [12].

Sensor arrays for the various dummies varied slightly due to differences in dummy design. However, all tests included a core suite of instrumentation, including triaxial accelerometers at the head CG and thorax CG, a single accelerometer at T1, angular rate sensors mounted in the head and upper spine, 6-axis load cells in the upper and lower neck, and a 3-axis load cell in the lumbar spine. All sensor data were collected using an on-board TDAS-Pro data acquisition system. In addition to the sensor output, dummy kinematics were recorded for each test using an on-board IMC Phantom 4 digital video camera operating at 1000 frames per second. The two components of a custom designed head contact switch were attached to the posterior surface of the head and front surface of the head restraint to serve as a switch to determine head contact times.

RESULTS

Measured responses for the different ATDs varied considerably under identical test conditions. In addition, the sensitivity of each dummy to changes in the critical seat design parameters varied greatly. An overall comparison of the dummy responses to rear impact is shown below in Figures 2-5 for tests with a baseline recliner stiffness and a relatively good head restraint position with a height of 800 mm and a backset of 50 mm. Clear differences in responses are readily observable between dummies. Relative head-to-torso extension rotations (Figure 2) range from a maximum of 11 degrees for the Hybrid III down to almost zero for both the BioRID2 and THOR. Lower neck extension moments (Figure 3) also varied considerably from 96 Nm for the Hybrid III down to almost zero for THOR. Upper neck tension forces (Figure 4) ranged from roughly 1100 N to 1700 N, but the differences were not as dramatic between dummies. Upper neck posterior shear forces (Figure 5) varied from 287 N for the RID3 down to almost zero for THOR.

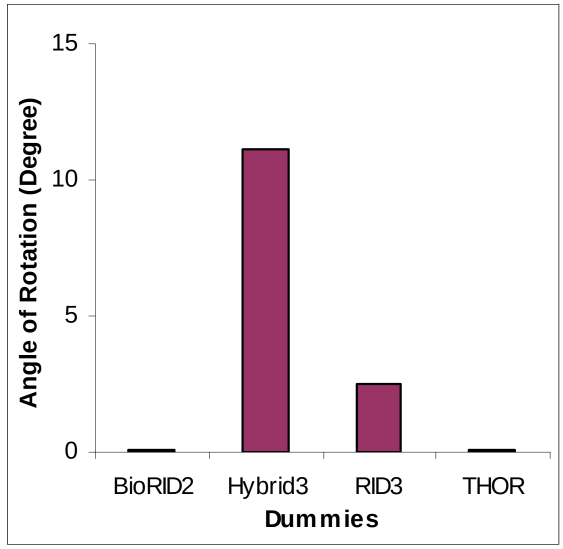

Figure 2. Measured relative head-to-torso rotation for the various dummies at baseline stiffness and good head restraint position.

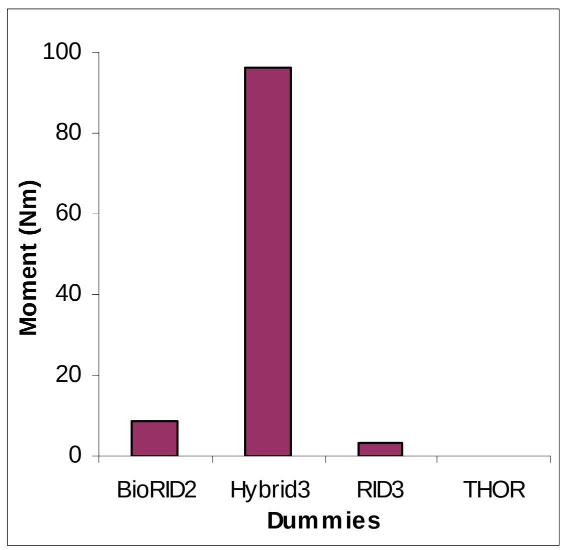

Figure 3. Measured lower neck extension moment for the various dummies at baseline stiffness and good head restraint position.

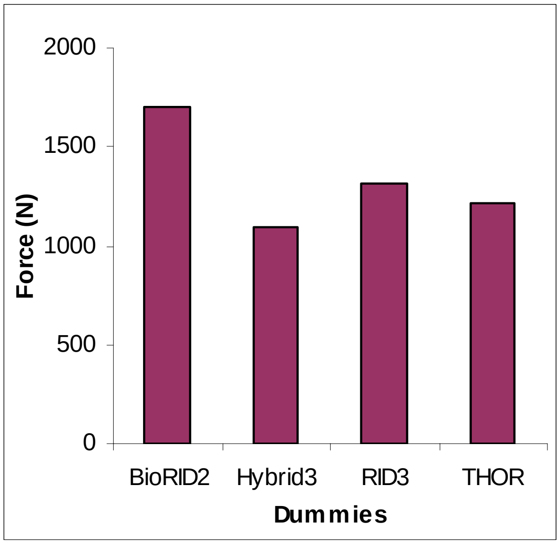

Figure 4. Measured upper neck tension force for the various dummies at baseline stiffness and good head restraint position.

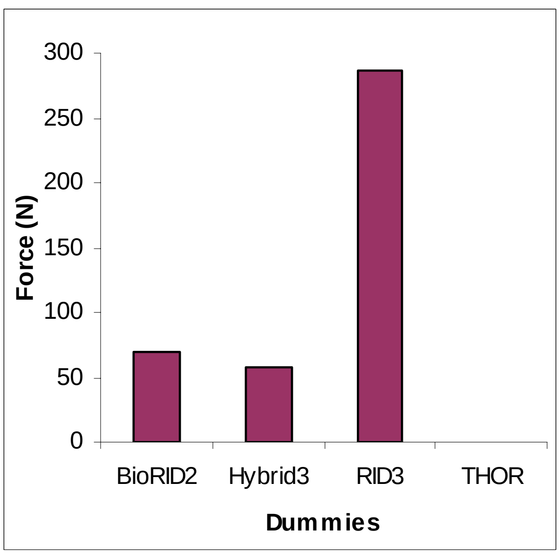

Figure 5. Measured upper neck posterior shear force for the various dummies at baseline stiffness and good head restraint position.

The time until the initial contact between the head and head restraint was also found to vary significantly between the various dummies, ranging from 83 ms for the THOR dummy to 113 ms for the BioRID2 dummy. Figure 6 shows a comparison of these initial contact times, and Figure 7 shows the position of each dummy at the point of contact. It should be noted that the contact location on the posterior surface of the head is different for each dummy, and is affected by the overall dummy design. For example, the BioRID2 and THOR dummies were found to have a higher initial seated height than the Hybrid III and RID3 dummies, which resulted in head contact on the inferior aspect of the skull cap.

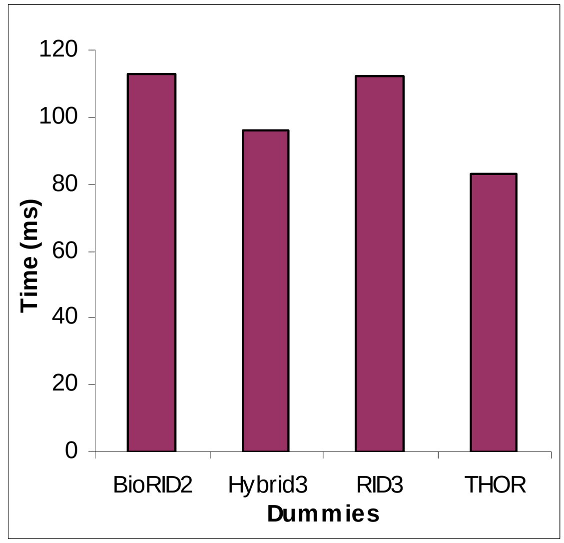

Figure 6. Measured initial head contact times for the various dummies at baseline stiffness and good head restraint position.

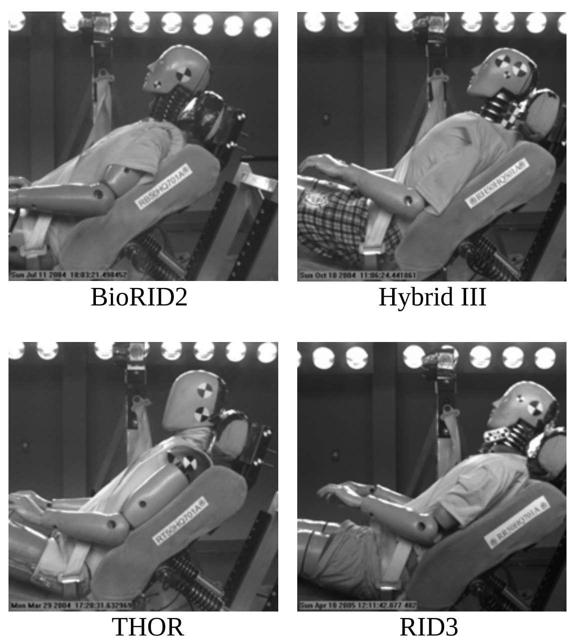

Figure 7. Dummy positions at point of initial head to head restraint contact.

The effects of head restraint position are shown in Figures 8-11 for each of the dummies. In these figures, the head restraint positions are shown on the horizontal axes, where H represents the "High" height of 800 mm and L represents the "Low" height of 750 mm. Similarly, the backset position is represented by the number, where "5" represents a backset of 50 mm and "7" represents a backset of 75 mm. Therefore, in these figures, H5 represents the best case head restraint position with an 800 mm height and 50 mm backset, while L7 represents the worst case head restraint position with a 750 mm height and 75 mm backset.

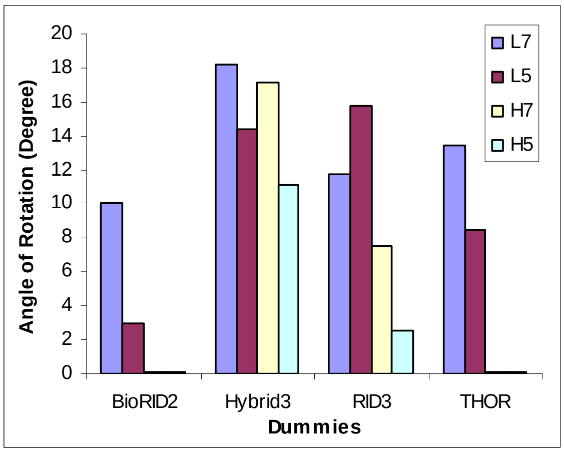

Figure 8. Effect of head restraint position on measured head-to-torso rotation for a baseline stiffness.

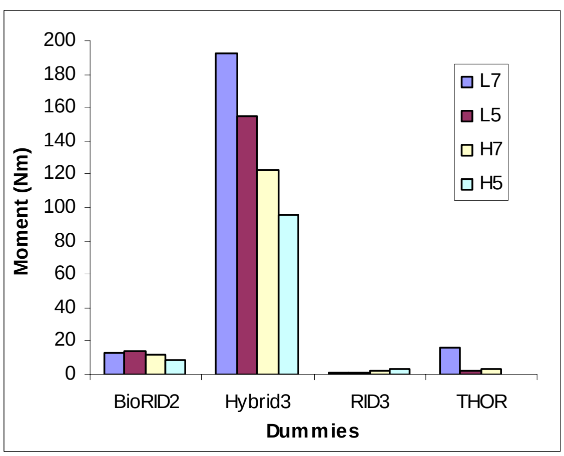

Figure 9. Effect of head restraint position on measured lower neck extension moment for a baseline stiffness.

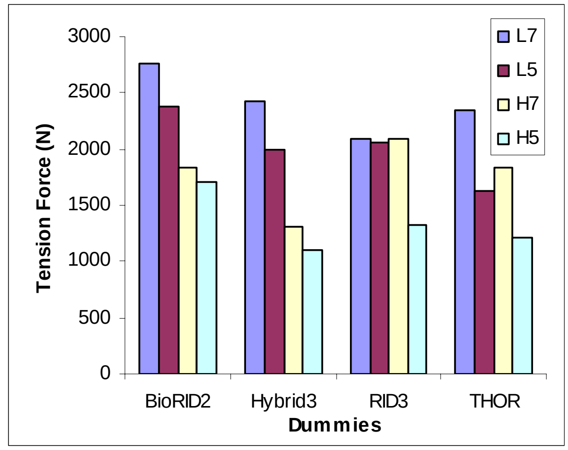

Figure 10. Effect of head restraint position on measured upper neck tension force for a baseline stiffness.

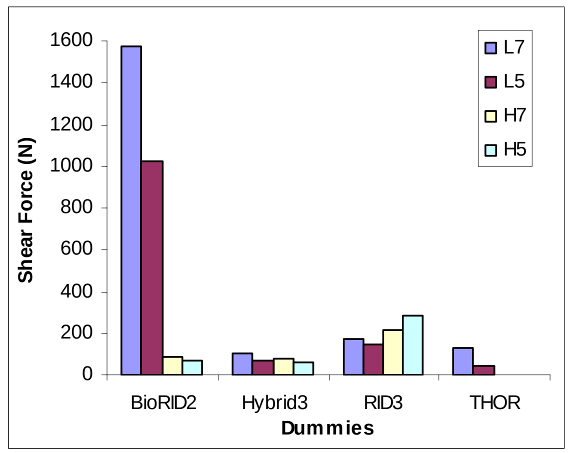

Figure 11. Effect of head restraint position on measured upper neck shear force for a baseline stiffness.

The effects of seatback recliner stiffness are shown in Figure 12 for each of the dummies using the best case head restraint position (H5) with a height of 800 mm and a backset of 50 mm. The baseline (100%) recliner stiffness of 35 Nm/deg represents a relatively compliant single recliner automotive seat, while the 105 Nm/deg recliner stiffness represents a seat that is nominally three times stiffer (300%). Figure 13 shows similar data for the worst-case head restraint position (L7) with a height of 750 mm and a backset of 75 mm. It is important to note in Figure 12 that even though the relative head-to-torso rotations measured with the Hybrid III dummy were larger than the other dummies, the values were below the 12-degree threshold established for the dynamic option within the FMVSS 202a standard for both the baseline and 300% recliner stiffnesses with the best head restraint position. Conversely, the head-to-torso rotations of the Hybrid III dummy exceeded the 12-degree threshold for the worst-case head restraint position as shown in Figure 13.

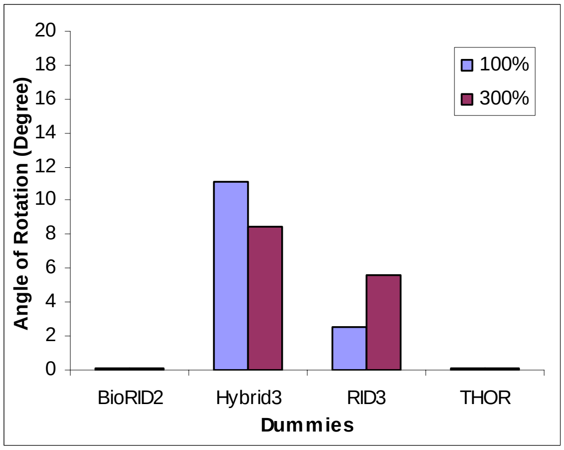

Figure 12. Effect of seatback recliner stiffness on measured head-to-torso rotation for best-case (H5) head restraint position.

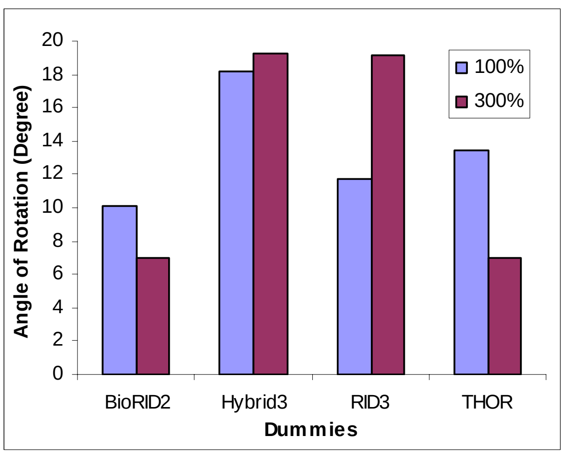

Figure 13. Effect of seatback recliner stiffness on measured head-to-torso rotation for worst-case (L7) head restraint position.

Data from all of the tests in this study are shown in the Appendix in Table A1. This includes a summary of results from a total of 32 tests, including all combinations of four dummies, two head restraint heights, two head restraint backsets, and two recliner stiffness levels.

DISCUSSION

Results from this series of testing clearly demonstrate the complexity of the occupant response to rear impact, and also the difficulty of designing an automotive seat when there is no consensus on injury criteria and thresholds, or even on which dummy is most appropriate. However, history has shown us that effective vehicle design does not require an absolutely biofidelic dummy, rather a dummy and test protocol that can distinguish between good and bad vehicle and component designs. Therefore, the analysis of these results will focus on the sensitivity of each dummy and associated injury criteria to the seat design parameters that have been shown to be important to providing protection against whiplash injuries to the occupants. The three seat design parameters that will be evaluated include head restraint height, head restraint backset, and seatback recliner stiffness. For the purpose of these analyses, a head restraint position that is higher and closer to the occupant's head is considered to be preferable to one that is lower with a larger backset.

In an attempt to quantify the sensitivity of the various dummies and injury criteria to the critical seat design parameters, a "sensitivity score" was used to rank the dummy responses. This score quantifies the percent difference in measured response for each dummy as one of the design parameters is modified. Sensitivity values are assigned for each test comparison using the criteria shown below in Table 1.

Table 1. Definition of Sensitivity Values

Percent Change	Sensitivity Value
< 15 percent	0
15 – 50 percent	1
> 50 percent	2

The Sensitivity Score for each injury criteria is obtained by adding up the individual sensitivity values for each seat design parameter, while the remaining parameters are held constant. This Sensitivity Score will therefore be based on the summation of four individual test comparisons, representing the different combinations of the remaining two design parameters. Since each individual sensitivity value can range from 0 to 2, the Sensitivity Score for each injury criteria can range from 0 to 8 for each dummy. An Overall Sensitivity Score is also calculated for each dummy as the sum of the four individual Sensitivity Scores for each injury criteria, namely head-to-torso rotation, lower neck extension moment, upper neck tension, and upper neck shear. The value of the Overall Sensitivity Score can therefore range from 0 to 32.

Effects of Head Restraint Height

To obtain the Sensitivity Score for a particular dummy and injury criteria to head restraint height, a total of four individual sensitivity values will be added. Responses will be compared for data from tests with High versus Low head restraint heights for each combination of head restraint backset and recliner stiffness. This process is repeated for each of the four injury criteria under consideration to obtain the Overall Sensitivity Score. Table 2 shows a summary of the sensitivity results with respect to head restraint height.

Table 2. Dummy Sensitivity Scores for head restraint height.

Criteria	L5-H5 (100)	L7-H7 (100)	L5-H5 (300)	L7-H7 (300)	SS
BioRID II Dummy					
Rotation	2	2	2	2	8
LN Ext.	1	0	0	0	1
Tension	1	1	1	1	4
Shear	2	2	2	2	8
Overall Height Sensitivity Score					21
Hybrid III Dummy					
Rotation	1	0	1	0	2
LN Ext.	1	1	1	1	4
Tension	1	1	1	1	4
Shear	0	1	1	0	2
Overall Height Sensitivity Score					12
RID-III Dummy					
Rotation	2	1	2	1	6
LN Ext.	0	0	0	0	0
Tension	1	0	2	2	5
Shear	0	0	0	0	0
Overall Height Sensitivity Score					11
THOR Dummy					
Rotation	2	2	2	2	8
LN Ext.	2	2	0	0	4
Tension	1	1	1	2	5
Shear	2	2	0	0	4
Overall Height Sensitivity Score					21

Based on the analysis of test results for the sensitivity of each dummy to head restraint height, it can be seen that the BioRID II and THOR dummies were found to be the most sensitive ATDs to distinguish this seat design parameter. It is important to once again note that the objective of these analyses is not to make a determination relative to the biofidelity of each dummy, but only to determine which dummies are suitable to distinguish between differences in critical seat design parameters. It is also important to note that the calculated sensitivities depend on the injury criteria selected, and that the values presented in Table 2 are specific for the four criteria under investigation. Figure 14 shows the sensitivity of each dummy to head restraint height.

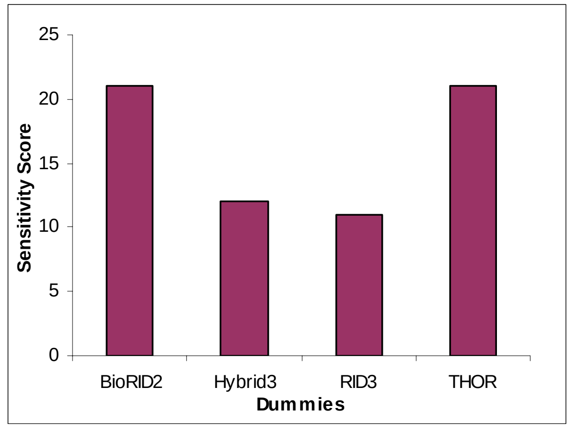

Figure 14. Overall sensitivity of various dummies to changes in head restraint height.

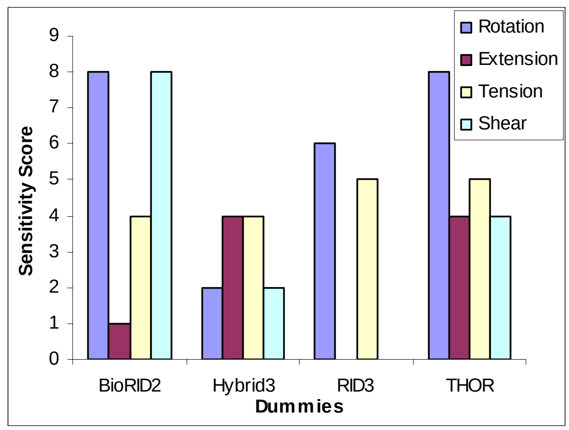

Figure 15. Breakdown of head restraint height sensitivity by injury criteria.

The results presented in Table 2 can also be analyzed to examine the sensitivity of each dummy to head restraint height based on the individual injury criteria. Figure 15 shows a breakdown of the height sensitivity scores for each injury criteria. It can be clearly seen from this breakdown of the data that the selection of a specific dummy does not guarantee sufficient sensitivity to the seat design parameters. The selection of a particular injury criterion is also an important determinant. For example, even though the BioRID II dummy was found to have one of the highest sensitivities to head restraint height, this dummy would not be a good choice if lower neck extension was selected as the distinguishing injury criteria. Likewise, although the RID-III dummy was found to be the least sensitive dummy overall to head restraint height, it might prove to be a useful dummy if head-to-torso rotation or upper neck tension was selected as the injury criteria.

As shown in Table 2 and Figure 15, the BioRID II and THOR dummies had the highest sensitivities to relative head-to-torso rotations. This may be due largely to the fact that these dummies had higher initial seated heights than the other dummies. Since the 750 mm head restraint height is located roughly at the CG of the Hybrid III 50th percentile male dummy head, this height should be sufficient to effectively limit the rearward movement of the Hybrid III head and neck. Increasing the height to 800 mm with no change in backset would offer only slight improvements in limiting the rearward movement of the head and neck. In contrast, since the 750 mm head restraint height may be located below the head CG for the BioRID II and THOR dummies due to their higher initial seated heights, an increase in height to 800 mm would be expected to significantly increase the level to which the head restraint limits the rearward motion of the head and neck.

Effects of Head Restraint Backset

In a manner similar to the analysis of head restraint height, the sensitivity of each dummy to head restraint backset can be calculated by comparing data from tests with Far (75 mm) versus Close (50 mm) head restraint backsets for each combination of head restraint height and recliner stiffness. This process is repeated for each of the four injury criteria under consideration to obtain the Overall Sensitivity Score. Figure 16 and Table 3 show a summary of the sensitivity results for head restraint backset. A breakdown of sensitivities by injury criteria is shown in Figure 17.

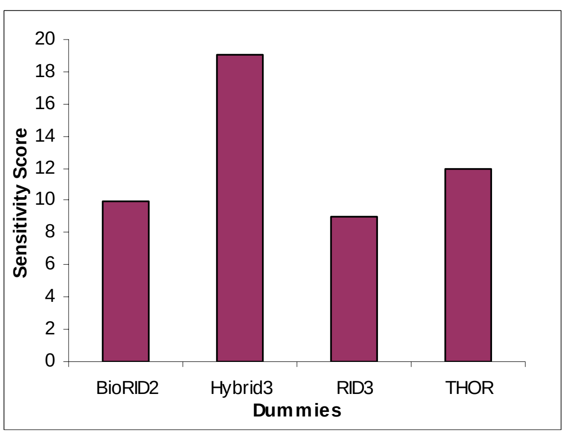

Figure 16. Overall sensitivity of various dummies to changes in head restraint backset.

Table 3. Dummy Sensitivity Scores for head restraint backset.

Criteria	L7-L5 (100)	H7-H5 (100)	L7-L5 (300)	H7-H5 (300)	SS
BioRID II Dummy					
Rotation	2	0	2	0	4
LN Ext.	0	1	1	1	3
Tension	0	0	0	0	0
Shear	1	1	1	0	3
Overall Backset Sensitivity Score					10
Hybrid III Dummy					
Rotation	1	1	1	2	5
LN Ext.	1	1	1	1	4
Tension	1	1	2	1	5
Shear	1	1	1	2	5
Overall Backset Sensitivity Score					19
RID-III Dummy					
Rotation	0	2	1	2	5
LN Ext.	1	0	0	0	1
Tension	0	1	0	2	3
Shear	0	0	0	0	0
Overall Backset Sensitivity Score					9
THOR Dummy					
Rotation	1	0	2	0	3
LN Ext.	2	2	0	0	4
Tension	1	1	1	0	3
Shear	2	0	0	0	2
Overall Backset Sensitivity Score					12

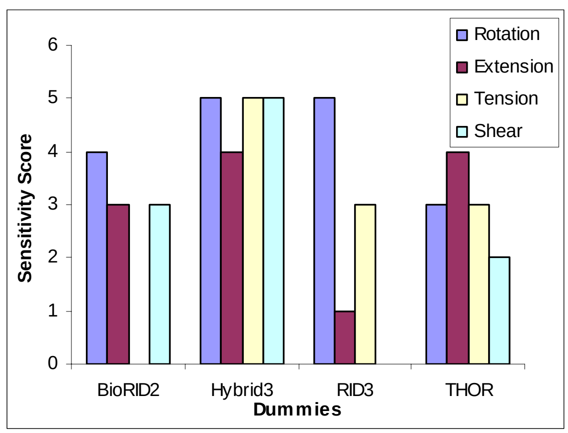

Figure 17. Breakdown of head restraint backset sensitivity by injury criteria.

Based on the analysis of test results for the sensitivity of each dummy to head restraint backset, it can be seen that the Hybrid III dummy is most sensitive to this seat design parameter. Furthermore, the sensitivity of the Hybrid III dummy for backset was fairly consistent across the four different injury criteria. The RID-III dummy was equally sensitive to relative head-to-torso extension rotation but had low sensitivity to lower neck extension moment and upper neck shear force. The BioRID-II dummy was reasonably sensitive to backset, except for the case where upper neck tension force is selected as the criteria. The THOR dummy had the second highest sensitivity to backset with a relatively consistent response to all four injury criteria.

CONCLUSIONS

Results from this study clearly demonstrate the difficulty of selecting an optimal dummy and injury criteria by which to evaluate the performance of automotive seats in rear impact. Each of the tested dummies showed differences in sensitivities for the various seat design parameters and injury criteria under consideration. Since there is currently no consensus on injury criteria, nor on which design parameter is most critical, the selection of the most appropriate dummy should be based on which one provides the best overall sensitivity to all of these factors. Combining the results from Tables 2 and 3, we can determine the Combined Sensitivity Score for each dummy, which has a potential range from 0 to 64. These results are shown in Table 4.

Table 4. Combined Sensitivity Scores for the various dummies.

Dummy	Sensitivity		
	Height	Backset	Combined
BioRID II	21	10	31
Hybrid III	12	19	31
RID-III	11	9	20
THOR	21	12	33

Based on these combined findings, it appears that the BioRID II, Hybrid III, and THOR dummies are all suitable ATDs for the evaluation of seat design parameters. Again, it must be pointed out that these sensitivity scores are dependent on the injury criteria selected and may change if other criteria are chosen. Of these three potential dummies, the Hybrid III had the least number of test comparisons with a low level of sensitivity (<15% difference). In fact, the Hybrid III dummy showed at least a moderate level of sensitivity (15+ percent) for 28 out of the total 32 individual test comparisons, although only three of these 28 cases showed a high level of sensitivity (>50%). This finding implies that the Hybrid III dummy may be suitable for the evaluation of rear impact protection for a broader set of test conditions than the other dummies despite the fact that it may not have the same level of sensitivity to certain variables as the BioRID II or THOR dummies.

The THOR dummy showed reasonably consistent Overall Sensitivity Scores for each of the various injury criteria considered, although this dummy showed low sensitivity (<15%) values in 12 of the 32 individual test comparisons. Another 13 of the 21 comparisons showed a high level of sensitivity, with the remaining 7 showing moderate sensitivity.

The BioRID II dummy showed reasonably good sensitivity to the various injury criteria, except for the cases of lower neck extension moment during the evaluation of head restraint height and upper neck tension during the evaluation of head restraint backset. The finding that this dummy showed a sensitivity value of zero for tension during backset evaluation may be a consequence of the more flexible spine design of this dummy. Additional testing is needed to further explore this finding.

If we consider the suitability of the various dummies and injury criteria for ranking the different seat design parameters, assuming again that increased height and decreased backset provide increased rear impact protection, then we find that the combination of the Hybrid III dummy with head-to-torso rotation correctly ranks the various seat designs for all combinations of height, backset, and recliner stiffness. In fact, our data suggests that the Hybrid III dummy can properly rank seat designs using all four of the injury criteria under consideration in this study. This is based on a comparison of the specific values in Table A1 of the Appendix without consideration of the relative sensitivities of the measured responses. In contrast, the BioRID II and THOR dummies are able to properly rank the seat designs only using the upper neck tension criteria, which may again be related to the fact that these dummies have a higher initial seating height. The RID III dummy was not able to properly rank the seat designs using any of the injury criteria considered in this study.

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APPENDIX

Table A1. Summary of results for all tests in this study.

Recliner Stiffness	Dummy	Head-To-Torso Rotation (Degrees)				Lower Neck Ext. Moment (Nm)†				Upper Neck Tension Force (N)				Upper Neck Post. Shear Force (N)			
		L7	L5	H7	H5	L7	L5	H7	H5	L7	L5	H7	H5	L7	L5	H7	H5
100%	BioRID2	10.1	2.9	*	*	13.0	13.7	11.6	8.6	2766.3	2379.6	1830.7	1700.3	1571.0	1020.7	89.5	69.8
	Hybrid3	18.2	14.4	17.1	11.1	192.9	155.0	122.5	96.2	2423.5	1990.6	1306.0	1097.0	102.0	64.9	75.1	57.2
	RID3	11.7	15.8	7.5	2.5	1.3	1.0	1.8	3.2	2093.0	2055.2	2097.8	1317.5	169.5	146.4	213.9	286.8
	THOR	13.4	8.5	*	*	15.9	2.3	2.9	*	2339.1	1628.5	1836.4	1217.6	129.5	41.2	*	*
300%	BioRID2	7.0	3.0	*	*	11.4	8.7	12.0	8.3	2227.3	2145.8	1411.9	1275.1	1463.2	1144.2	20.6	22.7
	Hybrid3	19.3	12.2	17.4	8.5	131.2	69.6	81.5	46.5	1589.8	774.7	809.9	466.9	127.9	69.7	115.5	48.2
	RID3	19.1	15.6	15.9	5.6	6.5	6.8	5.7	6.4	1625.1	944.1	750.1	304.3	275.4	284.0	264.7	325.4
	THOR	7.0	2.9	*	*	*	*	*	*	1247.1	675.9	502.4	480.1	*	*	*	*

† = Lower neck extension moment values are as recorded by the load cell and have not been corrected to the T1 location.
* = These measured values were either zero or negative, indicating that the measured response was in the opposite direction. (Flexion rotation, flexion moment, or anterior shear)

Notes:

1. Recliner Stiffness:
   100% = baseline stiffness of 35 Nm/deg
   300% = Nominal 3 times increase from baseline stiffness at 105 Nm/deg
2. Head Restraint Positions:
   L7 = 750 mm height with 75 mm backset
   L5 = 750 mm height with 50 mm backset
   H7 = 800 mm height with 75 mm backset
   H5 = 800 mm height with 50 mm backset