INFLUENCE OF SEAT FOAM AND GEOMETRICAL PROPERTIES ON BIORID P3 KINEMATIC RESPONSE TO REAR IMPACTS

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ABSTRACT

As the primary interface with the human body during rear impact, the automotive seat holds great promise for mitigation of Whiplash Associated Disorders (WAD). Recent research has chronicled the potential influence of both seat geometrical and constitutive properties on occupant dynamics and injury potential. Geometrical elements such as reduced head to head restraint rearward offset and increased head restraint height have shown strong correlation with reductions in occupant kinematics. The stiffness and energy absorption of both the seating foam and the seat infrastructure are also influential on occupant motion, however the trends in injury mitigation are not as clear as for the geometrical properties. It is of interest to determine whether, for a given seat frame and infrastructure, the properties of the seating foam alone can be tailored to mitigate WAD potential.

Rear impact testing was conducted using three model year 2000 automotive seats (Chevrolet Camaro, Chevrolet S-10 pickup and Pontiac Grand Prix), using the BioRID P3 anthropometric rear impact dummy. Each seat was distinct in construction and geometry. Each of the seat backs were tested with various foams (i.e. standard, viscoelastic, low or high density). Seat geometries and infrastructure were constant so that the influence of the seating foams on occupant dynamics could be isolated.

Three tests were conducted on each foam combination for a given seat (total of 102 tests), with a nominal Delta V of 11 km/h (nominal duration of 100 msec). The seats were compared across a host of occupant kinematic variables most likely to be associated with WAD causation. No significant differences ($p<0.05$) were found between seat back foams for tests with any given seat. However, between seat comparisons yielded several significant differences ($p<0.05$). The Camaro seat was found to result in several significantly different occupant kinematic variables when compared to the other seats. No significant differences were found between the Grand Prix and S-10 seats. Seat geometrical characteristics obtained from the Head Restraint Measuring Device (HRMD) showed good correlation with several occupant variables. It appears that, for these seats and foams, the head-to-head restraint horizontal and vertical distances are overwhelmingly more influential on occupant kinematics and WAD potential than the local foam properties within a given seat.

Keywords: Whiplash, Seats, Head-restraints, Neck

CURRENT ESTIMATES IN the United States indicate that whiplash associated disorders (WAD) cost in excess of $19 billion annually, with claim data from 40 leading automobile insurers containing approximately 3,383,000 private passenger auto injury claims from 1997 alone [22]. Many have reported the high costs of WAD in many countries, with estimates ranging from the millions to the billions of dollars annually [20].

The current study endeavors to mitigate WAD through automotive seat design. Since the occupant initially moves rearward relative to the vehicle during rear impact, and necessarily interacts with the seat back in doing so, the seat back provides the primary "restraint system" for the body in a rear impact. Accordingly, the design of the seat back is very influential on the manner in which the occupant moves in response to the impact (i.e. the occupant kinematics), and thus likely the injury potential. The seat back's properties can be divided into 2 major groupings: the geometrical properties, and the constitutive properties.

Several studies of injured populations have found head restraints to be beneficial in reducing injury approximately 10-30 percent [12,26,36,39]. One reason for the relatively modest gains cited in these studies is that it may not be the mere *existence* of a head restraint, but rather the *characteristics* of the head restraint which most significantly influences WAD incidence. Crash tests, sled tests and mathematical models have typically found a decrease in occupant kinematics with increasing head restraint height, using both dummies and human subjects [25,29,43,53]. Several studies have evaluated the effects of head restraint height retroactively in epidemiological studies, and similarly found a decrease in injury incidence with increasing head restraint height [10,11,19,38].

The rearward offset, or distance between the head restraint and the back of the head, has also been found to be overwhelmingly associated with WAD potential and occupant kinematics. Almost uniformly, crash test and epidemiological studies have found a relationship between increased rearward offset and occupant kinematics and/or WAD potential [10,11,12,16,25,46,47,48,52,53].

The seat constitutive properties most often considered for influence on occupant motion include the stiffness and energy absorption of the seat back and head restraint. Note that the seatback's interaction with the occupant is dependant on both the localized seatback padding and the properties of the seat bottom-seatback joint (seat infrastructure).

While most researchers agree on the combination of seat geometrical properties to most effectively mitigate WAD potential (i.e. higher and closer head restraint), the constitutive properties have not enjoyed a similar consensus to date. Some studies have found decreased occupant kinematics with decreased seat stiffness [2,18,33,46,52]. In a series of tests using human subjects and high speed x-rays, Ono et al. [41,42] found earlier straightening of the cervical spine and increased intervertebral compression for a more rigid seat. By contrast, Svensson et al. [47] advocated a stiffening of the upper seatback in conjunction with a softening of the lower seatback. Haland et al. [18] recommended a stiffer lower seat back and softer upper seat back, which promoted rotation of the upper torso of the dummy in their tests, and an associated reduction in head-to-head restraint distance. Similarly, Muser et al. [37] noted that less stiff seats may yield benefits related to a decreased head-to-head restraint distance which occurs dynamically.

A number of studies have noted the inter-relationship of seatback stiffness and head restraint geometry [7,16,53], in that different effects of stiffness can be found depending on the nature of the head restraint geometry. Altering the head restraint stiffness may also influence occupant kinematics, although no consensus has been reached on this issue. Some have advocated a stiffer head restraint for WAD protection [9], while other have recommended decreased head restraint stiffness [6,25].

Since the rebound phase of a rear impact has been implicated in WAD injury causation, investigations into the effects of seat energy absorption have been conducted. It is generally understood that some measure of damping or energy absorption in the seat back results in a reduction of occupant forward speed during rebound, reducing injury potential [9,17,32,34,37,46,51,53]. One measure of a seat's energy absorption in an impact lies in the plastic deformation undergone by the seat. Several epidemiological studies have retroactively looked at the relationship between seatback plastic deformation and WAD injury, and found decreased neck injury incidence for those seats which underwent permanent, or plastic deformation [19,24,27,35].

Of interest to automotive seat designers, manufacturers and material suppliers is whether the mere modification and replacement of a seating foam on an existing seat infrastructure can positively influence occupant kinematics, and potentially mitigate WAD likelihood, during rear impact. The current study examined this approach for 3 production seats from model year 2000 vehicles by conducting a series of rear-impact tests on each using the BioRID P3 rear impact anthropometric dummy. Various combinations of seatback or head restraint foams were evaluated in different seatback areas for each seat, and the resulting BioRID kinematics statistically compared.

METHOD

VEHICLE - A test buck was constructed using the chassis of a contemporary mini-van, equipped with a universal seat mount so that different seats could be affixed in the driver's position. The vehicle frame was stiffened and the rear bumper interface modified by removing the existing bumper and replacing it with a rectangular foam "bumper" before each test so that a repeatable yet realistic crash pulse could be realized. The impact was delivered using the bumper impact pendulum employed in federally mandated bumper impact tests (Title 49 CFR Part 581), however the impacting face was modified by increasing both the height and width to simulate the bumper of a typical pickup truck.

The pendulum weight and impact speed (as monitored via optical speed trap) were tuned so as to deliver a nominal 11 km/h Delta V impact with a duration of approximately 100 msec for all impacts. This Delta V is above most contemporary indications of minor WAD tolerance, especially for those seats with poor geometry, and was also indicated as the most prevalent speed change in a German population of rear impacts [30]. The duration of 100 msec is typical for low speed rear impacts between a variety of bumper types. Figure 1 shows a representative acceleration vs. time history.

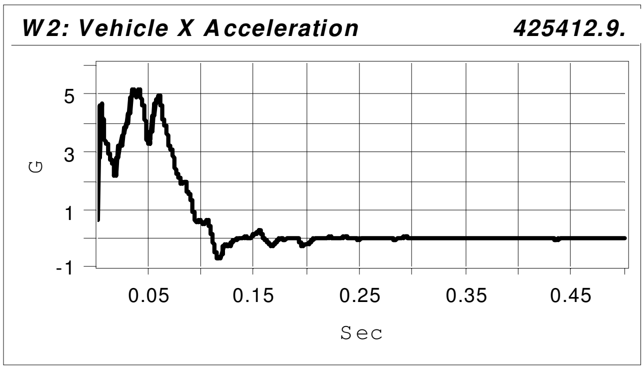

Figure 1: Typical 11 km/h (100msec) Delta V Crash Pulse

OCCUPANT - Since the goal of the study was to determine relative influences of various seating foams on occupant kinematics, it was desirable to simulate the kinematics of an unprepared, relaxed occupant, since such an occupant would likely elicit more dynamic motions than a tensed occupant, and be more likely to isolate subtle differences between seat foams. Accordingly, the BioRID P3 was selected as surrogate, since that dummy likely best represents a relaxed occupant subjected to rear impact [8]. The BioRID was checked periodically for signs of degradation, and the manufacturer's recommended preparatory protocol was followed before each day of testing.

As noted by Kim et al. [28], when seated in vehicle seats according to standard positioning protocol the BioRID adopts a somewhat forward-leaning posture as compared to the Hybrid III (which ostensibly represents the seating posture of a 50th percentile human male). Further, in positioning the BioRID it was found that the dummy did not adopt a consistent seating posture when placed in a given seat, and could be manually manipulated somewhat relative to the seatback prior to a test. To address these issues, a specially designed jig was constructed. For each seat, the upper torso and head positions of a normally situated, 50th percentile adult male human occupant were recorded using the jig. The BioRID was then positioned similarly in the vehicle, ensuring upper torso and head positions relative to the vehicle seat and head restraint which were both consistent and representative of an actual occupant. The jig standardized the locations of the top of the seatback, pelvis, upper torso and nose of the dummy prior to each test via metal dowels inserted through the roof of the van. Figure 2 shows the dowels from the positioning jig.

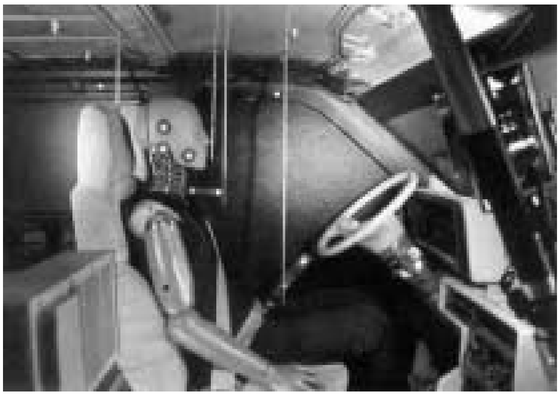

Figure 2: BioRID with Positioning Jig Dowels in Chevrolet S-10 Seat

As a measure of overall system repeatability, 5 impacts were conducted with the BioRID in the same seat (Camaro). The bumper foam and seat were replaced before each impact, and the BioRID re-positioned.

SEATS - Driver's seats from the 2000 Chevrolet Camaro, 2000 Pontiac Grand Prix, and 2000 Chevrolet S-10 pickup were selected for testing. Each seat bottom was rigidly mounted to the van, and the seatback angle was set at a nominal 25 degrees to the vertical. The same vehicle mounted lap and shoulder belt was used for all tests, and each seat underwent only one impact before being replaced.

2000 Chevrolet Camaro - The Camaro seat was not equipped with an adjustable head restraint. The seat back was conceptually divided into 3 areas: upper seatback, middle seatback, and lower seatback. The approximate relative dimensions of these areas are indicated schematically in Figure 3.

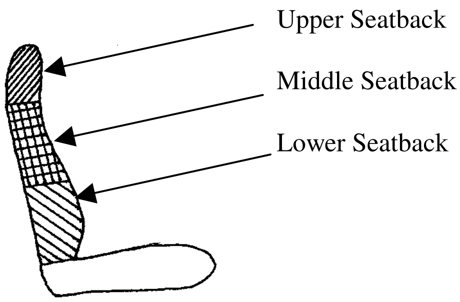

Figure 3: Camaro Seatback Foam Modification Areas

One of three foam types (viscoelastic, low-density, or high-density) were tested in each area. Three impacts were conducted on each combination of foams tested (3 areas with 3 foams = 27 possible combinations).

2000 Pontiac Grand Prix -The standard Grand Prix seat was equipped with an adjustable, halo-type head restraint. In addition to this standard head restraint, testing was also conducted on 4 modified head restraints, constructed from standard, high density, viscoelastic high density, or viscoelastic low density foam. Figure 4 shows schematics of the seats.

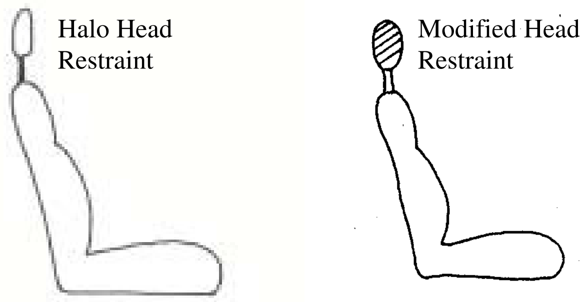

Figure 4: Grand Prix Seat

The geometry of the head restraint was also altered for the modified head restraints by increasing the thickness and depth of the head restraint by approximately 2 cm as compared with the stock, halo version. No modifications were conducted to the remainder of the seatback. The bottom of the modified Grand Prix head restraints were set approximately 10 cm from the top of the seatback, and fixed using a specially designed locking device. The standard, halo head restraint was tested in the up position. Three tests were conducted on each head restraint type, for a total of 15 tests.

2000 Chevrolet S-10 -This seat was not equipped with an adjustable head restraint. Foam modifications were tested in the upper and middle seatback areas, with no modifications to the lower seatback (Figure 5). Either standard or high-density viscoelastic foams were tested in the upper and middle seatback, with the standard foam in the lower seatback for all tests. Three tests were conducted on three combinations, for a total of 9 tests.

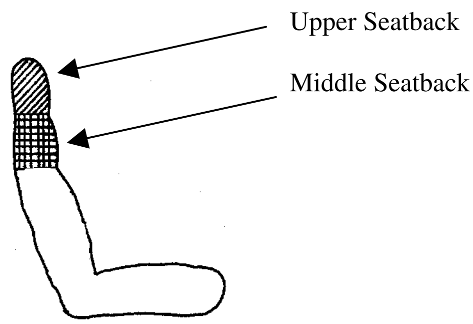

Figure 5: Chevrolet S-10 Seatback Foam Modification Areas

Head Restraint Geometry - Each seat was evaluated using the Head Restraint Measuring Device (HRMD)[13,14,15]. This device was used to quantify the horizontal (Dx) and vertical (Dy) distances from the head of an approximately 50^{th} percentile male occupant to the head restraint for each seat. The measurements obtained from the device served as the basis for the rating of the seats as "good", "acceptable", or "poor", according to the ranking system recommended by Insurance Institute of Highway Safety [21].

INSTRUMENTATION AND DATA PROCESSING - The sign convention for all instrumentation and data collection followed SAE J211 protocol. Vehicle instrumentation included 2 triaxial accelerometers (front and rear) and one redundant uniaxial accelerometer (sensitive axis in the X direction) at the front of the vehicle at the center of gravity. Vehicle change in velocity was calculated by integrating the average X direction acceleration pulse. Occupant instrumentation included a triaxial accelerometer and a rotational accelerometer (Y axis rotation) an the head center of gravity. The upper neck was equipped with a bi-axial load cell which monitored shear (X) and compressive-tensile (Z) forces, and a moment transducer which monitored neck Y axis bending moment. Biaxial accelerometers were located at T1, T8, and L1 "vertebrae", while a triaxial accelerometer monitored pelvic accelerations.

All data were collected at 10,000 Hz. As there is no current consensus on appropriate filters for BioRID data, a review of rear-end low speed impact data, BioRID test results in prior research, frequency and power spectral density analysis of some of our preliminary impacts was conducted in order to determine appropriate data filters. The chosen filters are indicated in Table 1. The filters are more stringent than those proposed by Langweider et al. [31] in some areas, with modifications to the filtering for the neck and pelvic sensors. These modifications were deemed appropriate in light of some relatively high frequency components noted during the Camaro impacts, which were likely the result of mechanical artifacts unique to the BioRID, and thought unlikely to be realizable by a human neck or torso contacting relatively compliant structures such as padded seat backs and head restraints. Although some have recommended using an 18 Hz low pass cut-off filter for spinal accelerometer data, Class180 filters were used for this data and for the NIC calculations. This approach has been endorsed by some researchers [5,31], and was also felt to increase the likelihood that differences between seats would be isolated.

Sensor	Type	Axis	SAE Filter Class
Head	acceleration	x,y,z	Class1000*
Neck	force	x,z	Class180
Neck	moment	y	Class180
T1,T8,L1	acceleration	x,z	Class180
Pelvis	acceleration	x,y,z	Class180
Vehicle	acceleration	x	Class60**

* Class180 used for NIC calculations

** Class180 used for Delta V calculations

Table 1: Filtering Specifications

An on-board high speed video camera captured each test at 500 frames per second. Data collection was initiated via a tape switch mounted to the rear bumper, and 0.5 seconds of data collected. The BioRID was equipped with photoreflective target mounts protruding from the upper thorax (T1) and pelvis (see Figure 2) so that the displacement of these segments could be tracked externally. In addition to these targets, photoreflective targets were affixed to the head at the sagittal projection of the center of gravity, chin and occipital condyles. Displacements for each test were digitized using the Image Express motion analysis system.

SEAT EVALUATION VARIABLES - Since the exact variable(s) associated with WAD causation have not been established and are the issue of much current debate and research, it was decided to evaluate seat performance via a host of variables which logically *might* be associated with WAD causation. Their inclusion here is not meant to imply any established relationship between a given variable and WAD causation. These variables are, however, most often associated with WAD in the literature and seem appropriate for relative seat evaluation. Table 2 lists the variables used to compare seats. In all cases, only the maximum (or minimum) quantity was used.

Kinematic quantities of one level of the spine relative to a lower one were resolved into the lower level's coordinate system. Two values of the Neck Injury Criterion were calculated – the overall maximum (NIC) and that occurring at 50 mm of head retraction on the torso (NIC-50). Bostrom et al. [1] introduced a variation on the NIC which takes into account the sign of the velocity difference between the head and the torso, referred to as $NIC_{generic}$, which was also calculated.

The Neck Injury Criterion (Nij) was also calculated for both compression and tensile forces in the neck during both extension and flexion, using intercept values proposed by Bostrom et al. [1] for AIS 3 neck injury. Similarly, the Neck Injury Criterion (Nkm) evaluated shear forces during extension and flexion, using intercept values proposed by Muser et al. [37] which were similar to those proposed by Kim et al. [28] for AIS 1 neck injury. Since only relative comparisons between seats were sought, the fact that the Nij and Nkm addressed different AIS injury levels was not an issue.

Primary Variable	Units
+ve Head X Acceleration Relative to T1	G
-ve Head X Acceleration Relative to T1	G
-ve Head X Displacement Relative to T1	mm
+ve Head Y Angular Displacement Relative to T1	degrees
+ve Head Y Angular Acceleration	rad/s^2
-ve Head Y Angular Acceleration	rad/s^2
+ve Head X Acceleration Relative to T1	G
+ve Neck X Force (retraction)	kN
+ve Neck Z Force (tension)	kN
+ve Neck Y Moment (extension)	Nm
-ve Neck Y Moment (flexion)	Nm
+ve NIC	m^2/s^2
+ve NIC generic	m^2/s^2
+ve NIC-50	m^2/s^2
-ve NIC generic	m^2/s^2
+ve Nij Compression-Extension	unitless
+ve Nij Compression-Flexion	unitless
+ve Nij Tension-Extension	unitless
+ve Nij Tension-Flexion	unitless
+ve Nkm Protraction-Extension	unitless
+ve Nkm Protraction-Flexion	unitless
+ve Nkm Retraction-Extension	unitless
+ve Nkm Retraction-Flexion	unitless
-ve T1 X Acceleration Relative to T8	G
-ve T1 X Velocity Relative to T8	m/s
-ve T8 X Acceleration Relative to L1	G

Table 2: Seat Evaluation Variables

RESULTS

In order to eliminate impact severity as a variable, all crash pulses were evaluated by statistically comparing peak acceleration and Delta V for all tests. No significant differences in Delta V or peak acceleration across tests for a given seat (or between seats) were found ($p<0.05$), indicating a consistent impact severity both within and between tests of different seats.

As a measure of overall system repeatability, 5 tests using the Camaro seat were conducted. A new seat and bumper were installed for each test, and the BioRID removed from the vehicle and re-positioned for each test. Statistical analysis found that the BioRID responses listed in Table 2 were not significantly different between these tests ($p<0.05$), and thus system test protocol was eliminated as a variable. Since BioRID response and impact severity were eliminated as independent variables, the assumption was that any differences found within seats would be due to the independent variable of foam type and/or foam location.

For all three test series, an analysis of variance was conducted to determine whether any of the evaluation variables differed significantly from each other (95% confidence level). For those variables found to differ significantly between seats, a Tukey post-hoc analysis was conducted to determine whether the foam had a positive or negative influence on the variable as compared to the other foams or seats. This allowed for a determination of whether the particular seat foam or seat performed significantly better or poorer than the others for a given occupant variable.

CAMARO SEAT - Each of the 24 combinations of foams (i.e. 2-2-1, 1-2-3 etc.) was statistically evaluated for its' individual effect on occupant variables. Subgroups of upper/middle, upper/lower, and middle/lower foam groups were also explored for significant effects. The analysis of this interaction of the foam groups showed no significant effects, indicating that no significant differences were found between the performance of any of the specific seat foam combinations in the Camaro.

A further analysis considered isolating the presence of a foam in a given area, regardless of which foam was in the remaining 2 areas. Although differences between mean results existed, none were statistically significant ($p<0.05$). The performance of the seat was essentially similar, regardless of which foam occupied a given area.

GRAND PRIX SEAT - Each of the head restraint foams (including the standard halo head restraint) were compared for significant influence on occupant kinematics. No significant differences were found between any of the head restraint foams tested in the Grand Prix seat.

CHEVROLET S-10 SEAT - Each combination of upper and middle seatback foam was compared statistically for influence on occupant kinematics. As with the other seats, no significant differences were observed between any of the foam combinations tested.

BETWEEN SEAT COMPARISONS -A statistical analysis was also conducted in order to compare the performance of each seat relative to the others. The "standard" configurations of the Camaro, Grand Prix (halo head restraint) and S-10 seats were compared using analysis of variance. Table 3 contains the means for this comparison.

Several variables emerged as being significantly different for the Camaro seat as compared to the Grand Prix and S-10. In particular, the Camaro seat resulted in significantly greater rearward retraction of the head relative to T1, higher Nij in retraction and extension, and higher head and T1 acceleration relative to T1 and T8, respectively. The relatively high $NIC_{generic}$ values and head acceleration relative to T1 observed in the Camaro tests were likely the result of occipital head contact with the relatively rigid top of the seatback which resulted in a short duration reversal in head rotation, a phenomenon not observed in either the Grand Prix or S-10 seat tests.

Variable	**Units**	**Seat**		
		Camaro	**Grand Prix**	**S-10**
+ve Head Y Angular Acceleration	rad/s^2	528.9	*910.3**	450.1
-ve Head Y Angular Acceleration	rad/s^2	*-2631.5**	-541.7	-988.5
+ve Neck X Force (retraction)	kN	*1.8**	1.1	1.1
+ve Neck Z Force (tension)	kN	*1.0**	0.2	0.3
+ve Neck Y Moment (flexion)	Nm	8.0	18.7	11.0
-ve Neck Y Moment (extension)	Nm	*-10.1**	-5.1	-4.1
-ve Head X Displacement Relative to T1(retraction)	mm	*-121.5**	-83.2	-84.5
+ve Head X Acceleration Relative to T1	G	*43.5**	10.6	10.9
-ve Head X Acceleration Relative to T1	G	-5.2	-6.5	-5.3
+ve Head Z Acceleration Relative to T1	G	*15.3**	8.3	7.9
-ve T1 X Acceleration Relative to T8	G	*-24.1**	-2.9	-2.2
-ve T1 X Velocity Relative to T8	m/s	*-1.3**	-0.5	-0.6
-ve T8 X Acceleration Relative to L1	G	*-18.4**	-2.2	-2.8
+ve NIC	m^2/s^2	21.4	15.7	13.4
+ve NIC-50	m^2/s^2	10.6	12.3	9.7
+ve NICgen	m^2/s^2	7.4	10.2	8.6
-ve NICgen	m^2/s^2	*-93.0**	-21.7	-23.3
+ve Nij Tension-Extension	unitless	*0.3**	0.06	0.07
+ve Nij Tension-Flexion	unitless	0.10	0.09	0.08
+ve Nij Compression-Extension	unitless	0.00	0.03	0.03
+ve Nij Compression-Flexion	unitless	0.00	0.05	0.03
+ve Nkm Retraction-Extension	unitless	*2.2**	1.20	1.21
+ve Nkm Retraction-Flexion	unitless	1.47	1.35	1.32
+ve Nkm Protraction-Extension	unitless	*1.7**	0.00	0.00
+ve Nkm Protraction-Flexion	unitless	0.31	0.12	0.00

** indicates significant difference (p>0.05)*

Table 3: Standard Camaro, Grand Prix and S-10 Variable Means

DISCUSSION

WITHIN SEAT COMPARISONS - Foams with differing stiffnesses, energy absorption and densities were employed in various combinations in the upper, middle and/or lower seatback areas of 3 contemporary passenger seats (2000 Camaro, Grand Prix, S-10), using the BioRID P3 as occupant. For impacts with a nominal Delta V of 11 km/h, no foam or combination of foams tested within a given seat was found to significantly influence occupant kinematic or kinetic parameters most often associated with WAD causation. There are several potential explanations for this lack of significant influence. The differences between foams may not have been sufficient for any differences to manifest, or the impact severity was such that the differences which did exist (some of which were impact velocity dependant) were not realized when the BioRID interacted with the seatback. The use of foams with different, or more divergent constitutive properties may result in significant differences.

It is also possible that the relatively small sample sizes, particularly for the Grand Prix and S-10, did not allow for the identification of subtle differences between seat foams and/or combinations. In addition, the specific BioRID kinematic variables chosen for evaluation may not have exposed differences. Further research using different seats, foams and impact severities are encouraged to more completely explore the concept of manipulating localized seatback foam characteristics to enhance occupant protection. It is also possible that the BioRID spine, or the instrumented levels, were not capable of detecting subtle differences in localized seat foam properties, if they existed.

Another consideration is that the localized seatback constitutive properties (i.e. seat foam) are not as influential as the overall stiffness and energy absorption of the seatback-seat bottom interface in the seats tested here. Thus, while stiffness and seatback energy absorption may very well influence occupant motion and injury potential, it may be prudent to include overall seat infrastructure property changes (perhaps in addition to localized foam modifications) in order to achieve significant reductions in occupant kinematics and injury potential. One example of this approach is the Volvo WHIPs seat, which incorporates an energy absorption element in the seat joint and specially tuned seatback foam to successfully influence occupant kinematics [32].

BETWEEN SEAT COMPARISONS - In comparing BioRID responses between seats, significant differences were found between seats. The Camaro allowed significantly greater head motion relative to the torso, as evidenced by higher head rearward displacement and greater acceleration relative to T1. The relative acceleration between T1 and T8, and T8 and L1, were also significantly greater for the Camaro. These differences are likely the result of the relatively poor head restraint geometry in the Camaro. Table 4 shows the head-to-head restraint distances for the 3 seats as obtained from the HRMD (Dy is distance from top of head to top of head restraint).

Vehicle	Head Restraint Type	Dx (horizontal)	Dy (vertical)	IIHS rating
Camaro	Integral	7.5 cm	16.0 cm	Poor
Grand Prix	Stock (up position)	5.4 cm	3.7 cm	Good
S-10	Integral	3.5 cm	3.8 cm	Good

Table 4: Head Restraint measurements from HRMD

Clearly, the Camaro head restraint was significantly further from the BioRID's head in both the horizontal and vertical directions. Although it is conceivable that other seat constitutive properties (such as differences between the Camaro's stiffness and energy absorption and those of the other seats) may have contributed to the Camaro's poorer performance, it would appear most likely that geometry was the influential variable in this series of tests. This is consistent with literature referenced earlier, and the observations of O'Neill [40] and Szabo [49], who cited head restraint geometry as the most influential seat property.

A multiple regression analysis was conducted to determine whether significant correlation existed between the horizontal (Dx) and vertical (Dy) head restraint measurements and occupant kinematics. In addition, the individual correlations between Dx and Dy and the occupant kinematic variables were calculated. The correlation coefficients are presented in Table 5. Note that R^2 values are only presented for those variables found significantly correlated with the geometric dimension in question.

Variable	Units	R^2*		
		Dy	Dx	Dy + Dx multiple regression
+ve Head Y Angular Acceleration	rad/s^2			0.68
-ve Head Y Angular Acceleration	rad/s^2	0.93	0.64	0.95
+ve Neck X Force (retraction)	kN	0.79	0.65	0.79
+ve Neck Z Force (tension)	kN	0.97	0.73	0.97
+ve Neck Y Moment (flexion)	Nm	0.43		0.72
-ve Neck Y Moment (extension)	Nm	0.83		0.90
-ve Head X Displacement Relative to T1(retraction)	mm	0.91	0.73	0.91
+ve Head X Acceleration Relative to T1	G	0.99	0.81	0.99
-ve Head X Acceleration Relative to T1	G			
+ve Head Z Acceleration Relative to T1	G	0.83	0.71	0.83
-ve T1 X Acceleration Relative to T8	G	0.98	0.83	0.99
-ve T1 X Velocity Relative to T8	m/s	0.92	0.70	0.93
-ve T8 X Acceleration Relative to L1	G	0.93	0.79	0.98
+ve NIC (up to 250 msec)	m^2/s^2	0.66	0.68	0.70
+ve NIC-50	m^2/s^2			
+ve NICgen	m^2/s^2	0.47		0.63
-ve NICgen	m^2/s^2	0.99	0.80	0.99
+ve Nij Tension-Extension	unitless	0.98	0.78	0.98
+ve Nij Tension-Flexion	unitless			
+ve Nij Compression-Extension	unitless	0.45		
+ve Nij Compression-Flexion	unitless	0.61		0.79
+ve Nkm Retraction-Extension	unitless	0.90	0.74	0.90
+ve Nkm Retraction-Flexion	unitless			
+ve Nkm Protraction-Extension	unitless	0.98	0.81	0.99
+ve Nkm Protraction-Flexion	unitless			

** R^2 values only presented if p<0.05*

Table 5: R-Squared Values for Correlation between Seat Geometry and Evaluation Variables

Several occupant kinematic variables correlated favorably with the HRMD measurements, again an indication of the importance of the head restraint geometry in moderating occupant kinematics. In particular, it appeared that the vertical head to head restraint distance was somewhat more influential than the horizontal, although both had significant effects on occupant kinematics. Some examples of significantly correlated variables are shown graphically in Figure 6.

BioRID P3 - Since this study focused on the *relative* differences between various seats and seat foams, the biofidelity of the BioRID P3 was not specifically addressed and is beyond the scope of this research. However, some observations are made. The BioRID P3 proved to be an effective, repeatable surrogate for multiple exposures to rear impacts. Including pre-test calibration and set-up impacts, the BioRID used in this study was subjected to over 100 impacts, with the only deterioration coming in the form of a tear in the skin cover which developed on the left anterior chestfrom repeated interaction with the shoulder belt upon rebound during the tests.

In the Camaro tests, some relatively high-frequency components were noted in the neck and spine response. These were felt to be associated with mechanical artifacts in the BioRID after contacting the relatively rigid superior surface of the Camaro seat during full extension. It is questionable whether a human would experience such a response. While attempts were made to digitally filter the data more stringently to account for this, it might be more desirable to incorporate a mechanical solution in future BioRID generations.

It was found that the dummy adopted a more leaned-forward position than did a human in the same seats, and also the dummy's head and upper torso could adopt myriad stable positions once seated in the vehicle, simply via manual manipulation. This study employed a jig which consistently ensured repeatable upper torso and head positioning which reflected that of a human occupant by locating several BioRID landmarks relative to the vehicle. It is recommended that a standardized BioRID positioning protocol be developed in the future to eliminate initial positioning as a variable.

CONCLUSIONS

1. No significant differences were found between the performance of three foams of varying properties in the Camaro seat when located in various combination in the upper, middle or lower portions of the seatback.
2. No significant differences were observed between the performance of the Grand Prix seat when tested using head restraints constructed of five foams of varying properties.
3. No significant differences were found between the performance of two foams of varying properties in the S-10 seat when located in various combination in the upper and middle portions of the seatback.
4. Significant differences were observed between seats, with the stock Camaro seat resulting in significantly greater values of WAD associated kinematic variables than the stock Grand Prix and S-10 seats. No significant differences were observed between the Grand Prix and S-10 seats.
5. Several kinematic variables correlated well with head restraint geometry measurements obtained from the HRMD in the between seat analysis, indicating a strong influence of head restraint height and backset on occupant kinematics.
6. The BioRID P3 anthropomorphic dummy proved a durable and repeatable performer throughout a tests series involving in excess of 100 tests. It is recommended that a positioning protocol be established when using the BioRID, since the dummy was found to adopt unrealistic and inconsistent postures when initially positioned in the vehicle.

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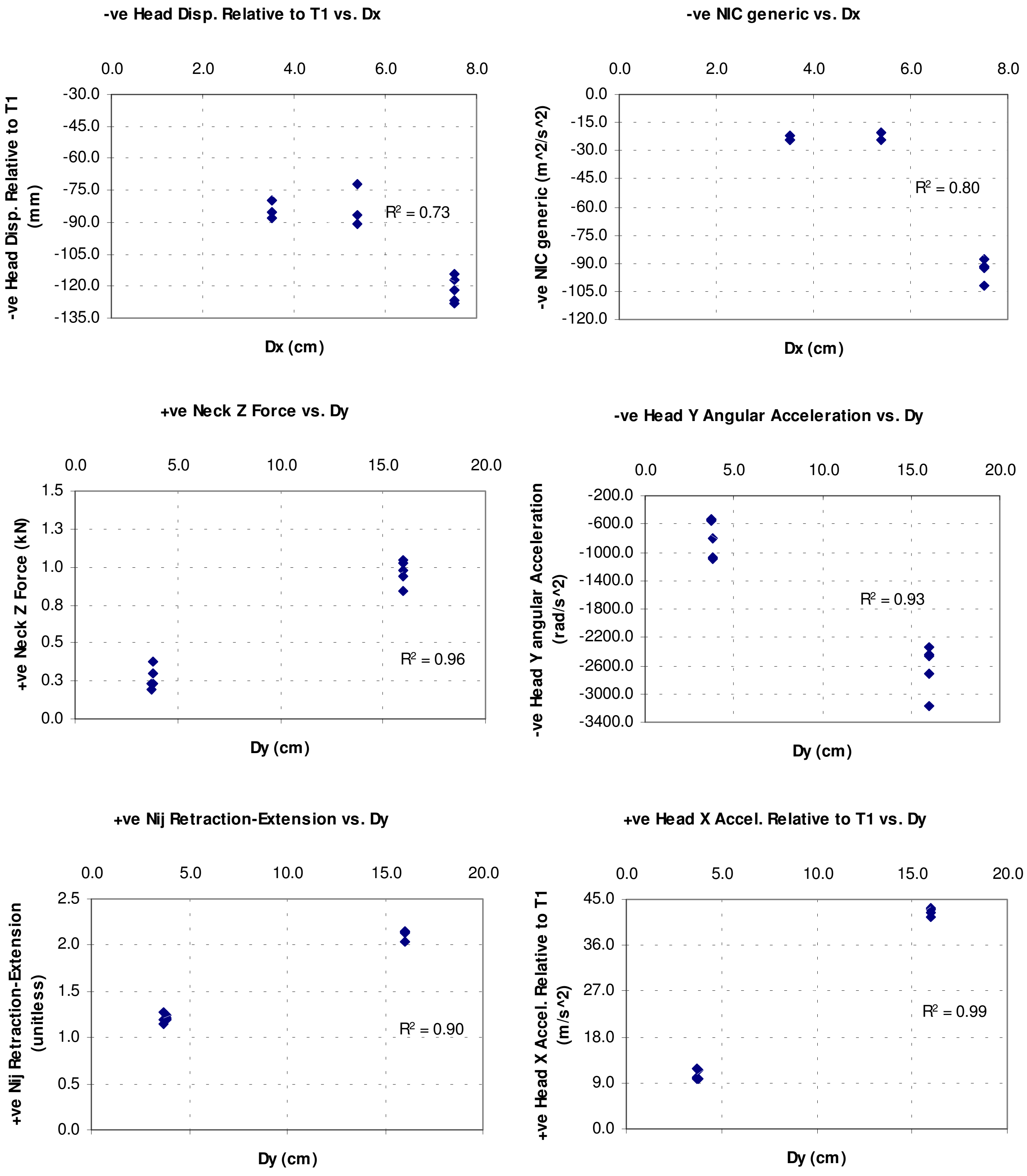

Figure 6: Horizontal and Vertical Head Restraint Correlations

REFERENCES

1. Bostrom O, Bohman K, Haland Y, Kullgren A, Krafft M: "New AIS1 Long-Term Neck Injury Criteria Candidates based on Real Frontal Crash Analysis", Proc. 2000 International IRCOBI Conference on the Biomechanics of Impacts, Sept 20-22, 2000, Montpellier, France, pp 249-264.
2. Bostrom O, Krafft M, Aldman B, Eichberger A, Fredriksson R, Haland Y, Lovsund P, Steffan H, Svensson M, Tingvall C: "Prediction of Neck Injuries in Rear Impacts Based on Accident Data and Simulations", Proc. 1997 International IRCOBI Conference on the Biomechanics of Impacts, Sept 24-26, 1997, Hannover, Germany, pp 251-264.
3. Bostrom O, Fredriksson R, Haland Y, Jakobsson L, Krafft M, Lovsund P, Muser M, Svensson M: "Comparison of Car Seats in Low Speed Rear-End Impacts using the BioRID Dummy and the New Neck Injury Criterion (NIC)", Compendium of the Whiplash Associated Disorders World Congress (Traffic Safety and Auto Engineering Session), February 1999, Vancouver, BC, pp 437-450.
4. Bostrom O, Haland Y, Fredriksson R, Svensson M, Mellander H: "A Sled Test Procedure Proposal to Evaluate the Risk of Neck Injury in Low Speed Rear Impacts using a New Neck Injury Criterion (NIC)", paper 98-S7-O-07, Proc. 16th International Technical Conference on Enhanced Safety of Vehicles, May 31-June 4, 1998, Windsor, Canada, pp 1579-1585.
5. Bostrom, O.; Personal communication, March 2001.
6. Chhor A, Svensson NL, Giffiths M, Kjellberg S: "An Investigation of Seat Design Parameters Influencing Neck Loads in Low Speed Vehicle Rear Impacts", Proc. 15th International Technical Conference on Enhanced Safety of Vehicles, May 13-16, 1996, Melbourne, Australia, pp 1717-1727.
7. Davidsson J, Deutscher C, Hell W, Linder A, Lovsund P, Svensson MY: "Human Volunteer Kinematics in Rear-End Sled Collisions", Proc. 1998 International IRCOBI Conference on the Biomechanics of Impacts, Sept 16-18, 1998, Goteborg, Sweden, pp 289-289.
8. Davidsson J, Lovsund P, Ono K, Svensson MY, Inami S: "A Comparison between Volunteer, BioRID P3 and Hybrid III Performance in Rear Impacts", Proc. 1999 International IRCOBI Conference on the Biomechanics of Impacts, September 1999, Spain, The Netherlands, pp 165-178.
9. Dippel C, Muser MH, Walz F, Niederer P, Kaeser R: "Neck Injury Prevention in Rear-Impact Crashes", Proc. 1997 International IRCOBI Conference on the Biomechanics of Impacts, Sept 24-26, 1997, Hannover, Germany, pp 239-250.
10. Eichberger A, Geigl BC, Fachbach B, Steffan H, Hell W, Langwieder K: "Comparison of Different Car Seats Regarding Head-Neck Kinematics of Volunteers During Rear End Impact", Proc. 1996 International IRCOBI Conference on the Biomechanics of Impacts, Sept 11-13, 1996, Dublin, Ireland, pp 153-164.
11. Farmer CM, Wells JK, Werner JV: "Relationship of Head Restraint Positioning to Driver Neck Injury in Rear-End Crashes", Compendium of the Whiplash Associated Disorders World Congress (Traffic Safety and Auto Engineering Session), February 1999, Vancouver, BC, pp 69-89.
12. Foret-Bruno JY, Dauvilliers F, Tarriere C, Mack P, "Influence of the Seat and Head Rest Stiffness on the Risk of Cervical Injuries", Proc. 13th International Technical Conference on Experimental Safety Vehicles, Nov 4-7, 1991, Paris, France, pp 968-974.
13. Gane J, Pedder J: "Head Restraint Measuring Device", Proc. 15th International Technical Conference on Enhanced Safety of Vehicles, May 13-16, 1996, Melbourne, Australia, pp 1788-1790.
14. Gane J: "Head Restraint Measuring Device", Compendium of the Whiplash Associated Disorders World Congress (Traffic Safety and Auto Engineering Session), February 1999, Vancouver, BC, pp 425-436.
15. Gane J: "Measurement of Vehicle Head Restraint Geometry", Society of Automotive Engineers, No.1999-01-0639, in Occupant Protection (SP-1432), pp 45-50, 1999.
16. Geigl BC, Leinzinger P, Roll, Muhlbauer M, Bauer G: "The Movement of the Head and Cervical Spine During Rear-end Impact", Proc. 1994 International IRCOBI Conference on the Biomechanics of Impacts, Sept 21-23, 1994, Lyon, France, pp 127-137.

17. Gupta V, Menon R, Gupta S, Mani A, Shanmugavelu I, Kossar J: "Improved Occupant Protection through Advanced Seat Design", Proc. 15th International Technical Conference on Enhanced Safety of Vehicles, May 13-16, 1996, Melbourne, Australia, pp 181-191.
18. Haland Y, Lindh F, Fredriksson R, Svensson M: "The Influence of the Car Body and the Seat on the loading of the Front Seat Occupant's Neck in Low Speed Rear Impacts:, Proceedings of the 29th ISATA Conference, June, 1996, Italy, pp 21-30.
19. Hell W, Langwieder K: "Reported Soft-Tissue Neck Injuries After Rear-End Car Collisions" Proc. 1998 International IRCOBI Conference on the Biomechanics of Impacts, Sept 16-18, 1998, Goteborg, Sweden, pp 261-274.
20. Holm L: "Whiplash associated disorders (WAD): work related consequences due to permanent impairment". International Symposium, Whiplash '96, Current Concepts in the Prevention, Diagnosis, and Treatment of the Cervical Whiplash Syndrome, November 16-16, Brussels, Belgium, 1996, p56-57.
21. Insurance Institute for Highway Safety: "A Procedure for Evaluating Motor Vehicle Head Restraints", Status Report, Issue 2, 2001.
22. Insurance Research Council: "Injuries in Auto Accidents: An Analysis of Auto Insurance Claims", Oak Brooks, IL, 1999.
23. Ishikawa T, Okano N, Ishikura K, Ono K: "An Evaluation of Prototype Seats using BioRID-P3 and Hybrid III with TRID Neck", Proc. 2000 International IRCOBI Conference on the Biomechanics of Impacts, September, 2000, Montpellier, France.
24. Jakobsson L, Norin H: "Suggestions for Evaluation Criteria of Neck Injury Protection in Rear End Car Impacts", Proc. 1999 International IRCOBI Conference on the Biomechanics of Impacts, September, 1999, Spain, pp 271-284.
25. Jakobsson L, Norin H, Jernstrom C, Svensson SE, Isaksson-Hellman I, Svensson MY: "Analysis of Different Head and Neck Responses in Rear-End Car Collisions Using a New Humanllike Mathematical Model", Proc. 1993 International IRCOBI Conference on the Biomechanics of Impacts, Sept 8-10, 1993, Eindhoven, The Netherlands, pp 109-125.
26. Kahane CJ: "An Evaluation of Head Restraints – FMVSS 202", US Department of Transportation, (DOT HS-806 108), NHTSA, 1982.
27. Kihlberg JK: "Flexion-Torsion Neck Injury in Rear Impacts", Proc. 13th Conference of the American Association for Automotive Medicine, 1969, pp 1-16.
28. Kim A, Anderson KF, Berliner J, Bryzik C, Hassan J, Jensen J, Kendall M, Mertz HJ, Morrow T, Rao A, Wozniak JA: "A Comparison of the Hybrid III and BioRID II Dummies in Low-Severity, Rear-Impact Sled Tests", No. 2001-22012, in Proc. 45th Stapp Car Crash Conference, November 2001, pp 257-284.
29. Kleinberger M, Sun E, Saunders J, Zhou Z: "Effects of Head Restraint Position on Neck Injury in Rear Impact", Compendium of the Whiplash Associated Disorders World Congress (Traffic Safety and Auto Engineering Session), February 1999, Vancouver, BC, pp 361-390.
30. Langweider K, Schick S, Hell W: "Rear-End Characteristics Leading to a Dynamic Seat Test Standard Proposal", Frontiers in Whiplash Trauma, pp 467-476, IOS Press, 2000.
31. Langweider K, Hell W, Schick S, Walz F, Muser M, Zellmer H: "Evolution of a Dynamic Seat Test Standard Proposal for a Better Protection after Rear-End Impact", Proc. 2000 International IRCOBI Conference on the Biomechanics of Impacts, September, 2000, Montpelier, France, pp 393-409.
32. Lundell B, Jakobsson L, Alfredsson B, Jernstrom C, Isaakson-Hellman I: "Guidelines for and the Design of a Car Seat Concept for Improved Protection Against Neck Injuries in Rear End Car Impacts", Society of Automotive Engineers, No. 980301, pp 1-12, 1998.
33. Mertz HJ, Patrick LM: "Strength and Response of the Human Neck", Proc. 15th Stapp Car Crash Conference, No. 710855, 1971, pp 207-255.
34. Minton R, Murray P, Pitcher M, Galasko CSB: "Causative Factors in Whiplash Injury: Implications for Current Seat and Head Restraint Design", Proc. 1997 International IRCOBI Conference on the Biomechanics of Impacts, Sept 24-26, 1997, Hannover, Germany, pp 207-222.
35. Molino LN: "Preliminary Assessment of NASS CDS Related to Rearward Seat Collapse and Occupant Injury", NHTSA Technical Report, DOT Docket Management System NHTSA-1998-4064-25, 1997.

36. Morris F, "Do Head Restraints Protect the Neck from Whiplash Injuries", Archives of Emergency Medicine, 6:17-21, 1989.
37. Muser MH, Walz FH, Zellmer H: "Biomechanical Significance of the Rebound Phase in Low Speed Rear End Impacts", Proc. 2000 International IRCOBI Conference on the Biomechanics of Impacts, Sept 20-22, 2000, Montpellier, France, pp 411-424.
38. Nygren A, Gustafsson H, Tingvall: "Effects of Different Types of Headrests in Rear-End Collisions", 10th International Technical Conference on Experimental Safety Vehicles, July 1-4,1985, pp 85-90.
39. O'Neill B, Haddon W, Kelley AB, Sorenson WW: "Automobile Head Restraints - Frequency of Neck Injury Claims in Relation to the Presence of Head Restraints", American Journal of Public Health, March:399-406, 1972.
40. O'Neill B: "Head Restraints: The Neglected Countermeasure", Compendium of the Whiplash Associated Disorders World Congress (Traffic Safety and Auto Engineering Session), February 1999, Vancouver, BC, pp 1-15.
41. Ono K, Kaneoka K, Inami S: "Influence of Seat Properties on Human Cervical Vertebral Motion and Head/Neck/Torso Kinematics During Rear-end Impacts", Proc. 1998 International IRCOBI Conference on the Biomechanics of Impacts, Sept 16-18, 1998, Goteborg, Sweden, pp 303-318.
42. Ono K, Kaneoka K, Wittek A, Kajzer: "Cervical Injury Mechanism Based on the Analysis of Human Cervical Vertebral Motion and Head-Neck-Torso Kinematics During Low Speed Rear Impacts", No. 973340, in Proc. 41st Stapp Car Crash Conference (P-315), Nov 13-14, 1997, Lake Buena Vista, FL, pp 339-356.
43. Ono K, Kanno M: "Influences of the Physical Parameters on the Risk to Neck Injuries in Low Impact Speed Rear-end Collisions", 1993 International IRCOBI Conference on the Biomechanics of Impacts, pp 201-212, 1993.
44. Severy DM, Brink HM, Baird JD: "Backrest and Head Restraint Design for Rear-End Collision Protection", Society of Automotive Engineers, No. 680079, 1968.
45. Siegmund GP, Heinrichs BE, Wheeler JB: "The Influence of Head Restraint and Occupant Factors on Peak Head/Neck Kinematics in Low Speed Rear-End Collisions", Accident Analysis and Prevention, 31(4): 393-407.
46. Song D, Uriot J, Trosseille P, Mack C, Tarriere C, Got C, Domont A: "Modelling and Analysis of Interactions between Occupant, Seatback and Headrest in Rear Impact", Proc. 1996 International IRCOBI Conference on the Biomechanics of Impacts, Sept 11-13, 1996, Dublin, Ireland, pp 165-185.
47. Svensson MY, Lovsund P, Haland Y, Larsson S: "The Influence of Seat-Back and Head-Restraint Properties on the Head-Neck Motion During Rear-Impact", Proc. 1993 International IRCOBI Conference on the Biomechanics of Impacts, Sept 8-10, 1993, Einhoven, The Netherlands, pp 395-406.
48. Szabo TJ, Welcher JB, "Human Subject Kinematics and Electromyographic Activity During Low Speed Rear Impacts", No. 962432 in Proc. 40th Stapp Car Crash Conference (P-305), Nov 4-6, 1996, Albuquerque, NM, pp 295-316.
49. Szabo TJ: "Influence of Seat Properties on Occupant Kinematics and Injury Potential in Low-Speed Rear Impacts", in Frontiers in Whiplash Trauma, pp 348-371, IOS Press, 2000.
50. Temming J: "Human Factors Data in Relation to Whiplash Injuries in Rear End Collisions of Passenger Cars", Society of Automotive Engineers, (SAE No. 981191), pp 1-9, 1998.
51. v Koch M, Kullgren A, Lie A, Nygren A, Tingvall C: "Soft Tissue Injury of the Cervical Spine in Rear-End and Frontal Car Collisions", Proc. 1995 International IRCOBI Conference on the Biomechanics of Impacts, Sept 13-15, 1995, Brunnen, Switzerland, pp 273-283.
52. Watanabe Y, Ichikawa H, Kayama O, Ono K, Kaneoka K, Inami S: "Relationship between Occupant Motion and Seat Characteristics in Low-Speed Rear Impacts", Society of Automotive Engineers, No. 1999-01-0635, in Occupant Protection (SP-1432), pp 13-22, 1999.
53. Welcher JB, Szabo TJ: "The Relationship Between Seat Properties and Human Subject Kinematics in Rear Impact Tests", Compendium of the Whiplash Associated Disorders World Congress (Traffic Safety and Auto Engineering Session), February 1999, Vancouver, BC, pp 243-274.