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STATISTICAL ANALYSIS OF THE JAMA SIDE IMPACT TEST DATA

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16. Abstract

This report presents the results of an analysis of 16 full-scale side impact crash tests that were conducted by the Japanese Automobile Manufacturers Association. The objective is to examine the influence of the major factors distinguishing the proposed U.S. and European passenger car side impact test procedures on the resulting injury measures. The factors addressed are the dummy, the moving deformable barrier, and the impact angle of the barrier.

Each of the factors examined had substantial effects on the injury measures. For the front seat position, the design of the EEVC barrier face and the EUROSID rib structure combined to produce a Thoracic Trauma Index 80 percent higher than in the U.S. test. Conversely, the EEVC barrier face produced a resultant peak pelvic acceleration 131 g's (74 percent) lower than the U.S. test.

When the results from the Japanese tests were compared with similar tests conducted by the U.S. manufacturers the differences were inconsistent. Some combinations of dummy and test procedure indicated that the injury measures were much higher in the Japanese compact car as compared to the full size U.S. car, while other combinations of dummy and test procedure showed similar injury numbers for the two cars. These results underscore the importance of the differences in the proposed U.S. and European side impact tests and the obstacles to international harmonization.

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1 INTRODUCTION

The United States automobile manufacturers, through the Motor Vehicle Manufacturers Association (MVMA), have conducted a series of 40 full-scale side impact crash tests of passenger cars to evaluate the National Highway Traffic Safety Administration (NHTSA) and European Experimental Vehicle Committee (EEVC) proposed side impact test procedures. The initial series of 16 tests[1] addressed the ability of the proposed NHTSA test to detect the effects of interior door padding, changes in the side structure, and the proximity of the dummy to the interior door surface. A later series of 24 tests[2,3] were conducted with the EUROSID dummy. Test configurations included the NHTSA and the EEVC procedures plus one combination of the two proposed procedures employing the crabbed barrier with the EEVC face.

During 1987 and 1988, the Japanese Automobile Manufacturers Association (JAMA) also conducted a series of side impact crash tests.[4] While not identical to the MVMA series, these tests provide additional insight into the differences between the EEVC and NHTSA testing procedures. The factors in the JAMA experiment included the dummy type, type of moving deformable barrier, and the crab angle of the barrier. Unlike the MVMA series, JAMA tested all combinations of the EEVC and NHTSA specifications

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1. *Results of the MVMA Sixteen Full Vehicle Side Impact Tests using the Proposed NHTSA Test Procedure.* C.A. Preuss and R.J. Wasko. Warrendale Pennsylvania: Society of Automotive Engineers, Inc., Paper No. 871115, May 1987.

2. "MVMA Full Vehicle Side Impact Harmonization Test Program". S.E. Hensen, R.J. Wasko, K.L. Campbell and E.J. Smith. *IRCOBI/EEVC Workshop on the Evaluation of Side Impact Dummies [Proceedings].* Bron (France): IRCOBI. September 1988, Bergisch-Gladlach (F.R.G.).

3. *Statistical Analysis of the MVMA Side Impact Test Data.* K.L. Campbell and E.J. Smith. Ann Arbor Michigan: The University of Michigan Transportation Research Institute, Report No. UMTRI-88-44, October 1988.

4. *Analysis of the Influence of Various Side Impact Test Procedures.* H. Ohmae, M. Sakurai, T. Harigae, K. Watanabe, and Y. Nakamura. Warrendale Pennsylvania: Society of Automotive Engineers, Inc., Paper No. 890378, February 1989.

for the three factors, making eight different test configurations. Instrumented dummies were placed in the front and rear seat positions on the struck side. Each combination tested was replicated for a total of 16 full-scale crash tests.

This report presents an analysis of the JAMA side impact crash test data. The objective of the analysis is to determine the relationship of the major factors distinguishing the U.S. and European proposed side impact tests to the resulting injury measures. The influence of these factors is pertinent to international harmonization of passenger car safety standards. These results may also assist those in government and industry seeking to improve the efficacy of side impact crash tests.

2 EXPERIMENTAL DESIGN

A Japanese compact car (four door sedan, Japanese market specifications, 1800cc engine displacement) with the roof, windshield, and side glass removed was used in each of the tests. The first eight tests were conducted in 1987. Each dummy was tested using both the NHTSA and EEVC test procedures as proposed. The remaining tests using the EEVC barrier crabbed and the NHTSA barrier uncrabbed were performed in 1988. The order in which the tests were performed within their respective years is not known.

The test matrix may be described as a 2^3 (8 run) factorial design. The 8 runs correspond to the 8 possible combinations of two dummies, two barriers, and two striking angles as shown below. Replication of each of these runs provides an independent estimate of the variance of each dependent variable. Only four of the possible combinations were included in the MVMA test series. These are indicated with an asterisk.

JAMA TEST SERIES

DUMMY/ANGLE/FACE	REPLICATIONS
1. SID/27°/NHTSA*	2
2. EUROSID/27°/NHTSA*	2
3. SID/0°/EEVC	2
4. EUROSID/0°/EEVC*	2
5. SID/27°/EEVC	2
6. EUROSID/27°/EEVC*	2
7. SID/0°/NHTSA	2
8. EUROSID/0°/NHTSA	2
TOTAL	16

*Combinations also in the MVMA test series.

Two dummies of each type were used. It appears that one dummy of each type was always used in the front seat and the other in the rear seat, rather than randomly assigning the dummies. In tests using the NHTSA barrier face, the front seat was placed in the middle position and neither of the dummies were restrained. In the tests involving the EEVC barrier face, the front seat was placed in the rearmost position and the dummy was restrained with a three point belt while the rear dummy was restrained with a two point belt. The dummies were placed according to NHTSA or EEVC proposed procedures, depending on the type of barrier face employed. The EUROSIDs were positioned with the upper arms set vertical (0° degrees) along the chest with the hands placed on the knees.

The barrier faces used were either the standard NHTSA type, which uses aluminum honeycomb elements in its construction and is carried by a cart with a mass of 1360 kg, or the EEVC type, which uses two stiff elements in the center section of the barrier and four softer ones for the outer sections. It is carried by a cart with a mass of 950 kg.

A major difference in the proposed NHTSA and EEVC procedures is the velocity of the barrier relative to the struck vehicle. In the EEVC test, the velocity vector of the barrier is perpendicular to the side of the struck vehicle. This simulates a collision in which the struck vehicle has no forward motion at the time of the impact and the striking vehicle is traveling at 50 km/hr. In the NHTSA test, the barrier is positioned forward of the target vehicle and approaches along a path that is at an angle of 27° degrees to the perpendicular. This is accomplished by mounting all four wheels on the barrier at the 27° "crab" angle so that the barrier face is perpendicular to the struck vehicle at the time of impact and the relative velocity is at the crab angle. The use of the crabbed barrier allows the NHTSA test to simulate a collision in which the striking vehicle is moving at 48.1 km/hr and the struck vehicle is moving at 24.5 km/hr. To characterize this difference, the proposed orientation of the EEVC barrier is described as "uncrabbed" or as angled at 0°.

The coding of the three independent variables—dummy type, barrier face, and crab angle—used for the analysis is shown below. The levels corresponding to the NHTSA test have been coded –1 and the EEVC test as the +1 level.

INDEPENDENT VARIABLES

	LEVELS	
FACTORS	–1 (NHTSA)	+1 (EEVC)
DUMMY	SID	EUROSID
BARRIER ANGLE	27°	0°
BARRIER FACE	NHTSA	EEVC

The data were obtained as a set of scalar values. No further processing of the data was carried out by UMTRI before the analysis. The dependent variables analyzed were the following:

- Peak Resultant Head Acceleration (g)
- Thoracic Trauma Index
- Peak Upper Rib Lateral Acceleration (g)
- Peak Lower Rib Lateral Acceleration (g)
- Peak Upper Spine Lateral Acceleration (g)
- Peak Lower Spine Lateral Acceleration (g)
- Peak Resultant Pelvic Acceleration (g)

Figures A.1 through A.7 in Appendix A are bar charts of the seven injury measures listed above. Each figure shows the average of the two replicated runs at each of the eight test conditions. The bars are grouped into pairs with the first bar corresponding to the SID and the second the EUROSID. Four pairs are shown corresponding to the combinations of barrier type and angle in the following order: NHTSA crabbed (27°), NHTSA uncrabbed (0°), EEVC crabbed (27°), and EEVC uncrabbed (0°). The first eight bars (four pairs) are the responses for the front seat position, and the last four pairs are for the rear seat position.

The actual data are contained in Appendix D. The columns show the different injury measures, while the grouped rows correspond to the different test conditions. All of the front seat data are presented first, followed by the rear seat data. For each test condition and injury measure, the two replicate runs are shown as the "minimum" and "maximum." The average and standard deviation of the two runs are also shown in Appendix D.

3 ANALYSIS METHOD

A linear least squares regression model was used to quantify the relationship of the three independent variables to the injury measures. The factorial design in two levels is very efficient. Factorial designs are balanced in that all combinations of the two levels of each independent variable are run. Independent estimates are produced for the main effects of each variable as well as all interactions of the variables. The basic model employed for each injury measure is the following:

$$
\begin{aligned}
\text{I.M.} = \ & C + b_1\text{*DUMMY} + b_2\text{*CRBANGLE} + b_3\text{*MDBFACE} \\
& + b_{12}\text{*DUMMY*CRBANGLE} + b_{13}\text{*DUMMY*MDBFACE} \\
& + b_{23}\text{*CRBANGLE*MDBFACE} \\
& + b_{123}\text{*DUMMY*CRBANGLE*MDBFACE} \qquad (1)
\end{aligned}
$$

Where:

I.M.	=	the injury measure
C	=	constant, or average value
DUMMY	=	dummy type (SID vs EUROSID)
CRBANGLE	=	barrier (crab) angle
MDBFACE	=	deformable barrier face
b_1	=	main effect of dummy type
b_2	=	main effect of crab angle
b_3	=	main effect of deformable barrier face
b_{12}	=	interaction of dummy type and crab angle
b_{13}	=	interaction of dummy type and barrier face
b_{23}	=	interaction of crab angle and barrier face
b_{123}	=	interaction of all three factors

The model shown in equation (1) is saturated. That is, there are as many coefficients (eight, the constant plus 7 "b" coefficients) as there are unique test conditions. Thus, the model will always reproduce the average value at each test condition *exactly*, for any set of observations, and the error sum of squares is only the variation of the replicate observations. An important advantage of the factorial design is that the estimates of the eight coefficients are independent of one another. This means that the estimated coefficients in a model with less than eight terms (no longer a saturated model) will be exactly the same as the corresponding terms in the saturated model. Consequently, models with fewer terms can be obtained by simply omitting the unwanted terms from the saturated model. (Of course, the error sum of squares will increase.)

Tables 1 and 2 in Appendix B summarize the results from the saturated model. Table 1 presents the effects for the front seat position, and Table 2 for the rear seat models. The injury measures have been grouped into four categories: head, chest, spine, and pelvis. Generally, the models were more similar within each group. Except for the constant, the effects shown in Tables 1 and 2 illustrate the differences that result when moving from the –1 level (NHTSA) to the +1 level (EEVC). For example, looking at the main effect of "DUMMY" on the upper rib acceleration, the effect shown in Table 1 is 69.6. This means that the main effect on upper rib acceleration of switching from the SID to the EUROSID was an increase of 69.6 g. Since the coding used results in a change of 2 units (from –1 to +1) in going from the low (NHTSA) level to the high (EEVC) level, the effects shown in Tables 1 and 2 are twice the value of the least squares ("b") coefficients shown in equation (1). Complete results for the models are in Appendix C.

At the bottom of these two tables, the multiple correlation coefficient, R^2, and the coefficient of variation, C.V., are shown. The multiple correlation coefficient is a measure of how well the model fits the observations. In this case it is the ratio of the variation explained by the model to the total variation of the observations, relative to the average value. If there were no variation in the replicate runs, R^2 would be 1.0. All of the models were highly significant ($p < .0001$). Individual effects that are not statistically significant at the 10 percent level are indicated in Tables 1 and 2 with an asterisk. The coefficient of variation shown at the bottom of the tables is a measure of the variation in the replicate runs. It is the standard deviation of the observations expressed as a percentage of the average value.

4 FRONT SEAT RESULTS

The effects from the fitted model quantify the relationships of the European and U.S. side impact test procedures on the injury measures. In general, the test procedures affect each injury measure differently. Furthermore, the results for the rear seat position were substantially different from the front seat position. Consequently, the influence of the test procedures is presented separately for each injury measure and seat position. The following material uses the calculated effects from the model to characterize the relationship of the dummy, the angle of impact and the barrier face to each of the injury measures for the front seat position. Results for the rear seat position are described in the next section.

Two observations were obtained at each set of test conditions for each injury measure and an average value was calculated. Figures A.1 though A.7 in Appendix A are bar charts of the average of the two replicate tests for each injury measure analyzed. The front seat results appear in the first eight bars.

HEAD ACCELERATION — As shown in Figure A.1, the highest head acceleration (over 200 g) was obtained with the stiffer (NHTSA) barrier face in the uncrabbed (EEVC) orientation. Three terms in the saturated model quantify this effect: a main effect for crab angle increasing the head acceleration by 60.8 g when the barrier was not crabbed, a main effect for barrier face decreasing head acceleration by 75.6 g with the softer (EEVC) face, and an interaction between barrier angle and face that eliminates the effect of the angle when the more compliant EEVC face was used. Thus, these three terms reproduce the major characteristics of the results shown in Figure A.1. The small decrease in head acceleration for the EUROSID dummy with the EEVC face was not significant.

To illustrate the application of these regression models, the calculated coefficients are shown in the equation (model) below:

Head Acceleration—Front Seat

$$ACC = 104.7 - 6.7*DUMMY + 30.4*CRBANGLE - 37.8*MDBFACE$$
$$- 0.4*DUMMY*CRBANGLE - 5.2*DUMMY*MDBFACE$$
$$- 35.3*CRBANGLE*MDBFACE + 2.3*DUMMY*CRBANGLE*MDBFACE \quad (2)$$

Notice that except for the constant, the coefficients in the model are half the effects shown in Table 1 for the corresponding term. The change in the dependent variable (head acceleration) in going from the low level (-1) of the independent variable associated with any of the terms in the model to the high level (+1) is referred to as the "effect" and is twice the coefficient from the least squares regression.

With seven terms in the model, it is sometimes difficult to relate effects from the model to the bar chart of the average responses at each test condition. This situation can be clarified by separating the model into two equations corresponding to the two levels of one of the independent variables.

The equation above (2) can best be illustrated by calculating the terms of separate models for each barrier face since this factor has both a large main effect and an interaction. This calculation is simple for the factorial design because each of the terms is independent of the rest. Consequently, the separate models can be obtained by substituting the code value for each barrier into the saturated model. Replacing the MDBFACE variable by −1 in equation (2) and combining like terms results in equation (3) below. Substituting +1 produces equation (4).

Head Acceleration—Front Seat

NHTSA Face (-1)

$$ACC = 142.5 - 1.5*DUMMY + 65.8*CRBANGLE - 2.8*DUMMY*CRBANGLE \quad (3)$$

EEVC Face (+1)

$$ACC = 66.9 - 11.9*DUMMY - 4.9*CRBANGLE + 1.9*DUMMY*CRBANGLE \quad (4)$$

The main effect of the barrier face is now reflected in the difference in the two constant terms, −75.6, as shown in Table 1 (and twice the coefficient of barrier face in equation (2)). Looking at equation (4) that describes the tests that used the EEVC barrier, the terms involving the barrier angle are not significant. The dummy effect is larger than in the combined equation, but not quite statistically significant. The value in looking at the separate equations is that the source of the interaction term between barrier face and angle is now obvious. The main effect of angle arises entirely from the results with the NHTSA barrier as shown by coefficient of CRBANGLE in equation (3) as compared to equation (4). The interaction term arises in the full model, equation (2), because angle has a large effect with the NHTSA barrier and essentially no effect with the EEVC face as illustrated by the comparison of equations (3) and (4). Viewing the separate models sometimes makes it easier to relate the coefficients to plotted data.

THORACIC MEASURES — The resulting models for the rib accelerations and the thoracic trauma index (TTI), which is based on the peak rib acceleration and the lower spine acceleration, were similar. In general, the EUROSID rib accelerations were much more sensitive to the barrier crab angle than the SID. The average response for the two runs at each of the eight test conditions is shown in Figures A.2 through A.4 for the TTI, upper rib acceleration and lower rib acceleration respectively. In general, the EUROSID rib accelerations (and TTI) were higher, particularly when the barrier was not crabbed.

Because there are so many significant terms in each of these models, the full model for TTI has been separated by dummy in order to better illustrate the result. This amounts to subtracting half the value of each effect involving the dummy in Table 1 to obtain the model for the SID, and adding half the value for the EUROSID. (Remembering that the effects shown in Table 1 are twice the coefficients from the regression model.)

Substituting the code values for the two dummy levels reduces the model from eight to four terms, as shown below for the TTI.

Thoracic Trauma Index

SID

$$TTI = 109.6 + 10.6*CRBANGLE + 7.6*MBDFACE + 9.6*CRBANGLE*MBDFACE \quad (5)$$

EUROSID

$$TTI = 137.4 + 37.4*CRBANGLE + 7.6*MBDFACE + 2.6*CRBANGLE*MBDFACE \quad (6)$$

Comparison of these two models highlights the differences in the effect of the test procedures on the SID and EUROSID. As measured by the SID, the TTI was not appreciably affected by either the barrier angle or face. The overall TTI response for the EUROSID was 27.8 g higher than the SID as indicated by the difference in the two constant terms above. The EUROSID TTI was much more sensitive to the barrier angle, increasing by 74.8 g in going from the crabbed barrier (-1 code) to the uncrabbed barrier (+1 code). The barrier face used did not appreciably affect the rib accelerations (or TTI) for either dummy.

Some rather large differences in the EUROSID rib accelerations occurred in the replicate runs of the EUROSID with the EEVC barrier (softer face, not crabbed). For the upper rib acceleration, the replicate runs at this condition produced 143 and 305 g, while the corresponding lower rib accelerations were 172 and 259 g, and the center rib, 350 and 408 g. The fit of the regression model for the upper rib was the poorest with a multiple correlation coefficient (R^2) of only 0.66 as compared to over 0.9 for the other measures (except the lower rib acceleration with $R^2 = 0.88$). The coefficient of variation for the upper rib was 34.1 percent and 23.6 percent for the lower rib as compared to about 10 percent for the rest of the acceleration measures. The upper rib acceleration of 143 g was omitted for calculation of the effects shown in Table 1 because the resulting model was more comparable to the TTI and lower rib acceleration model. Omitting this observation increased the multiple correlation coefficient to 0.94 and reduced the coefficient of variation to 14.3 percent. Omission of either of the observations for the lower rib at the same test conditions did not appreciably alter the model results. These large variations in rib acceleration in replicate runs of the EUROSID may be the consequence of design problems described by Hoefs.[5]

SPINE ACCELERATIONS — Average values for upper and lower spine accelerations in the front seat position are shown in the first four pairs of bars in Figures A.5 and A.6 respectively. Looking at the calculated effects in

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5. "Analysis of the EUROSID in 21 Full Scale Side Impact Tests." R. Hoefs. *IRCOBI/EEVC Workshop on the Evaluation of Side Impact Dummies [Proceedings].* Bron (France): IRCOBI. September 1988, Bergisch-Gladlach (F.R.G.).

Table 1, the lower spine acceleration is characterized by two strong main effects. This measure is decreased 27.8 g (29.3 percent of the average response) for the EUROSID as compared to the SID. The other main effect increases the lower spine acceleration by 25.8 g when the barrier was not crabbed. The final effect for the lower spine acceleration is an interaction with the barrier angle. When the barrier was crabbed, the EEVC face decreases the lower spine acceleration by 23.5 g. This effect was not present when the barrier was not crabbed.

The upper spine acceleration response was more complicated. The upper spine response is similar to the lower spine in that the major effect is due to the barrier angle, increasing the upper spine acceleration by 16.0 g when the barrier was not crabbed. With two significant interaction terms, the rest of the upper spine response is more difficult to interpret. Since both of the interactions involve the barrier angle, calculating separate models of the upper spine acceleration for each level of this factor will facilitate interpretation, as shown below:

Upper Spine Acceleration

<u>Crabbed</u>

UPSPN = 79.1 – 13.6*DUMMY – 12.6*MBDFACE

+ 1.6*DUMMY*MBDFACE (7)

<u>Not Crabbed</u>

UPSPN = 95.1 + 2.6*DUMMY + 11.6*MBDFACE

+ 7.6*DUMMY*MBDFACE (8)

Now it is apparent that the upper spine acceleration response when the barrier was crabbed is similar to the lower spine response. With the crabbed barrier, the upper spine acceleration was 27.2 g lower for the EUROSID, and the EEVC face lowers the response by 25.2 g. However, when the barrier was not crabbed, as described by equation (8) above, the dummy effect was negligible and the EEVC face has the opposite effect, increasing the response by 23.2 g.

PELVIC ACCELERATION — The resultant pelvic acceleration was dominated by the effect of the barrier face, as shown in Figure A.7. The NHTSA face produces resultant pelvic accelerations 130.8 g higher than the EEVC face on the average. The only other significant term is a small increase, by comparison, of 26.0 g associated with the uncrabbed barrier. The resultant pelvic accelerations were essentially the same for the two dummies.

5 REAR SEAT RESULTS

The results for the rear seat position were much different from the front seat position. All of the injury measures from the rear seat, except the head and pelvis acceleration, were less than half the magnitude of the front seat. These results indicate that the rear seat collision environment may not be nearly as severe as the front seat in the proposed side impact tests.

Furthermore, the relationship of the injury measures to the dummy type, barrier face and angle are fundamentally different in the rear seat position as compared to the front, with pelvic acceleration the single exception. Two-thirds of the main effects change sign. For example, the barrier angle was consistently the largest main effect in the front seat, increasing the injury measures substantially when the barrier was not crabbed. In the rear seat, the effect of the barrier angle was also substantial, but of the opposite sign. This result may be related to the rearward velocity component relative to the struck vehicle of the barrier in the crabbed orientation and to the differences in the striking position in relation to the rear seat for the crabbed and uncrabbed barrier. In the front, uncrabbed was more severe; in the rear crabbed was more severe.

Most difficult to understand is the reversing of the comparison between the SID and EUROSID in the rear seat. While the EUROSID generally gave higher injury numbers in the front, they were generally lower in the rear. It is hard to imagine how the seat position could cause this reversal. In describing the tests, the authors[6] state "the same dummies and sitting conditions were used in each test to preclude the influence of dummy differences." If the same dummy of each type was always in the same seat position, any differences in the two dummies of the same type would bias the results, the opposite of the stated intention. If the same pair of dummies (one SID and one EUROSID) were always tested in the front seat and a different pair in the rear, then the difference in the dummy main effect in the front seat versus the rear may be the result of dummy differences. Random assignment of the dummies to the seated positions would be necessary to eliminate bias due to dummy differences.

The average responses for the rear seat position are shown in the last eight bars of Figures A.1 through A.7 at each test condition for the seven injury measures respectively. The effects calculated by the regression model for the rear seat position are summarized in Table 2 in Appendix B.

HEAD ACCELERATION — The EUROSID head acceleration was significantly lower than SID in the rear seat. While the EUROSID head acceleration was also lower in the front, the difference was not significant. Looking at Figure A.1, where the average values of the replicate tests for the rear seat are shown in the last eight bars, one can see that this effect comes almost entirely from the NHTSA test procedure (crabbed barrier and stiff face). Although this was the only configuration to show such a large difference in head accelerations between the two dummies, the result was replicated, 164 and 192 g with the SID, versus 65 and 86 g for the EUROSID.

The greatest effect on the head acceleration was caused by the barrier angle. The main effect of the barrier angle decreased the response by 65.4 units in the uncrabbed orientation, opposite the effect for the front seat dummy. While the head acceleration was high for SID in both the crabbed test configurations, the EUROSID head acceleration was high for only the

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6. *Analysis of the Influence of Various Side Impact Test Procedures.* H. Ohmae, M. Sakurai, T. Harigae, K. Watanabe, and Y. Nakamura. Warrendale Pennsylvania: Society of Automotive Engineers, Inc., Paper No. 890378, p.3, February 1989.

EEVC face in the crabbed orientation. A two-factor interaction term involving barrier angle and face and an unusually large three-factor term were required to reproduce the head acceleration response in the rear seat as a function of the dummy, barrier face and angle.

THORACIC MEASURES — The character of the rib acceleration responses in the rear seat was also essentially different from the front. In the rear seat, barrier face was the major factor. The NHTSA face resulted in TTI values that were 47.9 percent higher overall. This result is evident in Figure A.2. In addition to the main effect, the barrier face interacted with both the dummy and the barrier angle. The barrier face did not play an important role in the TTI for the front seat position. Again, to assist in interpreting this result separate equations are shown, this time for the NHTSA and EEVC barrier faces.

Thoracic Trauma Index

<u>NHTSA Face</u>

$$TTI = 61.9 - 10.9*DUMMY - 21.4*CRBANGLE + 3.4*DUMMY*CRBANGLE \quad (9)$$

<u>EEVC Face</u>

$$TTI = 38.0 + 0.0*DUMMY - 4.3*CRBANGLE + 4.3*DUMMY*CRBANGLE \quad (10)$$

Separating the model in this way shows how the TTI response is related to the barrier face. As before, the main effect of the barrier face is reflected in the difference between the two constant terms in the equations above. For the EEVC face, shown in equation (10), no other term has a significant effect. However, with the NHTSA face, equation (9), both the dummy and the barrier angle have significant effects. The EUROSID TTI was 21.8g lower and the uncrabbed orientation lowers the response another 42.8 g.

All of the main effects for the rib accelerations and TTI are of the opposite sign in the rear seat position as compared to the front seat. These measures were lower with the softer EEVC barrier. When the stiffer NHTSA barrier was used, both the EUROSID and the uncrabbed orientation produced substantially lower rib accelerations and TTI . Both of these results are contrary to the front seat results and intuition. It is difficult to understand how the EUROSID rib accelerations would be higher than the SID in the front seat environment and lower than the SID in the rear.

SPINE ACCELERATIONS — The barrier orientation was the major factor affecting the spine accelerations in the rear seat as in the front seat position. However, the effect was in the opposite direction with the crabbed barrier orientation increasing the upper spine acceleration by 25.7 g overall and the lower spine acceleration by 29.0 g. This result is evident in Figures A.6 and A.7. The influence of the dummy and the barrier face on the spine accelerations was similar in the front and rear seat position. Separate equations are shown below for the crabbed and uncrabbed orientation for both the upper and lower spine accelerations.

Upper Spine Acceleration

Crabbed

$$UPSPN = 57.0 - 10.8*DUMMY - 18.3*MBDFACE + 4.0*DUMMY*MBDFACE \quad (11)$$

Not Crabbed

$$UPSPN = 31.3 - 5.3*DUMMY + 1.5*MBDFACE - 2.5*DUMMY*MBDFACE \quad (12)$$

Lower Spine Acceleration

Crabbed

$$LOSPN = 63.0 - 4.0*DUMMY - 20.8*MBDFACE - 2.3*DUMMY*MBDFACE \quad (13)$$

Not Crabbed

$$LOSPN = 34.0 - 4.0*DUMMY - 9.3*MBDFACE + 1.3*DUMMY*MBDFACE \quad (14)$$

These models are fairly similar to the front seat. For the upper spine with the crabbed barrier, the EUROSID dummy and the EEVC barrier face both reduced the spine acceleration substantially. When the barrier was not crabbed, these factors do not significantly affect the spine acceleration. The response of the lower spine was similar, except that the dummy effect was not significant with either barrier orientation.

PELVIC ACCELERATION — Resultant pelvic acceleration was the only injury measure to show essentially similar results in the front and rear seat positions. As in the front seat, the largest effect resulted from the NHTSA barrier face where the responses were 90.4 g higher than those from the EEVC face. The only other statistically significant effect arose from the dummy type used, unlike the front seat position. The EUROSID resultant pelvic acceleration was 9.6 g higher than the SID. Overall, the pelvic acceleration was 22.5 percent lower in the rear seat position as compared to the front. The similarity of the front and rear seat pelvic acceleration is evident in Figure A.7.

6 COMPARISON WITH THE MVMA TESTS

This section compares the results of the JAMA test series with the previously published MVMA data.[7] The MVMA test series included four of the eight combinations tested by JAMA. These four included the SID with the NHTSA barrier in the crabbed orientation (16 tests), the EUROSID with the NHTSA barrier in the crabbed orientation (8 tests), the EUROSID with the EEVC barrier in the crabbed orientation (8 tests), and the EUROSID with the EEVC barrier uncrabbed (8 tests). No dummies were tested in the rear seat position in the MVMA tests.

Before discussing the comparison, the differences between the MVMA and the JAMA tests are reviewed here. First consider the test vehicle: a full size sedan in the MVMA tests and a Japanese compact four door sedan in the JAMA tests. All of the JAMA tests were conducted with production vehicles. Second, the MVMA tests included other factors. The first MVMA test series included three other factors, proximity of the dummy to the door, interior door padding, and reinforcement of the side structure. Door padding and side structure were included in the tests run with the other three combinations. This is the reason for the greater number of runs in the MVMA tests. For purposes of comparison with the JAMA data, all of the MVMA tests with the same combination of dummy, barrier type and crab angle have been averaged. These averages are presented in Appendix D after the JAMA data.

In order to address these additional factors, the MVMA tests used modified vehicles. The production door interior was replaced with either hardboard or a thick pad. Half of the vehicles had the production side structure, and half had a reinforced side structure. Although the modified side structure did not have a strong effect on the injury numbers, the padding did in many cases. Thus, the differences in the vehicles used in the MVMA and JAMA tests go beyond the production differences between a full size and a compact four door sedan since the full size sedan was also modified.

A direct comparison of the JAMA and MVMA data for the four common tests is presented in Figures A.8 through A.11 in Appendix A. For example, Figure A.8 compares the JAMA injury measures with the MVMA results for the SID in the front seat with the NHTSA barrier in the crabbed orientation. In general, the JAMA tests appear to be more severe in that higher injury numbers result. However, most of the differences shown in Figure A.8 are not statistically significant. The MVMA results have fairly tight confidence intervals because they are based on 16 runs in this case. Thus, the 95 percent confidence interval on TTI is within 3 percent for TTI and within 5 percent for pelvic acceleration. Variance on the head acceleration is appreciably higher so that a 95 percent confidence interval spans plus or minus 22 percent.[8] Confidence intervals on the JAMA injury numbers are generally much larger since they are based on only two replications of the

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7. *Statistical Analysis of the MVMA Side Impact Test Data*. K.L. Campbell and E.J. Smith. Ann Arbor Michigan: The University of Michigan Transportation Research Institute, Report No. UMTRI-88-44, October 1988.

8. Ibib.

test. Despite this, the differences between the TTI and the pelvic acceleration are statistically significant at the 95 percent significance level. Based on this comparison, one would conclude that the compact Japanese vehicle is a more severe environment for the SID in the NHTSA side impact test.

However, when the JAMA and MVMA results are compared for the same test, except that the EUROSID is used, no difference is evident. Only the pelvic acceleration is appreciably higher, and this difference is not statistically significant. This comparison is shown in Figure A.9. The comparison is also mixed with the EUROSID and the EEVC barrier in the crabbed orientation as shown in Figure A.10. The TTI and upper rib are significantly higher, but the pelvic acceleration is significantly lower in the JAMA tests.

The largest differences between the JAMA and the MVMA tests are shown in Figure A.11 for the EUROSID in the European test (EEVC barrier in the uncrabbed orientation). For these test conditions, the JAMA tests produced rib accelerations and TTI values that were more than double the values from the MVMA tests. Both head acceleration and pelvic acceleration are lower, but these differences are not statistically significant.

In summary, there were four combinations of dummy, barrier type, and barrier angle that were tested by both JAMA and MVMA. One might have expected differences in the injury measures due to the differences in the two vehicles used. However, the differences observed were not consistent across the four combinations or across injury measure. The JAMA tests tended to produce higher numbers, indicating that the smaller vehicle is a more severe environment for the dummy. This result was most evident when the SID was used with the NHTSA procedure and when the EUROSID was used with the European procedure. This later comparison highlights the very high rib accelerations produced by the EUROSID in the JAMA tests. The comparable MVMA test with the EUROSID did not produce similar rib acceleration levels. The JAMA and the MVMA data were almost identical when the EUROSID was used with the NHTSA procedure, and the comparison was mixed when the EUROSID was tested with the EEVC barrier in the crabbed orientation.

7 SUMMARY

The results presented do not lend themselves to a simple summarization. In the most general sense, the objective was to determine if the major differences in the proposed U.S. and European side impact test procedures (the dummy, the barrier angle, and the barrier face) significantly affect the resulting injury measures. Certainly these results demonstrate the significance of the effects of these factors. The two proposed side impact test procedures produce very different results. The pervasive influence of their distinguishing features do not readily lend themselves to harmonization.

These results also demonstrate the complexity of the relationships between the injury measures and the dummy, barrier face and angle. Injury measures from the head, chest and pelvis were affected differently by the various test conditions, and these effects were much different in the rear seat as compared to the front. An important advantage of the factorial design is that independent estimates are provided for all of the possible interactions of the independent variables as well as the more common main effects. The need for such a design is confirmed by the fact that almost half of the possible interaction terms were significant. Given that each factor was investigated at only two levels, the saturated linear model employed is completely adequate. Replicate runs demonstrated the repeatability of the observations and the models were all highly significant. Since the saturated model reproduces the average of the pairs of replicated runs at each of the eight test conditions *exactly*, the model provides an accurate description of the relationship of the dependent variables (dummy, barrier angle, and barrier face) to each of the various injury measures. Thus, the complexity indicated by the significant coefficients in the model cannot be attributed to any inability of the model to fit the data, and should be regarded as an accurate representation of the test results.

Having underscored the abundant detail provided by the analysis, this section moves on to restate the more important findings. The Summary is organized topically around the three primary factors of interest, the dummy, the barrier angle and the barrier face. Within each, the various injury measures are characterized for the front and rear seat position.

SID VERSUS EUROSID — While it is clear that the rib acceleration and TTI responses of the two dummies were different as would be expected from their respective designs, it is an apparent weakness of the experimental design that the front and rear seat positions produced conflicting results. In the front seat, the EUROSID produced higher rib accelerations than the SID, particularly when the barrier was not crabbed, while in the rear seat the EUROSID rib accelerations were lower than the SID when the NHTSA barrier face was used. As suggested earlier, this conflicting result may be a consequence of dummy reproducibility that was not eliminated by randomly assigning the dummies of the same type to the specified seat position.

Spine accelerations from the EUROSID were significantly lower when the barrier was crabbed. Head accelerations from the two dummies were not significantly different, except in the rear seat for the NHTSA test (NHTSA face crabbed). In this test, the EUROSID head acceleration was more than 100 g less then the SID. The resultant pelvic acceleration was not significantly different in the two dummies.

BARRIER CRAB ANGLE — The barrier crab angle was the most pervasive factor in the analysis. The main effect was statistically significant for every injury measure except the pelvic acceleration in the rear seat. In the front seat, every injury measure was higher when the barrier was not crabbed, while in the rear seat every measure was lower for this orientation. This result would seem to be consistent with the rearward velocity component of the barrier relative to the struck vehicle and contact point of the crabbed barrier.

The barrier angle had the largest effect on the rib and spine accelerations in both the front and rear seat. In the front seat, the interaction of the NHTSA face in the uncrabbed orientation produced the highest head acceleration, while in the rear the barrier crab angle had the largest effect on head acceleration. Only the pelvic acceleration was relatively unaffected by the barrier crab angle.

BARRIER FACE — The most striking effect of the deformable barrier face was on the resultant pelvic acceleration. The EEVC face lowered the resultant pelvic acceleration from 176.2 g with the NHTSA face to 45.4 g in the front seat position, and from 131.1 to 40.7 g in the rear seat. No other factor appreciably influenced the pelvic acceleration.

The EEVC face generally lowered other injury measures also in both the front and rear. The most notable exception to this occurred with the upper rib acceleration and TTI. While the barrier face was not the major factor for the ribs in the front seat, the main effect was statistically significant. Of particular interest is the direction of the effect, with the EEVC face producing higher values for the TTI and upper rib acceleration. In the rear seat, the EEVC face was the dominant effect reducing rib accelerations and the TTI. The difference in the effect of the EEVC face in the front and rear may be related to varying stiffness across the face of the EEVC barrier, stiffer in the center and softer on the sides. The barrier face was not a major factor in spine accelerations. An interaction with the barrier angle lowered the spine acceleration when the barrier was crabbed in both the front and rear.

The authors believe that the lack of consistency in the comparison between the JAMA and the MVMA data is cause for concern. A difference was expected based on the differences in the vehicles used, but it was also expected that the difference would be more consistent across the various combinations of dummy, barrier type, and barrier orientation. This lack of consistency underscores the conclusion already stated: the dummy type, barrier type, and barrier orientation all have significant effects on the resulting injury numbers. Hence, the resolution of these side impact test issues is essential to international harmonization.

Appendix A

Mean Value Plots

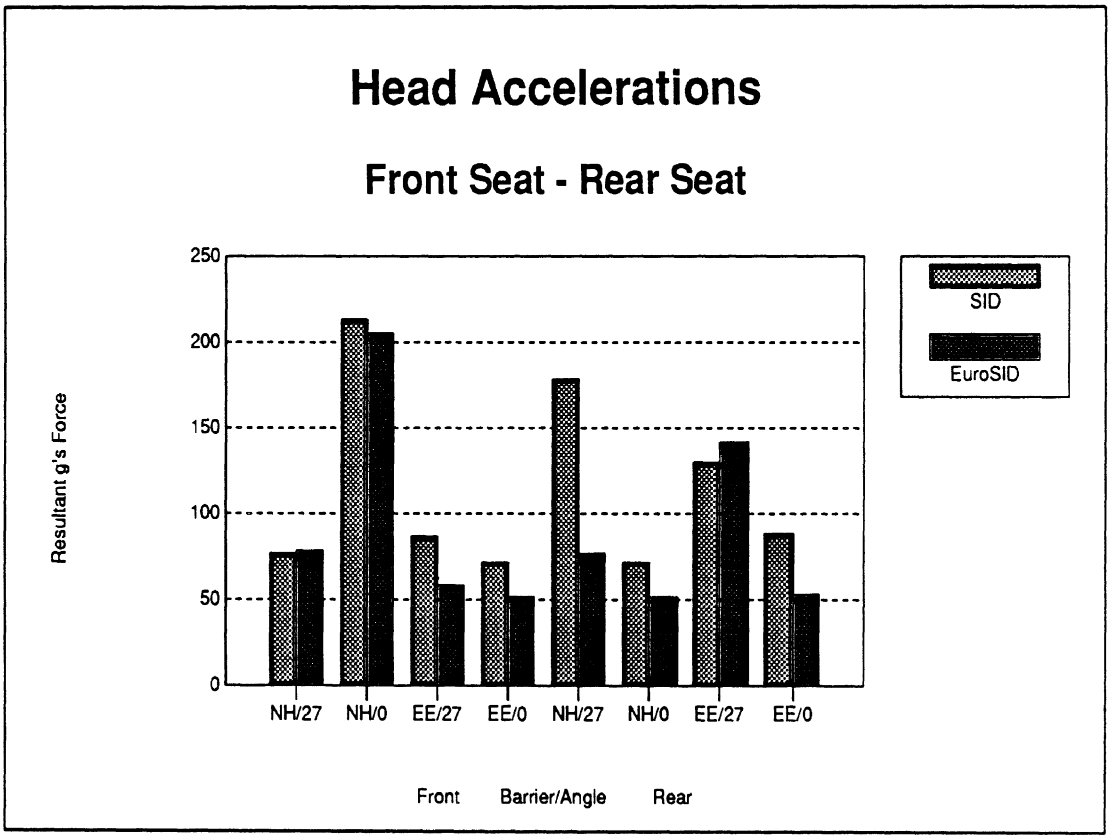

Figure A.1: Head Accelerations

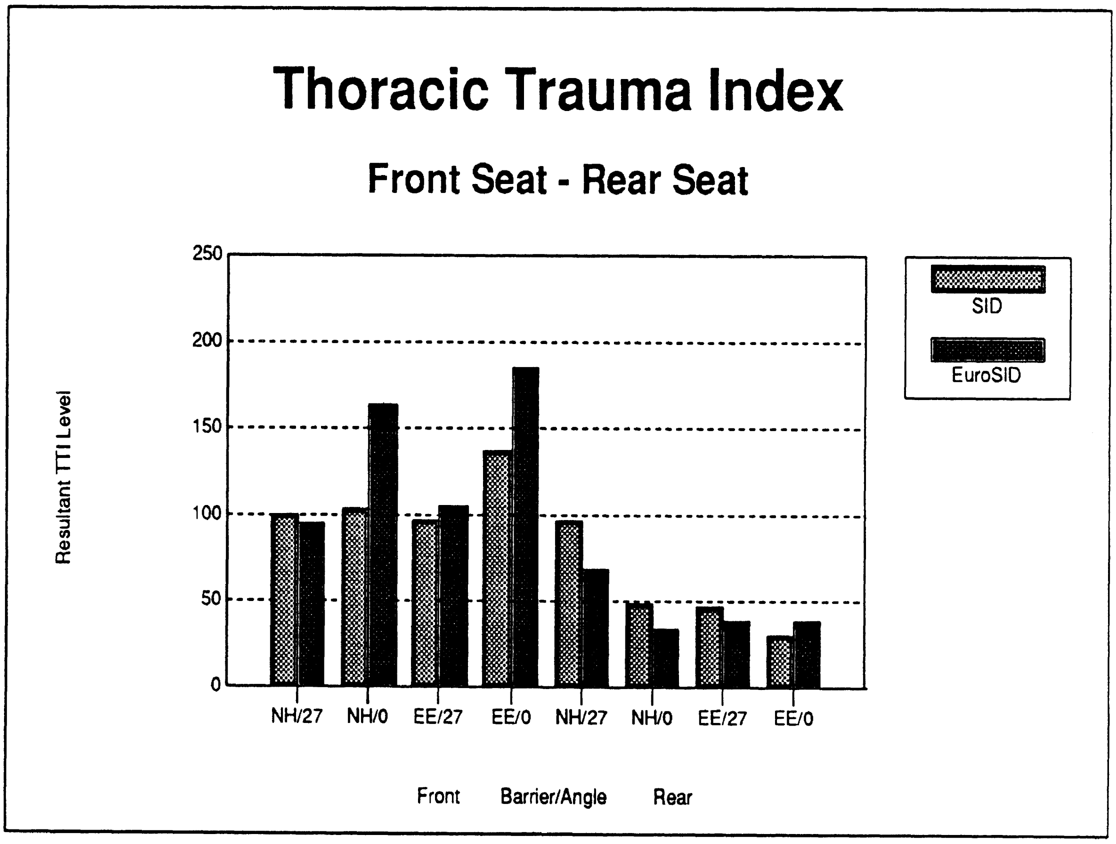

Figure A.2: Thoracic Trauma Index

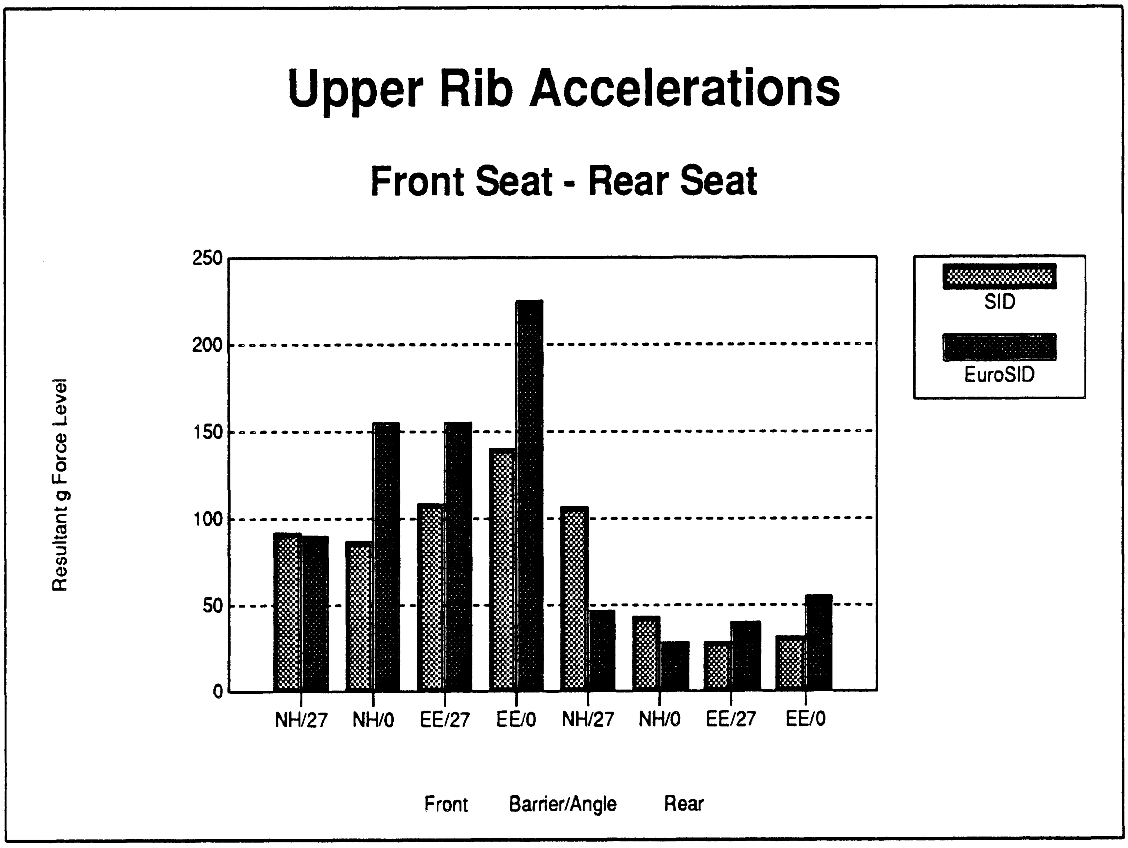

Figure A.3: Upper Rib Acccelerations

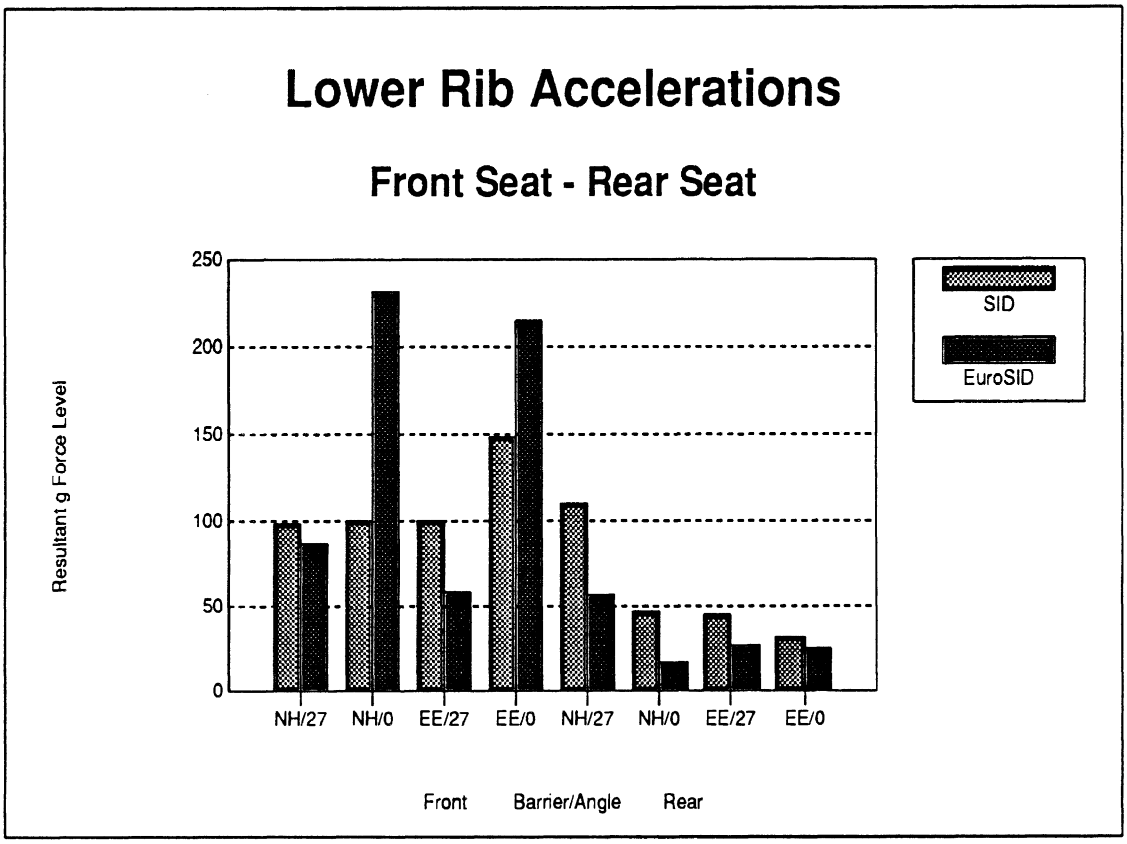

Figure A.4: Lower Rib Accelerations

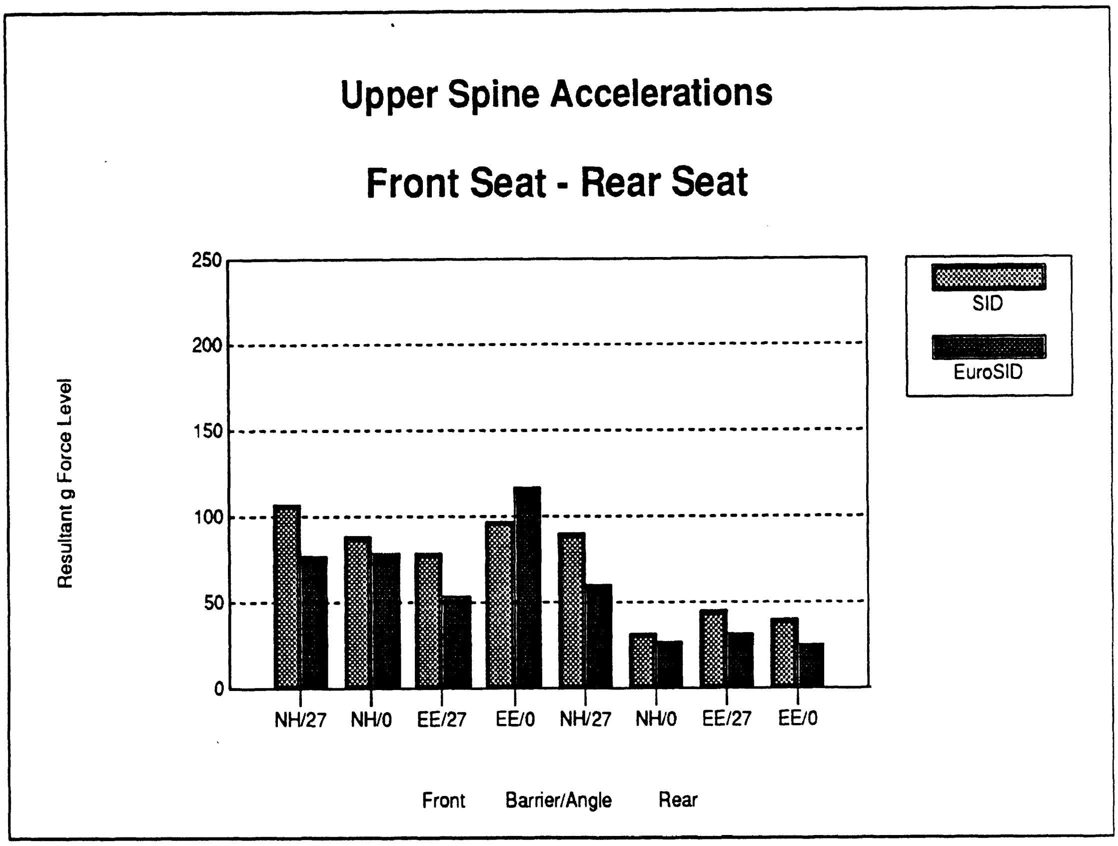

Figure A.5: Upper Spine Accelerations

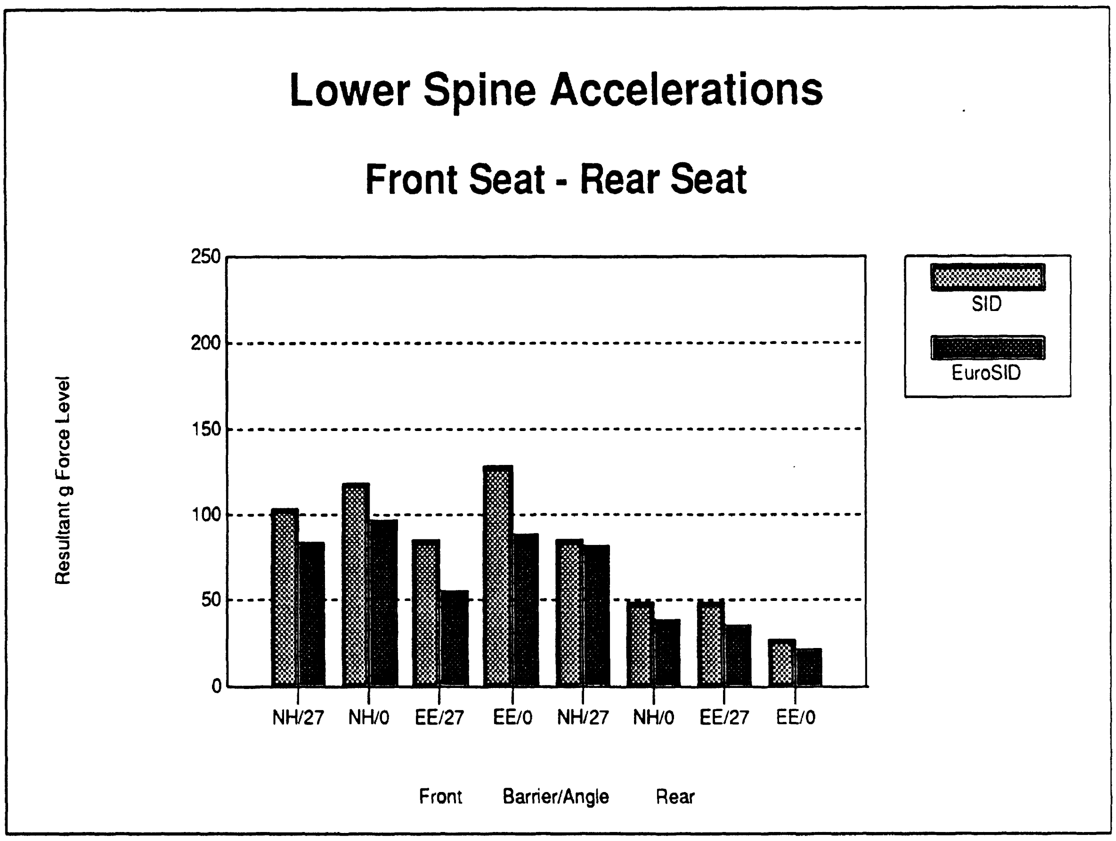

Figure A.6: Lower Spine Accelerations

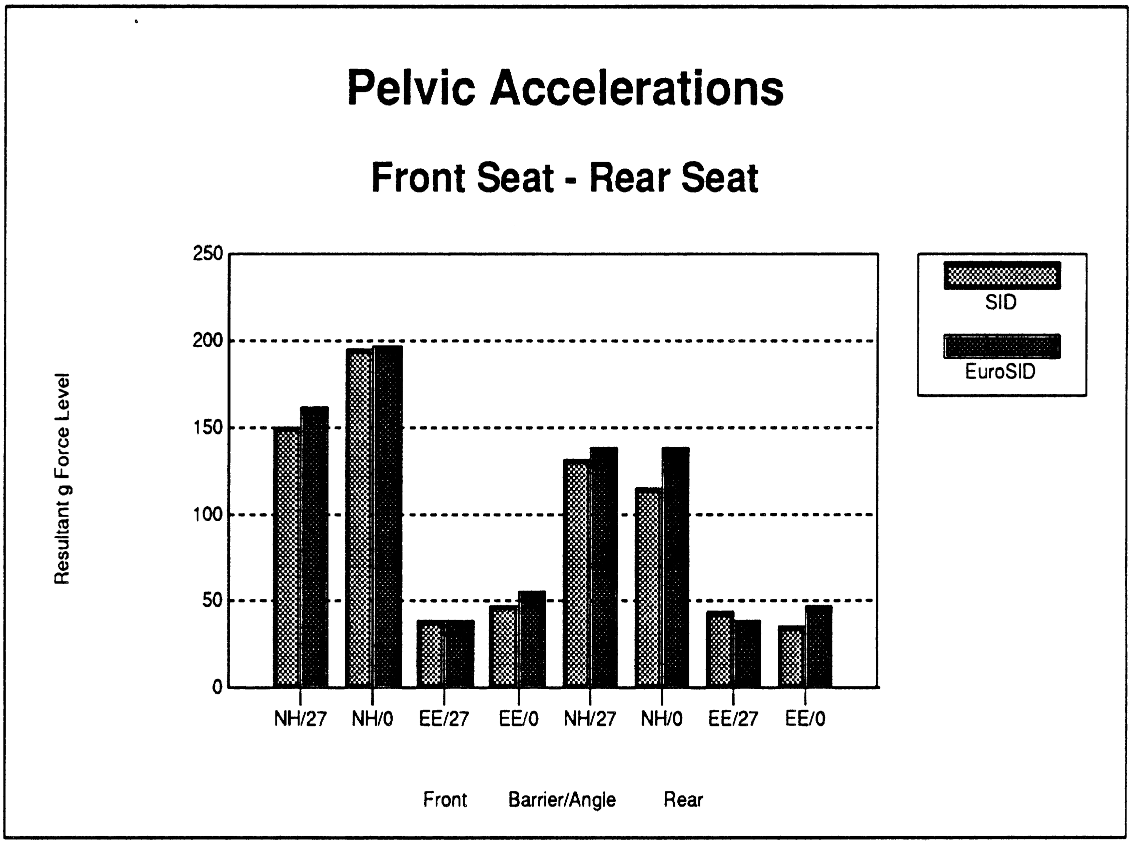

Figure A.7: Pelvic Accelerations

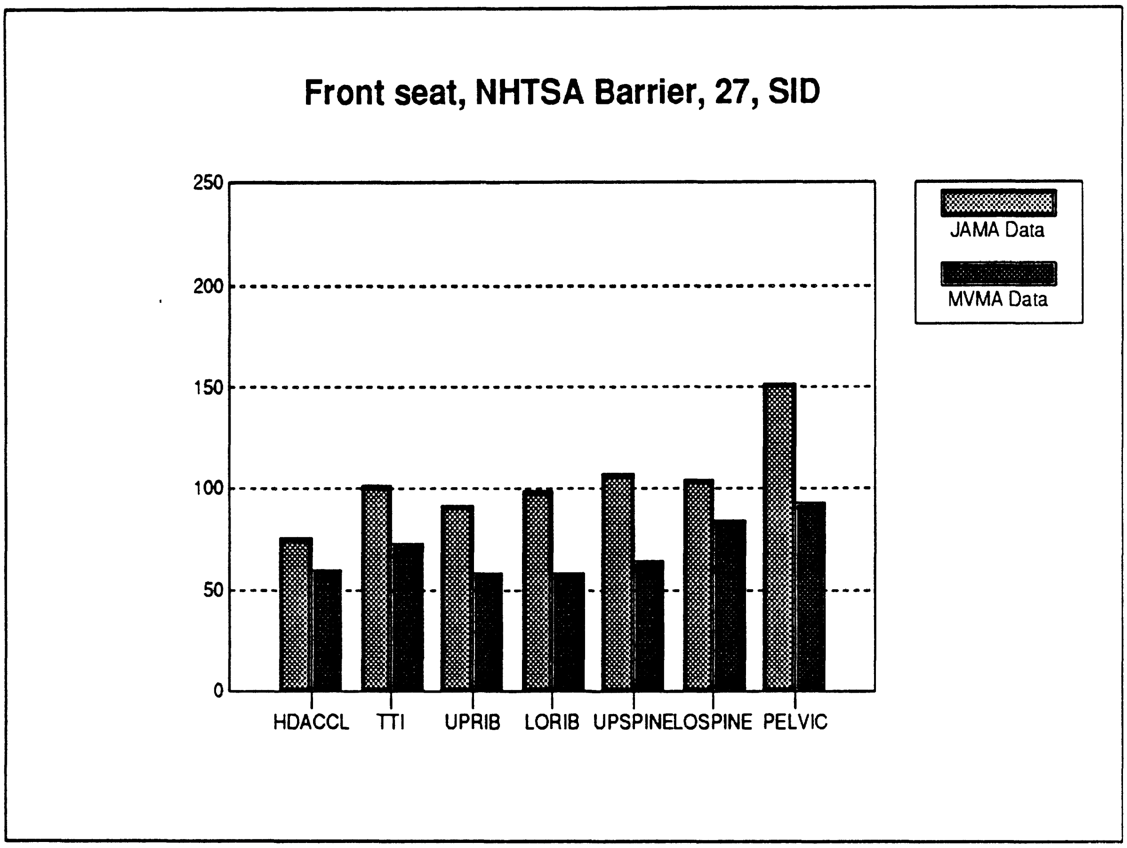

Figure A.8: Comparing JAMA and MVMA Tests: SID, NHTSA Face, Crabbed

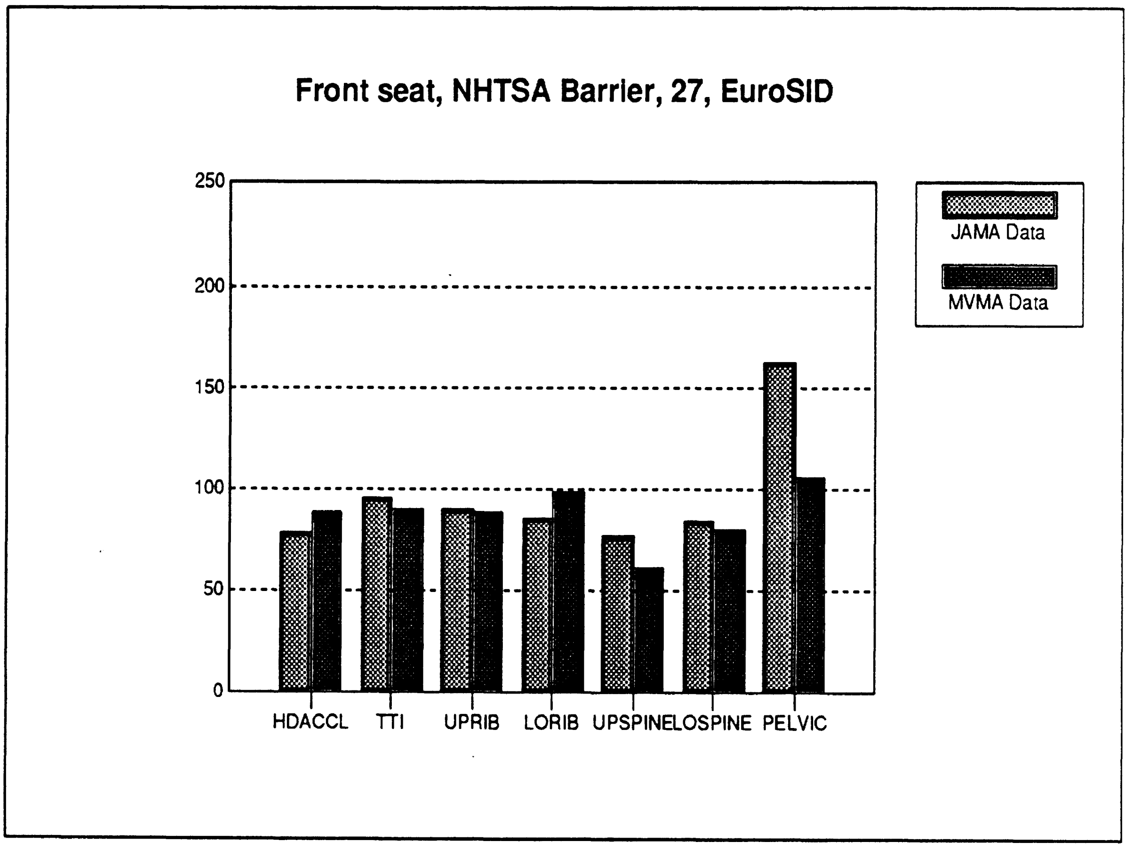

Figure A.9: Comparing JAMA and MVMA Tests: EuroSID, NHTSA Face, Crabbed

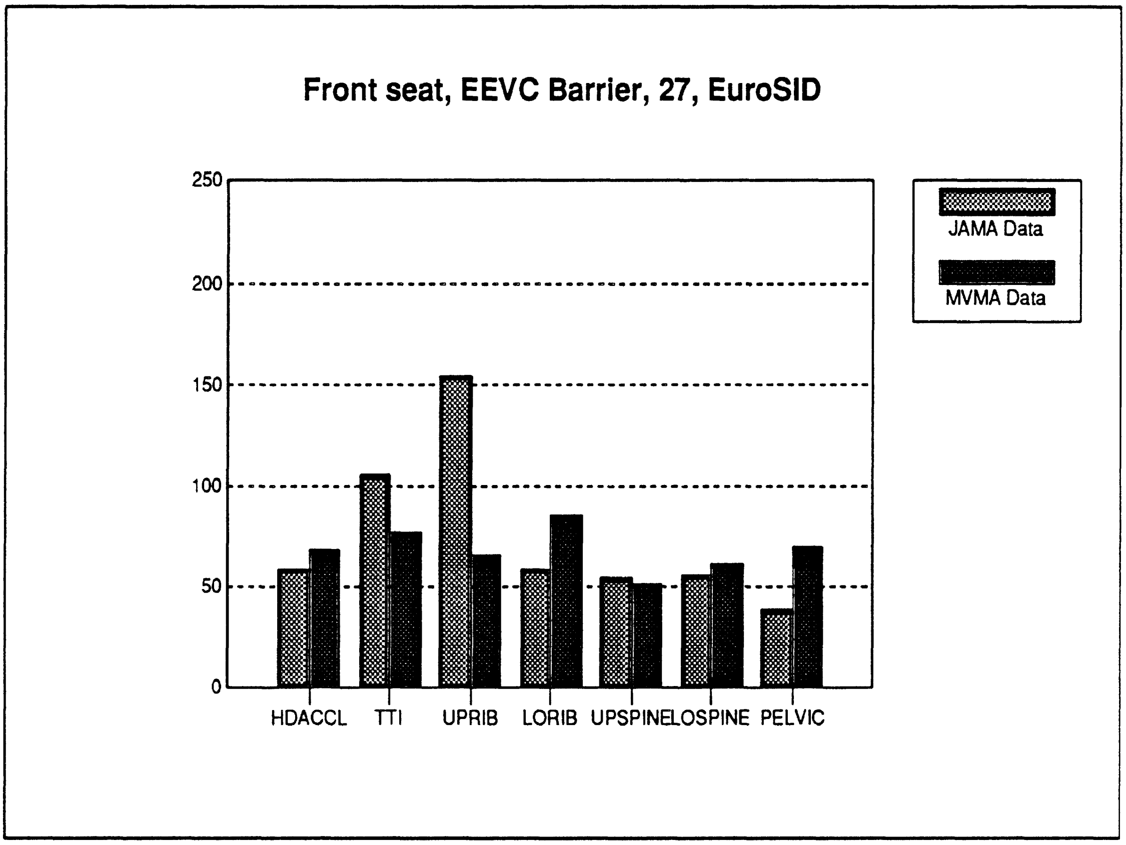

Figure A.10: Comparing JAMA and MVMA Tests: EuroSID, EEVC Face, Crabbed

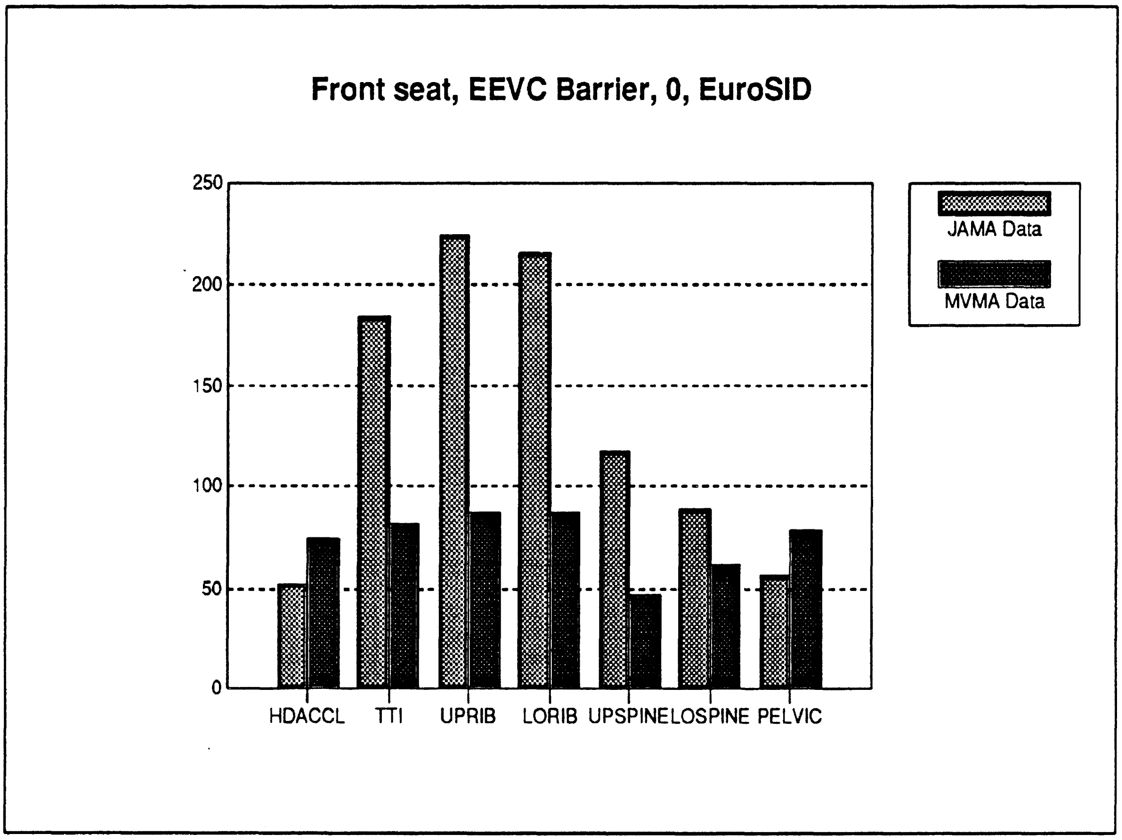

Figure A.11: Comparing JAMA and MVMA Tests: EuroSID, EEVC Face, Uncrabbed

Appendix B

Tables

TABLE 1

Front Seat Position
Calculated Effects from the Saturated Model

EFFECT	HEAD	CHEST			SPINE		PELVIC
		TTI	UPRIB	LORIB	UPPER	LOWER	
CONSTANT	104.7	123.5	141.2	129.6	87.1	94.9	110.8
DUMMY	-13.4*	27.8	69.6	36.5	-11.0	-27.8	5.5*
BARRIER ANGLE	60.8	48.0	60.4	87.8	16.0	25.8	26.0
BARRIER FACE	-75.6	15.3	71.1	1.5*	-1.0*	-11.2	-130.8
DUMMY*ANGLE	-0.8*	26.8	47.1	63.6	16.3	-2.8*	-0.5*
DUMMY*FACE	-10.4*	-0.0*	36.4	-23.2*	9.2	-6.8*	-1.3*
ANGLE*FACE	-70.6	12.2*	30.1	14.6*	24.3	12.3	-13.3*
DUMMY*ANGLE*FACE	4.6*	-7.0*	12.9*	-8.8*	6.0	-2.3*	4.8*
R^2	0.92	0.90	0.94	0.88	0.96	0.91	0.98
COEF. VARIATION	22.8%	12.3%	14.3%	23.6%	5.8%	9.8%	13.6%

*Not significantly different from zero at the 10% level.

TABLE 2

Rear Seat Position
Calculated Effects from the Saturated Model

EFFECT	HEAD	CHEST			SPINE		PELVIC
		TTI	UPRIB	LORIB	UPPER	LOWER	
CONSTANT	98.0	49.9	47.1	44.4	44.1	48.5	85.9
DUMMY	-36.1	-10.9	-10.0	-27.3	-16.0	-8.0	9.6
BARRIER ANGLE	-65.4	-25.6	-16.0	-29.8	-25.8	-29.0	-5.8*
BARRIER FACE	9.1*	-23.9	-17.3	-25.5	-16.8	-30.0	-90.4
DUMMY*ANGLE	8.9*	7.6	-13.8	8.3	5.5	-0.0*	8.4*
DUMMY*FACE	25.4	10.9	27.0	15.0	1.5*	-1.0*	-5.7*
ANGLE*FACE	0.6*	17.1	25.0	22.0	19.8	-11.5	4.4*
DUMMY*ANGLE*FACE	-32.1	0.9*	-7.8	2.5*	-6.5*	3.5*	0.1*
R^2	0.94	0.98	0.95	0.97	0.96	0.97	0.98
COEF. VARIATION	16.0%	9.7%	17.0%	14.8%	12.7%	11.6%	11.2%

*Not significantly different from zero at the 10% level.

Appendix C

Analysis of Variance Output

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = FRONT

DEP VAR: HDACCL N: 16 MULTIPLE R: .964 SQUARED MULTIPLE R: .928
ADJUSTED SQUARED MULTIPLE R: .866 STANDARD ERROR OF ESTIMATE: 23.826

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	104.688	5.957	0.000	.	17.575	0.000
DUMTYPE	-6.688	5.957	-0.106	.100E+01	-1.123	0.294
CRBANGL	30.438	5.957	0.483	.100E+01	5.110	0.001
MDBFACE	-37.813	5.957	-0.601	.100E+01	-6.348	0.000
DUMTYPE* CRBANGL	-0.438	5.957	-0.007	.100E+01	-0.073	0.943
DUMTYPE* MDBFACE	-5.188	5.957	-0.082	.100E+01	-0.871	0.409
CRBANGL* MDBFACE	-35.313	5.957	-0.561	.100E+01	-5.928	0.000
DUMTYPE* CRBANGL* MDBFACE	2.312	5.957	0.037	.100E+01	0.388	0.708

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	58885.938	7	8412.277	14.818	0.001
RESIDUAL	4541.500	8	567.687		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = REAR

DEP VAR: HDACCL N: 16 MULTIPLE R: .968 SQUARED MULTIPLE R: .938
ADJUSTED SQUARED MULTIPLE R: .883 STANDARD ERROR OF ESTIMATE: 15.710

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	98.313	3.928	0.000	.	25.031	0.000
DUMTYPE	-18.063	3.928	-0.406	.100E+01	-4.599	0.002
CRBANGL	-32.688	3.928	-0.735	.100E+01	-8.323	0.000
MDBFACE	4.562	3.928	0.103	.100E+01	1.162	0.279
DUMTYPE* CRBANGL	4.438	3.928	0.100	.100E+01	1.130	0.291
DUMTYPE* MDBFACE	12.688	3.928	0.285	.100E+01	3.230	0.012
CRBANGL* MDBFACE	0.313	3.928	0.007	.100E+01	0.080	0.939
DUMTYPE* CRBANGL* MDBFACE	-16.063	3.928	-0.361	.100E+01	-4.090	0.003

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	29668.938	7	4238.420	17.173	0.000
RESIDUAL	1974.500	8	246.813		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = FRONT

DEP VAR: TTI N: 16 MULTIPLE R: .949 SQUARED MULTIPLE R: .901
ADJUSTED SQUARED MULTIPLE R: .814 STANDARD ERROR OF ESTIMATE: 15.244

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	123.500	3.811	0.000	.	32.407	0.000
DUMTYPE	13.875	3.811	0.405	.100E+01	3.641	0.007
CRBANGL	24.000	3.811	0.701	.100E+01	6.298	0.000
MDBFACE	7.625	3.811	0.223	.100E+01	2.001	0.080
DUMTYPE* CRBANGL	13.375	3.811	0.391	.100E+01	3.510	0.008
DUMTYPE* MDBFACE	-0.000	3.811	-0.000	.100E+01	-0.000	1.000
CRBANGL* MDBFACE	6.125	3.811	0.179	.100E+01	1.607	0.147
DUMTYPE* CRBANGL* MDBFACE	-3.500	3.811	-0.102	.100E+01	-0.918	0.385

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	16885.000	7	2412.143	10.380	0.002
RESIDUAL	1859.000	8	232.375		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = REAR

DEP VAR: TTI N: 16 MULTIPLE R: .987 SQUARED MULTIPLE R: .975
ADJUSTED SQUARED MULTIPLE R: .952 STANDARD ERROR OF ESTIMATE: 4.867

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	49.938	1.217	0.000	.	41.042	0.000
DUMTYPE	-5.438	1.217	-0.252	.100E+01	-4.469	0.002
CRBANGL	-12.813	1.217	-0.594	.100E+01	-10.530	0.000
MDBFACE	-11.938	1.217	-0.553	.100E+01	-9.811	0.000
DUMTYPE* CRBANGL	3.813	1.217	0.177	.100E+01	3.133	0.014
DUMTYPE* MDBFACE	5.438	1.217	0.252	.100E+01	4.469	0.002
CRBANGL* MDBFACE	8.563	1.217	0.397	.100E+01	7.037	0.000
DUMTYPE* CRBANGL* MDBFACE	0.438	1.217	0.020	.100E+01	0.360	0.728

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	7261.438	7	1037.348	43.793	0.000
RESIDUAL	189.500	8	23.688		

```
THE FOLLOWING RESULTS ARE FOR:
          DUMPOS       =        FRONT
    1 CASES DELETED DUE TO MISSING DATA.

DEP VAR:   UPRIB       N:       15  MULTIPLE R:  .969  SQUARED MULTIPLE R:  .939
ADJUSTED SQUARED MULTIPLE R:   .879    STANDARD ERROR OF ESTIMATE:        20.148

  VARIABLE     COEFFICIENT     STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)

CONSTANT          141.188         5.342         0.000  .           26.427    0.000
 DUMTYPE           34.813         5.342         0.621 0.9523810     6.516    0.000
 CRBANGL           30.188         5.342         0.539 0.9523810     5.650    0.001
 MDBFACE           35.563         5.342         0.635 0.9523810     6.657    0.000
 DUMTYPE*
 CRBANGL           23.563         5.342         0.420 0.9523810     4.410    0.003
 DUMTYPE*
 MDBFACE           18.188         5.342         0.325 0.9523810     3.404    0.011
 CRBANGL*
 MDBFACE           15.063         5.342         0.269 0.9523810     2.819    0.026
 DUMTYPE*
 CRBANGL*
 MDBFACE            6.438         5.342         0.115 0.9523810     1.205    0.267

                             ANALYSIS OF VARIANCE

   SOURCE    SUM-OF-SQUARES     DF  MEAN-SQUARE      F-RATIO        P

 REGRESSION        44051.433     7      6293.062       15.503        0.001
   RESIDUAL         2841.500     7       405.929
----------------------------------------------------------------------------------

THE FOLLOWING RESULTS ARE FOR:
          DUMPOS       =         REAR

DEP VAR:   UPRIB       N:       16  MULTIPLE R:  .973  SQUARED MULTIPLE R:  .946
ADJUSTED SQUARED MULTIPLE R:   .900    STANDARD ERROR OF ESTIMATE:         7.992

  VARIABLE     COEFFICIENT     STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)

CONSTANT           47.125         1.998         0.000  .           23.586    0.000
 DUMTYPE           -5.000         1.998        -0.205  .100E+01    -2.502    0.037
 CRBANGL           -8.000         1.998        -0.328  .100E+01    -4.004    0.004
 MDBFACE           -8.625         1.998        -0.353  .100E+01    -4.317    0.003
 DUMTYPE*
 CRBANGL            6.875         1.998         0.282  .100E+01     3.441    0.009
 DUMTYPE*
 MDBFACE           13.500         1.998         0.553  .100E+01     6.757    0.000
 CRBANGL*
 MDBFACE           12.500         1.998         0.512  .100E+01     6.256    0.000
 DUMTYPE*
 CRBANGL*
 MDBFACE           -3.875         1.998        -0.159  .100E+01    -1.939    0.088

                             ANALYSIS OF VARIANCE

   SOURCE    SUM-OF-SQUARES     DF  MEAN-SQUARE      F-RATIO        P

 REGRESSION         9026.750     7      1289.536       20.188        0.000
   RESIDUAL          511.000     8        63.875
```

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = FRONT

DEP VAR: LORIB N: 16 MULTIPLE R: .939 SQUARED MULTIPLE R: .881
ADJUSTED SQUARED MULTIPLE R: .777 STANDARD ERROR OF ESTIMATE: 30.625

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	129.625	7.656	0.000	.	16.931	0.000
DUMTYPE	18.250	7.656	0.291	.100E+01	2.384	0.044
CRBANGL	43.875	7.656	0.699	.100E+01	5.731	0.000
MDBFACE	0.750	7.656	0.012	.100E+01	0.098	0.924
DUMTYPE* CRBANGL	31.750	7.656	0.506	.100E+01	4.147	0.003
DUMTYPE* MDBFACE	-11.625	7.656	-0.185	.100E+01	-1.518	0.167
CRBANGL* MDBFACE	7.250	7.656	0.115	.100E+01	0.947	0.371
DUMTYPE* CRBANGL* MDBFACE	-4.375	7.656	-0.070	.100E+01	-0.571	0.583

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	55576.750	7	7939.536	8.465	0.004
RESIDUAL	7503.000	8	937.875		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = REAR

DEP VAR: LORIB N: 16 MULTIPLE R: .986 SQUARED MULTIPLE R: .972
ADJUSTED SQUARED MULTIPLE R: .948 STANDARD ERROR OF ESTIMATE: 6.586

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	44.375	1.646	0.000	.	26.951	0.000
DUMTYPE	-13.625	1.646	-0.486	.100E+01	-8.275	0.000
CRBANGL	-14.875	1.646	-0.530	.100E+01	-9.034	0.000
MDBFACE	-12.750	1.646	-0.454	.100E+01	-7.744	0.000
DUMTYPE* CRBANGL	4.125	1.646	0.147	.100E+01	2.505	0.037
DUMTYPE* MDBFACE	7.500	1.646	0.267	.100E+01	4.555	0.002
CRBANGL* MDBFACE	11.000	1.646	0.392	.100E+01	6.681	0.000
DUMTYPE* CRBANGL* MDBFACE	-1.250	1.646	-0.045	.100E+01	-0.759	0.470

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	12244.750	7	1749.250	40.329	0.000
RESIDUAL	347.000	8	43.375		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = FRONT

DEP VAR: UPSPINE N: 16 MULTIPLE R: .982 SQUARED MULTIPLE R: .963
ADJUSTED SQUARED MULTIPLE R: .932 STANDARD ERROR OF ESTIMATE: 5.062

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	87.125	1.266	0.000	.	68.845	0.000
DUMTYPE	-5.500	1.266	-0.294	.100E+01	-4.346	0.002
CRBANGL	8.000	1.266	0.427	.100E+01	6.321	0.000
MDBFACE	-0.500	1.266	-0.027	.100E+01	-0.395	0.703
DUMTYPE* CRBANGL	8.125	1.266	0.434	.100E+01	6.420	0.000
DUMTYPE* MDBFACE	4.625	1.266	0.247	.100E+01	3.655	0.006
CRBANGL* MDBFACE	12.125	1.266	0.647	.100E+01	9.581	0.000
DUMTYPE* CRBANGL* MDBFACE	3.000	1.266	0.160	.100E+01	2.371	0.045

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	5406.750	7	772.393	30.142	0.000
RESIDUAL	205.000	8	25.625		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = REAR

DEP VAR: UPSPINE N: 16 MULTIPLE R: .982 SQUARED MULTIPLE R: .964
ADJUSTED SQUARED MULTIPLE R: .932 STANDARD ERROR OF ESTIMATE: 5.590

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	44.125	1.398	0.000	.	31.573	0.000
DUMTYPE	-8.000	1.398	-0.385	.100E+01	-5.724	0.000
CRBANGL	-12.875	1.398	-0.620	.100E+01	-9.213	0.000
MDBFACE	-8.375	1.398	-0.403	.100E+01	-5.993	0.000
DUMTYPE* CRBANGL	2.750	1.398	0.132	.100E+01	1.968	0.085
DUMTYPE* MDBFACE	0.750	1.398	0.036	.100E+01	0.537	0.606
CRBANGL* MDBFACE	9.875	1.398	0.475	.100E+01	7.066	0.000
DUMTYPE* CRBANGL* MDBFACE	-3.250	1.398	-0.156	.100E+01	-2.326	0.049

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	6657.750	7	951.107	30.435	0.000
RESIDUAL	250.000	8	31.250		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = FRONT

DEP VAR: LOSPINE N: 16 MULTIPLE R: .955 SQUARED MULTIPLE R: .912
ADJUSTED SQUARED MULTIPLE R: .835 STANDARD ERROR OF ESTIMATE: 9.247

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	94.875	2.312	0.000	.	41.042	0.000
DUMTYPE	-13.875	2.312	-0.630	.100E+01	-6.002	0.000
CRBANGL	12.875	2.312	0.585	.100E+01	5.570	0.001
MDBFACE	-5.625	2.312	-0.255	.100E+01	-2.433	0.041
DUMTYPE* CRBANGL	-1.375	2.312	-0.062	.100E+01	-0.595	0.568
DUMTYPE* MDBFACE	-3.375	2.312	-0.153	.100E+01	-1.460	0.182
CRBANGL* MDBFACE	6.125	2.312	0.278	.100E+01	2.650	0.029
DUMTYPE* CRBANGL* MDBFACE	-1.125	2.312	-0.051	.100E+01	-0.487	0.640

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	7071.750	7	1010.250	11.816	0.001
RESIDUAL	684.000	8	85.500		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = REAR

DEP VAR: LOSPINE N: 16 MULTIPLE R: .984 SQUARED MULTIPLE R: .969
ADJUSTED SQUARED MULTIPLE R: .941 STANDARD ERROR OF ESTIMATE: 5.612

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	48.500	1.403	0.000	.	34.566	0.000
DUMTYPE	-4.000	1.403	-0.178	.100E+01	-2.851	0.021
CRBANGL	-14.500	1.403	-0.646	.100E+01	-10.334	0.000
MDBFACE	-15.000	1.403	-0.669	.100E+01	-10.690	0.000
DUMTYPE* CRBANGL	-0.000	1.403	-0.000	.100E+01	-0.000	1.000
DUMTYPE* MDBFACE	-0.500	1.403	-0.022	.100E+01	-0.356	0.731
CRBANGL* MDBFACE	5.750	1.403	0.256	.100E+01	4.098	0.003
DUMTYPE* CRBANGL* MDBFACE	1.750	1.403	0.078	.100E+01	1.247	0.248

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	7802.000	7	1114.571	35.383	0.000
RESIDUAL	252.000	8	31.500		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = FRONT

DEP VAR: PELVIC N: 16 MULTIPLE R: .988 SQUARED MULTIPLE R: .975
ADJUSTED SQUARED MULTIPLE R: .954 STANDARD ERROR OF ESTIMATE: 15.116

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	110.750	3.779	0.000	.	29.306	0.000
DUMTYPE	2.750	3.779	0.040	.100E+01	0.728	0.488
CRBANGL	13.000	3.779	0.191	.100E+01	3.440	0.009
MDBFACE	-65.375	3.779	-0.962	.100E+01	-17.299	0.000
DUMTYPE* CRBANGL	-0.250	3.779	-0.004	.100E+01	-0.066	0.949
DUMTYPE* MDBFACE	-0.625	3.779	-0.009	.100E+01	-0.165	0.873
CRBANGL* MDBFACE	-6.625	3.779	-0.098	.100E+01	-1.753	0.118
DUMTYPE* CRBANGL* MDBFACE	2.375	3.779	0.035	.100E+01	0.628	0.547

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	72007.000	7	10286.714	45.018	0.000
RESIDUAL	1828.000	8	228.500		

THE FOLLOWING RESULTS ARE FOR:
DUMPOS = REAR

DEP VAR: PELVIC N: 16 MULTIPLE R: .989 SQUARED MULTIPLE R: .979
ADJUSTED SQUARED MULTIPLE R: .960 STANDARD ERROR OF ESTIMATE: 9.601

VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	85.938	2.400	0.000	.	35.802	0.000
DUMTYPE	4.813	2.400	0.104	.100E+01	2.005	0.080
CRBANGL	-2.188	2.400	-0.047	.100E+01	-0.911	0.389
MDBFACE	-45.188	2.400	-0.975	.100E+01	-18.825	0.000
DUMTYPE* CRBANGL	4.188	2.400	0.090	.100E+01	1.745	0.119
DUMTYPE* MDBFACE	-2.813	2.400	-0.061	.100E+01	-1.172	0.275
CRBANGL* MDBFACE	2.188	2.400	0.047	.100E+01	0.911	0.389
DUMTYPE* CRBANGL* MDBFACE	0.062	2.400	0.001	.100E+01	0.026	0.980

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
REGRESSION	33601.438	7	4800.205	52.070	0.000
RESIDUAL	737.500	8	92.188		

Appendix D

Mean Values

JAMA DATA-FRONT

	HDACCL	TTI	UPRIB	LORIB	UPSPINE	LOSPINE	PELVIC
[Front,NHTSA,27,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	57	87	68	80	101	94	145
MAXIMUM	94	115	114	117	113	114	156
MEAN 1111	75.5	101	91	98.5	107	104	150.5
STANDARD DEV	26.163	19.799	32.527	26.163	8.485	14.142	7.778
[Front,NHTSA,27,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	69	91	70	68	75	79	139
MAXIMUM	87	99	110	104	78	88	186
MEAN 1112	78	95	90	86	76.5	83.5	162.5
STANDARD DEV	12.728	5.657	28.284	25.456	2.121	6.364	33.234
[Front,NHTSA,0,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	200	100	84	85	85	114	186
MAXIMUM	225	106	90	114	92	122	204
MEAN 1121	212.5	103	87	99.5	88.5	118	195
STANDARD DEV	17.678	4.243	4.243	20.506	4.95	5.657	12.728
[Front,NHTSA,0,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	198	144	145	201	76	86	185
MAXIMUM	210	185	164	262	81	107	208
MEAN 1122	204	164.5	154.5	231.5	78.5	96.5	196.5
STANDARD DEV	8.485	28.991	13.435	43.134	3.536	14.849	16.263
[Front,EEVC,27,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	64	89	98	96	74	80	33
MAXIMUM	107	105	119	104	83	90	45
MEAN 1211	85.5	97	108.5	100	78.5	85	39
STANDARD DEV	30.406	11.314	14.849	5.657	6.364	7.071	8.485
[Front,EEVC,27,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	44	98	141	53	54	55	38
MAXIMUM	72	112	168	64	55	56	40
MEAN 1212	58	105	154.5	58.5	54.5	55.5	39
STANDARD DEV	19.799	9.899	19.092	7.778	0.707	0.707	1.414
[Front,EEVC,0,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	41	135	129	145	96	120	47
MAXIMUM	103	140	149	150	97	136	48
MEAN 1221	72	137.5	139	147.5	96.5	128	47.5
STANDARD DEV	43.841	3.536	14.142	3.536	0.707	11.314	0.707
[Front,EEVC,0,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	46	172	143	172	112	86	47
MAXIMUM	58	198	305	259	122	91	65
MEAN 1222	52	185	224	215.5	117	88.5	56
STANDARD DEV	8.485	18.385	114.551	61.518	7.071	3.536	12.728

JAMA DATA-REAR

	HDACCL	TTI	UPRIB	LORIB	UPSPINE	LOSPINE	PELVIC
[Rear,NHTSA,27,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	164	90	95	100	89	80	130
MAXIMUM	192	105	116	119	91	91	134
MEAN 2111	178	97.5	105.5	109.5	90	85.5	132
STANDARD DEV	19.799	10.607	14.849	13.435	1.414	7.778	2.828
[Rear,NHTSA,27,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	65	69	42	49	51	75	125
MAXIMUM	86	69	52	64	70	89	153
MEAN 2112	75.5	69	47	56.5	60.5	82	139
STANDARD DEV	14.849	0	7.071	10.607	13.435	9.899	19.799
[Rear,NHTSA,0,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	55	48	40	47	32	48	104
MAXIMUM	87	48	46	47	33	49	126
MEAN 2121	71	48	43	47	32.5	48.5	115
STANDARD DEV	22.627	0	4.243	0	0.707	0.707	15.556
[Rear,NHTSA,0,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	49	28	23	15	22	32	132
MAXIMUM	52	38	32	16	32	44	145
MEAN 2122	50.5	33	27.5	15.5	27	38	138.5
STANDARD DEV	2.121	7.071	6.364	0.707	7.071	8.485	9.192
[Rear,EEVC,27,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	111	44	24	40	45	48	42
MAXIMUM	147	49	33	49	46	49	44
MEAN 2211	129	46.5	28.5	44.5	45.5	48.5	43
STANDARD DEV	25.456	3.536	6.364	6.364	0.707	0.707	1.414
[Rear,EEVC,27,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	138	37	38	26	30	35	38
MAXIMUM	145	39	41	27	34	37	39
MEAN 2212	141.5	38	39.5	26.5	32	36	38.5
STANDARD DEV	4.95	1.414	2.121	0.707	2.828	1.414	0.707
[Rear,EEVC,0,SID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	82	28	28	29	40	27	34
MAXIMUM	93	31	35	33	41	28	35
MEAN 2221	87.5	29.5	31.5	31	40.5	27.5	34.5
STANDARD DEV	7.778	2.121	4.95	2.828	0.707	0.707	0.707
[Rear,EEVC,0,EuroSID]							
N OF CASES	2	2	2	2	2	2	2
MINIMUM	46	36	47	23	23	19	45
MAXIMUM	61	40	62	26	27	25	49
MEAN 2222	53.5	38	54.5	24.5	25	22	47
STANDARD DEV	10.607	2.828	10.607	2.121	2.828	4.243	2.828

MVMA DATA

	HDACCL	TTI	UPRIB	LORIB	UPSPINE	LOSPINE	PELVIC
[Front,NHTSA,27,SID]							
N OF CASES	16	16	16	16	16	16	16
MINIMUM	36.39	52	42.29	38	47.86	56.11	40.25
MAXIMUM	145.3	107	95.79	109.16	106.36	123.08	159.39
MEAN 1111	59.811	72.813	58.354	58.291	64.832	83.904	92.146
[Front,NHTSA,27,EuroSID]							
N OF CASES	8	8	8	8	8	8	8
MINIMUM	33.95	64	54.42	72	42.33	49.39	53.67
MAXIMUM	184.28	130	147.24	162.13	83.83	113.22	154.42
MEAN 1112	88.324	89.813	87.906	98.695	61.779	80.099	104.868
[Front,NHTSA,0,SID]							
N OF CASES							
MINIMUM							
MAXIMUM				No Data to Match			
MEAN 1121							
[Front,NHTSA,0,EuroSID]							
N OF CASES							
MINIMUM							
MAXIMUM				No Data to Match			
MEAN 1122							
[Front,EEVC,27,SID]							
N OF CASES							
MINIMUM							
MAXIMUM				No Data to Match			
MEAN 1211							
[Front,EEVC,27,EuroSID]							
N OF CASES	8	8	8	8	8	8	8
MINIMUM	31.61	47.5	37.42	52.88	41.64	38.86	37.38
MAXIMUM	117.96	107	125.1	139.09	77.5	105.4	114.5
MEAN 1212	68.059	76.625	65.075	85.87	51.491	61.931	69.455
[Front,EEVC,0,SID]							
N OF CASES							
MINIMUM							
MAXIMUM				No Data to Match			
MEAN 1221							
[Front,EEVC,0,EuroSID]							
N OF CASES	8	8	8	8	8	8	8
MINIMUM	26.07	50	40.51	59.83	32.8	37.56	49.48
MAXIMUM	149.55	119	144.65	138.41	66.75	94.62	114.77
MEAN 1222	74.851	81.5	88.338	88.059	46.119	62.76	78.589