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EXPERIMENTAL INJURY STUDY OF CHILDREN SEATED BEHIND COLLAPSING FRONT SEATS IN REAR IMPACTS

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KEYWORDS

Rear-Impacts, Seat-Collapse, Children, Rear-Seated Children, Child Head-Injury, Biomechanics, Experimental Methods

ABSTRACT

In the mid 1990's the U.S. Department of Transportation made recommendations to place children and infants into the rear seating areas of motor vehicles to avoid front seat airbag induced injuries and fatalities. In most rear-impacts, however, the adult occupied front seats will collapse into the rear occupant area and pose another potentially serious injury hazard to the rear-seated children. Since rear-impacts involve a wide range of speeds, impact severity, and various sizes of adults in collapsing front seats, a multi-variable experimental method was employed in conjunction with a multi-level "factorial analysis" technique to study injury potential of rear-seated children. Various sizes of Hybrid III adult surrogates, seated in a "typical" average strength collapsing type of front seat, and a three-year-old Hybrid III child surrogate, seated on a built-in booster seat located directly behind the front adult occupant, were tested at various impact severity levels in a popular "mini-van" sled-buck test set up. A total of five test configurations were utilized in this study. Three levels of velocity changes ranging from 22.5 to 42.5 kph were used. The average of peak accelerations on the sled-buck tests ranged from approximately 8.2 G's up to about 11.1 G's, with absolute peak values of just over 14 G's at the higher velocity change. The parameters of the test configuration enabled the experimental data to be combined into a polynomial "injury" function of the two primary independent variables (i.e. front seat adult occupant weight and velocity change) so that the "likelihood" of rear child "injury potential" could be determined over a wide range of the key parameters. The experimentally derived head injury data was used to obtain a preliminary HIC (Head Injury Criteria) polynomial fit at the 900 level for the rear-seated child. Several actual accident cases were compared with the preliminary polynomial fit. This study provides a test efficient, multi-variable, method to compare the injury biomechanical data with actual accident cases.

INTRODUCTION

Concern with serious injuries inflicted on front seated children and infants from airbag deployment has resulted in Government recommendations that children should be placed in the rear seat area of a motor vehicle. Unfortunately, during a rear impact most adult occupied front seats will collapse rearward into the area now occupied by the children and infants. A recent study examined motor vehicle seat system performance as it generally related to injury of rear seated children and infants during rear impacts [1]. The study reviewed accident data, field accident case studies, and controlled tests based on some of the case studies. The results indicated, among other things, that the probability of serious injury to the rear seated occupant increased by a significant factor when the occupied front seat experienced failure or collapse into the rear seat area. However, many factors influence when a motor vehicle seat system will collapse into the rear seat area occupied by a child, and whether it will cause injury to the child. This current study presents a "test efficient" experimental/analytical method for analyzing and examining "multi-variable" effects that are likely to influence the injury potential of rear seated children when seated behind adult occupied front seats that are likely to collapse rearward during rear impacts.

EXPERIMENTAL/ANALYTICAL MULTI-VARIABLE METHOD

Among the many variables that influence whether or not adult occupied front seat collapse is likely to cause serious injury to children located behind the collapsing seat are factors, or variables, such as: front seat collapse strength; size and weight of the adult in the collapsing seat; and the rear impact severity levels, such as "change in velocity" and peak loads.

Prior studies have demonstrated a wide range of occupant load resistance for commercially available motor vehicle front seats [2, 3], with the more common "single recliner" types having an average "collapse" strength of about 3,220 N (725 lbs) versus the less common, but much stronger, "belt-integrated" seats that reach strength levels as high as 20,340 N (4,575 lbs). The more common average strength (3,220 N) "single recliner" collapsing type seat was utilized in this study. This average strength front seat is used in a popular "family" mini-van vehicle. During rear impact, the seat collapses rearward in a continuos manner, through metal bending, rather than catastrophically from effects such as "seat track separation" or recliner "gear teeth shearing" failures. The vehicle body structure used in this test sled-buck arrangement is the same mini-van from which the collapsing front seat type was chosen. During the tests, the sled-buck arrangement was towed rearward into a crushable barrier that provided a crash pulse modeled after actual vehicle crash test data for the mini-van used. A three-year-old Hybrid-III child surrogate was seated on a "built-in" booster seat located behind the adult occupied "single recliner" driver seat of the mini-van during each test. Figure 1 shows a video clip from one of the tests.

Figure 1 – Head Impact to Rear Seated 3-year-old Child Surrogate Under Average Rear Impact Conditions

Figure 1 illustrates the sled-buck system and surrogates at about 150 milliseconds into the crash test representing average rear-impact conditions (i.e. average strength collapsing seat (3,220 N), average size front adult surrogate (80 kg), and average rear impact severity (32.5 kph)).

The "experimental/analytical" method employed in this study to evaluate injury potential to children seated behind occupied collapsing front seats is based on a "2-level factorial" approach [4], where a "high-low" range of certain independent variables are selected in a manner that allows for "test-efficient" characterization of various dependent variables such as Head-Injury Criteria (HIC) calculated from the experimentally measured accelerations. In this study, front seat adult "occupant size"(i.e. weight) and impact "severity level"(i.e. speed change) were chosen to be the primary independent variables. Each independent variable was tested with "high", "low", and "average" values, equally spaced so as to enable development of "Polynomial Response Functions" that allow evaluation of the dependent variables at configurations of the independent variables that were not tested (i.e. "interpolation" and "extrapolation" at combinations of independent variables not tested).

The sizes of the front seated adult surrogates ranged from a fifth percentile Hybrid-III female of 50 kg (110 lbs) up to a 50 percentile male Hybrid-III ballasted up 110 kg (242 lbs). A standard Hybrid-III 50 percentile male surrogate weighing 80 kg (175 lbs) was used for the average size occupant in this study. The three levels of impact severity employed in this test method resulted in vehicle velocity changes of 22.5 kph (13.5 mph), 32.5 kph (19.5 mph), and 42.5 kph (25.5 mph). As noted, the crash pulses for the sled-buck tests were modeled after actual vehicle-to-vehicle crash test data. The average of peak accelerations (obtained from the slope of the longitudinal "speed change" curve) ranged from 8.2 G's for the low level impact (i.e. 22.5 kph) up to 11.1 G's for the high level of impact (i.e. 42.5 kph) with peak G level oscillations reaching as high as 14 G's at the high level of impact. All surrogates were fully restrained and the front seat position and seat-back angles were kept constant for each test. A total of five test configurations were run with the range of parameters indicated above. Table 1 summarizes the level of each "independent variable" parameter used for each test configuration, as well as the resulting experimentally measured "dependent variable" of child HIC (Head Injury Criteria), calculated over a 36 ms interval of dummy head acceleration [5], for the rear seated three-year-old Hybrid-III child surrogate.

Table 1. Test Configurations, Parameter Levels, and Some Results, for 2-Level Factorial Method

Test Configuration Number	Independent Variable X1 - Speed Change (kph)	Independent Variable X2 – Front Occupant Wt (kg)	Dependent Variable Resultant "HIC" for Rear Child
1	32.5	80	1,903.6
2	22.5	50	47.4
3	22.5	110	2,335.2
4	42.5	50	178.3
5	42.5	110	8,515.9

Configurations 2 through 5 of Table 1 provide data for the development of a "2-level factorial" polynomial description of the rear seated child HIC, or other such parameters, over a wide range of front occupant "weights" and "impact severities" (i.e. speed change) related to the "average" strength collapsing front seat. The first test configuration of Table 1 represents an "average" rear impact situation, as noted above in figure 1. The second configuration represents a low impact severity situation (i.e. 22.5 kph speed change) with the lightest front seat surrogate (i.e. 50 kg small female) also in the "average" strength collapsing front seat. In this case however, the occupant in the front seat collapses rear but does not collapse far enough rearward to make head-to-head contact with the rear-seated child. Thus the only head loads experienced by the rear-seated child in this configuration are those developed as a result of the inertial interaction of the child head with the seatback of the rear "booster" seat that the child is seated in. For the remaining three cases (i.e. 3 through 5), involving "high" and "low" combinations of the independent variables, "head-to-head" contact was made between the front seated adult and the rear seated child.

Table 2 illustrates the "computation matrix" used to develop the polynomial coefficients for the child HIC as a function of the two independent variables of "speed change" (X1) and front "occupant weight" (X2) scaled to non-dimensional levels. For instance, the "high" value of weight (110 kg) would be represented as "+1" and the "low" weight (50 kg) would be equated to a "-1" value. The "average" weight (80 kg) would be represented by a value of "0". Similarly, values between, or beyond, the "high", "low" and "average" levels would be scaled accordingly. For instance, a weight of 136 kg would be represented by a dimensionless X2 value of "+1.92" and a weight of 65 kg would be represented by a dimensionless X2 value of "-0.5". Similar scaling is used to arrive at various dimensionless values for X1 the speed change independent variable, where the "low" speed of 22.5 kph is represented by "-1", etc..

Table 2. Polynomial Coefficient Matrix for Child HIC Polynomial

Test Configuration	A0	A1	A2	A12	Child HIC Results
2	+	–	–	+	47.4
3	+	+	–	–	178.3
4	+	–	+	–	2,335.2
5	+	+	+	+	8,516.0
Σ	11,076.9	6,311.7	10,625.5	6,049.9	
Σ/4	2,769.2	1,577.9	2,656.4	1,512.5	

The polynomial coefficients in a given column are calculated by simply multiplying the "result" column HIC value in a given row by the appropriate "plus" or "minus" sign of that row, under a desired "coefficient" column, and then summing the values in that column. Finally, divide the sum by 4 and the result yields the polynomial coefficient. Thus the Child Head-Injury-Criteria HIC polynomial based on the experimental results, in dimensionless form, is given as:

$$HIC\ (Exp) = 2{,}769.2 + 1{,}577.9*(X1) + 2{,}656.4*(X2) + 1{,}512.5*(X1)*(X2) \qquad (eq.\#1)$$

RESULTS AND DISCUSSION

Setting the left hand side of equation (1) equal to a HIC value of 900 and solving in dimensionless form for the resulting speed change (i.e. X1) for given values of front occupant weight (i.e. X2) results in the polynomial curve shown in figure 2, which is plotted as a function of the two independent variables. The region above the curve indicates likelihood of head injury to the rear child.

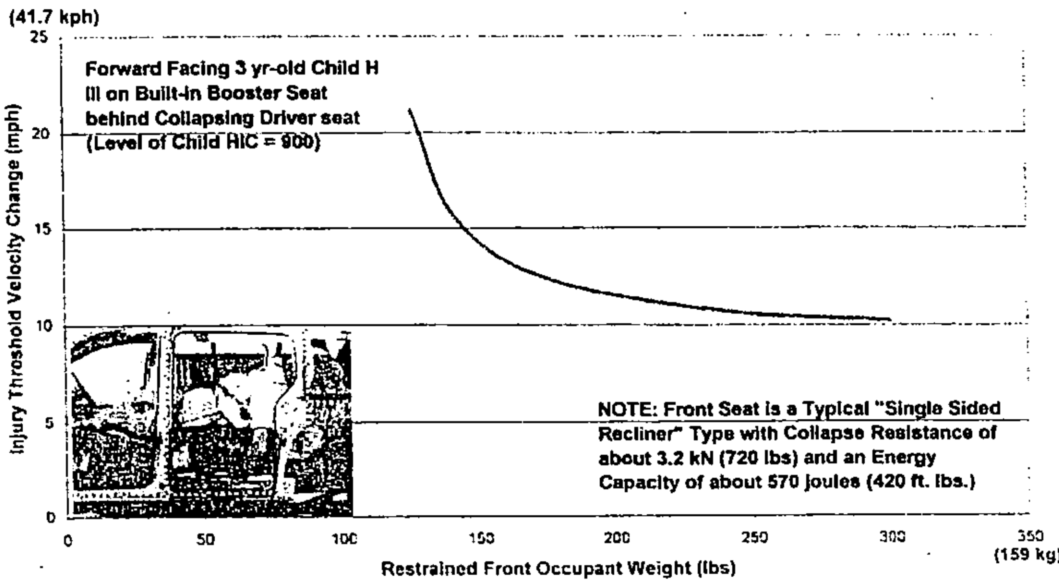

Figure 2. Rear-Impact "Experimental 900 HIC Curve" for 3-year-old Behind Average Collapsing Front Seat

In order to address the biofidelity of the above child surrogate head response curve, data from reference 1, related to accident cases involving injury to rear children, has been summarized and put into Table 3.

Table 3. Summary of Field Accident Case Data Involving Rear Child Head Injury (Ref. 1)

Case No.	Veh. Type	DeltaV (kph)	Front Occupant Data Seat Pos.; Gender-age; Wt.			Rear Occupant Data Seat Pos.; Gender-age; Wt. ; Restraint; Injury group				
1A	MV	23	1	F-35y	125 kg	4	F-4y	21 kg	LS	IG-2 (Serious)
1B	SUV	43	1	M-34y	93 kg	5	M-6y	23 kg	LS	IG-1
			3	F-32y	61 kg	6	M-3y	16 kg	LS	IG-3 (Fatal)
2B	SD4	42	1	M-22y	75 kg	4	F-22y	NA	LS	IG-1
			3	M-20y	77 kg	5	F-20y	NA	LS	IG-1
						6	M-3y	13 kg	FCRS	IG-3 (Fatal)
4A	SD4	33	1	M-35y	73 kg	4	F-3y	21 kg	LS	IG-2 (Serious)
			3	F-33y	73 kg	6	M-10y	37 kg	LS	IG-1
5A	MV	30	1	F-30y	102 kg	4	F-4y	18 kg	LS	IG-2 (Serious)
						6	F-8y	34 kg	NA	IG-1
						9	M-2y	14 kg	FCRS	IG-1
6A	MV	33	1	M-42y	98 kg	4	F-3y	13 kg	LS+B	IG-2 (Serious)
			3	F-37y	61 kg	7	F-13y	NA	LS	IG-1
						9	M-12y	NA	LS	IG-1
5B	MV	37	1	M-37y	95 kg	4	M-3y	18 kg	LS	IG-2 (Serious)
			3	M- 7y	34 kg	6	F-37y	61 kg	LS	IG-1

In Table 3, the "vehicle type" abbreviations denote the following: MV = Mini-van; SUV = Sport Utility Vehicle; and SD4 = 4 door Sedan. Under the heading of "Restraint": LS denotes "lap and shoulder belt"; LS+B denotes "lap, shoulder and booster seat"; and FCRS denotes "Forward facing Child Restraint Seat". With regard to "Injury Groups": IG-1 denotes AIS 0 to 2 level of injury (i.e. minor injury); IG-2 denotes AIS 3 to 5 (i.e. Serious to Severe); and IG-3 denotes AIS 6 (i.e. fatal). Also, "seat position" 1 denotes the driver seat, and position 3 denotes the "right front" position, etc.. Figure 3 shows the Table 3 data for serious and fatal injury to rear seated children plotted on the figure 2 experimental injury curve.

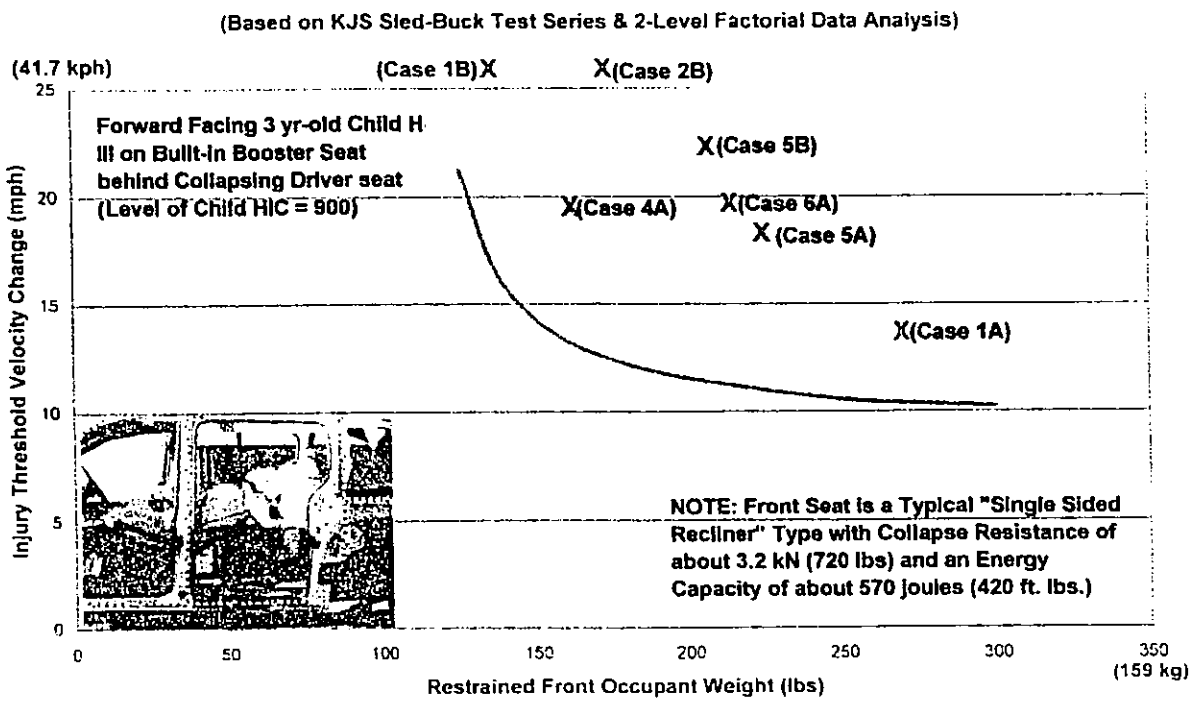

Figure 3. Comparison of Case Study Child Head Injury with Experimental/Analytical Derived Head Injury Curve

A brief review of standards on the head injuries is presented below. In 1966 Gadd proposed a severity index, SI based upon the Wayne State Tolerance Curve (WSTC) [6]. In 1971, the Head Injury Criterion (HIC) was proposed by Versace [7]. The HIC attempted to incorporate the observation that a higher peak acceleration was tolerable if presented in a shorter period of time. Versace emphasized that the WSTC represented only the boundary between acceptable and unacceptable levels and that it did not provide a scaling for injury. In 1984, Mertz again emphasized that injury assessment values should only be used to interpret the response of dummies and thereafter only as a guide to design [8]. Nevertheless, a graph relating HIC to percent population expected to experience life threatening brain injury was advanced. The basis for the curve was a series of 54 cadaver impacts [9]. The result of the impact was scored on the presence or absence of a skull fracture. By using the lowest HIC for which a fracture was observed (450), the highest HIC resulting in a non-fracture (2351), a normal curve was generated between the two. The appearance of a skull fracture was equated to life-threatening brain injury. A review of the recent Head Injury Criterion for child and adult dummies is given by Sances et al [10, 11]. The value of HIC <= 1000 for an integration duration of up to 36 ms is recommended in the Federal Motor Vehicle Standards (FMVSS) Standard 208 for the mid-sized male (50% Hybrid III). The value of

1000 has been adopted for the mid-sized male, small female, and 6 year-old child. This decision was made after reviewing a large number of test data available in the NHTSA databases [12].

In summary, plotting of the appropriate data from Table 3 for "serious" and "fatal" child head injuries onto figure 2 demonstrates that the polynomial curve is a first approximation to indicate serious or fatal head injury level for a rear seated child, under given impact conditions. Figure 3 shows the overlay plot of the table 3 data onto the experimentally derived 900 HIC curve. Several actual accident cases were compared with the preliminary polynomial fit and found to fall above the polynomial curve. The present methodology can be extended to the current head injury criteria by NHTSA [13].

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