THE EFFECT OF RESTRAINT USE AND CRASH MODE ON INJURY SEVERITY RISK FOR CHILDREN

Santokh Singh, Linda McCray
National Highway Traffic Safety Administration
Washington, DC, U.S.A.

John Brewer
Volpe National Transportation Systems Center
Cambridge, MA, U.S.A.

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ABSTRACT

The safety of children in motor vehicle crashes is a major concern. Although Child Restraint Systems (CRS) are required by law for their protection, children are still exposed to the risk of injuries ranging from minor to fatal. The effect of restraint use is studied under different risk scenarios consisting of some possible contributors to injury risk: the restraint use, impact type, injury severity, and age of crash involved children. The data are analyzed at rather a micro level to estimate the relative risks associated with risk scenarios and test for possible risk factor interactions. Specifically, children of age groups: infants, 1 to 3, 4 to 8, and 9 to 12 year olds, who were either uninjured, or sustained minor to fatal injuries in frontal, side, rear-end, or rollover crashes, formed the study population. Some data concerns are also raised in course of the study.

The analysis dataset is extracted from the National Automotive Sampling System– Crashworthiness Data System (NASS-CDS). The study population is segmented, based on three injury risk factors: age group, restraint use, and impact crash mode. Clusters of data are identified in which the quantity of data are limited or contains insufficient 'information', thereby suggesting the importance of collecting more data in certain segments of the population. Injury risk factors may have an individual as well as joint influence on the outcome (injury severity) of a crash. The significance of the overall association between these factors is tested by the contingency analysis. This, however, provides only a broad picture of the phenomenon. Configural frequency analysis is used to identify the factor-based clusters of the children population that show strong to complete absence of factor association. The estimates of the relative risks associated with different clusters are obtained to compare the two groups of children: restrained and unrestrained. In general, the restrained children were found much safer against injuries.

1. INTRODUCTION

In motor vehicle crashes, the use of child restraint systems is as important a safeguard for children against crash impacts as the safety belt use is for adults. Research has shown that the proper restraint use can considerably reduce the injury risk to a child (1986, 1996.) The recognition of this fact led to mandatory requirement of restraint use. Nevertheless, children are still injured in crashes. The question, therefore, arises as to why they are injured and what saves them from being injured. This could be merely 'due to chance' or attributable to certain risk factors, such as age, impact, and restraint use. This study conducts an in-depth analysis of the crash data to identify those sectors of the data in which the injury severity can be attributed to some general risk factors. In the course, some other issues, such as sample size etc. are also discussed.

Statistical analysis based on ten years of data brings out some interesting facts about restraint use and its effectiveness in protecting children in crashes. This can provide guidelines for further improvement in restraint use and give some ideas about further research in this area. The study starts with the rationale of segmenting the data into clusters based on some potential risk factors, such as age, restraint use, impact etc. This is done in Section 2 as a preparation of the analysis data. In Section 3, it is established whether or not there is an overall dependence among these risk factors. To compare restrained and unrestrained children of different age groups with respect to the risk factors, relative risk is estimated for all data clusters in Section 4. The cell sample sizes are assessed for sufficiency in Section 5. The analysis continues in Section 6, where the strength of association among risk factors is tested for clusters of the data. Section 7 summarizes the findings of this study.

2. DATA

The present study is focused on injury severity risk to children 12 years and under. Both experimental and field data are available on child safety restraint use. The experimental data, however, is based on a limited number of conditions used under a controlled experimental environment. The data thus generated can reflect only a part of what happened in real life conditions and lack capability of generalizing the results to the entire population of children. The field data, on the other hand, has inherent in them the characteristics of a probabilistic phenomenon under which crashes occurred and the crash-involved children sustained injuries due to different types of crash impacts. Ten years of NASS-CDS field data (1994 through 1996 and 1998 through 2004) are used in the study. Studying the effectiveness of restraint systems in mitigating children's injury severity is of concern. Many factors are likely to play a role, individually or jointly. The effects of these factors, if present, can bring variation into the data. In order to explain if the variation is actually due to these factors or is merely due to chance, it is important to take them into account in the analysis. This was done by segmenting the data at several layers.

It is recommended that for best possible protection children use age appropriate child restraints in the back seat. In this study, age is used as one of the criteria for data segmentation. This was done based on the following guidelines recommended by NHTSA: Infants (less than a year) – Rear-facing infant seat, 1≤ Age <4 (forward facing seat), 4≤ Age < 8 (booster seat), and 8≤ Age < 13 (adult seat belt). Specifically, the data were segmented in four age groups: 0 to <1 year, 1 to 3 (<4) years, 4 to 8 (<9) years and 9 to 12 (<13) years old children. Each of these age groups, characterized by the presence or absence of restraint use, forms a population in itself. In the subsequent analysis and discussion, the data pertaining to these age groups are treated as independent (with respect to restraint use) populations.

The next layer of data segmentation consisted of classifying the children in each age category, based on the restraint use status, i.e., whether the child was restrained or unrestrained. To account for the child injury severity, the data in each of these categories were segmented into three sub-categories, depending on the maximum injury severity on the Abbreviated Injury Scale (MAIS). Three levels of injury severity were considered: MAIS=0 (no injury), MAIS=1 (minor injury), and MAIS=2^+ (moderate to severe or fatal injury). Research shows that a child's (restrained or unrestrained) injury severity also depends on the type of impact. To account for this variation in the data, four types of impacts: Frontal, Side, Rear-end, and Rollover were considered as another layer of segmentation. This sets up the analysis data for this study.

3. ANALYSIS: INDEPENDENCE OF RISK FACTORS: RESTRAINT, MAIS, IMPACT

Based on three classification criteria, restraint use at 2 levels, MAIS at three levels, and impact at 4 levels, the segmented data were arranged in a 2x3x4 contingency table of 24 cells. Each cell in this table can be identified by a combination of the levels of these factors, to be referred to as a 'crash scenario' or 'configuration'. In the subsequent discussion, these terms will be used alternatively.

The analysis data as explained above can be thought of as a sample from a multivariate population with various probabilities and partitions of the categories subject to restrictions, in addition to those of the multinomial distribution. In studying the effectiveness of restraint use, the data were first analyzed to confirm if there were actually an interaction effect of the three factors, i.e., testing the hypothesis of dependence of the three classifications.

Consider the events, defining the incidences related to Restraint, MAIS, and Impact.

Restraint = 1, if the child was restrained,
= 2, if the child was unrestrained;

MAIS = 1, if child suffered no injury (MAIS=0)
= 2, if child suffered minor injury (MAIS=1)
= 3, if child suffered moderate to fatal or serious injury (MAIS=2^+)

Impact = 1, if the crash impact was Frontal,
= 2, if the crash impact was Side,
= 3, if the crash impact was Rear-end,
= 4, if the crash impact was Rollover.

Also, define the joint and marginal probabilities of these events.

$$p_{ijk} = \Pr ob\{\text{Re stra int} = i, \text{MAIS} = j, \text{Im pact} = k\},$$
$$i = 1,2;\ j = 1,2,3;\ k = 1,2,3,4$$

$p_{i...} = \text{Prob}\{\text{Restraint}=i\}, i = 1, 2$
$p_{.j.} = \text{Prob}\{\text{Mais}= j\}, j = 1,2,3$
$p_{..k} = \text{Prob}\{\text{Impact} = k\}, k = 1,2,3,4.$

Using these definitions, the hypotheses of dependence among risk factors can be expressed as

$$H_0 : p_{ijk} \neq p_{i..} p_{.j.} p_{..k}, \text{ for at least one } i, j, k,$$
$$\sum\sum\sum p_{ijk} = 1, \; i = 1,2 \text{ (Restraint)}, \; j = 1, 2, 3 \text{ (MAIS)}, \quad (1)$$
$$\text{and } k = 1, 2, 3, 4 \text{ (Impact)}.$$

Alternatively, the hypothesis of independence can be expressed as

$$H_1 : p_{ijk} = p_{i..} p_{.j.} p_{..k}, \; i = 1, 2 \text{ (restraint)}, \; j = 1, 2, 3 \text{ (MAIS levels)}, \text{ and } k = 1, 2, 3, 4 \text{ (impact type)}$$
(2)

The hypothesis H_0 was tested against H_1 using the information measure

$$I(1:2) = N_{...} \sum_i \sum_j \sum_k p_{ijk} * \log\left(\frac{p_{ijk}}{p_{i..} p_{.j.} p_{..k}}\right) \quad (3)$$

where

$$p_{ijk} = \frac{N_{ijk}}{N...}, \text{ with } N_{...} = \sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{k=1}^{4} N_{ijk}, \text{ and}$$

$$p_{i..} = \frac{\sum_{j=1}^{3}\sum_{k=1}^{4} N_{ijk}}{N_{...}}, \; p_{.j.} = \frac{\sum_{i=1}^{2}\sum_{k=1}^{4} N_{ijk}}{N_{...}}, p_{..k..} = \frac{\sum_{i=1}^{2}\sum_{j=1}^{3} N_{ijk}}{N...} \quad (4)$$

The information measure in (3) is, basically, a measure of the joint relation among row-, column-, and depth categories [3]. If row, column, and depth classifications are independent, the quantity $2I(1:2)$ is asymptotically distributed as χ^2 with 17 degrees of freedom . Based on the analysis data, the information, $2I(1:2) = 2981.9$ (Infants), 4983 (1 to 3 year-olds), 2612 (4 to 8 year-olds), and 6532 (9 to 12 year-olds) is highly significant at 95% confidence level, in favor of H_0. This shows a strong evidence of overall interrelationship among three factors for all age groups.

Having inferred the interrelationship among three classifications, it is of further interest to identify those clusters of the data where this relationship is more significant as compared with other sectors of the data. A micro level categorical analysis can reveal this and in turn can highlight those risk scenarios where the use of restraint systems can be more or less effective.

4. RELATIVE RISK COMPARISON OF RESTRAINED VS. UNRESTRAINED CHILDREN

The relative risk (RR), in general, is a measure of how much a particular risk factor influences the risk of a specified outcome (say, injury sustained by a child due to being unrestrained and having been involved in a frontal impact). For example, a relative risk of 2 associated with this risk factor means that children with that risk factor (unrestrained in a frontal impact) have a 2 fold increased risk of having been injured to the level associated with the configuration as compared to children without that risk factor. Similarly, a relative risk of 0.5 means that the children with the risk factor have half the risk as compared to the children without the risk factor.

Estimation of Relative risk:

In the present context, the risk factor is the combination of Restraint use (i = 1, 2), Injury level (k=1, 2, 3), and Impact type (j=1, 2, 3, 4). As an example, R_{111} is the relative risk associated with infants, for instance, who were restrained, uninjured and involved in frontal impact. The relative risk associated with the ijk-th configuration is given by

$$R_{ijk} = \frac{N_{ijk}}{E_{ijk}} \quad (5)$$

where N_{ijk} and E_{ijk} are, respectively, the observed and expected frequencies corresponding to Restraint = i, MIAS= j, and Impact = k [4]. In terms of the probabilities defined in (2), the relative risk R_{ijk} can be alternatively expressed as

$$R_{ijk} = \frac{p_{ijk}}{p_{i..} p_{.j.} p_{..k}}, i = 1,2, j = 1,2,3, k = 1,2,3,4 \quad (6)$$

Interpretation of results:

The purpose of the analysis in this section is to compare groups of restrained children (with selected injury levels and impact types) to the unrestrained children with the same injury levels and impact types to see if the risk factors have contributed to the level of injury sustained by a child under different risk scenarios. Table 1 through Table 4 show risk factors and the associated relative risks. As an aid for comparison of injury risk for the two groups: restrained and unrestrained, the relative risks are shown as bars on a logarithmic scale in Figure 1 through Figure 4. While interpreting the results presented in these tables and figures, it is important to remember that $R_{ijk} > 1$ shows that more cases were observed than were expected under the assumption of no factor interaction in the ijk-th risk factor combination, also referred to as configuration. On a logarithmic scale in these figures, this case emerges as an upward bar. Similarly, $R_{ijk} < 1$, shows that less than expected cases were observed for the ijk-th risk factor combination. The bars in the figures for such scenarios show as dropping bars. Obviously, in case of no injury (MAIS=0), evidence goes in favor of the restraint use if more than expected children were observed uninjured, i.e., $R_{ijk} > 1$ or if R_{ijk} (restrained) > R_{ijk}(unrestrained). However, in case of minor or serious injury, evidence goes in favor of restraint use if less than expected children were observed injured, i.e., $R_{ijk} < 1$ or if R_{ijk} (restrained) < R_{ijk}(unrestrained) .

4.1 Relative Risk Comparison of Restrained and Unrestrained Children Under 1

Table 1 shows risk factors and the corresponding relative risk for the restrained and unrestrained infants. Correspondingly, the results are also presented in Figure 1. The values of RR for MAIS=0 being greater than 1 (relative risk bars in Figure 1 rising above 1) shows that the restrained infants were protected against any type of injury in frontal, side, and rear-end crashes. Although in rollover crashes, the relative risk for the restrained group is slightly less than 1, it is much greater than the unrestrained group, thereby showing that being unrestrained is much more riskier in rollover crashes.

Similarly, the values of RR being less than 1(relative risk bars in Figure 1 dropping below 1,) the restrained infants have low risk of having minor injury in frontal, side, and rear-end crashes. The relative risk of 9.9 of minor injury in rollover crashes for the unrestrained and 1.4 for the restrained group shows that an unrestrained infant is much more susceptible (about 10 times) to minor injuries as compared with restrained group in rollover crashes.

The third segment in Figure 1 shows that restraint use did provide protection to infants against moderate to serious injuries in frontal and rear-end crashes. The relative risk of 29.1 for the unrestrained and 1.6 for the restrained group in rollover crashes shows that an unrestrained infant is much more at risk (about 18 times) of sustaining moderate to serious injuries as compared with a restrained infant.

Table 1. Risk factors and the associated Relative risks for restrained and unrestrained infants.

RISK FACTOR		RELATIVE RISK (RR)	
MAIS	IMPACT	RESTRAINED	UNRESTRAINED
0	Frontal	1.0109	0.5365
0	Side	1.0782	0.7705
0	Rear-end	1.1062	0.5666
0	Rollover	0.8709	0.0444
1	Frontal	0.8726	4.631
1	Side	0.7438	0.0452
1	Rear-end	0.6186	0
1	Rollover	1.3997	9.0908
2+	Frontal	0.9157	4.3601
2+	Side	0.3087	0.4559
2+	Rear-end	0.3866	2.7414
2+	Rollover	1.6161	29.0755

Data source: NASS-CDS, NHTSA

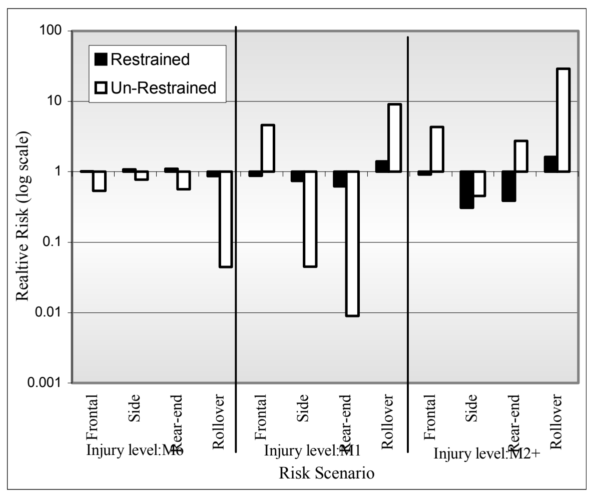

Figure 1. Risk scenarios and the associated Relative risks presented as bars for Restrained and Unrestrained Infants.

4.2 Relative risk comparison of Restrained and Unrestrained children of ages 1 to 3 years

Table 2 shows risk factors and the corresponding relative risk for restrained and unrestrained children of ages 1 to 3 years. Correspondingly, the results are also presented in Figure 2. The relative risks 0.303, 0.349, and 0.76 for MAIS=0 in frontal, side and rollover crashes, respectively, show that there are low chances of protection against injuries for these children when they are unrestrained. In a rollover crash, the relative risk 1.74 of being uninjured for an unrestrained child is higher than 1.09 for a restrained child.

In the case of minor injury, the relative risks 0.88, 0.79, 0.51, respectively, in frontal, side, and rear-end crashes are indicative of low risk of minor injury to 1 to 3 year olds in these types of crash modes. In rollover crashes, the relative risk 10.33 of minor injury to an unrestrained child is about 7 times higher than the relative risk 1.42 to a restrained child.

Table 2. Risk factors and the associated Relative risks for restrained and unrestrained children of ages 1 to 3 years.

RISK FACTOR		RELATIVE RISK (RR)	
MAIS	IMPACT	RESTRAINED	UNRESTRAINED
0	Frontal	1.0882	0.3032
0	Side	1.058	0.3459
0	Rear-end	1.0904	1.74
0	Rollover	0.6188	0.7599
1	Frontal	0.8854	1.5969
1	Side	0.7958	3.2671
1	Rear-end	0.5112	0.1483
1	Rollover	1.4225	10.3345
2+	Frontal	0.7167	1.6512
2+	Side	0.9222	2.2707
2+	Rear-end	0.8828	1.9386
2+	Rollover	1.4773	10.4377

Data source: NASS-CDS, NHTSA

The third segment of Figure 5 shows a comparison of the two groups with respect to moderate to serious injuries. The situation for this injury level is somewhat the same as for other levels of injury. The results for this case in Table 5 and Figure 5 again show that the restrained children have low relative risks of serious injury; being 0.71, 0.92, and 0.88, respectively, for frontal, side, and rear-end crashes.

The risk (10.44) to an unrestrained child in rollover crashes is about 10 times higher than the relative risk (1.48) to a restrained child.

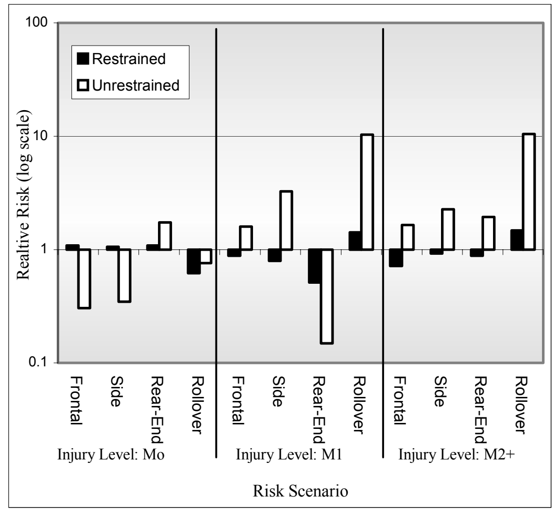

Figure 2. Risk scenarios and the associated Relative risks presented as bars for Restrained and Unrestrained children of ages 1 to 3 years.

4.3 Relative risk comparison of Restrained and Unrestrained children of ages 4 to 8 years

Table 3 and Figure 3 show risk factors and the corresponding relative risks for restrained and unrestrained 4 to 8 year olds. Comparison of relative risks for the two groups: restrained and unrestrained in Table 3 or the corresponding Figure 3 shows that in side, rear-end, and rollover crashes, these children have greater chance (RR>1) of being uninjured when they are restrained. The relative risk 0.95 of no injury for the restrained group and 0.47 for the unrestrained in frontal crashes show that there are lower chances of an unrestrained child being uninjured as compared with a restrained child. In the case of minor injury, the restrained children showed a low risk in side, rear-end, and rollover crashes. These children have a higher risk 1.6 of sustaining minor injury in frontal crashes when they are unrestrained as compared with restrained children who have a relative risk of 1.15. Also, the restrained children of this age group have much lower relative risks of moderate to serious injuries: 0.47 in frontal, 0.80 in side, 0.15 in rear-end, and 0.24 in rollover crashes. In fact, correspondingly, the relative risks for the unrestrained group were, respectively, 7.7, 7.6, 13.3, and 23.6 times higher than the restrained children.

Table 3. Risk factors and the associated Relative risks for restrained and unrestrained children of ages 4 to 8 years.

RISK FACTOR		RELATIVE RISK (RR)	
MAIS	IMPACT	RESTRAINED	UNRESTRAINED
0	Frontal	0.9534	0.4716
0	Side	1.25284	0.52181
0	Rear-end	1.42773	0.3928
0	Rollover	1.03627	0.98064
1	Frontal	1.15827	1.59928
1	Side	0.63271	0.84333
1	Rear-end	0.48905	0.55191
1	Rollover	0.64491	3.00161
2+	Frontal	0.47209	3.62583
2+	Side	0.80188	6.1002
2+	Rear-end	0.15117	2.00729
2+	Rollover	0.24525	5.79946

Data source: NASS-CDS, NHTSA

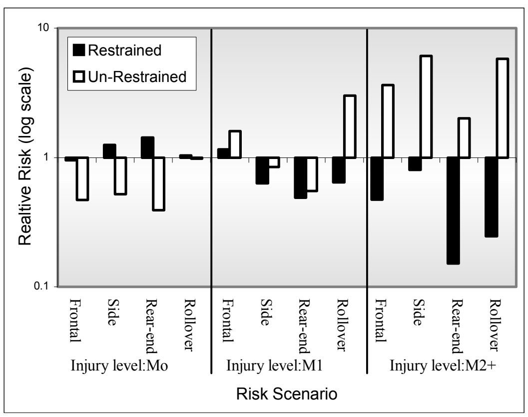

Figure 3. Risk scenarios and the associated Relative risks presented as bars for Restrained and Unrestrained children of ages 4 to 8 years.

4.4 Relative risk comparison of Restrained and Unrestrained 9 to 12 years old children

Table 4 shows risk factors and the corresponding relative risks for restrained and unrestrained children of ages 9 to 12 years old. These results are also presented in Figure 4. The relative risks (>1) of no injury: 1.07 in frontal, 1.13 in rear-end, and 1.45 in rollover crashes for the restrained group show that the restraint use provided protection against injuries to these children in frontal, rear-end, and rollover crashes. Also, the relative risk of sustaining injuries for these children in side impacts was higher for the unrestrained children.

The relative risks of minor injury in the case of frontal, side, and rollover crashes being smaller than 1, the restraint use was beneficial in these types of impacts. The relative risks of serious to moderate injuries: 0.81 in frontal, 0.87 in side, 0.68 in rear-end, and 0.79 in rollover crashes for the restrained group show that the restraint was protective for 9 to 12 years old children against moderate to serious injuries in these types of crashes

Table 4. Risk factors and the associated Relative risks for restrained and unrestrained children of ages 9 to 12 years.

RISK FACTOR		RELATIVE RISK (RR)	
MAIS	MAIS	RESTRAINED	UNRESTRAINED
0	Frontal	1.07126	0.67079
0	Side	0.88159	0.68854
0	Rear-end	1.12815	0.86815
0	Rollover	1.45299	0.27941
1	Frontal	0.98574	1.17309
1	Side	0.89873	2.6549
1	Rear-end	1.00757	0.53779
1	Rollover	0.51268	0.8082
2+	Frontal	0.81206	1.16263
2+	Side	0.87419	1.76099
2+	Rear-end	0.67774	0.75465
2+	Rollover	0.78829	5.36293

Data source: NASS-CDS, NHTSA

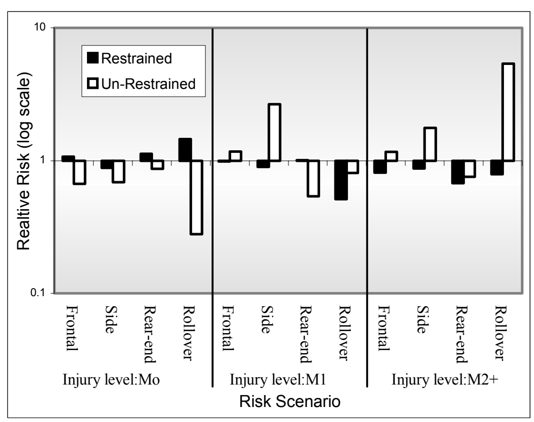

Figure 4. Risk scenarios and the associated Relative risks presented as bars for Restrained and Unrestrained children of ages 9 to 12 years.

5. IDENTIFICATION OF CLUSTERS WITH LIMITED DATA

Sample sizes in some of the 24 cells appeared to be small. However, whether a cell sample size is actually small depends on the purpose for which it is used. In the present context, the end objective is to compare injury risk to a restrained and unrestrained child under different risk scenarios. This was done by comparing the relative risks associated with the risk scenarios considered in this study. It is, therefore, important to precisely estimate RR. An important concept embodied in the confidence limits of an estimate is the precision of estimation. The wider the confidence interval, the less is its precision. This concept was exploited to assess the precision of RR for different configurations, using the width of the confidence limits as a yardstick for comparison. Using the normal approximation for the probability distribution of RR, defined in (5), the 95% confidence limits were computed for each of the four age groups. Figure 5 shows the lower and upper limits of RR associated with each configuration for the four age groups.

The results (width of the confidence interval) show that the sample sizes in segments: 11, 15, 18, 20, 22, 23, and 24 for age group $0 \leq Age < 1$; 15, 19, 22, 23, and 24 for age group $1 \leq Age \leq 3$; 11, 15, and 23 for age group $4 \leq Age \leq 8$; and 11, 15, 19, and 24 for age group $9 \leq Age \leq 12$ were not sufficiently large to precisely estimate RR. Therefore, care must be taken to interpret results for these scenarios.

6. CONFIGURAL FREQUENCYANALYSIS: STRNGTH OF FACTOR ASSOCIATION FOR EACH RISK SCENARIO

The multivariate analysis technique, Configural Frequency Analysis (CFA) was used to examine every configuration, i.e., risk scenario (e.g., an unrestrained child who suffered severe injury in frontal impact crash) to determine how close the observed frequencies are to the expected frequencies. A first order CFA model was used, meaning that the variables (factors) are totally independent of each other, i.e., they are assumed to be not associated in pairs or triplets in every configuration. However, main effects are assumed to exist. For this analysis, alpha, the significance level α, was set to 0.05, which after the

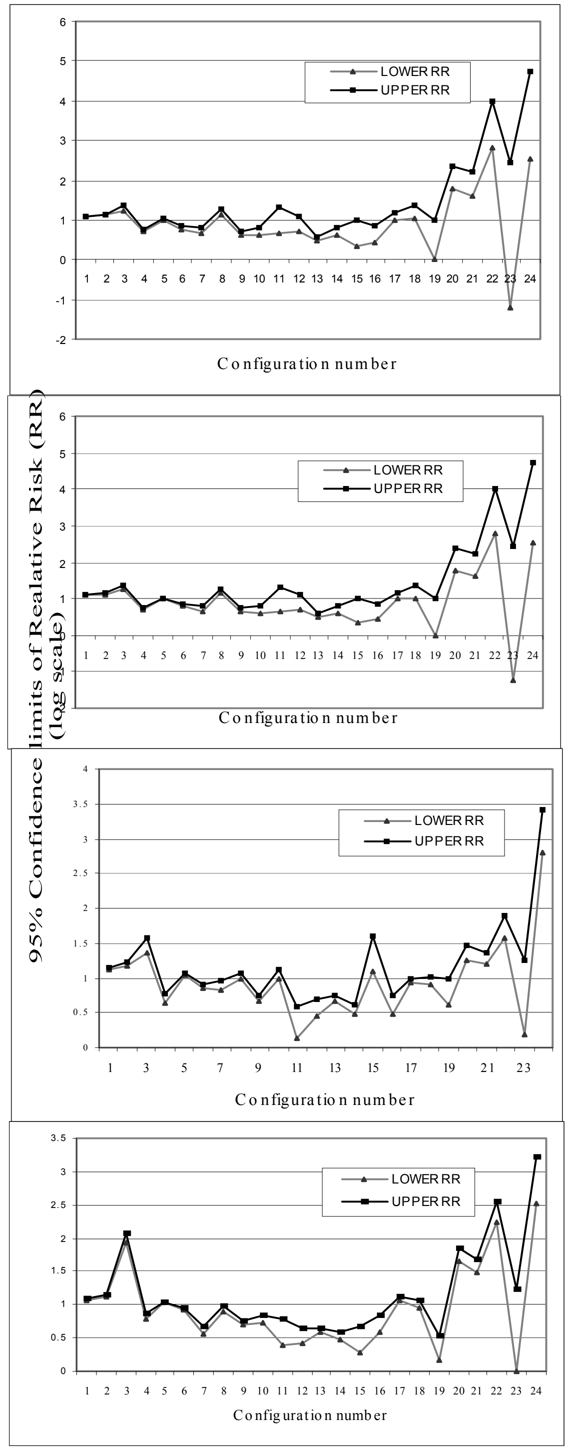

Figure 5. 95% confidence limits for 24 configurations in four age groups: infants, 1 to 3, 4 to 8, and 9 to 12 year olds.

Bonferroni adjustment reduces to $\alpha^* = 0.0021$, where $\alpha / \text{Number of configurations}$. Z-test (Standard normal test) was applied to determine if the deviation of an observed (N) frequency from an expected (E)

frequency is significantly large to conclude the presence of factor interaction for a risk scenario. Assuming $H_0 : N_{ijk} = E_{ijk}$ is true, the statistic

$$Z = \frac{N_{ijk} - E_{ijk}}{\sqrt{E_{ijk}}}, i = 1,2, j = 1,2,3, k = 1,2,3,4 , \qquad (7)$$

is distributed as standard normal. This test statistic will be used to test the hypothesis H_0 against the alternative H_A: $N_{ijk} \neq E_{ijk}$ meaning the presence of factor interaction for the ijk-th configuration. The results for four age groups of crash-involved children are presented in Table 5 through Table 8 that show risk scenarios and the corresponding Z- and p-values.

A positive or negative significant Z-value (with p-value smaller than α^*= 0.0021) corresponding to a risk scenario is indicative of the presence of factor interaction in the corresponding cluster of children in an age group.

6.1 Risk factor association for Infants

Table 5 shows risk scenarios and the corresponding Z- and p-values for infant population. Comparison of p-values with the adjusted level of significance $\alpha^* = 0.0021$ shows that for all but one configuration, '111', the deviations are significant.

However, the configurations 111, 133, 134 in the restrained category and 213, 214, 222, 223, 224, 232, 233, and 234 in the unrestrained cases will be omitted from discussion of results due to insufficiency of their sample sizes, as assessed in the previous section. Significant positive values of Z for configurations 112 and 113 and significant negative Z-values for the configurations 121, 122, 131, and 132, show strong evidence in favor of the hypothesis $H_A : N_{ijk} \neq E_{ijk}$. This in turn means that in clusters of infant population as defined by these configurations, in addition to main effects, there is an evidence of significant interaction of the factors: restraint use, injury level, and crash impact mode.

Table. 5 95% Significance of difference between observed and expected frequencies of configurations and relative risk for infants

CONFIGU-RATION	RESTRAINT STATUS	MAIS	IMPACT	Z-VALUE	p-VALUE
111	Restrained	0	Frontal	2.8076	0.002
112	Restrained	0	Side	14.3067	0
113	Restrained	0	Rear-end	10.0471	0
114	Restrained	0	Rollover	-11.7849	0
121	Restrained	1	Frontal	-12.818	0
122	Restrained	1	Side	-18.3208	0
123	Restrained	1	Rear-end	-14.1039	0
124	Restrained	1	Rollover	14.2687	0
131	Restrained	2+	Frontal	-3.1204	0.0009
132	Restrained	2+	Side	-18.188	0
133	Restrained	2+	Rear-end	-8.3477	0
134	Restrained	2+	Rollover	8.0932	2.2E-16
211	Unrestrained	0	Frontal	-30.1682	0
212	Unrestrained	0	Side	-10.6158	0
213	Unrestrained	0	Rear-end	-10.3713	0
214	Unrestrained	0	Rollover	-22.0752	0
221	Unrestrained	1	Frontal	92.399	0
222	Unrestrained	1	Side	-17.2721	0
223	Unrestrained	1	Rear-end	-9.3571	0
224	Unrestrained	1	Rollover	73.0809	0
231	Unrestrained	2+	Frontal	31.4632	0
232	Unrestrained	2+	Side	-3.6221	0.0001
233	Unrestrained	2+	Rear-end	5.9959	1E-09
234	Unrestrained	2+	Rollover	93.315	0

Data source: NASS-CDS, NHTSA

6.2 Risk factor association for 1 to 3 year old children

Table 6 shows risk scenarios and the corresponding Z- and p-values for children in the age group: 1 to 3 years. Comparison of p-values with the adjusted level of significance $\alpha^* = 0.0021$ shows that the Z-values (positive or negative) for all configurations are significant. However, this inference for configurations 133, 213, 214, 223, 233, 234 is not based on sufficient sample size as shown in an earlier section. These configurations will therefore be excluded in the following discussion.

Following the same argument as for infants, significant positive Z-values for 111, 112, 113, 124 and significant negative value of Z for configurations 114, 121, 123

131, and 132 show strong evidence for significant factor interaction in clusters of 1 to 3 year olds population, as defined by these configurations.

Table. 6 95% Significance of difference between observed and expected frequencies of configurations and relative risk for 1 to 3 Years Old Children

CONFIGU-RATION	RESTRAINT STATUS	MAIS	IMPACT	Z-VALUE	p-VALUE
111	Restrained	0	Frontal	42.218	0
112	Restrained	0	Side	22.69	0
113	Restrained	0	Rear-end	21.45	0
114	Restrained	0	Rollover	-69.03	0
121	Restrained	1	Frontal	-29.098	0
122	Restrained	1	Side	-42.434	0
123	Restrained	1	Rear-end	-61.553	0
124	Restrained	1	Rollover	40.615	0
131	Restrained	2+	Frontal	-20.931	0
132	Restrained	2+	Side	-4.707	1.2E-06
133	Restrained	2+	Rear-end	-4.293	8.8E-06
134	Restrained	2+	Rollover	13.349	0
211	Unrestrained	0	Frontal	-103.239	0
212	Unrestrained	0	Side	-79.302	0
213	Unrestrained	0	Rear-end	54.368	0
214	Unrestrained	0	Rollover	-13.467	0
221	Unrestrained	1	Frontal	46.946	0
222	Unrestrained	1	Side	145.889	0
223	Unrestrained	1	Rear-end	-33.215	0
224	Unrestrained	1	Rollover	277.861	0
231	Unrestrained	2+	Frontal	14.901	0
232	Unrestrained	2+	Side	23.793	0
233	Unrestrained	2+	Rear-end	10.65	0
234	Unrestrained	2+	Rollover	81.742	0

Data source: NASS-CDS, NHTSA

6.3 Risk factor association for 4 to 8 years old children

Table 7 shows risk scenarios and the corresponding Z- and p-values for 4 to 8 year olds. Comparison of p-values with the adjusted level of significance $\alpha^* = 0.0021$ shows that only for configuration 214 the z-value is not significant. Of the remaining clusters, sample sizes for configurations 133, 213, and 233 are not large enough as established earlier. The results for all other risk scenarios in Table 7 show significant factor interaction in clusters of 4 to 8 year olds population.

Table 7. 95% Significance of difference between observed and expected frequencies of configurations and relative risk for 4 to 8 Years Old Children

CONFIGU-RATION	RESTRAINT STATUS	MAIS	IMPACT	Z - VALUE	p-VALUE
111	Restrained	0	Frontal	-25.665	0
112	Restrained	0	Side	90.224	0
113	Restrained	0	Rear-end	80.71	0
114	Restrained	0	Rollover	10.142	0
121	Restrained	1	Frontal	63.506	0
122	Restrained	1	Side	-95.484	0
123	Restrained	1	Rear-end	-70.239	0
124	Restrained	1	Rollover	-72.327	0
131	Restrained	2+	Frontal	-61.778	0
132	Restrained	2+	Side	-15.021	0
133	Restrained	2+	Rear-end	-34.032	0
134	Restrained	2+	Rollover	-44.836	0
211	Unrestrained	0	Frontal	-111.908	0
212	Unrestrained	0	Side	-65.616	0
213	Unrestrained	0	Rear-end	-44.058	0
214	Unrestrained	0	Rollover	-2.082	0.018
221	Unrestrained	1	Frontal	92.465	0
222	Unrestrained	1	Side	-15.661	0
223	Unrestrained	1	Rear-end	-23.687	0
224	Unrestrained	1	Rollover	156.776	0
231	Unrestrained	2+	Frontal	118.162	0
232	Unrestrained	2+	Side	148.697	0
233	Unrestrained	2+	Rear-end	15.529	0
234	Unrestrained	2+	Rollover	109.636	0

Data source: NASS-CDS, NHTSA

6.4 Risk factor association for 9 to 12 years old children

Table 8 shows risk scenarios and the corresponding Z- and p-values for crash involved children of ages 9 to 12 years. Comparison of p-values with the adjusted level of significance $\alpha^* = 0.0021$ shows that except configuration 123, the z-values for all configurations are significant. However, of the remaining clusters, clusters defined by configurations 133, 213, 223, and 234 have insufficient sample sizes. Thus, except for these clusters and the one corresponding to configuration 123, the factor interaction is significant.

Table 8. 95% Significance of the difference between observed and expected frequencies of configurations and relative risk for 9 to 12 Years Old Children

CONFIGU-RATION	RESTRAINT STATUS	MAIS	IMPACT	Z-VALUE	p-VALUE
111	Restrained	0	Frontal	28.41	0
112	Restrained	0	Side	-33.392	0
113	Restrained	0	Rear-end	24.125	0
114	Restrained	0	Rollover	93.482	0
121	Restrained	1	Frontal	-4.649	0
122	Restrained	1	Side	-23.353	0
123	Restrained	1	Rear-end	1.165	0.12208
124	Restrained	1	Rollover	-82.231	0
131	Restrained	2+	Frontal	-21.884	0
132	Restrained	2+	Side	-10.363	0
133	Restrained	2+	Rear-end	-17.72	0
134	Restrained	2+	Rollover	-12.761	0
211	Unrestrained	0	Frontal	-62.795	0
212	Unrestrained	0	Side	-42.024	0
213	Unrestrained	0	Rear-end	-11.876	0
214	Unrestrained	0	Rollover	-71.147	0
221	Unrestrained	1	Frontal	26.997	0
222	Unrestrained	1	Side	182.581	0
223	Unrestrained	1	Rear-end	-34.042	0
224	Unrestrained	1	Rollover	-15.485	0
231	Unrestrained	2+	Frontal	9.061	0
232	Unrestrained	2+	Side	29.99	0
233	Unrestrained	2+	Rear-end	-6.455	0
234	Unrestrained	2+	Rollover	125.82	0

Data source: NASS-CDS, NHTSA

7. DISCUSSION OF RESULTS

It is generally believed that an age appropriate restraint system, if used properly according to NHTSA's guidelines, 'Child Passenger Safety- A Parents primer' http://www.boosterseat.gov/CPSpostcard.pdf can provide protection to a child against different types of crash modes. Based on ten years of field data, this study statistically investigated how restrained and unrestrained children were injured in different crash modes. Preliminary statistical screening of the segmented data (based on age, restraint, injury, and impact mode) revealed that sample sizes in some sectors of the data were not large enough to statistically validate the findings. The reason for limited or insufficient data could either be the rare occurrence of certain risk factor combinations or the result of insufficient attention in collecting the pertinent data. This shows the necessity of collecting more data in such sectors of the data so that valid conclusions could be drawn about restraint systems effectiveness. The question, however, remains as to how much and how these sample sizes should be increased. The research on this issue is underway at NHTSA.

As regards the effectiveness of restraint use, it was found, in general, that for both infants and 1 to 3 year olds, restraint use was effective in all crash modes. For 4 to 8 year olds, being restrained was beneficial in side as well as rear-end impacts. The relative risk of injury to these children in frontal and rollover crashes was greater when they were unrestrained. The restrained 9 to 12 years old children were found safer against injuries in frontal, rear-end, and rollover crashes and had higher risk of injuries in side impacts. The results show the overall effectiveness of restraint use in protecting the children from different crash impacts. As minor injuries typically result from things, such as flying glass, interior surfaces, etc., a considerably large number of cases falling in the category of MAIS=1 shows success of CRS in protecting children.

The level of injury to a child may further depend on whether the frontal impact was full, offset, or center and side impact was near-side or far-side. Although accounting for these details was considered important while conducting this study, due to the resulting smaller cell sample sizes, the results could not be statistically validated. In addition, factors, such as impact speed and vehicle incompatibility are some of the vehicle related parameters that can be considered in the model.

8. REFERENCES

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