ACCELERATION-BASED OCCUPANT INJURY CRITERIA FOR PREDICTING INJURY IN REAL-WORLD CRASHES

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ABSTRACT

This paper presents an estimate of the probability of serious occupant injury in frontal crashes based on two vehicle acceleration-based metrics: the 10 ms peak acceleration and the 50 ms peak acceleration. Both of these metrics are used to evaluate injury potential in crash test involving roadside hardware, such as guardrail. For this study, Event Data Recorder (EDR) data provides vehicle kinematics information for real world crashes with known injury outcomes. Based on a data set of 180 cases, binary logistic regression was used to generate injury risk curves for belted and unbelted occupant data subsets. Model fit statistics and a Receiver Operator Characteristic (ROC) analysis was then used to compare the injury predictive capability of these two metrics. No statistically significant difference was found between the injury prediction capabilities of the 10 ms and 50 ms peak acceleration metrics.

Keywords: Acceleration, Crash Injury Criteria, Event Data Recorders, Roadside Hardware

INTRODUCTION

Maximum change in vehicle velocity, or delta-v, has been the traditional metric used to predict injury in real-world crashes. Delta-v is typically estimated by measuring the post-crash vehicle deformation. Researchers have long correlated this metric to occupant injury outcome [1]-[4]. Acceleration-based metrics provide an alternative to delta-v and have been used in full-scale crash tests to assess occupant injury risk. For crash tests involving roadside hardware, e.g. guardrail, the peak acceleration computed using a 50 ms moving average (i.e. 50 ms peak acceleration metric) has been used in the past to estimate occupant risk [5]. In the current procedures, a 10 ms moving average procedure (i.e. 10 ms peak acceleration metric) is used in the “occupant ridedown” portion of occupant risk evaluation in the US [6] and a variant of the 50 ms peak acceleration metric is used in Europe [7]. Traditionally, these acceleration-based metrics have been limited to crash tests as detailed kinematics data for real-world crashes has not been available.

With the installation of Event Data Recorders (EDRs) in many late model vehicles, however, there is the possibility of capturing vehicle kinematics for real-world crashes. Information stored by these manufacturer-specific devices includes vehicle change in velocity versus time, seat belt status, airbag deployment status, and vehicle speed prior to impact [8]. EDRs typically provide a more accurate depiction of the crash pulse with accuracy within 6% of the true delta-v [9]. The National Highway Traffic Safety Administration (NHTSA) has collected EDR data from over 2200 General Motors (GM) cars and light trucks involved in traffic collisions in the United States from year 2000 through 2005. This EDR data was collected in conjunction with the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) program. NASS/CDS data is collected by field investigators and provides detailed injury outcomes from a random sample of roughly 5,000 vehicular crashes in the US each year.

Several researchers have investigated how mean and peak accelerations affect occupant injury risk [10]-[12]. There has been no investigation, however, of whether there is an advantage to using the 10 ms or 50 ms
peak acceleration metrics to predict occupant injury. This would be particularly useful to the roadside safety community, which currently employ these vehicle-based metrics.

**OBJECTIVE**

The specific goals of this study are (1) to develop injury risk functions using the 10 ms and 50 ms peak acceleration metrics as predictors and (2) to compare these two acceleration-based measures in terms of ability to predict serious occupant injury in real-world crashes.

**METHODS**

The general approach consisted of selecting appropriate cases from the available NASS/CDS cases with matched GM EDR data, computing the 10-ms and 50-ms maximum average accelerations for each case, fitting binary logistic regression models, and comparing the metrics. Cases suitable for analysis were chosen based on the following criteria: (1) airbag deployment, (2) comprised of only a single impact, (3) complete velocity versus time data stored in the EDR, (4) a frontal collision, and (5) known injury data for the left front seat occupant. The first two criteria ensure that the data recorded by the EDR correspond to the injury-causing event. To ensure that the EDR captured the entire crash pulse, all cases are required to have velocity profiles that converge to a constant value (i.e., zero acceleration). Only frontal collisions were considered since the GM EDR only records change in velocity information in the longitudinal direction. For the purpose of this study, a frontal collision was defined as damage to the front of the vehicle and an impulse vector direction ± 10 degrees of the vehicle’s longitudinal axis. In addition, injury to the driver must be known. Based on these selection criteria, a total of 180 cases were available for analysis with 145 belted and 35 unbelted occupants.

EDR velocity data was used to compute the average peak accelerations for each case. For the 50 ms peak acceleration, the difference in velocity was found at points 50 ms apart and then divided by 0.05 seconds, as shown in the equation below. Note that $a$ is acceleration, $v$ is velocity, $\Delta t$ is the time step, and $\Delta t_{TOTAL}$ is the moving average time window, which is 50 ms in this case.

$$
\bar{a}(t_i) = 50 \text{ ms moving average} = \frac{\sum_{i-5}^{i} a(t_i) \Delta t}{\Delta t_{TOTAL}} = \frac{\sum_{0}^{i} a_i \Delta t - \sum_{0}^{i-5} a_i \Delta t}{\Delta t_{TOTAL}} = \frac{v_i - v_{i-5}}{0.05s}
$$

The largest absolute 50-ms acceleration value was selected and then converted to G units. A similar procedure was used for the 10 ms average, except the difference in velocity was found at points 10 ms apart and then divided by 0.01 seconds. Note that the averages are only computed for known velocity points. For instance, if a pulse is 50 ms in duration, only a single 50-ms average acceleration is computed from the EDR data (0–50 ms). Similarly, because the GM EDR provides the velocity information in 10 ms increments, the 50 ms and 10 ms averages are available only in 10 ms increments until the end of the velocity pulse. Twenty-seven (27) New Car Assessment Program (NCAP) frontal barrier tests conducted by the NHTSA were examined to estimate the accuracy of the computations outlined above. Each car tested had GM EDR data available in conjunction with the more detailed vehicle acceleration data typically recorded for the test. For the 10 ms average acceleration, the EDR error (compared with the lab grade instrumentation) was 6.9 percent on average with a range between 0.4 and 18 percent. For the 50 ms average acceleration, the EDR error was 7.1 percent on average with a range between 0.3 and 18.2 percent.
The AIS scale is an injury severity metric that measures threat to life based on a 0 to 6 scale; zero corresponds to no injury while six corresponds to maximum or fatal injury [13]. In NASS/CDS, each injury is rated according to this scale and the highest AIS value of all injuries to an occupant is referred to as the maximum occupant AIS (MAIS) value. For this study, two injury threshold levels were used to define “serious” injury: (1) a maximum AIS value of 3 or greater (MAIS 3+), and (2) MAIS 2+. For each of these threshold definitions, injury risk curves were generated for both acceleration predictors for two data subsets: (1) belted and airbag restrained occupants (referred to hereafter as ‘belted’) and (2) airbag-only restrained occupants (referred to hereafter as ‘unbelted’). The models were compared using various fit statistics and a Receiver Operating Characteristic (ROC) curve analysis. All statistical analyses were completed with the SAS® version 9.1 software.

RESULTS

The results of the MAIS 3+ binary logistic regressions for the unbelted and belted data subsets are shown in Figure 1 and Figure 2, respectively. Both figures show the model predicted cumulative probability of MAIS 3+ injury as a function of either 10 ms (dashed) or 50 ms (solid) peak vehicle acceleration. The corresponding shaded areas represent the 95 percent confidence bounds. The data points are also plotted as a function of each predictor; note that a value of “1” corresponds to the “serious” injury group. For the belted subset, all tests for the global null hypothesis were significant to the 0.0002 level while the unbelted subset was significant to the 0.0053 level or better. As both predictors are continuous, the Hosmer and Lemeshow test is used to determine goodness-of-fit. All models generated statistically adequate (>0.05) fits with Hosmer and Lemeshow values of 0.0712 or greater. Table 1 presents the 10 ms and 50 ms peak accelerations that correspond to a 25 and 50 percent risk of MAIS 2+ and MAIS 3+ occupant injury.

![Figure 1. Probability of Serious Occupant Injury – Unbelted (Airbag Restrained Only Occupants)](image-url)
Table 1. Peak Acceleration Thresholds for a 50 Percent Probability of Serious Occupant Injury

<table>
<thead>
<tr>
<th>Injury Level</th>
<th>Data Subset</th>
<th>Probability of Serious Injury (%)</th>
<th>Peak 10 ms Average Acceleration (G)</th>
<th>Peak 50 ms Average Acceleration (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Belted</td>
<td>25</td>
<td>26.7</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>34.1</td>
<td>26.0</td>
<td></td>
</tr>
<tr>
<td>3+</td>
<td>Unbelted</td>
<td>25</td>
<td>17.4</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>23.3</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td>2+</td>
<td>Belted</td>
<td>25</td>
<td>16.0</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>23.7</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unbelted</td>
<td>25</td>
<td>12.0</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>17.9</td>
<td>13.5</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Probability of Serious Occupant Injury – Belt and Airbag Restrained Occupants

Table 2 summarizes how well each model predicts the original data set assuming that a probability of serious injury greater than 50 percent results in “serious” occupant injury. “Correct” refers to the percentage of correct predictions. Sensitivity is a numerical measure of how well the model can predict serious injury when serious injury is observed while specificity is a measure of how well the model can avoid predicting injury when no injury is present. A value of 100 percent in each of the three categories would denote a model that matches the observed data perfectly. Also, larger maximum rescaled R² values indicate a better model fit. Maximum rescaled R² is a logistic regression measure of fit analogous to the R² used in linear regression.

ROC comparison was used to further compare the 10 ms and 50 ms acceleration metrics. Figure 3 provides a graphical comparison of the ROC curves for the MAIS 3+ data. Referring to the figure, note that an ROC curve that follows the diagonal offers no advantage over random guessing while a curve that follows the left and upper bounds of the plot is a perfect predictor. The area under the ROC curve provides a
means of statistically comparing different predictors. Pairwise comparisons of the area under the ROC curve for both predictors are summarized in the rightmost column of Table 2.

Table 2. Summary of MAIS 2+ and MAIS 3+ Model Fit Parameters and ROC Comparison

<table>
<thead>
<tr>
<th>Injury Level</th>
<th>Data Subset</th>
<th>Predictor</th>
<th>Max Rescaled R²</th>
<th>Correct (%)*</th>
<th>Sensitivity (%)*</th>
<th>Specificity (%)*</th>
<th>ROC P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+</td>
<td>Belted</td>
<td>10 ms</td>
<td>0.2857</td>
<td>92.4</td>
<td>23.1</td>
<td>99.2</td>
<td>0.867</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 ms</td>
<td>0.2645</td>
<td>92.4</td>
<td>15.4</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unbelted</td>
<td>10 ms</td>
<td>0.4949</td>
<td>77.1</td>
<td>58.3</td>
<td>87.0</td>
<td>0.111</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 ms</td>
<td>0.7026</td>
<td>80.0</td>
<td>66.7</td>
<td>87.0</td>
<td></td>
</tr>
<tr>
<td>2+</td>
<td>Belted</td>
<td>10 ms</td>
<td>0.2840</td>
<td>82.1</td>
<td>38.9</td>
<td>96.3</td>
<td>0.963</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 ms</td>
<td>0.2696</td>
<td>79.3</td>
<td>33.3</td>
<td>94.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unbelted</td>
<td>10 ms</td>
<td>0.4855</td>
<td>77.1</td>
<td>70.6</td>
<td>83.3</td>
<td>0.086</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 ms</td>
<td>0.6567</td>
<td>85.7</td>
<td>82.4</td>
<td>88.9</td>
<td></td>
</tr>
</tbody>
</table>

*Reported for P(Injury) = 50 percent

Figure 3. MAIS 3+ ROC Curve Comparison: Belted Occupants (left) and Unbelted Occupants (right)

DISCUSSION

Binary logistic regression models were used to correlate occupant injury in frontal crashes to the 10 ms and 50 ms acceleration injury metrics for MAIS 2+ and MAIS 3+ injury levels. As expected, unbelted occupants were found to have a higher risk of injury at the same peak vehicle acceleration. Also, both acceleration criteria predicted injury better for unbelted occupants as evident by the higher maximum rescaled R² values and higher sensitivities in Table 2. This was also evident graphically in Figure 3 as the unbelted ROC curves tend to follow the left and upper bounds of the plot more closely. All of the models poorly predicted injury when injury occurred in belted occupants. This is evident by the fact that no sensitivity values for the belted subset exceeded 40 percent. Interestingly, a variant of the 50 ms peak acceleration metric is used in European roadside crash test procedures with the assumption that average acceleration provides a better prediction of occupant injury risk to occupants restrained by a seatbelt.

Based on the maximum rescaled R² values in Table 2, the 50 ms peak acceleration metric appears to have an advantage for predicting injury to unbelted occupants while the 10 ms peak acceleration appears to be a better discriminator of injury to belted occupants. In all cases, however, the ROC comparison p-values...
exceed 0.05 suggesting no statistically significant difference between the areas under the respective ROC curves. This implies no statistically significant difference in injury predicting capability between the 10 and 50 ms average acceleration metrics for either belted or unbelted occupants. Although no statistically significant differences are noted, the p-values for the unbelted data are substantially less than those for the belted data, suggesting a larger difference between the 50 ms and 10 ms metrics for predicting injury to unbelted occupants. This issue should be revisited once more data becomes available for analysis, especially given that the current analysis only includes 35 unbelted occupants.

CONCLUSIONS

This paper has developed injury risk curves relating the probability of serious injury to the 10 ms and 50 ms peak vehicle accelerations based on the injury outcomes 180 occupants subjected to a frontal crash. For occupants restrained by a belt and airbag, a 50 percent probability of serious (MAIS 3+) occupant injury was found to correspond to a 10 ms and 50 ms peak vehicle acceleration of 34.1 and 26.0 G, respectively. Likewise, for unbelted occupants, probability of serious occupant injury was found to correspond to a 10 ms and 50 ms peak vehicle acceleration of 23.3 and 16.9 G, respectively. Using the developed risk curves as a basis for an ROC comparison, there was no statistically significant difference in injury predictive capability found between the 10 ms and 50 ms peak acceleration metrics.

ACKNOWLEDGMENTS

The authors gratefully acknowledge NHTSA for the provision of the data used for the study and Dr. Priya Prasad for his insights into this problem.

REFERENCES