INVITED DISUSSION: "ROOF STRENGTH AND INJURY RISK IN ROLLOVER CRASHES"

Jeya Padmanaban (JP Research, Inc., Mountain View, CA, USA)
Edward A. Moffatt (Biomech, Inc., Orinda, CA, USA)

ABSTRACT

When using crash data to study the influence of roof strength on injury, it is essential to consider all factors that might affect the likelihood of injury. For example, if it is known that rural rollovers tend to be more severe than urban rollovers, then the analysis should control for rural vs. urban because some vehicles may have more rural crashes than others. The statistical study that considers these extraneous influences is more accurate than the study that ignores them.

Unfortunately, the current paper by the Insurance Institute for Highway Safety (IIHS), "Roof Strength and Injury Risk in Rollover Crashes" (IRCOBI Conference, 2008), ignores many of the important confounding factors that would influence their results. When these errors are corrected, the IIHS data are consistent with the results of prior research: that there is no relationship between roof strength-to-weight ratio and serious injury/fatality likelihood for vehicles which comply with FMVSS 216.

Keywords: Rollover Accidents, Roof Strength, Injury Risk

THE ABSTRACT TO THE IIHS REPORT STATES: "Federal Motor Vehicle Safety Standard (FMVSS) 216 regulates minimum roof strength, but no study to date has established a relationship between performance in this or any other test condition and occupant protection in real-world rollover crashes." This statement is incorrect.

Two previous, more extensive studies addressed this issue and both reached conclusions directly opposite to those of the IIHS (Moffatt and Padmanaban, 1995) and (Padmanaban et al., 2005). The two previous studies controlled for belt use, ejection, driver age, gender, alcohol, rural/urban, aspect ratio, number of doors, drive wheels, roof damage, vehicle age, vehicle weight, and roof strength. Furthermore, these studies reported that belt use, ejection, alcohol, vehicle aspect ratio, gender, rural/urban, and driver age all influence the likelihood of injury/fatality. These two previous analyses of state data involved 60,000 and 100,000 single-vehicle rollovers, respectively, and both found that there was no relationship between vehicle roof strength-to-weight ratio and likelihood of serious/fatal injury.

The current IIHS study used police-reported crash data from 12 states for 11 midsize four-door sport utility vehicle (SUV) platforms involved in 23,000 single-vehicle rollovers, and used logistic regression to assess the relationship between vehicle roof strength-to-weight ratio (which they termed "SWR") and odds of serious injury or fatality. Yet when the IIHS performed the current study, they ignored those variables that had previously been reported to be significant for injury outcome and controlled only for driver age, static stability factor, and state.

For these Comments, we performed statistical analyses replicating the IIHS data. While our raw data counts do not differ significantly from theirs, our studies have important differences in their statistical interpretation and their conclusions. The failure of the IIHS study to control for confounding factors known to affect injury outcome (belt use, alcohol, rural/urban, gender, aspect ratio, and ejection) led to erroneous conclusions. When these deficiencies were addressed, their data showed the same results presented in the 1995 and 2005 studies by Padmanaban and Moffatt. Specifically, like these previous studies, the IIHS

data shows roof strength-to-weight ratio is not significant in influencing odds of fatality/serious injury in rollovers.

These Comments address some of the confounding factors that the IIHS study ignores.

RURAL OR URBAN

The severity of a rollover is often related to the environment where it occurs. Numerous studies have demonstrated that collisions in rural areas are more likely to be severe that those in urban areas.

The 2005 NHTSA Report, "Contrasting Rural and Urban Fatal Crashes 1994-2003," offers the following findings**:** Rural crashes tend to be more severe, cause greater injury, involve higher concentrations of blood alcohol, have more than twice the ejection rate, and involve lower belt usage rates than urban crashes.

Figure 3 from NHTSA's "Traffic Safety Facts 2006 Data" (NHTSA, 2008) is reprinted here as Figure 1. This figure confirms previous findings and adds that many more fatal rural crashes (62%) involve alcohol *plus* speeding *plus* unrestrained drivers than is the case for fatal urban crashes (38%).

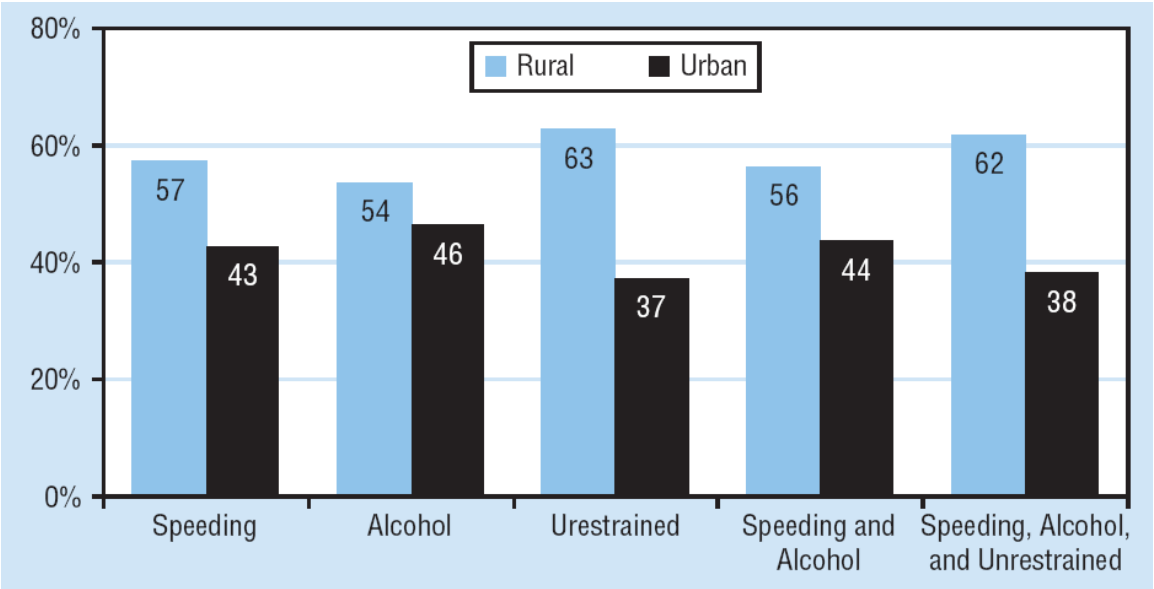
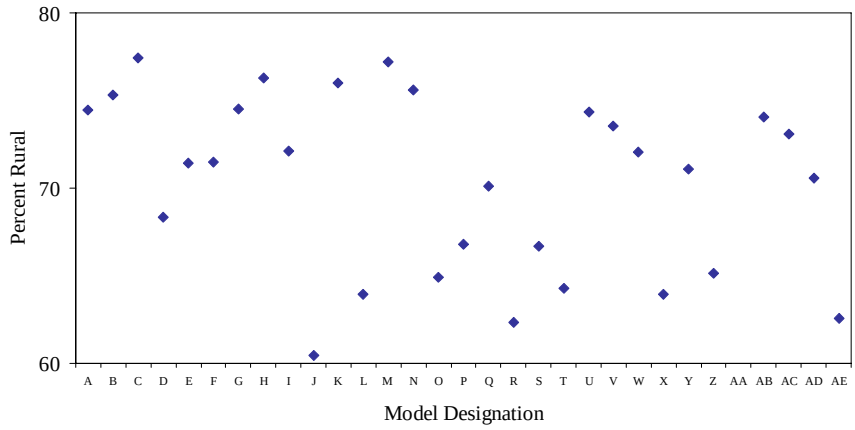


Figure 1 — Speeding, Alcohol Involvement, and Unrestrained Drivers Involved in Fatal Crashes by Location, 2006 (NHTSA, 2008)

It is clear by virtually all measures that rural crashes tend to be more severe. In addition, as seen in Figure 2, among the four-door midsize SUVs included by the IIHS, there is a wide variation of percent of rural rollover crashes, which could influence injury severity for these SUVs.

Of the 12 states used for the current IIHS study, 9 had codes to identify rural/urban, including 13,841 belted, non-ejected drivers. The IIHS did not control for rural/urban. When we repeated the IIHS analysis and controlled for rural/urban for belted, non-ejected drivers, roof strength-to-weight ratio dropped out as a significant factor in the prediction of injury outcome. Our models became even more stable as further controls such as alcohol, gender and aspect ration were included, but if IIHS had simply controlled for rural/urban alone they would have concluded that roof strength-to-weight ratio is not a significant factor.



Source: State Accident Data. Model Years 1996-2005. Vehicles with no data are not show on the graph.

Figure 2 — Percent of Rollover Crashes in Rural Areas for Different Model SUVs Included in the IIHS Data

ALCOHOL

Alcohol impairment was identified as a statistically significant and important variable in both of our previous studies. We examined the effects of alcohol on the IIHS data by using those states which coded the Blood Alcohol Content (BAC) test and/or "had been drinking". Again, alcohol showed up to be statistically significant in influencing injury/fatality likelihood in rollovers.

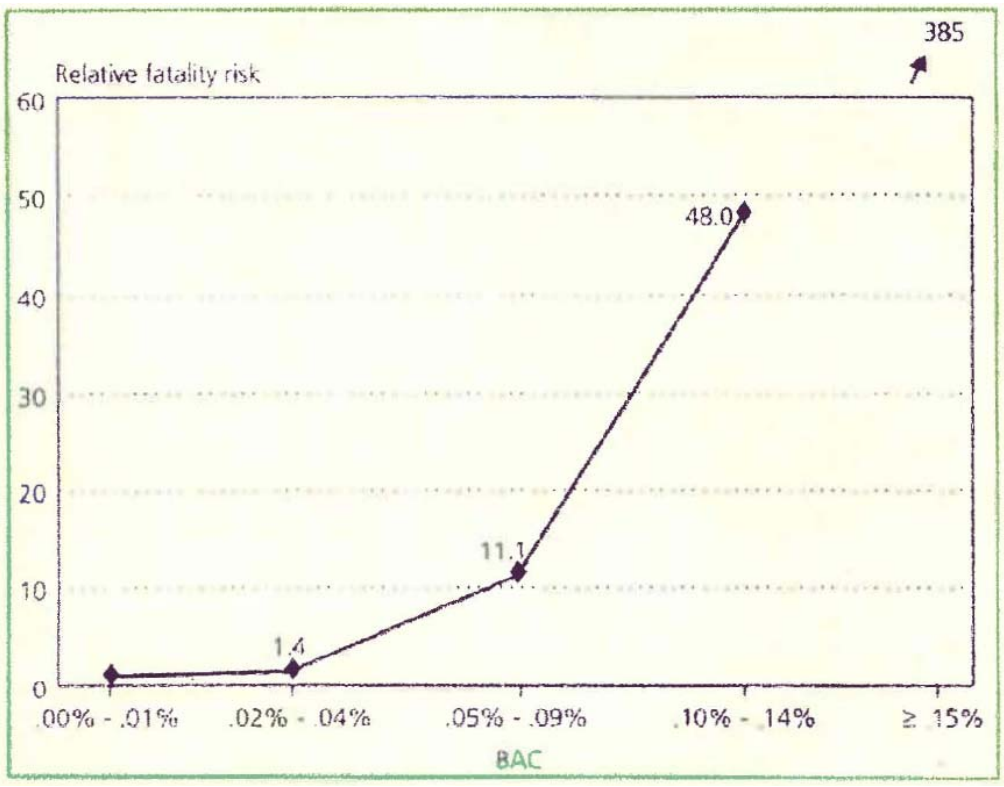
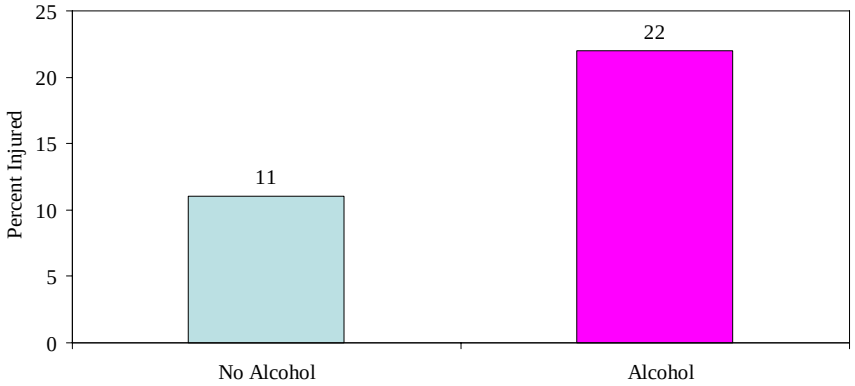


Figure 3 — Crude Relative Fatality Risk for Drivers in Single-Vehicle Crashes at Different BAC Levels (Zador, 1991)

Why is alcohol related to injury outcome? Because, as many studies (NHTSA, 1971; Warren, 1981; Klein et al., 1998; Zador, 1991) reflect, crashes involving alcohol tend to be more severe and have a higher likelihood of fatality. For example, the IIHS study by Zador (1991) showed that, for single-vehicle crashes, the relative risk of fatality is greatly increased as alcohol concentration is increased (Figure 3, above).

The observation that alcohol involvement increases the risk of serious injury/fatality is also reflected in the data from the current IIHS rollover sample. Figure 4 shows that those coded as having indications of alcohol (either "had been drinking" or positive BAC) are twice as likely to suffer serious/fatal injury.



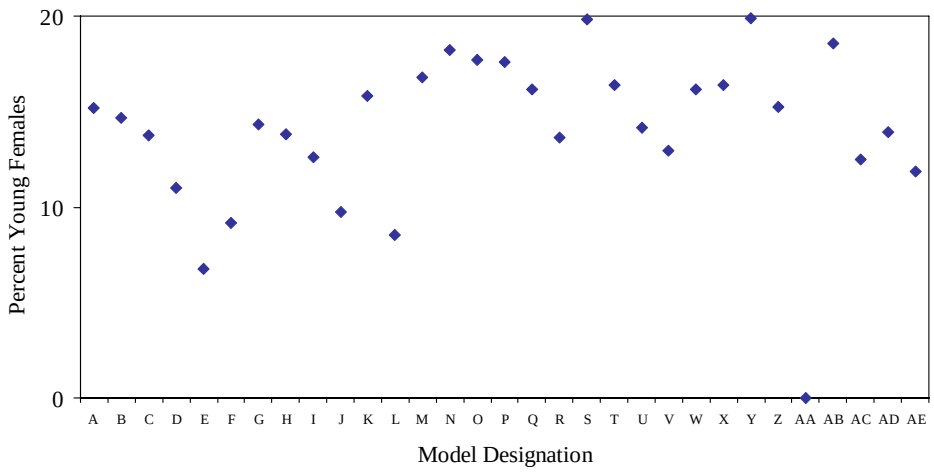
Serious Injury include police reported K (fatal) and A (incapacitating) injuries. Includes SVA rollovers.

Figure 4 — Risk of Serious/Fatal Injury in Rollovers with Alcohol Use in the IIHS Data

Numerous crash data, including the current IIHS study, indicate that alcohol use is related to increased likelihood of serious injury/death. Yet, the IIHS did not control for alcohol as a confounding factor. When the IIHS data is analyzed with the inclusion of alcohol as a confounding factor, the model not only finds alcohol to be highly significant (p less than 0.0001), but finds that roof strength-to weight ratio is not a significant factor in injury/fatal outcome.

GENDER

The IIHS study did not include gender as a confounding factor. There is no question that females have different driving habits and different susceptibility to injury than males. If certain vehicle models are more popular with women than men, then those differences might be reflected in the injury outcomes. When we included gender as a controlling factor, we found it to be highly significant ($p < 0.0001$) and it increased the robustness of our statistical model. Figure 5 gives the percentage of young females in each model in the IIHS sample.



Source: State Accident Data. Model Years 1996-2005. Young females includes ages 16-25.

Figure 5 — Percent of Young Females in Four-Door Midsize SUVs Included in the IIHS Data

BELT USE

IIHS omitted belt use from their model on the grounds that, "because this variable is difficult to know with precision, inclusion as predictor variable can bias any analysis of roof strength." We disagree with this statement because recent surveys from some of the states included in the IIHS data set show that the over reporting is minimal. For example, Figure 6 gives the belt use rates from North Carolina. For the years 2000-2005 (which account for 85% of the IIHS data), the police reporting is close to state survey results on belt use. In addition, there is no evidence that these reporting inaccuracies are biased in favor of or against any specific vehicle model.

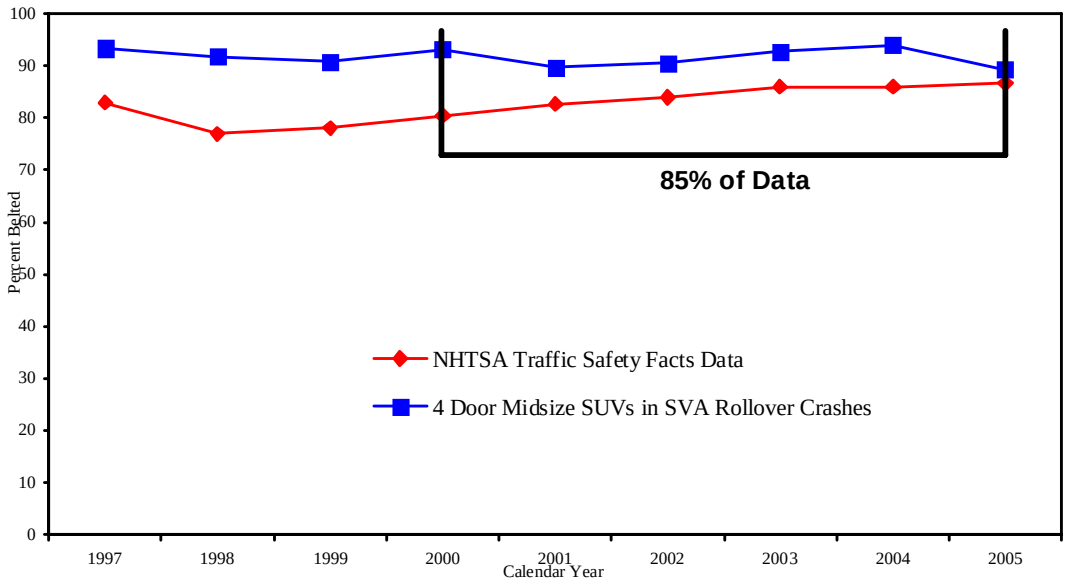


Figure 6 — Belt Use Rates in North Carolina
(Source: NHTSA, Traffic Safety Facts; State Accident Data)

Assuming that belt use is slightly over-reported, there are valid statistical approaches to address the reporting bias in a logistic model. For example, our statistical model included error terms to address the biases. With belt-use and ejection widely recognized as the single two most important factors in injury prevention in rollovers, we believe the IIHS model would have been more robust had they addressed belt-use, rather than ignoring it.

EJECTION

In the IIHS study, 56% of the fatalities and 28% of the serious/fatal injuries were unbelted and completely ejected. The conclusions of the IIHS report, however, are based upon models which do not control for either belt use or ejection.

OTHER EFFECTS

IIHS LIVES SAVED CALCULATION. For belted non-ejected drivers, if the IIHS had included the other significant variables in their model, the number of lives saved for increasing roof strength-to-weight ratio from 1.5 to 2.5 would be 8 lives saved, with 95% confidence bounds ranging from -13 (lives lost) to 26 (lives saved).

BUBBLE PLOT. The IIHS's Figure 1 ("bubble plot") presents their raw data serious/fatal injury rate as a function of peak roof strength-to-weight ratio. They acknowledge that "no adjustment was made for potentially confounding factors," but the report implies statistical significance to this plot, stating "The slope of the line represents an injury rate 24% lower than average for an SWR one unit higher than average." What is not presented are the minimal statistical parameters to indicate whether the slope of this regression line is statistically significant, and R^2. Our replication of their Figure 1 shows a p-value of 0.09, indicating that its slope is not statistically significant, and an R^2 of 0.07, meaning that the line is a poor fit to the data.

CONCLUSIONS

The statistical model in the IIHS study did not include important variables that had previously been identified as statistically significant factors for injury outcome in rollovers. Specifically, the IIHS study did not control for belt use, ejection, alcohol, gender, aspect ratio, or rural/urban. If they had controlled for these variables, they would have found that roof strength-to-weight ratio is not a statistically significant factor in the likelihood of serious/fatal injuries in rollovers.

FURTHER INFORMATION

These "Comments" are a brief summation of two reports the authors submitted to the National Highway Traffic Safety Administration FMVSS 216 Roof Strength Docket on March 27, 2008, and May 30, 2008. In the same docket, the IIHS submitted the current report and a second submission dated May 13, 2008, which was presented as a rebuttal to our March 27, 2008 submission. We encourage review of all of these submissions for more detailed information and bibliographies.

REFERENCES

Brumbelow M, Teoh ER, Zuby DS, and McCartt AT (2008). "Roof Strength and Injury Risk in Rollover Crashes," Report for the Insurance Institute for Highway Safety, March 2008.

Burgess M (2005). "Contrasting Rural and Urban Fatal Crashes 1994-2003," NHTSA Technical Report No. DOT HS 809 896, December, 2005.

Insurance Institute for Highway Safety (2008a). Comment to the National Highway Traffic Safety Administration concerning proposed changes to Federal Motor Vehicle Safety Standard 216, Roof Crush Resistance (includes report by Brumbelow et al., March 2008); Docket No. NHTSA-2008-0015-0077, March 27, 2008.

Insurance Institute for Highway Safety (2008b). Comment to the National Highway Traffic Safety Administration concerning "Logical and Statistical Errors in Comments by Padmanaban and Moffatt on the Insurance Institute for Highway Safety Study, 'Roof

Strength and Injury Risk in Rollover Crashes',” submitted to the Roof Crush Resistance; Docket No. NHTSA-2008-0015-0088, May 13, 2008.

Klein TM and Walz MC (1998). “Estimating Alcohol Involvement in Fatal Crashes in Light of Increases in Restraint Use,” National Center for Statistics and Analysis, March 1998.

Moffatt E and Padmanaban J (1995). "The Relationship between Vehicle Roof Strength and Occupant Injury in Rollover Crash Data," *Proceedings of the 39th Annual Meeting of the Association for the Advancement of Automotive Medicine*, Chicago, Illinois, October 1995.

National Highway Traffic Safety Administration (1971). “Alcohol and Highway Safety: Behavioral and Medical Aspects,” Perrine et al., Final Report, Prepared for US Department of Transportation, September 1971.

National Highway Traffic Safety Administration (1997). “Traffic Safety Facts 1997-Occupant Protection,” National Highway Transportation Safety Administration, DOT HS 808 768, 1997.

National Highway Transportation Safety Administration (1997). “Traffic Safety Facts 1996-Occupant Protection,” National Highway Transportation Safety Administration, DOT HS 808 768, 1997

National Highway Traffic Safety Administration (2008). "Traffic Safety Facts 2006 Data, Rural/Urban Comparison," NHTSA, NCSA, Report No. DOT HS 810 812, March 2008.

Padmanaban J, Moffatt EA, and Marth DR (2005). "Factors Influencing the Likelihood of Fatality and Serious/Fatal Injury in Single-Vehicle Rollover Crashes," Society of Automotive Engineers World Congress & Exhibition, Rollover Session, Detroit, Michigan, April 11-15, 2005; SAE Paper No. 2005-01-0944, 2005.

Padmanaban J and Moffatt EA (2008). “Evaluation of IIHS Study: Roof Strength and Injury Risk in Rollover Crashes,” submitted to the Roof Crush Resistance Docket, No. NHTSA-2008-0015-0081, March 27, 2008.

Padmanaban J and Moffatt EA (2008). “JP Research's Response to IIHS Docket Submission of May 13, 2008,” submitted to the Roof Crush Resistance Docket, No. NHTSA-2008-0015-0091, May 30, 2008.

Warren RA, Simpson HM, Buhlman MA, Bourgeois LA, and Chattaway LD (1981). "Relationship of Driver Blood Alcohol to Injury Severity," *Proceedings of the American Association for Automotive Medicine*, October 1981.

Zador PL (1991). "Alcohol-Related Relative Risk of Fatal Driver Injuries in Relation to Driver Age and Sex," Insurance Institute for Highway Safety, *Journal of Studies on Alcohol*, Vol. 52, No. 4, 1991.