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STATISTICAL EVALUATION OF THE EFFECTIVENESS OF FEDERAL MOTOR VEHICLE SAFETY STANDARD 202: HEAD RESTRAINTS

Report No. 2 of 7

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FINAL REPORT

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CONTRACT TECHNICAL MANAGER'S ADDENDUM

Prepared for the National Highway Traffic Safety Administration in support of a program to review existing regulations, as required by Executive Order 12044 and Department of Transportation Order 2100.5. Agency staff will perform and publish an official evaluation of Federal Motor Vehicle Safety Standard 202 based on the findings of this report as well as other information sources. The values of effectiveness and benefits found in this report may be different from those that will appear in the official Agency evaluation.

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16. Abstract

This is the Final Report for the statistical evaluation of FMVSS 202 (Head Restraints). It is one of seven statistical evaluations to be conducted under this contract. The seven Standards are: .

1. FMVSS 108: Side Marker Lamps (only)
2. FMVSS 202: Head Restraints
3. FMVSS 207: Seat Back Locks (only)
4. FMVSS 213: Child Restraints
5. FMVSS 214: Side Door Beams
6. FMVSS 222: School Bus Seating and Crash Protection
7. FMVSS 301: Fuel System Integrity

FMVSS 202 is designed to reduce the frequency and severity of neck injuries in rear end crashes. Head restraints may be either an integral type or a separate adjustable type.

The study involved the development of statistical models for estimating the effectiveness of FMVSS 202 relative to three different effectiveness measures. The results showed that integral head restraints were significantly effective in reducing overall injury at an AIS level of one or greater relative to no head restraint. In general, for other head restraint types and other injury characterizations, head restraint effectiveness estimates were positive, but were not statistically significant. Injuries to rear seat occupants were also examined and head restraints were not found to be a safety hazard for these occupants.

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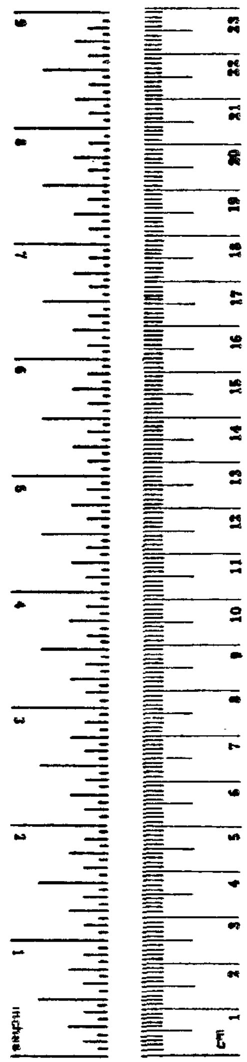
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

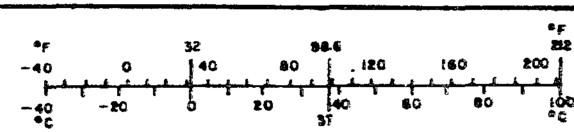
Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Executive Summary

This is the Final Report of the statisitcal evaluation of Federal Motor Vehicle Safety Standard (FMVSS) 202: Head Restraints.

The evaluation was carried out using data from the National Crash Severity Study (NCSS) on drivers and right front seat passengers involved in rear-end crashes. Using data on the 3,380 such occupants, injury rates were estimated for those with integral head restraints, adjustable head restraints, and no head restraint. Three characterizations of injury were considered.

a.) Whiplash symptoms or specific injury to the neck,

b.) Overall injury at an AIS level of one or greater,

c.) Overall injury at an AIS level of two or greater.

In order to obtain unbiased estimates of injury rates analyses were performed to identify relevant covariants that were associated with both head restraint type and occupant injury. The list of such covariants included occupant age and sex, a variable indicating whether or not the occupant was using a seat belt, the weight of the vehicle the occupant was in, and the extent to which the vehicle was damaged in the crash.

For each characterization of occupant injury, an appropiate set of covariants was included in a weighted least squares categorical data model which produced estimates of injury rates for each head restraint type. The model also produced estimates of head restraint effectiveness, defined as the percent reduction in injury rate for each head restraint type relative to no head restraint. Estimates of standard errors of effectiveness estimates were also determined so that the statistical significances of the effectiveness estimates could be assessed.

The results showed that in crashes that were severe enough that the case vehicle (vehicle hit in the rear) had to be towed from the scene, integral head restraints were 31.6% effective in reducing overall injuries at an AIS level of one or greater. This result was statistically significant at the 5% level. When projected to the national level, it was estimated that integral head restraints would have resulted in 56,782 fewer injuries in automobile crashes in 1978, compared to those that would have occurred if no head restraints were present. The effectiveness estimates for other restraint

types and other injury characterizations were generally positive, but none were statistically significant at the 5% level.

An investigation of injuries to rear seat occupants caused by head restraints seems to indicate that head restraints did not present much of a safety hazard to these occupants.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

The work being performed by CEM and HSRC in statistically evaluating the effectiveness of seven Federal Motor Vehicle Safety Standards is the product of an interdisciplinary team effort. Under subcontract to CEM, HSRC has principal responsibility for the evaluation of three Standards. Dr. Richard Stewart of HSRC had principal responsibility for the overall preparation of this report. Dr. Donald Reinfurt is Principal Scientist in charge of all work performed by HSRC. Dr. Gaylord Northrop of CEM is Principal Investigator for the study. We wish to gratefully acknowledge the other Study Team members who made contributions to this report. They are:

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ABBREVIATIONS USED

AIS	Abbreviated Injury Scale
BMDP3F	Biomedical Computer Program for Log-linear Analysis of Multiway Frequency Tables
CEM	The Center for the Environment and Man, Inc.
FMVSS	Federal Motor Vehicle Safety Standard
GENCAT	A Computer Program for the Generalized Chi-square Analysis of Categorical Data Using Weighted Least Squares
H-ICDA	Hospital Adaptation of the International Classification of Diseases
HSRC	Highway Safety Research Center
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
OAIS	Abbreviated Injury Scale for Overall Injury

1.0 INTRODUCTION

1.1 Background

This is the second in a series of reports of the statistical evaluation of the effectiveness of seven Federal Motor Vehicle Safety Standards (FMVSS). This work is being conducted under Contract DOT-HS-8-02014, by The Center for the Environment and Man, Inc. (CEM) and its subcontractor, the Highway Safety Research Center (HSRC) of the University of North Carolina. The seven Standards to be statistically evaluated are:

- FMVSS 108: Side Marker Lamps (only)
- FMVSS 202: Head Restraints
- FMVSS 207: Seat Back Locks (only)
- FMVSS 213: Child Restraints
- FMVSS 214: Side Door Beams
- FMVSS 222: School Bus Seating and Crash Protection
- FMVSS 301: Fuel System Integrity

The Final Report for FMVSS 202 (Head Restraints) is presented herein.

FMVSS 202 originally went into effect on January 1, 1969, requiring passenger cars to be equipped with head restraints. Volkswagen had head restraints as standard equipment in their 1968 models, while Ford installed them on almost all their 1969 models. General Motors and Chrysler did not install head restraints on many vehicles until a mid-model year change. Two methods evolved for complying with the Standard. Some seats were manufactured with separate head restraints, some of which are adjustable. Other seats were manufactured with an integrated head restraint as part of a higher seat back. Initially, the foreign cars complied primarily with the integrated head restraint, while domestic manufacturers provided separate head restraints. This sharp difference no longer applies.

The head restraint device must conform to either a dynamic test in which the angular displacement of the manikin's head is measured, or a static test where the rearward displacement of the test dummy head form is measured while applying a load to the head form. In the dynamic test, the acceleration has an amplitude of between 8.0 and 9.6 g and a duration of between 80 and 96 milliseconds. In the static test, the maximum load is 200 pounds (or less if the seat fails).

If the head restraint complies under the dynamic test requirements, no specific dimensions for the head restraint are established. If the head restraint complies under the static test requirements, the dimensions of the fully extended head restraint must be as follows:

- The top of the restraint must be at least 27.5 in. above the seating reference point.
- The lateral width, when measured either 2.5 in. below the top of the restraint or 25 in. above the seating reference point, must be at least 10 in. for bench type seats or 6.75 in. for individual seats.

1.2 Objective

The primary objective of this analysis was to determine the effectiveness of FMVSS 202 in reducing the frequency and severity of neck injuries in passenger cars equipped with head restraints. In addition, the effectiveness of integrated head restraints was compared with that of adjustable restraints when correctly adjusted and when incorrectly adjusted. Another objective of the analysis was to investigate the extent to which injuries to occupants resulted from their striking some part of the head restraint.

1.3 Scope

The analysis of FMVSS 202 was done using National Crash Severity Study (NCSS) data. This data contains detailed information on head restraints and their adjustment and on the presence of neck injuries occurring to occupants of the involved vehicles. The data also includes information on many other factors such as age and sex of occupant, type and severity of crash, etc., that were important to consider relative to the occurrence of neck injuries. Statistical models for estimating head restraint effectiveness were developed using some of these variables.

The data was also examined to identify the occurrence of injuries to occupants caused by head restraints. The severity of these injuries was compared to the severity of injuries to similar occupants in similar crashes when head restraints were not present.

1.4 Approach

1.4.1 Data Source

The evaluation of FMVSS 202 was based on an analysis of the NCSS data which was recently collected. The NCSS was a multi-year effort which began in October 1976 and continued through March 1979. The goal was to collect Level 2-type (or intermediate-level) accident investigation data on over 10,000 towaway accidents. This accident data was collected by seven NHTSA-sponsored organizations in eight locations: Western New York (CALSPAN), Michigan (HSRI), Miami (University of Miami), San Antonio, Texas (SwRI), thirteen other countries in Texas (SwRI), Kentucky (University of Kentucky), Indiana (University of Indiana), and Los Angeles, California (Dynamic Sciences).

The data base represents a stratified probability sample of police-reported towaway accidents (i.e., at least one automobile was not drivable and hence was towed from the scene) where, for each area, the sampling frame represents approximately 10,000 accidents annually. The sampling criteria results in the following three strata:

- 100 percent of those accidents involving the transport to a treatment facility and overnight hospitalization or death of at least one towaway-involved automobile occupant;
- A 25 percent systematic random sample of accidents which involved transport of at least one towaway-involved automobile occupant to a treatment facility but not overnight hospitalization; and
- A 10 percent systematic random sample of all other police-reported towaway accidents (where at least one car is not drivable).

To the extent obtainable, each case contains information on all vehicles and occupants involved in the accident. For the "applicable" or case car(s) which is any towed (i.e., non-drivable) automobile involved in an accident meeting one of the sampling criteria, there is maximum information which includes the following reports (when appropriate): police, environmental, off-road object struck, vehicle, side structure, passenger compartment intrusion, seat performance, fire, rollover, interview, medical and surgical procedures, and an overall summary report. Variables from the seven-page summary report constitute the computerized master file currently available for analysis.

1.4.2 Population Involved

The population used for evaluating standard 202 consisted of drivers and right hand front seat passengers involved in rear end crashes. The passengers were also restricted to be tall enough to derive some benefit from the head restraint when it was present. From the data file appropriately weighted for the sampling scheme described above, there was a total of 3,380 such occupants. Of these, 2,522 were drivers and 858 were passengers. An examination of the injuries occurring to these occupants showed that 1,110 or 32.8% suffered neck injuries or complained of whiplash symptoms. In terms of overall injury 1,464 had injuries with an overall AIS rating of 1, while 99 were rated at AIS 2 or more.

1.4.3 Data Characteristics

Of particular importance relative to the evaluation of the effectiveness of FMVSS 202 were data elements in the NCSS file containing information on head restraints in the involved vehicles, and on the occurrence of neck injuries to the occupants of these vehicles. In addition to these items, the NCSS file contains information on a variety of other factors that were considered in the evaluation. These included:

- Occupant age, sex, and height
- Seating position
- Seat type
- Restraint use
- Injury severity
- Occupant contact (first)
- Characteristics of the accident
  - Impact type
  - Delta V
  - Extent of damage
- Vehicle weight, model year, model type, etc.
- Head restraint type
- Front seat type
- Front seat/head restraint measurements (left and right front)

1.5 Limitations of the Study

Although the NCSS data contains detailed information on head restraints, neck injuries and many other contributing factors, the analysis was limited by relatively small sample sizes of occupants in vehicles with various head restraint systems involved in rear-end crashes. As a result, it was only possible to include some of the most important factors in models for head restraint effectiveness rather than all factors of interest. The small sample sizes also yielded relatively large variances for many of the estimated quantities. This, in turn, resulted in many of these quantities not being statistically significant.

1.6 Outline of the Report

Section 2 of this report summarizes the analyses performed for FMVSS 202. It includes a discussion of the measures of effectiveness; the estimates of effectiveness based on the various measures (i.e., injury characterizations); confidence limits of the effectiveness estimates; and overall success of the evaluation.

Section 3 contains the details of the statistical analyses which resulted in the effectiveness estimates summarized in Section 2.

1.7 References for Section 1

1. Ball, J.T., J.C. Reidy and G.M. Northrop. *CEM 4229-596: Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 202: Head Restraints, and FMVSS 207: Seating Systems,* Hartford, Connecticut, CEM, December 1977. (DOT-HS-7-01675)

2. Northrop, G.M., J.T. Ball, D. Bancroft and J.C. Reidy, *CEM 4228-4229-600: Evaluation Methodologies for Nine Federal Motor Vehicle Safety Standards: FMVSS 105, 108, 122, 202, 207, 213, 220, 221, 222.* Hartford, Connecticut, The Center for the Environment and Man, Inc., March 1978. (DOT-HS-7-01674 & DOT-HS-7-01675)

3. Stewart, J.R. *CEM 4254-633: Work Plan for Statistical Evaluation of the Effectiveness of FMVSS 202: Head Restraints.* Chapel Hill, North Carolina, Highway Safety Research Center, and Hartford Connecticut, The Center for the Environment and Man, Inc., December 1978.

2.0 SUMMARY OF ANALYSES PERFORMED ON FMVSS 202

2.1 Measures of Effectiveness

The NCSS data contains a variable which indicates the presence or absence of head restraints in each case vehicle. When head restraints are present, the variable indicates the type of restraint (integral or adjustable), and for adjustable restraints gives the height of the restraint above the seat cushion. For cases where this variable was missing or coded as unknown it was usually possible to determine if head restraints of some type were present by examining the vehicle make and model year. Thus, four conditions relative to head restraints were considered:

a) Integral Head Restraints;
b) Adjustable Head Restraints;
c) Head Restraint Present (type unknown);
d) No Head Restraint Present

The measure of effectiveness of some head restraint type (a, b, c, or some combination thereof) was taken to be the percentage change in the injury rate for that head restraint type relative to the injury rate for no head restraint. That is, effectiveness for head restraint type r was estimated as,

$$E_r = \frac{\text{(injury rate/no restraint)} - \text{(injury rate/type r restraint)}}{\text{injury rate/no restraint}} \times 100$$

Three different characterizations of occupant injury were used in estimating the injury rates for calculating head restraint effectiveness. These were:

1) Presence or absence of whiplash symptoms;
2) Any injury at AIS 1 or greater, versus no injury;
3) Any injury at a level of AIS 2 or greater, versus no injury or lesser injury.

2.2 Estimated Effectiveness of FMVSS 202

2.2.1 Methods

Many factors pertaining to the crash, the vehicle, and the occupant may be associated with both the presence or absence of head restraints, and with the degree of injury to the occupant. Thus, in order to obtain unbiased estimates of head restraint effectiveness it is necessary to first identify these factors. Models using these factors could then be developed to estimate head restraint effectiveness.

As an initial step in this factor identification or variable selection, the marginal association between each potential variable and head restraint type, and between each variable and injury was examined from a series of two-way contingency tables. When only a few variables (two or three) were significantly associated with both head restraint type and injury, these variables were further examined by including them in a log linear model to determine their partial associations using the procedure described by Fuchs (1979). The variables that showed significant interactions with both injury and head restraint type were retained for use in models for head restraint effectiveness.

When a larger number of variables were significantly associated with both injury and head restraint type, the stepwise variable selection procedure of Clarke and Koch (1976) was used to select those variables most strongly associated with injury from the subset of those that were significantly associated with head restraint type. With this procedure, partial associations are tested using Chi-square and Mantel-Haenszel tests.

After the appropriate set of variables was selected, head restraint effectiveness estimates were obtained by fitting linear models to the injury rate data for the various head restraint types partitioned by the control variables. The weighted least squares procedure (GENCAT) was used for the modeling. The effectiveness estimates produced by these models are shown in Table 2-1.

2.2.2 Results

As can be seen from Table 2-1, separate effectiveness estimates were made for towed and non-towed case vehicles. Detailed information on type and adjustment of head restraints was generally missing for non-towed case vehicles. Thus, comparisons could only be made for head restraint present (as determined by vehicle make and model year) versus no head restraint. Also, no injuries at a level of AIS 2 or greater were suffered by occupants of non-towed case vehicles, and, hence, no comparisons could be made relative to this measure.

The table shows that most of the effectiveness estimates are positive, indicating that the injury rates for the occupants with the various types of head restraints are usually smaller than the injury rates for occupants with no head restraints. Only for the comparison of integral head restraints versus no restraints relative to OAIS $\geq$ 1, however, was the effectiveness estimate statistically different from zero at a 5 percent level of significance (as can be seen by the fact that the lower confidence limit is positive for this case).

TABLE 2-1

EFFECTIVENESS ESTIMATES

Head Restraint Comparison	Injury Criterion	Case Vehicle Condition	Effectiveness	95% Confidence Interval
All Types vs. None	Whiplash	Towed	9.95%	(-10.00, 29.90)
All Types vs. None	OAIS $\geq$ 1	Towed	13.57%	(-4.81, 31.95)
All Types vs. None	OAIS $\geq$ 2	Towed	-20.60%	(-180.63, 139.43)
All Types vs. None	Whiplash	Non-Towed	-1.35%	(-65.46, 62.76)
All Types vs. None	OAIS $\geq$ 1	Non-Towed	19.28%	(-16.98, 55.54)
Integral vs. None	Whiplash	Towed	20.27%	(-3.47, 44.01)
Adjustable vs. None	Whiplash	Towed	-1.27%	(-24.16, 21.62)
Integral vs. None	OAIS $\geq$ 1	Towed	31.61%	(17.38, 45.86)
Adjustable vs. None	OAIS $\geq$ 1	Towed	12.02%	(-3.72, 27.76)
Integral vs. None	OAIS $\geq$ 2	Towed	47.41%	(-22.76, 117.58)
Adjustable vs. None	OAIS $\geq$ 2	Towed	-2.35%	(-125.34, 120.64)

Table 2-2 shows comparisons of correctly positioned adjustable head restraints with adjustable restraints not correctly positioned, in terms of

TABLE 2-2

COMPARISON OF CORRECTLY ADJUSTED AND INCORRECTLY ADJUSTED ADJUSTABLE HEAD RESTRAINTS

Injury Criterion	Injury Rate Difference (P_I-P_C)	Standard Deviation
Whiplash	-1.96 per hundred	5.63
OAIS $\geq$ 1	-4.38 per hundred	5.93
OAIS $\geq$ 2	-1.36 per hundred	2.11

differences in their respective injury rates. None of the differences in rates was significantly greater than zero, and in fact, the injury rates for the correctly positioned restraints always slightly exceeded the injury rates for those not correctly positioned. In view of these results, and those of Table 2-1 for adjustable restraints, separate effectiveness estimates (relative to no head restraint) for correctly and incorrectly positioned adjustable head restraints were not made.

2.2.3 National Estimate of Injuries Avoided Due to Presence of Integral Head Restraints

Since a significant effectiveness was found for integral head restraints relative to no head restraint, an estimate is given below of the number of injuries, nationwide, that were avoided in 1978 due to the presence of integral head restraints in cars relative to no head restraint. The estimate is given by the formula

$$\text{Injuries Avoided} = (R_N - R_I) P_I A_O P_{RT} N_R \quad ,$$

where $R_N - R_I$ is the difference in injury rates between cars with no head restraints and those with integral restraints, P_I is the proportion of cars in use having integral head restraints, A_O is the average number of occupants (driver and right front) in rear-end crashes, P_{RT} is the proportion of rear-end crashes in which the rear-ended car was towed, and N_R is a national estimate of rear-end crashes.

An estimate of $R_N - R_I = 18.37$ per hundred is derived from the main analysis in this report. Estimates for the other quantities are as follows:

P_I = .3046 (from NCSS data),

A_O = 1.46 from 1978 North Carolina data,

P_{RT} = .1511 from 1978 North Carolina data,

N_R = 4,600,000 from 1979 Accident Facts (National Safety Council).

Using these estimates in the formula gives

Injuries avoided = 56,782.

That is, if all cases with integral head restraints had had none, then it would be expected that 56,782 additional injuries would have occurred in rear-end crashes in 1978.

2.2.4 Examination of Injuries Caused by Head Restraints

The NCSS data file shows that there were 2123 (weighted) cases of injuries occurring to rear seat occupants in cars equipped with head restraints. In 32 (about 1.5%) of these cases the object contacted was the head restraint. Nearly all of these occupants also had other injuries caused by contacting other objects, and the head restraint caused injury was not always the most severe. The average severities of the head restraint caused injuries were compared with the average severities of injuries occurring to similar (in age and sex) rear seat occupants in similar (with respect to extent of damage) crashes, in cars not equipped with head restraints. For most of the age by sex by extent of damage categories, the average severity of the head restraint caused injuries did not exceed the average severity of the injuries occurring to rear seat occupants when head restraints were not present. In view of these results, it does not appear that head restraints represent a safety hazard to rear seat occupants.

2.3 Evaluation of Effectiveness Analysis

All of the analyses were done using a weighted data file. That is, for example, an observation from the 10 percent sample was treated as 10 identical observations. To compensate for this inflation of the actual data, all variances were similarly inflated by the ratio of weighted to unweighted cases. This variance inflation factor varied from situation to situation, but was generally on the order of 5. Even with the weighted data, however, sample sizes often became quite small, especially with respect to frequencies of injured occupants with specific types of head restraints in certain accident configurations. This, together with the inflated variances, resulted in many of the effectiveness estimates, while being of substantial magnitudes not being statistically significant. While not significant at a 5 percent level, the effectiveness estimates of integral restraints relative to whiplash, adjustable restraints relative to OAIS $\geq$ 1, and all restraints (towed cases) relative to OAIS $\geq$ 1 all had p-values in the .10 to .20 range.

It is of interest to note that integral restraints were found to be more effective than adjustable restraints and that the positioning of the adjustable restraint did not seem to matter.

2.4 References for Section 2

Clarke, S. H. and Koch, G. G. (1976). *The Effect of Income and Other Factors on Whether Criminal Defendents Go to Prison.* The Law and Severity Review.

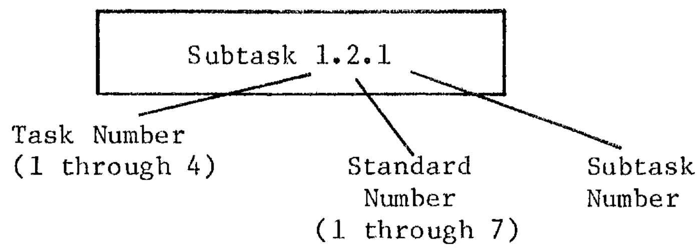
Fuchs, Caniel (1979). *Possible Biased Inferences in Tests for Average Partial Association.* The American Statistician, Vol. 33, No. 3, 120-125.

3.0 DATA PREPARATION AND DATA ANALYSIS

3.1 Introduction

The analysis of FMVSS 202 (Head Restraints) was based on NCSS data. Figure 3-1 is a flow diagram indicating the steps followed in this analysis.

The Subtask numbering system is explained as follows:



This numbering sequence was chosen for the following reasons:

- Task Number. All seven Standards involve three Tasks:

  Task 1: Review Methodology and Develop Work Plans

  Task 2: Analysis of Data

  Task 3: Final Analysis and Final Report on the Standard

- Standard Number. For convenience, throughout the entire study, we use the following "Standard Numbers."

  1 = FMVSS 108: Side Marker Lamps

  2 = FMVSS 202: Head Restraints

  3 = FMVSS 207: Seat Back Locks

  4 = FMVSS 213: Child Seating Systems

  5 = FMVSS 214: Side Door Beams

  6 = FMVSS 222: School Bus Seats and Crash Protection

  7 = FMVSS 301: Fuel System Integrity

  All CEM report numbers have last digits in the sequence noted above.

- Subtask Number. Sequential numbers, beginning with "1".

A discussion of each Subtask indicated within Figure 3-1 completes this section.

3.2 Preparation of NCSS Data for Analysis

As shown in Figure 3-1, the first steps in the analysis were to obtain the NCSS data file and prepare it for use.

3.3 Construct Working File For FMVSS 202 Evaluation

In determining the variables and data items to be included in the analysis file several terms were defined as follows:

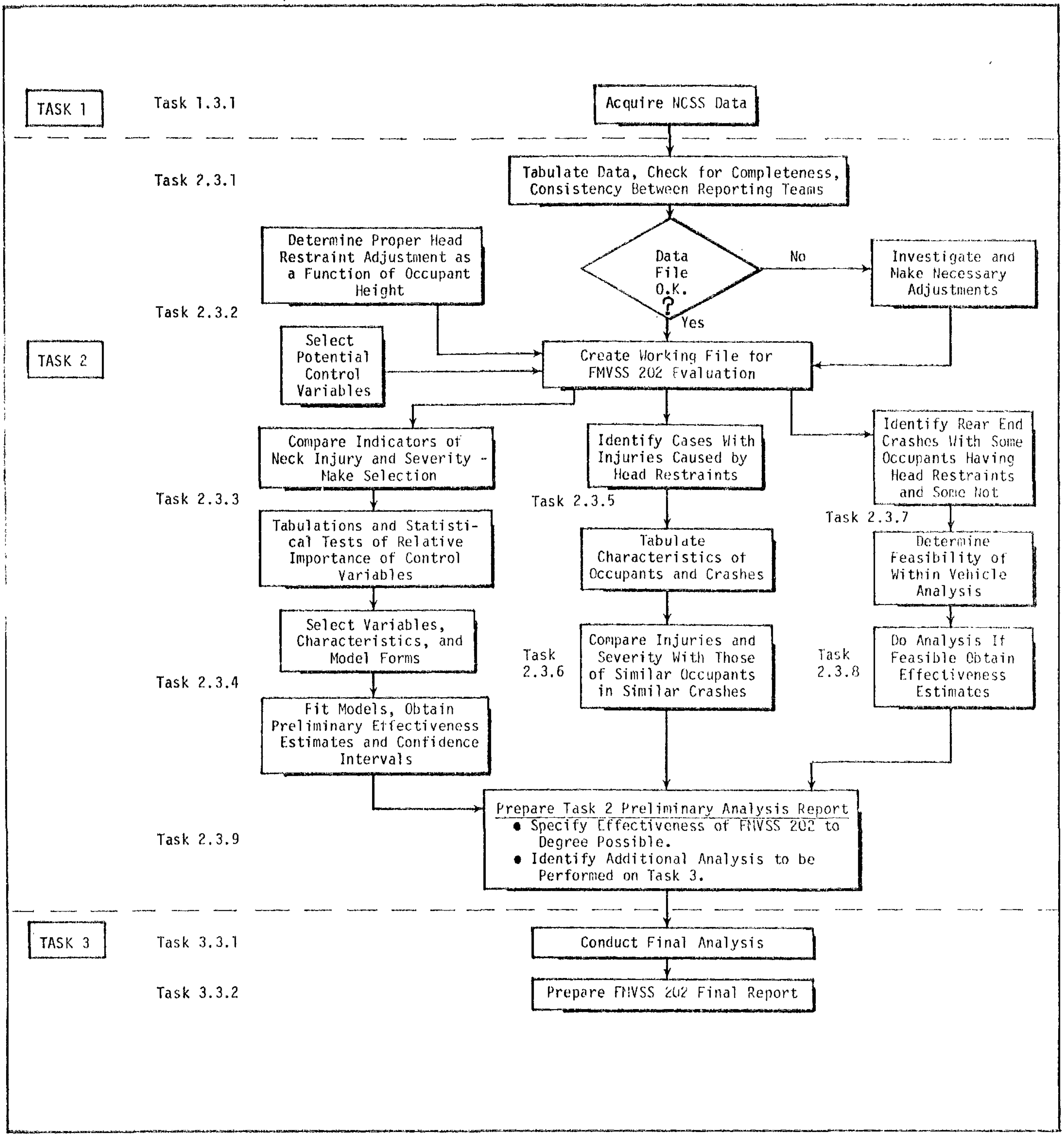


Figure 3-1. Flow diagram for evaluation of FMVSS 202: Head Restraints.

1. Rear-end crash: The NCSS data file contains information on as many as two impacts occurring to each vehicle, listed in order of decreasing severity. A second variable gives the order in which the impacts occurred. For the purpose of this analysis a crash was considered to be a rear-end crash if the impact which occurred first had the principal direction of force in the range from 5 to 7 o'clock (inclusive). The rear impact need not have been the most severe impact. Only the first impact was considered since for subsequent impacts it could not be assumed that the occupants would be in a position to be protected by the head restraints.

2. Occupants (relative to neck injuries): For the purpose of evaluating head restraints, only occupants tall enough to benefit from the restraints were considered. From an examination of anthropometric tables and seat back heights it was decided that only occupants at least 47 inches tall would be considered. In addition only occupants seated in the front left and front right positions were considered since only these positions are equipped with head restraints.

3. Head restraints: The NCSS data contains a special variable which provides information on head restraint type -- integral, adjustable, or none -- for each occupant. For cases where this variable was missing (primarily when the case vehicle was not towed), the occupants could usually be classified as having some type of head restraint or no restraint by examining the vehicle make and model year (as described in Section 1.1).

4. Head restraint adjustment: For vehicles with adjustable head restraints, the NCSS data includes measurements of the distance from the top of the restraint to the top of the (undeflective) seat cushion for each restraint. From anthropometric tables it was estimated that this distance should lie in the range of from 39 percent to 45 percent of the occupants height in order for the head restraint to be correctly positioned behind the occupant's head.

5. Occupant injury: For each occupant the NCSS data contains information on as many as three specific injuries, recorded in order of decreasing severity. This information includes the body region to which the injury occurred and an AIS severity score for each injury. In addition to the information on the three most severe injuries an overall AIS severity score is also included. When an occupant is uninjured all of the variables pertaining to the three specific injuries are left blank, while the overall AIS severity score should be coded as zero. When the occupant is involved in a rear-end crash an additional item of information is available which tells when the occupant first noticed whiplash symptoms, if, indeed, such symptoms did occur. An examination of these injury-related variables showed that in many cases where whiplash symptoms were indicated, a neck injury was not listed as one of the three most severe injuries. There were also cases with neck injuries such as sprains, dislocations, etc. but no whiplash symptoms indicated. In view of the above discussion two characterizations of injury were used in the evaluation of head restraints. These are as follows.

a) Indication of neck injury (whiplash): This is a yes or no variable, where a yes indicates that there is an indication of neck injury either in terms of whiplash symptoms or some other kind of neck injury. A no on this variable says that there is no indication of neck injury. There may, of course, be other types of injuries, or the occupant may be uninjured. Of 3380 (weighted) occupants in rear-end crashes meeting the criteria of 1 and 2, 1110 suffered a neck injury according to this definition.

b) Overall AIS: This variable is taken directly from the NCSS file. Of 3380 occupants for whom this variable was available, 1563 had some injury with an AIS severity score of at least one, and 99 had an AIS of 2 or more. No injury by this definition means that the occupant was uninjured. Two injury characterizations based on overall AIS were used. One contrasted occupants who were uninjured with those having injuries with severity levels of 1 or more, while the other dichotomized overall AIS into the categories of injuries with severity levels of 1 or less, and those with levels of 2 or more. When overall AIS was unknown, the variable NCSS classification was used to determine whether or not an injury with a severity of AIS 1 or greater or AIS 2 or greater had occurred as is shown in Tables 3-1 and 3-2.

Using each of the injury characterizations given above, comparisons of injury rates were made for:

A. Restrained occupants vs. Unrestrained occupants.

B. Occupants with integral restraints vs. Occupants with adjustable restraints vs. Unrestrained occupants.

C. Properly restrained occupants vs. Improperly restrained occupants vs. Unrestrained occupants.

3.4 Selection of Control Variables

The relationships between head restraints and the various characterizations of occupant injury as reflected by the raw data are shown in Tables 3-3 and 3-4 for towed and non-towed case vehicles respectively. However, in order to estimate the effectiveness of head restraints in reducing injury , it was first necessary to determine which of the many potentially pertinent variables were significantly associated with both occupant injury and the variable indicating the presence of the standard. The variables which were considered as potential control variables are shown in Table 3-5 along with the levels considered for each variable.

The marginal associations between each variable and standard, and each variable and injury were first investigated through a series of two-way contingency tables. The results of these analyses are shown in Table 3-6 and 3-7. The χ^2 statistics shown in these tables were computed by first calculating χ^2 statistics for the weighted contingency tables, and then dividing these values by the ratio of weighted to unweighted cases. Thus, each χ^2 in

Table 3-1

DETERMINATION OF INJURY CRITERION OAIS $\geq$ 1

NCSS Classification	OAIS 0	1-6	Severity Unknown (8)	Unknown If Injured (9)
1-6 (injured)	No	Yes	Yes	Yes
7 (treatment unknown)	No	Yes	Yes	Unknown
8 no treatment	No	Yes	Yes	No
9 unknown	No	Yes	Yes	Unknown

Table 3-2

DETERMINATION OF INJURY CRITERION OAIS $\geq$ 2

NCSS Classification	OAIS 0,1	2-6	Severity Unknown (8)	Unknown If Injured (9)
1-3 Fatal	No	Yes	Yes	Yes
4 Overnight Hospitalization	No	Yes	Unknown	Unknown
5 Transported & Released	No	Yes	No	No
6 Other Treatment	No	Yes	No	No
7 Treatment Unknown	No	Yes	Unknown	Unknown
8 No Treatment	No	Yes	No	No
9 Unknown	No	Yes	Unknown	Unknown

Table 3-3

HEAD RESTRAINTS BY INJURY FOR TOWED CASE VEHICLES

a.

Whiplash	Head Restraint Type		
	Integral	Adjustable	None
Yes	352 (34.68)	579 (35.22)	171 (28.45)
No	663 (63.52)	1065 (64.78)	430 (71.55)

b.

OAIS $\geq$ 1	Head Restraint Type		
	Integral	Adjustable	None
Yes	460 (45.19)	785 (46.98)	307 (51.17)
No	558 (54.81)	886 (53.02)	293 (48.83)

c.

OAIS $\geq$ 2	Head Restraint Type		
	Integral	Adjustable	None
Yes	26 (2.56)	55 (3.35)	16 (2.79)
No	989 (97.44)	1588 (96.65)	557 (97.21)

Table 3-4

HEAD RESTRAINTS BY INJURY FOR NON-TOWED CASE VEHICLES

a.

Whiplash	Head Restraint: Present	Head Restraint: Absent
Yes	482 (26.3)	117 (23.7)
No	1349 (73.7)	482 (76.3)

b.

OAIS $\geq$ 1	Head Restraint: Present	Head Restraint: Absent
Yes	430 (23.8)	123 (24.9)
No	1376 (76.2)	370 (75.1)

Table 3-5

POTENTIAL CONTROL VARIABLES

Variable	Levels
1. Occupant Sex	Male, Female
2. Occupant Age	(0-19),(20-29),(30-54),(55 & over)
3. Extent of Damage	(1 & 2), (3 & 4), (5-9)
4. Belt Use	Belted, Not Belted
5. Direction of Force	6 o'clock, 5 or 7 o'clock
6. Object Contacted	Compact or subcompact car, intermediate car, standard or luxury, small truck, other vehicle, other non-vehicle
7. Seat Position	Driver, right front
8. Seat Type	Bench, bucket, split
9. Vehicle Weight	Up to 2300, 2400-3300, 3400 and over
10. V Total	(0-5), (6-10), (11-15), (16-20), (21-25), (26-30), (30 & over)

Table 3-6.1 and in the first column of 3-6.2 was derived by dividing the weighted χ^2 by the scale factor $5.13 = \frac{3380 \text{ weighted cases}}{659 \text{ unweighted cases}}$. For the second column of Table 3-6.2 the scale factor was 5.28, while for Table 3-7 it was 7.94.

When the number of variables that had significant marginal associations with both the standard and injury was small (e.g., two or three), a log linear model was fit, using the BMDP3F computer program, to the frequencies of the multidimensional contingency table containing all of the significant control variables together with injury and the standard. Partial associations were then determined by examining the interactions (first order and higher) of the control variables with both standard and injury. Control variables which had significant marginal and partial associations with standard and injury were then included in models for estimating head restraint effectiveness. It might be again noted that the log-linear models were fit to weighted frequencies and that the test statistics (χ^2) were divided by the appropriate scale factors.

For example, in comparing all types of head restraints combined with no restraint relative to whiplash injury, it can be seen from Table 3-6.1 that the

Table 3-6.1

MARGINAL ASSOCIATION OF CONTROL VARIABLES WITH "STANDARD" AND INJURY FOR TOWED VEHICLES

Variable	Standard-Head Restraint Present or Absent	Whiplash Injury	OAIS ≥ 1 Injury	OAIS ≥ 2 Injury
Sex	7.65 1 p < .01	3.24 1 .05 < p < .10	5.39 1 p < .025	0.52 1 p > .25
Age	14.04 3 p < .005	4.87 3 .05 < p < .10	2.91 3 p > .25	2.06 3 p > .50
Extent of Damage	5.31 2 .05 < p < .10	1.73 3 p > .25	7.16 2 p < .05	6.35 2 p < .05
Belt Use	17.48 1 p < .005	4.46 1 p > .05	1.88 1 p > .10	1.39 1 p > .10
Object Struck	8.85 5 .10 < p < .25	3.22 5 p > .50	2.11 5 p > .50	2.11 5 p > .50
Seating Position	0.04 1 p > .50	8.02 1 p < .005	0.56 1 p > .50	0.29 1 p > .50
Seat Type	14.34 2 p < .005	2.15 2 p > .25	4.70 2 .05 < p < .10	0.37 2 p > .50
Vehicle Weight	2.49 2 p > .25	11.84 2 p < .005	14.70 2 p < .005	0.52 2 p > .50
ΔV Total	3.21 6 p > .50	8.16 6 p > .20	19.55 6 p < .005	10.45 6 p > .10
Direction of Force	0.95 1 p > .50	49.16 1 p < .005	13.96 1 p < .005	0.02 1 p > .50

Each cell of the table contains a χ^2 statistic together with its degrees of freedom and P-value. The χ^2 is calculated from the weighted data and then divided by the sample weight factor.

Table 3-6.2

TOWED CASE VEHICLES Continued

Variable	Standard-Integral, Adjustable, None	Adjustment Correct or Not
Sex	11.13 2 $p < .005$	22.25 1 $p < .0005$
Age*	18.52 4 $p < .005$	0.62 2 $p > .50$
Extent of Damage	15.83 4 $p < .005$	0.05 2 $p > .50$
Belt Use	26.17 2 $p < .0005$	5.23 1 $p < .025$
Object Struck	17.17 10 $.05 < p < .10$	10.20 5 $.05 < p < .10$
Seating Position	1.22 2 $p > .50$	1.11 1 $p > .20$
Seat Type	183.20 4 $p < .0005$	16.72 2 $p < .0005$
Vehicle Weight	87.10 4 $p < .0005$	8.56 2 $p < .025$
ΔV Total*	4.54 6 $p > .50$	8.30 3 $p < .05$
Direction of Force	1.06 2 $p > .50$	0.33 1 $p > .50$

The χ^2 statistics shown in this table were calculated using weighted data and then divided by the appropriate sample weight factor.

*For the analyses summarized in the above table the variables age and ΔV were found to be more significant when collapsed as follows

Age - (0-19), (20-54), (55 & Over)
ΔV - (0-5), (6-10), (11-15), (16 & Over)

Table 3-7

MARGINAL ASSOCIATIONS OF CONTROL VARIABLES WITH "STANDARD" AND INJURY FOR NON-TOWED VEHICLES

Variable	Standard-Head Restraint Present or Absent	Whiplash Injury	OAIS $\geq$ 1 Injury
Sex	13.42 1 $p < .0005$	3.86 1 p .05	9.79 1 $p < .005$
Age	5.10 3 $.10 < p < .20$	5.13 3 $.10 < p < .20$	4.49 3 $p > .20$
Extent of Damage	9.16 2 p .01	0.85 2 $p > .50$	0.79 2 $p > .50$
Belt Use	0.81 1 $p > .50$	0.51 1 $p > .50$	0.00 1 $p > .50$
Direction of Force	1.93 1 $.10 < p < .20$	28.16 1 $p < .0005$	8.62 1 $p < .005$
Object Struck	1.13 5 $p > .50$	5.23 5 $p > .30$	4.65 5 $p > .40$
Seating Position	0.34 1 $p > .50$	0.56 1 $p > .40$	0.60 1 $p > .40$
Vehicle Weight	4.79 2 p .10	0.41 2 $p > .50$	0.75 2 $p > .50$

The χ^2 statistics shown in this table were calculated using weighted data and then divided by the appropriate sample weight factor.

Note: The variables Seat Type and ΔV were not available for these cases of non-towed cars.

variables driver sex, age, and belt use are the only ones with significant (at a .10% level) marginal associations with both standard and injury. Log-linear models fit to these variables revealed significant partial associations between each of the three control variables and injury and standard, thus all three were retained for modeling head restraint effectiveness. On the other hand, in comparing head restraints relative to OAIS $\geq$ 1, the variables with significant marginal associations were sex, extent of damage, and seat type. The log-linear model for these variables, however, shows the partial association between seat type and injury to be quite nonsignificant. This, plus the fact that the marginal association between seat type and injury was not especially strong led to seat type being omitted from the effectiveness model.

When a larger number of variables had significant marginal associations with standard and injury a stepwise selection procedure was used as follows. The first control variable selected was that having the strongest association with injury (as measured by χ^2/degrees of freedom) chosen from the subset of variables significantly associated with standard. In subsequent steps the relationships between the control variables and injury were examined within levels of standard and the previously selected control variables. Again, candidate control variables were restricted to those significantly associated with standard, and at each step the variable selected was the one with the largest overall χ^2/degrees of freedom, provided that its partial association with injury was significant, as indicated either by a Mantel-Haenszel statistic or the χ^2's summed over the various subtables.

For example, this procedure was used in selecting variables for comparing integral restraints and adjustable restraints with no restraint relative to whiplash injury. The first variable selected was the one with the largest value of χ^2/degrees of freedom relative to whiplash injury, chosen from among the variables significantly associated with the three level head restraint type variables. From tables 3-6.1 and 3-6.2 it can be seen that this variable is vehicle weight. At the next step the relationships between the possible control variables and whiplash injury were examined within levels of head restraint type and vehicle weight. The variable extent of damage had the highest overall χ^2/degrees of freedom, but the Mantel-Haenszel statistic for this variable was not significant. The variable with the next highest χ^2/degrees of freedom, which was significant, was belt use, and so this was the second variable selected. No additional variables were significant beyond these two.

The application of these selection procedures led to the selection of variables for the various models as shown in Table 3-8.

Table 3-8

VARIABLES SELECTED

Head Restraint Comparison	Injury Criterion	Case Vehicle Condition	Variables in Model
All Types Vs. None	Whiplash	Towed	Age, Sex, Belt Use
All Types Vs. None	OAIS $\geq$ 1	Towed	Sex, Extent of Damage
All Types Vs. None	OAIS $\geq$ 2	Towed	Extent of Damage
All Types Vs. None	Whiplash	Non-Towed	Sex
All Types Vs. None	OAIS $\geq$ 1	Non-Towed	Sex
Integral, Adjustable Vs. None	Whiplash	Towed	Vehicle Weight, Belt Use
Integral, Adjustable Vs. None	OAIS $\geq$ 1	Towed	Vehicle Weight, Extent of Damage
Integral, Adjustable Vs. None	OAIS $\geq$ 2	Towed	Extent of Damage
Correctly Adjusted Vs. Not Correctly Adjusted	Whiplash	Towed	Vehicle Weight
Correctly Adjusted Vs. Not Correctly Adjusted	OAIS $\geq$ 1	Towed	Vehicle Weight
Correctly Adjusted Vs. Not Correctly Adjusted	OAIS $\geq$ 2	Towed	Extent of Damage

3.5 Estimation of Head Restraint Effectiveness

The next step in the analysis consisted of fitting models to injury data for each of the head restraint comparisons listed in Table 3-8, using the appropriate control variables. Head restraint effectiveness estimates were then computed using the smoothed injury rates resulting from the model fitting.

As an illustration of the model fitting procedure, consider the comparison of all types of restraints combined versus no restraints relative to OAIS $\geq$ 1 injury in towed case vehicles. The basic (weighted) data for this comparison is given in Table 3-9. In some preliminary analyses both linear and log-linear models were fit to the data for several of the comparisons, and it was found

Table 3-9

DATA FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO OAIS $\geq$ 1 INJURY IN TOWED VEHICLES

Extent of Damage	Occupant Sex	Head Restraint	OAIS $\geq$ 1 Injury Yes	No	Percent Injured
1 & 2	M	R	263	490	34.93
1 & 2	M	N	82	139	37.10
1 & 2	F	R	473	434	52.15
1 & 2	F	N	71	79	47.33
3 & 4	M	R	136	112	54.84
3 & 4	M	N	48	40	54.55
3 & 4	F	R	208	193	51.87
3 & 4	F	N	40	14	74.07
5 - 9	M	R	120	95	55.81
5 - 9	M	N	17	20	45.95
5 - 9	F	R	96	100	48.98
5 - 9	F	N	9	0	100.00

that the linear models generally gave a somewhat better fit. For this reason the model fit to the data of Table 3-9 was of the form

$$\hat{\underset{\sim}{P}} = \underset{\sim}{X}\,\underset{\sim}{\beta} ,$$

where $\underset{\sim}{P}$ is the vector of proportions of injured occupants in the various subpopulations defined by extent of damage, sex, and head restraint, $\underset{\sim}{X}$ is a design matrix, and $\underset{\sim}{\beta}$ is a vector of model coefficients. Figure 3-2 shows the vector of proportions, the initial design matrix, and the estimated model coefficients resulting from fitting the design matrix to the data. A weighted least squares procedure, GENCAT, was used to fit the model.

$$\underset{\sim}{P} = \begin{bmatrix} .349 \\ .371 \\ .522 \\ .473 \\ .548 \\ .545 \\ .519 \\ .741 \\ .558 \\ .459 \\ .490 \\ .989^{*} \end{bmatrix} \qquad \underset{\sim}{X} = \left[\begin{array}{ccc|ccc|ccc} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{array}\right] \qquad \underset{\sim}{\hat{\beta}_1}\ (\text{s.d.}) = \left[\begin{array}{cc} .356 & (.039) \\ .160 & (.050) \\ -.007 & (.063) \\ \hline .520 & (.068) \\ .016 & (.082) \\ .104 & (.102) \\ \hline .492 & (.072) \\ .072 & (.097) \\ .356 & (.097) \end{array}\right]$$

Figure 3-2. Injury Rates, Initial Design Matrix, and Model Coefficients.

It can be seen that the design matrix $\underset{\sim}{X}_1$ is in block diagonal form. By comparing the rows of $\underset{\sim}{X}_1$ with the subpopulations of Table 3-9 it is seen that the three blocks of $\underset{\sim}{X}_1$ correspond to the three levels of extent of damage. The first column in each block is a base line effect for the block whose coefficient gives the injury rate for male occupants with head restraint. The second column in each block is a sex effect, while the last column is the head restraint effect. The vector of estimated coefficients has been similarly partitioned, and an examination of the coefficients and their standard deviations suggest certain reductions that might be made in the design matrix. For example, the difference in the baseline coefficients of the second and third blocks is quite small relative to their standard deviations so that the columns corresponding to these effects might be combined. To the extent that a model fails to provide an adequate fit to the data, either in an overall sense or for certain subpopulations, the design matrix might need to be expanded in certain areas in addition to being reduced. Through a sequence of tests of hypotheses concerning the model coefficients a design matrix can be determined which provides an adequate fit to the data with as few parameters (columns) as possible.

*Zero frequencies are replaced by 0.1 for computational purposes.

Figure 3-3 shows the final design matrix and model coefficients for the example used above. Again interpretation of the model coefficients or the columns of the design matrix can be found by comparing the rows with the subpopulations. Thus, for this example,

Figure 3-3

Model for Head Restraint Effectiveness Based on OAIS $\geq$ 1 Injury for Towed Case Vehicles

Extent of Damage	Driver Sex	Head Restraint	Injury Rates	Predicted Injury Rates	Design Matrix				
1 & 2	M	R	.349	.356	1	0	0	0	0
1 & 2	M	N	.371	.348	1	0	0	0	1
1 & 2	F	R	.522	.516	1	1	0	0	0
1 & 2	F	N	.473	.508	1	1	0	0	1
3 & 4	M	R	.548	.528	0	0	1	0	0
3 & 4	M	N	.545	.521	0	0	1	0	1
3 & 4	F	R	.519	.528	0	0	1	0	0
3 & 4	F	N	.741	.927	0	0	1	1	0
5-9	M	R	.558	.528	0	0	1	0	0
5-9	M	N	.459	.521	0	0	1	0	1
5-9	F	R	.490	.528	0	0	1	0	0
5-9	F	N	.989	.927	0	0	1	1	0

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4	β_5
.356	.160	.528	.398	-.007
(.036)	(.050)	(.034)	(.075)	(.054)

χ^2 due to error = 3.46 with 7 degrees of freedom

Effectiveness estimate · E = 13.57%
Standard deviation = 9.38

β_1 is the baseline effect (injury rate) for extent of damage equal 1 or 2,

β_2 is the sex effect for extent = 1 or 2,

β_3 is the baseline for extent = 3-9,

β_4 is the head restraint effect for female occupants in crashes with extent = 3-9, and

β_5 is the head restraint effect in all other situations.

The head restraint effect β_5, is quite nonsignificant. It is retained in the model, however, since it is used in estimating head restraint effectiveness. For more complicated models (i.e., models containing more interactions) the interpretation of the model coefficients can be obtained in the same way, but the explanation becomes quite cumbersome.

The subpopulations and injury frequencies to which the other models were fit are shown in Tables 3-10 through 3-19.

The procedure for using the models to estimate head restraint effectiveness is illustrated below also using the example of Table 3-7 and Figure 3-3. In this model there are six subpopulations defined by the three levels of extent of damage and the two of occupant sex. Each subpopulation can be given a weight,

$$w_i = \frac{N_i}{N} \quad \text{, where}$$

N_i = number of occupants in ith subpoulation, and

$$N = \sum_{i=1}^{6} N_i \ .$$

Within each subpopulation expressions for the injury rate of unrestrained occupants, P_N, and for the difference in injury rates between unrestrained and restrained occupants, P_N-P_R, are given in terms of the model coefficients. Thus, the design matrix shows that in the first subpopulation (extent = 1 or 2, sex = M).

$$P_N = \beta_1+\beta_5 \quad \text{and} \quad P_N-P_R = \beta_5 \quad ,$$

while adding up the frequencies from Table 3-9 gives w_1 = .2970. Overall estimates of the quantities P_N and P_N-P_R are, thus, obtained as weighted sums over the subpopulations. Finally, these sums have the form

Table 3-10.

DATA FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO WHIPLASH INJURY IN TOWED VEHICLES

Occupant Age	Belt Use	Occupant Sex	Head Restraint	Whiplash Injury Yes	Whiplash Injury No	Percent Injured
≤ 19	yes	M	R	10	8	55.50
≤ 19	yes	M	N	0	0	--
≤ 19	yes	F	R	10	10	50.00
≤ 19	yes	F	N	0	0	--
≤ 19	no	M	R	49	98	33.33
≤ 19	no	M	N	10	97	9.35
≤ 19	no	F	R	63	148	29.86
≤ 19	no	F	N	3	44	6.38
20-54	yes	M	R	58	123	32.04
20-54	yes	M	N	4	0	100.00
20-54	yes	F	R	98	94	51.04
20-54	yes	F	N	8	0	100.00
20-54	no	M	R	203	478	29.81
20-54	no	M	N	77	98	44.00
20-54	no	F	R	321	508	38.72
20-54	no	F	N	50	93	34.97
55+	yes	M	R	14	29	32.56
55+	yes	M	N	4	0	100.00
55+	yes	F	R	12	25	32.43
55+	yes	F	N	4	0	100.00
55+	no	M	R	52	97	34.90
55+	no	M	N	2	67	2.90
55+	no	F	R	49	94	34.27
55+	no	F	N	9	31	22.40

Table 3-11

DATA FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO OAIS $\geq$ 2 INJURY IN TOWED VEHICLES

Extent of Damage	Head Restraint	OAIS $\geq$ 2 Injury Yes	OAIS $\geq$ 2 Injury No	Percent Injured
1 & 2	R	34	1579	2.11
1 & 2	N	6	398	1.49
3 & 4	R	23	633	3.51
3 & 4	N	4	139	2.80
5 - 9	R	26	384	6.34
5 - 9	N	6	40	13.04

Table 3-12

DATA FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO WHIPLASH INJURIES IN NON-TOWED VEHICLES

Occupant Sex	Head Restraint	Whiplash Injury Yes	Whiplash Injury No	Percent Injured
M	R	213	768	21.7
M	N	79	298	21.0
F	R	269	581	31.6
F	N	38	78	32.8

Table 3-13

DATA FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO OAIS $\geq$ 1 INJURY IN NON-TOWED VEHICLES

Occupant Sex	Head Restraint	OAIS $\geq$ 1 Injury Yes	OAIS $\geq$ 1 Injury No	Percent Injured
M	R	140	832	14.4
M	N	95	282	25.2
F	R	290	544	34.8
F	N	28	88	24.1

Table 3-14

DATA FOR COMPARING INTEGRAL RESTRAINTS AND ADJUSTABLE RESTRAINTS* WITH NO RESTRAINT RELATIVE TO WHIPLASH INJURY

Vehicle Weight	Belt Use	Head Restraint	Whiplash Injury Yes	Whiplash Injury No	Percent Injured
Light	Yes	Integral	38	29	56.7
Light	Yes	Adjust.	4	48	7.7
Light	Yes	None	0	0	--
Light	No	Integral	144	212	40.4
Light	No	Adjust.	57	148	27.8
Light	No	None	45	62	42.1
Med.	Yes	Integral	46	101	31.3
Med.	Yes	Adjust.	57	14	80.3
Med.	Yes	None	12	0	100.0
Med.	No	Integral	80	166	32.5
Med.	No	Adjust.	170	154	52.5
Med.	No	None	49	132	27.1
Heavy	Yes	Integral	15	24	38.5
Heavy	Yes	Adjust.	42	73	36.5
Heavy	Yes	None	8	0	100.0
Heavy	No	Integral	29	127	18.6
Heavy	No	Adjust.	245	603	28.9
Heavy	No	None	57	235	19.5

*Towed Case Vehicles Only

Vehicle Weight: Light = $\leq$ 2300 lbs., Med. = 2400-3300,
Heavy = $\geq$ 3400

Table 3-15

DATA FOR COMPARING INTEGRAL RESTRAINTS AND ADJUSTABLE RESTRAINTS*WITH NO RESTRAINT RELATIVE TO OAIS ≥ 1 INJURY

Vehicle Weight	Extent of Damage	Head Restraint	OAIS ≥ 1 Injury Yes	OAIS ≥ 1 Injury No	Percent Injured
Light	1 & 2	Integral	88	61	59.1
Light	1 & 2	Adjust.	88	79	52.7
Light	1 & 2	None	44	30	59.5
Light	3 & 4	Integral	45	84	34.9
Light	3 & 4	Adjust.	24	18	57.1
Light	3 & 4	None	20	20	50.0
Light	5 - 9	Integral	83	66	55.7
Light	5 - 9	Adjust.	17	31	35.4
Light	5 - 9	None	3	0	100.0
Med.	1 & 2	Integral	76	180	29.7
Med.	1 & 2	Adjust.	184	100	64.8
Med.	1 & 2	None	70	62	53.0
Med.	3 & 4	Integral	84	10	89.4
Med.	3 & 4	Adjust.	45	29	60.8
Med.	3 & 4	None	39	24	61.9
Med.	5 - 9	Integral	29	14	67.4
Med.	5 - 9	Adjust.	35	21	62.5
Med.	5 - 9	None	2	0	100.0
Heavy	1 & 2	Integral	30	114	20.8
Heavy	1 & 2	Adjust.	221	400	35.6
Heavy	1 & 2	None	75	127	37.1
Heavy	3 & 4	Integral	13	15	46.4
Heavy	3 & 4	Adjust.	129	155	45.4
Heavy	3 & 4	None	32	10	76.2
Heavy	5 - 9	Integral	12	10	54.5
Heavy	5 - 9	Adjust.	37	53	41.1
Heavy	5 - 9	None	21	20	51.2

*Towed Case Vehicles Only

Table 3-16

DATA FOR COMPARING INTEGRAL RESTRAINTS AND ADJUSTABLE RESTRAINTS* WITH NO RESTRAINT RELATIVE TO OAIS ≥ 2 INJURY

Extent of Damage	Head Restraint	OAIS ≥ 2 Injury Yes	OAIS ≥ 2 Injury No	Percent Injured
1 & 2	Integral	3	546	0.5
1 & 2	Adjust.	29	1020	2.8
1 & 2	None	6	398	1.5
3 & 4	Integral	8	245	3.2
3 & 4	Adjust.	15	384	3.8
3 & 4	None	4	139	2.8
5 - 9	Integral	15	198	7.0
5 - 9	Adjust.	11	184	5.6
5 - 9	None	6	40	13.0

Table 3-17

DATA FOR COMPARING CORRECTLY POSITIONED WITH INCORRECTLY POSITIONED ADJUSTABLE HEAD RESTRAINTS* RELATIVE TO WHIPLASH INJURY

Vehicle Weight	Head Restraint Position	Whiplash Injury Yes	Whiplash Injury No	Percent Injured
Light	Correct	44	121	26.7
Light	Incorrect	16	74	17.8
Med.	Correct	153	124	55.2
Med.	Incorrect	55	40	57.9
Heavy	Correct	152	359	29.8
Heavy	Incorrect	108	278	28.0

*Towed Case Vehicles Only

Table 3-18

DATA FOR COMPARING CORRECTLY POSITIONED WITH INCORRECTLY POSITIONED ADJUSTABLE RESTRAINTS RELATIVE TO OAIS ≥ 1 INJURY

Vehicle Weight	Head Restraint Position	OAIS ≥ 1 Injury Yes	OAIS ≥ 1 Injury No	Percent Injured
Light	Correct	88	77	53.3
Light	Incorrect	40	50	44.4
Med.	Correct	182	115	61.3
Med.	Incorrect	63	31	67.0
Heavy	Correct	217	302	41.8
Heavy	Incorrect	133	253	34.5

Table 3-19

DATA FOR COMPARING CORRECTLY POSITIONED WITH INCORRECTLY POSITIONED ADJUSTABLE RESTRAINTS RELATIVE TO OAIS ≥ 2 INJURY

Extent of Damage	Head Restraint Position	OAIS ≥ 2 Injury Yes	OAIS ≥ 2 Injury No	Percent Injured
1 & 2	Correct	24	582	4.0
1 & 2	Incorrect	5	363	1.4
3 & 4	Correct	11	222	4.7
3 & 4	Incorrect	4	137	2.8
5 - 9	Correct	4	113	3.4
5 - 9	Incorrect	7	58	10.8

$$P_N = \sum_{j=1}^{5} C_{Nj}\beta_j \quad \text{and}$$

$$P_N - P_R = \sum_{j=1}^{5} C_{N-Rj}\beta_j \quad , \text{where}$$

the C_{Nj} and C_{N-Rj} are sums of the w_i's. The vector, $Q = \begin{bmatrix} P_N \\ P_N - P_R \end{bmatrix}$

can be estimated by the GENCAT program along with its covariance matrix V_Q. These, in term can be further analyzed to give

$$E^* = f_3(f_2(f_1(Q))) = \exp.\ (A \log Q),$$

where A is the one-rowed matrix (-1, 1). The quantity E* is computed in three steps corresponding to the three transformations. At each step a covariance matrix is also computed of the form,

$$V_f = HV^*H^1,$$

where H is the matrix $\left[\frac{df}{dq^*}\right]$, V* is the estimated covariance matrix from the preceding step, and q* is an element from the transformed vector Q. Finally, the effectiveness estimate is given by

$$E = 100\ E^*$$

and its standard deviation by

$$SD_E = 100\left[\frac{N_w}{N_{uw}} V_E{}^*\right]^{1/2},$$

where N_w and N_{uw} are, respectively, the numbers of weighted and unweighted cases upon which the analysis was based.

Details of the model fit to the data of Tables 3-10 to 3-19 are given in the Appendix. Results are shown in Tables 3-20 and 3-21. Since no significant differences in injury rates were found between correctly and incorrectly positioned adjustable restraints, no separate effectiveness estimates were made.

From Table 3-20 it is seen that most of the effectiveness estimates are positive indicating that occupants having head restraints were found generally to have lower injury rates than occupants not having head restraints. It was only for the comparison of integral restraints with no restraint that the results were statistically significant at a five percent level.

3.6 Injuries Caused by Head Restraints

Injuries to rear seat occupants resulting from striking the head restraint system were also examined. Table 3-22 shows the number of such injuries as a function of age and sex of the occupant and extent of damage to the vehicle. Each cell of this table gives a frequency count (unweighted), the average AIS score of the head restraint caused injuries and the average AIS score of similar (age, sex, extent) occupants who were injured in cars not equipped with head restraints. In general, the head restraint caused injuries seem to be no more severe than the injuries occurring when head restraints were not present. Moreover, using weighted counts the 32 head restraint caused injuries made up only about 1.5 percent of the 2123 injuries suffered by rear seat occupants in cars equipped with head restraints, and occurred to only 0.5% of the 6461 exposed rear seat occupants involved in crashes (of all types). Moreover, only four of these injured occupants did not also receive injuries from other contact sources. Thus, only four occupants were injured by contact with the head restraints who, otherwise, might have been uninjured. By contrast, if the 6461 occupants had been seated in the front right and left hand positions in rear end crashes, 1186 fewer injuries would have been expected had they been protected by integral head restraints as opposed to no head restraints. It should be noted, however, that the crashes in which the 6461 rear seat occupants were involved were not pre-selected to be those for which a head restraint caused injury was considered to be most likely. In any case it does not appear that head restraints present much of a safety hazard to rear seat occupants.

TABLE 3-20

EFFECTIVENESS ESTIMATES

Head Restraint Comparison	Injury Criterion	Case Vehicle Condition	Effectiveness	95% Confidence Interval
All Types vs. None	Whiplash	Towed	9.95%	(-10.00, 29.90)
All Types vs. None	OAIS $\geq$ 1	Towed	13.57%	(-4.81, 31.95)
All Types vs. None	OAIS $\geq$ 2	Towed	-20.60%	(-180.63, 139.43)
All Types vs. None	Whiplash	Non-Towed	-1.35%	(-65.46, 62.76)
All Types vs. None	OAIS $\geq$ 1	Non-Towed	19.28%	(-16.98, 55.54)
Integral vs. None	Whiplash	Towed	20.27%	(-3.47, 44.01)
Adjustable vs. None	Whiplash	Towed	-1.27%	(-24.16, 21.62)
Integral vs. None	OAIS $\geq$ 1	Towed	31.61%	(17.38, 45.86)
Adjustable vs. None	OAIS $\geq$ 1	Towed	12.02%	(-3.72, 27.76)
Integral vs. None	OAIS $\geq$ 2	Towed	47.41%	(-22.76, 117.58)
Adjustable vs. None	OAIS $\geq$ 2	Towed	-2.35%	(-125.34, 120.64)

TABLE 3-21

COMPARISON OF CORRECTLY ADJUSTED AND INCORRECTLY ADJUSTED ADJUSTABLE HEAD RESTRAINTS

Injury Criterion	Injury Rate Difference ($P_I - P_C$)	Standard Deviation
Whiplash	-1.96 per hundred	5.63
OAIS $\geq$ 1	-4.38 per hundred	5.93
OAIS $\geq$ 2	-1.36 per hundred	2.11

Table 3-22

OCCUPANTS INJURED FROM CONTACT WITH HEAD RESTRAINTS

Sex	Age	Extent of Damage 1	2	3	4	5	6
M	0-10	1 1.00 (1.00)		1 2.00 (1.13)			
	11-20		4 1.00 (1.38)	4 2.00 (1.28)			1 3.00 (3.00)
	21-30			1 1.00 (1.71)	1 2.00 (2.00)		
	31-40						
	41-55						
	56 & Over						
F	0-10	4 1.00 (1.00)		2 1.00 (1.40)			
	11-20			7 1.71 (1.52)			
	21-30						
	31-40						
	41-55					4 1.00 (none)	
	56 & Over		1 1.00 (1.50)	1 1.00 (2.33)			

Cell entries:
number of injured occupants
average AIS of head restraint injuries
(average AIS of injuries when head restraints not present)

FIGURE A-1

MODEL FOR HEAD RESTRAINT EFFECTIVENESS BASED ON WHIPLASH INJURY FOR TOWED CASE VEHICLES

Populations: Driver Age	Belt Use	Driver Sex	Head Restraint	Injury Rates	Predicted Injury Rates	Design Matrix							
≤ 19	yes	M	R	.556	.526	1	0	0	0	0	0	0	0
≤ 19	yes	M	N	.500	.526	1	0	0	0	0	0	0	0
≤ 19	yes	F	R	.500	.526	1	0	0	0	0	0	0	0
≤ 19	yes	F	N	.500	.526	1	0	0	0	0	0	0	0
≤ 19	no	M	R	.333	.317	0	1	0	0	0	0	0	0
≤ 19	no	M	N	.093	.059	0	1	0	0	1	0	0	0
≤ 19	no	F	R	.299	.317	0	1	0	0	0	0	0	0
≤ 19	no	F	N	.064	.059	0	1	0	0	1	0	0	0
20-54	yes	M	R	.320	.317	0	1	0	0	0	0	0	0
20-54	yes	M	N	.976	.854	0	1	0	0	0	1	0	0
20-54	yes	F	R	.510	.483	0	1	1	0	0	0	0	0
20-54	yes	F	N	.988	1.000	0	1	1	0	0	1	0	0
20-54	no	M	R	.298	.317	0	1	0	0	0	0	0	0
20-54	no	M	N	.440	.371	0	1	0	0	0	0	1	0
20-54	no	F	R	.387	.375	0	1	0	1	0	0	0	0
20-54	no	F	N	.350	.428	0	1	0	1	0	0	1	0
55+	yes	M	R	.326	.317	0	1	0	0	0	0	0	0
55+	yes	M	N	.976	.976	0	1	0	0	0	0	0	1
55+	yes	F	R	.324	.317	0	1	0	0	0	0	0	0
55+	yes	F	N	.976	.976	0	1	0	0	0	0	0	1
55+	no	M	R	.349	.317	0	1	0	0	0	0	0	0
55+	no	M	N	.029	.059	0	1	0	0	1	0	0	0
55+	no	F	R	.343	.375	0	1	0	1	0	0	0	0
55+	no	F	N	.225	.116	0	1	0	1	1	0	0	0

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8
.526	.317	.166	.057	-.259	.536	.053	.658
(.181)	(.027)	(.079)	(.041)	(.041)	(.100)	(.066)	(.125)

χ^2 due to error = 4.14 with 16 degrees of freedom

Effectiveness estimates: E = 9.95%

Standard deviation = 10.18

FIGURE A-2

MODEL FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO OAIS $\geq$ 2 INJURY IN TOWED VEHICLES

Extent of Damage	Head Restraint	Injury Rates	Predicted Injury Rates	Design Matrix			
1 & 2	R	.0211	.0208	1	0	0	0
1 & 2	N	.0149	.0156	1	0	0	1
3 & 4	R	.0351	.0347	1	1	0	0
3 & 4	N	.0280	.0294	1	1	0	1
5-9	R	.0634	.0674	1	0	1	0
5-9	N	.1304	.0622	1	0	1	1

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4
.0208	.0138	.0122	-.0052
(.0079)	(.0161)	(.0276)	(.0143)

X^2 due to error = 0.397 with 2 degrees of freedom

Effectiveness estimate E = -20.60%
S.D. = 81.65

FIGURE A-3

MODEL FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO WHIPLASH INJURY IN NON-TOWED VEHICLES

Occupant Sex	Head Restraint	Injury Rates	Predicted Injury Rates	Design Matrix		
M	R	.217	.216	1	0	0
M	N	.210	.213	1	0	1
F	R	.316	.318	1	1	0
F	N	.328	.315	1	1	1

Model Coefficients (and standard deviations)

β_1	β_2	β_3
.2160	.1022	-.0034
(.0358)	(.0535)	(.0614)

χ^2 due to error = 0.0159 with 1 degree of freedom

Effectiveness estimate = -1.35%
Standard deviation = 32.71

FIGURE A-4

MODEL FOR COMPARING ALL HEAD RESTRAINTS WITH NONE RELATIVE TO OAIS $\geq$ 1 INJURY IN NON-TOWED VEHICLES

Occupant Sex	Head Restraint	Injury Rates	Predicted Injury Rates	Design Matrix		
M	R	.144	.155	1	0	0
M	N	.252	.209	1	0	1
F	R	.348	.324	1	1	0
F	N	.241	.378	1	1	1

Model Coefficients (and standard deviations)

β_1	β_2	β_3
.1550	.1692	-.0537
(.0310)	(.0516)	(.0609)

χ^2 due to error = 2.335 with 1 degree of freedom

Effectiveness estimate = 19.28%
Standard deviation = 18.50

FIGURE A-5

MODELS FOR EFFECTIVE ESTIMATES OF INTEGRAL AND ADJUSTABLE HEAD RESTRAINTS RELATIVE TO NO HEAD RESTRAINT FOR WHIPLASH INJURY

Vehicle Weight	Belt Use	Head Restraint	Injury Rates	Predicted Injury Rates	Design Matrix										
light	yes	integral	.567	.553	1	0	0	1	0	0	0	0	0	0	0
light	yes	adjust.	.077	.077	1	0	0	0	0	0	0	1	0	0	0
light	yes	none	.500	.444	1	0	0	0	0	0	0	0	0	0	0
light	no	integral	.404	.407	1	0	0	0	1	0	0	0	0	0	0
light	no	adjust.	.278	.269	1	0	0	0	0	0	1	0	0	0	0
light	no	none	.421	.444	1	0	0	0	0	0	0	0	0	0	0
medium	yes	integral	.313	.327	0	1	0	0	0	1	0	0	0	0	0
medium	yes	adjust.	.803	.824	0	1	0	0	0	0	1	0	0	0	0
medium	yes	none	.999	.999	0	1	0	0	0	0	0	0	0	0	0
medium	no	integral	.325	.329	0	0	1	1	0	0	0	0	0	0	0
medium	no	adjust.	.527	.525	0	0	1	0	0	0	0	0	1	0	0
medium	no	none	.271	.220	0	0	1	0	0	0	0	0	0	0	0
heavy	yes	integral	.386	.327	0	1	0	0	0	1	0	0	0	0	0
heavy	yes	adjust.	.365	.365	0	1	0	0	0	0	0	0	0	1	0
heavy	yes	none	.999	.999	0	1	0	0	0	0	0	0	0	0	0
heavy	no	integral	.186	.183	0	0	1	0	1	0	0	0	0	0	0
heavy	no	adjust.	.289	.289	0	0	1	0	0	0	0	0	0	0	1
heavy	no	none	.195	.220	0	0	1	0	0	0	0	0	0	0	0

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8
.444 (.061)	.999 (.016)	.220 (.041)	.109 (.072)	-.037 (.063)	-.672 (.079)	-.175 (.072)	-.367 (.104)

β_9	β_{10}	β_{11}
.305 (.075)	-.633 (.102)	.069 (.054)

χ^2 due to error = .934 with 7 degrees of freedom

Effectiveness estimates: E_I = 20.27%
SD = 12.11

E_A = -1.27%
SD = 11.68

FIGURE A-6

MODEL FOR COMPARING INTEGRAL RESTRAINTS AND ADJUSTABLE RESTRAINTS WITH NO RESTRAINT RELATIVE TO OAIS $\geq$ 1 INJURY (TOWED VEHICLES)

Vehicle Weight	Extent of Damage	Restraint Use	Injury Rates	Predicted Injury Rates	Design Matrix										
light	1 & 2	integral	.591	.585	1	0	0	0	1	0	0	0	0	0	0
light	1 & 2	adjust.	.527	.488	1	0	0	0	0	0	0	1	0	0	0
light	1 & 2	none	.595	.562	1	0	0	0	0	0	0	0	0	0	0
light	3 & 4	integral	.349	.298	1	0	0	0	0	1	0	0	0	0	0
light	3 & 4	adjust.	.571	.639	1	0	0	0	0	0	0	0	1	0	0
light	3 & 4	none	.500	.562	1	0	0	0	0	0	0	0	0	0	0
light	5 - 9	integral	.557	.672	0	0	1	0	0	1	0	0	0	0	0
light	5 - 9	adjust.	.354	.354	0	0	1	0	0	0	0	0	0	0	1
light	5 - 9	none	1.000	.935	0	0	1	0	0	0	0	0	0	0	0
medium	1 & 2	integral	.297	.298	1	0	0	0	0	1	0	0	0	0	0
medium	1 & 2	adjust.	.648	.639	1	0	0	0	0	0	0	0	1	0	0
medium	1 & 2	none	.530	.562	1	0	0	0	0	0	0	0	0	0	0
medium	3 & 4	integral	.894	.894	0	1	0	0	0	0	1	0	0	0	0
medium	3 & 4	adjust.	.608	.629	0	1	0	0	0	0	0	1	0	0	0
medium	3 & 4	none	.619	.703	0	1	0	0	0	0	0	0	0	0	0
medium	5 - 9	integral	.674	.672	0	0	1	0	0	1	0	0	0	0	0
medium	5 - 9	adjust.	.625	.676	0	0	1	0	0	0	0	0	0	1	0
medium	5 - 9	none	1.000	.935	0	0	1	0	0	0	0	0	0	0	0
heavy	1 & 2	integral	.208	.163	0	0	0	1	0	1	0	0	0	0	0
heavy	1 & 2	adjust.	.356	.353	0	0	0	1	0	0	0	1	0	0	0
heavy	1 & 2	none	.371	.427	0	0	0	1	0	0	0	0	0	0	0
heavy	3 & 4	integral	.464	.439	0	1	0	0	0	1	0	0	0	0	0
heavy	3 & 4	adjust.	.454	.444	0	1	0	0	0	0	0	0	0	1	0
heavy	3 & 4	none	.762	.703	0	1	0	0	0	0	0	0	0	0	0
heavy	5 - 9	integral	.545	.585	1	0	0	0	1	0	0	0	0	0	0
heavy	5 - 9	adjust.	.411	.488	1	0	0	0	0	0	0	1	0	0	0
heavy	5 - 9	none	.512	.562	1	0	0	0	0	0	0	0	0	0	0

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8
.562 (.051)	.703 (.074)	.935 (.053)	.427 (.055)	.023 (.101)	-.263 (.055)	.191 (.103)	-.074 (.057)

β_9	β_{10}	β_{11}
.077 (.078)	-.259 (.087)	-.581 (.168)

χ^2 due to error = 5.399 with 16 degrees of freedom

Effectiveness estimates and standard deviations

$E_{Integral}$ = 31.61% $E_{Adjusted}$ = 12.02%

S.D. = 7.27 S.D. = 8.03

FIGURE A-7

MODEL FOR COMPARING INTEGRAL RESTRAINTS AND ADJUSTABLE RESTRAINTS WITH NO RESTRAINT RELATIVE TO OAIS $\geq$ 2 INJURY

Extent of Damage	Restraint Type	Injury Rate	Predicted Injury Rate	Design Matrix					
1 & 2	Integral	.005	.006	1	0	0	1	0	0
1 & 2	Adjust.	.028	.026	1	0	0	0	1	0
1 & 2	None	.015	.014	1	0	0	0	0	0
3 & 4	Integral	.032	.023	0	1	0	1	0	0
3 & 4	Adjust.	.038	.043	0	1	0	0	1	0
3 & 4	None	.028	.031	0	1	0	0	0	0
5 - 9	Integral	.070	.063	0	0	1	0	0	1
5 - 9	Adjust.	.056	.063	0	0	1	0	0	1
5 - 9	None	.130	.130	0	0	1	0	0	0

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4	β_5	β_6
.014 (.014)	.031 (.018)	.130 (.115)	-.008 (.014)	.012 (.016)	-.067 (.117)

χ^2 due to error = 0.278 with 3 degrees of freedom

Effectiveness estimate

$E_{Integral}$ = 47.41% $E_{Adjusted}$ = -2.35%

S.D. = 35.80   S.D. = 62.75

FIGURE A-8

MODEL FOR COMPARING CORRECTLY POSITIONED WITH INCORRECTLY POSITIONED ADJUSTABLE HEAD RESTRAINTS REALTIVE TO WHIPLASH INJURY

Vehicle Weight	Head Restraint Position	Injury Rates	Predicted Injury Rates	Design Matrix			
Light	Correct	.267	.290	1	0	0	0
Light	Incorrect	.178	.255	1	0	1	0
Medium	Correct	.552	.552	0	1	0	0
Medium	Incorrect	.579	.579	0	1	0	1
Heavy	Correct	.298	.290	1	0	0	0
Heavy	Incorrect	.280	.255	1	0	1	0

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4
.290	.552	-.035	.027
(.039)	(.069)	(.060)	(.135)

χ^2 due to error = 1.035 with 2 degrees of freedom

Injury rate difference $(P_I - P_C)$ = -1.96 per hundred
Standard deviation = 5.63

FIGURE A-9

MODEL FOR COMPARING CORRECTLY POSITIONED WITH INCORRECTLY POSITIONED ADJUSTABLE RESTRAINTS RELATIVE TO OAIS $\geq$ 1 INJURY

Vehicle Weight	Head Restraint Position	Injury Rate	Predicted Injury Rate	Design Matrix			
Light	Correct	.533	.577	1	0	0	0
Light	Incorrect	.444	.487	1	0	1	0
Medium	Correct	.613	.577	1	0	0	0
Medium	Incorrect	.670	.670	1	0	0	1
Heavy	Correct	.418	.425	0	1	0	0
Heavy	Incorrect	.345	.335	0	1	1	1

Model Coefficients (and standard deviations)

β_1	β_2	β_3	β_4
.577	.425	-.090	.093
(.048)	(.076)	(.064)	(.122)

χ^2 due to error = 0.720 with 2 degrees of freedom

Difference in Injury Rates ($P_I - P_C$) = -4.38 per hundred

Standard Deviation = 5.93

FIGURE A-10

MODEL FOR COMPARING CORRECTLY POSITIONED WITH INCORRECTLY POSITIONED ADJUSTABLE RESTRAINTS RELATIVE TO OAIS $\geq$ 2 INJURY

Extent of Damage	Head Restraint Position	Injury Rate	Predicted Injury Rate	Design Matrix		
1 & 2	Correct	.040	.040	1	0	0
1 & 2	Incorrect	.014	.016	1	1	0
3 & 4	Correct	.047	.040	1	0	0
3 & 4	Incorrect	.028	.016	1	1	0
5 - 9	Correct	.034	.040	1	0	0
5 - 9	Incorrect	.108	.108	1	0	1

Model Coefficients (and standard deviations)

β_1	β_2	β_3
.0404	-.0245	.0390
(.0147)	(.0193)	(.0894)

χ^2 due to error = 0.253 with 2 degrees of freedom

Difference in Injury Rates $P_I - P_C$ = -1.36 per hundred

Standard Deviation = 2.11