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U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

An Evaluation of Head Restraints
Federal Motor Vehicle Safety Standard 202

Plans and Programs
Office of Program Evaluation

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An Agency staff review of an existing Federal regulation performed in response to Executive Order 12291.

16. Abstract
Head restraints were installed in passenger cars largely in response to Federal Motor Vehicle Safety Standard 202. The purpose of a head restraint is to prevent whiplash injury of the neck in rear impact crashes. The objectives of this Agency staff evaluation are to determine how many injuries integral and adjustable head restraints have eliminated in highway accidents, to measure the actual cost of the restraints, to assess cost effectiveness and to describe the operational performance and problems of integral and adjustable restraints. The evaluation is based on statistical analyses of three years of Texas accident data and the National Crash Severity Study, National Accident Sampling System and Fatal Accident Reporting System files; cost analyses of actual head restraint assemblies; a review of laboratory and crash tests and in-depth accident investigations; and head restraint sales data. It was found that:

- 75 percent of adjustable restraints are left in the down position.
- Integral head restraints reduce the overall injury risk in rear impacts by 17 percent; adjustable restraints, by 10 percent.
- Integral restraints add $12 to the lifetime cost of owning and operating a car; adjustable restraints, $40.
- 72 percent of the cars sold during 1969-81 had adjustable restraints; 28 percent had integral.
- The existing mix of adjustable and integral restraints prevents 64,000 injuries per year.

17. Key Words
head restraint; rear impact; rear-end collisions; Federal Motor Vehicle Safety Standard; Standard 202; accident analysis; evaluation; statistical analysis; cost effectiveness

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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

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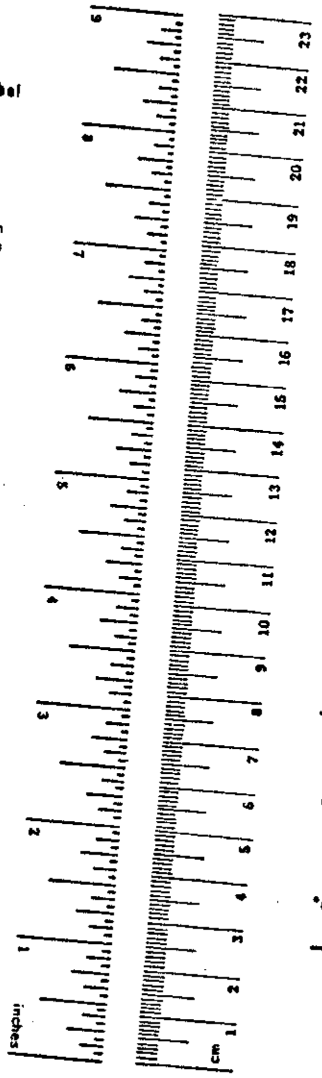
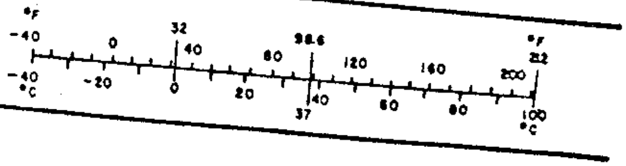
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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



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LIST OF ABBREVIATIONS

ACIR	Automotive Crash Injury Research
AIS	Abbreviated Injury Scale
ANPRM	Advance Notice of Proposed Rulemaking
BMDP	Biomedical programs (P series)
CDC	Collision Deformation Classification
cov	covariance
CY	Calendar Year
df	degrees of freedom
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GM	General Motors
GSA	General Services Administration
HSRC	Highway Safety Research Center
K+A	fatal and serious injuries (police rated)
K+A+B	nonminor injuries (police rated)
MDAI	Multidisciplinary Accident Investigation
MY	Model Year
NAS	National Accident Summary
NASS	National Accident Sampling System
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
PDOF	Principal Direction Of Force
SAE	Society of Automotive Engineers
TAD	Traffic Accident Data project accident severity scale

UCLA	University of California at Los Angeles
var	variance

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Dr. John Garrett of Calspan Field Services, Inc., resolved my questions on National Crash Severity Study data elements.

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Alleyne Monkman and Michele Stewart typed the report.

EXECUTIVE SUMMARY

Whiplash is one of the most common and annoying types of injuries in motor vehicle crashes. It is by far the predominant injury in rear impact crashes. During the 1960's, more than 400,000 persons a year suffered whiplash when their car was struck in the rear. In the most common form of whiplash, crash forces jerk the victim's head rearward, past the top of the seatback, twisting and injuring the neck.

The logical response to this problem is to effectively raise the seatback and prevent excessive rearward motion of the head. During the 1950's and 1960's, motor vehicle manufacturers and safety research institutions, with the advice of the medical community, devised head restraints which serve the purpose of extending the seatback. There are adjustable restraints which are attached to the seatback and can be moved up or down to suit the occupant. There are integral restraints which are of fixed height and usually a homogeneous part of the seatback.

The General Services Administration mandated head restraints for the front outboard seats of Government cars in 1966 and established criteria for testing the performance of restraints. In 1968, the National Highway Traffic Safety Administration established a head restraint requirement for all passenger cars sold in the United States after January 1, 1969. The requirement and its associated test criteria were promulgated as Federal Motor Vehicle Safety Standard 202.

Executive Order 12291 (February 1981) requires agencies to evaluate their existing major regulations, including any rule whose annual effect on the economy is $100 million or more. This study is an evaluation of the head restraints installed in response to Standard 202, based on the actual operating experience of passenger cars. The evaluation objectives are:

(1) Estimating the benefits of head restraints - the number of injuries they have eliminated in highway accidents.

(2) Measuring the cost of head restraints installed in cars currently on the road.

(3) Assessing cost-effectiveness.

(4) Comparing the performance of integral and adjustable restraints.

(5) Comparing the compliance requirements and test performance of head restraints to their actual performance in highway accidents.

(6) Explaining why head restraints are (or are not) effective; identifying their principal shortcomings.

(7) Exploring the sensitivity of head restraint effectiveness to changes in seatback height.

The injury reduction due to head restraints was estimated principally by analyzing three years of Texas accident files. The National Crash Severity Study (NCSS) and a published analysis of insurance claim files provided additional information on injury reduction. NCSS also supplied information on the height and positioning of head restraints in crash-involved cars. The National Accident Sampling System (NASS) yielded a national estimate of the number of persons injured in rear impact crashes during 1979. The effect of head restraints on fatalities was studied by analyzing Fatal Accident Reporting System (FARS) files for 1975-80, the Multidisciplinary Accident Investigation file and long-term fatal accident trends. The cost of head restraints was calculated by disassembling and analyzing the individual components of a representative sample of head restraints and seatbacks. Detailed sales data for head restraints in model years 1977-81 were acquired and studied.

The results from the Texas, NCSS, NASS and FARS analyses were compared to published statistical studies of head restraints, including a major study of insurance claims. Laboratory and crash tests were reviewed, as were selected accident and injury case histories. The research, rulemaking and enforcement activities related to Standard 202 were discussed with Agency engineers and the public Docket was studied. The conclusions of this evaluation are based on all of the information sources - statistical, clinical and engineering.

The most important conclusions of this evaluation are: (1) Head restraints - both the integral and adjustable types - have significantly reduced the number of injuries in rear impact crashes. (2) Integral seats are significantly more effective than adjustable restraints. The first conclusion is based on statistically significant findings from Texas and insurance claim files. The second is based on statistically significant results from Texas and NCSS. The statistical findings, moreover, are consistent with engineering intuition, clinical analyses and test results.

The principal shortcoming of the evaluation was that the National Crash Severity Study, the National Accident Sampling System and other detailed files did not contain a large enough sample of cars without head restraints (i.e., pre model year 1969) for statistically meaningful effectiveness comparisons of head restraints versus no head restraints. As a result, it was necessary to rely on State data which do not explicitly distinguish whiplash from other injuries and which are suspected of reporting biases, especially for older cars. A major analytic effort was devoted to removing or minimizing the biases, so as to make the effectiveness estimates as accurate as possible. This effort resulted in some statistically complex estimates for which only approximate, rather than exact, confidence bounds were obtained.

The conclusions on <u>why</u> head restraints have been effective are intuitive judgements based on a thorough review of the available data sources. The conclusion on why integral restraints have not claimed a larger share of the market is based on analysis of sales data, not on a direct survey of consumer attitudes. The findings on the relationship between restraint height and injury risk are based on a statistical model which, at this time, is just partly verified by in-depth accident or crash test data.

The principal findings and conclusions of the study are the following:

Principal Findings

The problem

o In 1979, when 86 percent of the passenger cars on the highway were equipped with head restraints, 446,000 drivers and right front passengers were injured in rear impact crashes (confidence bounds: 330,000 to 560,000). There would have been 502,000 injuries if none of the cars were equipped with head restraints (confidence bounds: 370,000 to 640,000).

o The severity of rear impact crash injuries was:

	Number of Victims	Percent of Victims
Fatal	700	0.1
Nonfatal injury and treatment:		
Hospitalization	16,000	3
Emergency room	130,000	26
Doctor's office	130,000	26
Not treated	220,000	44
		100

o 73 percent of the injuries occurred in nontowaway crashes.

o The types of injuries in 1979 were:

	Percent of Victims
Whiplash	60
Whiplash plus other injuries	18
Nonwhiplash	22

o 35 percent of the injuries were not listed in police reports.

o Whiplash victims missed an average of 4 days of work.

Sales of integral restraints

- 28 percent of the cars sold during 1969-81 had integral head restraints.

- The market share for integral restraints peaked at 39 percent in 1975, declined to 22 percent by 1978, but recovered to 33 percent by 1981.

Height and positioning of restraints

- Standard 202 requires that adjustable restraints, when fully extended, provide a 27.5 inch seatback. But 75 percent of the occupants leave their adjustable restraints down. As a result, 75 percent of adjustable restraints are actually positioned at a level where seatback height is less than 27.3 inches.

- 85 percent of integral seatbacks are 28 inches or taller - i.e., they exceed the minimum height requirement of Standard 202.

Effectiveness of head restraints

- Head restraints reduced the overall risk of driver injury in rear impacts, as follows:

	Injury Reduction (%)	Confidence Bounds
Integral restraints	17	9 to 25
Adjustable restraints (75 percent of which are not extended)	10	4 to 17
Average of integral and adjustable (weighted by crash involvement rates)	13	7 to 19

Benefits of head restraints

- There would have been 502,000 drivers and right front passengers injured in rear impacts in 1979, if none of the cars were equipped with head restraints. If all cars had been equipped with them, this number would have been reduced as follows:

	Number of Injuries Prevented	Confidence Bounds
Fleet of 100 percent integral restraints	85,000	40,000 to 130,000
Fleet of 100 percent adjustable restraints (75 percent of which would not be extended)	52,000	17,000 to 87,000
Fleet with 1979 mix of integral and adjustable restraints	64,000	28,000 to 100,000

Cost of head restraints

- The average consumer cost of head restraints, per car, in 1981 dollars:

	Car Purchase Price Increase	Lifetime Fuel Consumption*	Lifetime Total Cost
Integral restraints	$ 6.65	$ 5.68	$12.33
Adjustable restraints	24.33	15.81	40.14
Sales-weighted average	19.38	12.97	32.35

*@ $1.51 per pound of weight added to a car

Cost-effectiveness

- The average societal cost of a whiplash injury is $670 (in 1981 dollars); this amount does not include a value for pain and suffering. The average insurance compensation for whiplash victims' economic losses and pain and suffering is $2150. Thus, $670-2150 is a reasonable price for avoiding whiplash, if we accept societal costs and insurance compensation as proxies for a range of what persons would be willing to pay to avoid injuries. When $670-2150 per whiplash are divided into a million dollars, we obtain a range of 460-1500 whiplashes. Thus 460-1500 whiplashes eliminated could be thought of as a reasonable level of benefits per million dollars spent on whiplash protection.

- The number of injuries eliminated by a million dollars worth of head restraints is

	Injuries Eliminated Per Million Dollars of Cost	Confidence Bounds
Integral restraints	690	360 to 1060
Adjustable restraints	130	40 to 220
1979 mix of integral and adjustable	200	90 to 310

Effectiveness as a function of head restraint height

- Increases in the height of restraints would achieve the following reductions relative to the injury risk with the current mix of integral, properly positioned and mispositioned adjustable restraints:

Height of the Restraints*	Injury Reduction Relative to Current Restraint Mix (%)	Confidence Bounds
31 inches	9	2 to 23
30 inches	8	2 to 18
29 inches	7	2 to 11
28 inches	4	2 to 6

*As positioned by the occupant

Conclusions

Effectiveness of head restraints

- Head restraints - both the integral and adjustable types - have significantly reduced whiplash injuries in rear impact crashes.
- Head restraints are effective because they have been performing as intended in highway crashes: they support the head and neck and prevent hyperextension.
- The restraints do not appear to have had any unforeseen benefits, such as reducing rear impact fatalities, nonwhiplash injuries, or forms of whiplash other than hyperextension.
- The restraints do not appear to have any significant negative side-effects, such as increasing rear impact fatalities, aggravating rear-seat occupants' injuries in frontal crashes or causing accidents because they block a driver's view to the side and rear.

Integral versus adjustable restraints

- Integral seats are nearly twice as effective as adjustable restraints. The difference can be attributed to the failures by occupants to position their adjustable restraints correctly - current adjustable restraints, when left unextended, do not adequately protect a person of average height.

- Integral seats are far less costly than adjustable restraints.

- Integral seats eliminate about 5 times more injuries per dollar of cost than adjustable restraints.

- Adjustable restraints, despite their higher cost and lower benefit, continue to be installed in the majority of cars (through 1981). From our analysis of auto sales data, it appears to us that the high sales of adjustable restraints, to a large extent, reflect customer preferences based on styling and comfort.

CHAPTER 1

INTRODUCTION

1.1 Federal Motor Vehicle Safety Standards - the program and its evaluation

The primary goal of the National Highway Traffic Safety Administration is to reduce deaths, injuries and damages resulting from motor vehicle accidents. The Federal Motor Vehicle Safety Standards are one of NHTSA's principal safety programs. Each standard requires certain types of new motor vehicles or motor vehicle equipment sold in the United States to meet specified safety performance levels. Over 50 standards, affecting cars, trucks, buses, motorcycles or aftermarket parts, have been issued since 1966.

The National Traffic and Motor Vehicle Safety Act of 1966 [52] which provides the authority to issue safety standards, specifies that each standard shall be "practicable," "meet the need for motor vehicle safety" and "provide objective criteria." It defines "motor vehicle safety" to mean protection against "unreasonable" risk of accidents, deaths or injuries. Thus, to meet the requirements of the Act, a standard must:

(1) Incorporate performance tests that can be carried out under controlled conditions. The test conditions are relevant to some aspect of operational performance.

(2) Address a specific motor vehicle safety problem.

(3) Be within the financial capability of manufacturers.

The Federal Motor Vehicle Safety Standards set minimum performance requirements but do not specify the design of safety equipment. Manufacturers may choose any design that meets or, for that matter, exceeds the minimum requirements. They may provide additional safety equipment which generally mitigates the highway safety problem addressed by the standard but is not actually needed to meet the specific compliance test requirements.

The Government, the motor vehicle manufacturers and independent researchers have contributed to the development of motor vehicle standards. In the case of the early (1968-69) standards especially, it was the motor vehicle industry that conducted or sponsored much of the research and sought self-regulation through the Society of Automotive Engineers' Recommended Practices. The Government subsequently promulgated performance requirements that many vehicles were already meeting or exceeding.

In 1975, the NHTSA Administrator directed the Office of Program Evaluation to evaluate existing Federal Motor Vehicle Safety Standards [44]. The specific objectives of each evaluation were

(1) To determine if a standard was actually performing as intended.

(2) To determine benefits and costs.

Since 1975, the Agency has received a number of directives to continue reviewing its existing standards. In mid-1981, the extent legislation and orders governing the review are:

Executive Order 12291, dated February 17, 1981, requires agencies to initiate reviews of existing regulations and perform Regulatory Impact Analyses of existing major rules [29]. "Major" rules include, among others, those which result in an annual effect on the economy of $100 million or more. The Regulatory Impact Analysis shall determine the actual costs and actual benefits of the existing rule and the potential costs and benefits of viable alternatives to the current rule, if any exist. The Analysis must test whether: (1) The benefits to society of the existing rule outweigh the costs. (2) The net benefits of the existing rule exceed the net benefits of the potentially viable alternatives. (3) The rule, in combination with the Agency's other regulations, maximizes the aggregate net benefits to society taking into account the condition of the particular industries affected by regulations, the condition of the national economy, and other regulatory actions contemplated for the future.

Department of Transportation Order 2100.5 is dated May 22, 1980 and titled "Policies and Procedures for Simplification, Analysis and Review of Regulations" [55]. The Department publishes a "Semiannual Review List" that shows which evaluations of existing regulations are in progress or planned and their target completion dates [30].

The Agency published a Federal Register Notice on July 10, 1980 which solicited public views on its safety evaluations, particularly on which standards should receive priority consideration for evaluation [28].

The Regulatory Flexibility Act of 1980 requires that evaluations of existing regulations also consider their economic impact and administrative burden on small businesses [57]. Most safety standards, however, primarily affect the major manufacturers and have little or no impact on small businesses.

The first evaluation published by the Agency was a preliminary "Evaluation of Standard 214" - Side Door Strength [41]. The report appeared in September 1979 and assessed the actual costs and actual benefits of Standard 214 and measured cost- effectiveness.

The main recommendation in public and intra-Agency reviews of the 214 evaluation was that future reports should include in-depth analyses of why a standard has been effective or what have been its shortcomings - including, if possible, a comparison of statistical findings with laboratory tests and individual case histories. This would make the evaluation a more useful tool for guiding possible future rulemaking activity. That recommendation was followed in the Agency's "Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies: Standard 203 - Impact Protection for the Driver; Standard 204 - Rearward Column Displacement," published in January 1981 [40] and it is also followed in this study.

1.2 What is Standard 202?

Federal Motor Vehicle Safety Standard 202, which became effective for the front outboard seats of passenger cars manufactured after January 1, 1969, aims to prevent excessive rearward motion of the occupant's head in rear impact crashes. Thereby it seeks to reduce the incidence of "whiplash" due to hyperextension of the neck [26].

Standard 202 has led to the installation of head restraints in passenger cars. There are adjustable restraints which are attached to the seatback and can be moved up or down to suit the occupant. There are integral restraints which are of fixed height and usually a homogeneous part of the seatback.

Research organizations, motor vehicle manufacturers and the medical community contributed to the development of head restraints. They were optionally available on some cars as early as 1964.

The head restraints in cars currently on the road often exceed the minimum height requirement specified in Standard 202.

It is the objective of this evaluation to measure the costs and benefits of all the head restraints that are actually in cars on the road, including cars that were voluntarily equipped with restraints before the standard's effective date or voluntarily equipped with restraints that exceed the standard's minimum requirements.

1.3 Why evaluate Standard 202?

The main reason that Standard 202 was given high priority for evaluation is that preliminary research suggested that it is one of the Agency's costlier standards [36].

The evaluation attempts to characterize the achievements of head restraints in objective cost-effectiveness terms and to compare their actual performance in crashes to expectations based on testing and research. Previous accident analyses showed that head restraints do reduce injuries [54], but did not fully address whether the restraints' performance in highway accidents lives up to costs or expectation.

The evaluation provides the first statistically significant comparisons of adjustable and integral restraints.

1.4 Contents of the evaluation

Chapter 2 describes the principal findings and conclusions of the evaluation. It also summarizes why head restraints have been effective and assesses the strengths and weaknesses of the analyses.

Chapter 3 surveys the safety problem addressed by Standard 202. It describes the number, severity and mechanisms of passenger car occupant injuries in rear impact crashes.

Chapter 4 reviews the history of head restraints from their initial development to their current sales trends.

The overall effectiveness of head restraints is estimated in Chapter 5, based on a literature review and analyses of Texas, National Crash Severity Study and Fatal Accident Reporting System data.

The effectiveness of integral and adjustable restraints is compared in Chapter 6, based on a literature review and analyses of Texas and NCSS data.

Chapter 7 estimates the actual costs, benefits and cost-effectiveness of head restraints, both overall and separately for adjustable and integral restraints.

Chapter 8 examines the relationship between head restraint height and injury risk. This relationship is a key to understanding "why" head restraints have been effective.

CHAPTER 2

FINDINGS AND CONCLUSIONS

The results from the evaluation of Standard 202 (Head Restraints - Passenger Cars) are presented in this chapter. The findings are based on statistical analyses of the National Accident Sampling System (NASS), the National Crash Severity Study (NCSS), the Fatal Accident Reporting System (FARS) and Texas accident files for 1972, 1974 and 1977; a component cost analysis of a representative sample of vehicles; analyses of vehicle sales; a review of the literature on laboratory and crash test results, clinical analyses of selected accident and injury cases and statistical accident analyses; and discussion with engineers about the research, rulemaking and enforcement activities related to head restraints.

2.1 Principal statistical findings

The problem

- In 1979, when 86 percent of the passenger cars on the highway were equipped with head restraints, 446,000 drivers and right front passengers were injured in rear impact crashes (confidence bounds: 330,000 to 560,000). There would have been 502,000 injuries if none of the cars were equipped with head restraints (confidence bounds: 370,000 to 640,000).

- The severity of rear impact crash injuries was:

	Number of Victims	Percent of Victims
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- The market share for integral restraints peaked at 39 percent in 1975, declined to 22 percent by 1978, but recovered to 33 percent by 1981.

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- Standard 202 requires that adjustable restraints, when fully extended, provide a 27.5 inch seatback. But 75 percent of the occupants leave their adjustable restraints down. As a result, 75 percent of adjustable restraints are actually positioned at a level where seatback height is less than 27.3 inches.

- 85 percent of integral seatbacks are 28 inches or taller - i.e., they exceed the minimum height requirement of Standard 202.

Effectiveness of head restraints

- Head restraints reduced the overall risk of driver injury in rear impacts, as follows:

	Injury Reduction (%)	Confidence Bounds
Integral restraints	17	9 to 25
Adjustable restraints (75 percent of which are not extended)	10	4 to 17
Average of integral and adjustable (weighted by crash involvement rates)	13	7 to 19

Benefits of head restraints

- There would have been 502,000 drivers and right front passengers injured in rear impacts in 1979, if none of the cars were equipped with head restraints. If all cars had been equipped with them, this number would have been reduced as follows:

	Number of Injuries Prevented	Confidence Bounds
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Fleet of 100 percent adjustable restraints (75 percent of which would not be extended)	52,000	17,000 to 87,000
Fleet with 1979 mix of integral and adjustable restraints	64,000	28,000 to 100,000

Cost of head restraints

- The average consumer cost of head restraints, per car, in 1981 dollars:

	Car Purchase Price Increase	Lifetime Fuel Consumption*	Lifetime Total Cost
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31 inches	9	2 to 23
30 inches	8	2 to 18
29 inches	7	2 to 11
28 inches	4	2 to 6

*As positioned by the occupant

2.2 Discussion of findings

2.2.1 The problem: injuries in rear impact crashes

Standard 202 was promulgated to reduce the frequency and severity of neck injuries to drivers and right front occupants of passenger cars in rear impact crashes. Pre-standard seats, in general, did a good job protecting occupants from serious injury. The seatback is a smooth, padded surface that gradually dissipates the occupant's load when he is driven back into the seat by rear impact crash forces. Its shortcoming, however, was that it was not tall enough to adequately support the occupant's head and neck. Crash forces jerk the occupant's head rearward while the seatback holds his torso in place. The resultant strain on the neck may produce a variety of injury symptoms known collectively as "whiplash."

The starting point for the evaluation is to determine the number of drivers and right-front occupants of passenger cars who would be injured in rear impact crashes without Standard 202. Specifically, how many casualties would there have been in the United States during the base year for this evaluation - 1979 - if no cars had been equipped with head restraints (but the accident environment was otherwise that of 1979)?

The National Accident Sampling System (NASS) is a probability sample of the Nation's accidents during 1979. From this file, it is possible to obtain directly an estimate of 446,000 drivers and right-front passengers who were actually injured in rear impacts in 1979 (confidence bounds: 330,000 to 560,000). By that time, however, 86 percent of the cars on the highway had head restraints. The average effectiveness of head restraints in cars on the road during 1979 was 12.8 percent. If none of the cars had been equipped with head restraints, the number of casualties would have increased to 502,000 (confidence bounds: 370,000 to 640,000 - one sided $\alpha = .05$, see Section 3.1.2).

The National Accident Summary (NAS) is a census of police accident reports from 39 States for the year 1971. From this file, in combination with certain NASS statistics, a corresponding estimate of 594,000 casualties is obtained - a quantity well within the confidence bounds of the NASS estimate (see Section 3.1.3).

Rear impact crash injuries are, on the average, less severe than injuries in other crash modes. The seat and seatback, as mentioned above, provide good "occupant packaging" in rear impacts (except for the neck). The rear structure of a car dissipates crash energy gradually. Rear impacts rarely involve fixed objects or vehicles moving in opposite directions - the most dangerous crash types. Table 2-1 clearly shows that rear impact injuries are far less likely to be fatal or serious than injuries in other crash modes. (See Section 3.2 for further discussion.)

TABLE 2-1

INJURY SEVERITY IN REAR IMPACTS VERSUS OTHER CRASH MODES: FRONT OUTBOARD PASSENGER CAR OCCUPANTS, 1979

	Rear Impacts		Other Crash Modes	
Treatment/Mortality	N	Column %	N	Column %
Fatal	700	0.1	24,000	1
Hospitalization	16,000	3	330,000	14
Emergency room	130,000	26	770,000	33
Doctor's office	130,000	26	220,000	10
Injured-but not treated	220,000	44	970,000	42
TOTALS	500,000		2,310,000	

Table 2-1, on the other hand, also shows that rear impacts account for a substantial portion of the less severe crash injuries.

A distinctive feature of rear impact crash injuries is that they often occur in low severity crashes: 73 percent of the injuries occur in nontowaway crashes. By contrast, in other crash modes, only 32 percent of the injuries are in nontowaways. This is because it doesn't take a high crash velocity to produce whiplash, the most common type of rear impact crash injury.

Whiplash is a noncontact injury to tissues in the neck: the muscles, ligaments or vertebrae. It happens when crash forces cause displacement or rotation of the head relative to the torso to the degree that the neck is extended, twisted or flexed beyond its normal range of motion. (See Section 3.3.1 for further discussion.)

The most common form of whiplash in a rear impact of a car without head restraints involves the unsupported head moving backwards and downwards relative to the fixed torso, with resultant hyperextension of the neck. This is the principal injury mechanism that head restraints are designed to mitigate.

This sequence of events, however, is by no means the only one that leads to whiplash.

Neck pain and stiffness is the most common whiplash symptom. But involvement of the cervical nerves and spine often leads to symptoms in the head, shoulders, arms or upper back. In nearly all cases, however, the injuries are neither visible nor detectable by X-rays.

The pain and disability associated with whiplash may last anywhere from several days to a year. Whiplash victims in the National Crash Severity Study missed an average of 4 days of work.

Whiplash symptoms often take hours or days to appear. Partially because of this, they are not reported to the police in about 35 percent of the cases.

In 1979, 78 percent of the persons injured in rear impact crashes had whiplash symptoms. That includes 60 percent with whiplash-related injuries exclusively plus 18 percent with whiplash and nonwhiplash injuries. Since, in 1979, head restraints were installed in 86 percent of the cars on the road, it may be presumed that the preponderance of whiplash relative to other injuries was even greater prior to Standard 202. (See Section 3.3.3 for further discussion.)

The nonwhiplash injury mechanisms that are known to occur in rear impacts are:

- Rebounding from the seat and striking the steering assembly, windshield, etc.

- Ramping: crash forces propel the occupant up toward the roof - or toward the back seat if the front seat tilts backwards

- Contact with side surfaces; ejection through side doors

- Burns from postcrash fires

- Superficial arm and leg injuries from interior contacts

As injury severity increases, the preponderance of whiplash sharply decreases. Whiplash was the most severe injury of 65 percent of the nonhospitalized victims but only 36 percent of the hospitalized ones. The rear impact fatalities that have been fully documented (28) primarily involved occupant compartment collapse, fire, ejection and/or ramping/seat failure (see Sections 3.3.3 and 3.3.4).

2.2.2 Integral and adjustable restraints

A major objective of the evaluation is to compare the two main types of head restraints - integral and adjustable - in regard to their operational characteristics, market shares, their effectiveness (Section 2.2.3) and cost (2.2.4).

An integral restraint, most commonly, consists of little more than a seatback which, behind the driver's and right front seat positions, is tall enough to meet or exceed the 27.5 inch height requirement of Standard 202 by itself, without any attached pad or restraint. A much rarer alternative type consists of a fixed restraint attached to the top of the seatback, with openings to allow the driver to see through it. During 1969-81, 28 percent of the cars sold in the United States had integral restraints.

Adjustable restraints are not part of the seatback but are separate pads which are attached to the seatback by sliding metal shafts. The occupant may slide the restraint to the top, bottom or any intermediate position. Standard 202 requires that the restraint reach at least 27.5 inches above the seat cushion when it is in the "up" position, but there is no minimum height requirement for the "down" position (see Sections 4.2 and 4.3).

The principal safety advantage of integral restraints is that they do not require action by the occupant to lift them to a level that provides adequate support. This is a very distinct advantage because, in fact, 75 percent of the adjustable head restraints in cars on the highway are left in the "down" position by the occupants (see Section 4.4). As a result, the actual median height of adjustable restraints, in the positions in which they are set by occupants, is less than 26 inches. By contrast, the actual median height of integral restraints is over 28 inches. Since the median height of pre-standard seatbacks was about 22 inches, adjustable seats in effect provide only two thirds as much additional height as integral seats provide (see Section 8.3.1 for the complete height distributions).

Other possible safety advantages of integral restraints are that they furnish a smooth surface, homogeneous with the seatback, without exposed metal parts.

A disadvantage of the ordinary type of integral restraint which was demonstrated in laboratory tests [11] is that it may obstruct a shorter-than-average (e.g., 5 feet 2 inches) driver's vision to the rear and to the back part of the right side window. We do not know if the see-through types of integral restraints eliminate this problem, since no laboratory data on them has been published. A related shortcoming, which has been suggested in mnnufacturers' submissions to the Agency's public dockets [65], is that integral restraints may contribute to a feeling of isolation between front and rear-seat occupants. Both of these problems are presumably not so great in cars with bucket seats: partly, because it is easier to see around a bucket seat; partly, because Standard 202 only places a 6.75 inch width requirement on head restraints for bucket seats, but a 10 inch requirement for other kinds of seats (see Section 4.4).

Have vision obstructions associated with integral restraints increased the risk of accidents (i.e., because drivers are unable to see cars in adjacent lanes)? The authoritative Indiana Tri-Level Study on the Causes of Accidents indicates that the effect, if any, is negligible. In that study, only 0.1 percent of the accidents were attributed to "vision obstructions due to objects in or attached to vehicles" - a class that includes many objects besides head restraints.

The manufacturers initially produced and sold large numbers of integral restraints, presumably because of their lower costs and safety advantages. Table 2-2 shows that the market share for integral restraints increased from 9 percent in 1969 to 34 percent in 1972. During 1972, integral restraints were installed not only on 71 percent of the cars with bucket seats but also on 17 percent of the bench seats and 32 percent of the split bench seats. After 1973, however, production of integral restraints on bench and split bench seats waned rapidly. The market share for integral restraints, which peaked at 39 percent in 1975, had dropped to 22 percent in 1978. In that year, integral restraints were installed on only 56 percent of bucket seats and had nearly disappeared from bench and split bench seats. Integral restraints made a comeback during the 1979-80 downsizing wave, during which large numbers of small, weight-conscious cars with bucket seats were produced. They regained their 39 percent peak market share in 1980 and leveled off to 33 percent in 1981.

A more detailed, model-by-model analysis of 1980-81 car sales indicates that:

- On the majority of makes and models, the customer has a <u>choice</u> of adjustable or integral restraints. On large cars, the choice is typically adjustable bench, adjustable split bench or integral bucket, at the same cost. On smaller cars, the choice is standard bucket seats with integral restraints or extra-cost deluxe bucket seats with adjustable restraints.

- A large percentage of car buyers, typically 50-90 percent, choose the extra cost deluxe seat package, which includes adjustable restraints.

o In general, the more prestigious the car, the higher the percent of buyers who choose the deluxe seats with adjustable restraints.

In view of these market trends and in the absence of actual in-depth surveys of consumer attitudes on head restraints, we speculate that the high sales of adjustable restraints, to a large extent, reflect customer preferences based on styling and comfort. Vision obstructions due to integral restraints may be an influential factor for shorter-than-average drivers (e.g., 5 feet 2 inches) but are probably of secondary importance for the majority of customers. Consciously or, in most cases, unconsciously, the majority of car buyers have apparently accepted the idea that adjustable restraints should be one of the features of a deluxe seating package. (For further discussion see Section 4.5.)

TABLE 2-2

PERCENT OF CARS WITH INTEGRAL RESTRAINTS, BY MODEL YEAR AND SEAT TYPE

Percent with Integral Restraints

Model Year	Overall	Bench Seats	Split Bench	Bucket Seats
1969	9	0	0	27
1970	17	1	31	59
1971	28	7	35	65
1972	34	17	32	71
1973	35	7	17	82
1974	32	10	8	70
1975	39	8	7	76
1976	31	3	3	72
1977	30	2	4	71
1978	22	4	0	56
1979	25		N/A	
1980	39		N/A	
1981	33		N/A	

2.2.3 Effectiveness of head restraints

Head restraints are, essentially, extensions of the seatback behind the driver and right front passenger. They are designed to make the seatback tall enough to provide support for the occupant's head and neck and to prevent an excursion of the head behind the plane of the seatback. Thus, they are designed to mitigate the most common form of whiplash (neck hyperextension due to rearward and downward motion of the head relative to the torso).

Laboratory and crash tests demonstrated positively that head restraints have the potential to mitigate this form of whiplash (see Section 8.2). It is not so clear that they would be effective against other forms of whiplash, such as torsion, translation or lateral rotational forces on the neck (see Section 3.3.1). Head restraints, generally speaking, would not have much effect on nonwhiplash injury mechanisms.

Moreover, the potential of head restraints to mitigate the common form of whiplash may be diminished because

- An adjustable restraint was mispositioned by an occupant
- The restraint was not tall enough to support a tall occupant's head
- Ramping by the occupant lifted his head beyond the restraint
- The occupant had been leaning far forward and his head was unsupported during the injury-producing kinematics.

(For more discussion, see Section 4.4.)

In view of these considerations, head restraints cannot be expected to eliminate all rear impact crash injuries nor even all rear impact whiplash injuries but can be expected to eliminate a substantial proportion of the injuries that involve rearward hyperextension of the neck.

The primary estimates of head restraint effectiveness are derived from the 1972, 74 and 77 Texas State accident files. Effectiveness estimates are obtained for integral restraints, adjustable restraints and a weighted average of the two that reflects the current (1978-81) on-the-road mix of head restraints.

Texas State data are used for the primary estimates because the more detailed, investigator-collected data files such as the National Crash Severity Study do not contain a large enough sample of pre-Standard cars for statistically meaningful results on head restraint effectiveness (more discussion of NCSS may be found later in this Section). Texas data were chosen in preference to other State files available to the Agency because rear impacts are clearly identified and because the sample size is very large. Three nonadjacent years of data were available for access and all were used. (The nonadjacency of the years makes it possible to perform the regression described later in this Section.)

The measure of effectiveness used in the analyses of Texas data is the reduction of <u>any</u> kind of <u>driver</u> injury <u>in rear impacts</u> to <u>no</u> injury. Since Texas data do not specify the type or source of injury, whiplash is not singled out from other kinds of injury. Since the data do not describe the severity of the injuries (most rear impact injuries in Texas are simply classified level "C" - minor), we cannot meaningfully estimate the effectiveness of head restraints in reducing severe injuries to less severe ones. Finally, the analysis is limited to drivers because of data problems with right-front passengers in Texas. (For more discussion about Texas data, see Section 5.3.1.)

Two factors complicate the derivation of effectiveness estimates. One is that the Texas data do not specify whether an accident-involved car had integral, adjustable or no head restraints - the type of restraint can only be inferred from the make, model and model year and even that only for certain models and years. The other problem is that cars without restraints are, in general, older than cars with head restraints. Part of the injury reduction observed for restraint-equipped cars may not be due to head restraints. It may be due to other safety devices or an artifact of incomplete accident reporting for older cars. In the comparison of cars with and without head restraints, analytic techniques are needed to eliminate or compensate for the vehicle age differences.

Because of these factors, we had to subdivide the analysis into 5 steps:

(1) Find the injury reduction for integral restraints relative to adjustable restraints in cars of comparable age and size.

(2) Find the injury reduction for 1969 model cars (most of which have adjustable restraints but some have integral and some have no head restraints) relative to 1968 model cars (most of which have no head restraints but some have integral or adjustable restraints).

(3) From the preceding results, it is possible to calculate the effectiveness of adjustable restraints and integral restraints relative to no restraints.

(4) Take a weighted average of adjustable and integral restraint effectiveness to obtain the effectiveness of the current (1978) on-the-road restraint mix.

(5) Two alternative analysis procedures to check the results obtained in Steps 2 and 3.

These procedures and their results will now be described step by step:

Step 1 (refer to Sections 6.3.1 and 6.3.2): The 1972, 74 and 77 Texas State accident files were gleaned for those models of passenger cars which were equipped primarily with just one type of restraint. It was possible to draw a sample of 21,205 mostly compact and subcompact cars involved in rear impacts wherein 96 percent had integral restraints. It was likewise possible to find 17,758 cars of comparable sizes, 97 percent of which had adjustable restraints. (In order to avoid a vehicle size related bias, intermediate and full-size cars with adjustable restraints were not selected except in the few cases where a model had exclusively integral restraints in certain years.)

Since the cars in the two samples are of the same ages, there is little concern about age-related reporting biases. Multidimensional contingency table analysis is used to remove the possible biases due to differences between the two samples in regard to damage severity, driver age and sex. As noted above, the vehicle weights are similar in the two samples.

The result of the analysis is that the driver overall injury rate (in rear impacts) in cars with integral restraints is a statistically significant 7 percent lower than the rate for adjustable restraints (confidence bounds: 2 to 12 percent). (An injury rate is the number of injured drivers divided by the number of crash-involved drivers.) Since adjustable restraints are so frequently mispositioned, it is little wonder that integral restraints are more effective.

Step 2 (refer to Sections 5.6.1 and 5.6.2 and 3.5): The 1972, 74 and 77 Texas files were gleaned for rear impacts involving 1968 or 1969 model passenger cars. It was possible to draw a sample of 20,214 rear impacts of 1968 model cars; 1531 drivers were injured. There were 23,051 cars of model year 1969; 1605 drivers were injured. This is an 8 percent reduction in the injury rate. Since the 1968 model cars are only 1 year older than the 1969 model cars, this significant injury reduction is not due to vehicle age-related reporting biases. Since no major safety devices (other than head restraints) that affect rear impact injury risk were installed in 1969 cars but absent in 1968 cars, the injury reduction cannot be attributed to safety devices other than head restraints. In other words, the reduction is primarily due to the fact that most 1969 models had head restraints and most 1968 models did not.

Step 3 (refer to Sections 5.6.2 and 6.3.3): In fact, 81 percent of the 1969 cars had adjustable restraints, 7 percent had integral restraints and 12 percent had no restraints. (Recall that Standard 202 did not take effect till mid-model year 1969.) In 1968, 6 percent of the cars had adjustable restraints, 6 percent had integral restraints and 88 percent had no restraints. Let I_o, I_1, and I_2 be the injury rate with no restraints, adjustable restraints and integral restraints, respectively. From Step 2, we found that

$$1 - \frac{\text{injury rate 1969}}{\text{injury rate 1968}} = 1 - \frac{.81 I_1 + .07 I_2 + .12 I_0}{.06 I_1 + .06 I_2 + .88 I_0} = 8 \text{ percent}$$

From Step 1, we found that

$$1 - \frac{I_2}{I_1} = 7 \text{ percent}$$

These two equations are solved to find the <u>effectiveness of adjustable restraints to no restraints</u>,

$$1 - \frac{I_1}{I_0} = 10 \text{ percent}$$

and the <u>effectiveness of integral restraints relative to no restraints</u>

$$1 - \frac{I_2}{I_0} = 17 \text{ percent}$$

Both effectiveness estimates are statistically significant. Table 2-3 provides the confidence bounds.

<u>Step 4</u> (refer to Section 5.6.5): There have been no far-reaching changes in the design of head restraints since 1969. The only thing that has changed from year to year is the mix of adjustable and integral restraints in cars on the road. The overall effectiveness of head restraints for cars on the road is the weighted average of the adjustable and integral effectiveness found in Step 3, weighted by the

adjustable-integral mix of crash-involved cars. In the National Crash Severity Study (1978), 62 percent of the head-restraint equipped cars had adjustable restraints; 38 percent had integral. Thus, the overall average effectiveness of head restraints for cars on the road in 1978 was

$$.62 \times 10\% = .38 \times 17\% = 13 \text{ percent}$$

The 1981 adjustable-integral mix is about the same as the 1978 mix, so the overall average effectiveness for 1981 is also about 13 percent. Table 2-3 provides the confidence bounds for this statistically significant effectiveness estimate.

TABLE 2-3

EFFECTIVENESS OF HEAD RESTRAINTS

(Analysis of 1972, 74 and 1977 Texas data)

Basis of Comparison	Overall Injury Reduction In Rear Impacts (%)	Confidence Bounds*
Integral vs. no restraints	17	9 to 25
Adjustable vs. no restraints (75 percent of adjustable restraints are not extended)	10	4 to 17
Average of integral and adjustable (weighted by 1978 crash involvement rates)	13	7 to 19
Integral vs. adjustable	7	2 to 12

*One-sided $\alpha = .05$

Step 5 (refer to Sections 5.6.1, 5.6.3, 5.6.4 and 3.5): Step 2 relied on a comparison of 1968 and 1969 models alone. Two analysis procedures that involve a wider range of model years were developed to check the results of Step 2 and to insure that the results were not due to some idiosyncracy of these two model years.

In the first procedure, injury rates are computed by model year (1965-72) and calendar year (1972, 74 and 77). A regression is performed to determine the injury rate as a function of vehicle age and percent of cars with head restraints. The objective of the regression is to separate the injury reduction due to head restraints from the reductions due to other safety devices and reporting biases. The regression lines, which fit the data very well (multiple r = .93), lead to an estimate of 12 percent injury reduction for adjustable restraints (which is 2 percent higher than the estimate from Steps 2 and 3).

In the second procedure, the rear impact and side impact injury rates are calculated for 1969-70 model cars and compared to 1967-68 model cars. There was a 15 percent reduction in rear impact injury risk and only a 6 percent reduction in side impact injury risk. Under these specific circumstances (viz., a comparison of 1969-70 and 1967-68 models in 1972, 74 and 77 accidents), it is not unreasonable to attribute the excess of the 15 percent reduction over the 6 percent reduction to head restraints - i.e., to use the side impacts as a control group which reflects injury reductions due to reporting biases or safety devices other than head restraints. Our assessment of the appropriateness of a side impact control group is based on a standard-by-standard review of safety devices in the 1966-70 model cars (Section 3.5) and an analysis of vehicle age-related reporting biases (the last part of Section 5.6.3). Thus, by this procedure, the effectiveness of adjustable restraints is estimated to be 10 percent (the same as for Steps 2 and 3).

Prior to this evaluation, one statistical analysis of head restraints had been performed which involved a sample of accidents large enough for precise results. B. O'Neill et al. analyzed insurance claims for rear impact crashes of 0-4 year old cars in the Los Angeles area during 1979 [54]. In the pre-standard cars, 29 percent of the crash-involved drivers claimed they had a neck injury; in the post-standard cars, only 24 percent. This is an 18 percent reduction of neck injury risk (confidence bounds: 10 to 25 percent - see Section 5.1.1). An 18 percent neck injury reduction is highly consistent with the 13 percent overall injury reduction observed in the Texas analysis, in view of the fact that 80 percent of the rear impact injury victims had whiplash.

The National Crash Severity Study (NCSS) is a probability sample of towaway accidents. The sample of rear impact crashes involving pre-Standard cars was far too small for a statistically meaningful analysis of head restraint effectiveness: there were only 967 (unweighted) front outboard occupants of cars struck in the rear and only 179 of them were in pre-standard cars. Multidimensional contingency table analysis was used to estimate the injury reduction due to head restraints. The results were: no change in overall injury risk (confidence bounds: -19 to +14 percent); -22 percent reduction of neck injury risk (confidence bounds: -72 to +9 percent). When these confidence bounds are compared to the bounds of Texas and insurance data analyses, it is evident that the NCSS results should be given little weight (see Section 5.2 for further discussion).

The National Crash Severity Study, however, did contain a large enough sample of post-Standard cars to confirm that integral seats are significantly more effective than adjustable restraints. On NCSS, the overall injury risk is 20 percent lower with integral seats than with adjustable ones (confidence bounds: 5 to 33 percent) and the neck injury risk is 25 percent lower (confidence bounds: 2 to 43 percent - see Section 6.2).

Five statistical studies on neck injury reduction were performed prior to this evaluation on in-depth accident samples that were even smaller than NCSS [13], [31], [32], [46], [61]. Their results, which were generally consistent with the large sample studies, are summarized in Table 2-4. The weighted average neck injury reduction for NCSS and the other 5 studies was 9 percent - each estimate being weighted by the inverse square of the confidence interval. (Two other analyses are omitted from the table because they are suspected of biases; one involved a regression with excessively correlated independent variables [39]; the other used incompatible data files for the pre- and post-standard cases [4]. All of the studies are reviewed in Section 5.1.)

TABLE 2-4

RESULTS OF HEAD RESTRAINT EFFECTIVENESS ANALYSES

Data Source	Effectiveness (%)	Confidence Bounds*	Refer to Section
LARGE SAMPLE - OVERALL INJURY REDUCTION			
Texas, 1972, 74 and 77	13	7 to 19	5.6.5
LARGE SAMPLE - NECK INJURY REDUCTION			
L.A. insurance claims, 1970 [54]	18	10 to 25	5.1.1
SMALL SAMPLE - OVERALL INJURY REDUCTION			
NCSS	0	-19 to 14	5.2.2
SMALL SAMPLE - NECK INJURY REDUCTION			
NCSS	-22	-72 to 9	5.2.2
Rochester, 1972 [61]	15	-4 to 34	5.1.3
North Carolina, 1972-73 [46]	6	-10 to 22	5.1.3
Sweden, 1973 [13]	55	23 to 88	5.1.3
MDAI [31]	-5	-36 to 26	5.1.3
ACIR [32]	0	-30 to 30	5.1.3
Average of these 6 studies	9		
SMALL INJURY SAMPLE - FATAL OR SERIOUS INJURY REDUCTION			
FARS, 1975-81 (Fatals)	0 or -12**	-29 to 16	5.4
NCSS (hospitalizations)	34	-10 to 54	5.2.2
Texas, 1972 (K + A)	26	0 to 41	5.3.3

*One-sided $\alpha = .05$

**various procedures were used

Since the predominance of whiplash-type injuries sharply decreases as injury severity increases, it is reasonable to expect head restraints to be relatively less effective in mitigating serious injuries. Serious injury reduction was estimated using Texas files ("K" or "A" injuries) and NCSS (hospitalizations). Because serious casualties are uncommon in rear impacts (see Table 2-1), the results of the analyses were not statistically precise. None of the analyses, however, indicated a significant reduction of serious injuries by head restraints. The results and their confidence bounds are shown in Table 2-2.

There has been concern that head restraints could pose an injury hazard to rear seat occupants in frontal crashes. Two statistical analyses suggest that the hazard, if any, is negligible [31], [63] (See Section 4.4).

There have been 28 fatalities in rear impact crashes for which in-depth information on the causes of death is available. (These cases, investigated by multidisplinary, NCSS or NASS teams during 1968-79, are less than 1 percent of the rear impact fatalities that have occurred in the United States during that period.) A case-by-case review (see Section 3.3.4) suggests that the possible effect of head restraints on fatalities is small (viz., they might have made a difference in 3 of the 28 cases) and does not indicate whether the effect, if any, is beneficial or detrimental. Statistical analyses of accident data produce similar findings. Analyses of Fatal Accident Reporting System data found no significant effect for head restraints: depending on the procedure used, the results varied from no change to a nonsignificant 12 percent increase due to the restraints (see Section 5.4). Analyses of the trend in fatal rear-end collisions during 1966-80 (the time during which a fleet with no head restraints was replaced by a fleet with restraints) shows that the number of fatal rear-end collisions has decreased by a few percent, both in absolute terms and relative to other fatal collisions (see Section 5.5). The effect of head restraints on fatalities seems to be negligible.

2.2.4 Benefits, costs and cost-effectiveness

The benefits of head restraints are defined to be the number of injuries that would have been prevented in the base year 1979 if all cars on the road had been equipped with restraints - assuming the same mix of integral, properly positioned and mispositioned adjustable restraints that actually prevailed in the restraint-equipped cars that were on the road during that year.

Since there would have been 502,000 rear impact injuries in 1979 if none of the cars had head restraints, (see Section 2.2.1), and since the current mix of restraints would have eliminated 12.8 percent of these injuries (Section 2.2.3), the benefits of head restraints are 64,000 injuries eliminated (confidence bounds: 28,000 to 100,000 - see Section 7.3).

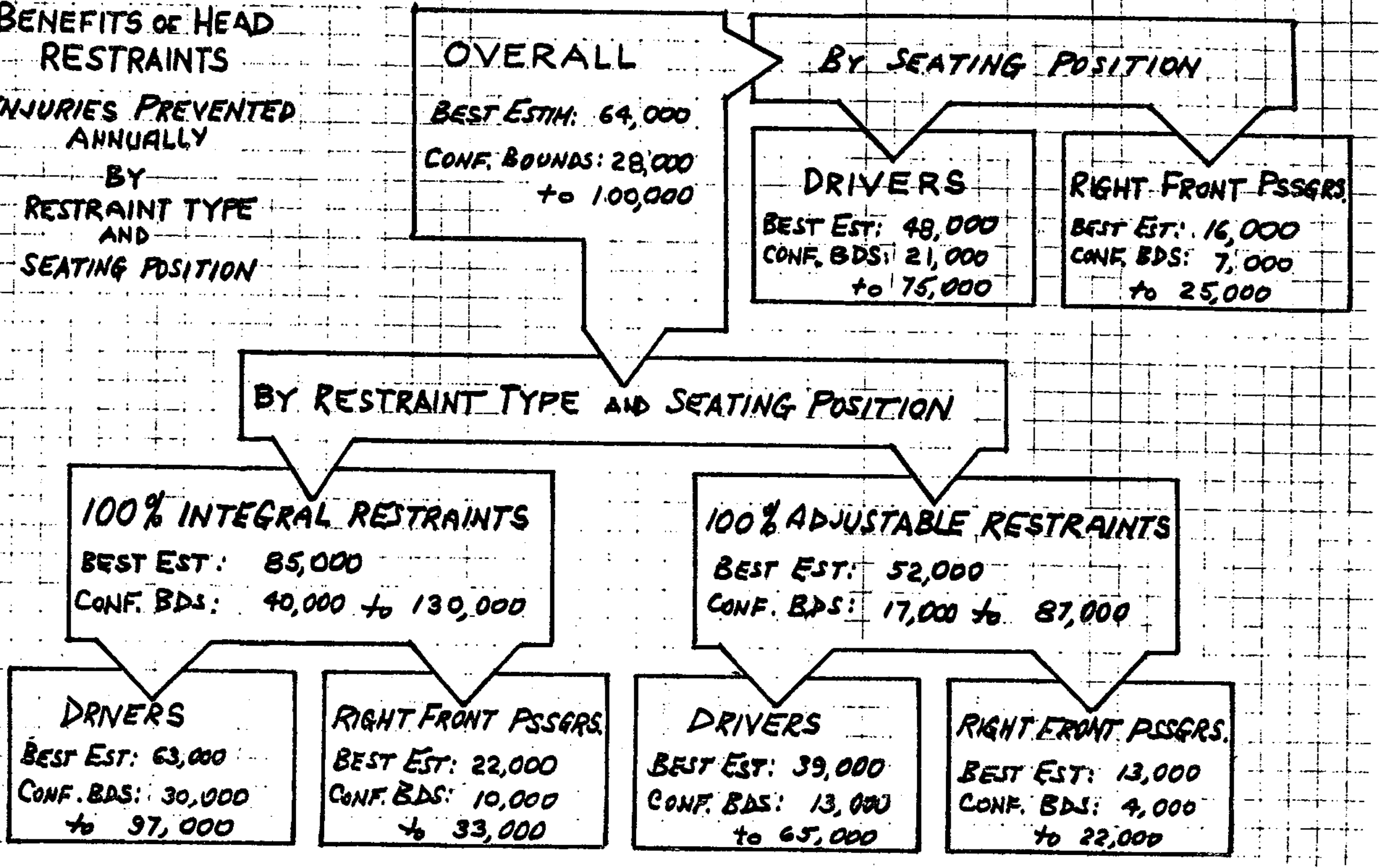
Table 2-5 shows that a 100 percent integral restraint fleet would result in annual benefits of 85,000 injuries eliminated; a 100 percent adjustable restraint fleet would eliminate only 52,000 injuries - assuming occupants position the restraints at the levels actually observed in 1979. Table 2-5 also breaks down the benefits by seat position: just under 75 percent of the benefits accrue to drivers; the remainder to right front passengers.

The costs of head restraints are defined to be the average costs of the restraints which were actually installed in cars that were on the road during 1979 - i.e., in cars that were sold up to that date. The costs are expressed in 1981 dollars.

TABLE 2-5

BENEFITS OF HEAD RESTRAINTS

INJURIES PREVENTED ANNUALLY
BY
RESTRAINT TYPE
AND
SEATING POSITION



OVERALL
BEST ESTIM: 64,000
CONF. BOUNDS: 28,000 to 100,000

BY SEATING POSITION

DRIVERS
BEST EST: 48,000
CONF. BDS: 21,000 to 75,000

RIGHT FRONT PSSGRS.
BEST EST: 16,000
CONF. BDS: 7,000 to 25,000

BY RESTRAINT TYPE AND SEATING POSITION

100% INTEGRAL RESTRAINTS
BEST EST: 85,000
CONF. BDS: 40,000 to 130,000

DRIVERS
BEST EST: 63,000
CONF. BDS: 30,000 to 97,000

RIGHT FRONT PSSGRS.
BEST EST: 22,000
CONF. BDS: 10,000 to 33,000

100% ADJUSTABLE RESTRAINTS
BEST EST: 52,000
CONF. BDS: 17,000 to 87,000

DRIVERS
BEST EST: 39,000
CONF. BDS: 13,000 to 65,000

RIGHT FRONT PSSGRS.
BEST EST: 13,000
CONF. BDS: 4,000 to 22,000

The cost of head restraints is the net increase in the lifetime cost of owning and operating an automobile. There are two principal sources of increased cost:

(1) The consumer price increase due to the addition of head restraints

(2) The lifetime increase in fuel consumption resulting from the incremental weight of head restraints.

In the Agency's cost estimation procedure, representative post-standard head restraints and seatbacks and, where needed, pre-standard seatbacks are torn down and examined in detail. The incremental consumer cost and weight are estimated for the post-standard components. The consumer cost includes materials, labor, tooling, assembly, overhead, manufacturer's and dealer's markups and taxes. A sales weighted average was used to determine the overall cost and weight per car, for integral and adjustable restraints and for all cars combined. (For further discussion, see Section 7.2.1.)

Each pound of weight added to a car results in average fuel consumption of 1.1 gallons over the lifetime of the average car [17]. At 1981 fuel prices, this amounts to a $1.51 penalty per added pound.

At 1981 fuel prices, this amounts to a $1.51 penalty per added pound.

TABLE 2-6

AVERAGE COST PER CAR FOR HEAD RESTRAINTS

(1981 Dollars)

	Purchase Price Increase	Incremental Weight (Pounds)	Lifetime Fuel Penalty	Total Lifetime Cost
Integral	$ 6.65	3.76	$ 5.68	$12.33
Adjustable	$24.33	10.47	$15.81	$40.14
Fleet average	$19.38	8.59	$12.97	$32.35

Table 2-6 shows that installation of head restraints added an average of $32 (in 1981 dollars) to the lifetime cost of owning and operating a car. This is the average for cars on the road in 1979: a fleet that was 28 percent integral and 72 percent adjustable restraints. (The same mix prevailed in 1981.)

Integral restraints cost about $12 over the lifetime of a car; adjustable restraints cost $40. Adjustable restraints are costlier than integral seats, above all, because they are far more complex in design. They are also over twice as bulky (see Section 7.2.2).

Since very nearly 10 million cars were sold annually during the 1970's, the annual average cost of head restraints was $324 million ($32.35 x 10,000,000).

If all cars on the road had been equipped with integral restraints, the annual cost would have been just \$123 million; a 100 percent adjustable restraint fleet would cost \$401 million per year.

The cost-effectiveness of head restraints is expressed by the number of injuries eliminated per million dollars of cost. Since the 1979-81 mix of head restraints eliminates 64,000 injuries per year (Table 2-5) and costs \$324 million per year (in 1981 dollars), the cost-effectiveness is

$$64{,}000/324 = 200 \text{ injuries eliminated per million dollars}$$

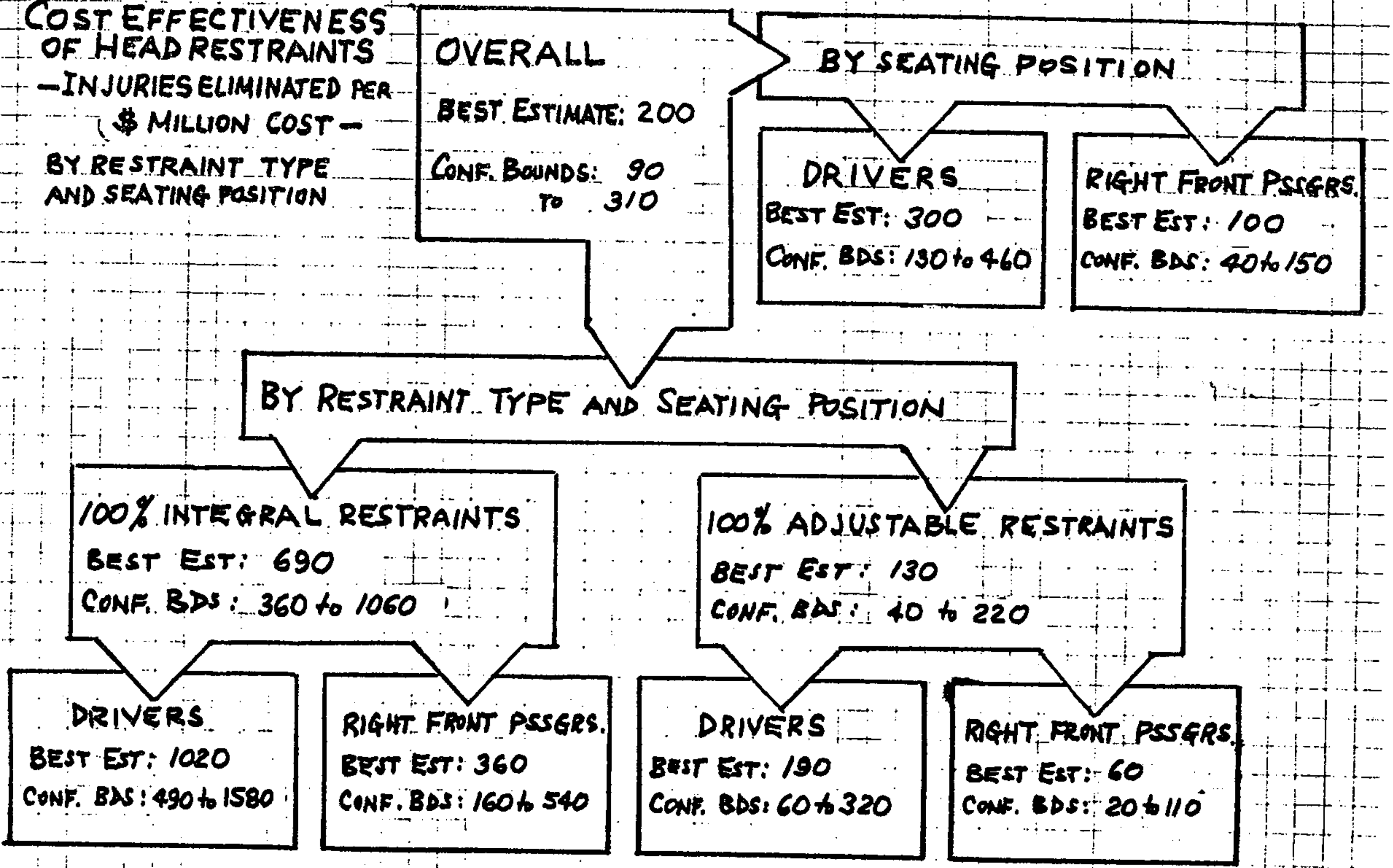
The confidence bounds (one-sided $\alpha = .05$) are 90-310 injuries per million dollars.

Integral restraints eliminate 690 injuries per million dollars (confidence bounds: 360-1060); adjustable restraints, only 130 (confidence bounds: 40-220). Thus, integral restraints are significantly more cost-effective than adjustable restraints.

Table 2-7 gives a further breakdown of cost-effectiveness by restraint type and seat position. Since the restraints for the driver and right-front passenger are usually identical, half of the total cost is assigned to each position. (This is not meant to be a cost estimate for a hypothetical vehicle with only one restraint-equipped position, but an assignment of costs, by position, for existing vehicles.) Cost-effectiveness ranges from 1020 injuries eliminated per million dollars worth of drivers' integral restraints down to 60 for passengers' adjustable restraints.

TABLE 2-7

COST EFFECTIVENESS OF HEAD RESTRAINTS
—INJURIES ELIMINATED PER $ MILLION COST—
BY RESTRAINT TYPE AND SEATING POSITION



What is a "reasonable" price range for consumers to pay in order to avoid a whiplash injury? To a limited extent, this can be answered by examining the societal costs and liability payments for rear impact injuries. The societal costs of rear impact injuries (medical costs lost wages, legal and insurance administration costs) were found to average approximately $670 in 1981 dollars. Liability payments for whiplash, which include compensation for the victim's pain and suffering as well as the economic losses, averaged $2153 in 1981 dollars. These two estimates (when divided into a million dollars) establish a range of 460-1500 whiplashes eliminated as a reasonable level of benefits per million dollars of consumers' expenditures on whiplash protection. (See Section 7.4 for further discussion.)

2.2.5 Head restraint height and injury reduction

The purpose of a head restraint is to effectively extend the seatback up to a height where it provides adequate support for the occupant's head and neck. Standard 202 sets a 27.5 inch height requirement for integral seats and for adjustable restraints in the "up" position. In actual vehicles, most integral restraints exceed this requirement while most adjustable restraints are mispositioned and, in effect, fail to meet it (see Section 2.2.2).

- o What is the relation between head restraint height and injury reduction?
- o To what extent is adjustable restraint performance degraded because occupants misposition them?
- o What would be the effect of making restraints taller (or shorter)?

Anthropometric study of the distribution of seated heights of adults, the lengths of their necks, etc., suggests that a head restraint height of 39 percent of an occupant's standing height (e.g., 27 1/2 inches for an occupant 70 inches tall) will provide adequate support for the occupant's head and neck. A restraint taller than that would not provide much additional support. A restraint shorter than 31 percent of the occupant's standing height (e.g., 22 inches for a 70 inch occupant) would essentially not support the neck at all. Restraints between 31 and 39 percent of the occupant's standing height give intermediate levels of support. (For further discussion, see Section 8.1.)

It is important to note, in this context, that the "correct" or "incorrect" positioning of an adjustable restraint is not an "all or nothing" proposition. An adjustable restraint in the "down" position (typically 25 inches) still provides partial support for a 64 inch occupant. Even a pre-standard seatback (typically 22 inches) gives partial support for a 62 inch occupant. In other words, even though 75 percent of adjustable restraints are left in the "down" position by the occupants, they are still providing partial benefits in this position.

The results of a limited number of sled tests with 22, 24, 26 and 28 inch restraints and 70 inch dummies appear to be quite consistent with the predictions of the anthropometric study. Crash test results are also generally consistent with the predictions, except that in some crashes the occupant <u>ramped</u> upwards in the seat, thereby effectively lowering the restraint. If ramping is a significant problem in highway crashes, it would take restraints that are greater than 39 percent of the occupant's standing height to provide adequate support. (See Section 8.2 for further discussion.)

The National Crash Severity Study cases include measurements of occupant height, restraint height and type and injury severity. It is possible to perform a regression on injury severity as a function of restraint height divided by occupant height. The NCSS sample size, however, was too small for statistically significant regression coefficients. The results, however, were consistent with the anthropometric predictions: they suggested that restraint effectiveness increases as restraint height increases from 31 percent to 39 percent of occupants' height. Effectiveness increases to a much lesser extent as their height is increased beyond 39 percent of occupants' height (see Section 8.3.2).

Since NCSS, by itself, is too small a sample to provide a statistically meaningful relationship between restraint height and injury, another approach was used:

The Texas files provide reliable estimates of the relative injury risks with integral, adjustable and pre-standard seats. NCSS provides reliable distributions of restraint height relative to occupant height for the 3 systems. Based on the anthropometric study, it is proposed that injury risk is constant for seatbacks less than h_c percent of occupant height; injury risk decreases at a linear rate as restraint height increases from h_c to h_c + 8 percent of occupant height; injury risk is constant above h_c + 8 and is ε percent lower than at h_c. What values for h_c and ε will generate the effectiveness results obtained from Texas - i.e., that adjustable restraints are 10 percent better than no restraints and integral restraints are 7 percent better than adjustable restraints?

The solution for h_0 is 35 percent of occupant height (confidence bounds: 30-40 - see Section 8.4.1). In other words, restraints begin to provide support if they are h_0 = 35 percent of the occupant's height and provide adequate support at h_0 + 8 = 43 percent or more of the occupant's height (30 inches for a 70 inch occupant). These point estimates are respectively 4 percent higher than the predictions from the anthropometric study. Although the confidence bounds suggest this difference could be due to chance, it is also possible that occupant ramping is taking place in highway crashes to an extent that taller restraints are needed for adequate protection.

The solution for ε is 23 percent (confidence bounds: 14-42 percent). This is the hypothetical "full" effectiveness of head restraints. The observed effectiveness of integral restraints in highway crashes relative to pre-standard seats is only 17 percent because they do not fully protect the tallest occupants.

Since the Texas effectiveness results are so well predicted by an intuitively reasonable model which expresses injury risk as a function of restaint height alone it is possible to infer that restraint height is indeed the major determinant of injury risk. If this is the case, the inferior performance of adjustable restraints, in the field, relative to integral restraints is mainly due to their mispositioning by occupants. If all adjustable restraints were correctly positioned, they would be about as effective as integral seats - i.e., they might reduce injury risk by 17 percent rather than 10 percent.

If the above relationship of restraint height and injury reduction is valid, it becomes possible to predict the potential benefits of restraints that are taller (or shorter) than those in cars today (see Section 8.4.3). Figure 2-1 shows the incremental percentage of injury reduction, relative to the 1979 mix of integral, properly positioned and mispositioned adjustable restraints, for a population consisting exclusively of integral restraints of the height shown on the x-axis. Similar gains would be achieved by a fleet of adjustable restraints that attain the indicated height when they are in the down position. For example, a population consisting entirely of 31 inch integral restraints would reduce injuries by 9 percent relative to the current (1979) restraint mix (confidence bounds: 2 to 23 percent). Further increases in the height of the restraints would have few additional benefits, because even tall occupants receive good protection from the 31 inch seats.

A fleet of 28 inch integral restaint vehicles (more or less the average height of current integral restraints) would offer a 4 percent improvement on the current mix of adjustable and integral restraints.

Each of these projections of injury rates must be considered speculative at this time. While the projected rates are consistent with the limited body of laboratory and crash tests that have been performed in the past, they would have to be confirmed by more extensive testing or a larger accident sample than was available in NCSS.

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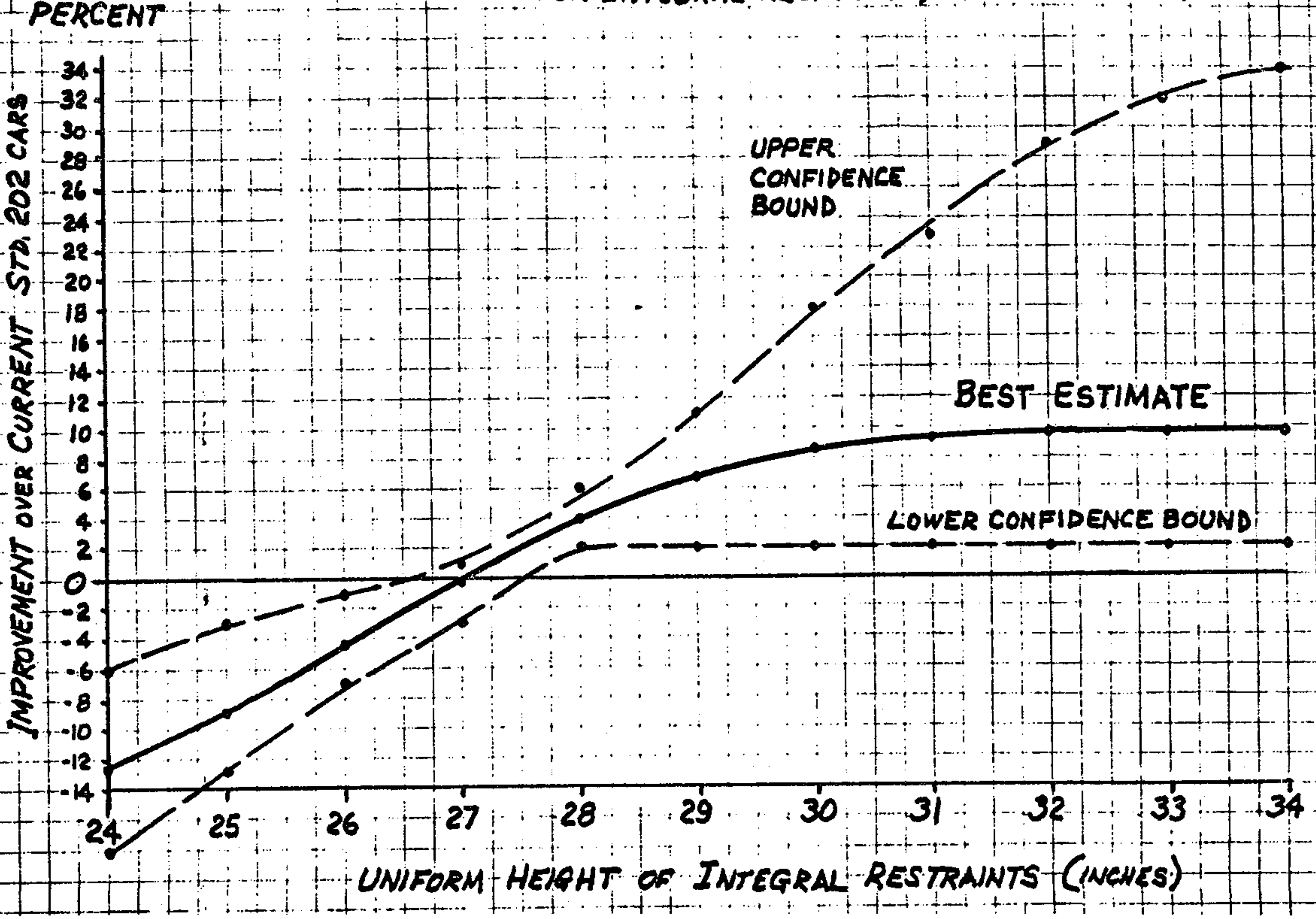
FIGURE 2-1: INJURY REDUCTION RELATIVE TO CURRENT HEAD RESTRAINTS, FOR INTEGRAL RESTRAINTS, BY SEATBACK HEIGHT



2.3 Summary: why are head restraints effective?

The analyses of this evaluation, in combination with previous studies, suggest that head restraints have functioned according to their intended purpose: they have reduced the risk of whiplash injuries involving rearward and downward motion of the head relative to the torso (neck hyperextension). Their success has been demonstrated in laboratory and crash tests and by their 13 percent reduction of injuries in highway accidents. Since whiplash symptoms were present in 80 percent or more of the persons injured in rear impacts, a 13 percent overall injury reduction is unlikely unless head restraints help prevent whiplash.

Further evidence that restraints have performed as intended is offered by the analysis of restraint height and injury risk. The observed incremental effectiveness of integral over (frequently mispositioned) adjustable restraints in highway accidents is consistent with an anthropometric model and test results in which the degree of neck hyperextension depends on the positioning of the restraint.

At the same time, laboratory and crash tests did not indicate that head restraints had substantial unforeseen effectiveness against injuries other than neck hyperextension. The analyses of FARS and other accident data did not show head restraints to significantly affect fatal and serious injuries, which are primarily nonwhiplash injuries.

Is the actual injury reduction in highway accidents - 13 percent - lower than what should have been anticipated? Does it indicate a serious shortcoming of head restraints? The answer to both questions is partly yes and mainly no. Yes, because the frequent mispositioning of adjustable restraints by occupants is their principal shortcoming. If all cars had integral restraints (or if all adjustable restraints were correctly positioned), effectiveness would have risen to 17 percent. Still, this is not much higher than 13 percent.

Is the 17 percent effectiveness of integral restraints lower than what should have been anticipated? It probably is not, considering the intended purpose of the restraints. Nearly 40 percent of the victims had at least one nonwhiplash injury. Even if head restraints had eliminated their whiplash, they would still have had other injuries: this reduces the highest potential effectiveness to 60 percent. Clinical case histories suggest that neck hyperextension is by no means the only occupant motion that produces whiplash symptoms. But neck hyperextension is the only form of whiplash that head restraints are designed to protect against.

Even against this form of whiplash, head restraints are of diminished effectiveness if the occupant leans far forward in the seat or if crash forces or seat tilting cause him to ramp up the seat. Thus, the potential effectiveness of integral restraints is further reduced. Finally, even current integral seats offer inadequate protection against whiplash to tall occupants or in crashes where significant ramping occurs. Thus, the 17 percent injury reduction of <u>current</u> integral restraints underestimates the number of injuries that could potentially be eliminated by raising seatbacks. In short, current integral restraints appear to eliminate a large percentage of the injuries that they can reasonably be expected to eliminate.

What can be done to enhance the effectiveness of head restraints? It was projected that a change to an all-integral restraint fleet would contribute a 4 percentage point improvement over the current restraint mix. An increase in the height of integral restraints to

31 inches might lead to a further 6 percent improvement. A similar improvement might be obtained by adjustable restraints that measure 31 inches in the down position.

Modifications in the strength, contours or padding texture of seatbacks and restraints might perhaps reduce the degree of occupant ramping or rebound. The potential benefits, however, cannot be estimated by the techniques of this evaluation.

2.4 Strengths and weaknesses of the evaluation

The principal strength of the evaluation was the consistency of the statistical accident analyses with laboratory and crash test results, biomechanical considerations and in-depth accident case reviews. Findings were consistent in regard to the overall effectiveness of head restraints, the effect of integral restraints relative to adjustable ones, the relation of restraint height to injury risk and the failure of head restraints to significantly affect fatalities and serious injuries.

Furthermore, the only two large-sample statistical analyses of head restraint effectiveness that have been performed to date - the Texas analysis of this evaluation and O'Neill's study of insurance claims - produced highly consistent results and confirm one another.

The principal weakness of the evaluation was the virtual absence of statistically significant effectiveness findings from the National Crash Severity Study, the National Accident Sampling System and other detailed, investigator-collected accident data thereby precluding a direct and accurate measurement of whiplash injury reduction. These files had too few cases of pre-standard cars in rear impact crashes for a statistically significant comparison with cars that had head restraints. The rear impact sample size was further limited in NCSS because it is a towaway file whereas 73 percent of rear impact injuries occur in nontowaways. (NCSS did, however, contain enough post-Standard cars with adjustable and integral restraints to demonstrate that the integral restraints were significantly more effective than adjustable ones.) As Table 2-4 showed, the observed neck injury reduction was significantly greater than zero in only one of six analyses of investigator-collected data. In the other 5 studies, the confidence bounds included a range of positive and negative numbers, with negative best estimates in 2 of the 5 studies.

As a result, it was necessary to rely primarily on Texas State data for effectiveness estimates. Because State data do not explicitly mention the types of injuries (whiplash vs. nonwhiplash), the contact points, etc., it is only possible to measure the overall injury reduction, not the whiplash or neck injury reduction. There is always a lingering fear that the observed result is an artifact, because it is not based on a direct, explicit measurement of the effect under investigation. This weakness is partly mitigated by the fact that the overwhelming majority (80%) of rear impact crash injury victims suffer whiplash. A significant overall injury reduction cannot easily happen unless there is a reduction of whiplash. Thus even though a whiplash reduction cannot be directly observed in the State data, it can be inferred from the overall effectiveness result.

In the comparison of cars with head restraints to those without the restraints (but not in the comparison of adjustable and integral restraints) there is the inherent shortcoming of a "before-after" design: the cars with head restraints are almost all newer than the cars without them. Biases resulting from vehicle age differences are especially worrisome in State data. This vulnerability was mitigated by the analysis procedures used in deriving the effectiveness estimates. Three largely independent analysis procedures were used to remove or compensate for age biases and they produced nearly identical effectiveness estimates. The procedures were:

(1) Using only 1968 and 1969 model cars for computing injury rates, thereby largely eliminating vehicle age differences.

(2) Regression of the rear impact injury rate by vehicle age and type of head restraint, using 1965-72 model cars in 1972, 74 and 77 accident files.

(3) Comparison of 1967-68 versus 1969-70 cars, using side impacts as a control group. Under these circumstances, side impacts may be a valid control group.

Relatively complex statistical estimation formulas were used in many of the Texas, NCSS and NASS analyses. As a result, many of the confidence bounds shown in the report are approximate rather than exact.

A major advantage of using three years of Texas data was the very large combined sample size. It was possible to obtain statistically precise results, even on analyses restricted to subsets of the data. The confidence bounds on the Texas results are narrow. Even if we make allowance for the bounds being approximate rather than exact, we still have a high degree of statistical confidence in the results.

Analyses were performed on three possible "side effects" of head restraints:

(1) The effect of head restraints on fatalities and serious injuries.

(2) Head restraints as an injury hazard to rear seat occupants.

(3) Accidents caused by head restraints blocking a driver's vision.

The analyses did not provide definitive estimates of the size of these effects. But they did provide strong evidence that the effects, if any, are very small.

The conclusions on <u>why</u> adjustable restraints command such a large share of the market are based primarily on analyses of production and sales data, not on in-depth surveys of consumer attitudes and preferences, etc. These conclusions should be considered speculative.

The relationship between restraint height and injury risk, especially, could not be derived explicitly from NCSS because of its inadequate sample size. The height-injury model based on Texas and NCSS data, although producing quite reasonable results, relies on many assumptions and should be considered speculative at this time.

The availability of NCSS and NASS greatly strengthened the evaluation, even though they did not contain enough cases for effectiveness estimates. NCSS offered reliable joint distributions of head restraint height and occupant height for adjustable and integral restraints, which made it possible to study the relationship of restraint height and injury risk. NCSS also provided a lookup table of restraint type by vehicle make, model and model year, which was used in preparing the Texas data for analysis.

NASS is a probability sample of the Nation's reported accidents. It greatly improved the reliability of national estimates of the number of injuries in rear impact crashes. The availability of the National Accident Summary (NAS) for 1971 helped confirm the NASS estimate.

2.5 Conclusions

Effectiveness of head restraints

- Head restraints - both the integral and adjustable types - have significantly reduced whiplash injuries in rear impact crashes.

- Head restraints are effective because they have been performing as intended in highway crashes: they support the head and neck and prevent hyperextension.

- The restraints do not appear to have had any unforeseen benefits, such as reducing rear impact fatalities, nonwhiplash injuries, or forms of whiplash other than hyperextension.

- The restraints do not appear to have any significant negative side-effects, such as increasing rear impact fatalities, aggravating rear-seat occupants' injuries in frontal crashes or causing accidents because they block a driver's view to the side and rear.

Integral versus adjustable restraints

- Integral seats are nearly twice as effective as adjustable restraints. The difference can be attributed to the failures by occupants to position their adjustable restraints correctly - current adjustable restraints, when left unextended, do not adequately protect a person of average height.

- Integral seats are far less costly than adjustable restraints.

- Integral seats eliminate about 5 times more injuries per dollar of cost than adjustable restraints.

- Adjustable restraints, despite their higher cost and lower benefit, continue to be installed in the majority of cars (through 1981). From our analysis of auto sales data, it appears to us that the high sales of adjustable restraints, to a large extent reflect customer preferences based on styling and comfort.

CHAPTER 3

THE PROBLEM: INJURIES IN REAR IMPACT CRASHES

Rear impacts are far less serious than frontals, side impacts or rollovers as a source of fatalities and serious injuries. This is partly because there is usually not much of a "second collision" between the occupant and the passenger compartment. Instead of colliding violently with the steering wheel, windshield or other components, the occupant is forced backwards against a well-padded seatback and "rides down" the collision remaining in his seat. Another mitigating factor is that rear impact collisions usually involve two vehicles travelling in the same direction or, at least, not travelling in opposite directions. The crashes are less severe than head-on or fixed-object collisions.

On the other hand, rear impacts are a major source of injuries at the lower severity levels. They account for an estimated 500,000 injured passenger car occupants annually, which is nearly one-sixth of all passenger car occupant injuries. The estimate is derived in this Chapter from National Accident Accident Sampling System data.

Prior to Standard 202, over 80 percent of these injured occupants - i.e., over 400,000 persons annually - suffered from "whiplash," which is a neck injury mechanism that may cause symptoms in various body regions.

3.1 The number of injuries in rear impacts

The objective is to estimate the number of drivers and right-front passengers of passenger cars who were injured in rear impacts, since this is the population at risk to which Standard 202 is directed.

3.1.1 Estimates from earlier studies

In previous years it was difficult to estimate the number of injuries in rear impacts because there was no national accident file containing the necessary information.

B. O'Neill noted that there are an estimated 3,800,000 rear-end automobile collisions yearly, according to the 1971 edition of *Accident Facts* [54]. The drivers' neck injury rate in his sample of rear impacts was 29 percent. "If the collision data obtained in [his study] are typical [of the collisions in *Accident Facts*] there may be as many as 1,000,000 drivers claiming such injury each year." ([54], p. 403)

The numbers in *Accident Facts*, however, are known to include a large percentage, probably a majority, of noninjury, unreported "fender benders". So the injury rate in O'Neill's sample is probably not typical of the *Accident Facts* cases and leads to an overestimate of neck injuries.

O'Day et al extrapolate from Texas State files to obtain a national estimate of 2,180,000 police-reported rear impacts per year [53]. The vehicles contain just over 3,000,000 front outboard occupants. Based on special study follow-ups of police reported accidents (such as States and Balcerak [61]), O'Day et al estimate that 41 percent of these occupants suffered whiplash - a total of 1,233,000 whiplashes per year.

The special studies that O'Day refers to, however, were mostly performed in New York State, where the police reporting criteria for accidents are much stricter than in Texas. Occupant injury rates in New York, as a result, are often more than double the rates in Texas.

Further evidence that O'Day's estimate is overstated may be found in the <u>reported</u> rear-impact injury rate in Texas, which was only 8.9 percent and included whiplash <u>and</u> non-whiplash injuries. If the actual whiplash rate were indeed 41 percent (as in the special studies) it would imply that Texas police are underreporting whiplash by 80 percent or more.

3.1.2 <u>The prime estimate: from the National Accident Sampling System</u>

The National Accident Sampling System (NASS) is a probability sample of the Nation's police-reported traffic accidents. Its first full year of data was 1979. The data can be used for national estimates. Because only 10 teams were in operation, the estimates are not statistically precise. But the imprecise estimates from NASS are much better than what is available from other files, in the context of rear impact injuries.

The main difficulties in estimating the number of rear impact injuries are that

- The majority of them occur in nontowaways
- A large percentage of the injuries are not evident at the accident scene and are not reported by police.

The first difficulty rules out the exclusive use of a towaway file such as NCSS. The second makes it undesirable to extrapolate the police reported injuries in one or more States to a National estimate.

The NASS file for 1979 contains 3419 motor vehicle occupants classified as "injured" according to the NASS investigator. Each occupant is assigned a <u>weight</u> equal to the inverse of the probability that his accident occurred in an area covered by a NASS team <u>and</u> was selected for investigation by the team's sampling scheme. The weighted occupant counts yield National estimates for 1979. The 3419 NASS cases, when weighted, yield a count of 3,800,000. In other words, based on NASS, an estimated 3,800,000 motor vehicle occupants were injured in police-reported traffic accidents in 1979. (The injuries were not necessarily reported by the police - just the accidents.)

Of these 3,800,000 injured persons, 3,100,000 were passenger car occupants. Of these, 2,750,000 were drivers or right front passengers. (The vehicle type or seat position were unknown in well under 1 percent of NASS cases and these unknowns were discarded.)

"Rear" impacts are defined in this Chapter to be those with damage to the rear of the car (according to the Collision Deformation Classification [14]) or with primarily rear force direction (5 to 7 o'clock) or whose most severe impact, according to the investigator, was "rear-end: struck by vehicle" or "rear impact with object." Vehicles in "other" crash modes are those with known damage location or known most severe impact type (excluding non-applicable) which are not defined to be rear impacts. All other vehicles are defined to have "unknown" crash modes according to NASS investigators.

"Towed" vehicles are those which police specifically stated to have been towed. All other vehicles are assigned to the "nontowaway" category in this Chapter.

Table 3-1 classifies the 2,750,000 injured front outboard occupants of passenger cars by crash mode and towaway status of their vehicle.

TABLE 3-1

INJURED FRONT OUTBOARD OCCUPANTS OF PASSENGER CARS, BY CRASH MODE AND VEHICLE TOWAWAY STATUS, NASS

	Crash Mode			
	Rear Impact	Other Known Impact	Unknown	Total
Nontowaway N	79,900	219,790	769,486	1,069,176
Row %	7	21	72	
Towaway N	117,442	1,492,466	66,161	1,676,029
Row %	7	89	4	
Row % of Known Cases	7	93	--	

TABLE 3-2

INJURED FRONT OUTBOARD OCCUPANTS OF NONTOWAWAY PASSENGER CARS, BY CRASH MODE AND NECK WHIPLASH STATUS, NASS

	Crash Mode			
	Rear Impact	Other Known Impact	Unknown	Total
Persons with neck whiplash N	43,963	40,641	326,080	410,684
Row %	11	10	79	
Row % of known cases	52	48	--	
Persons without neck whiplash N	35,937	179,149	443,406	658,492
Row %	5	27	68	
Row % of known cases	17	83	--	

About 1,680,000 of them occupied cars that were towed from the scene. NASS investigators ascertained the crash mode in 96 percent of these cases. The ratio of rear impacts to other impacts was 7 to 89. The same ratio may readily be assumed for the small number of towaways with unknown crash mode.

By contrast, the crash mode is unknown for 72 percent of the 1,070,000 injured occupants of nontowaways. The ratio of rear impacts to other impacts was 1 to 4, for the 300,000 persons with known crash modes. It would be possible to assume the same ratio for the 770,000 persons with unknown crash mode, but a little foolhardy. Is it possible to believe that a fifth of these persons were really involved in rear impacts? These imputed persons would be nearly as numerous as those who were known to have been in rear impacts (towaway plus nontowaway).

It is prudent to further subdivide the unknown nontowaways according to another criterion that would provide some confidence that imputed rear impacts were indeed rear impacts. The best criterion appears to be the presence of neck whiplash injury - the type of injury so characteristic of rear impacts. Table 3-2 subdivides the nontowaways by neck whiplash status. An occupant is defined to have suffered "neck whiplash", in this context, if one of his injuries was an injury to the neck muscles or an injury to the posterior region of the neck. This definition excludes the "possible whiplash" cases discussed in Section 3.3. Its purpose is merely to serve as an aid in classifying the cases with unknown crash modes.

The majority of neck whiplash sufferers with known crash mode were involved in rear impacts. It is reasonable to assume that a similar fraction of the neck whiplash cases with unknown crash mode were actually rear impacts. On the other hand, only a sixth of the injured persons without neck whiplash whose crash mode was known were in rear impacts. The unknowns in this group are assumed to have the same distribution of crash modes.

Thus, an estimate of the number X of front outboard occupants of passenger cars who were <u>actually</u> injured in rear impacts <u>in 1979</u> is given by the formula:

$$X = X_{111} + \left[\frac{X_{111}}{X_{111}+X_{121}}\right] X_{131} + X_{112} + \left[\frac{X_{112}}{X_{112}+X_{122}}\right] X_{132}$$

$$+ X_{21.} + \left[\frac{X_{21.}}{X_{21.}+X_{22.}}\right] X_{23.}$$

where

$$X_{ijk} \left\{ \begin{array}{lll} i=1 \text{ - nontowaway} & i=2 \text{ - towaway} & \\ j=1 \text{ - rear impact} & j=2 \text{ - other known} & j=3 \text{ - unknown} \\ k=1 \text{ - neck whiplash} & k=2 \text{ - no neck whiplash or} & \\ & \quad\text{unknown whiplash} & \end{array} \right.$$

In other words

$\hat{X}$ = 43,963 + 169,442 + 35,937 + 74,085 + 117,442 + 4,926 = 445,695 persons actually injured in 1979

Since X is based on a complex estimation formula and a multistage sample design, it is best to determine the sampling error by empirical means. A jackknife procedure was used to determine the standard deviation of X: the NASS file of injured front outboard occupants of passenger cars is divided into 10 systematic random subsamples of equal size. One of the subsamples is removed and X is calculated for the remaining nine-tenths of NASS, using the same estimation formula as was used on the full file. The subsample is returned, another is removed, and the injury rates recalculated, etc. The variation from subsample to subsample is observed (see [40], pp. 188-189).

Based on the jackknife procedure, X has standard deviation

$$s_X = 63,970$$

and $(X - \hat{X})/s_X$ is approximately t distributed with 9 df.

(Although NASS is a cluster sample, it was not treated as one in the preceding calculation of sampling error. Since none of the other files used in this evaluation is treated as a cluster sample or otherwise adjusted for regional biases, NASS is treated in a manner consistent with the other files.)

So far, X measures the number of injuries that actually occurred in 1979. The objective is to estimate how many would have occurred if none of the cars on the road had been equipped with head restraints. In fact, 85.7 percent of the cars did have head restraints (based on Automotive News 1980 Market Data Book [8]). These cars would have had $1/(1-\varepsilon)$ more injuries if they had not been so equipped, where is the injury-reducing effectiveness of head restraints.

In Section 5.6.5 it is shown that effectiveness

$$\hat{\varepsilon} = 12.8\% = .128$$

and its standard deviation

$$s_{\varepsilon} = .0386$$

The number N of injuries that would have occurred in 1979 if no cars had head restraints is estimated by

$$\begin{aligned} \hat{N} &= \hat{X}\left(.143 + \frac{.857}{1-\varepsilon}\right) \\ &= 445{,}695\left(.143 + \frac{.857}{.872}\right) = 445{,}695\ (1.126) \\ &= 501{,}763 \text{ injured persons} \end{aligned}$$

The standard deviation of N,

$$s_N \cong \hat{N} \left(\frac{\mathrm{Var}\, X}{\hat{X}^2} + \frac{\mathrm{Var}\,(.143 + .857/(1-\varepsilon))}{(.143 + .857/(1-\varepsilon))^2} \right)^{1/2}$$

$$= 501{,}763 \left(\frac{63{,}970^2}{445{,}695^2} + \frac{.857^2\, \mathrm{Var}\,(1/(1-\varepsilon))}{1.126^2} \right)^{1/2}$$

$$\cong 501{,}763 \left(.0206 + \frac{.857^2\, \mathrm{Var}\,(1-\varepsilon)}{1.126^2\,(1-\hat{\varepsilon})^2} \right)^{1/2}$$

$$= 501{,}763 \left(.0206 + \frac{.857^2\,(.0386)^2}{1.126^2\,(.872)^2} \right)^{1/2}$$

$$= 501{,}763 \left(.0206 + .0011 \right)^{1/2}$$

$$= 73{,}914$$

N is estimated by a product of X and a term involving ε. Since $(X - \hat{X})/s_X$ is approximately t distributed with 9 df and since the relative variance of X (.0206) completely dominates the relative variance of the ε term (.0011), $(N-\hat{N})/S_N$ will also be close to a t distribution with 9 df.

A lower confidence bound (one-sided $\alpha = .05$) for N is given by

$$N_\ell \cong \hat{N} - 1.833 s_N = 366{,}278 \text{ injuries in 1979}$$

The upper bound is

$$N_u \cong \hat{N} + 1.833\ s_N = 637{,}247 \text{ injuries in 1979}$$

The confidence bounds for N are relatively wide because there were only 10 NASS teams operating in 1979. But the confidence bounds are narrow indeed when they are compared to the biases in the estimates pieced together from data files that preceded NASS (see Section 3.1.1).

3.1.3 Three alternative estimates

Partial estimates of the number of injuries in rear impacts can be made from the National Accident Summary, the Texas State file and the National Crash Severity Study. The estimates provide consistency checks for the primary estimate based on NASS.

The National Accident Summary (NAS) is a census of police-reported accidents during 1971 in 39 States. The file contains 433,143 passenger car occupant injuries in rear-end crashes. It also contains 42,369 traffic fatalities. Since there were 54,381 fatalities in the United States in 1971, a National estimate of the injuries is,

$$\frac{54,381}{42,369} 433,143 = 568,778$$

This estimate, however, <u>includes</u>

- o Injured occupants in the striking car involved in a rear-end collision
- o Occupants in positions other than the driver's and right front seat

But <u>excludes</u>

- o Injuries not reported by police

Imputation factors are derived from NASS. The fraction of the injuries in the struck car is .73. The fraction in front outboard seats is .89. The fraction of rear impact injuries is .65. Thus the NAS suggests that there were

$$\frac{568,778\ (.73)\ (.89)}{.65} = 568,515$$

front outboard occupants actually injured in the rear impacts in 1971. In that year, about 30 percent of the cars on the road were equipped with head restraints. Since the effectiveness of the restraints is estimated to be 12.8 percent (Section 5.6.5), the number of injuries that would have occurred in 1971 if no cars were equipped with head restraints is

$$N_{NAS} = 568,515\left(.7 + \frac{.3}{1-.128}\right) = 593,550$$

This number is relatively close to the straight NASS estimate of 501,763 and well within its confidence bounds of 366,278 - 637,247. (Actually, this estimate is for 1971 and the NASS estimate for 1979, but the overall level of casualties for those two years is virtually the same - see Accident Facts for 1972 and 1980 [2], [3].)

The Texas State accident file for 1972 is used in Section 5.3 to obtain estimates of head restraint effectiveness. It can also be applied in a manner similar to NAS for an estimate of injuries.

The Texas file contains 2106 injured drivers of 1965-68 model cars that were struck in the rear and were not equipped with head restraints. In 1972, Texas contained 5.5 percent of the passenger cars registered in the United States. Thus, a corresponding national estimate of this type of injury is

$$\frac{2106}{.055} = 38,291$$

This estimate, however, excludes

- Cars from before 1965 or after 1968
- Right front passengers
- Injuries not reported by the police
- Rear impacts whose crash mode was not reported by the police

Imputation factors are derived from various sources. The 4 - 7 year-old cars constitute about 30 percent of the population at risk.

The ratio of front outboard occupants to drivers is 1.34 (based on NCSS). The fraction of rear impact injuries reported by police is .65 (based on NASS). The proportion of vehicles in Texas with unreported impact site is about .15 [12]. Thus, the Texas data suggest that there would have been

$$N_{Texas} = \frac{38,291\,(1.34)}{(.30)(.65)(1-.15)} = 309,562 \text{ injuries in 1972}$$

if no cars had been equipped with head restraints.

This number is well below the estimates based on NASS or NAS. It suggests that rear impact crashes are less prevalent in Texas than in the rest of the United States and/or that police underreporting of rear impact injuries is greater than the 35 percent experienced in NASS. It illustrates the inaccuracy of an estimate of a national total which is based on data from one State.

The National Crash Severity Study (NCSS) is a probability sample of towaway accidents, only. In the NASS estimate of rear impact injuries (Section 3.1.2), towaways accounted for less than 30 percent of the total. Also, most of the uncertainty in the NASS estimate was in the nontowaways, where a large number of cases with unknown crash modes were presumed to be rear impacts. The towaways on NASS did not involve a serious missing data problem. But just to be safe, it is useful to check the NASS towaway estimate against NCSS.

NCSS contains 416 (weighted) injured front outboard occupants of rear-impacted cars that did not contain head restraints. There were

2000 corresponding casualties in post-Standard cars. Since the effectiveness of head restraints is estimated to be 12.8 percent, the number of casualties would have been

$$416 + \frac{2000}{1 - .128} = 2710$$

if all cars had been pre-Standard.

The NCSS file contains 943 towaway-involved passenger car occupant fatalities. In 1978, the middle year of NCSS data collection, there were 28,411 passenger car occupant fatalities in the United States. Also, 20.5 percent of the NCSS occupants rode in vehicles whose crash mode was not determined by the investigator. A national estimate of rear-impact casualties in towaways in 1978, based on NCSS data, is

$$N_{NCSS,tow} = 2710 \frac{28,411}{943} \frac{1}{1 - .205} = 102,701$$

The corresponding estimate from NASS, for 1979, is 135,000 (see Table 3-4). In general, national estimates based on NCSS have tended to be lower than those from NASS (compare, for example, Figure 7 of [51] with Table 3-3 of [40]).

3.2 The severity of rear impact injuries

Occupant injuries in rear impacts are, on the average, much less severe than the injuries in other crash modes. Table 3-3 shows

TABLE 3-3

NUMBER OF INJURIES THAT WOULD HAVE OCCURED IN 1979 WITHOUT HEAD RESTRAINTS, BY SEVERITY LEVEL: REAR IMPACTS VERSUS OTHER CRASH MODES: FRONT OUTBOARD OCCUPANTS OF PASSENGER CARS

Injury Severity		Rear Impacts	Other Crash Modes
Fatalities	N of persons	700	24,000
	Row %	3	97
	Column %	0.1	1
Hospitalizations (non-fatal)	N of persons	16,000	330,000
	Row %	5	95
	Column %	3	14
Transported to emergency room and released	N of persons	130,000	770,000
	Row %	14	86
	Column %	26	33
Saw a doctor - not transported	N of persons	130,000	220,000
	Row %	37	63
	Column %	26	10
Injured - did not see a doctor	N of persons	220,000	970,000
	Row %	18	82
	Column %	44	42
TOTAL	N of casualties	500,000	2,310,000
	Row %	18	82

that, if no cars had been equipped with head restraints, there would have been 2,810,000 front outboard occupants of passenger cars killed or injured in 1979. Rear impacts would have accounted for 18 percent (500,000) of these casualties. But they represent only 3 percent of the fatalities (700 out of 24,700) and 5 percent of the hospitalized occupants (16,000 out of 346,000). Only 29 percent of the persons injured in rear impacts were transported from the accident scene (to a hospital or emergency room) - whereas 48 percent of the persons injured in other types of crashes were transported.

The lower incidence of serious injuries in rear impacts reflects the rather crashworthy combination of "occupant packaging" and vehicle structure that a passenger car presents in this crash mode. The vehicle seat and seatback is a smooth, padded surface that is already in contact with the occupant at the beginning of a crash. The crash forces drive the occupant back into the seat, maintaining the pre-existing contact, with the occupant's load distributed over a wide surface area. The occupant "rides down" the crash forces gradually, remaining in his seat. In other crash modes, the crash forces tend to propel the occupant out of his seat. He becomes a projectile which is suddenly brought to a stop, possibly by a hard or narrow contact surface such as the windshield or steering assembly.

Furthermore, the typical passenger car's rear structure is long and readily crushable. Both the trunk and the rear seat are between the front seat occupant and the striking vehicle. The structure dissipates the crash energy gradually, limiting the load of the occupant against the seat. By contrast, the front structure is less crushable and somewhat shorter (except in rear-engine cars). The side and roof structures, of course, are quite vulnerable.

Serious injuries also are less common in rear impacts because the crashes are of lower severity than in other modes. The most severe types of crashes are the fixed object collision which can bring a moving vehicle to a full stop and the head-on collision in which two moving vehicles meet at a high closing speed. Rear impacts, on the other hand, rarely involve fixed objects and the closing speed is usually the difference rather than the sum of the speeds of the striking and struck vehicles.

There is one area, however, in which pre-Standard 202 cars did not provide good occupant packaging: the occupant's head and neck largely extended beyond the top of the seatback, especially if the occupant was tall.

Table 3-3 shows that 26 percent of the persons injured in rear impacts were not transported from the accident scene but did go to a doctor at a later time. Only 10 percent of the injured in other types of crashes did so. This overrepresentation is due to a characteristic feature of whiplash, the predominant type of rear impact injury. The symptoms are often not apparent at the accident scene but arrive several hours to a week later.

The entries in Table 3-3 are derived as follows: let X_{ijk}, $\hat{X}$ and $\hat{N}$ be the quantities defined in Section 3.1.2.

Define the injury severity level

m=1 - fatal
m=2 - hospitalized
m=3 - emergency room
m=4 - doctor's office
m=5 - no treatment
m=6 - unknown

and let X_{ijkm} be a further subclassification of the NASS counts X_{ijk} by injury severity.

N_1, the number of rear impact fatalities in Table 3-3, is the actual count of front outboard fatalities in the 1979 FARS, rounded to the nearest 100.

Let N_2 be the number of rear impact hospitalizations in Table 3-3. Then

$$N_2 \approx \left[X_{1112}\left(\frac{X_{1.1}}{X_{111}+X_{121}}\right) + X_{1122}\left(\frac{X_{1.2}}{X_{112}+X_{122}}\right) + X_{21.2}\left(\frac{X_{2..}}{X_{21.}+X_{22.}}\right)\right] U$$

where

$$U = X_{.1.} \Big/ \sum_{m=1}^{5} X_{.1.m}$$

is an imputation factor for injuries of unknown severity

Let N_3 be the number of rear impact injuries with emergency room treatment in Table 3-3. Then

$$N_3 = \left[X_{1113} \left(\frac{X_{1.1}}{X_{111} + X_{121}} \right) + X_{1123} \left(\frac{X_{1.2}}{X_{112} + X_{122}} \right) + X_{21.2} \left(\frac{X_{2..}}{X_{21.} + X_{22.}} \right) \right] U \frac{1}{R}$$

where

$$R = \frac{\hat{X} - N_1 - N_2}{\hat{N} - N_1 - N_2}$$

is the ratio of actual nonserious injuries in 1979 to the number that would have occurred if no cars had head restraints. In other words, the injury reduction $\hat{N}-\hat{X}$ for head restraints is assumed to apply only to the three lower levels of injury severity and to be proportionally distributed among them.

N_4 (doctor's office) and N_5 (untreated injuries) are defined by the same type of formula as N_3.

O_1, the number of fatalities in other crash modes in Table 3-3, is the actual count of front outboard fatalities in the 1979 FARS, rounded to the nearest 1000.

Let p_2 be the proportion of motor vehicle occupants in the 1979 NASS who were killed <u>or</u> hospitalized; p_3 the proportion transported and released; p_4 receiving other treatment; p_5 injured but not treated. The proportions are shown on p. 29 of [51] and are approximately correct for front outboard occupants of passenger cars.

Let O_2 be the number of nonfatal hospitalizations in other crash modes. Then

$$O_2 = \left[\frac{p_2}{p_2 + p_3 + p_4 + p_5} 2{,}750{,}000 \right] - O_1 - N_2 - N_2$$

where 2,750,000 is the total number of front outboard occupants of passenger cars who were injured in 1979.

Let O_3 be the number transported to the emergency room and released, in other crash modes. Then

$$O_3 = \left[\frac{p_3}{p_2 + p_3 + p_4 + p_5} 2{,}750{,}000 \right] - RN_3$$

O_4 (doctor's office) and O_5 (untreated injuries) are defined by the same type of formulas as O_3.

Another distinctive feature of rear impact injuries is that a substantial majority of them - 73 percent according to Table 3-4 - occur in crashes where the struck vehicle is not towed away. By contrast, only 32 percent of the injuries in other crash modes happen in nontowaways (and an even smaller percentage of serious injuries). Table 3-4 makes it clear that any evaluation of Standard 202 must take into account the nontowaway as well as the towaway accident experience.

There are several reasons why nontowaways generate a higher percentage of the rear impact injuries than they do in other crash modes. The rear portion of a car contains fewer of the subsystems essential to driving than the front end and the rear structure protects them better. It takes more damage in the rear to disable a car than it does in the front. The deceleration pattern in rear impacts hits a peak during the initial contact with the hard bumper and remains fairly constant while the soft trunk collapses; as a result, the force levels on an occupant are nearly as high in low-speed crashes as in high-speed crashes. Finally, whiplash is an injury that can readily occur at low velocity levels.

TABLE 3-4

NUMBER OF INJURIES THAT WOULD HAVE OCCURRED IN 1979 WITHOUT HEAD RESTRAINTS, BY VEHICLE TOWAWAY STATUS: REAR IMPACTS VERSUS OTHER CRASH MODES: FRONT OUTBOARD OCCUPANTS OF PASSENGER CARS

		Rear Impacts	Other Crash Modes
Nontowaways	N of injured	365,000	750,000
	Row %	33	67
	Column %	73	32
Towaways	N of injured	135,000	1,560,000
	Row %	8	92
	Column %	27	68

The entries in Table 3-4 are derived as follows: let X_{ijk}, $\hat{X}$ and $\hat{N}$ be the quantities defined in Section 3.1.2. The number of injuries in rear-impact nontowaways is

$$\frac{\hat{N}}{\hat{X}} \sum_{k=1}^{2} \left(X_{11K} + \left[\frac{X_{11K}}{X_{11K} + X_{12K}} \right] X_{13K} \right)$$

The number of injuries in rear-impact towaways is

$$\frac{\hat{N}}{\hat{X}}\left(X_{21.} + \left[\frac{X_{21.}}{X_{21.} + X_{22.}}\right] X_{23.}\right)$$

The number of injuries in other-impact nontowaways is

$$\sum_{k=1}^{2}\left(X_{12k} + \left[\frac{X_{12k}}{X_{11k} + X_{12k}}\right] X_{13k}\right)$$

Finally, there are

$$X_{22.} + \left[\frac{X_{22.}}{X_{21.} + X_{22.}}\right] X_{23.}$$

injuries in other-impact towaways.

3.3 Injury mechanisms

Most injuries in rear impact crashes fall within the conglomeration of mechanisms and symptoms commonly called "whiplash."

3.3.1 "The enigma of whiplash injuries"

The title of this section is borrowed from a 1969 paper by States, Korn and Massengill [62]. They considered whiplash an enigma even though they probably understood more about it than anyone since the term "whiplash" was first coined in 1928.

Whiplash is a noncontact injury to tissues in the neck. It may happen when crash forces cause the neck muscles, ligaments or vertebra to be extended, twisted or flexed beyond their normal range of motion.

The most common form of whiplash is in a rear impact of a car without head restraints. The crash forces cause the unsupported head to move backwards while the torso is held in place by the seatback. Since the neck attaches the head to the torso, the rearward motion of the head initially stretches the neck and pulls it backward. Since the neck cannot stretch very far, it soon exerts a centripetal force on the head and pulls it into a rotational movement relative to the torso - backwards and downwards. In severe cases, the occupant's torso remains upright in the seat and the head is upside-down, facing the rear of the car.

The neck is sharply twisted - hyperextended - and the posterior tissues of the neck are strongly compressed. The sequence is called "whiplash" because the motion of the neck - back and sharply around and rebounding to the initial position - resembles the cracking of a whip.

The greatest enigma of whiplash is that it ordinarily leaves no externally visible, palpable or radiological evidence of injury, yet causes pain and disability that may last from a few days to a year or more. The average whiplash victim in the National Crash Severity Study missed 4 days of work. It took medical researchers a long time to determine what lesions were actually characteristic of whiplash. For that matter, it took a long time to convince some that the injuries were not psychosomatic or "litigation syndromes." Medical researchers established the reality of whiplash and its pathology through self-inflicted injuries [49], tests using animals, electroencephalographic studies and the autopsy of a driver whose car was hit in the rear a few seconds after he had suddenly died of a heart attack. These studies revealed lesions such as muscular and ligamentous tears; hemorrhages of muscles and other tissues; disturbances to the brain waves or nervous system damage due to forces transmitted to the upper spinal cord [61].

A second difficulty was to determine exactly what occupant kinematics were causing the injuries. It turns out that whiplash is no single injury mechanism. The pattern described previously - rearward rotation of the head relative to the torso - is now generally recognized as the most common one.

Whiplash injuries can also occur due to sideways or forward rotation of the head, although in these cases the shoulders or chin, respectively, act to limit the excess motion. As a result, whiplash is by no means limited to rear impacts (see Table 3-2) although it is most common there. Moreover, the lesions need not occur only at the instant of maximum neck rotation, but perhaps also take place earlier, during the initial rearward translation of the head relative to the body, or later, when the head rebounds forward [49]. Torsion injuries may occur if the occupant is facing partially sideways at the beginning of the rear impact. All of these injury mechanisms are not necessarily mitigated by a properly positioned head restraint (see Section 4.4).

The third puzzle is the symptoms of whiplash. The most common symptoms are pain and stiffness in the neck, especially the posterior neck. But symptoms may also develop in other body regions as a result of forces transmitted to the cervical spinal cord or the nerves emanating from the cervical spine. Disturbance of a nerve may be manifested by symptoms in other parts of the body traversed by that nerve. Thus, whiplash victims may experience pain, weakness or abnormal response in the shoulders, arms, or upper back - areas enervated by the cervical nerves. They may experience headache, concussion, sight or hearing disturbances and other symptoms involving the central nervous system. Many of the seemingly inexplicable noncontact injuries in rear impacts are, in fact, due to whiplash.

A fourth unusual feature of whiplash is that it occurs frequently in accidents of low severity (see Section 3.2). The initial pulse of acceleration when a car's rear bumper is struck is apparently sufficient to bring about some forms of whiplash kinematics.

Finally, whiplash differs from visible injury in that the symptoms may not appear until sometime after the accident. For example, even in the relatively severe National Crash Serverity Study cases, only 73 percent of the whiplash victims were aware of their injury at the accident scene.

Symptoms appeared some time later in the first day among 23 percent of the injured and did not appear until 2 to 7 days after the accident for 4 percent of the victims. In the Rochester special study (less severe accidents than NCSS), States and Balcerak found that the majority of victims did not experience their symptoms until after leaving the accident scene [61]. As a result, the injuries are often not reported to the police.

When these features occur in combination, it is easy to see why whiplash is "enigmatic." A driver is involved in a low-speed rear impact in which the other vehicle's driver is obviously at fault from a legal standpoint. The person does not mention any injury or complaint of pain to the investigating police officer. But the next day he complains of pain in the neck, the arm and blurred vision. X-rays and an opthalmic exam show no evidence of neck or eye injury. There are no bruises on the arm. No evidence of arm contact or any other contact is discovered in the vehicle. Besides, the crash was a fenderbender. Is it not easy to believe that the victim consciously or unconsciously "invented" these injuries when he woke up the next day and realized he was sure to collect damages?

3.3.2 Other injury mechanisms

The initial occupant movement in a rear impact is into the seatback. The seatback is springy, however, and propels the occupant forward after absorbing only a part of his kinetic energy. The rebounding occupant's kinematics resemble those in a frontal collision. Injuries may result from contact with the steering assembly, windshield, instrument panel, etc. Similarly, a secondary frontal impact following a rear impact (e.g., a chain collision) may result in frontal contacts.

Some rear impacts, by the definitions of this evaluation, may involve rear damage with partially lateral forces or side damage with primarily rear forces. These oblique rear impacts and same-direction sideswipes may produce injury patterns characteristic of side impacts (contacts with side interior surface, pillars and side windows).

Many superficial arm and leg injuries in rear impacts may be due to slapping or scraping various interior contact surfaces such as the doors, floor, steering control, seats, etc. These injuries are often not reported to the police, perhaps because of their low severity.

A more serious injury mechanism may occur when the rearward forces on the occupant, possibly in combination with the seat bending or tipping rearwards, result in an upward motion of the occupant relative to the seatback. It is called <u>ramping</u> and may cause the occupant to contact the roof, head first. If the seatback has tipped backwards a lot or the seat has broken from its anchorage, the occupant may be propelled head first towards the rear window or its surrounding structures.

An even graver threat of injury may result from roof crush or other compartment intrusion when a large truck strikes a car in the rear and overrides it partially or completely. Rear impacts may also present a danger of postcrash fire if the fuel tank, usually located in the rear, is badly damaged.

Occupants may be ejected in a secondary rollover following a primary rear impact or when the integrity of the side structure is lost. Ejection is rare in rear impacts but when it does happen the risk of injury is great.

3.3.3 Statistical analysis of injury mechanisms

Table 3-5 shows the great preponderance of whiplash among the drivers and right front passengers who were injured in the rear impacts on the 1979 NASS file: 60 percent of the victims suffered only whiplash type injuries. These included noncontact neck injuries and other noncontact injuries apparently due to disturbance of the cervical nerves (see Section 3.3.1). A further 18 percent of the victims suffered a combination of whiplash type and nonwhiplash injuries. Thus, a total of 78 percent of the injured persons had whiplash.

Since 86 percent of the cars on NASS were equipped with head restraints and since the restraints are primarily designed to mitigate whiplash type injuries, it can be assumed that prior to Standard 202 even more than 78 percent of the injured occupants had whiplash. This assumption is supported by the results of States' and Balcerak's special study, which was conducted in Rochester during 1972 [61]. They found that 156 out of 159 victims (98%) suffered whiplash. (Their study, however, did not necessarily use the same injury definitions as NASS. It involved only urban accidents which were probably less severe than the NASS cases.)

Table 3-5 shows that the predominance of whiplash decreases as crash severity increases. In the nontowaways, 69 percent of the victims had whiplash related injuries alone - but only 34 percent in the towaways.

The percentages in portions (a) and (b) of Table 3-5 were obtained by examination of a listing of NASS rear impact injury cases. The cases were classified by injury type and the case weights added for each group. No

TABLE 3-5

WHIPLASH VERSUS NONWHIPLASH INJURIES, DRIVERS AND RIGHT FRONT PASSENGERS IN REAR IMPACTS, NASS 1979

Types of Injuries: Whiplash or Possible Whiplash	Nonwhiplash Injuries	Percent of Injured Occupants
	(a) In Nontowaways	
Yes	No	69
Yes	Yes	13
No	Yes	18
	(b) In Towaways	
Yes	No	34
Yes	Yes	32
No	Yes	35
	(c) Nontowaways and Towaways Combined	
Yes	No	60
Yes	Yes	18
No	Yes	22

attempt was made in portions (a) and (b) to adjust the percentages for missing data on crash mode or injury type. A case-by-case examination was needed because the classification of noncontact or unknown contact pain injuries as "possible whiplash" is a matter of judgement (see Section 3.3.1). The percentages in portion (c) are the weighted averages of (a) and (b), using the N in the left column of Table 3-4 as the weights.

Table 3-6 is a more detailed classification of the most severe injury mechanism among persons not hospitalized in NASS. In 48 percent of the cases, simple whiplash - noncontact neck injury - was the most severe complaint. An additional 17 percent of the victims suffered primarily from shoulder, arm, upper back or headache pain not attributable to any contact point in the vehicle. These injuries were classified as "possible whiplash" (see Section 3.3.1).

The remaining 35 percent of the occupants' primary injury was due to mechanisms other than whiplash (see Section 3.3.2). Contact surfaces in the front of the car (steering assembly, windshield, etc.) took the lead with 15 percent - that includes "rebound" injuries and superficial injuries to the arms and legs. There were a fair number of minor injuries involving contact with the seat (6%) or floor (3%). Relatively few injuries resulted from contact with the vehicle's side (2%), roof or rear (2%) surface areas.

The percentages in Table 3-6 are based on a case-by-case review of NASS. The cases were classified by primary injury source and the case weights added for each group. No attempt was made to adjust the percentages for missing data on crash mode or injury type.

TABLE 3-6

SOURCE OF MOST SEVERE INJURY, NONHOSPITALIZED DRIVERS AND RIGHT FRONT PASSENGERS IN REAR IMPACTS, NASS 1979

(Unweighted N=112)

Source	Percent of Non-hospitalized Victims	
Whiplash (noncontact neck injury)	48	
Possible whiplash*	17	
Whiplash or possible whiplash		65
Frontal contacts (steering assembly, windshield, etc.)	15	
Side contacts (doors, side windows, etc.)	2	
Seat contact	6	
Roof, rear window	2	
Floor	3	
Other**	7	
Nonwhiplash injuries		35

*Noncontact injuries characteristic of cervical nerve disturbances (shoulder, arm, upper back pain; headache)

**Noncontact injury (nonwhiplash); contact with occupants, cargo; rounding error

Table 3-7 is a classification of most severe injury sources, analogous to Table 3-6, but for <u>hospitalized</u> occupants. NCSS was used instead of NASS because it contains 85 hospitalized cases, versus only 12 on NASS.

The ratio of whiplash to other injuries is just over 1 to 2, which is almost exactly the reverse of the nonhospitalized cases. Whiplash accounts for 36 percent of the hospitalizations. Nearly half of these are neurological problems of the head, shoulders, arms or upper back, classified as possible whiplash.

Rebound injuries involving the steering assembly and other frontal contact areas account for 28 percent of the injuries - they are nearly as common as whiplash. Side surface contact (doors, pillars and side windows) comprise a substantial 14 percent of the hospitalizations. The less common injury sources are the roof and rear window (2%), postcrash fire (2%), and ejection (3%).

Since whiplash accounts for a minority of the hospitalizations and is rarely the only injury in these cases, the potential for head restraints reducing serious injury is much less than their utility in reducing minor injury.

<u>The completeness of police reporting</u> of rear impact injuries appears to vary among jurisdictions. It is also sensitive to the definition of "injury." For example, if "injury" means that the victim sought medical treatment or had at least a day of disability, a higher degree of reporting completeness could be expected than if "injury" means any type of discomfort.

TABLE 3-7

SOURCE OF MOST SEVERE INJURY, HOSPITALIZED DRIVERS AND RIGHT FRONT PASSENGERS IN REAR IMPACTS, NCSS

(unweighted N=85)

Source	Percent of Hospitalizations	
Whiplash (noncontact neck injury)	21	
Possible whiplash*	15	
Whiplash or possible whiplash		36
Frontal contacts (steering assembly, windshield, etc.)	28	
Side contacts (doors, side windows, etc.)	14	
Seat contact	7	
Roof, rear window	2	
Ejection	3	
Burns	2	
Other**	8	
Nonwhiplash injuries		64

*Noncontact injuries characteristic of cervical nerve disturbances (shoulder, arm, upper back pain; headache)

**Noncontact injury (nonwhiplash); contact with occupants, cargo; rounding error

In their Rochester special study, States and Balcerak found that 56 percent of the whiplash injuries were not reported to the police - a percentage roughly equal to those who did not experience the injury symptoms at the accident scene [61]. McLean found that 67 percent of the injuries in the North Carolina special study were not reported to the police [46].

The National Crash Severity Study's towaway accidents are more severe than those in the special studies and, perhaps, are investigated in greater detail by the police. Nevertheless, 29 percent of the whiplash injuries in NCSS were not police-reported - corresponding approximately to the 23 percent with delayed onset of symptoms.

In the National Accident Sampling System's 1979 data, 35 percent of the rear impact injuries (including nonwhiplash injuries) were not police-reported. The rate of nonreporting was 24 percent in the towaways and 38 percent in the nontowaways.

3.3.4 Analysis of rear impact fatalities

Fatal rear impacts are rare events. Approximately 700 drivers and right front passengers are killed annually (see Table 3-3). Because they are rare, only a small number (28) of fatalities in rear impacts have been investigated in detail by NHTSA-sponsored or multidisciplinary teams. A case-by-case analysis of these fatalities is useful in exhibiting the prevalent fatal injury mechanisms and illustrating the head restraints' role, if any, in the accidents.

Researchers are not sure whether head restraints would be beneficial or detrimental in really severe accidents. It is conceivable that restraints could prevent life-threatening nerve damage due to extremely severe hyperextension. But it is also conceivable that a poorly designed or mispositioned head restraint could give a dangerous "karate chop" to the neck.

The Multidisciplinary Accident Investigation (MDAI) file contains 18 of the 28 documented fatalities; NCSS contains 7 and NASS, 3. Because MDAI was mostly restricted to cars of the latest model years and became NCSS and NASS were conducted at a time when most cars had head restraints, there is only one pre-Standard car among the 28 cases.

The 8 MDAI fatalities, listed in the order that they appear on the automated file, involve the following injury mechanisms:

1. Incineration in a fire which broke out on impact.
2. Fatal ejection in collisions with multiple off-road objects.
3. Catastrophic override by a tractor-trailer. Crushed to death by the intruding tractor-trailer.
4. and 5. A car was hit in the rear, rolled over with severe roof crush and burst into flames. Both front outboard occupants had multiple fatal lesions of unknown origin.
6. Apparent pre-crash heart attack.
7. Catastrophic override by a tractor-trailer. Fatal brain hemorrhage due to contact with improperly positioned adjustable head restraint and 2 fatal internal injuries due to other contacts.
8. Fatal ejection in an end-over-end rollover.
9. A pre-standard 202 car. Skull fracture and head injury due to contacting the pre-Standard seatback.
10. Occupant was thrown into the rear header/C pillar after the seat tilted backwards. Fatal head injuries.

11. Fatal burns in a fire which broke out on impact.

12. Fatal ejection in rollover following rear impact.

13. and 14. A tractor-trailer hit a car in the rear, spun it around, and hit it in the side. Both front outboard occupants were fatally ejected.

15. Occupant was propelled into the roof (ramping). Moderate head injuries from the roof contact and serious torso injuries due to contact with the correctly positioned adjustable head restraint.

16. and 17. Both front outboard occupants fatally ejected in end-over-end rollover.

18. Catastrophic override by a tractor-trailer. Occupant crushed by the collapsing side structure.

The causes of death in 7 **NCSS** cases were:

19. Fatal chest injuries due to contacting the steering wheel on the rebound.

20. Catastrophic impact due to skidding into a tree. Fatal brain injury due to contacting incorrectly positioned adjustable head restraint.

21. Catastrophic tractor-trailer override followed by fire. Driver was burned to death and sustained fatal abdominal injury from the steering wheel contact and a broken neck from the adjustable head restraint as the compartment collapsed.

22. Elderly driver suffered fatal brain injury when he contacted the windshield on the rebound.

23. Catastrophic override by a large truck. Fatal neck injury due to contact with an unknown object in the collapsing compartment.

24. Catastrophic override by a tractor-trailer. Fatal head injury due to contact with the collapsing roof.

25. Catastrophic override by a tractor-trailer. Fatal head injury due to contact with the intruding B-pillar.

The 3 NASS fatalities involved:

26. Fatal burns.

27. and 28. Both front outboard occupants were thrown into the rear seat area when the front seats tilted backwards. They sustained fatal head injuries.

It is evident that the overwhelming majority of the fatalities have nothing to do with head restraints. The prevalent factors are catastrophic truck override with compartment collapse (8 cases), ejection (7), fire (6) and ramping/seat failure (4). Head restraints or seatbacks appear to have been a factor in 5 of the 28 cases: Nos. 7, 9, 15, 20 and 21. Cases 7 and 21 were catastrophic tractor-trailer overrides in which the occupants each suffered two fatal lesions besides the head restraint contact: thus, the head restraint was essentially irrelevant to their survival.

That leaves 3 cases, Nos. 9, 15 and 20, in which head restraints or seatbacks affected survival. In Case 9, the only pre-Standard car on the list, the occupant's head contacted the pre-Standard seatback violently enough to produce fatal head injury. It is conceivable that a head restraint could have given the occupant's head a better ride-down and saved his life. Case 20 may have involved a "karate chop" to the neck by an incorrectly positioned adjustable restraint and might have been prevented by an integral restraint. In Case 15, severe ramping by the occupant resulted in fatal head restraint-torso contact; the fatality might have been prevented if there had been no head restraint.

The case-by-case analysis of rear impact fatalities shows that the potential effect of head restraints, if any, is bound to be small. It does not give a clear indication of whether the effect is positive or negative.

Sections 5.4 and 5.5, which are statistical analyses of rear impact fatalities, support the same conclusions.

3.4 Factors influencing rear impact injury risk

The neck injury risk for females in rear impact crashes is substantially greater than for males. Overall injury risk increases as crash severity increases, although the relationship is not as strong as for other types of injuries in other crash modes.

3.4.1 Occupant sex and and neck injury risk

Statistical studies have shown that female occupants are more vulnerable to neck injury than males. J. Kihlberg's analysis of ACIR data in 1969 suggested a 2 to 1 ratio of neck injury risk [42]. B. O'Neill et al. analyzed insurance claims made in 1970 and found that female drivers of cars without head restraints claimed neck injury in 37 percent of their reported rear impact crashes; males, only in 24 percent [54]. States and Balcerak found pre-Standard 202 whiplash injury rates of 51 percent for females and 40 percent for males in their 1972 special study [61].

In Texas rear impacts during 1972 the police-reported overall injury rate of female drivers of pre-Standard cars was 84 percent higher than for male drivers.

In the National Crash Severity Study towaway file, the overall injury rate in pre-Standard rear impacts was 16 percent higher for females than for males and the neck injury rate was 25 percent higher.

The most evident explanation is that females, on the average, have considerably narrower necks than males and, especially, a smaller muscle mass. Yet their necks must support heads of roughly the same volume as males'. Whiplash injury typically occurs when crash forces give momentum to the head relative to the torso and this momentum strains the neck muscles beyond their capacity to withstand injury. Obviously, that capacity is greater for males than females. This is the only explanation provided by States and Balcerak [61].

In contrast to rear impact injury, males' and females' risks of serious injury due to the steering assembly in frontal crashes are about equal ([40], p.172).

3.4.2 Crash severity and overall injury risk

Table 3-8 shows the overall injury risk as a function of vehicle velocity change (Delta V) in NCSS rear impacts. For comparison purposes, the corresponding function is shown for nonminor injury in frontal crashes ([59], p.85).

TABLE 3-8

NCSS INJURY RATES BY DELTA V

REAR IMPACTS VERSUS FRONTALS

Delta V (mph)	Percent Injured - Rear Impacts	Percent AIS ≥ 2 - Frontal Impacts
1 - 10	45	2
11 - 20	54	9
21 - 30	86	25
31+	96	56

It is clear from Table 3-8 that overall injury risk in rear impacts increases as Delta V increases, but not nearly so steeply as in frontal impacts.

3.5 Other standards that may protect occupants in rear impacts

The other Federal Motor Vehicle Safety Standards need to be reviewed as to whether they might have reduced overall injury risk in rear impact crashes. If so, their benefits must be taken into account in this evaluation and should not be wrongly attributed to head restraints.

Specifically, this evaluation relies heavily on analyses of Texas accident data (Sections 5.3 and 5.6). Head restraints were installed for the first time, in most models, in 1969. But some of the Texas analyses consider accident data from a range of model years before and after 1969, which in some cases is as wide as 1965-72. Any device installed in 1965 or earlier would be found on all of these cars; any device installed in 1973 or later, on none. Thus, we must concern ourselves primarily with devices installed during 1966-72, with special emphasis on those installed in 1969.

Furthermore, since some of the Texas analyses use side impacts as a control group, we must ask whether any of the safety devices had different effects on side and rear impact injury rates.

Finally, since 80 percent of the rear impact injury victims had whiplash, we are especially concerned with devices that might affect whiplash. Since 97 percent of the rear impact injuries are nonserious (see Table 3-3), we are especially concerned with devices that affect nonserious injury. Conversely, devices that are primarily effective against serious or nonwhiplash injuries are not going to have that much effect on rear impact overall injury rates.

o Standard 201, effective 1-1-68, sets padding and other protection requirements for certain front interior surfaces of the passenger compartment. The General Accounting Office's report on the safety standards suggests that one-third of the cars complied with Standard 201 in 1966, one-half by 1967 and all by model year 1968 [18]. This standard is likely to have significantly reduced the risk of nonserious nonwhiplash injury in rear impacts that occurs when the occupant rebounds from the seat and strikes the front of the passenger compartment (see Section 3.3.2). It may also reduce nonserious injury risk in oblique side impacts.

o Standards 203 and 204, effective 1-1-68, require energy-absorbing steering columns. Two-thirds of the cars had these devices in 1967, all by 1968 [40]. They are likely to be quite effective against serious nonwhiplash injuries involving occupant rebound, with a smaller effect on nonserious injuries. They may also reduce injuries in oblique side impacts.

o Standard 205, effective 1-1-68, applies to window glazing materials. All manufacturers installed high penetration resistant windshields that meet this standard in their 1966 models. The improved windshields are likely to have reduced nonserious injuries involving occupant rebound and may also be effective in oblique side impacts.

o Standard 206, effective 1-1-68, applies to door locks. The manufacturers installed door locks meeting this standard in 1965. Thus, this safety device does not belong in the 1966-72 range.

o Standard 207, effective 1-1-68, sets requirements for seat strength and seat back locks. This is the only standard (other than Standard 202) that had the potential to affect whiplash significantly. Crash testing has demonstrated that a seatback which yields at a controlled rate, but does not tilt back excessively, can help prevent whiplash [13], [49], [60], [62]. In actual practice, however, it appears that Standard 207 did not lead to any significant changes in seat design or strength other than the installation of seat back locks [10], [36]. The latter are only relevant in frontal impacts.

- Standards 208, 209 and 210 regulate lap belts. In actual practice, lap belts were installed in the front outboard seats throughout the 1965-72 period. But in 1972, the installation of warning buzzers led to an initial 10-15 percent increase in belt usage over previous years. Belts are effective against many types of nonwhiplash injuries. Their effect on minor injuries, however, is smaller than their effect on serious injuries [58]. Lap belts are not thought to have any significant effect on whiplash [49], [60]. Since most rear impact injuries are minor whiplash, a 10-15 percent increase in belt usage will not greatly affect the overall rear impact injury rate.

- Standard 214, effective 1-1-73, led to the installation of side door beams. One quarter of the 1969 model cars had beams, as did about half of the 1970-72 models. Side door beams help reduce serious injuries in side impacts but are unlikely to affect nonserious injuries significantly in either rear or side impacts [42].

- Standard 215 relates to bumpers. A change in bumpers can affect the collision performance of vehicles - e.g., a stiffer rear bumper could conceivably increase the risk of whiplash in "fenderbender" accidents. _Rear_ bumpers, however, were not modified prior to 1973.

- Standard 301, with various effective dates, sets requirements for fuel system integrity and is designed to reduce postcrash fires. Furthermore, any structural changes resulting from Standard 301 may affect other injuries. The Standard 301 requirements for frontal crashes took effect in 1968, for rear and side impacts in 1976. In actual practice, the manufacturers made _no_ significant changes in their vehicles throughout 1966-72 for reasons related to Standard 301 [4].

The implications of this review on potential biases in analyses of Texas data are the following:

(1) In a comparison of 1965-68 models (pre-Standard 202) versus 1969-72 models (post-Standard 202) there might be significant biases in the rear impact injury rates as a result of Standards 201, 203, 204, 205, 208, 209, 210 and 214. It is not clear that the use of a side impact control group would adequately compensate for these biases.

(2) If the comparison is limited to 1967-68 versus 1969-70 models, it would eliminate the bias from Standards 205, 208, 209 and 210 and substantially reduce the biases from Standards 201, 203, 204 and 214. The net bias, at this point, may be small enough that a side impact control group offers an adequate first-order correction.

(3) If the comparison is further limited to just 1969 versus 1968 models, there is virtually no bias due to other standards.

CHAPTER 4

THE DEVELOPMENT OF HEAD RESTRAINTS

By the mid-1950's highway safety researchers understood that whiplash was a common injury source in rear impacts. They judged that hyperextension of the neck could be mitigated by raising the seatback to support the head and they began to test their judgement by laboratory experiments. By the mid 1960's enough was known about head restraints that they became the subject of one of the earliest Federal auto safety regulations.

4.1 Before Federal regulations

The University of California at Los Angeles pioneered the use of staged tests to study rear impacts. In 1954, they conducted rear impact tests to study whiplash and by 1956 they were running the tests with prototype head restraints [60]. In 1965, D.M. Severy and others at UCLA began a controlled program of staged rear-end collisions of cars with dummy occupants. They tested integral and adjustable head restraints positioned at various heights as well as a number of seatback designs. Measurements of neck and head displacement, rotation and acceleration were made on the dummies. The tests clearly demonstrated the value of head restraints in reducing hyperextension of the neck. They formed much of the scientific basis for subsequent Federal regulation.

The motor vehicle manufacturers also tested head restraints. R.J. Berton of the Ford Motor Co. in 1968 subjected dummies to sled and crash tests with integral restraints of various heights [11]. He found that 28 inch seats provide excellent protection for 50th percentile male dummies but caused rearward vision obstructions for a driver shorter than 5 feet 2 inches whereas 26 inch seats provide good protection without vision obstructions.

Head restraints were offered as optional equipment for the front outboard seats by many of the manufacturers for several years before the effective date of Standard 202; some as early as 1964. They were installed in 3 percent of the 1967 model year cars and 12 percent of the 1968 cars. By 1968, in fact, head restraints were standard equipment on some Volkswagen models. Although installation did not become mandatory until the middle of model year 1969, they were installed in 88 percent of the cars that year. (All percentages are based on National Crash Severity Study data.)

The medical community encouraged the development of head restraints. Perhaps their major contribution was to demonstrate that whiplash is a genuine physiological injury pattern and not just a "litigation syndrome" (see Section 3.3.1).

4.2 Regulatory history

The General Services Administration (GSA) had a Standard 515 concerning safety devices in Federally purchased vehicles. In March 1966, the GSA proposed its Standard 515/22 which would require head restraints a minimum of 25 inches high, 10 inches wide and capable of meeting a 200 pound static test [20]. The Standard made it clear that both adjustable and integral restraints were permissible. Restraints were required for the driver's and right front passenger's seat.

The GSA's proposed Standard 515/22 became a final rule in July 1966 with an effective date of October 1967 [21]. The final rule, however, raised the minimum height from 25 to 27.5 inches and no longer explicitly mentioned the 200 pound static test.

NHTSA issued a Notice of Proposed Rulemaking in December 1966 which would have extended the GSA Standard to all passenger cars sold in the United States [22]. In this NPRM, the static strength requirement was raised to 300 pounds. The head restraint requirement was called Federal Motor Vehicle Safety Standard 202 and it would have been one of the Agency's initial standards.

In February 1967, Standard 202 was dropped from the list of initial standards. An Advance Notice of Proposed Rulemaking was issued for the purpose of compiling additional information on head restraints and rear impact injuries and refining the performance requirements [23].

After the Agency examined the information collected in response to the ANPRM, it issued a new NPRM in December 1967 [24]. Proposed Standard 202 retained the 27.5 inch height requirement but the static test was reduced to 200 pounds. Minimum width was 10 inches for bench seats but was reduced to 6.75 inches for bucket seats. The Agency also defined a dynamic sled test involving a dummy head/torso and a complete seating system. The dynamic test was offered as an alternative to the static strength, height and width requirements.

The NPRM became a final rule in February 1968, with an effective date of January 1, 1969, after some clarifications of the dynamic test were made in response to comments [25]. Petitions for reconsideration then led to additional minor clarifications and amendments of the dynamic and static tests and the procedure for measuring height and width. Standard 202 in its present form was issued in October 1968 and became effective on January 1, 1969 [26].

In March 1974, NHTSA issued an NPRM to combine Standard 202 with Standard 207 (Seating Systems) and to strengthen the head restraint requirements as follows [27]:

- 31 inch (integral) driver's head restraint
- 31 inch height in the right front seat; if an adjustable restraint is used, it must be at least 27.5 inches high in the in the down position.
- Extension to light trucks and multipurpose vehicles

The proposal was never adopted. Its objectives were to overcome the hazards associated with ramping, seat failure and, above all, mispositioned adjustable restraints (see Section 4.4).

NHTSA has always used the static strength test to check vehicles for compliance with Standard 202 and has not encountered compliance failures.

4.3 Head restraint designs

There are two types of head restraints: adjustable ones which can be moved up or down to suit the occupant and integral seats which are fixed at one height.

Adjustable restraints are not part of the seatback but are separate pads which are attached to the seatback by one or two sliding metal shafts. The restraint remains in a raised position by means of a latch or by friction alone. The restraint pads average 3 inches high. On top of an average 22 inch seatback, they provide a 25-inch seat when they are in the "down" position. This is 2.5 inches less than the 27.5 inches required by Standard 202 (which, of course, does not apply to restraints in the down position). The restraints can be raised about 3.5 inches. Thus, in the "up" position, adjustable restraints average about 28.5 inches and exceed the minimum requirements of Standard 202 by an inch. (For more details, see Section 8.3.1.) Adjustable restraints may be found in cars with bucket as well as bench seats.

"Integral" restraints are somewhat misnamed because the category is generally defined to include all restraints that are fixed in position - i.e., not adjustable. Three types may be distinguished. By far the most common is the truly integral type which is used with bucket seats. It consists of nothing more than a seatback which is tall enough to meet the height requirements of Standard 202 by itself, without any attached pad or restraint. The second type is a bench seatback whose top is not of uniform height, but is taller in the outboard seat positions. The third type is a "see through" fixed restraint attached to the top of the seatback. It may be shaped like the top three quarters of a figure 8 or a flat-topped letter A or a suitcase handle. The openings allow the driver to see through it. Integral seats average about 28.5 inches in height and exceed the minimum requirements of Standard 202 by an inch.

Data on the sales distribution of adjustable and integral restraints is presented in Section 4.5.

4.4 Problems with head restraints

The most obvious shortcoming of adjustable restraints is that the task of raising them to the correct position is left to the occupant. Observational and accident data agree closely that about 75 percent of adjustable restraints are left in the "down" position. Specifically, the findings from 5 studies were:

* O'Neill et al, L.A. & Washington, 1971 [54]: 71-84% down
* Garrett & Morris, W. New York, 1972 [32]: 73% down
* Fell, MDAI, 1972 [31]: 59% down
* States & Balcerak, Rochester, 1973 [61]: 72% down
* McLean, N. Carolina, 1973 [46]: 84% down

Since adjustable restraints in the "down" position provide a seat only about 25 inches tall, the 75 percent of the occupants who leave them down have, in a sense, defeated Standard 202, which specifies 27.5 inch seats.

The problem of adjustment, however, is not quite as severe as it would appear from the preceding statistics. Many occupants are short enough that they can obtain adequate protection from a restraint in the "down" position, even if the height is well under 27.5 inches. Standard 202 was designed to protect males of larger than average size and is more than sufficient for smaller persons. An extensive, nationwide observational survey conducted by Stowell and Bryant in 1978 showed that 51 percent of the adjustable restraints, whatever their position, reached at least to the base of the occupant's skull, providing full protection for the neck [64]. Moreover, even some of the remaining 49 percent were high enough to provide some protection for the neck. In other words, a head restraint in the down position is not nearly as useless as an unbuckled seatbelt.

The main advantages of integral seats are that they eliminate the problem of "defeat" by the occupant and cost considerbly less to manufacture than adjustable restraints.

A disadvantage of integral restraints is that they may reduce visibility to the side and rear for shorter drivers. R.J. Berton's tests showed that an integral restraint would create a vision obstruction for a 62 inch driver but an adjustable restraint in the "down" position would not [11]. The American and Japanese manufacturers, in their Docket comments on the Agency's 1974 proposal to raise height requirements to 31 inches, emphasized this visibility problem. They also reported that customers had complained that integral seats give rear seat occupants a feeling of confinement, partially block the driver's view through the rear view mirror and prevent the driver of a following car from seeing through the car ahead to the traffic in front of it. The problem may be aggravated in the case of bench seats, for which Standard 202 requires a wider restraint (10 inches versus 6.75 for bucket seats) and where there is no open space in the center. Chyrsler specifically stated in their comments to the Docket that demand for their cars with integral restraints was decreasing because of customer dissatisfaction over visibility restrictions and feelings of confinement [65].

A natural question, at this point, is whether the possible vision obstructions with some kinds of head restraints have detrimental <u>safety</u> consequences. For example, there might be an increase in collisions involving lane changing if drivers have greater difficulty seeing cars just behind them in adjacent lanes. The best information source on the causes of accidents is the Tri-Level Study performed by the University of Indiana under the direction of J.R. Treat (National Technical Information Service, Report No. DOT HS-805 085, May 1979). In this study, 2258 accidents were investigated during 1972-75, a period during which the majority of cars on the road had head restraints. The investigators felt that only 2 of the 2258 accidents had "vision obstructions due to objects in or attached to vehicle" as a probable cause and they were not certain in either of these cases (p. A-66). Since this category of vision obstruction includes many objects other than head restraints, it is clear that the number of accidents caused by head restraint vision obstructions, if any, is extremely small and need not be given further consideration in this evaluation.

A potential disadvantage of head restraints is that they might injure rear seat occupants who contact them in frontal and other crashes. The potential risk is greatest for adjustable restraints whose supporting metal shaft is close to the rear surface of the seatback. Accident analyses by J.R. Stewart [63] and J.C. Fell [31], however, suggest that the safety problem is minimal.

Stewart worked with the National Crash Severity Study data. He found that:

(1) Only 32 out of 2153 injured rear seat occupants -i.e. 1.5 percent of the casualties - suffered injury due to contact with head restraints.

(2) Only 4 of them were injured by head restraint contact alone -i.e. 0.2 percent of the casualties. The other 28 had multiple injuries.

(3) None of the 32 injuries were life-threatening and only one was AIS 3 [1].

(4) The 32 rear seat occupants with head restraint contact injury were matched with rear seat occupants of crash involved cars without head restraints. Matching was performed on the basis of crash mode, damage severity, occupant age and sex. The average AIS of the occupants of cars without head restraints was higher than the average AIS of the head restraint caused injuries.

Fell analyzed Multidisciplinary Accident Investigation data and used a slightly different technique than Stewart. He compared head restraint caused injuries to injuries caused by contact with other parts of the front seatback. His findings were

(1) In post-Standard cars, there were 34 head-restraint caused injuries to rear seat occupants and 126 injuries due to contact with other parts of the front seatback. The average severity of the injuries was the same.

(2) The pre-Standard 202 seatback injured nearly the same proportion of rear-seat occupants as the post-Standard seatback and head restraint <u>combined</u>.

A potential hazard of adjustable restraints occurs when a short front-seat occupant leaves the restraint in the up position. It is conceivable that in a rear impact the occupant's head could enter the space between the seatback and the restraint, striking the metal shaft. Most restraints, however, have been designed in a manner that prevents this hazard.

Another possible problem with adjustable restraints is that they are often firmer than the seatback and protude in front of the seatback. This could cause the head to rebound before the torso after a rear impact, stretching the neck. Also, a tall occupant sitting with the restraint in the down position could get a sort of "karate chop" in the back of the neck from the protruding restraint.

An injury hazard that has persisted despite Standard 202 is the occupant motion in rear impacts known as "ramping." The rearward impact forces are translated into upwards motion of the occupant along the seatback -i.e. the seatback becomes a ramp for climbing. Ramping is especially prevalent when the seatback tilts backward under occupant load. The associated injury hazard is that the occupant's head may travel over the top of the head restraint and become unprotected by the restraint. A taller head restraint might have prevented the hazard. In other words, the height requirement specified in Standard 202 may not be adequate when ramping in taken into consideration. (See Sections 3.3.4 and 8.2 for evidence of ramping in highway accidents and crash tests and Section 8.4 for the possible benefits of raising height requirements.)

Crash and laboratory tests indicated that head restraints' effectiveness in reducing hyperextension is diminished when the occupant is leaning forward in his seat - when there are 12 inches or more offset between the occupant's head and the restraint at the beginning of the crash. In these cases, rotation of the neck may begin before the head contacts the restraint. Furthermore, when the head does contact the restraint, it does so at a high relative velocity [11], [60].

Finally, head restraints are designed primarily to prevent whiplash due to neck hyperextension. It is not clear that they would be effective against other forms of whiplash: torsion, sideways or forward rotation, translational forces on the neck (see Section 3.3.1). They are, generally speaking, not designed to prevent nonwhiplash injuries in rear impacts (Section 3.3.2).

4.5 Sales trends of adjustable and integral restraints

Integral restraints became increasingly popular in the early 1970's, reaching a peak market penetration of 39 percent in 1975. Since then, they have become less popular on all but the least expensive cars.

Table 4-1 shows and Figure 4-1 graphs the market penetration of integral restraints during 1969-81, by vehicle size. Sales trends for model years 1969-78 are based on NCSS data. The trends for 1979-81 are based on a special analysis of production and sales, which is described later in the Section. At first, integral restraints were found primarily on imports. During 1970-72 the domestic manufacturers installed them on an ever-increasing percentage of their cars. It can be presumed that during this period there was considerable enthusiasm about the lower cost and apparent higher effectiveness of integral restraints.

In 1969, only bucket seats contained integral restraints. For bucket seats, an integral restraint is little more than a taller seatback. It is easy to manufacture and the incremental cost is low. Table 4-2 and Figure 4-2 show, however, that the manufacturers achieved a breakthrough during 1970-71 by building an integral (fixed) restraint into bench and split bench seats. This made it possible to offer integral restraints on the larger and

TABLE 4-1
PERCENT OF CARS WITH INTEGRAL RESTRAINTS, BY MODEL YEAR AND MARKET CLASS

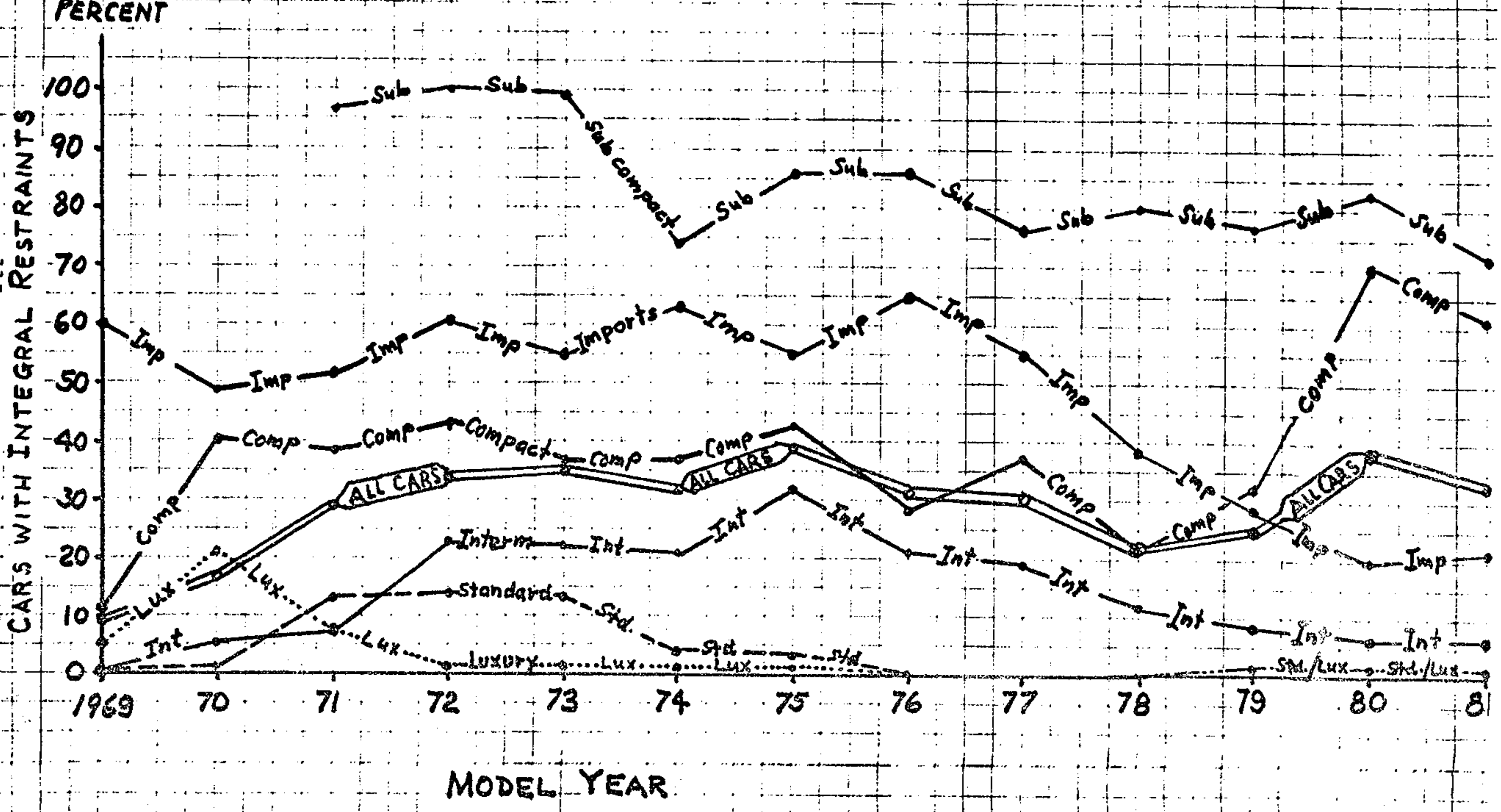
(Data sources: 1969-78 NCSS; 1979-81 McVetty & Heinen's sales analysis)

Percent with Integral Restraints

Model Year	Domestic					Imports	All Cars on the Road	All Tow-away-Involved Cars
	Subcompact	Compact	Intermediate	Standard	Luxury			
1969	N.A.	11	0	0	5	60	9*	8
1970	N.A.	40	5	1	21	48	17*	18
1971	97	38	7	13	7	52	28*	32
1972	100	43	23	14	1	61	34*	37
1973	99	37	22	13	1	55	35*	38
1974	74	37	21	4	1	63	32*	43
1975	86	43	32	3	1	55	39*	45
1976	86	28	21	0	0	65	31*	38
1977	76	37	19	0	0	55	30*	33
1978	80	22	12	0	0	38	22*	30
1979	77	32	8	1	1	29	25	N.A.
1980	83	70	6	1	1	20	39	N.A.
1981	71	61	6	1	1	21	33	N.A.

* Sales-weighted average based on sales data from [8] and [67].

FIGURE 4-1: PERCENT OF CARS WITH INTEGRAL RESTRAINTS – BY MODEL YEAR AND MARKET CLASS



more luxurious cars. The marketing of integral seats as a novel and desirable item is hinted at by their 21 percent penetration of luxury cars in 1970 (Thunderbirds) and their over 30 percent installation with split bench seats during 1970-72. During 1971-73, integral seats even had some success on full-sized family cars with bench seats (especially Plymouths).

During 1973-74 the decline began for integral seats. Integral seats were no longer the manufacturer's first choice on cars in the less cost-sensitive markets. For example, the Mustang II was equipped with adjustable restraints from its 1974 market entry. At the same time, Ford retained integral restraints on the equally small but less expensive Pinto.

The initial decline of integral seats is not easily seen in the overall sales figures (Table 4-1) - in fact, they achieved maximum penetration in 1975. This is because the 1974 energy crisis and subsequent recession caused a trend to smaller, less expensive cars: the type most often equipped with integral seats. The breakdown by seat type (Figure 4-2), however, clearly shows that demand for integral seats dropped steeply on bench and split bench seat cars and just held its own with bucket seats.

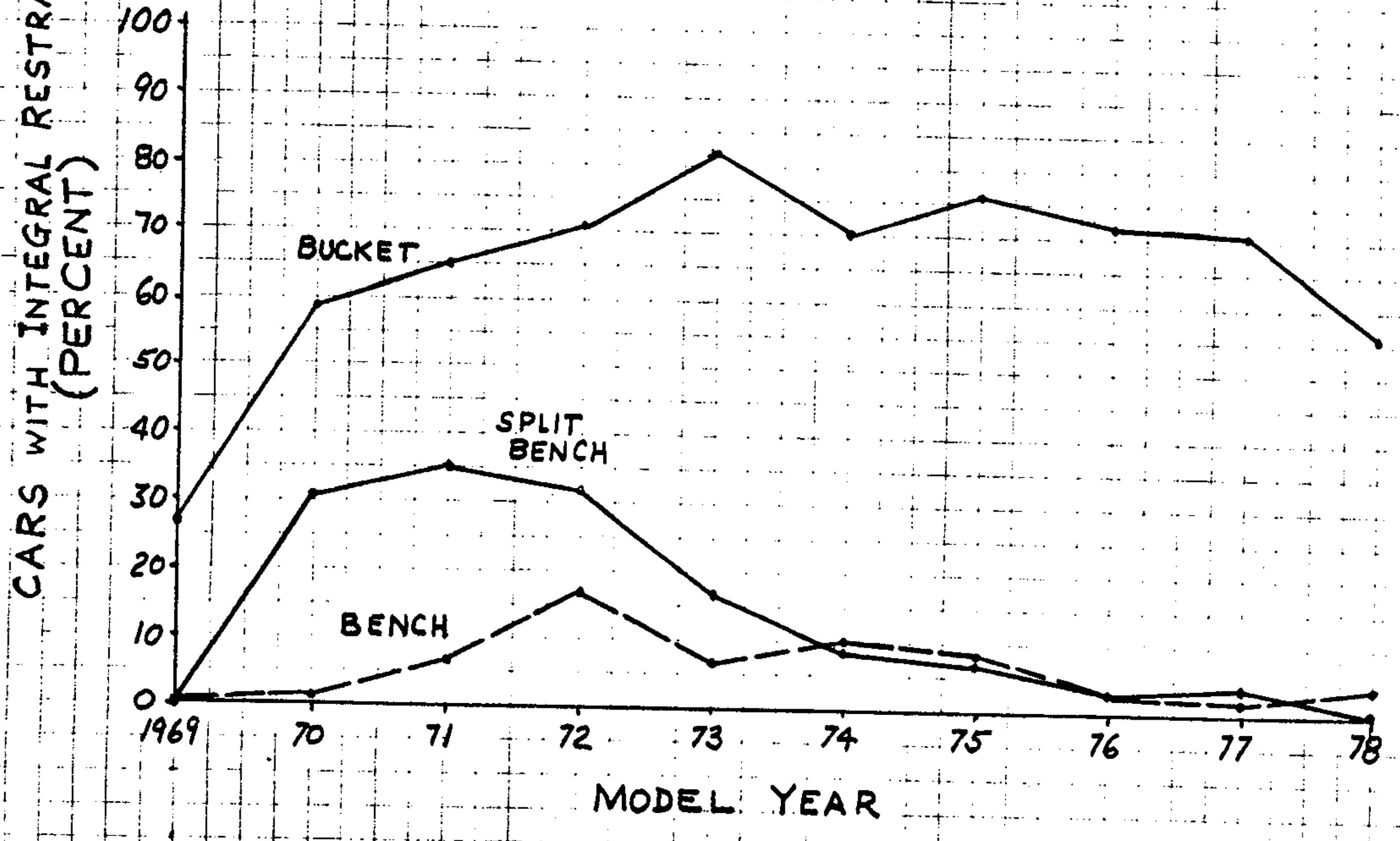
The far-reaching model changeovers during 1976-78 led to further setbacks for integral seats. Also, the economic recovery in this period renewed demand for larger and more luxurious cars. Towards the end of this period, imports increased their share of the medium-priced market. As imports became less spartan, there was a corresponding increase in adjustable restraints.

TABLE 4-2

PERCENT OF CARS WITH INTEGRAL RESTRAINTS BY MODEL YEAR AND FRONT SEAT TYPE, NCSS

Model Year	Percent with Integral Restraints		
	Bench Seats	Split Bench	Bucket Seats
1969	0	0	27
1970	1	31	59
1971	7	35	65
1972	17	32	71
1973	7	17	82
1974	10	8	70
1975	8	7	76
1976	3	3	72
1977	2	4	71
1978	4	0	56

FIGURE 4-2: PERCENT OF CARS WITH INTEGRAL RESTRAINTS — BY MODEL YEAR AND FRONT SEAT TYPE



By 1978, integral restraints were installed in only 22 percent of the cars, the lowest percentage since 1970.

Sales trends for model years 1979-81 cannot be obtained from NCSS data, which were collected before 1979. T.N. McVetty and C.M. Heinen of the IIT Research Institue, under contact to NHTSA, estimated the sales of integral and adjustable restraints in those years based on information supplied to them by the automobile manufacturers.

Their study shows that integral seats made a partial comeback during 1979-80, returning to their earlier peak market penetration of 39 percent in 1980. The principal reasons for the comeback were:

(1) The fuel crisis of 1979, which spurred a major shift to small car purchasing, just like the 1974 crisis. The smaller cars are more often equipped with integral seats.

(2) The introduction of GM's front-wheel-drive X-body cars, which had exclusively integral restraints, even on bench and split-bench seats. (The Pontiac Phoenix had see-through integral restraints.) Ford introduced a Mustang with integral seats as standard equipment, where previously the Mustang II had all adjustable restraints. The new Chrysler subcompacts had integral seats standard. It seems probable that cost and weight consciousness during this period of slumping profits and fuel shortages were a factor in motivating the domestic manufacturers to install the less costly, lighter integral seats.

The lower part of Table 4-1, however, shows that the "comeback" for integral seats was limited to small domestic cars. The market penetration for integral seats in imported cars dropped from 65 percent in 1976 to

38 percent in 1978 to 20 percent in 1980. Imports during those years were successfully moving from a low-cost market to an image of quality, comfort and convenience. Toyota, Datsun and Volkswagen offered adjustable seats as part of an extra-cost seat option - which was selected by 75 percent of their customers. By 1980, the market share for integral restraints was half as high in imports as in domestic cars, whereas during 1969-76 it was twice as high.

The decline for integral restraints also continued for intermediate-sized domestic cars: from 32 percent of the market in 1975 to 12 percent in 1978 to 6 percent in 1981. Customers expressed a strong willingness to buy extra-cost seats that included adjustable restraints (e.g., 75 percent of 1981 Grand Prix's) but seldom chose optional bucket seats with integral restraints at no extra cost (e.g., 4 percent of 1981 Pontiac LeMans').

Furthermore, the Escort/Lynx, introduced in 1981, sold large numbers of extra-cost optional adjustable restraints (35 percent of sales) and the Aries/Reliant offered adjustable restraints as standard equipment. Both of these new lines were projected in advertizing as more luxurious then the cars they replaced (Pinto/Bobcat and Aspen/Volare); perhaps this image has some correlation with the higher sales of adjustable restraints. As a result of these new car lines, the market share for integral restraints dropped back to 33 percent in 1981 (from 39 percent in 1980). If public concern about fuel shortages eases in 1982-83 and larger cars regain some of the market they lost in 1979-81, the market share for integral restraints may again fall to 25 percent.

There are three market patterns that become evident from a study of the sales data, especially from McVetty and Heinen's detailed sales analysis:

(1) The customer's choice between adjustable and integral restraints was generally not a Hobson's choice. On most makes and models, the consumer could buy either adjustable or integral restraints. The principal exceptions in 1980-81 were the GM X-cars, the Chrysler K-cars, intermediate and full-size Fords and certain Datsun's. Otherwise, the typical choice on smaller cars was standard bucket seats with integral restraints or extra-cost deluxe bucket seats which, among other things, have adjustable restraints. For these makes and models, 42 percent of the domestic car buyers and 70 percent of the imported car buyers purchased the deluxe seats which included adjustable restraints. Of course, this does not necessarily mean that the choice was primarily influenced by the head restraints. On larger carsincluding all large GM cars except Cadillacs the typical choice was between bucket integral and bench - or split-bench adjustable. Here, 93 percent purchased the seats with adjustable restraints. Here, however, the choice would appear greatly influenced by whether the purchaser wanted bench or bucket seats.

(2) There was a clear tendency in the sales data: the more luxurious or prestigious the car, the greater the percentage of adjustable restraints. Thus, for example, Ford Mustangs have more adjustable restraints than Ford Escorts, Ford Escorts more than Ford Pintos, 1981 Toyotas more than 1977 Toyotas, etc.

(3) Manufacturers attempted to market bench seats with integral restraints during the early 1970's but turned away from this effort after a

few years, even while continuing to offer integral bucket seats on the same makes and models.

Finally, then, what are the main reasons that adjustable restraints, which are evidently more costly and less effective, get such a large share of the market? To fully answer this question would require extensive surveying of the car-buying public and the manufactuers and would be outside the scope of the evaluation. But since the overall benefits and costs of head restraints are influenced by the type of restraints sold, let us at least provide some speculative answers based on the sales data and other available evidence.

In view of the market trends, it seems likely that the high sales of adjustable restraints, to a large extent, reflect actual consumer preferences based on styling and comfort. It would not appear that customers are generally being forced to buy adjustable restraints. On the contrary, the manufacturers have made a continued effort to furnish integral restraints to those who want them.

Vision obstructions experienced with integral restraints (see Section 4.4) would appear to be only a secondary factor in their overall unpopularity. The obstructions primarily affect short drivers (e.g., shorter than average females). Yet, 75 percent of the customers are buying adjustable restraints and there simply aren't that many short car purchasers.

Adjustable restraints, as part of a deluxe seating package, seem to be associated with an image of comfort, prestige, styling and convenience. They might be viewed, to some extent, as a nice head rest that can be adjusted to suit one's comfort - a deluxe convenience item somewhat like adjustable seats, tilt steering wheels, etc. This image, we presume, has gradually been achieved through feedback between car owners, dealers, and the manufacturers' styling and marketing staffs. Consciously or, in most cases, unconsciously, the majority of car buyers have apparently accepted the idea that finer seats and adjustable restraints go together.

CHAPTER 5

THE OVERALL EFFECTIVENESS OF HEAD RESTRAINTS

5.1 Review of previous effectiveness studies

Eight statistical studies of the effectiveness of head restraints were found in the literature. A 1972 study of accidents reported to insurance companies provided unambiguous, statistically significant results. Another study was based on police reported accident data. There were 6 analyses of investigator-reported data, all involving small samples.

5.1.1 Studies based on insurance company data

In 1972, B. O'Neill et al published an analysis of neck injury claims by drivers of automobiles that were struck in the rear by another car [54]. The sample frame was the claim files of the State Farm Mutual Insurance Company for the Los Angeles area in the first 9 months of 1970. The study was restricted to automobiles of model years 1966-70 and to manufacturer/model year combinations for which the authors believed that head restraint installation was virtually nil or virtually 100 percent.

They obtained a sample of 5663 cars that were struck in the rear: 3830 without head restraints and 1833 with restraints. Table 5-1 shows that 29 percent of the drivers of the pre-Standard cars claimed they had a neck injury. Only 24 percent of the post-Standard car drivers claimed a neck injury. This is a statistically significant 18 percent reduction in the rate of claimed neck injuries.

TABLE 5-1

CLAIMED NECK INJURIES TO DRIVERS OF 1966-70 CARS STRUCK IN THE REAR, BY HEAD RESTRAINT AVAILABILITY; LOS ANGELES AREA STATE FARM CLAIMS, 1970

(O'Neill et al., 1972)

Availability of Head Restraint	N of Rear Impacts	Percent of Drivers Claiming Neck Injury	Reduction for Head Restraints (%)
Not supplied	3830	29	--
Standard equipment	1833	24	18*

* Statistically significant reduction (z= 4.06, p<.001)

O'Neill also found that head restraints were more effective for females than males. Restraints reduced females' neck injury claims by 22 percent but males' claims by only 10 percent. (The difference of effectiveness is, however, not statistically significant.) This finding is consistent with the fact that head restraints are more likely to be properly adjusted for females than for males.

In 1973, H. Joksch proposed that O'Neill's results may exaggerate the effectiveness of the restraints because no attempt was made to control for the "age effect" - the fact that the pre-Standard cars are, on the average, 3 years older than the post-Standard cars in O'Neill's data [39]. It is unknown, however, whether insurance-reported data had "age effects" like police-reported data or is relatively free of them like the National Crash Severity Study.

Joksch's proposal can be tested by disaggregating O'Neill's data by model year, manufacturer and driver sex and running a weighted regression of the injury rates by Standard 202 compliance, vehicle age, manufacturer and driver sex. The regression results indicate a moderate age effect. After the age effect was removed, the injury reduction for head restraints was 11 percent rather than the 18 percent in Table 5-1.

The validity of the regression can be questioned because all the data were collected in the same calendar year. As a result, there is a strong correlation between vehicle age and Standard 202 compliance and a high likelihood that the model may confuse their effects. Intuitively, not much age effect would be expected for liability claims of cars which are 0-4 years old. (By contrast, for collision claims there could be substantial underreporting of minor accidents involving old cars.) Since a collision where a car is struck in the rear by another car would normally result in a liability claim, the age effect in O'Neill's data is probably smaller than what was indicated by the regression. Moreover, since O'Neill's post-Standard cars are primarily equipped with adjustable restraints (there were few integral restraints in 1970, except on Volkswagens) and since adjustable restraints are less effective than integral ones, his effectiveness contains a bias against Standard 202 that may cancel out the age effect. All in all, O'Neill's findings should be considered essentially unbiased.

5.1.2 Studies based on State data

In 1973, H. Joksch published an "Evaluation of Motor Vehicle Safety Standards" based on analyses of 1971 and 1972 Texas accident files [39]. His general procedure for crashworthiness standards was to observe the trend of injury rates by model year and determine whether a break in the trend occurred for the model year in which the standard was implemented. In other words, he obtained a regression equation:

$$P\ (\text{injury}) = c\ f\ (\text{make})\ g\ (\text{acc. year})\ h\ (\text{model year})\ k\ (\text{standard})$$

The data were disaggregated by vehicle make in order to obtain repeated measurements.

The purpose of the regression was to eliminate the "age effect": with police data, the injury rates rise as the car gets older, a trend that is not due to safety equipment, but to the different accident characteristics and reporting completeness for cars of various ages.

Joksch found that a statistically significant 25 percent reduction of a minor (C) injury could be attributed to head restraints in rear impact crashes of minor or moderate severity (TAD rating 1-3). There was no significant reduction however, in the overall injury rate for all types of rear impact crashes.

The validity of the regression model can be questioned because the data were collected in only 2 calendar years and they were adjacent years. As a result, there is a strong correlation between vehicle age and Standard 202 compliance and a high likelihood that the model may confuse their effects. The problem was aggravated because Joksch's assumptions on the implementation dates for head restraints are somewhat inaccurate, in light of the NCSS results (see Table 5-15). Regression models on vehicle age and a safety standard cannot be trusted unless there is a sufficient span of calendar years of data to include "old" cars that meet the standard and "new" cars that do not (see the FARS analyses, Section 5.4 in which 6 calendar years were used).

This is the only way to overcome the problem of correlation between two key independent variables.

5.1.3 Studies based on investigator-collected data

The six accident analyses based on more detailed, investigator-collected data generally did not involve sample sizes large enough to assure statistically significant results. Because of the divergent ground rules for the data collection, there does not appear to be a defensible procedure for combining the data from the six studies to build one large file.

J.D. States and J.C. Balcerak performed a special study of rear-end crashes in Rochester, New York during January - April, 1972 [61]. The Rochester accident investigation team followed up on police reports by attempting to interview the drivers and gather medical information specifically concerning "whiplash." The follow-up information was obtained on 389 drivers and right-front passengers, divided fairly evenly among pre and post-Standard cars. This is about 7 percent of the sample size that O'Neill obtained from insurance files (see Section 5.1.1).

Table 5-2 shows that 43 percent of the drivers and right front passengers of pre-Standard cars had a whiplash injury severe enough to require medical treatment or to result in absence from work or disability in daily activity. Only 37 percent of the post-Standard drivers and right-front passengers had whiplash. This is a 15 percent reduction in the incidence of whiplash. Since the sample size was small, the reduction is not significant, but it comes close ($z = 1.29$, $p<.10$).

TABLE 5-2

WHIPLASH* INJURY RATES OF DRIVERS AND RIGHT-FRONT PASSENGERS IN REAR IMPACTS, BY HEAD RESTRAINT AVAILABILITY, ROCHESTER, WINTER 1972

(States and Balcerak, 1973)

Availability of Head Restraint	N of Rear Impacts	Percent with Whiplash	Reduction for Head Restraints (%)
No head restraints	179	43	--
Head restraints installed	210	37	15**

*Discomfort or stiffness requiring treatment or causing temporary disability

**$z = 1.29$ $p < .10$

States and Balcerak also found that head restraints are more effective for females than for males. Standard 202 reduced females' incidence of whiplash by 24 percent but males' whiplash by only 11 percent. This finding is nearly identical to O'Neill's results (22% reduction for females; 10% for males) and is consistent with the fact that restraints are more likely to be properly adjusted for females than for males.

Another important finding was that whiplash often goes unreported by the police, largely because the onset of whiplash symptoms may occur after the police complete their investigation. This aspect of States' study is discussed in Section 3.3.3.

A.J. McLean analyzed data from a special study in 14 North Carolina counties (Fall 1972 - Winter 1973) [46]. The data collection was quite similar to the Rochester special study: police reports supplemented by interview and medical data on neck injuries (including but not limited to "whiplash"). The follow-up information was obtained on 750 drivers and right-front passengers, divided fairly evenly among pre- and post-Standard cars.

Table 5-3 shows that 38 percent of the drivers and front-right passengers of pre-Standard cars had a neck injury. Only 36 percent of the post-Standard car occupants had neck injuries. This is a 6 percent reduction in the neck injury rate, which is, however, not a significant reduction.

TABLE 5-3

NECK INJURY RATES OF DRIVERS AND RIGHT-FRONT PASSENGERS IN REAR IMPACTS, BY HEAD RESTRAINT AVAILABILITY, 14 NORTH CAROLINA COUNTIES, 1972-73

(McLean, 1974)

Availbility of Head Restraint	N of Persons in Rear Impacts	Percent with Neck Injury	Reduction for Head Restraints (%)
No head restraints	325	38	--
Head restraints installed	425	36	6*

*Not significant: z=0.62,p>.10

AB Volvo maintains an extensive program of follow-up investigations of Swedish highway accidents involving their vehicles. In 1973, Bohlin, Norin and Andersson published several analyses of the Volvo data base, invluding one on the effectiveness of head restraints [13]. The data base contained only 171 rear impacts. In the 45 cars without head restraints, 35 percent of the drivers suffered a neck injury. In the 126 post-Standard cars, the neck injury rate was only 16 percent. This is a statistically significant 55 percent reduction of neck injury risk ($z=2.78$, $p<.01$). In fact, the observed effectiveness of head restraints is much higher than in any of the other studies. Although there are no apparent biases in the data, which are a census of severe rear impacts to Volvos under warranty in 4 Swedish metropolitan areas, the results from this study should be given relatively light weight in view of the very small sample of pre-Standard cars.

In 1972, J.C. Fell analyzed the rear impact crashes on the Multidisciplinary Accident Investigation (MDAI) file [31]. Since the MDAI data were collected primarily in the 1970's and emphasize cars of the most recent model year, there are only 49 drivers and right-front passengers on the file who occupied a pre-Standard rear-impacted car; 37 percent of them had whiplash. There were 229 drivers and right-front passengers in cars with head restraints that were struck in the rear; 39 percent had whiplash. The observed 5 percent increase in the incidence of whiplash is not statistically significant.

J.W. Garrett and D.F. Morris analyzed head restraint effectiveness using a combination of data files [32]. The Automotive Crash Injury Research (ACIR) file contained 909 drivers and right-front passengers of pre-Standard

(1980-68) cars that were struck in the rear. But even after combining the ACIR with Calspan's Level 3a (in-depth) accident investigations, they were able to obtain only 52 comparable occupants of post-Standard cars (1969-71). The incidence of neck injury was 36 percent in both the pre and post-Standard samples.

T.E. Anderson updated Garrett and Morris' analysis by adding rear impacts of 1972 and 1973 model cars from Calspan Level 3a data [4]. This increased the post-Standard sample size from 52 to 68. He also limited the pre-Standard cars to model years 1960-65 and apparently used additional sources of ACIR data because the pre-Standard sample size grew to 980 despite the reduction in the span of model years. As a result of these changes, the pre-Standard neck injury rate decreased to 24 percent and the post-Standard rate increased to 44 percent. This amounts to an 83 percent increase in neck injury for Standard 202! Anderson also found that lap belts, energy absorbing steering systems and other safety devices were associated with higher injury rates. It would appear from a comparison of Garrett and Morris' study with Anderson's that the ACIR file may be neither internally homogeneous nor comparable to Calspan Level 3. This could be an explanation for the inconsistent results of the two studies as well as the latter report's generally anomalous findings.

5.2 Analysis of National Crash Severity Study data

Since 1977, the National Crash Severity Study has been a primary source of detailed information on vehicle and injury performance in highway accidents involving passenger cars. NCSS is a probability sample of towaway accidents. It contains data elements that are especially useful for evaluating head restraints, such as the type of restraint installed in each car, the nature and cause of the occupants' injuries and the time at which whiplash symptoms appeared. On the other hand, because injury-producing rear-impact towaway crashes are relatively uncommon and because only 18 percent of the cars are pre-Standard, the NCSS sample sizes are too small to provide statistically significant results on the overall effectiveness of head restraints. NCSS is also unrepresentative because the majority of rear-impact injuries occur in nontowaways (see Table 3-4). It is necessary to analyze the much larger Texas file (Sections 5.3 and 5.6) to obtain significant results.

Initial NCSS analyses were performed by J.R. Stewart of the Highway Safety Research Center under contract to NHTSA and are documented in detail in their report [63]. These analyses were reworked using data definitions and models which were more suitable for this evaluation. It is primarily these reworked analyses that will be described here. The Highway Safety Research Center's results will also be shown, for comparison.

A detailed description of NCSS may be found in [40], pp. 138-148, and in [56].

5.2.1 Overview and definitions

The effectiveness of head restraints is the relative difference of the injury rates, per 100 rear-impact involved occupants, in cars with and without restraints. In order to calculate injury rates it is necessary to know

(1) How many persons were involved in "rear" impacts.
(2) How many of them rode in cars equipped with head restraints.
(3) How many of them were "injured."

NCSS data include a Collision Deformation Classification [14] which indicates both damage location and direction of force. Rear impacts are defined here to be vehicles damaged in the rear plus those which were exposed primarily to rear force vectors(principal direction of force 5,6 or 7 o'clock).

NCSS specifies, for each vehicle, whether or not it is equipped with head restraints, even those manufactured before the Standard's effective date (see Section 4.1). The sample is limited to drivers and right front occupants, since they occupy the only seats normally equipped with the restraints.

Three definitions of "injury" are used:

- Any kind of injury
- Neck injury
- Injury resulting in at least overnight hospitalization

Investigators were unable to obtain detailed injury data in about 20 percent of the NCSS cases. The problem of missing data is minimized by defining the above 3 injury levels as follows:

An occupant is injured if the investigator said so (overall AIS=1-8 [1] or NECKINJU=0-7) or if the investigator didn't know (AIS=9) but the police said so (police rating K,A,B or C). This definition eliminated missing data.

An occupant suffered whiplash-type neck injury if the investigator knew at what time whiplash symptoms appeared (NECKINJU=0-7) or if the investigator didn't know about the symptoms' appearance (NECKINJU=9) but did code the occupant as having non-contact neck-muscle pain -i.e., "whiplash." This definition reduced missing data to 6 percent.

An occupant was transported to be hospitalized if he was killed or was transported from the scene (according to the police report) and then hospitalized (WEIGHTFA=1 and NCSSCLAS=1-4). In NHTSA's evaluation of the steering column [40], pp. 146-149, this definition of injury was chosen in preference to AIS-based schemes [1] because missing data are eliminated and because it greatly enhances statistical precision when used with the NCSS sampling scheme.

It should be noted that these definitions are not identical to the Highway Safety Research Center's schemes [63] and that they eliminate missing data to a larger extent.

NCSS is not a simple random sample. It is a stratified random sample, with 4 strata, whose sampling proportions are 100, 25, 10 and 5 percent, respectively [56]. In order to produce unbiased tabulations for the universe of accidents that NCSS is drawn from, it is necessary to weight each NCSS case by the inverse of the sampling fraction, i.e., by a factor of 1,4, 10 or 20 for the 4 respective strata.

There are 967 (unweighted) NCSS cases of front outboard occupants involved in rear impacts but they correspond to 4904 weighted cases. Thus, the cell entries in (weighted) NCSS tabulations exaggerate the actual sample sizes by a factor of about 5. The exaggeration must be taken into account when confidence bounds for effectiveness are calculated. Only in the case of hospitalizing injury, where all injured persons are constrained to be in the 100% sampling stratum, is the weighted and unweighted number of injuries identical.

Table 5-4 shows the (weighted) NCSS injury rates in pre and post-Standard cars. Occupants in cars with head restraints were observed to

TABLE 5-4

INJURY RATES IN REAR IMPACTS OF
PASSENGER CARS, BY HEAD RESTRAINT INSTALLATION,
DRIVERS AND RIGHT FRONT PASSENGERS, NCSS

	Without Head Restraints	With Head Restraints	Observed Reduction for Head Restraints (%)
N of rear impacts (weighted)	864	4040	
Percent of occupants injured	48.1	49.5	-3
Percent with neck injury*	23.1	29.1	-26
Percent hospitalized	3.8	2.6	32

*Because of missing data, N is reduced to 815 (pre-Standard) and 3792 (post-Standard).

have higher rates of overall injury (3%) and neck injury (26%) than those in cars without the restraints, but a 32 percent lower risk of hospitalization.

It is likely, though, that the observed injury rate differences are partly due to age effects -i.e. differences in the occupants, vehicles and crashes of pre- and post-Standard cars that are not due to head restraints but only to the fact that the pre-Standard cars are older. Above all, in NCSS, the post-Standard cars are more likely to be occupied by females than the older cars. Females are considerably more prone to whiplash and other minor rear impact injury than males. This creates a bias against the post-Standard cars which partially explains their poor performance, on Table 5-4, in regard to overall injury and neck injury.

A program of multidimensional contingency table analysis is needed to identify and remove the age effects and to calculate the residual injury rate differences attributable to Standard 202.

5.2.2 Effectiveness based on multidimensional contingency table analysis

The procedure whereby multidimensional contingency table analysis programs such as BMDP3F [15] or GENCAT [34] can be used to identify and remove factors that confound injury rates and to calculate the injury reduction actually due to a standard is described in Section 5.3.2 and in [40], pp. 164-183.

The Highway Safety Research Center developed a list of 10 potential control variables (confounding factors) on the NCSS file and, by an iterative procedure, selected those variables which had the strongest interactions with injury risk and vehicle age (see [63], pp. 3-4 - 3-13). Between one and three variables were selected, depending on the type of injury under consideration.

Next, the GENCAT multidimensional contingency table analysis was applied to the table of head restraint status x injury x the selected control variables ([63], pp. 3-14 - 3-17 and Appendix A). The immediate objective of this step is to "fit a model" to the data, -i.e. to specify a minimal set of important interactions between the variables that gives a "good" prediction of the observed cell entries. Its broader purpose is to replace the observed cell entries - which are subject to large sampling error when the data are broken up into many small cells - with "expected" entries which are less prone to sampling error (see Section 5.3.2 of this report or pp. 173-176 of [40]).

When the data file is a simple random sample, likelihood-ratio Chi-squares or similar statistics reliably indicate whether a model has "good" fit. But with the NCSS sampling scheme, these statistics have to be explained. A single NCSS injury from the 5 percent stratum, weighted as 20 injuries, is destined to appear in only one of the small cells of a large table. GENCAT sees the 20 injuries in this one cell and gives great significance to high-order interaction terms that "explain" why 20 injuries happened there but never more than one or two in neighboring cells. The "significance" of this higher order term is, of course, overstated. The analyst must be aware, therefore, of any high Chi-squares of higher-order interaction terms that cannot be given a logical explanation. It is also worthwhile to apply GENCAT to unweighted NCSS data and to question any high Chi-sqares in the weighted data that are not duplicated in the unweighted data.

The Highway Safety Research Center analysis tended to overfit the data and included more interaction terms than necessary in their GENCAT models. This resulted in their models predicting that head restraints increase the whiplash risk of unbelted occupants younger than 20 by 437 percent but decrease it for 20-54 year old occupants by 15 percent (Figure A-1 of their report). The models also predicted that head restraints reduce overall injury of females by 43 percent in crashes with damage extent zones 3-9 but have an effectiveness of -1 percent in all other crash situations (Figure 3-3); that adjustable restraints are 34 percent more effective than integral restraints in reducing neck injuries of unbelted occupants in cars up to 2300 pounds but integral restraints are 37 percent more effective than adjustable restraints in 2400-3300 pound cars (Figure A-15). These predictions appeared counterintuitive. With the model for neck injury, the aggregate effectiveness for head restraints (10% - see Table 2-1) came out 33 percent higher than the estimate based on raw data (-23% - see Table 3-3). This large change is probably not due to having successfully controlled for confounding factors but more likely the result of sampling error inherent in an overfitted model.

The models were reworked using a more conservative approach, as follows: HSRC's preliminary screening indicated 4 variables that might be significant confounding factors based on interactions with Standard 202 and with injury as well as on intuitive grounds. The variables are occupant age and sex, vehicle weight and damage severity. The continuous variables are dichotomized:

- Age: Less than 40, 40+
- Vehicle weight: Up to 3000 pounds, More than 3000
- Damage extent zones [14]: 1-2, 3-9

The 6 way tables of head restraint status, injury, and the 4 control variables are analyzed. The 2 way interaction terms are of primary interest. Higher order terms are ignored because the Chi-squares are not that high and there are no intuitive bases for such interactions.

If a control variable does not show significant 2 way interactions with head restraint status and with injury risk, it is eliminated from the model, thereby simplifying the tables. The confounding factors that remain at this point are:

- overall injury reduction: damage severity and occupant sex
- whiplash reduction: occupant sex
- hospitalization reduction: damage severity

The models that were selected contained the interaction of head restraint and injury risk, plus all significant 2 way interactions. Only those significant 3 and 4 way interactions which could be intuitively justified were included. The chosen models are shown in Table 5-5.

Finally, the effectiveness of head restraints is calculated using the cell entries predicted by the model and the effectiveness formulas shown in Section 5.3.2. Table 5-6 shows that head restraints, in NCSS, had no effect on overall injury rates. Neck injury increased by 22 percent, but hospitalization decreased by 34 percent. Each of these point estimates is 2-4 percent more favorable to the restraints than the raw data were (Table 5-4). Recall that occupant sex, a control variable for overall injury and neck injury (Table 5-5), had biased the raw data against Standard 202 because there was a higher proportion of females in the newer cars. Vehicle damage,

TABLE 5-5

MODELS SELECTED FOR ANALYSIS OF NCSS; ANY HEAD RESTRAINT VS. NONE

I = injury
H = head restraint
S = occupant sex
D = vehicle damage

Injury Criterion	Selected Model
Any injury	IH, IS, ID, HS, HD, SD
Neck injury	IH, IS, HS
Hospitalization	IH, ID, HD

TABLE 5-6

EFFECTIVENESS OF HEAD RESTRAINTS AND CONFIDENCE BOUNDS: MULTIDIMENSIONAL CONTINGENCY TABLE ANALYSIS OF NCSS

Type of Injury	Effectiveness of Head Restraints (Reduction of Injury Risk - %)	Confidence Bounds*(%) Lower	Upper	HSRC's Effectiveness Estimate
Any injury	0	-19	14	14
Neck injury	-22	-72	9	10
Hospitalization	34	-10	54	N/A

*One-sided $\alpha = .05$

paradoxically, also biased the raw data against Standard 202 because in the rather small NCSS sample of rear impacts, the newer cars had slightly more severe damage than the older ones (opposite to the usual age trend and perhaps due to softer rear structures on more recent cars).

Table 5-6 shows that none of the effectiveness estimates based on NCSS differ significantly from zero and that, moreover, the confidence bounds are too wide for the point estimates to be statistically meaningful. The most precise of the three estimates is the one for overall injury reduction, whose one-sided 95% confidence bounds extend from -19 to +14 percent.

The jackknife technique was used to obtain, empirically, the confidence bounds shown in Table 5-6. This technique was used in the steering column evaluation and is described step-by-step in [40], pp. 187-193. The identical procedure is used here: the NCSS file of rear impacts is divided into 10 systematic random subsamples of equal size. One of the subsamples is removed and the injury rates are calculated for the remaining nine tenths of NCSS, using the same model as was used for the full file. The subsample is returned, another is removed, and the injury rates recalculated, etc. The variation from subsample to subsample is observed.

It is perhaps reassuring that the point estimate of hospitalization reduction (37%) is not significantly greater than zero. After all, it was shown in Section 3.3.3 that whiplash is the primary injury mechanism in only 36 percent of the hospitalizations, that whiplash usually is accompanied by other injuries and that the other injuries would not be strongly influenced by head restraints. It is possible, nevertheless, that the observed reduction is real - i.e., that head restraints are effective in preventing the more serious kinds of whiplash while other safety devices have mitigated nonwhiplash injuries (and their benefits were attributed to head restraints by the simple model of Table 5-5). For example, rebound injuries may have been mitigated by energy absorbing steering columns. Side door beams could have reduced injury risk in side impacts with a rear force direction.

The NCSS tabulations and analyses used to derive effectiveness and its confidence bounds are documented in Appendix B.

The NCSS analyses of overall effectiveness of head restraints are based on too small a sample to draw any sort of firm conclusion. It is necessary to analyze a much larger file for precise results. This will be done in Sections 5.3 and 5.6.

5.3 Analysis of 1972 Texas accident data

Each year, police agencies in Texas investigate over 400,000 traffic accidents. Because most of the agencies make use of the TAD classification system for vehicle damage [66], it is easy to identify the cars that were struck in the rear. A single year of Texas data contains a sample of clearly identified rear impacts two orders of magnitude larger than NCSS. These virtues - large sample size and nearly complete damage information - make Texas data uniquely suitable for evaluation of head restraints. With appropriate analysis techniques, Texas data can yield a statistically precise and fairly unbiased estimate of the nonfatal injury reduction attributable to head restraints.

This Section summarizes two analyses performed by Opportunity Systems, Inc., under contract to NHTSA, on a single year of Texas data (1972). The analyses are documented in detail in the contractor's report [12]. The more conservative of the two analyses suggests that head restraints reduce the risk of rear impact injury by 18 percent.

After the contract was completed, access to 1974 and 1977 Texas files was obtained. It became possible to perform in-house analyses on the combined 3 years of data, using techniques that eliminate some of the potential biases that might have occurred in the analyses of this Section. The in-house analyses of 1972, 74 and 77 Texas files are described in Section 5.6.

5.3.1 Overview and motivation

In the most general terms, the effectiveness of head restraints is the relative difference of the injury rates, per 100 rear-impact involved occupants, in pre-Standard cars and post-Standard cars. In order to calculate injury rates, it is necessary to know

(1) How many persons were involved in "rear" impacts

(2) How many of them were "injured"

Texas police reports do not normally contain information on uninjured occupants, but a record is made of each injured occupant. Thus occupant injury rates cannot be immediately computed. Nearly all motor vehicles in transport, however, have only one driver. If a police report describes a vehicle but gives no injury information on the driver, it is reasonable to assume that there was a driver and he was not injured. In this manner it is possible to obtain a count of uninjured drivers and compute driver injury rates. No such assumption can be made at the other seating positions, so no meaningful injury rates can be computed at the other positions. As a result, the Texas analyses must be limited to drivers.

Rear impacts can be reliably identified in Texas data based on the TAD classification of damage location [66], which is completed on nearly 90 percent of the reports.

Texas data do not specify the location or nature of the injury nor the contact point that caused it. It is not possible to distinguish neck injury or whiplash from other injuries. The police do classify injury by their severity, however, using the categories K, A, B and C. Thus the effectiveness of head restraints is calculated based on overall injury rates, K+A+B injury and K+A injury rates. Since whiplash symptoms often do not appear until some time after the accident, they tend to be underreported in police reports made at the accident scene (see Section 3.1.3).

Texas data do not specify whether a car was equipped with head restraints. The assignment of cars to pre or post-standard is based on a NCSS look-up table of head restraint availability by make/model and year. Make/model/year combinations with partial or unknown head restraint installation are excluded from the ana'ysis (see Appendix B of [12]).

A characteristic problem of State accident data files is the vehicle age effect: the injury rates of occupants of older cars are higher than the rates in newer cars and the difference in injury rates exceeds that which could reasonably be attributed to safety standards (see, for example, [16]). Some possible causes for the age effect are discussed in detail in the "Evaluation of Standard 214" [41]. Since the objective is to determine the injury reduction in rear impacts that is due to head restraints, it is necessary to identify and remove or compensate for age effects that cause pre-standard (older) cars to have higher injury rates than post-standard (newer) cars.

The first step in removing age effects is to limit the analysis to a relatively narrow range of model years. Cars of model year 1964 and earlier were removed and the study was limited to model years 1965-72, i.e., cars ranging from 0 to 7 years old. Further reductions in the span of model years would have serously downgraded the statistical precision of the results.

The 1972 Texas file contains 63,645 passenger cars of model years 1965-72 that were struck in the rear; 4306 of the drivers were injured, 826 sustained K, A or B injury and only 180 suffered fatal or serious (K or A) injury. Table 5-7 shows the injury rates in pre and post-standard cars. Drivers in cars with head restraints had a 27 percent lower injury rate than those in cars without the restraints and they experienced even greater reductions in K+A+B (29%) and K+A (37%) injuries.

TABLE 5-7

DRIVER INJURY RATES IN REAR IMPACTS OF 1965-72 PASSENGER CARS, BY HEAD RESTRAINT INSTALLATION, TEXAS 1972

	Without Head Restraints	With Head Restraints	Observed Reduction for Head Restraints (%)
N of rear impacts	26,193	37,452	
Percent of drivers injured	8.04	5.88	27
Percent with K, A A or B injury	1.57	1.11	29
Percent with K or A injury	0.36	0.23	37

It is likely, though, that the observed injury reductions are to a significant extent due to age effects that remain in the data even after the pre-1965 cars were removed. Two alternative procedures were developed to control for the remaining age effects and to calculate the injury reduction attributable to head restraints:

(1) Four specific control variables are selected (factors that are confounded with vehicle age and bias injury rates). With the aid of multidimensional contingency table analysis, the pre and post-standard populations are adjusted to have identical distributions on the 4 control variables. The injury reduction is recalculated and since it is not biased by the control variables, it comes closer to measuring the actual effectiveness of head restraints.

(2) The injury reduction in rear impacts is compared to the injury reduction in side impacts. Head restraints have little effect on side impact injury and relatively few improvements in side impact crashworthiness took place during 1965-72. Any difference in the side impact injury rates of pre-Standard 202 cars and head restraint equipped cars can be attributed to "age effects" in the data. Therefore, the extent to which the rear impact injury reduction exceeds the side impact injury reduction is a measure of the effectiveness of head restraints.

5.3.2. Effectiveness based on multidimensional contingency table analysis

The BMDP3F program of multidimensional contingency table analysis can effectively handle 6 dimensions [15]. Two dimensions are needed for the independent and dependent variables: head restraint iinstallation and injury severity. Four dimensions remain available for control variables. The are 4 data elements on the Texas file that immediately come to mind as suitable controls (confounded with vehicle age and correlated with injury):

1. TAD extent of damage [66]: Older cars have more severe crashes.

2. Driver age: Older cars have, on the average, older drivers. Older drivers are prone to whiplash and other injuries.

3. Driver sex: Older cars are more likely to be driven by males. Males are considerably less prone to neck injury females. (Note: this variable creates a bias in the opposite direction).

4. Vehicle weight: During 1965 - 72, cars were getting heavier, on the average. Added vehicle weight reduces injury risk, especially in car-to-car rear-end crashes. This variable is also of interest as a control because integral restraints were installed primarily on lighter cars.

When these 4 control variables are used, BMDP3F has as many dimensions as it can handle. No other potential controls can be considered and it is not necessary to use a sequential procedure to select controls (as in the NCSS analyses for this standard or for Standards 203 and 204 [40]). Instead, it is possible to proceed directly to finding a model (as in the Restraint Systems Evaluation Project [58]).

The continuous variables (Driver Age, Vehicle Weight and TAD severity) are categorized and the 6 way table is analyzed. None of the 4, 5 or 6 way interaction terms is significant for any of the 3 dichotomies of injury (any injury, K+A+B, K+A). Various models comprising 2 and 3 way terms are tested. Table 5-8 shows the models that adequately fit the data ($p > .05$) while maximizing degrees of freedom:

TABLE 5-8

MODELS SELECTED FOR BEST FIT:
6-WAY ANALYSIS OF 1972 TEXAS REAR IMPACTS

I = injury (dichotomized as shown below)
H = head restraint (none, installed)
T = TAD severity (1-2, 3-4, 5-7)
A = Age (up to 29, 30-49, 50+)
S = Sex
V = Vehicle weight (up to 3499, 3500+)

Injury Dichotomy	Selected Model	df	Chi-square	p
Any injury, uninjured	IH, ITS, HTV, HAS, HAV, HSV, TAV, ASV, IA, IV	94	114.7	.07
K+A+B, C + uninjured	IH, ITS, HTV, HAS, HAV, HSV, ASV, IA, IV	102	111.7	.24
K+A, B+C + uninjured	IH, HTV, HAS, HAV, ASV, IT, TS	108	128.8	.08

Let N_{ihtasv} be the cell entries predicted by the models shown in Table 5-8. Then

$$N_{11} = \sum_{t=1}^{3} \sum_{a=1}^{3} \sum_{s=1}^{2} \sum_{v=1}^{2} \left(\frac{N_{11tasv}}{N_{\cdot 1tasv}} N_{\cdot\cdot tasv} \right)$$

is a prediction of the number of rear impact injuries that would have occurred if none of the cars had been equipped with head restraints. Similarly,

$$N_{12} = \sum_{t=1}^{3} \sum_{a=1}^{3} \sum_{s=1}^{2} \sum_{v=1}^{2} \left(\frac{N_{12tasv}}{N_{\cdot 2tasv}} N_{\cdot\cdot tasv} \right)$$

is a prediction of the number of injuries that would have occurred if all of the cars had been equipped with head restraints. The effectiveness of head restraints, after adjusting the pre and post-Standard populations to have identical distributions on the 4 control variables, is

$$E = \frac{N_{11} - N_{12}}{N_{11}}$$

Table 5-9 shows the effectiveness of head restraints at various injury levels. Head restraints, by this analysis procedure, reduced overall injury in rear impacts by 26 percent. They reduced the risk of K, A or B injury by 27 percent and K+A (fatal or serious) injury by 35 percent.

TABLE 5-9

EFFECTIVENESS OF HEAD RESTRAINTS AND CONFIDENCE BOUNDS: MULTIDIMENSIONAL CONTINGENCY TABLE ANALYSIS OF REAR IMPACTS, TEXAS 1972

Type of injury	Effectiveness of Head Restraints (Reduction of Injury Risk - %)	Confidence Bounds*(%) Lower	Upper
Any Injury	26	21	30
K, A or B injury	27	16	36
K or A injury	35	16	49

*One-sided $\alpha = .05$

Empirical confidence bounds for effectiveness are obtained by decomposing the file into systematic random subsamples. For overall and KAB injury reduction, the file is split into tenths. Since there are only 180 K or A injuries on the file, it is split into fifths when these injuries are studied. The models from Table 5-8 are applied to each subfile and the number of injuries N_{11} and N_{12} are predicted for each subfile. Based on the variation of N_{11} and N_{12} from subfile to subfile, it is possible to empirically assess the sampling error of these numbers predicted from the entire file. Finally, confidence bounds for effectiveness are estimated from the sampling error of N_{11} and N_{12}. These confidence bounds (one-sided $\alpha = .05$) are shown in Table 5-9. Since effectiveness E is a ratio estimate, the bounds are not symmetric but are slightly skewed to the left of the point estimate. (The formulas for sampling error and confidence bounds may be found on pp. 22-23 of [12].) It is evident from Table 5-9 that the effectiveness of head restraints is significantly greater than zero at all injury levels and that the estimate of overall injury reduction is quite precise (confidence interval: 21 to 30 percent).

5.3.3 Effectiveness based on comparison of rear and side impact injury rates

A potential shortcoming of the multidimensional contingency table analysis is that it only removes the biases due to the specific control variables introduced in the analysis. It does not remove biases due to other variables or underreporting of accidents involving older cars, except to the extent that these biases are reflected by the distributions of TAD severity, age, sex and vehicle size. So it is possible that the effectiveness estimates are still overstated, because only part of the biases have been removed. Indeed, the effectiveness estimates in Table 5-9 (based on multidimensional contingency table analysis) are only 1 or 2 percent lower than the simple injury reductions calculated from the raw data (Table 5-7). Whereas this does not, by itself, prove that the procedure overstates effectiveness, it would be desirable to check the results with another procedure that removes biases in more of a blanket fashion.

The injury reduction in rear impacts (raw data from Table 5-7) is compared to the analogous reduction in a control group of crashes unaffected by head restraints or any other safety improvements. It is hypothesized that any injury reduction observed in the control group is due to biases in the raw data (and that similar biases exist in the rear impact data). Therefore, the effectiveness of head restraints is equal to the amount that the injury reduction in rear impacts exceeds the analogous reduction in the control group. (See, for example, pp. 158-164 of [40].)

Side impacts are selected to serve as the control group. Side impact injury rates would not be substantially affected by head restraints. Side impacts are less than perfect as a control group. Although they somewhat resemble rear impacts (e.g., mostly urban, daytime accidents) they need not be subject to the same vehicle age-related reporting biases as rear impacts. Also, safety devices (other than head restraints) introduced during 1965-72 may have different benefits in side and rear impacts(see Section 3.5). For example, side door beams (introduced in some 1969-72 models) are designed to be effective primarily in side impacts whereas high penetration resistant windshields (introduced in 1966) may be effective in preventing rebound injuries in rear impacts. Thus, we cannot be certain that the side impact injury rate reduction is the appropriate correction for biases in the rear impact injury rates. Our uncertainty increases as the range of model years under study is widened, since the biases become greater and since there may be further confounding by the effects of other safety devices. These reservations abcut side impacts as a control group for 1965-72 model cars, in part, motivated the additional analyses of Section 5.6.

The side impacted vehicles are extracted from the 1972 Texas file by a procedure exactly analogous to the one for rear impacts, including the assignment of cars to the head restraint equipped or unequipped categories. The drivers involved in the side impacts are tabulated by injury severity and head restraint availability. Three dichotomies of injury severity are used (K+A+B+C, K+A+B, K+A).

The upper portion of Table 5-10 shows that the drivers of cars with head restraints have a 10.37 percent lower injury rate in side impact

TABLE 5-10

EFFECTIVENESS OF HEAD RESTRAINTS AND CONFIDENCE BOUNDS, BASED ON COMPARISON OF REAR AND SIDE IMPACT INJURY RATES

	Type of Injury		
	Any Injury	K, A, or B Injury	K or A Injury
IN SIDE IMPACTS			
Percent of drivers injured			
without head restraints (N=61,722)	8.252	5.01	1.50
with head restraints (N=75,336)	7.396	4.25	1.26
S = Reduction for post-Standard 202 (%)	10.37	15.2	16.0
IN REAR IMPACTS			
Percent of drivers injured			
without head restraints (N=26,193)	8.037	1.57	0.363
with head restraints (N=37,452)	5.877	1.11	0.227
R = Reduction for post-Standard 202(%)	26.87	29.3	37.4
EFFECTIVENESS OF HEAD RESTRAINTS			
Effectiveness = $1 - \frac{1-R}{1-S}$ (%)	18.4	17	26
Lower confidence bound*	13	6	0
Upper confidence bound*	23	26	41

*one-sided α = .05

crashes than the drivers of cars without head restraints. The middle portion of Table 5-10, which recapitulates Table 5-7, shows that in rear impacts, the injury rate with head restraints is 26.87 percent lower than without them. Thus, the injury reduction with head restraints is substantially larger in the rear impacts than in the control group. The effectiveness of head restraints is calculated in the lower section of Table 5-10: it is the amount whereby the rear impact injury reduction exceeds the side impact injury reduction (in relative terms). Thus,

effectiveness = 1 - (1 - .2687/1 - .1037) = 18.4 percent

Similarly, head restraints are found to be responsible for eliminating 17 percent of the K, A or B injuries in rear impacts and 26 percent of the K or A injuries.

The effectiveness estimates generated by this more conservative procedure are 8-10 percent lower than the effectiveness estimates based on the multidimensional contingency table analysis.

The effectiveness estimator used in this procedure is a ratio of ratios of proportions of drivers injured. The sample sizes are generally large. Thus, the Taylor series expansion gives a good approximation to the standard deviation of the estimates [50]. In other words, let

$$N_{ij} = \text{sample size} \qquad p_{ij} = \text{observed proportion of drivers injured} \qquad \left\{ \begin{array}{l} i=1 \text{ rear impact} \\ i=2 \text{ side impact} \\ \\ j=1 \text{ no head restraint} \\ j=2 \text{ head-restraint equipped} \end{array} \right.$$

Define effectiveness $\mathcal{E}$ by

$$\hat{\mathcal{E}} = 1 - \hat{r}$$

where

$$\hat{r} = \frac{p_{12}}{p_{11}} \Big/ \frac{p_{22}}{p_{21}}$$

and the standard deviation of effectiveness,

$$S \cong \hat{r} \left(\frac{1 - p_{11}}{N_{11}\, p_{11}} + \frac{1 - p_{12}}{N_{12}\, p_{12}} + \frac{1 - p_{21}}{N_{21}\, p_{21}} + \frac{1 - p_{22}}{N_{22}\, p_{22}} \right)^{1/2}$$

Since the effectiveness is based on a ratio estimate, the confidence bounds are not symmetric but are skewed to the left. The following equations, although not rigorous, should provide fairly realistic confidence bounds (one-sided $\alpha = .05$). For the lower confidence bound $\mathcal{E}_{\ell}$, solve

$$\frac{\mathcal{E}_{\ell} - \hat{\mathcal{E}}}{\frac{(1-\mathcal{E}_{\ell})}{\hat{r}}\, S} = -1.645$$

For the upper bound $\mathcal{E}_{u}$, solve

$$\frac{\mathcal{E}_{u} - \hat{\mathcal{E}}}{\frac{(1-\mathcal{E}_{u})}{\hat{r}}\, S} = +1.645$$

The lower portion of Table 5-10 displays the confidence bounds associated with each effectiveness. It is evident that the effectiveness of head restraints in reducing overall injury is significantly greater than zero ($\alpha = .05$) and that the estimate of injury reduction is quite precise (confidence interval: 13 to 23 percent). The reduction of K, A or B injury is also significantly greater than zero (confidence interval: 6 to 26 percent). The estimate of K or A injury reduction "comes close" to significance (confidence interval: 0 to 41 percent).

5.3.4 Summary

The Texas 1972 accident file yields a sample of drivers involved in rear impacts which is of ample size for statistically meaningful results on the effectiveness of head restraints. A key analytic task is to control for biases in the injury rates that result from the pre-Standard cars being older than the post-Standard cars. In addition to removal of the oldest cars, two alternative statistical procedures are used to control for bias: multidimensional contingency table analysis and comparison of rear impacts with a control group (side impacts). The former yielded an effectiveness estimate of 26 percent for head restraints; the latter, 18.4 percent. Based on earlier experiences in applying multidimensional contingency table analysis to police reported data [9], [18], [43], there is cause for concern that this procedure may not fully control for biases and thereby may produce somewhat exaggerated estimates of effectiveness (by contrast, multidimensional contingency table analysis seems to do an excellent job controlling for age biases in investigator-reported towaway files such as NCSS [40], pp. 158-164). The second procedure, on the other hand, may theoretically make insufficient or excessive correction for bias and yield a slight over or underestimate of effectiveness. Good results have been achieved with this procedure when an appropriate control group was used ([40], pp. 158-164 and 197-211; [41] pp.175-178; [9]), but unrealistic resuslts have been obtained in another application [43].

Thus, there is considerable evidence that the first procedure, used with police data, resulted in an overestimate of 26 percent effectiveness. The second procedure resulted in an estimate of 18.4 percent which may or may not contain a bias of unknown direction and magnitude. It would be desirable to perform the analysis with a narrower range of model years and/or eliminate the need for a control group. This, in turn, requires a larger sample. The analyses of the combined 1972, 74 and 77 Texas files, described in Section 5.6, are planned to achieve these goals.

5.4 Analysis of Fatal Accident Reporting System data

In rear impact crashes, nonserious injuries and fatal injuries involve very different mechanisms. In Section 3.3.3, it was shown that the most frequent mechanism, by far, of nonserious injuries was whiplash, which has the potential for alleviation, in many cases, by head restraints. The 28 well-documented fatalities described in Section 3.3.4 rarely involved seatbacks or head restraints. It is evident that the effect of head restraints on fatalities, if any, is unlikely to be the same as the effect on injuries, so it needs to be studied separately. Moreover, we cannot be sure that the effect of head restraints on fatalities, if any, is necessarily beneficial. It is conceivable that a head restraint could prevent hyperextension so severe that it would have caused like-threatening nerve damage. But it is also conceivable that a poorly designed and mispositioned head restraint could give a dangerous "karate chop" to the neck. In short, the expected effect on fatalities is close to zero and if it is nonzero, it might be either positive or negative.

Two data sources are used to study the effect of head restraints on fatalities. This Section contains detailed statistical analyses of the Fatal Accident Reporting System. Section 5.5 is a macroanalysis of the trend in fatal rear-end collisions during 1966-80 as reported in Accident Facts.

The Fatal Accident Reporting System (FARS) contains a virtual census of the fatalities that have occurred since January 1, 1975. As of March 1981, FARS contained over 150,000 passenger car occupant fatalities, versus approximately 900 on NCSS or 2000 in a year of Texas accident data. Given suitable analysis techniques, FARS has the potential to provide more reliable results on fatality reduction than other files. For example, in the "Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies," the estimate of fatality reduction was based on FARS [40].

Head restraints do not have a significant effect on rear impact occupant fatalities, according to the FARS analyses. The analytic procedures and results are described below.

5.4.1 Method

There are some difficulties in using FARS data. Since FARS only contains fatal accidents, it is not possible to compute fatality rates per 100 (fatal or nonfatal) crash involved occupants. So it is not possible to directly compare the occupant fatality rates in crashes of pre and post-Standard cars. Two surrogate procedures are developed.

(1) FARS can be used to compute indirectly the relative fatality risk of pre and post Standard cars: the rear impact fatalities are compared to a control group of deaths unaffected by head restraints. The rear impacts and the control group should be similar except for the effect of Standard 202. The fatalities are then tabulated by pre/post, for the control group and the rear impacts:

FATALITIES	control group	rear impacts
pre-Standard cars	N11	N12
post-Standard cars	N21	N22

The ratio N21/N11 is an indirect measure of the likelihood of post-Standard car fatalities relative to pre-Standard. If Standard 202 had no effect on rear impact fatalities, the expected number of rear impact fatalities in post-Standard cars would be N12(N21/N11). Thus

$$\varepsilon = \left(1 - \frac{N22 \quad N11}{N12 \quad N21}\right) \%$$

is a measure of the effectiveness of head restraints in reducing rear impact fatalities. This is the same general method that was used in the steering column evaluation [40].

Specifically fatality counts for model years 1965-68 (pre-Standard) and 1969-71 (post-Standard) were used. A relatively large number of model years was needed because rear impact fatalities are so infrequent: using only the last pre-Standard and first post-Standard year (as in [40]) would yield counts too small for statistical significance.

Three potential control groups, described below, could be identified for the FARS data elements. The prime control group was passenger fatalities in frontal impacts. This group was, relatively, the least affected by safety improvements during 1965-71 (the high penetration resistant windshield was installed in all years except 1965). Side impact fatalities were second best as a control group because Standard 214 - Side Door Strength - was satisfied by many of the

1969-71 cars and none of the 1965-68 cars. Driver frontal fatalities were not a valid control group because effective energy absorbing steering systems were installed beginning in 1967-68.

The tabulations were based on the 1975-80 FARS data that were on file on March 11, 1981. At that time the 1980 file was approximately 90 percent complete.

Frontal, side and rear impacts are defined according to the "principal impact point" on FARS. For example, rear impacts had a principal impact point of 5-7 o'clock.

A fairly large number of model years (1965-71) was used to guarantee a sufficient number of rear impacts for statistically meaningful results. In turn, this creates a possibility of vehicle age bias (i.e., the oldest pre-Standard cars are 6 years older than the newest post-Standard). In order to check and control for the bias, the simple contingency table analysis described above was supplemented by a regression of rear impact fatality risk by Standard 202 compliance, vehicle age and FARS calendar year. The details of the regression procedure are described in Section 5.4.3.

(2) The approach of Section 5.4.4 uses passenger car registration figures by model year and calendar year to obtain rear impact fatality rates per million car years. The fatality rates of pre and post-Standard cars are compared.

5.4.2 Results of the contingency table analyses

Table 5-11 compares the overall occupant fatalities in rear impacts to the passenger fatalities in frontal impacts. Based on the trend in passenger frontal fatalities, (5646/4982) 791 = 896 rear impact fatalities were expected in the post-Standard cars. In fact, 1018 deaths occurred. This is an increase of 14 percent in rear impact fatalities for the post-Standard cars.

TABLE 5-11

PASSENGER FATALITIES IN FRONTAL IMPACTS AND
OCCUPANT FATALITIES IN REAR IMPACTS OF
1965-71 PASSENGER CARS, FARS 1975-80

	Fatalities	
	Passenger Frontals	Rear Impacts
Model years 1965-68	4982	791
Model years 1969-71	5646	1018

$$\text{Effectiveness of head restraints} = 1 - \frac{1018 \quad 4982}{791 \quad 5646} = -14\%$$

The FARS result is based on combining 6 calendar years of data (1975-80). Each of the individual calendar years of FARS is a subsample of the file that was used. An empirical and conservative method for testing the significance of the observed change in fatality risk is to perform the calculation of effectiveness separately for each of the 6 years of FARS and to examine the variation of the results.

Table 5-12 compares the rear impact and passenger frontal impact fatalities by calendar year of FARS. It is identical to Table 5-11, except the data have been subdivided by calendar year of FARS. The effectiveness of Standard 202 is also calculated for each calendar year. It ranges from -45 percent in 1976 to +16 percent in 1979.

Let $\mathcal{E}_i$ be the effectiveness estimate based on FARS data from calendar year i. Then

$$\bar{\mathcal{E}} = \sum_{i=1975}^{1980} \mathcal{E}_i/6 = -11.5\%$$

$$S = \left(\sum_{i=1975}^{1980} \frac{(\mathcal{E}_i - \bar{\mathcal{E}})^2}{5} \right)^{1/2} = 20.7$$

are the average effectiveness for a year of FARS and its standard deviation (calculated from the sample).

TABLE 5-12

PASSENGER FATALITIES IN FRONTAL IMPACTS AND OCCUPANT FATALITIES IN REAR IMPACTS OF 1965-71 PASSENGER CARS, FARS, BY CALENDAR YEAR

Calendar Year	Model Years	Fatalities Passenger Frontals	Rear Impacts	Observed Effectiveness of Head Restraints (%)
1975	1965-68	1264	201	-3.1
	1969-71	1073	176	
1976	1965-68	1144	144	-45.1
	1969-71	1117	204	
1977	1965-68	869	139	-20.4
	1969-71	1049	202	
1978	1965-68	746	122	-14.3
	1969-71	995	186	
1979	1965-68	576	111	+15.9
	1969-71	802	130	
1980	1965-68	383	74	-1.8
	1969-71	610	120	

Average of effectiveness	-11.5
Standard deviation of effectiveness	20.7
Lower bound for effectiveness	$-11.5 - \frac{2,015}{\sqrt{6}} 20.7 = -29$ percent
Upper bound for effectiveness	$-11.5 + \frac{2.015}{\sqrt{6}} 20.7 = +6$ percent

Let E be the effectiveness of head restraints calculated using 6 years of FARS. Then $(E-\bar{\mathcal{E}})/(s/\sqrt{6})$ is roughly t distributed with 5 degrees of freedom. Thus, a lower confidence bound for effectiveness (one-sided $\alpha = .05$) is given by

$$\bar{\mathcal{E}} - 2.015\ s/\sqrt{6} = -29 \text{ percent}$$

The upper confidence bound for effectiveness is

$$\bar{\mathcal{E}} + 2.015\ s/\sqrt{6} = +6 \text{ percent}$$

The null hypothesis that effectiveness is zero can be tested by computing $\bar{\mathcal{E}}/(s/\sqrt{6}) = -1.36$. Since this quantity is within the acceptance region ($\alpha = .05$) of a t distribution with 5 df, the null hypothesis is accepted. We conclude that head restraints have no effect on fatality risk in rear impact crashes.

The above analysis included all occupant fatalities in rear impacts. But head restraints were only installed in the driver's and right front seat. All occupants were included in the analysis, however, because (1) about 80 percent of them do sit in the driver's or right front seat; (2) possible reservations about the completeness and accuracy of seat position reporting in FARS; (3) although inclusion of the other occupants may change effectiveness results slightly, it should not change the estimate of net benefits.

As a check, however, the calculations were repeated using only the drivers and right front passengers in rear impacts. Table 5-13 is the basic contingency table. Note that rear impact counts are considerably smaller than in Table 5-11. The results, however, are the same as in the preceding analysis: the observed effectiveness of Standard 202 is -14 percent and the confidence bounds for effectiveness (based on year-to-year variation of FARS results) are -28 to +6 percent. Again, the data are consistent with the hypothesis that head restraints have no effect on fatalities.

TABLE 5-13

PASSENGER FATALITIES IN FRONTAL IMPACTS AND DRIVER AND RIGHT-FRONT PASSENGER FATALITIES IN REAR IMPACTS, FARS 1975-80

	Fatalities	
	Passenger Frontals	Driver & RF Rear Impacts
Model years 1965-68	4982	576
Model years 1969-71	5646	741

Effectiveness of head restraints: -14 percent

The results were also checked by using <u>side impact</u> fatalities as the control group. Table 5-14 is the basic contingency table. The results with this control group are slightly less unfavorable for head restraints: the observed effectiveness for Standard 202 is -5 percent and its confidence bounds range from -20 to +12 percent. The data are consistent with the hypothesis that head restraints have no effect on fatalities.

TABLE 5-14

SIDE VS. REAR IMPACT OCCUPANT FATALITIES
IN 1965-71 PASSENGER CARS, FARS 1975-80

	Fatalities	
	Side Impacts	Rear Impacts
Model years 1965-68	8391	797
Model years 1969-71	10255	1025

Effectiveness of head restraints: -5 percent

The most plausible explanation for the less negative result with this control group is that the vehicle age factor has different effects on side and frontal impacts (i.e. older cars and their drivers have a higher ratio of frontal impacts to side impacts than newer cars). The vehicle age regression analyses of the next section support this explanation: they establish almost the same value of Standard 202 effectiveness using either of the 2 control groups.

5.4.3. Results of the regression analyses

The use of 7 model years (1965-71) in the preceding analyses may have resulted in a bias against Standard 202: the post-Standard cars are, on the average, 3.5 years newer than the pre-Standard cars. Newer cars tend to have a higher ratio of (fatal and nonfatal) rear impacts to frontal impacts than old cars - see, for example, Appendix F of [41]. Therefore, a somewhat higher ratio of rear impact fatalities to frontal fatals would also be expected in the post-Standard cars: a spurious "negative" effect for Standard 202.

Multiple regression analysis permits removal of the vehicle age bias. The FARS fatality counts (rear impacts and passenger frontals) are tabulated by model year (1965-71) and calendar year (1975-80). The dependent variable is

$$R = \frac{\text{rear impact fatalities} \times 100}{\text{passenger frontal fatalities} + \text{rear impact fatalities}}$$

for a given model year of cars in a given calendar year. Thus, there are 42 observations of the dependent variable. The independent variables are

H = proportion of cars with head restraints in a given model year (see Table 5-15)

A = vehicle age = calendar year - model year

Y = calendar year - 1975 (added to detect secular trends)

Over the 6 years of FARS data, A ranges from 7-15 for the pre-Standard cars and from 4-11 for the post-Standard cars. In other words, the ranges overlap considerably and A is not confounded with H in a manner that would invalidate the regression. The regression weight factor is

N = passenger frontal fatalities + rear impact fatalities.

TABLE 5-15

PERCENT OF CARS WITH HEAD RESTRAINTS AND SIDE DOOR BEAMS, BY MODEL YEAR, NCSS

Model Year	% with Head Restraints	% with Side Door Beams
1965	0	0
1966	0	0
1967	3	0
1968	12	0
1969	88	23
1970	97	49
1971	100	55

The regression equation which best fits the observed, weighted data points is

$$R = 13.3 + 1.709\ H + .039\ A + .383Y$$

and the multiple correlation coefficient is .39 and df=37. The positive coefficient for H suggests that the observed effectiveness of head restraints is still negative after controlling for vehicle age and calendar year - i.e. cars with head restraints (H=1) have a higher proportion of rear impact fatalities than cars without head restraints (H=0).

The weighted average of R was

$$\overline{R} = 14.734$$

Since about half of the cars in the sample were equipped with head restraints, a good approximation of the observed effectiveness of head restraints is given by

$$1 - \frac{\bar{R} + 1.709/2}{\bar{R} - 1.709/2} = -12 \text{ percent}$$

where 1.709 is the regression coefficient for H.

Thus, after controlling for vehicle age and calendar year, the observed effectiveness is not quite as negative as it was in the simple contingency table analysis (-14 percent).

The standard deviation of the regression coefficient for H is 2.084.

The null hypothesis that the coefficient is zero can be tested by computing t = 1.709/2.084 = 0.82. Since this quantity is within the acceptance region of a t distribution with 37 df, the null hypothesis is accepted. We again conclude that head restraints have no effect on fatality risk in rear impact crashes.

The result was checked by performing an identical regression, except using side impact fatalities instead of passenger frontal fatals in computing R. The observed effectiveness of head restraints, based on this regression is -14 percent, which is nearly identical to the result with passenger frontals. Apparently, by controlling for vehicle age and calendar year, the differences of the control groups (which led to different results in the simple contingency table analyses) were more or less eliminated.

A potential criticism of the above regression using side impacts is that it failed to control for the effect of side door beams (Standard 214) which were installed in many 1969-71 vehicles. The regression should have contained another independent variable.

S = proportion of cars with side door beams in a given model year

The values of S are shown alongside the values of H in Table 5-15. Unfortunately, S and H are exceedingly correlated ($r = .94$), causing a high likelihood of meaningless results if both are entered in the regression. This is exactly what happened: the regression equation had a small negative coefficient for H (suggesting head restraints reduce rear impact fatalities by 6%) and a large positive coefficient for S (suggesting side door beams reduce all types of side impact fatalities by 43% - an absurd result). Obviously, this regression equation is not meaningful and the preceding one (without S) should be used with the understanding that failure to control for side door beams causes a modest bias against Standard 202.

5.4.4 Analysis of rear impact fatalities per million vehicle years

The need for a frontal or side impact control group (and its concommitant potential biases) can be obviated by using a combination of FARS and exposure data. FARS supplies the number of rear impact fatalities by model year and calendar year, for model years 1965-71 and calendar years 1975-80. On p.24 of "MVMA Motor Vehicle Facts and Figures '81" (published by the Motor Vehicle Manufacturers Association, Detroit, 1981), there is a table of the number of cars, by model year, that are still on the road in a given calendar year. With these two sources, it is possible to calculate the fatality risk - the number of rear impact fatalities per million vehicle exposure years. Table 5-16 shows that pre-Standard 202 cars (model years 1965-71) had identical rates of 8.3 rear impact fatalities per million car years during 1975-80. It suggests that head restraints neither increased nor decreased fatality risk.

Empirical confidence bounds for the estimate can obtained by calculating the effectiveness of head restraints separately in each calendar year and observing the year-to-year variation (see Section 5.4.2). The confidence bounds are -16 percent to +16 percent.

TABLE 5-16

REAR IMPACT FATALITY RATES IN

1965-71 PASSENGER CARS DURING 1975-80

	Rear Impact Fatalities	Vehicle Exposure Years (millions)	Fatalities per Million Car Years
Model years 1965-68	797	96.603	8.3
Model years 1969-71	1025	123.850	8.3

The preceding comparison, however, is somewhat biased in favor of Standard 202 because the post-Standard cars are newer and tend to have lower fatality rates. Moreover, the cars with head restraints are more likely to be equipped with other life-saving devices such as energy-absorbing steering columns, which could have had some effect on rear-impact fatality risk. The vehicle age bias is removed by computing fatality rates by model year and calendar year and performing a regression on the rates. The dependent variable is

$$R = \frac{\text{rear impact fatalities} \times 1{,}000{,}000}{\text{registered vehicle years}}$$

for a given model year MY of cars in a given calendar year CY. The independent variables are

H = proportion of cars with head restraints in model year MY (see Table 5-15)

A = vehicle age = CY-MY

CY76 = 1 if CY=76, 0 otherwise

:

:

CY80 = 1 if CY=80, 0 otherwise

The regression weight factor is

N (MY,CY) = registered vehicle years

The regression weight equation which best fits the data is

$$R = 7.88 + .85H - .35A + .035A^2 + .11\ CY76 + .77\ CY77 + .85\ CY78$$
$$-.002\ CY79 - .65\ CY80$$

and the multiple correlation coefficient is .38 with 33 df. The positive coefficient for H suggests that the observed effectiveness of head restraints is negative. The weighted average of R is

$$\bar{R} = 8.44$$

Since about half of the cars in the sample were equipped with head restraints, a good approximation of the observed head restraint effectiveness is given by

$$1 - \frac{R + .85/2}{R - .85/2} = -11 \text{ percent}$$

The standard deviation of the regression coefficient for H is 1.39. The null hypothesis that the coefficient is zero can be tested by computing $t = .85/1.39 = 0.61$. Since this quantity is within the acceptance region of a t distribution with 33 df, we accept the null hypothesis that head restraints had no effect on fatalities. Moreover, the observed negative result of the regression may partly be spurious. The regression contains a bias against head restraints, because the life-saving benefits of other safety devices in rear impacts, if any, are attributed by the regression to vehicle age and tend to exaggerate the true age effect. The regression compensates for a larger age effect by a more unfavorable head restraint effect.

In summary, the analysis of rear impact fatalities per million vehicle years yields nearly the same results as the analyses of rear impact fatalities relative to control groups of fatalities (Sections 5.4.1 - 5.4.3): no significant effect in either direction for Standard 202, with a slight fatality increase observed in some of the analyses.

5.5 The long-term trend in fatal rear-end collisions

The slight (although nonsignificant) increases in fatality risk observed in most of the FARS analyses of Section 5.4 and the concern that has been raised about head restraints as a possible source of serious injury motivate further analysis of fatalities.

If head restraints have caused a truly substantial increase in fatality risk it should be reflected by an increase in the annual number of rear impact fatalities during 1969-80, the years during which the percentage of cars on the road with head restraints grew from 1 to over 90. Of course, a subtle change in fatalities of a few percent would not be revealed by such a gross analysis. But an increase of hundreds of deaths would not remain concealed.

FARS only dates back to 1975. Accident Facts, however, gives annual counts of fatal rear end collisions for 1966-80. The counts include collisions where the fatality is in the striking car as well as collisions involving only trucks, motorcycles, etc. Rear impact fatalities occur in only 1/3 to 1/2 of these accidents. Accident Facts also warns that the counts are not necessarily comparable from year to year. These circumstances should be kept in mind when Table 5-17 is examined. The table shows the annual counts of fatal rear-end collisions for 1966-80, both in absolute terms and as a percentage of fatal multivehicle collisions.

TABLE 5-17

FATAL REAR-END COLLISIONS 1966-80

(Accident Facts)

Year	n of Fatal Rear-End Collisions	N of Fatal Two-Vehicle Collisions	n/N (%)
1966	2400	18,500	13.0
1967	2400	18,800	12.8
1968	2400	18,600	12.9
1969	2200	18,300	12.0
1970	2100	18,100	11.6
1971	2100	18,100	11.6
1972	2200	18,900	11.6
1973	2300	19,700	11.7
1974	1800	16,800	10.7
1975	1900	15,600	12.2
1976	1500	15,900	9.4
1977	1900	17,200	11.0
1978	2400	18,300	13.1
1979	1800	18,200	9.9
1980	2000	17,400	11.5

Table 5-17 shows that fatal rear-end collisions have certainly not increased since head restraints were introduced. In fact, both the absolute number of rear-end fatal accidents and the poroportion of rear end collisions relative to other fatal accidents have declined a little. There are significant negative correlations between the proportion of the fleet with head restraints and the absolute number ($r = -.59$, $p < .05$) and relative proportion ($r = -.53$; $p < .05$) of fatal rear-end collisions - i.e., the more cars with head restraints, the fewer fatal accidents. Of course, the correlation does not necessarily imply that head restraints reduce fatalities, for the reduction could have been due to other safety standards and nonvehicular factors. But, at the very least, head restraints did not substantially increase rear impact fatalities.

5.6 Analysis of 1972, 74 and 77 Texas accident data

Access to Texas State accident files for 1974 and 1977 was established during the analysis of integral versus adjustable restraints (Section 6.3). These files, in combination with the 1972 data, can be used to obtain more reliable estimates of head restraint effectiveness than those based on 1972 data alone (Section 5.3).

5.6.1 Overview and motivation

The analysis of 1972 Texas data, performed by Opportunity Systems, Inc., under contract to NHTSA [12], was restricted for the sake of homogeneity to cars of model years 1965-72. Cars of 1965-68 were called pre-Standard and, of 1969-72, post-Standard. Overall injury rates were computed for drivers involved in rear impacts and side impacts. The injury reduction in side impacts, for 1969-72 cars versus 1965-68, was attributed to vehicle age biases and safety devices other than head restraints. The 18 percent excess of the injury reduction in rear impacts over the reduction in side impacts was attributed to head restraints (see Sections 5.3.1 and 5.3.3).

Two possible criticisms of the preceding analysis are:

(1) Restricting attention to 1965-72 cars is an improvement over using cars of all ages, but the restriction does not go far enough. Eight years is still a substantial age span. Moreover, 1965-72 was the time during which many of the important safety devices other than head restraints were first installed (see Section 3.5).

(2) Side impacts, as a control group, are better than no control group at all, but still leave something to be desired. The vehicle age bias on side impact injury rates is not necessarily the same as on rear impacts. Safety devices other than head restraints may have affected side and rear impact injury rates differently.

The availability of Texas files for 1974 and 1977 makes it possible to overcome these problems. With the combined data file for the 3 years, the sample is large enough for statistically precise injury rates on a single model year of cars. As a result, the rear impact injury rates for 1968 models (pre-Standard) and 1969 models (post-Standard) can be meaningfully compared. With just a one-year difference in the age of the cars, age biases become negligible. Also, the possible confounding effects of safety devices other than head restraints are largely eliminated, since hardly any were introduced in the 1969 model year (see Section 3.5). Therefore, the use of a control group is superfluous and the rear impact injury rates for 1968 and 1969 can be compared directly. This is the analytic approach used in Section 5.6.2.

Another advantage of having accident data from 1972, 74 and 77 is that the pre-Standard cars are no longer of necessity older than the post-Standard cars. The 72 file contains 4-year old pre-Standard cars (model year 1968) and the 77 file contains 8-year old post-Standard cars (model year 1969). Under these circumstances, it becomes possible to compute rear impact injury rates by accident year and model year (1965-72) and to perform a meaningful regression of the injury rates by percent of cars equipped with restraints and vehicle age. The regression finds the average year-to-year drop in injury rates due to vehicle age biases and safety devices, other than head restraints, introduced in 1965-68 and 1970-72. It separates these annual reductions from the one-time effect of head restraints. Thus, instead of using a side impact control group to find the biases, it finds them directly from the rear impact injury rates. This is the analytic approach used in Section 5.6.3.

Finally Section 5.6.4 repeats the analysis with a side impact control group that was performed in Section 5.3.3, but with a difference: thanks to the enlarged sample, the range of model years can be restricted to 1967-68 for pre-Standard and 1969-70 for post-Standard. Cutting the age range in half diminishes the importance of age-related biases and their possible inconsistency between side and rear impacts. It also eliminates the confounding effects of safety devices such as improved windshields (introduced in 1966) and seat belt buzzers (1972) and reduces the confounding from energy absorbing steering systems and seat back locks (mostly introduced in 1967) and side door beams (mostly introduced in 1971-73).

Throughout Section 5.6, the definitions of rear impacts, injuries, etc., are the same as in Section 5.3.

5.6.2 Rear impact injury rates in 1968 versus 1969 models

Table 5-18 shows that drivers of 1969 model cars involved in rear impacts were 8 percent less likely to be injured than drivers of 1968 model cars.

TABLE 5-18
DRIVER INJURY RATES IN REAR IMPACTS OF 1968 AND 1969
PASSENGER CARS, TEXAS 1972, 74 AND 77

	Model Year 1968	Model Year 1969
N of drivers in rear impacts	20,214	23,051
n of drivers injured	1,531	1,605
Injury rate (p)	.0757	.0696

The 8 percent reduction understates the effectiveness of head restraints because many 1968 cars already had the restraints while some

1969 cars did not. Table 5-19 shows the proportions of crash-involved cars with adjustable and integral restraints, by model year. It is based on NCSS data.

TABLE 5-19
HEAD RESTAINT INSTALLATION BY MODEL YEAR,
CRASH-INVOLVED CARS, NCSS

Model Year	Proportion of Cars with		
	Adjustable Restraints	Integral Restraints	No Head Restaints
1965	0	0	1
1966	0	0	1
1967	.02	.01	.97
1968	.06	.06	.88
1969	.81	.07	.12
1970	.80	.17	.03
1971	.68	.32	0
1972	.63	.37	0

Let ε be the actual effectiveness of adjustable restraints and let $r = 1 - \varepsilon$. Let ε_2 be the effectiveness of integral seats relative to adjustable restraints and let $r_2 = 1 - \varepsilon_2$. Let

$$r_1 = \frac{P_{69}}{P_{68}}$$

be the observed injury reduction for 1969 cars relative to 1968.

Based on the distribution of head restraints for 1968 and 1969 cars shown in Table 5-19,

$$r_1 = \frac{.81r + .07r_2r + .12}{.06r + .06r_2r + .88} \qquad (1)$$

From Table 5-18,

$r_1 = .9193$

and from Section 6.3.2,

$r_2 = .927$

Thus

$$.9193 = \frac{.81r + .07(.927)r + .12}{.06r + .06(.927)r + .88}$$

and

$r = .896$

In other words, the overall effectiveness of adjustable restraints is 10.4 percent.

For approximate confidence bounds on this effectiveness, we express r as a statistic of r_1 and r_2:

$$r = \frac{.88r_1 - .12}{.81 + .07r_2 - .06r_1 + .06r_1r_2}$$

The expression is obtained by solving formula (1) for r.

Thanks to the generous sample sizes in Table 5-18, r_1 can be treated as an approximately normal variable with standard deviation

$$S_1 = \hat{r}_1 \left(\frac{1 - p_{68}}{n_{68}} + \frac{1 - p_{69}}{n_{69}} \right)^{1/2} = .0316$$

From Section 6.3.3, r_2 is independent of r_1 and can be treated as approximately normal with standard deviation

$$S_2 = .0304$$

As a result, r has standard deviation

$$S \cong \hat{r}\left(\frac{\text{var}(.88 r_1 - .12)}{(.88 r_1 - .12)^2} + \frac{\text{Var}(.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)}{(.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)^2} - 2\frac{\text{cov}(.88 r_1 - .12,\ .81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)}{(.88 r_1 - .12)(.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)} \right)^{1/2}$$

$$\cong .896 \left(\frac{.88^2 s_1^2}{.4747} + \frac{.07^2 s_2^2 + .06^2 s_1^2 + .06^2 \text{Var}(r_1 r_2) - 2(.07)(.06)\text{cov}(r_2, r_1 r_2) + 2(.06)^2 \text{cov}(r_1, r_1 r_2)}{.5907} + \frac{(.88)(.06) s_1^2 + (.88)(.06)\text{cov}(r_1, r_1 r_2)}{.2648} \right)^{1/2}$$

$$\cong .896 \left(.001478 + .0000146 + .00609\, r_1^2 r_2^2 \left(\frac{s_1^2}{r_1^2} + \frac{s_2^2}{r_2^2} \right) + .0003838 \right)^{1/2}$$

In the preceding formulas, it was assumed that $\mathrm{cov}(r_1, r_1 r_2) = s_1^2 r_2$ and $\mathrm{cov}(r_2, r_1 r_2) = s_2^2 r_1$, which is approximately correct when r_1 and r_2 are close to 1 and s_1, s_2 are small relative to r_1, r_2.

$$s \cong .896 \left(.001884 + (.00442)(.00225)\right)^{1/2} = .0339$$

Although r is a ratio estimate, the small size of s relative to r suggests that the confidence bounds will be nearly symmetric. The lower confidence bound for effectiveness of adjustable restraints

$$\mathcal{E}_\ell \cong 1 - \left(r + 1.645\,s\right) = 4.0 \text{ percent}$$

The upper confidence bound is

$$\mathcal{E}_u \cong 1 - (r - 1.645\,s) \quad = 16.8 \text{ percent}$$

5.6.3 Regression of rear impact injury rates

Let

$$R(MY,CY) = \frac{\text{n of injured drivers in cars of model year MY in accident year CY}}{\text{N of drivers in rear impacts in model year MY, acc. year CY}}$$

The rear impact injury rates R(MY, CY) are expected to drop slightly from one model year to the next, in a given calendar year, as the cars get newer and safety devices other than head restraints are introduced. If head restraints are effective, the rates are expected to drop more substantially in the year that the restraints are introduced in the fleet (primarily 1969). Regression is used to separate the effect of head restraints from the year-to-year effects of age biases on injury risks.

The dependent variable for the regression is R as defined above. An initial list of independent variables is

H_1 = proportion of cars in model year MY with adjustable restraints (see Table 5-19)

H_2 = proportion with integral restraints (see Table 5-19)

A = vehicle age = CY - MY

CY74 = 1 if CY = 74, 0 otherwise

CY77 = 1 if CY = 77, 0 otherwise

(Note that when CY = 72, CY74 = CY77 = 0.)

The regression weight factor is

N (MY, CY) = N of drivers in rear impacts in mod. year MY, acc. year CY

It is necessary to consider the effect of adjustable and integral restraints separately, in one way or another, because integral restraints are significantly more effective (see Section 6.3.2). As a result, during 1970-72, when there was a substantial shift from adjustable to integral (see Table 5-19), injury rates can be expected to drop. If the regression were merely to use the independent variable "head restraints" with no distinction of adjustable and integral, all the injury reduction in model years 1970-72 would be attributed to vehicle age biases, to the detriment of head restraints. The effectiveness of restraints would be underestimated.

On the other hand, it would also be improper to run the regression using directly the above list of independent variables. Since H_1 and H_2 (the proportion of cars with adjustable and integral restraints, respectively) have a fixed relationship in a given model year, they are not really independent variables and any regression using both of them is likelty to produce meaningless results. In fact, the regression using the initial list of independent variables produced a very large effectiveness for adjustable restraints and a large negative effect for integral restraints.

The solution to the dilemma is to develop a regression model which expresses head restraints as a single independent variable but which also contains an externally derived imputation factor for the split between adjustable and integral restraints.

Table 6-4, which was derived independently from this analysis, shows that drivers with integral restraints had an injury rate in rear impacts that is .0053 lower (in absolute terms) than drivers with adjustable restraints. This absolute difference may vary slightly as a function of vehicle age, but may for practical purposes be treated as a constant.

Develop a regression model as follows. Let

R_0 = injury rate for 100% no restraints

R_1 = injury rate for 100% adjustable restraints

R_2 = injury rate for 100% integral restraints

Let the model be

$$R_0 = a_0 + a_1 A + a_2 A^2 + a_3 \ CY74 + a_4 \ CY77$$

$$R_1 = R_0 + a_5$$

$$R_2 = R_1 - .0053$$

where the a_i's are unknown coefficients to be determined by regression. Note, however, that the relationship between R_1 and R_2 is fixed and known, based on the results of Section 6.3.2.

By definition, the population injury rate R(MY,CY) for any given model year and calendar year is

$$\begin{aligned} R(MY,CY) &= H_1 R_1 + H_2 R_2 + (1-H_1-H_2)R_0 \\ &= H_1 (R_0+a_5) + H_2 (R_0 + a_5 - .0053) + (1-H_1-H_2)R_0 \\ &= R_0 + a_5 (H_1 + H_2) - .0053 H_2 \end{aligned}$$

Define a new dependent variable

$$R' = R + .0053\ H_2$$

and a new variable

$$H = H_1 + H_2 = \text{proportion of cars with head restraints}$$

Note that the model

$$\begin{aligned} R' &= R_0 + a_5\ H \\ &= a_0 + a_1\ A + a_2\ A^2 + a_3\ CY74 + a_4\ CY77 + a_5\ H \end{aligned}$$

is well suited for fitting by regression and expresses head restraints in a single variable. Note, however, that the coefficient a_5, by definition, measures the effectiveness of adjustable restraints.

The regression is based on 22 data points: injury rates for model years 1965-72 for Texas 72 and 74 and model years 1967-72 for Texas 77. Model years 1965-66 are not available from Texas 77 because, on the automated file, all cars from model years 1966 and earlier are coded as 66.

The regression equation which best fits the observed weighted data points is

$$R' = .0652 + .00285\ A - .000155\ A^2 + .003CY74 + .0123\ CY77 - .00932\ H$$

and the multiple correlation coefficient is .93 and df = 16. The negative coefficient for H indicates that adjustable restraints reduce injuries.

The effectiveness of adjustable restraints is measured by computing R_0 and R_1 (see above) for the "average" car. The average car is 6.6 years old, according to "MVMA Motor Vehicle Facts and Figures '81," and the mean values of CY74 and CY77 are .37 and .14 respectively. With these average values

$$R_0 = .0801$$

$$R_1 = .0708$$

and the <u>effectiveness of adjustable restraints</u> is

$$\mathcal{E} = 1 - R_1/R_0 = 11.6 \text{ percent}$$

The standard deviation of the regression coefficient for H is .00463. The null hypothesis that this coefficient is zero can be tested by computing t= -.00932/.00463 = -2.01. Since this quantity is within the rejection region (one-sided $\alpha = .05$) of a t distribution with 16 df, the null hypothesis is rejected. The effectiveness of adjustable restraints is significantly greater than zero.

The preceding regression used an externally derived imputation factor for the incremental effect of integral restraints. As a check that this approach is not distorting the results, another regression can be performed without this factor. Let R by the simple injury rate as defined at the beginning of this Section and H, A, CY74 and CY77, as defined above, be the independent variables. The regression model is

$$R = a_0 + a_1 A + a_2 A^2 + a_3 \text{CY74} + a_4 \text{CY77} + a_5 H$$

but in this model, the coefficient a_5 measures the average effectiveness of adjustable and integral restraints, not the effectiveness of adjustable as in the preceding model. This model can be expected to attribute the injury reduction for model years 1970-72 to age effects rather than the shift from adjustable to integral restraints and, as a result, predict a lower effectiveness for restraints. The result of the regression was

$$R = .0628 + .00337A - .000169\ A^2 + .0022\text{CY74} + .0104\ \text{CY77} - .00896\ H$$

and the multiple correlation coefficient was .94 and df = 16. Note that the coefficient for A is larger than in the preceding regression (stronger age effect for the newer cars).

The effectiveness of head restraints in Texas is measured by setting A = 6.6, CY74 = .37, CY77 = .14 (see above) and H = 0 (pre-Standard and 1 (post-Standard)

$$\mathcal{E} = 1 - \frac{.0695}{.0785} = 11.5 \text{ percent}$$

The crash-involved post-Standard vehicle fleet up through model year 1972 was equipped with 75 percent adjustable restraints, 25 percent integral (weighted average of data in Table 5-19). Integral restraints are approximately 7.3 percent more effective than adjustable restraints (see Section 6.3.2). Let $\mathcal{E}'$ be the effectiveness of adjustable restraints that would be needed to produce the $\mathcal{E}$ = 11.5 percent predicted by the regression. Then

$$1 - \mathcal{E} = .885 = .75\ (1 - \mathcal{E}') + .25\ (.927)(1 - \mathcal{E}')$$

$$\mathcal{E}' = 9.9 \text{ percent}$$

In other words, this regression predicts that the effectiveness of adjustable restraints is 9.9 percent. As expected, the effectiveness is slightly lower than in the first regression, which took the shift to integral restraints into account.

The standard deviation of the regression coefficient of H in this regression is .00453. Since $t = -.00896/.00453 = -1.98$ is in the rejection region of a t distribution with 16df, this regression also indicates that the effectiveness of restraints is significantly greater than zero.

As a further check on the results, the regression was rerun on side impact injury rates. The result was

$$R_{side} = .0747 + .00062\ A + .000126\ A^2 - .002\ CY\ 74 + .0021\ CY77 - .00266\ H$$

The equation measures the observed "effect" of head restraints on side impact injuries. When the average values of A, CY74 and CY77 are entered, this effect is

$$\varepsilon = 1 - \frac{.0822}{.0838} = 1.9 \text{ percent}$$

The standard deviation of the coefficient for H is .00361. Since $t = -.00166/.00361 = -0.46$ is well within the acceptance region of a t distribution with 16 df, we accept the null hypothesis that head restraints had no effect on side impact injury rates. This is reassuring, for if the regression had "shown" any substantial "effect" of head restraints on side impacts it would have raised serious doubts about the validity of this technique for rear impacts.

It is interesting to compare the coefficients for A and A^2 in the side and rear impact regressions.

	Coeff. for A	Coeff. for A^2
Rear impacts	.00285	-.000155
Side impacts	.00062	.000126

In rear impacts the escalation of injury rates with increasing age is strong when the cars are new and decreases as the cars get older. This is intuitively reasonable, since drivers of older cars may well be less prone to report whiplash - i.e., the underreport accidents and injuries. In side impacts, the age effect gets stronger with increasing age - property-damage accidents of older cars are underreported, but not injuries. The age effect in side and rear impacts is about the same when

$$.00285 - 2\ (.000155)A = .00062 + 2\ (.000126)\ A$$

$$A = 4 \text{ years}$$

In other words, side impacts make a relatively good control group for cars close to 4 years old but are not a good control group if the cars are either brand new or substantially older than 4 years.

5.6.4 Rear and side impact injury rates in 1967-68 versus 1969-70 models

The discussion of the regression results (Section 5.6.3) indicates that side and rear impact injury rates are subject to roughly similar vehicle age biases when the cars are, say 2-6 years old. In other words, side impact injury rates make a good control group for rear impact injury rates provided that most of the cars are in this age range and there are no excessive biases from safety devices other than head restraints which affect rear and side impact injury risk. Model years 1967-70, to a large extent, satisfy both of these requirements.

Table 5-29 shows that drivers of 1969-70 model cars involved in rear impacts were 15 percent less likely to be injured than drivers of 1967-68 model cars. It also shows that drivers of 1969-70 model cars involved in side impacts were only 6 percent less likely to be injured than drivers of 1967-68 model cars The relative excess of the rear impact injury reduction over the reduction in side impacts is 9.5 percent.

TABLE 5-20

DRIVER INJURY RATES IN REAR AND SIDE IMPACTS
OF 1967-68 AND 1969-70 PASSENGER CARS,
TEXAS 1972, 74 and 77

	Model Years 1967-68	Model Years 1969-70
REAR IMPACTS		
N of drivers	N_{11} = 35,479	N_{12} = 46,580
n of injured drivers	n_{11} = 2758	n_{12} = 3072
injury rate	P_{11} = .07774	P_{12} = .06595
SIDE IMPACTS		
N of drivers	N_{21} = 87,130	N_{22} = 107,102
n of injured drivers	n_{21} = 7139	n_{22} = 8228
injury rate	P_{21} = .08194	P_{22} = .07682

The 9.5 percent relative reduction slightly understates the effectiveness of head restraints because some 1967-68 cars already had the restraints while a few 1969-70 cars did not. Based on Table 5-19, the distribution of restraints was

1967-68: 4% adjustable, 3.5% integral, 92.5% none

1969-70: 80.5% adjustable, 12% integral, 7.5% none

Let ε be the actual effectiveness of adjustable restraints and let $r = 1 - \varepsilon$. Let ε_2 be the effectiveness of integral seats relative to adjustable restraints and let $r_2 = 1 - \varepsilon_2$. Let

$$r_1 = (P_{12}/P_{11})/(P_{22}/P_{21}) = .9048 \qquad \text{(from Table 5-20)}$$

Note that

$$r_1 = \frac{.805r + .12r_2r + .075}{.04r + .035r_2r + .925} = .9048 \qquad (2)$$

From Section 6.3.2, $r_2 = .927$

Thus, $r = .896$

In other words, the overall effectiveness of adjustable restraints is 10.4 percent.

For approximate confidence bounds on this effectiveness, we express r as a statistic of r_1 and r_2:

$$r = \frac{.925r_1 - .075}{.805 + .12r_2 - .04r_1 - .035r_1r_2}$$

The expression is obtained by solving formula (2) for r.

Thanks to the generous sample sizes in Table 5-20, r_1 can be treated as an approximately normal variable with standard deviation

$$S_1 \cong \hat{r}_1 \left(\frac{1-P_{11}}{n_{11}} + \frac{1-P_{12}}{n_{12}} + \frac{1-P_{21}}{n_{21}} + \frac{1-P_{22}}{n_{22}} \right)^{1/2} = .0268$$

From Section 6.3.3, r_2 is independent of r_1, and can be treated as approximately normal with standard deviation

$S_2 = .0304$

As a result, r has standard deviation

$$s \cong \hat{r}\left(\frac{\mathrm{Var}(.925r_1 - .075)}{(.925r_1 - .075)^2} + \frac{\mathrm{Var}(.805 + .12r_2 - .04r_1 - .035r_1r_2)}{(.805 + .12r_2 - .04r_1 - .035r_1r_2)^2}\right.$$

$$\left. - 2\,\frac{\mathrm{cov}(.925r_1 - .075,\ .805 + .12r_2 - .04r_1 - .035r_1r_2)}{(.925r_1 - .075)(.805 + .12r_2 - .04r_1 - .035r_1r_2)}\right)^{1/2}$$

$$= .896\left(\frac{.925^2 s_1^2}{.5806} + \frac{.12^2 s_2^2 + .04^2 s_1^2 + .035^2\,\mathrm{Var}(r_1r_2) - 2(.036)(.12)\,\mathrm{cov}(r_2, r_1r_2) + 2(.04)(.035)\,\mathrm{cov}(r_1, r_1r_2)}{.724}\right.$$

$$\left. + \frac{(.925)(.04)s_1^2 + (.925)(.035)\,\mathrm{cov}(r_1, r_1r_2)}{.3242}\right)^{1/2}$$

Since r_1 and r_2 are approximately normal with mean slightly less than 1 and standard deviations that are small relative to the mean, it is reasonable and conservative to use $\mathrm{cov}(r_1, r_1r_2) \cong s_1^2\hat{r}_2$ and $\mathrm{cov}(r_2, r_1r_2) \cong s_2^2\hat{r}_1$.

$$s \cong .896\left(.001054 + .0000039 + .00169\,r_1^2r_2^2\left[\frac{s_1^2}{r_1^2} + \frac{s_2^2}{r_2^2}\right] + .0001485\right)^{1/2}$$

$$= .896\left(.001247 + .00119(.00195)\right)^{1/2}$$

$$= .0313$$

Although r is a ratio estimate, the small size of s relative to r suggests that the confidence bounds will be nearly symmetric. The lower confidence bound for effectiveness of adjustable restraints

$$\mathcal{E}_l = 1 - (r + 1.645s) = 5.3 \text{ percent}$$

The upper confidence bound

$$\mathcal{E}_u = 1 - (r - 1.645s) = 15.5 \text{ percent}$$

5.6.5 The overall effectiveness of head restraints

The effectiveness estimates developed in Sections 5.6.2 - 5.6.4 were for adjustable restraints. They can be used to obtain estimates for the overall effectiveness of head restraints - the average effectiveness for the fleet of adjustable and integral restraint cars currently on the road - by noting that

- 38 percent of the cars involved in crashes have integral restraints (based on NCSS data).
- The effectiveness ε_2 of integral restraints relative to adjustable restraints is 7.3 percent (see Section 6.3.2).

Let $r_2 = 1 - \varepsilon_2 = .927$. Let ε be the effectiveness of adjustable restraints and let $r = 1 - \varepsilon$. Then ε_c, the overall effectiveness of restraints, is

$$\varepsilon_c = 1 - r_c = (.62 r + .38 r_2 r)$$

The comparison of 1969 and 1968 models (Section 5.6.2) and the comparison with a side impact control group (Section 5.6.4) produced identical effectiveness estimates of 10.4 percent for adjustable restraints - i.e., = .896. From these estimates, the overall effectiveness of head restraints is

ε_c = 12.8 percent

The regression on rear impact injury rates (Section 5.6.3) produced a slightly higher effectiveness estimate of 11.6 percent for adjustable restraints - i.e., r = .884. From this estimate,

$\mathcal{E}_c$ = 14.1 percent

Confidence bounds are obtained, as follows, using the estimate based on the comparison of 1968 and 1969 vehicles:

Recall that

$$r = \frac{.88 r_1 - .12}{.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2}$$

where r_1 was the injury reduction for 1969 models relative to 1968 (refer to Section 5.6.2). Also,

$\hat{r}_1$ = .9193

S_1 = .0216 (the standard deviation of r_1)

$\hat{r}_2$ = .927

S_2 =.0304 (the standard deviation of r_2)

$$r_0 = .62\,r + .38\,r_2\,r$$

$$= (.62 + .38\,r_2)\,r$$

$$= \frac{(.62 + .38\,r_2)(.88\,r_1 - .12)}{.81 + .07\,r_2 - .06\,r_1 - .06\,r_1 r_2}$$

$$= \frac{.546\,r_1 - .074 + .334\,r_1 r_2 - .046\,r_2}{.31 + .07\,r_2 - .06\,r_1 - .06\,r_1 r_2}$$

Its standard deviation

$$S_0 \cong \hat{r}_0 \left(\frac{\mathrm{Var}\,(.546\,r_1 - .074 + .334\,r_1 r_2 - .046\,r_2)}{(.546\,r_1 - .074 + .334\,r_1 r_2 - .046\,r_2)^2} + \frac{\mathrm{Var}\,(.81 + .07\,r_2 - .06\,r_1 - .06\,r_1 r_2)}{(.81 + .07\,r_2 - .06\,r_1 - .06\,r_1 r_2)^2} \right.$$

$$\left. - 2\,\frac{\mathrm{cov}\,(.546\,r_1 - .014 + .334\,r_1 r_2 - .046\,r_2\,,\ .81 + .07\,r_2 - .06\,r_1 - .06\,r_1 r_2)}{(.346\,r_1 - .074 + .334\,r_1 r_2 - .046\,r_2)(.81 + .07\,r_2 - .06\,r_1 - .06\,r_1 r_2)} \right)^{1/2}$$

$$\cong .872 \left(\frac{.546^2 s_1^2 + .334^2\,\mathrm{Var}\,(r_1 r_2) + .046^2 s_2^2 + 2(.546)(.334)\,\mathrm{cov}(r_1\,, r_1 r_2) - 2(.046)(.334)\,\mathrm{cov}\,(r_2\,, r_1 r_2)}{.4488} \right.$$

$$+ \frac{.07^2 s_2^2 + .06^2 s_1^2 + .06^2\,\mathrm{Var}\,(r_1 r_2) + 2(.07)(.06)\,\mathrm{cov}(r_2\,, r_1 r_2) - 2(.06)^2\,\mathrm{cov}\,(r_1\,, r_1 r_2)}{.5407}$$

$$\left. + \frac{(.546)(.06)s_1^2 + (.046)(.07)s_2^2 + [.046(.06) + .334(.07)]\,\mathrm{cov}(r_2\,, r_1 r_2) - [.334(.06) + .546(.06)]\,\mathrm{cov}(r_1\,, r_1 r_2) + (.334)(.06)\,\mathrm{Var}(r_1 r_2)}{.2574} \right)^{1/2}$$

As in preceding sections, the approximations $\mathrm{cov}(r_1, r_1 r_2) \cong \hat{r}_2 s_1^2$ and $\mathrm{cov}(r_2, r_1 r_2) \cong \hat{r}_1 s_2^2$ are used. Also

$$\mathrm{var}(r_1 r_2) \cong \hat{r}_1^2 \hat{r}_2^2 \left(\frac{s_1^2}{r_1^2} + \frac{s_2^2}{r_2^2} \right) = .00164$$

Thus

$$s_c \cong .872 \left(.001769 + .0000245 + .0001627 \right)^{1/2}$$

$$= .0386$$

The small size of s_c relative to r_c suggests that the confidence bounds will be nearly symmetric. The lower confidence bound for overall effectiveness of head restraints

$$\mathcal{E}_{o\ell} \cong 1 - (r_c + 1.645\, s_c) = 6.5 \text{ percent}$$

The upper confidence bound is

$$\mathcal{E}_{ou} \cong 1 - (r_c - 1.645\, s_c) = 19.1 \text{ percent}$$

5.6.6 Summary of findings

Three techniques were used to estimate the injury-reducing effectiveness of adjustable restraints and the overall effectiveness of head restraints (fleet-weighted average for adjustable and integral restraints):

(1) The primary method was based on a direct comparison of rear impact injury rates in 1968 and 1969 models. The results were

- o Adjustable restraints: 10 percent injury reduction (confidence bounds 4 to 17)

- Head restraints overall: 13 percent injury reduction

  (confidence bounds 7 to 19)

(2) Regression on rear impact injury rates by vehicle age and type of head restraint equipped

- Adjustable: 12 percent injury reduction
- Overall: 14 percent injury reduction

(3) Reduction of rear impact injury rates in 1969-70 versus 1967-68 model cars, relative to analogous reduction in side impact injury rates

- Adjustable: 10 percent injury reduction
- Overall: 13 percent injury reduction

CHAPTER 6

EFFECTIVENESS COMPARISONS OF INTEGRAL AND ADJUSTABLE HEAD RESTRAINTS

From the start, there have been two distinct methods of complying with Standard 202: a separate, adjustable restraint attached to the seatback and a fixed restraint which is usually an integral part of the seat. Integral restraints received favorable attention in the early 1970's because they were clearly less expensive (see Sections 4.5 and 7.2) and were felt to be more effective than adjustable restraints. At that time there were no statistical studies to corroborate the claim that they were significantly more effective.

Now, however, the National Crash Severity study and an analysis of 3 years of Texas data both supply the evidence that integral seats are significantly more effective than adjustable restraints. It is important to compare the effectiveness of adjustable and integral restraints, because both systems currently (1980-81) sell in large volumes and the cost differences are substantial.

6.1 Earlier comparative studies

Researchers unanimously stated that integral seats were likely to be more effective than adjustable restraints. The principal reason was that

- Adjustable restraints are left in the "down" position by about 75 percent of the occupants but integral seats are, so to speak, always "up." [31], [32], [46], [54], [61].

Other possible reasons suggested by some researchers were:

* Integral restraints provide a flat, homogeneous seatback surface. Adjustable seats might be shaped in a way that gives a "karate chop" to the neck [54] or causes the head and torso to rebound from the seat at different velocities [62].

* Some adjustable seats have potentially hazardous exposed metal surfaces when they are in the "up" position [54].

Severy, Brink and Baird ran two crash tests (10 and 40 mph) with an adjustable driver's restraint and an integral right front seat, both positioned at the <u>same height</u> [60]. On the 10 mph test, the dummy in the integral seat had substantially less neck rotation because it did not ramp upwards in the seat. The authors concluded that integral seats help to prevent ramping in some cases. This conclusion is not to be found elsewhere in the literature. On the 40 mph test, however, the dummy with the integral restraint actually had slightly greater neck rotation than the other dummy. So it appears that no firm conclusion can be drawn from these two tests about whether integral seats are more effective than correctly positioned adjustable restraints.

All of the statistical studies were inconclusive because of small sample sizes, generally, and because they were conducted before integral seats were common on domestic cars.

When B. O'Neill analyzed insurance data, the cases of integral restraints were virtually confined to Volkswagens [54]. Their occupants had a 7 percent higher risk of whiplash than the other (i.e., adjustable restraint) post-Standard cars. The difference is not statistically significant. Moreover, as O'Neill himself points out, the light weight and stiff rear structure of Volkswagens may have presented a more severe rear impact crash environment than other cars of the 1968-70 era. If so, this would create a bias against integral restraints.

A.J. McLean analyzed data from a special study in 14 North Carolina counties [46]. The occupants with integral seats had a 4 percent lower rate of whiplash than those with adjustable restraints. Since there were only 95 persons with integral seats, the observed difference is not significant.

J.C. Fell's analysis of multidisciplinary accident investigations included a sample of 57 persons occupying integral seats [31]. They had a 20 percent lower incidence of whiplash than occupants with adjustable restraints. The observed difference is not statistically significant.

States and Balcerak reported that incidence of whiplash was lower with integral seats than with adjustable restraints in their Rochester special study [61]. The injury rates are not specified in [61], but with an overall post-Standard sample of 210 and predominantly adjustable restraints, it is reasonable to assume that the whiplash reduction for integral restraints is not statistically significant.

6.2 Analysis of National Crash Severity Study data

The National Crash Severity Study is the only probability sample of rear impacts which specifies, for each vehicle, the type of head restraints. NCSS can be used in a straightforward manner to compare occupants' injury risk with adjustable and integral restraints.

It was shown in Section 5.2 that the NCSS sample did not provide statistically significant results on the overall effectiveness of head restraints, primarily because the sample of pre-Standard cars was so small (see Table 5-4). NCSS does, on the other hand, contain a larger sample of post-Standard cars and it is reasonably well balanced between adjustable and integral seats. As a result, NCSS is large enough to show that integral restraints are significantly more effective than adjustable ones. The confidence bounds on the effectiveness, however, are wide compared to the results based on Texas data (Section 6.3).

J.R. Stewart of the Highway Safety Research Center performed comparisons of adjustable and integral restraints based on NCSS that more or less paralleled his analyses of pre vs. post-Standard cars [63]. These comparisons were reworked in-house for the same reasons that are described in detail in Sections 5.2.1 and 5.2.2. But Stewart's findings are shown alongside the in-house results in Table 6-3.

The remainder of Section 6.2 describes the in-house analyses.

The two alternative restraint designs are compared in terms of three injury rates:

- Any kind of injury
- Neck injury
- Injury resulting in at least overnight hospitalization

These injury criteria are defined in Section 5.2.1.

There are 788 (unweighted) NCSS cases of front outboard occupants of post-Standard cars involved in rear impacts, but they correspond to 4040 weighted cases. Table 6-1 shows the (weighted) NCSS injury rates for adjustable and integral seats. Occupants with integral seats have lower rates of overall injury (9%) and neck injury (15%) but a slightly higher risk of hospitalization.

TABLE 6-1

INJURY RATES IN REAR IMPACTS OF STANDARD 202 CARS, BY HEAD RESTRAINT TYPE, DRIVERS AND RIGHT FRONT PASSENGERS, NCSS

	Adjustable Restraints	Integral Restraints	Observed Reduction for Integral Restraints (%)
N of rear impacts (weighted)	2663	1377	
Percent of occupants injured	51.1	46.5	9
Percent with neck injury*	30.6	25.0	15
Percent hospitalized	2.6	2.7	-5

* Because of missing data, N is reduced to 2477 (adjustable) and 1315 (integral).

There are substantial differences, however, between cars with adjustable and integral seats. Above all, integral seats are far more common in small cars. To a lesser extent, integral seats are characteristic of "sportier" cars - i.e., younger occupants and greater damage severities. Small car size is a strong bias against integral seats: the large, deformable rear structures of big cars protect against whiplash and minor injuries.

Higher damage severity also creates bias against integral seats, but younger occupants, in favor of them.

Thus, although integral and adjustable cars are about equally old and there is no "age effect," a program of multidimensional contingency table analysis is needed to identify and remove biases due to the differences in the two groups of cars.

The modeling process for integral versus adjustable restraints is completely analogous to the one for pre versus post-Standard 202. HSRC's preliminary screening indicated 3 variables that might be significant confounding factors based on their interactions with restraint type and with injury as well as on intuitive grounds: occupant age, vehicle weight and damage severity. Since the ratio of males to females was nearly identical, in NCSS, for adjustable and integral restraints, occupant sex is not a confounding factor. The 3 variables are dichotomized as follows:

- Age: less than 40, 40+
- Vehicle weight: up to 3000 pounds, more than 3000
- Damage extent zones [14]: 1-2, 3-9

The 5 way table of head restraint type, injury and the 3 control variables is analyzed. The 2 way interaction terms are of primary interest. Higher order interaction terms are mostly ignored because the Chi-squares are not that high and there are no intuitive bases for such interactions.

If a control variable does not show significant 2 way interactions with head restraint and with injury risk, it is eliminated from the model, thereby simplifying the tables. The confounding factors that remain at this point are:

- overall injury reduction: vehicle weight, damage severity
- neck injury reduction: occupant age, vehicle weight, damage
- hospitalization reduction: damage severity

The models that were selected contained the interaction of head restraint type and injury risk, plus all significant 2 way interactions. Only those significant 3 and 4 way interactions which could be intuitively justified were included. The chosen models are shown in Table 6-2.

TABLE 6-2

MODELS SELECTED FOR ANALYSIS OF NCSS: INTEGRAL VS. ADJUSTABLE RESTRAINTS

I = injury
H = head restraint type
A = occupant age
W = vehicle weight
D = vehicle damage

Injury Criterion	Selected Model
Any injury	IH, IWD, HW, HD
Neck injury	IH, IAD, IW, HA, HW, HD, AW
Hospitalization	IH, ID, HD

Finally, the effectiveness of integral restraints relative to adjustable restraints is calculated using the cell entries predicted by the model and the effectiveness formulas shown in Section 5.3.2.

Table 6-3 shows that integral restraints are significantly more effective than adjustable ones in preventing injury in general and neck injury in particular. The models suggest that integral seats reduce overall injury risk by 20 percent and neck injury by 25 percent, relative to adjustable restraints.

TABLE 6-3

EFFECTIVENESS OF INTEGRAL SEATS

RELATIVE TO ADJUSTABLE RESTRAINTS, NCSS

Type of Injury	Effectiveness of Integral Relative to Adjustable (Reduction of Injury Risk - %)	Confidence Bounds*(%)		HSRC's Effectiveness Estimate
		Lower	Upper	
Any injury	20	5	33	22
Neck injury	25	2	43	21
Hospitalization	5	-42	44	N/A

*One-sided $\alpha = .05$

Each of the estimates is 10-11 percent more favorable to integral seats than the raw data were (Table 6-1), reflecting primarily the strong bias of vehicle weight against integral seats.

The wide confidence bounds in Table 6-3 suggest, however, that the NCSS point estimates, although significantly greater than zero, cannot be considered precise. The confidence bounds for overall injury reduction using Texas data are only 10 percent wide but in NCSS they are 28 percent wide. Thus, the point estimates from Texas need to be given much more weight than the NCSS point estimates, even though the latter are based on more detailed data. The confidence bounds for the estimates from the two files largely overlap, indicating statistical consistency of the two results.

The confidence bounds in Table 6-3 are empirically derived by the jackknife technique, as in Section 5.2.2 and in [40], pp. 187-193.

The model's point estimate of hospitalization reduction (5%) is of no significance whatever, since the confidence bounds range from -42 to +44 percent.

The NCSS tabulations and analyses used to derive effectiveness and its confidence bounds are documented in Appendix B.

The NCSS analyses support a conclusion that integral restraints are more effective than adjustable ones, but the NCSS sample is too small to indicate clearly how much more effective they are. The next section will provide a reliable effectiveness estimate.

6.3 Analysis of 1972, 74 and 77 Texas accident data

In 1972, 74 and 77, police agencies in Texas investigated a total of 1,370,000 traffic accidents. The samples of rear impacts involving integral and adjustable restraints gleaned from these files are large enough to allow statistically meaningful comparisons of the two systems.

Integral restraints were found to be significantly more effective than adjustable restraints in eliminating injury. The injury reducing effectiveness of integral restraints is 17 percent; for adjustable restraints it is 10 percent.

6.3.1 Method

Injury rates are computed for integral and adjustable restraints using multidimensional contingency table analysis. The procedure is nearly identical to one that was used for comparing head restraints to no restraints in 1972 Texas data (Sections 5.3.1 and 5.3.2).

The 1974 and 1977 Texas data files are nearly identical in their layout and data definitions to the 1972 file. A census of drivers of passenger cars struck in the rear can be drawn from each file. (Section 5.3.1 explains why right-front passengers must be excluded from the study.)

Texas data do not specify the type of head restraints in the vehicle. The assignment of cars to the integral or adjustable restraint class is based on a NCSS look-up table of head restraint installation by make/model and year. Make/model/year combinations in which 80 percent or more of the NCSS case vehicles had integral restraints are assigned to the "integral" class. Combinations for which 80 percent or more of the NCSS vehicles had adjustable restraints are assigned to the "adjustable" class.

Immediately excluded from the analysis are those make/model/year combinations for which

- Many or all of the cars were not equipped with any head restraints
- Between 20 and 80 percent of the cars had integral restraints.
- There were not enough NCSS cases to permit a defensible estimate of the percent of cars with integral restraints.

The above criteria result in an unbalanced file because the overwhelming majority of intermediate and full-size cars are equipped with adjustable restraints. There is not a single model in the larger size groups that had primarily integral restraints from year to year. By contrast, there are many compact and subcompact models that always have had adjustable restraints.

Therefore, all intermediate and full-size cars have been excluded from the study except those models which had 80 percent or more integral restraints in some years and 80 percent or more adjustable in other years.

One of the 3 tapes containing 1977 Texas data could not be used because it had apparently been damaged. As a result, about a third of the cases for that year were lost.

These definitions result in a file of 38,963 passenger cars that were struck in the rear: 21,205 of them are assigned to the "integral restraint" class by the table look-up procedure; 17,758 are assigned to the "adjustable restraint" class. In fact, the integral restraint class includes make/model/year combinations with up to 20 percent adjustable restraints (according to NCSS), so it does not consist purely of integral restraint vehicles. If, however, the NCSS and Texas distributions of restraint types are the same, nearly 96 percent of the cars assigned to this class actually do have integral restraints. Similarly, nearly 97 percent of the cars assigned to the "adjustable restraint" class actually do have adjustable restraints. (The look-up tables and file definitions may be found in Appendix A.)

The distribution of the accidents, by calendar year, is: 10,934 in 1972, 15,888 in 1974 and 12,141 in 1977. Table 6-4 shows the observed driver injury rates for the two restraint systems.

TABLE 6-4

DRIVER INJURY RATES IN REAR IMPACTS
BY HEAD RESTRAINT TYPE, TEXAS 1972, 74 and 77

	Adjustable Restraints	Integral Restraints	Observed Reduction for Integral Restraints (%)
N of rear impacts	17,758	21,205	
Percent of drivers injured	7.85	7.32	6.8
Percent of drivers with K, A or B injury	1.54	1.56	-1
Percent of drivers with K or A injury	0.30	0.26	15

The observed differences between the two systems in the K+A+B and K+A injury rates do not even come close to statistical significance, because of the rarity of these injuries in rear impacts. The available sample size would need to be many times larger for meaningful results. No further analyses are carried out for these rates.

The observed difference of 6.8 percent in the overall injury rates, on the other hand, is significant. The injury rates are suitable for more detailed statistical analyses.

The observed difference of the injury rates may be due, to some extent, to differences in the characteristics of the accidents involving integral and adjustable restraint cars (confounding factors). Multidimensional contingency table analysis, which was one of the techniques used with the 1972 Texas data to remove factors confounding pre-Standard 202 and post-Standard 202 injury rates (see Section 5.3.2) can also be used here.

There is an important reason, however, why multidimensional contingency table analysis should work better here than it did with those data: there is no "age effect" here. Integral and adjustable restraint cars were simultaneously produced during 1969-77 and, on the average, are the same age. (By contrast, the pre-Standard 202 cars are distinctly older than the post-Standard cars.) Thus, age-related reporting differences - a bias that cannot be corrected by multidimensional contingency table analysis - should not appear here.

Another important confounding factor that no longer applies is vehicle size. All intermediate and full-size cars have been removed from the data file except those few models in which both types of restraints were installed in large numbers. Thus, the integral and adjustable restraint cars that remain on the file are, on the average, the same size.

Three control variables that were used in the earlier analysis are also suitable here:

1. TAD extent of damage [66]: The integral restraint cars are involved in accidents of somewhat greater severity, on the average. This is a bias againts integral restraints.

2. Driver age: The drivers of integral restraint cars are somewhat younger. This is a bias <u>in favor of</u> integral restraints.

3. Driver sex: The drivers of integral restraint cars are more often males than the drivers of adjustable restraint cars. This is a bias <u>in favor of</u> integral restraints.

A fourth control variable, not applicable in the earlier analysis, is clearly required here:

4. Accident year: Adjustable restraints were relatively most abundant in 1972, when reported injury rates were lower than in 1974 and 1977 (reason unknown - possibly a change of reporting requirements). This is a bias <u>against</u> integral restraints.

When these 4 control variables are added to the dependent and independent variables (injury and restraint type), the BMDP3F contingency table analysis program has as many dimensions as it can effectively handle. The printouts of the BMDP3F analyses may be found in Appendix A.

6.3.2 Results - integral versus adjustable restraints

The six variables for the analysis are categorized as follows:

I = injury (any injury; no injury)

H = head restraint class (adjustable; integral)

T = TAD severity (1; 2; 3; 4-7)

A = Age (up to 24; 25-39; 40+)

S = Sex (male; female)

Y = Year of accident (1972; 1974; 1977)

The initial analysis of the 6 way table shows that none of the 4, 5 or 6 way interaction terms is significant. Various models comprising 2 and 3 way terms are tested. The model that adequately fits the data ($p > .05$) while maximizing degrees of freedom is

IH, HAS, ASY, ITS, ITY, TAY, HAY, IA, HT

(df = 206, Chi-Square = 216.4, p = .30)

The <u>effectiveness</u> of integral restraints <u>relative to</u> adjustable restraints (using the same formulas as in Section 5.3.2) is derived as follows:

Let N_{ihtasy} be the cell entries of the 6 way table predicted by the above model. Then

$$N_{11} = \sum_{t=1}^{4} \sum_{a=1}^{3} \sum_{s=1}^{2} \sum_{y=1}^{3} \left(\frac{N_{11tasy}}{N_{.1tasy}} N_{..tasy} \right) = 3060$$

is a prediction of the number of rear impact injuries that *would have* occurred if all of the cars on the file had belonged to the *adjustable* restraint class. Similarly,

$$N_{12} = \sum_{t=1}^{4} \sum_{a=1}^{3} \sum_{s=1}^{2} \sum_{y=1}^{3} \left(\frac{N_{12tasy}}{N_{.2tasy}} N_{..tasy} \right) = 2851$$

is a prediction of the number of injuries that would have occurred if all of the cars had belonged to the *integral* restraint class. The *effectiveness* of the integral restraint class *relative to* the adjustable restraint class is

$$E = \frac{N_{.1} - N_{.2}}{N_{.1}} = \frac{3060 - 2851}{3060} = 6.8\%$$

In other words, the model predicts that if all cars belonged to the integral restraint class there would be 6.8 percent fewer driver injuries in rear impacts than if all cars belonged to the adjustable restraint class.

The effectiveness predicted by the model (6.8%) is identical to the injury reduction observed in the raw data. The lack of change is not surprising because two of the control variables (age, sex) are biased in favor of integral restraints while the other two (TAD, accident year) are biased against them. In this analysis there is no "age effect" so there is no reason to suspect strong net bias in one direction.

Empirical confidence bounds for effectiveness are obtained by decomposing the file into 10 systematic random subsamples (as in Section 5.3.2). The same model that was applied to the entire file is applied to each subfile and the predicted injury totals $N_{11}(i)$ and $N_{12}(i)$ are calculated for each subfile by the same formulas that were used to derive N_{11} and N_{12} for the whole file. Table 6-5 shows the predicted injuries for each subfile:

TABLE 6-5

NUMBERS OF INJURIES PREDICTED BY THE MODEL, BY SUBFILE AND RESTRAINT CLASS

Subfile Number (All Cases with Case ID Ending in i)	Predicted Number of Injuries	
	If All Cars in Adjustable Restraint Class $N_{11}(i)$	If All Cars in Integral Restraint Class $N_{12}(i)$
1	293.83	284.97
2	282.72	292.47
3	324.54	278.08
4	337.61	273.96
5	329.95	294.92
6	297.11	277.09
7	296.43	262.52
8	327.43	281.85
9	270.51	278.09
0	299.26	324.08

Since there are 10 subfiles, the predicted number of injuries in each subfile ($N_{11}^{(i)}$ and $N_{12}^{(i)}$) should be approximately one-tenth of the predictions for the whole file (N_{11} and N_{12}). In fact, the variation from subfile to subfile is used to calculate the sampling error for the whole-file effectiveness estimate (See [40], pp. 171-193 and 204-205)

$$\text{Let } X = \sum_{i=0}^{9} N_{11}^{(i)} = 3060.39$$

$$Y = \sum_{i=0}^{9} N_{12}^{(i)} = 2848.03$$

$$S_x = \left(\frac{1}{9}\left[10\sum_{1}^{9} N_{11}^{(i)2} - X^2\right]\right)^{1/2} = 70.49$$

$$S_y = \left(\frac{1}{9}\left[10\sum_{1}^{9} N_{12}^{(i)2} - Y^2\right]\right)^{1/2} = 52.46$$

A <u>lower confidence bound</u> (one-sided $\alpha = .05$) for effectiveness E is obtained by solving

$$-1.833 = \frac{Y - \theta X}{(S_y^2 + (\theta S_x)^2)^{1/2}}$$

$$E_{\ell} = 1 - \theta$$

(where -1.833 is the 5th percentile of a distribution with 9df). In other words, the lower confidence bound for effectiveness of the integral restraint class relative to the adjustible class is 1.7 percent.

The upper confidence bound for effectiveness is obtained by solving

$$+1.833 = \frac{Y - \theta X}{(S_y^2 + (\theta S_x)^2)^{1/2}}$$

$$E_u = 1 - \theta$$

In other words, the upper confidence bound is 11.8 percent.

The null hypothesis that the integral and adjustable classes have the same injury rate can be tested by computing

$$\frac{Y - X}{(S_y^2 + S_x^2)^{1/2}} = -2.42$$

Since -2.42 is in the critical region ($\alpha = .05$) of a t distribution with 9 df, the null hypothesis is rejected. The injury rate in the integral restraint class is significantly lower than in the adjustable class.

The difference between the integral and adjustable restraint class understates the actual effectiveness of integral restraints. This is because the Texas data did not allow a complete segregation of integral and adjustable restraint cars but used a look-up table by make, model and year to assign the vehicles to classes. As a result, 3.06 percent of the cars assigned to the adjustable class actually had integral restraints and 4.05 percent of the cars in the integral class had adjustable restraints. The injury rate for the adjustable class slightly understates the true rate for adjustable restraints. Conversely, the integral class rate overstates the rate for integral restraints. The effectiveness E computed by the model for the class rates can be corrected to obtain the true effectiveness E′ of integral restraints versus adjustable restraints:

$$\frac{.0405 + .9595(1 - E')}{.9694 + .0306(1 - E')} = 1 - E = .932$$

Thus E′, the effectiveness of integral restraints, is 7.3 percent (which is 0.5 percent higher than the E computed by the model).

Similarly, the lower confidence bound E_ℓ' for true integral restraint effectiveness is obtained by solving

$$\frac{.0405 + .9595\,(1-E_\ell')}{.9694 + .0306\,(1-E_\ell')} = 1 - E_\ell = .983$$

$$E_\ell' = 1.8\%$$

The upper confidence bound E_u' is obtained by solving

$$\frac{.0405 + .9595\,(1-E_u')}{.9694 + .0306\,(1-E_u')} = 1 - E_u = .882$$

$$E_u' = 12.7\%$$

6.3.3 Results - integral versus no restraints

At this point it becomes possible to calculate the effectiveness of integral restraints relative to cars with no head restraints and to place approximate confidence bounds on this effectiveness.

Let $\mathcal{E}$ be the effectiveness of integral restraints relative to no restraints and let $R = 1 - \mathcal{E}$.

As in preceding section, let $E' = 7.3\%$ be the effectiveness of integral restraints relative to adjustable restraints. Now define $r_2 = 1 - E' = .927$.

In Section 5.6.2, we obtained our best estimate of the effectiveness of adjustable restraints relative to no restraints. It was 10.4 percent. Let $r = 1 - .104 = .896$.

The effectiveness of integral restraints relative to no restraints is the combined reduction of integral relative to adjustable and adjustable relative to no restraints:

$$\mathcal{E} = 1 - R = 1 - r_2 r = 1 - (.927)(.896) = 1 - .831 = 16.9 \text{ percent}$$

In order to derive confidence bounds for the effectiveness, it is necessary to recall how the effectiveness of adjustable restraints was measured in Section 5.6.2. The approach was to compare the injury rates in 1969 and 1968 model cars. Let

$$r_1 = \frac{\text{injury rate in 1969 models}}{\text{injury rate in 1968 models}}$$

The 1969 models were equipped with 81 percent adjustable restraints, 7 percent integral restraints and 12 percent no head restraints. The 1968 models had 6 percent adjustable, 6 percent integral, 88 percent no restraints. Therefore

$$r_1 = \frac{.81 r + .07 R + .12}{.06 r + .06 R + .88}$$

Since $R = rr_2$, $r = R/r_2$. Thus

$$r_1 = \frac{.81 R/r_2 + .07 R + .12}{.06 R/r_2 + .06 R + .88}$$

When this equation is solved for R, we obtain

$$R = \frac{.88 r_1 r_2 - .12 r_2}{.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2}$$

In Section 5.6.2, it was shown that r_1 is approximately normal with mean and standard deviation:

$$\hat{r}_1 = .9193$$

$$S_1 = .0316$$

In Section 6.3.2, it was shown that r_2 was close to a ratio of two t distributions Y and X, each of which had 9 df. (Recall that Y was the expected number of injuries with integral restraints, X with adjustable restraints). From Section 6.3.2,

$$\hat{Y} = 2848$$

$$S_y = 52.46$$

$$\hat{X} = 3060$$

$$S_x = 70.49$$

Since X and Y have very small coefficients of variation, it is not unreasonable to treat r_2 as a normal variate with mean and standard deviation

$$\hat{r}_2 = .927$$

$$S_2 = \frac{1.833}{1.645} \hat{r}_2 \left(\frac{S_y^2}{\hat{Y}^2} + \frac{S_x^2}{\hat{X}^2} \right)^{1/2} = .0304$$

where 1.833 is the 95th percentile of t (df = 9) and 1.645 is the 95th percentile of the unit normal distribution.

Thus R can be treated as a statistic of two independently derived normal variates, each of which has been a mean close to 1 and a standard deviation that is small relative to the mean.

The standard deviation S of the effectiveness $\mathcal{E}$ of integral restraints relative to no restraints is approximately

$$S = (\text{var } \mathcal{E})^{1/2} = [\text{Var}(1-R)]^{1/2} = (\text{Var } R)^{1/2}$$

$$\cong \hat{R} \left(\frac{\text{Var}(.88 r_1 r_2 - .12 r_2)}{(.88 r_1 r_2 - .12 r_2)^2} + \frac{\text{Var}(.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)}{(.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)^2} \right.$$

$$\left. - 2 \frac{\text{cov}(.88 r_1 r_2 - .12 r_2 , .81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)}{(.88 r_1 r_2 - .12 r_2)(.81 + .07 r_2 - .06 r_1 - .06 r_1 r_2)} \right)^{1/2}$$

$$\simeq .831 \left(\frac{.88^2 \text{Var}(r_1 r_2) + .12^2 s_2^2 - 2(.88)(.12) \text{cov}(r_1 r_2 , r_2)}{.3857} \right.$$

$$+ \frac{.07^2 s_2^2 + .06^2 s_1^2 + .06^2 \text{Var}(r_1 r_2) + 2(.07)(.06) \text{cov}(r_2 , r_1 r_2) - 2(.06)(.06) \text{cov}(r_1 , r_1 r_2)}{.5907}$$

$$\left. + \frac{(.88)(.06) \text{cov}(r_1 , r_1 r_2) + (.88)(.06) \text{Var}(r_1 r_2) - [.12(.06) + .88(.07)] \text{cov}(r_1 r_2 , r_2) + (.12)(.07) s_2^2}{.2386} \right)^{1/2}$$

Note that

$$\text{Var}(r_1 r_2) \cong \hat{r}_1^2 \hat{r}_2^2 \left(\frac{s_1^2}{r_1^2} + \frac{s_2^2}{r_2^2} \right) \qquad = .00164$$

Also, assume $\mathrm{cov}(r_1, r_2) \cong \hat{r}_2 S_1^2$ and $\mathrm{cov}(r_2, r_1 r_2) \cong \hat{r}_1 S_2^2$, which is approximately correct when r_1, r_2 are independent, normal, with means close to 1 and small standard deviations. Then

$$S \cong .831\ (.002862 + .0000245 + .0003553)^{1/2}$$
$$= .0473$$

The small size of S relative to R suggests that the confidence bounds will be approximately symmetric. The lower confidence bound for the effectiveness of integral restraints relative to no restraints is

$$\mathcal{E}_\ell = 1 - (R + 1.645\ S) = 9.1 \text{ percent}$$

The upper confidence bound is

$$\mathcal{E}_u = 1 - (R - 1.645 S) = 24.7 \text{ percent}$$

6.3.4 Summary

Drivers of cars with integral restraints were found to have a 7.3 percent lower injury risk than drivers of cars with adjustable restraints in comparable rear impact crashes. The injury reduction for adjustable restraints relative to pre-Standard cars is 10.4 percent. This means that integral restraints reduce injury risk by 17 percent relative to pre-Standard cars.

Table 6-6 shows the confidence bounds for these effectiveness estimates.

TABLE 6-6

EFFECTIVENESS OF INTEGRAL AND ADJUSTABLE RESTRAINTS FOR DRIVERS IN REAR IMPACT CRASHES, TEXAS 1972, 74 AND 77

	Effectiveness (Injury Risk Reduction)	Confidence Bounds* for Effectiveness	
		Lower	Upper
	%	%	%
Integral versus no restraint	17	9	25
Adjustable versus no restraint	10	4	17
Integral versus adjustable	7	2	12

*One-sided $\alpha = .05$

CHAPTER 7

THE ACTUAL COSTS AND BENEFITS OF HEAD RESTRAINTS

One of the goals of this evaluation is to estimate the actual cost and actual benefits of head restraints in a manner that allows a fair and meaningful comparison of costs and benefits.

7.1 Objectives

The benefits of head restraints are the injuries that will be prevented annually in highway accidents when all cars are equipped with the types of restraints which were actually installed and used in cars that were on the road in the late 1970's. Many of these restraints, in fact, exceed the minimum height requirements of Standard 202; the above definition includes the "extra" benefits from these restraints. It excludes the "potential" benefits that are "lost" when adjustable restraints are mispositioned by occupants.

By the same logic, costs of head restraints are the average annual costs of the restraints which were actually installed in cars that were on the road during the late 1970's, i.e., in cars that were sold up to the late 1970's. Here, too, we will not differentiate what portion of the cost went for meeting the minimum requirements of Standard 202 and what portion is due to the manufacturer's efforts to provide additional safety, comfort, or improved appearance. In particular, the mix of adjustable and integral restraints that prevailed in cars on the road in the late 1970's is the one that is used for calculating overall cost.

The chapter also calculates the costs and benefit of an all-integral restraint fleet and an all-adjustable fleet. It also contains separate calculations for drivers and right-front passengers.

All costs are estimated in 1981 dollars. It should be noted, though, that the data sources for this evaluation came from various years:

1979 - NASS estimates on the number of injuries in rear impacts (the "base" year)

1981 - cost factors

1978 - NCSS data on the mix of adjustable and integral restraints

1972, 74 and 77 - Texas estimates of effectiveness

1969 - Restraint hardware which was cost-analyzed

Since restraint hardware has changed relatively little over the years, it is believed that the biases due to using data from past years are small.

7.2 The cost of head restraints

7.2.1 Procedure for estimating costs

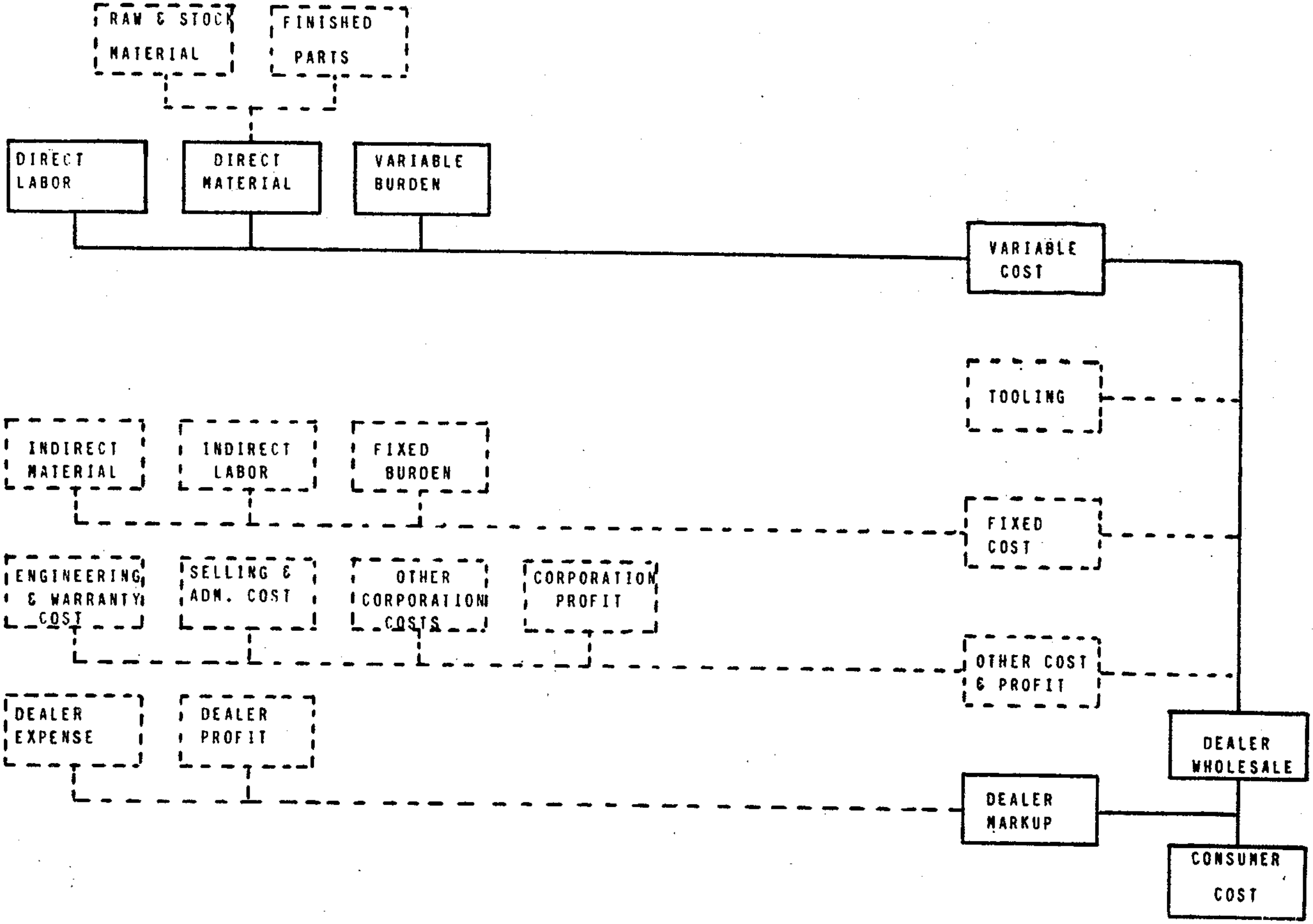
The "cost of head restraints" is defined as the net increase, due to the restraints, in the lifetime cost of owning and operating an automobile. There are two principal sources of increased cost: (1) The consumer price increase due to the addition of head restraints. (2) The lifetime increase in fuel consumption resulting from the incremental weight of head restraints.

A procedure has been developed for estimating the cost and weight of equipment changes in response to NHTSA standards [47]. It was used for estimating the cost of Standard 202 [36]. The procedure is based on component cost estimating techniques that are widely used in the automotive industry. It is illustrated in Figure 7-1.

The vehicle systems relevant to a standard are acquired, torn down and examined for a representative sample of post-standard cars and for corresponding

FIGURE 7-1
ELEMENTS OF CONSUMER COST

(Source: [36])



pre-standard cars. In the case of Standard 202, the only measurable change in the vehicles was the addition of head restraints. Seat reinforcements in pre and post-standard cars were compared and found to be similar. Moreover, since the restraints were essentially "add-on" equipment that had no counterpart in pre-Standard cars, no further detailed teardown of the pre-Standard cars was needed.

The weights, materials, processing and finishing of individual components and the assembly method are established. The type, rough weight and finished weight of material is determined for each detail part, as well as the processing and assembly labor required, the scrap rate, machines and tooling utilized, the production quantity and the amortization period.

These data are first used to calculate the total weight and variable cost of each head restraint in the study sample. As Figure 7-1 shows, the variable cost includes direct material, direct labor and variable burden (see [36], pp. 4-5). Next, the tooling cost per car is determined by dividing the total expense for special tooling by the volume produced during the amortization period ([36], p. 8). The dealer's wholesale cost is determined by adding, to the above, the manufacturer's fixed costs per car (including indirect material and labor and fixed burden, as defined in [36], p. 7); other corporate costs such as engineering, selling and administration; and the manufacturer's profit (p. 8). The percentage amount of manufacturer's markups is determined by taking the corporate average, in recent years, for wholesale price relative to variable cost plus tooling (see [36], p. 6). Finally, dealer markups for expenses and profits are added to the wholesale price to obtain the consumer price. The percentage amount of dealer's markup is based on the overall average ratio of retail to wholesale price for the particular make and model under consideration (see [36], p. 9 and [47], pp. 9-11).

The study sample consisted of adjustable restraints from 11 different 1969 cars, representing all 4 domestic manufacturers and the 3 types of front seats: bench, split bench, and bucket. The cost and weight of the adjustable system includes the head restraint itself and its attachment to the seatback. A sales weighted average was used to determine the overall cost and weight, per car, of adjustable restraints. Figure 7-2 shows the cost and weight for each car in the study sample.

The sample contained a single 1969 car with integral restraints. It was a bucket-seat car and the restraint was the truly integral type -- i.e., a seatback tall enough to meet the height requirements of Standard 202 by itself (see Section 4.3). The cost and weight of this system consisted only of the additional material and labor necessary to provide the increase in seatback height, relative to a corresponding 1968 model.

The study sample did not contain any examples of integral restraints built into bench seats or of "see through" fixed restraints. Neither of these types were featured on domestic vehicles in 1969, the year of the study sample. They have also been relatively uncommon in subsequent years and their omission from the study should hardly bias the estimate of average cost for vehicles <u>currently</u> on the road -- the quantity which is sought in this evaluation. On the other hand, both of these types might become more popular if the proportion of cars with integral restraints were ever to increase substantially. For this reason, the Agency intends to estimate their cost during 1982.

The costs in [36] are expressed in 1979 dollars. They have been inflated to 1981 dollars in this report by the use of the Consumer Price Index for automobiles and parts. This index was 171.9 in 1979 and 202.8 in mid 1981. Thus, the costs are inflated by 202.8/171.9 (or approximately 18 percent).

FIGURE 7-2

HEAD RESTRAINTS SUMMARY OF COMPONENT COST AND WEIGHT DATA

(Source: [36])

Item	Req'd Per Vehicle	Material	Weight	Total Tooling ($000)	COST PER VEHICLE $						
					VARIABLE COST				Whole-sale Cost	Dealer Markup	Consumer Cost
					Material	Labor	Burden	Total			
AMERICAN MOTORS											
1969 RAMBLER AMERICAN 2 DOOR	2	VAR	6.1508	495.	3.5889	1.2165	3.1186	7.9240	10.5968	2.1617	12.7585
CHRYSLER CORPORATION											
1969 PLYMOUTH VALIANT 4 DOOR	2	VAR	13.9838	693.	7.0430	2.6008	7.6037	17.2475	23.0651	4.7053	27.7704
1969 DODGE POLARA 2 DOOR	2	VAR	13.8776	518.	7.3538	2.0812	5.7459	15.1809	20.3014	4.1415	24.4429
FORD MOTOR COMPANY											
1969 FALCON 2 DOOR	2	VAR	10.8604	490.	6.0490	3.2191	8.4233	17.6914	23.6587	4.8264	28.4851
1969 LTD 4 DOOR	2	VAR	10.7446	550.	5.6720	2.4715	5.4060	13.5495	18.1197	3.6964	21.8161
1969 THUNDERBIRD 2 DOOR	2	VAR	8.5670	455.	4.8143	1.9258	4.5847	11.3248	15.1447	3.0895	18.2342
GENERAL MOTORS CORPORATION											
1969 CHEVROLET NOVA 2 DOOR	2	VAR	10.6070	570.	5.2637	2.1731	6.0619	13.4987	18.0518	3.6826	21.7344
1969 PONTIAC TEMPEST 2 DOOR	2	VAR	8.8564	710.	5.4559	1.7020	4.1349	11.2928	15.1019	3.0808	18.1827
1969 PONTIAC FIREBIRD 2 DOOR	2	VAR	9.7392	690.	5.5824	2.1931	4.6834	12.4589	16.6613	3.3989	20.0602
1969 CHEVROLET CORVETTE 2 DOOR	2	VAR	6.7896	445.	3.9031	1.4608	4.2691	9.6330	12.8822	2.6280	15.5102
1969 CADILLAC ELDORADO 2 DOOR	2	VAR	10.9870	520.	6.0548	1.8159	4.9758	12.8465	17.1796	3.5046	20.6842
FORD MOTOR COMPANY (INTEGRAL)											
1969 MUSTANG 2 DOOR	2	VAR	3.7598	155.	2.6115	.2631	.6302	3.5048	[illegible]	.9651	5.6431

7.2.2 Average and total cost

The average incremental price and weight per car of adjustable and integral restraints were found to be the following [36].

- Adjustable: $24.33 and 10.47 pounds (in 1981 dollars)
- Integral: $6.65 and 3.76 pounds

Adjustable restraints are about twice as bulky as integral restraints and require nearly 10 times as much labor to produce [36]. An integral seatback, in most cases, is nothing more than a tall version of a pre-standard seatback. The incremental cost is primarily in the additional layer of material and the incremental labor is negligible. Adjustable restraints, on the other hand, require the fabrication of a separate bulky pad and the installation of metal sockets within the seatback to hold the sliding shaft. The movable metal parts need to be durable and designed to close tolerances. The restraint's bulk is increased because it contains extra padding to prevent occupants from contacting the exposed shaft when the restraint is "up". Furthermore, adjustable restraints are especially common on bench seat cars, where Standard 202 requires a wider - i.e., bulkier - restraint than on bucket seats (see Section 4.2).

Each incremental pound of weight added to a car results in the consumption of an average of 1.1 additional gallons of fuel over the lifetime of the car [17]. The average mid-1981 price of fuel was $1.37 per gallon. Thus, each incremental pound of weight adds $1.51 (in 1981 dollars) to the lifetime consumer cost of operating a car.

In other words, the average lifetime consumer cost, per car, of adjustable and integral head restraints is

- o Adjustable: \$40.14, lifetime per car
- o Integral: \$12.33, lifetime per car

Secondary vehicle weight increases are sometimes needed to compensate for the weight added to certain parts of a car by a safety device. No secondary weight has been assumed for head restraints because their incremental weight appears to be too small (4 - 10 pounds) to require redesign of other vehicle systems. In particular, the cost analysis showed that not even the seats (to which the head restraints were attached) were reinforced or enlarged. It would seem unlikely, then, that subsystems remote from the head restraints were enlarged.

The calendar year sales of passenger cars in the United States during 1969-78 and the percentages and numbers with integral restraints are shown in Table 7-1. The percentages by model year were derived from NCSS in Section 4.5. The percentage for calendar year N is derived by the formula

$$CY_N = .75\ MY_N + .25\ MY_{N+1}$$

(For calendar year 1978, the percentage for model year 1978 was used.)

TABLE 7-1

PASSENGER CAR SALES BY YEAR AND PERCENT OF CARS WITH INTEGRAL RESTRAINTS, UNITED STATES, 1969-78

Calendar Year	Sales[1]	Percent with Integral Restraints[3]	Number with Integral Restraints
1969	9,441,000[2]	11	1,039,000
1970	8,397,000	20	1,679,000
1971	10,234,000	30	3,070,000
1972	10,935,000	34	3,718,000
1973	11,427,000	34	3,885,000
1974	8,851,000	34	3,009,000
1975	8,628,000	37	3,192,000
1976	10,100,000	31	3,131,000
1977	11,179,000	28	3,130,000
1978	11,304,000	22	2,487,000
10 YEAR TOTAL	100,496,000		28,340,000

[1] Based on "Automotive News 1980 Market Data Book," [8], except 1969

[2] Based on 1970 Ward's Almanac [67].

[3] Derived from NCSS

Table 7-1 shows that just over 28 percent of the cars sold during 1969-78 had integral restraints. Since almost exactly 10 million cars were sold per year, the annual average cost of head restraints was:

Annual cost = 10,000,000 x (.28 x \$12.33 + .72 x \$40.14)

- Annual average cost of head restraints: \$324 million (1981 dollars)

If all cars were equipped with integral restraints, the cost would be

- Annual cost for 100% integral restraints: \$123 million

For adjustable restraints, it would be

- Annual cost for 100% adjustable restraints: \$401 million

The estimate of \$32 per car derived for this evaluation is comparable to the cost estimate of \$19 per car (in 1974 dollars) contained in the General Accounting Office's report on the "Effectiveness, Benefits and Costs of Federal Safety Standards for Protection of Passenger Car Occupants" [18]. Their estimate was based on an average of quotations supplied by the vehicle manufacturers. Based on the Consumer Price Index for automobiles and parts, vehicle manufacturing costs escalated by about 70 percent from 1974 to 1981. Thus, \$19 in 1974 dollars corresponds to \$32 in 1981 dollars. The GAO's figure, however, excludes lifetime fuel costs but includes the cost of compliance with Standard 207 - Seating Systems. Since the Agency estimates that the compliance cost for Standard 207 is \$8 [36] and the lifetime fuel cost for head restraints is \$13 (weighted average of adjustable and integral), the GAO's estimate based on manufacturers' quotes translates to \$37. In other words, it is about \$5 higher than the Agency's estimate.

7.3 The benefits of head restraints

The actual benefits of head restraints are defined to be the casualities that will be prevented annually, by the types of restraints currently on the road, when all passenger cars are equipped with them (see Section 7.1)

The casualties prevented by head restraints are nonfatal injuries - viz., whiplash. Based on the FARS analysis (Section 5.4), the long-term fatality trends (Section 5.5), consideration of head restraint designs (Section 4.3) and case histories of rear impact fatalities (Section 3.3.4), it is not reasonable to claim that head restraints significantly affect fatalities. There is also little evidence that head restraints had a substantial effect on life-threatening injuries: neither the reductions of hospitalizing injuries (Section 5.2.2) nor K + A injuries (5.3.3) were statistically significant and the reductions that were observed were probably due to the effects of other safety improvements on injury mechanisms besides whiplash.

Thus, the benefits of head restraints are expressed by a single number: the number of nonfatal (mostly minor) injuries prevented.

The benefits B equal the number of injuries N that would have occurred in 1979 if <u>no</u> cars were equipped with head restraints, multiplied by the overall injury-reducing effectiveness of head restraints.

$$B = N\varepsilon$$

A best estimate of benefits and its confidence bounds will now be derived.

From Section 3.1.2, based on NASS data,

$$\hat{N} = 501{,}763$$

injuries would have occurred in 1979 if no cars had been equipped with head restraints. From Section 5.6.5 based on 1972, 74 and 77 Texas data,

$$\hat{\varepsilon} = 12.8\%$$

is the overall effectiveness of head restraints. Thus,

Benefits $= \hat{B} = \hat{N}\hat{\varepsilon} = 64{,}226$ injuries prevented annually if all cars had head restraints.

For confidence bounds on this estimate, recall that in Section 3.1.2 the standard deviation of N was

$$S_N = 73{,}914$$

and in Section 5.6.5 the standard deviation of ε was

$$S_\varepsilon = 3.86$$

The benefits B are the product of N and . Normal approximations will be used in deriving the confidence bounds for B. But in Section 3.1.2, N was, for all practical purposes, derived from a t distribution with 9 df. If N is to be treated as a normal variate, it is prudent to inflate S_N prior to using it in calculations -- i.e., use

$$S_N' = \frac{1.833}{1.645} s_N = 82{,}361$$

where 1.833 is the 95th percentile of t (df = 9) and 1.645 is the 95th percentile of the unit normal distribution.

Thus, it is possible to treat N and ε as normal variates with means $\hat{N}$ and $\hat{\varepsilon}$ and standard deviations S_N' and S_ε . Strictly speaking, N and ε are not independent: the deviation of N in Section 3.1.2 used NASS data to determine the current number of injuries X and then inflated X by $.147 + .853/(1- \varepsilon)$ to compensate for injuries already eliminated by head restraints. Recall, however, that 95 percent of the variance in N derived from X and 5 percent from the inflation factor involving ε.

As a result, N and ε are nearly uncorrelated and can be treated as independent normal variables. Thus

$$s_B \cong \hat{B}\left[(s_N/\hat{N})^2 + (s_\varepsilon/\hat{\varepsilon})^2\right]^{1/2}$$

$$= 64{,}226\ [.0269 + .0909]^{1/2}$$

$$= 22{,}044$$

is the standard deviation of B.

Even though the benefits are based on a product of two positive numbers, the confidence bounds will be nearly symmetric because the relative variance of ε (.0909) dominates the relative variance of N (.0269)

A lower confidence bound (one-sided $\alpha = .05$) for the overall annual benefits of head restraints is given by

$$B_l \cong \hat{B} - 1.645\, s_B = 27{,}963 \text{ injuries prevented}$$

The upper bound is

$$B_u \cong \hat{B} + 1.645\, s_B = 100{,}489 \text{ injuries prevented}$$

For integral restraints relative to no restraints, the effectiveness

$$\hat{\varepsilon}_I = 16.9\%$$

with standard deviation

$$s_I = 4.73$$

(see Section 6.3.3).

If all cars were equipped with integral restraints, there would be

$$\hat{B}_I = \hat{N}\,\hat{\mathcal{E}}_I = 84{,}798$$ injuries prevented annually.

Since the standard deviation of this estimate

$$s_{BI} \cong \hat{B}_I \left[(s_N' / \hat{N})^2 + (s_I / \hat{\mathcal{E}}_I)^2 \right]^{1/2} = 84{,}798 \left[.0264 + .0783 \right]^{1/2}$$

$$= 27{,}504$$

the lower bound for the benefits of a fleet of 100 percent integral restraints is

$$B_{\ell I} \cong \hat{B}_I - 1.645\, s_{BI}$$

$= 39{,}553$ injuries prevented annually

and the upper bound is

$$B_{uI} \cong \hat{B}_I + 1.645\, s_{BI} = 130{,}043$$ injuries prevented annually

Similarly, for adjustable restraints, the effectiveness is

$$\hat{\mathcal{E}}_A = 10.4\%$$

with standard deviation

$$s_A = 3.89$$

(see Section 5.6.2).

If all cars were equipped with adjustable restraints (with their current mix of properly positioned and mispositioned restraints) there would be

$$\hat{B}_A = \hat{N}\,\hat{\varepsilon}_A = 52{,}183 \text{ injuries prevented annually.}$$

Since the standard deviation of this estimate

$$s_{BA} \cong \hat{B}_A\left[(s'_N/\hat{N})^2 + (s_A/\hat{\varepsilon}_A)^2\right]^{1/2} = 52{,}183\left[.0269 + .1399\right]^{1/2}$$

$$= 21{,}312$$

the lower bound for benefits of a fleet of 100 percent adjustable restraints is

$$B_{\ell A} \cong 17{,}124 \text{ injuries prevented annually}$$

and the upper bound is

$$B_{uA} \cong 87{,}242 \text{ injuries prevented annually}$$

The benefits of head restraints may be further classified by seat position. There is no evidence from NCSS or other files to indicate that drivers and right front passengers differ in regard to rear impact injury proneness or head restraint effectiveness (see pp. 3-9 - 3-13 of [63]). Therefore it can be assumed that the benefits for drivers and right front passengers are in the same proportion as the number of crash involved occupants in the two positions. On the full NCSS passenger car file, 74.6 percent of the front outboard occupants were drivers and 25.4 percent sat in the right front seat ([59], p. 54).

Thus, the overall benefits for drivers are

$\hat{B}$ drivers = .746 $\hat{B}$ = 47,913 injuries prevented annually and for the right front passengers they are

$$\hat{B}_{RF} = .254\,\hat{B} = 16{,}313 \text{ injuries prevented annually}$$

The same proportions are applied to the confidence bounds B_ℓ and B_u to obtain interval estimates for each seat position as well as estimates, by seat position, for an all-integral or all-adjustable restraint fleet.

Table 7-2 gives a full classification of benefits - best estimate and confidence bounds - by restraint type and seat positions.

Another statistic of interest is the benefit of replacing the post-standard passenger car fleet with the current mix of integral, properly positioned and mispositioned adjustable restraints by another fleet of exclusively integral restraints. For a best estimate of these benefits, merely take the difference of the best estimates of overall benefits (current mix) and benefits of 100% integral restraints.

$$\text{Benefits} = \hat{B}_I - \hat{B} = \hat{N}(\hat{\varepsilon}_I - \hat{\varepsilon}) = 84{,}798 - 64{,}226$$

$$= 20{,}572 \text{ additional injuries prevented}$$

For an confidence bounds, note that only the 62 percent of crash involved vehicles currently equipped with adjustable restraints would be affected (see Section 6.3.3). Let

$$\hat{N}_A = .62\hat{N} = 311{,}093$$

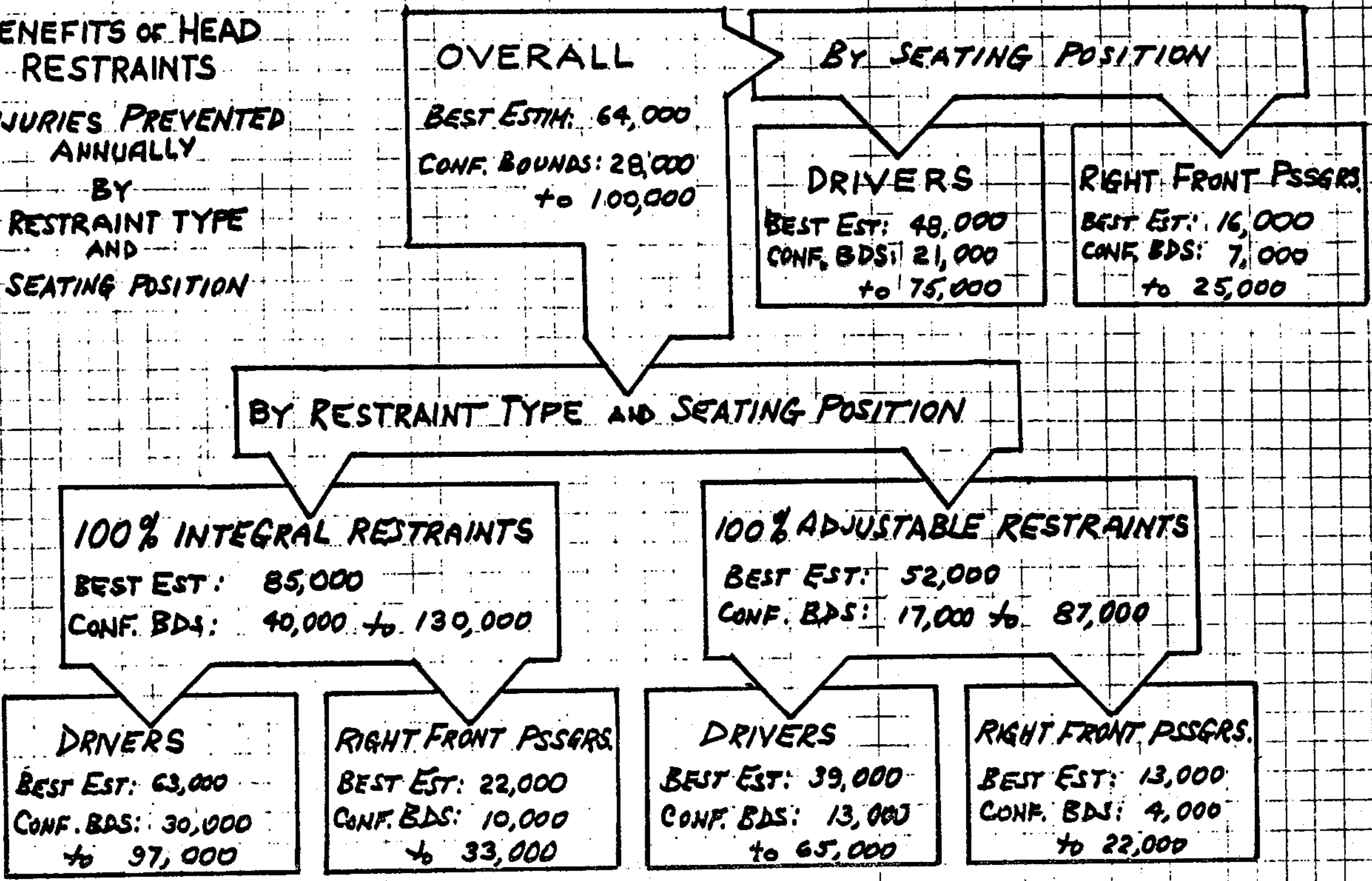
$$S'_{NA} = .62s'_N = 51{,}064$$

These vehicles are already receiving the benefits of adjustable restraints. Thus, N_A is already diminished by $1 - \varepsilon_A$. If E is the effectiveness

TABLE 7-2

BENEFITS OF HEAD RESTRAINTS

INJURIES PREVENTED
ANNUALLY
BY
RESTRAINT TYPE
AND
SEATING POSITION



of integral restraints <u>relative</u> to adjustable restraints then

$$\text{Benefits} = \hat{N}_A \; (1 - \hat{\varepsilon}_A)\,\hat{E}$$

Thus, benefits can be treated as the product of three more or less uncorrelated, normal variates. From Section 6.3.3,

$\hat{E} = 7.3\%$ (effectiveness of integral relative to adjustable)

$S'_E = 3.04$ (inflated to treat E as normal)

Therefore

$$S_{\text{Benefits}} \cong \text{Benefits}\left[\left(\frac{S'_{NA}}{\hat{N}_A}\right)^2 + \left(\frac{S_A}{1-\hat{\varepsilon}_A}\right)^2 + \left(\frac{S'_E}{\hat{E}}\right)^2\right]^{1/2}$$

$$= 20{,}572\left[\left(\frac{51{,}064}{311{,}093}\right)^2 + \left(\frac{3.89}{89.6}\right)^2 + \left(\frac{3.04}{7.3}\right)^2\right]^{1/2}$$

$$= 20{,}572\,[.0269 + .0019 + .1734]^{1/2}$$

$$= 9251$$

Since the relative variance of the third term in the product (.1734) greatly dominates the other two terms, the product of the three variables is close to a normal distribution. As a result, in this case, 1.645 standard deviations on either side provide fairly realistic confidence bounds.

A lower confidence bound for the incremental benefits of changing to an all-integral fleet is given by

$$\text{Benefits} - 1.645\, s_{\text{Benefits}} = 5{,}354 \text{ additional injuries prevented.}$$

The upper bound is

$$\text{Benefits} + 1.645 s_{\text{Benefits}} = 35{,}790 \text{ additional injuries prevented}$$

7.4 Cost-effectiveness

The cost-effectiveness of head restraints is expressed in this evaluation as the number of injuries eliminated per million dollars of cost. Since, overall, head restraints eliminate an estimated 64,226 injuries per year (when all cars comply - see Section 7.3) and cost $324 million per year (see Section 7.2), the cost-effectiveness is

$$(64{,}226/324) = 200 \text{ injuries eliminated per million dollars}$$

The confidence bounds for benefits (see Section 7.3 - one-sided $\alpha = .05$) were 27,963-100,489 injuries prevented annually. Thus, a lower confidence bound for cost-effectiveness is

$$(27{,}963/324) = 90 \text{ injuries eliminated per million dollars}$$

The upper bound is

$$(100{,}489/324) = 310 \text{ injuries eliminated per million dollars}$$

In the two preceding sections, costs and benefits were also calculated for a hypothetical fleet of 100 percent integral restraints and another fleet of all adjustable restraints. It is thus possible to calculate the cost-effectiveness of integral and adjustable restraints. Also, in Table 7-2, benefits were tabulated separately for the driver's and right front seats. Since the restraints at the two seat positions are identical, each one could be said to cost half of the total. Cost-effectiveness of head restraints at a given seat position, therefore, is the benefit shown in Table 7-2 divided by half of the total cost.

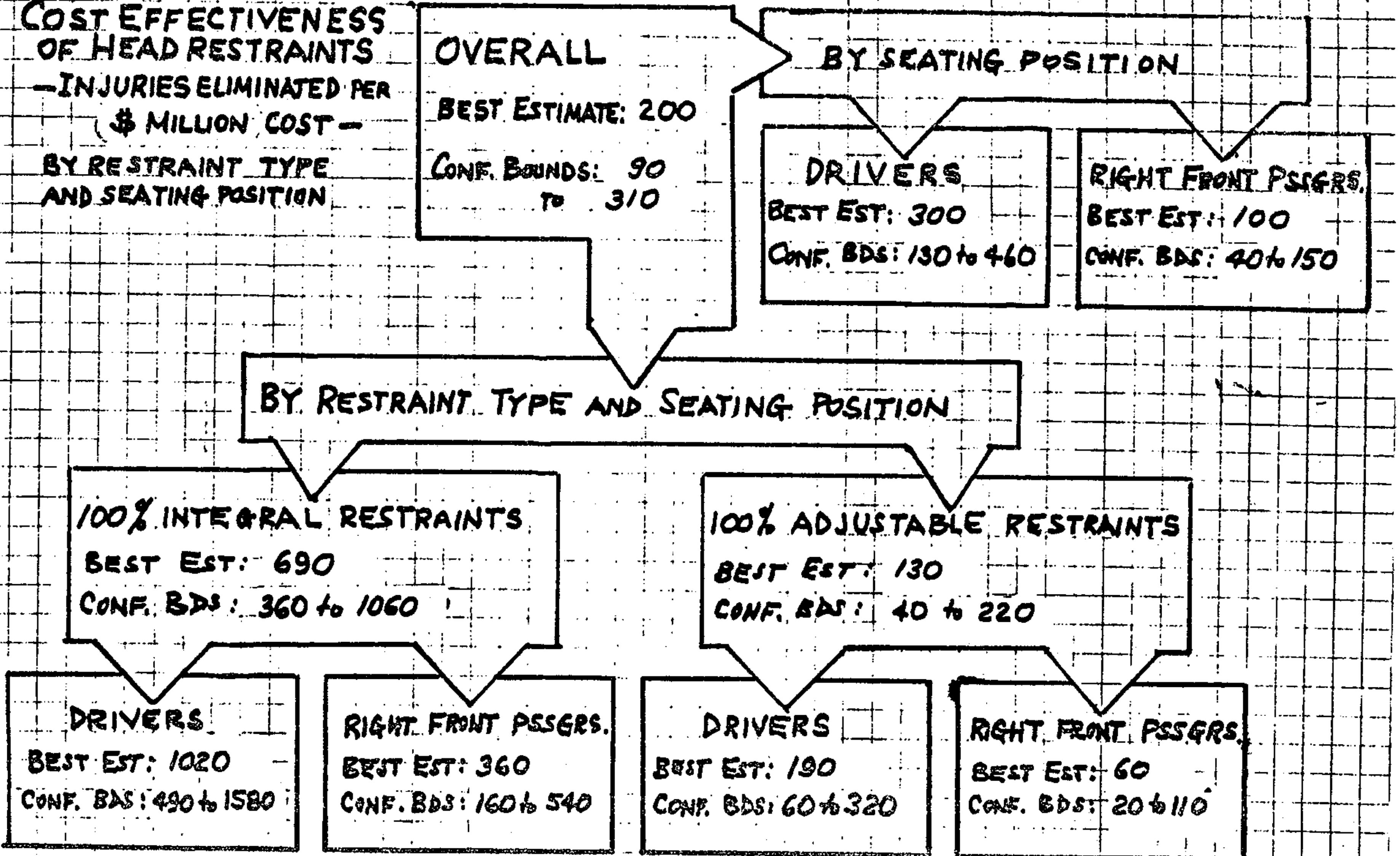
Note, however, that the cost-effectiveness by seat position, as defined above, is not exactly the same as the cost-effectiveness that would occur if only one seat position were equipped with restraints. In the latter situation, half of the variable costs and the fuel penalty would be saved, but not half of the (relatively small) fixed costs. The cost of one head restraint would be slightly greater than half of the total and the cost-effectiveness slightly lower.

Table 7-3 shows the cost-effectiveness estimates and their confidence bounds by restraint type and seat position.

Large variations in cost-effectiveness are evident from Table 7.3. At the one extreme are integral drivers' seats, which eliminate 1,020 injuries per million dollars of cost. At the other extreme is the right front passenger's adjustable restraint which eliminates 60 injuries per million dollars. This is a 17 to 1 ratio of cost-effectiveness. In general, integral restraints are about 5 times as cost-effective as adjustable restraints because they deliver about 60 percent higher benefits at 70 percent lower cost. Driver's restraints

TABLE 7-3

COST EFFECTIVENESS OF HEAD RESTRAINTS
—INJURIES ELIMINATED PER $ MILLION COST—
BY RESTRAINT TYPE AND SEATING POSITION



are nearly 3 times as cost-effective as passenger's restraints because of the difference in occupancy rates.

The cost-effectiveness findings beg an obvious question:

o What is a "reasonable" cost to pay to avoid whiplash and how does it compare to the cost of head restraints per injury eliminated?

Whiplash is a type of injury that usually results in quantifiable economic losses: the losses occur over a limited time period (almost always less than a year; usually much less) and the victim can be given full restitution for them. Whiplash hardly ever endangers life or causes permanent disability (economic losses that are harder to quantify). In addition to economic losses, however, whiplash causes pain and suffering which, although of limited duration, is not a directly quantifiable loss.

Therefore, it seems that a "reasonable cost of avoiding whiplash" can be expressed in absolute terms. But the cost should be expressed as a range rather than a single figure because the pain-and-suffering portion of the losses is only indirectly quantified.

The lower end of the range is based on analysis of the economic losses due to whiplash and does not include any valuation for pain and suffering. The upper end of the range is based on actual liability insurance payments to victims of whiplash which include compensation for pain and suffering.

In 1975 B. Faigin estimated that the average societal losses for a minor (AIS 1) injury were $435. The figure excludes pain and suffering but includes the victim's direct losses (medical expense and absence from work) and a prorating of insurance administration, legal costs and a few other indirect costs [19]. A. F. Seila's analysis of injury costs in connection with the Restraint Systems Evaluation Project showed that the average direct losses for "pain" injuries - predominantly whiplash - were within $2 of the average for all minor injuries (see [35], pp. 68-71). Likewise, an analysis of National Crash Severity Study data on days of bed rest, activity restriction and absence from work reveals little difference between nonserious rear impact casualties and other crash victims who were not seriously injured. Thus, B. Faigin's estimate of $435 in societal losses for all kinds of minor injuries also appears to be a good estimate of direct losses for whiplash in 1975. The Gross National Product deflator index was 125.5 in 1975 and 193.3 in 1981. The 1975 costs can be inflated to 1981 societal costs by multiplying by 193.3/125.5. As a result, the 1975 estimate corresponds to $670 in 1981 dollars - a lower bound for the price worth paying to avoid whiplash.

An extensive survey of liability claims payments during late 1977 was performed by the All-Industry Research Advisory Council [7]. The average payment for "neck strain" was $1499 which included $891 for "general damages," i.e., pain and suffering. The payments, of course, do not include the overhead cost of insurance administration. Based on a GNP deflator of

193.3 in 1981 and 139.8 in 1977, the estimate of $1499 in 1977 dollars corresponds to $2073 in 1981 dollars, including $1232 for pain and suffering. Add to the $2073 Faigin's estimate for insurance administration ($80 in 1981 dollars) to obtain a total of $2153. Since liability payments are often considered generous and since many whiplash victims do not seek or do not receive the payments, $2153 can be thought of as an upper bound for the price worth paying to avoid whiplash.

In short, $670 - $2153 appears to be a reasonable range of costs worth paying to avoid whiplash. To put it another way, it is worth spending a million dollars on whiplash reduction if at least 460 - 1500 whiplashes are eliminated.

CHAPTER 8

THE EFFECT OF HEAD RESTRAINT HEIGHT ON INJURY RISK

The purpose of a head restraint is to effectively raise the seat back, restraining rearward movement of the head and neck relative to the thorax (hyperextension). The higher the restraint, the more protection it provides. At some point, however, a restraint protects even the tallest occupants. Additional height would provide few incremental benefits.

What is the minimum level for head restraint height that approaches full benefits? What is the relationship between head restraint height and injury risk? To what extent is the performance of adjustable restraints degraded because they are left in the "down" position? What incremental benefits, if any, could be achieved by higher restraints? These questions and their implications are addressed in this chapter.

8.1 Anthropometric considerations

A head restraint or seatback should come close to achieving its full benefit if it is high enough to reach beyond the top of the occupants neck -i.e., up to the skull. Additional seatback height would provide little additional restraint. The seatback would provide little or no protection if it fails to reach even the bottom of the occupant's neck. If the seat back reaches somewhere between the top and bottom of the neck, it would presumably give an intermediate amount of protection.

The statistic of interest is the range of seatback heights that provide intermediate levels of protection. The range will now be calculated for 70 inch (50th percentile male) occupants, based on anthropometric data.

The mean height from a chair to the base of the skull of a 70 inch human is 27.5 inches if that person is sitting erect in the chair. This height is normally distributed with a standard deviation of 0.77 inches [5].

The typical automobile occupant, however need not be sitting erect, but may be a bit slouched. This may reduce the seated height by 0-2.5 inches (author's observations). Thus, the height reduction due to slouch may be assumed normally distributed with mean 1.25 inches and a standard deviation of 0.63 inches (1/2 and 1/4 of the observed range). Therefore, the sitting height to the base of the skull for the typical occupant is the difference of two normal distributions. It is normally distributed with:

$$\mu = 27.5 - 1.25 = 26.25$$

$$\sigma = (.77^2 + .63^2)^{1/2} = 1$$

The length of the posterior neck is about 4 inches in human beings [6]. For an individual occupant, the seatback provides an intermediate level of protection if its top is somewhere within the 4 inch range between the top and bottom of the neck -i.e. anywhere up to 4 inches below the base of the skull. Thus, for an individual occupant, the seatback heights with intermediate protection have the uniform distribution with range (-4,0), measured from the base of the skull.

For the diversity of 70 inch occupants, the distribution of heights providing intermediate protection is the sum of the normal distribution of heights to the base of the skull and the uniform distribution of 0 to 4 inches below the base of the skull. This distribution has the cumulative distribution function [50]

$$
\begin{aligned}
H(a) &= P(U_{(-4,0)}(x) + N_{(26.25,\,1)}(y) \leq a) \\
&= \int_{-\infty}^{\infty} \int_{-\infty}^{a-y} \begin{Bmatrix} 1/4\,\phi(y-26.25) & \text{if } -4<x<0 \\ 0 & \text{otherwise} \end{Bmatrix} dx\,dy \\
&= \int_{-\infty}^{a+4} \int_{-4}^{\min(a-y,\,0)} 1/4\ \phi(y-26.25)\,dx\,dy \\
&= \int_{-\infty}^{a} \int_{-4}^{0} 1/4\,\phi(y-26.25)\,dx\,dy + \int_{a}^{a+4} \int_{-4}^{a-y} \tfrac{1}{4}\,\phi(y-26.25)\,dx\,dy \\
&= \int_{-\infty}^{a} \phi(y-26.25)\,dy + \int_{a}^{a+4} (a-y+4)\tfrac{1}{4}\,\phi(y-26.25)\,dy \\
&= \Phi(a-26.25) + \tfrac{1}{4}\int_{a}^{a+4} (a-22.25)\,\phi(y-26.25)\,dy + \tfrac{1}{4}\int_{a}^{a+4} -(y-26.25)\,\phi(y-26.25)\,dy \\
&= \Phi(a-26.25) + \tfrac{1}{4}(a-22.25)\big(\Phi(a-22.25) - \Phi(a-26.25)\big) \\
&\qquad + \frac{1}{4\sqrt{2\pi}} \int_{a}^{a+4} -(y-26.25)\,e^{-(y-26.25)^2/2}\,dy \\
&= \Phi(a-26.25) + \tfrac{1}{4}(a-22.25)\big(\Phi(a-22.25) - \Phi(a-26.25)\big) \\
&\qquad + \frac{1}{4\sqrt{2\pi}} \left(e^{\frac{-(a-22.25)^2}{2}} - e^{-\frac{(a-26.25)^2}{2}} \right)
\end{aligned}
$$

Since H(21.35) = .025 and H(27.15) = .975, 95 percent of the range of seatback heights providing intermediate protection for 70 inch occupants is 21.35 - 27.15 inches. This interval can be construed as the effective range within which an increase of the seatback height will substantially enhance the resultant protection. The width of this interval is 5.8 inches. It is greater than the posterior neck length of a single person (4 inches) because it also incorporates the variation of sitting heights and amount of slouch among 70 inch occupants.

In <u>relative</u> terms, the range of 21.35 - 27.15 inches corresponds to 30.5 - 38.8 percent of the standing height of a 70 inch occupant. Approximately the same ratios of seatback heights to standing height are derived for persons taller or shorter than 70 inches, because seated height of the base of the skull is very nearly proportional to standing height [5].

Based on anthropometric considerations, then, it would appear that an occupant gets close to the maximum feasible protection from head restraints that attain 38.8 percent or more of his stature and is most vulnerable if the seatback is 30.5 percent or less of his standing height.

8.2 Sled and crash test results

In 1968, R.J. Berton ran 24 rear impact sled tests using 50th percentile male (70 inch) dummies [11]. He used seatback heights of 22, 24, 26 and 28 inches; test speeds of 10, 20 and 30 mph; and 1 and 4 inch offsets of the dummy head from the seat. Rigid seatbacks were used.

There was a strong, nearly linear relationship between the observed angle of neck hyperextension and the seatback height when the latter was in the 24-28 inch range. In other words, the 6 dummies with the 28 inch seatback all experienced less than 25 degrees of rearward rotation of the head relative to the torso (well within voluntary limits of neck extension). The dummies with 26 inch seats experienced a head/torso angle varying from 35 to 60 degrees - more or less the voluntary limit of neck extension. With 24 inch seats, the dummies suffered 80-110 degrees of head rotation, exceeding the voluntary limits [61], [62].

The dummies with the 22 inch seatbacks suffered hyperextensions which were on the average, just slightly larger than those of the dummies in the 24 inch seats.

Berton concluded that 26 inch seatbacks provide adequate protection for 50th percentile males without creating visibility restrictions for small females. After all, a 30 mph sled test is extremely severe compared to typical rear impact highway accidents, yet the dummy's neck extension was more or less within voluntary limits.

In relative terms, a 28 inch seatback is 40 percent of the height of a 70 inch dummy; a 26 inch seatback - 37 percent; a 24 inch seatback - 34 percent; and a 22 inch seatback - 31 percent. Thus, Berton concluded that a seatback 37 percent as tall as the dummy provides adequate protection. The range of seatback heights providing intermediate levels of protection would apprear to be about 33-39 percent of the dummy's height: 33 percent, because the 22 inch seatback (31 percent) performed slightly worse than the 24 inch seat (34 percent). So the lower bound may be just below 24 inches; 39 percent because the 28 inch seatback (40 percent) appears to exceed slightly the requirements for protection, whereas the 26 inch seat (37 percent) is already close to the top of the range.

It should be noted that Berton's dummies are all identical 50th percentile males. The study does not make allowances for the variations in seating height relative to standing height in the 70 inch human population. Also it can be assumed that the dummies were placed in the erect seating position. When Berton's interval (33-39%) is adjusted to allow for anthropometric and slouching variations, it expands and moves to the left. Thus, Berton's interval of 33 - 39 percent for dummies corresponds to an interval of 31 - 39 percent for human occupants.

The range of seatback heights providing intermediate protection, based on Berton's sled test (31 - 39 percent of the occupant's standing height) corresponds closely to the range calculated from anthropometric measurements in Section 8.1 (30.5 - 38.8 percent).

Severy, Brink and Baird staged 12 front-to-rear car-to-car collisions during the 1960's [60]. The vehicles struck in the rear were for the most part occupied by 95th percentile male dummies in the driver's and right front seats. These dummies are about 74 inches tall and weigh 205 pounds: this is a major variation from the 50th percentile male dummies used by Berton. It was found that 28 inch integral seatbacks or adjustable head restraints generally provided satisfactory protection against hyperextension of the neck. A 28 inch seatback is 38 percent of the height of a 74 inch dummy. On the other hand, 25 inch seatbacks (34 percent of dummy height) allowed a much greater degree of neck extension. Thus, even though the authors used taller dummies and seatbacks, the relation of seatback height to dummy height yielding various levels of protection appears to be consistent with Berton's findings.

Another difference in Berton's and Severy's experimental conditions was that the former only used "rigid" seatbacks whereas the latter employed a mix of "rigid" and production seatbacks. In a rear impact, production seatbacks can tilt backwards under the occupant's load. In severe impacts, the tilting seat facilitates upward movement of the occupant's torso relative to the seatback (ramping). This effectively lowers the head restraint relative to the neck. Severy observed significant amounts of ramping in the severe impacts with production seatbacks and the ramping was accompanied by hyperextension of the dummy necks. If ramping is frequent in highway accidents, it would require taller seatbacks to compensate for the lifting of the occupants. Thus, it is possible that the anthropometric calculations and Berton's results, neither of which made allowance for ramping, understate the relative seatback height needed for full protection.

8.3 Results from the National Crash Severity Study

The National Crash Severity Study is the only probability sample of rear impacts for which the occupants' height, the seatback height and the occupants' injuries are known. The NCSS data make it possible to reliably obtain the distribution of head restraint height as a percentage of occupant height for adjustable and integral restraints (Section 8.3.1). The NCSS sample is too small, however, to determine the relationship between relative restraint height and injury risk (Section 8.3.2). But the NCSS data on the actual distribution of restraint heights, in combination with the effectiveness estimates from Texas data, do permit speculative inferences about the height-injury relationship (Section 8.4).

8.3.1 Distribution of seatback heights

The cumulative NCSS distributions of actual seatback heights, for adjustable and integral restraints, are shown in Table 8-1. The seatback height is the distance, in inches, from the back of the seat cushion to the top of the head restraint. In cars with adjustable restraints, the investigator makes the measurement with the restraint remaining in the position that it was when the vehicle was located for examination. Note that this procedure is not the same as the Standard 202 compliance test, where height is measured from the "H position" of an occupied seat. According to Dr. John Garrett (the NCSS quality control manager) the measurements by the two procedures may differ by about 0.5 - 1 inches.

TABLE 8-1

CUMULATIVE NCSS DISTRIBUTIONS OF SEATBACK HEIGHTS BY HEAD RESTRAINT TYPE

Seatback Height (inches)	Cumulative Percent of Occupied Seats Adjustable (weighted N=2473)	Integral (N=1325)	Pre-Standard 202*
19	-	-	1
20	-	-	5
21	-	-	20
22	1	-	51
23	3	-	76
24	15	-	95
25	38	-	100
26	57	5	-
27	71	15	-
28	87	46	-
29	97	90	-
30	99	98	-
31	100	99	-
32	-	100	-

* Inferred distribution: first 75 percentiles of "adjustable" distribution, minus 3 inches

NCSS does not contain measurements of seatback height for pre-Standard cars. But a distribution can be inferred by noting that about 75 percent of adjustable restraints are in the "down" position (see Section 4.4). The lower 75 percent of the adjustable restraint height distribution is used and, moreover, 3 inches are subtracted because an adjustable restraint in the "down" position extends about 3 inches above the rest of the seat (author's observations of 100 cars).

Figure 8-1 is a graph of the cumulative distributions. The pre-Standard seats are the lowest and the integral seats the highest. The curves for the pre-Standard and integral distributions have nearly the same shapes but the integral seats are, on the average, 6 inches taller. In particular, the median pre-Standard seat is 22 inches and the median integral seat is more than 28 inches. The highest pre-Standard seats are lower than the shortest integral seats.

The height distribution for adjustable restraints is clearly broader than for the other 2 types: the distribution curve is not nearly as vertical. This is because restraints can be adjusted to a variety of heights. In its lower range, the curve for adjustable restraints is midway between the two other curves (restraints in the "down" position). In the higher percentiles, the curve approaches the distribution for integral seats (restraints in the "up" position). The median seatback with adjustable restraints is 25 1/2 inches high.

Table 8-2 shows the cumulative NCSS distributions of seatback heights as a <u>percentage</u> of the height of the person occupying the seat. The distributions for adjustable and integral restraints are based on actual NCSS cases. The distribution for pre-Standard cars is constructed from the inferred pre-Standard seatback heights (Table 8-1) and the distribution of occupant heights on NCSS. (Since pre-Standard seatbacks are not adjustable, it is reasonable to assume that their height and the occupant's height are independent).

FIGURE 8-1: CUMULATIVE NCSS DISTRIBUTIONS OF SEATBACK HEIGHTS, BY HEAD RESTRAINT TYPE

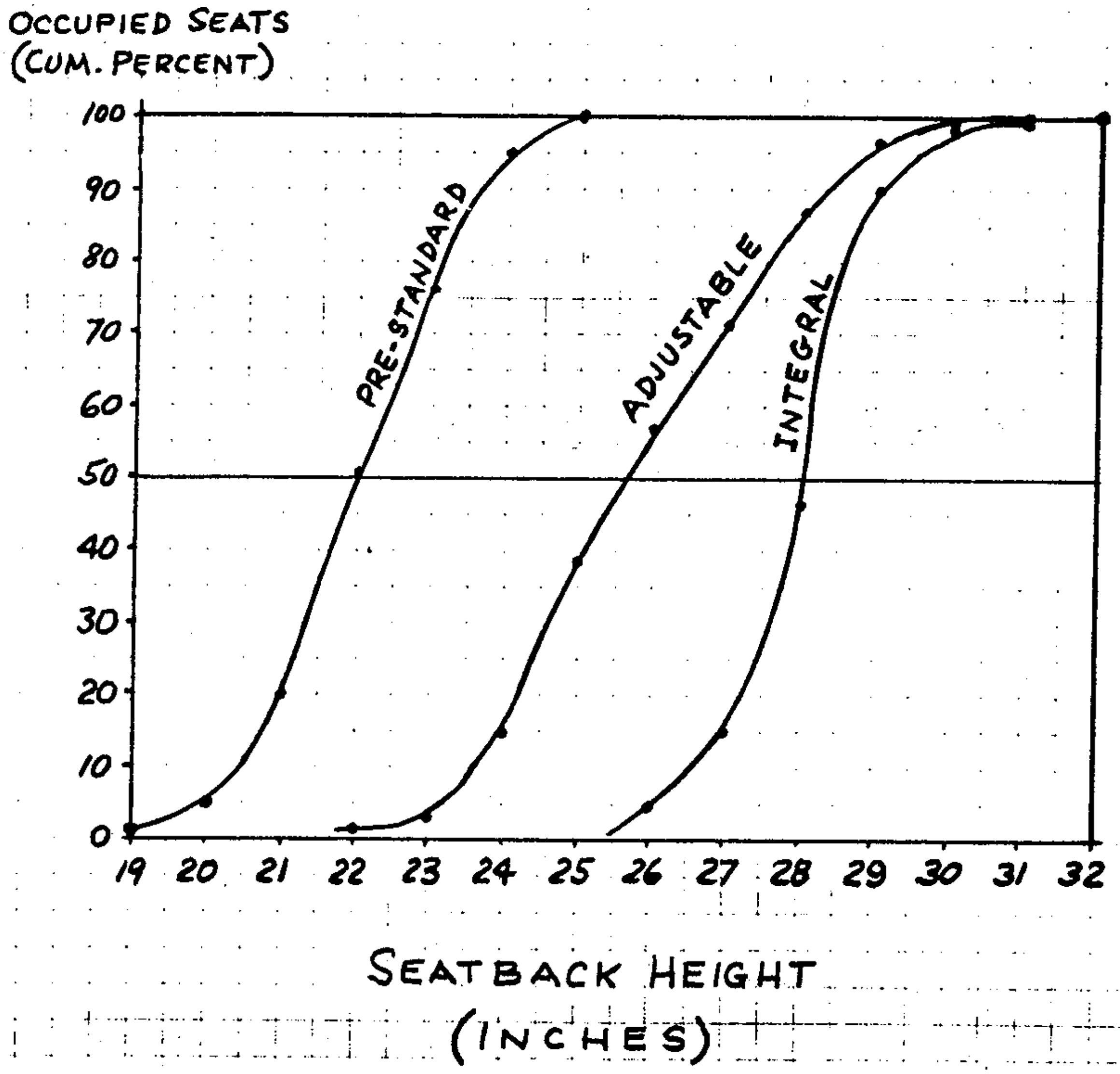


TABLE 8-2

CUMULATIVE NCSS DISTRIBUTIONS OF SEATBACK HEIGHT AS A PERCENTAGE OF OCCUPANT HEIGHT, BY HEAD RESTRAINT TYPE

$\frac{\text{Seatback Height}}{\text{Occupant Height}}$ (%)	Cumulative Percent of Occupied Seats		
	Adjustable	Integral	Pre-Standard 202*
27	--	--	1
28	--	--	3
29	--	--	7
30	--	--	16
31	1	--	27
32	2	--	38
33	6	--	53
34	9	--	65
35	13	--	76
36	20	--	85
37	26	2	90
38	41	11	95
39	52	20	96
40	68	31	98
41	77	40	99
42	85	48	99
43	90	64	100
44	93	71	--
45	94	80	--
46	97	90	--
47	98	94	--
48	99	96	--
49	99	98	--
50	100	100	--

*Inferred distribution

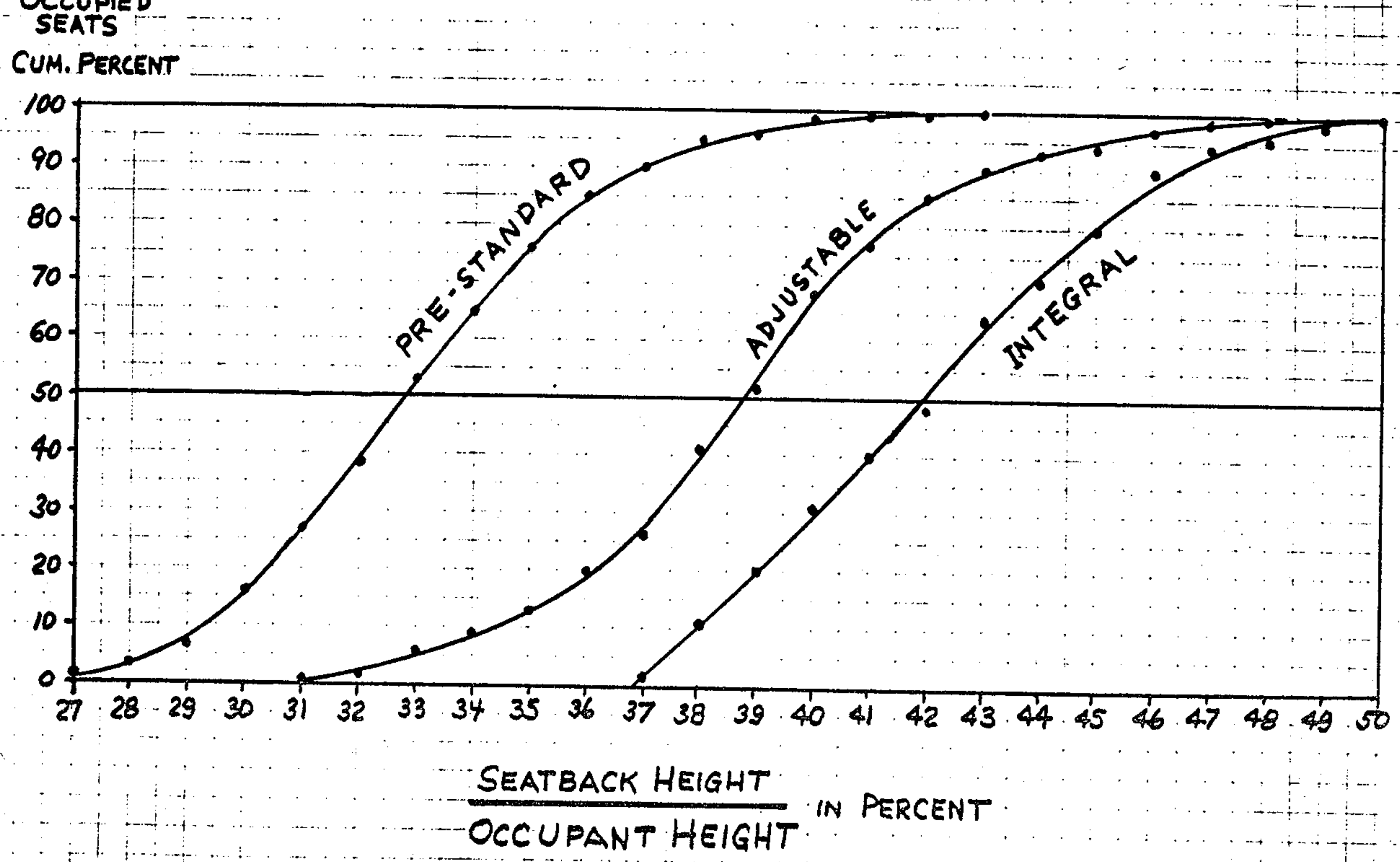
Figure 8-2 is a graph of the cumulative distributions of Table 8-2. The relative heights of integral seats are about 9 percent greater than pre-Standard seats and about 3 percent greater than adjustable head restraints (in the positions that the occupants have adjusted them).

The median height of pre-Standard seats is 33 percent of occupant height; the median of adjustable restraints is 39 percent of occupant height; of integral restraints, 42 percent. The 95th percentile of pre-Standard seats corresponds to the 41st percentile of adjustable restraints and the 11th percentile of integral restraints.

In Section 8.1 it was calculated that the range of intermediate restraint effectiveness was about 31-39 percent of occupant height. It should be noted that 80 percent of the pre-Standard seats fall in this range and only 16 percent are below it. In other words, even the pre-Standard seats provide at least some protection for many occupants, especially for shorter persons. As a result, the injury reduction for post-Standard seats relative to pre-Standard understates the injury reduction for "full" protection versus "no" protection (see Section 8.1).

It is interesting to compare Figure 8-2 (relative seatback height) to Figure 8-1 (absolute height). In the latter, the "adjustable" curve was less vertical than the other 2 curves, reflecting the variation in the adjustment of these restraints. In Figure 8-2, the "adjustable" curve is about as steep as the other 2 curves, at least in the 2 middle quartiles. This is because the taller occupants are more likely to raise the restraints - thereby reducing the variance of relative heights. The long tails of the "adjustable" curve represent the outliers - tall

FIGURE 8-2: CUMULATIVE NCSS DISTRIBUTION OF SEATBACK HEIGHT AS A PERCENTAGE OF OCCUPANT HEIGHT, BY RESTRAINT TYPE



persons who did not raise the restraints and short occupants who neglected to lower a restraint that was previously raised.

8.3.2 Seatback height and injury risk

Based on the anthropometric calculations of Section 8.1, a strong relationship of injury risk and seatback height was to be expected when the seatback ranged between 31 and 39 percent of occupant height. Outside this range, a weaker relationship was expected. For these reasons, multiple regression using relative seatback height as a piecewise linear continuous variable is the appropriate procedure for investigating the relationship.*

Two multiple regressions were run: one using neck injury as the dependent variable (1 = neck injury occurred; 0 = none) and the other using presence of any injury as the dependent variable. The regressions were, of course, limited to those cases where both the injury variable and the relative seatback height were defined. Both the seatback height and the occupant height had to be known. Specifically, since NCSS does not contain seatback height information on the pre-Standard 202 cases, they were excluded from this analysis.

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*The contractor's NCSS analysis treated seatback height as a dichotomy and defined as "improperly adjusted" any seat that was less than 39 percent of occupant height [63]. This method obviously does not properly model the suspected relationship and it will not be discussed here.

Relative seatback height was treated as a piecewise linear continuous independent variable as follows: two variables were defined

$$\text{Relhgt } (30.5\text{-}38.8) = \min \left(\frac{\text{seatback height}}{\text{occupant height}} \times 100, 38.8 \right)$$

$$\text{Relhgt } (38.8\,+) = \max \left(\frac{\text{seatback height}}{\text{occupant height}} \times 100, 38.8 \right)$$

Since none of the NCSS cases had relative seatback heights less than 30.5 percent, Relhgt (30.5-38.8) is a linear variable within the range of seatback heights with intermediate effectiveness (30.5-38.8% of occupant height - see Section 8.1). Relhgt (30.5-38.8) is a constant above this range. Relhgt (38.8+) is a constant within the range and a linear variable above the range.

Head restraint type (integral = 1, adjustable = 2) was another independent variable. Its role is to test whether integral restraints are more effective than adjustable restraints merely because, on the average, they are higher or whether integral restraints are even more effective than adjustable restraints positioned at the same height.

Occupant sex (0 = male, 1 = female) and CDC extent of damage (actual value) were also entered as independent variables (covariates) in order to control for any confounding between them and the preceding variables.

Finally, the cases were weighted by the inverse NCSS sampling fractions.

Table 8-3 shows the coefficients of the independent variables as predictors of neck injury. All of the coefficients are "in the right direction." Specifically, when the seatbacks range between 30.5 and 38.8 percent of the occupant's height, each 1 percent increase in seatback height leads to a 1.4 percent reduction of neck injury risk. But when the seatback is 38.8 percent or more of the occupant's height, a 1 percent increase only leads to a 0.6 percent reduction of neck injury risk. The regression suggests that adjustable restraints are slightly inferior to integral restraints of the same height, increasing neck injury risk by 2.1 percent. Within the 30.5-38.8 percent range, then, an adjustable seat would be equivalent to an integral seat 1.5 percent shorter.

The low t values of the coefficients and their high probabilities, however, clearly indicate that none of the coefficients are significantly different from zero. Because the NCSS sample is small, it could be pure coincidence that the observed results come so close to intuitive expectations.

Table 8-4 shows the coefficients of the independent variables as predictors of any kind of injury. The results are not too different from the neck injury regression, but do not match intuition quite as neatly. The regression again produces the correct relationship between Relhgt (30.5-38.8) and Relhgt (38.8 +): in the 30.5-38.8 range, increases in relative seatback height lead to modest decreases in injury risk, but in the higher range, increased height has virtually no effect; the model actually predicts a very small increase in injury risk. Integral restraints are predicted to be safer than adjustable restraints of the

TABLE 8-3

COEFFICIENTS OF REGRESSION OF NECK INJURY BY RELATIVE SEATBACK HEIGHT, NCSS

(Unweighted N=509)

Independent Variable	Coefficient	t for H_0: Coeff. = 0	P
Relhgt (30.5-38.8)	-0.014	-0.80	.43
Relhgt (38.8+)	-0.006	-0.83	.41
Head restraint type	0.021	0.44	.66
Sex	0.071	1.54	.12
Extent of damage	0.016	1.13	.26
(Intercept)	1.002	1.47	.14

TABLE 8-4

COEFFICIENTS OF REGRESSION OF INJURY BY RELATIVE SEATBACK HEIGHT, NCSS

(Unweighted N=524)

Independent variable	Coefficient	t for H_0: Coeff. = 0	P
Relhgt (30.5-38.8)	-0.003	-0.16	.87
Relhgt (38.8 +)	0.001	0.16	.87
Head restraint type	0.051	1.02	.31
Sex	0.085	1.77	.08
Extent of damage	0.022	1.52	.13
(Intercept)	0.421	0.59	.56

same height; in fact, the model predicts that the type of restraint is considerably more important than the height. Also in this regression, however, none of the coefficients differ significantly from zero and the observed relationships among the variables are not statistically meaningful.

8.4 Computations based on Texas effectiveness and NCSS seatback heights

It was shown in the preceding section that the NCSS sample was too small to permit derivation of a meaningful relationship between seatback height and injury risk. Nevertheless, the NCSS data did provide accurate estimates of the distribution of adjustable and integral seatback heights relative to occupant heights (Table 8-2 and Figure 8-2). From Texas data, the injury reducing effectiveness of adjustable and integral restraints is known within narrow confidence bounds. The purpose of this section is to compute a relationship between seatback height and injury which is consistent with the NCSS distributions of height and the Texas effectiveness results.

8.4.1 Head restraint height and injury risk

It takes 3 operations to compute a relationship between seatback height and injury which is consistent with NCSS height distributions:

(1) A relationship between seatback height and injury risk is hypothesized.

(2) This hypothesized relationship, in combination with the NCSS distributions of adjustable, integral and pre-Standard seatback heights relative to occupant heights (Table 8-2) leads to estimates of the effectiveness of adjustable and integral seats.

(3) These estimates of effectiveness are tested for their statistical compatability with the effectiveness observed in Texas; if they are compatible, the hypothesized relationship of seatback height and injury is plausible.

After a comprehensive list of possible relationships has been generated and tested, those that survive the test constitute the confidence ellipse for likely relationships between seatback height and injury.

The procedure involves assumptions, sometimes speculative, at various stages. The assumptions are marked with bullets as they are introduced in the text.

The anthropometric considerations of Section 8.1 (which are supported by the laboratory testing of Section 8.2) already provide a good idea of the likely relationship of seatback height and injury. They suggest that it is important to consider the seatback height <u>relative</u> to occupant height. There is a critical <u>range</u> of relative seatback heights within which increased height reduces injury. Outside the range, injury risk is insensitive to seatback height. The width of this range was about 8 percent of the height of the occupant. In view of these considerations, it will be assumed that

- There is a certain minimum percentage h_0 of an occupant's height below which the injury reduction is nil. At $h_0 + 8$ (the top of the critical range) and above, the injury reduction is ε where ε, in the terminology of Section 8.1, is the value of "full" protection versus "no" protection.

For simplicity, assume also that

- Between h_0 and $h_0 + 8$ (within the range of intermediate protection) injury risk decreases at a linear rate as seatback height increases.

An important assumption which has just been implicitly introduced but should be explicitly restated is that

- Injury risk is only a function of seatback height relative to occupant height. For example, an integral seatback that is 38 percent as tall as the occupant is no more effective than an adjustable restraint that was positioned at 38 percent of the occupant's height.

The validity of this last assumption is uncertain in light of the experimental evidence (see Section 6.1). Therefore, subsequent to the computations, the effects of a departure from the assumption will be discussed.

The first step - the generation of hypothesized relationships — has now been reduced to the specification of the 2 parameters h_0 and ε which determine the piecewise linear height-injury function.

Table 8-2 gave the cumulative distributions of seatback heights relative to occupant heights. Let c_{Ai}, c_{Ii} and c_{Pi} be the table entries for adjustable, integral and pre-Standard seats opposite the percentage i of occupant height; i varies from 27 to 50 percent in the table.

Then the calculated overall injury risk for adjustable restraints, based on the hypothesized relationship of seatback height to injury, is

$$r_A = \sum_{i=27}^{h_0} (c_{A_i} - c_{A_{i-1}}) + \sum_{i=h_0+1}^{h_0+7} \left(1 - \frac{(i-h_0)\varepsilon}{8}\right)(c_{A_i} - c_{A_{i-1}}) + \sum_{i=h_0+8}^{50} (1-\varepsilon)(c_{A_i} - c_{A_{i-1}})$$

$$= c_{A h_0} + \sum_{i=h_0+1}^{h_0+7} \left(1 - \frac{(i-h_0)\varepsilon}{8}\right)(c_{A_i} - c_{A_{i-1}}) + (1-\varepsilon)(100 - c_{A h_0+7})$$

Similarly, the overall injury risk for integral restraints is

$$r_I = c_{Ih_0} + \sum_{i=h_0+1}^{h_0+7} \left(1 - \frac{(i-h_0)\varepsilon}{8}\right)(c_{Ii} - c_{Ii-1}) + (1-\varepsilon)(100 - c_{Ih_0+7})$$

and for pre-Standard cars it is

$$r_P = c_{Ph_0} + \sum_{i=h_0+1}^{h_0+7} \left(1 - \frac{(i-h_0)\varepsilon}{8}\right)(c_{Pi} - c_{Pi-1}) + (1-\varepsilon)(100 - c_{Ph_0+7})$$

In other words, the effectiveness of adjustable restraints is calculated to be

$$\varepsilon_A = 1 - \frac{r_A}{r_P}$$

and the effectiveness of integral restraints is

$$\varepsilon_I = 1 - \frac{r_I}{r_P}$$

Now it remains to check whether the estimates ε_A and ε_I are statistically compatible with the Texas effectiveness results. It is assumed, at this point, that

- The Texas and NCSS distribution of occupant heights, seatback heights and restraint types are similar.

Recall that the Texas estimates of adjustable and integral restraint effectiveness were developed from separate studies of

(1) model year 1969 vs. model year 1968 in 1972-74-77 Texas data (5.6.2)

(2) integral vs. adjustable restraints in 1972-74-77 data (6.3.3)

Since 81 percent of the crash-involved MY 69 cars on NCSS have adjustable restraints and 7 percent have integral restraints, whereas only 6 percent of the MY 68 cars have adjustable restraints and 6 percent have integral restraints,

$$\varepsilon_1 = 1 - \frac{.81\ ra + .07\ rI + .12\ rp}{.06\ ra + .06\ rI + .88\ rp}$$

is the effectiveness estimate for model year 1969 versus model year 1968, based on the hypothesized height-injury relationship;

$$\varepsilon_2 = 1 - \frac{1 - \varepsilon_I}{1 - \varepsilon_A}$$

is the effectiveness estimate for integral versus adjustable restraints.

In the 1972 Texas data, the effectiveness of model year 1969 versus model year 1968 was 8.1 percent and its standard deviation was 3.16 (see Section 5.6.2). In the 1972-74-77 Texas data, the effectiveness of integral versus adjustable restraints was 7.3 percent and its standard deviation (when this effectiveness was treated as an observation from a normal population) was 3.04. Since the two effectiveness values are derived by procedures independent from one another, they can be treated jointly as observations from a bivariate normal distribution with zero correlation. In other words, if

$$\left(\frac{\varepsilon_1 - 8.1}{3.16}\right)^2 + \left(\frac{\varepsilon_2 - 7.3}{3.04}\right)^2 < (1.645)^2$$

then ε_1 and ε_2 are within the <u>90 percent confidence ellipse</u> of effectiveness values statistically compatible with the Texas results.

In turn, the parameters h_0 and ε that generated ε_1 and ε_2 define a relationship between seatback height and injury that is compatible with the Texas results.

Table 8-5 lists and Figure 8-3 plots the values of ho, ho+8 (interval within which seatbacks have intermediate effectiveness) and ε (injury reduction for "full" protection versus "no" protection) which are compatible with the Texas results. The lowest compatible intermediate range of seatback heights is 30-38 percent of occupant heights; the highest is 40-48 percent. Thus, the range obtained from anthropometric calculations and laboratory tests (31-39 percent) is within, but near the bottom of the envelope of ranges obtained here.

The compatible values of effectiveness ε range from 14 to 42 percent. Thus ε, the injury reduction for "full" protection versus "no" protection, is considerably larger than the average effectiveness of current head restraints (12.8%). This is because even pre-Standard seats are often higher than ho (especially for short occupants) while current head restraints are often shorter than ho+8 (especially for tall occupants) - see Table 8-2.

TABLE 8-5

PLAUSIBLE RELATIONSHIPS OF SEATBACK HEIGHT AND INJURY RISK

(compatible with NCSS height distribution and Texas effectiveness)

ho Height where Seatbacks Provide no Protection (% of Occupant Height)	**ho + 8** Height where Seatbacks Provide Full Protection (% of Occupant Height)	**ε** Injury Reduction for ho + 8 versus ho (%)
30	38	22-26
31	39	18-28
32	40	16-28
33	41	14-30
34	42	14-30
35*	43*	14-32, 23*
36	44	14-32
37	45	16-34
38	46	18-36
39	47	24-40
40	48	32-42

*** Values that come closest to predicting effectiveness observed in Texas**

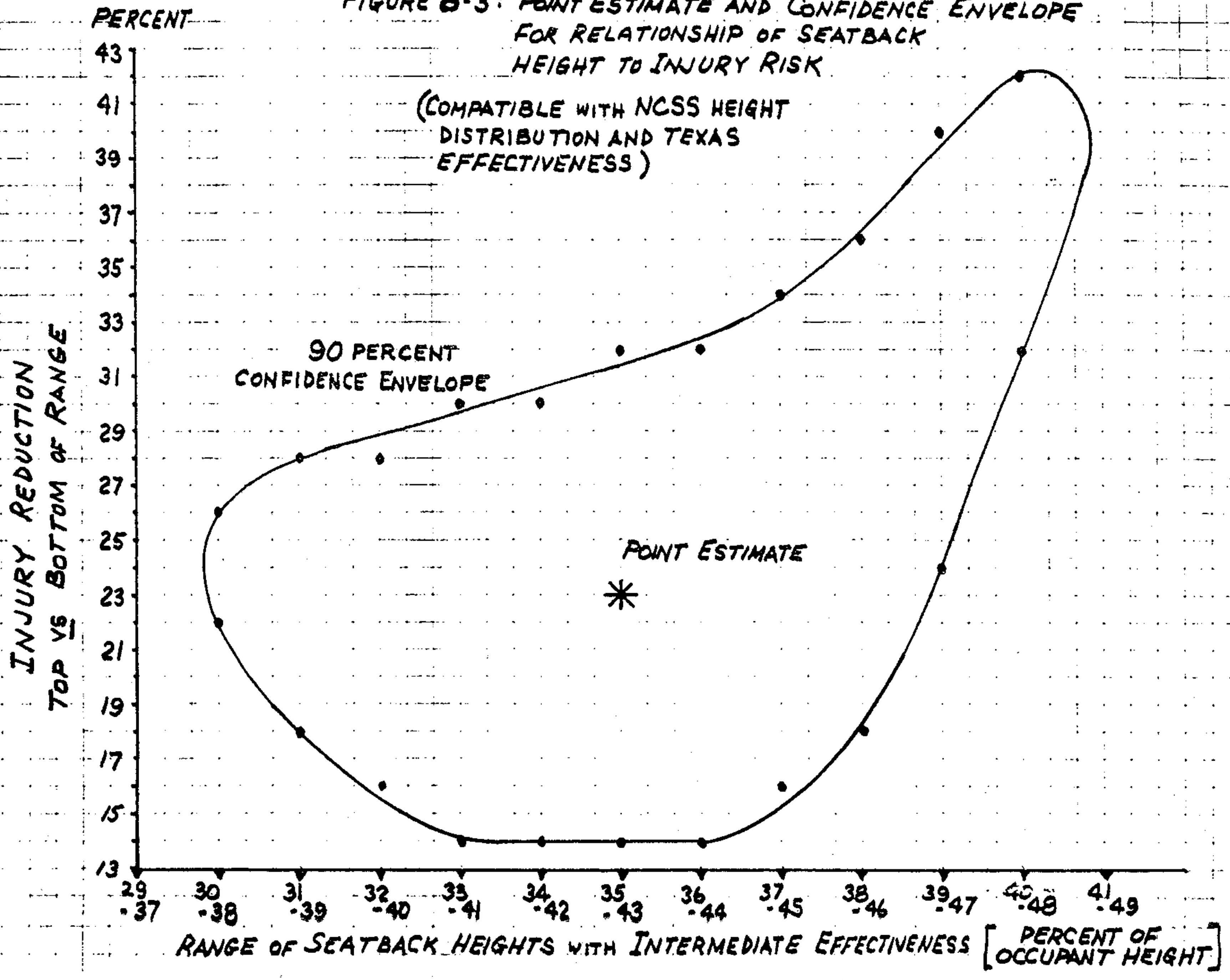


FIGURE B-3: POINT ESTIMATE AND CONFIDENCE ENVELOPE FOR RELATIONSHIP OF SEATBACK HEIGHT TO INJURY RISK

(COMPATIBLE WITH NCSS HEIGHT DISTRIBUTION AND TEXAS EFFECTIVENESS)

Specifically, the (integer) values of ho and E that come closest to predicting the effectiveness actually observed in Texas are 35 and 23.

In other words, the NCSS and Texas data imply that

(1) Seatbacks provide no protection if they are less than 35 percent as tall as the occupant

(2) They provide full protection if they are at least 43 percent as tall as the occupant

(3) A seatback 43 percent as tall as the occupant (31 inches for a 72 inch occupant) reduces rear impact injury risk by 23 percent relative to a seatback 35 percent as tall as the occupant (25 inches for a 72 inch occupant).

It should be noted that this point estimate of 35 for ho is 4 percent higher than the point estimates of 30.5 - 31 derived from anthropometric calculations and laboratory data (Sections 8.1 and 8.2). This discrepancy is obviously not statistically significant, since the confidence envelope for ho by this method is 30-40. Nevertheless, there are two possible reasons that this method could produce a higher estimate for ho:

(a) Neither the anthropometric calculations nor Berton's laboratory tests with rigid seats allowed for the occupant's torso ramping up the seatback during rear impact, thus requiring a higher seatback to protect the head and neck (see Section 8.2). The results by this method, which are based on highway crashes with production seats, do include cases of ramping.

(b) This method assumes that integral restraints are no more effective than adjustable restraints, except to the extent that the latter are adjusted to a lower position. If, in fact, integral restraints have greater benefits than adjustable restraints lifted to the same height, it would have caused this method to underpredict the effectiveness of integral restraints and, conversely, to overemphasize the role of tall seatbacks in preventing injury. In short, it would bias ho upwards.

Thus, if (a) is true, it would indicate that the anthropometric calculations and laboratory tests *understate* ho, while if (b) is true, this method *overstates* it. In either case, though, the discrepancy is just 4 percent of an occupant's height, or 3 inches for a 72 inch occupant. This is a remarkably close agreement for two entirely disparate methods, one of which involved numerous speculative assumptions.

Figure 8-3 clearly shows the shape of the confidence envelope. It is not symmetric: the range of permissible ε is higher when ho is larger. This is because, when ho is large, even integral seats provide inadequate amounts of protection. Thus, a much higher ε ("full" protection versus "no" protection) is needed to obtain the injury reduction actually observed for integral seats (partial protection versus no protection).

The confidence envelope may be explained as follows: when ε is too high, overall effectiveness of restraints is overpredicted (and when ε is too low, it is underpredicted). When ho is too high, the model assigns undue benefits to very tall restraints and overpredicts the benefits of integral restraints relative to adjustable ones (and when ho is too low the model ignores tall restraints and underpredicts the benefits of integral seats). As a result, the effectiveness levels observed in Texas constrain ϵ and ho within the envelope shown in Figure 8-3.

8.4.2 Effect of positioning adjustable restraints properly

The preponderant evidence suggests that the main reason that integral restraints are more effective than adjustable restraints is that they are taller, since occupants fail to raise the adjustable ones far enough. The most important evidence in support of this hypothesis is the consistency of the Texas effectiveness data and the anthropometric calculations, as shown in the preceding section. The NCSS data neither support nor contradict the hypothesis (Section 8.3.2) and Severy's crash tests are also inconclusive (Section 6.1).

If, in fact, the hypothesis is true then adjustable restraints could be made as effective as integral restraints if the occupants were to position them "properly." Proper positioning, in light of the preceding section, means all the way up or up to 43 percent of the occupant's height (to the middle of the skull), whichever is lower. Table 8-2 shows that, at this time, only 15 percent of adjustable restraints are positioned at 43 percent or more of occupant height, whereas 52 percent of integral restraints achieve it. If all adjustable restraints were properly positioned, there would be a 7.3 percent reduction of injury risk, since this is the incremental effectiveness of integral over adjustable seats. Conversely, the current mispositioning by occupants of adjustable restraints causes the injury rate to be 7.9 percent higher than it would be if they were properly positioned.

8.4.3 The effects of raising or lowering height requirements

In Section 8.4.1, rear impact injury risk was defined to be a function of two parameters: the relative seatback height ho where seatbacks begin to provide protection and the effectiveness ℰ, which is the injury reduction for a seatback ho +8 percent of occupant height relative to an ho seatback. Moreover, it was found that ho=35 and ℰ=23 come closest to predicting the effectiveness of adjustable and integral restraints actually observed in Texas. A confidence envelope of values of ho and ℰ compatible with the Texas results was also found and shown in Figure 6-3.

The piecewise linear seatback height-injury risk function defined by ho=33, ℰ=28 now makes it possible to estimate the injury risk for *any* hypothetical population of seatbacks, not merely for current adjustable and integral restraints. The hypothetical population need only be described by its distribution of seatback heights as a percentage of occupant heights - the height injury function is then applied to this distribution to determine overall injury risk.

Specifically, consider a population of exclusively *integral* restraints, *all of the same height* H inches. (Such a population could have occurred in real life if Standard 202 had required integral restraints of height H inches.) How much smaller (or larger) would the injury risk be for this population than for the current post-Standard 202 population of adjustable and integral restraints?

It takes two operations to find the reduction of injury risk:

(1) Convert the absolute height H inches into the distribution of seatback heights relative to occupant heights.

(2) Apply the height-injury function to this distribution to determine the overall injury risk and compare the result to the current post-Standard population.

Let f(x) be the frequency density function of the heights of crash-involved front-outboard passenger car occupants, specifically those on NCSS (truncated to the nearest inch). Let i be any positive integer. Let j be the largest integer such that $H/j < i+1$. Then

$$c_{Hi} = 100 \sum_{\ell=1}^{j} f(\ell)$$

is the cumulative distribution of seatback heights as a percentage of occupant heights for a seatback H inches tall.

To compute injury risk, it is now merely necessary to repeat the procedure of Section 8.4.1. Specifically, the calculated overall injury risk for seatbacks H inches tall is

$$r_H = C_{Hho} + \left[\sum_{i=ho+1}^{ho+7} \left(1 - \frac{(i-ho)\varepsilon}{8}\right) \left(C_{Hi} - C_{Hi-1}\right)\right] + (1-\varepsilon)\left(100 - C_{Hh0+7}\right)$$

The injury reduction for seatbacks H inches tall relative to current post-Standard seats is

$$E_H = 1 - \frac{r_H}{.62\, r_A + .38 r_I}$$

where r_A and r_I, the injury risks for adjustable and integral restraints, were defined in Section 8.4.1.

In order to obtain a <u>point estimate</u> of E_H use ho=35 and ε=23. This yields the best estimate of the injury reduction for a population of H-inch seatbacks, using the methods of this study.

In order to obtain one-sided 95% <u>confidence bounds</u> for E_H, compute E_H using the combinations of ho and ε that are marked by dots on the confidence envelope plotted in Figure 8-3. The lowest value of E_H obtained for any of these combinations is a lower confidence bound. The highest value is the upper bound.

Table 8-6 lists and Figure 8-4 plots the estimates of effectiveness of integral seatbacks ranging from 24 to 34 inches and their confidence bounds.

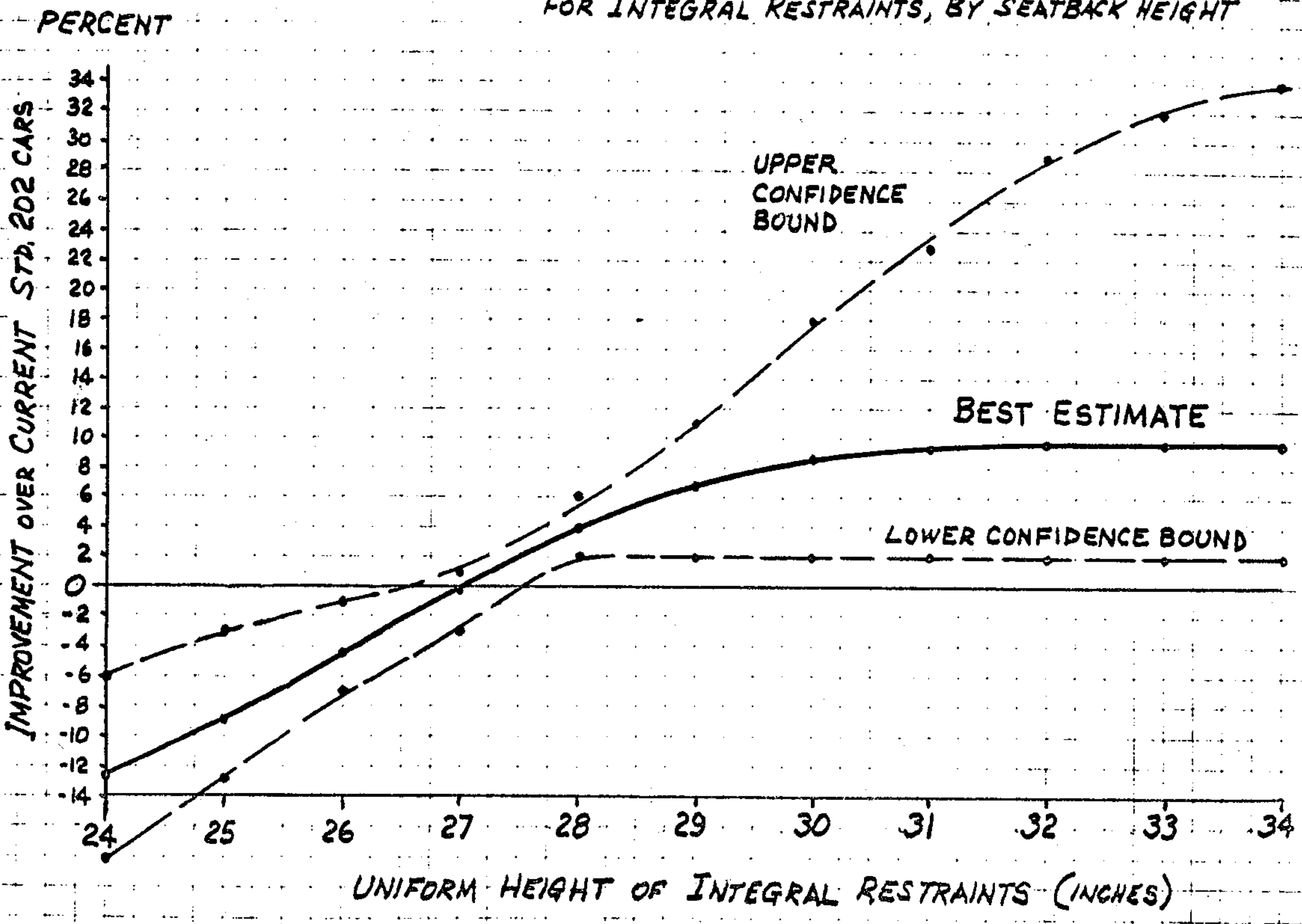
TABLE 8-6

INJURY REDUCTION - RELATIVE TO CURRENT STANDARD 202 CARS - FOR INTEGRAL RESTRAINTS, BY SEATBACK HEIGHT

H Uniform Height of Integral Restraints (inches)	Improvement over Current Standard 202 Cars (%) E_H Best Estimate	Confidence Bounds* Lower	 Upper
24	-12.4	-18	- 6
25	- 8.9	-13	- 3
26	- 4.2	- 7	- 1
27	- 0.1	- 3	1
28	4.0	2	6
29	6.6	2	11
30	8.3	2	18
31	9.4	2	23
32	9.8	2	29
33	9.8	2	32
34	9.8	2	34

* One-sided α = .05

FIGURE 8-4: INJURY REDUCTION RELATIVE TO CURRENT STD 202 CARS, FOR INTEGRAL RESTRAINTS, BY SEATBACK HEIGHT



While inspecting Table 8-6 it is useful to recall that

(1) The current Standard 202 specifies a seatback height of 27.5 inches (integral seats or adjustable restraints in the "up" position).

(2) 62 percent of the crash-involved vehicles have adjustable restraints, which their occupants have positioned at a median height of 26 inches (Table 8-1) -i.e. 1.5 inches below the current standard. Thus, even integral seats slightly below 27.5 inches constitute an improvement over these adjustable seats

(3) 38 percent of current crash-involved vehicles have integral seats. Their median height is over 28 inches - i.e., exceeds the minimum requirements of the standard. Thus, it would take integral seats of about 29 inches or more to improve on current integral seats.

(4) The current mix of integral and adjustable restraints (the latter being in the positions where occupants currently place them) corresponds roughly to a uniformly 26.7 inch integral seat population.

Figure 8-4 shows that any integral seat population of 27.5 inches or higher is likely to result in an improvement over current head restraints -i.e. even the lower confidence bound is positive. Higher integral seats result in even greater improvements. Similar gains could be achieved by height requirements for adjustable restraints in the <u>down</u> position. At about 31 inches, the improvements begin to level off at about 9 percent fewer injuries than current cars (best estimate). The upper confidence bounds, however, do not rule out a much larger potential improvement.

Conversely, any substantial reduction of seatback heights is likely to aggravate the current situation, even if integral restraints are used. For example, at 24 inches, there would be 12 percent more injuries than in the current fleet.

Figure 8-4 clearly indicates the shape of the effectiveness curve and its confidence bounds. Effectiveness rises steadily as seatback height increases through levels that would be in the "intermediate" range for most occupants. It levels off when the seats are high enough to provide "full" protection even for tall occupants- e.g. a 32 inch seat is nearly 43 percent as tall as a 6'3" occupant. The curve for the upper bound levels off later than the best estimate because it is based on that part of the confidence envelope for the height-injury function that had the highest ho.

The confidence bounds narrow perceptibly near 27 inches because, at this point, the seats would be close to the average for the current population. Thus, little change from current injury risk could be expected.

It is important to remember that the projections in Figure 8-4 are based on a speculative method of making inferences from accident data. While anthropometric calculations and limited laboratory data support the results of this method, the projections themselves are not based on direct analysis of detailed accident data or on a comprehensive crash test program. Moreover, the confidence bounds shown in Figure 8-4 are too wide for the "best" estimate to be considered reliable.

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