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HIGHWAY SAFETY

Causes of Injury in Automobile Crashes

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The Honorable Ernest F. Hollings
Ranking Minority Member
Committee on Commerce, Science,
and Transportation
United States Senate

The Honorable Richard H. Bryan
United States Senate

We are pleased to send you this report on the causes of injury in automobile crashes in response to your request that we expand our earlier research on automobile safety. In this study, we reviewed the research literature and conducted analyses of traffic accident data to examine the effects of crash characteristics, automobile size, safety belts, air bags, and occupant age and gender on the risk of injury in automobile crashes. The report also discusses promising areas for further reducing injury risk.

We will be sending copies of this report to the Secretary of Transportation, and we will also make copies available to others upon request. If you have any questions or would like additional information, please call me at (202) 512-3092. Other major contributors to this report are listed in appendix II.

Kwai-Cheung Chan
Director for Program Evaluation
in Physical Systems Areas

Executive Summary

Purpose

In recent years, automobiles have been associated with nearly 29,000 traffic fatalities annually in the United States, including the deaths of both automobile occupants and others involved in collisions with automobiles. The Senate Committee on Commerce, Science, and Transportation asked GAO to study the independent effects of important crash-related factors on the likelihood of injury once an automobile crash has occurred. This report addresses these questions: What are the most important predictors of injury in a crash? How is the risk of injury in a crash affected by the severity and type of the crash, automobile size, safety belts and air bags, and the occupant's age and gender? What are promising areas for reducing further the crash injury risk of automobile occupants?

Background

In Highway Safety: Have Automobile Weight Reductions Increased Highway Fatalities? (GAO/PEMD-92-1, October 1991), GAO presented a number of findings regarding the relationship between automobile size and safety. GAO noted there that the safety consequences of automobile weight or of any other automobile design factor are confounded by many other factors, chief among them driver attributes. For example, automobiles that attract risky drivers may have high fatality rates solely because they have dangerous drivers, not because the cars themselves are unsafe.

Three further GAO reports examine the safety effects of automobile and driver characteristics within the larger context of other factors that influence traffic safety. One, Highway Safety: Factors Affecting Involvement in Vehicle Crashes (GAO/PEMD-95-3, October 1994), examines the influence of driver and automobile characteristics on the likelihood of crash involvement. Another, Highway Safety: Reliability and Validity of DOT Crash Tests (GAO/PEMD-95-5, May 1995), looks at the extent to which results from the automobile crash test programs conducted by the National Highway Traffic Safety Administration (NHTSA) accurately predict injury risk in crashes.

This, the third report, focuses exclusively on the safety of automobile occupants (in contrast to that of occupants of other passenger vehicles, such as vans, minivans, and pick-up trucks). To study this issue, GAO reviewed technical reports from NHTSA and other sources and consulted auto safety experts and representatives of automobile manufacturers. GAO also conducted its own statistical analyses of automobile crash data obtained from NHTSA. GAO's statistical analyses looked at the experience of drivers of relatively new cars in three types of crashes: one-car rollover crashes, one-car nonrollover crashes, and collisions with cars, vans, pick-ups, and other light trucks.

Results in Brief

Not surprisingly, speed at impact and crash type are the most important determinants of the risk of injury to drivers. Driver age and safety belt use are also important, while automobile weight and the gender of the driver have less influence. Injury is more likely in high-speed crashes than in crashes with lower impact velocities, and one-car crashes, particularly one-car rollovers, are more dangerous than two-vehicle collisions. Compared to light cars, heavy cars both generally provide their occupants with more crash protection and pose a greater danger to other roadway users in multivehicle crashes. However, the protective effects of automobile weight differ by crash type. Heavy cars offer comparatively more protection to their occupants in one-car nonrollover and multivehicle crashes, but once a rollover has occurred, occupants of heavier cars are more likely to be hurt than are occupants of lighter cars.

Safety belts greatly reduce injury risk, but the effectiveness of safety belts is not the same in all crashes; they are more effective in single-car crashes than in multivehicle collisions. Air bags reduce injury risk in frontal impacts, but air bags alone are less effective than safety belts alone. In equivalent automobile crashes, women drivers and older drivers are more likely to be injured than men and younger drivers. GAO found evidence that safety belts are less effective overall for women drivers than for men drivers.

Principal Findings

Crash Severity and Crash Type Are the Most Important Predictors of Injury

In GAO's statistical analysis, speed at impact was the most important predictor of driver injury, followed by the type of crash, driver age, safety belt use, automobile weight, and gender of the driver. The risk of driver hospitalization or death was 25 times greater in very severe crashes (as measured by speed at impact) than in relatively mild crashes. The risk of driver injury was 9 times greater in dangerous types of crashes (one-car rollovers) than in relatively benign crashes (typical two-vehicle collisions). The risk of driver injury was 4.5 times greater for drivers age 65 and older than for drivers 16 to 24 years of age, 3 times greater for unbelted drivers than for drivers wearing manual lap and shoulder safety belts, 63 percent greater for drivers of light cars than for drivers of heavy automobiles, and 29 percent greater for women drivers than for men drivers (see chapter 4).

The Effects of Automobile Weight Differ by Crash Type

Considering all crash types together, GAO estimates that each 500-pound increase in car weight reduces the risk of driver injury by 14 percent in tow-away crashes. However, the protective effect of automobile weight differs by the type of crash. Compared to light cars, heavier cars offer more occupant protection in collisions with cars and light trucks, and in one-car nonrollover crashes, but drivers of heavier cars are more likely to be injured in one-car rollover crashes, once a rollover has occurred. One explanation for this is that it takes more energy to roll over a heavier car than a lighter one, meaning that rollover crashes involving heavy cars are typically more severe than those involving light cars. GAO estimates that in multivehicle collisions, each 500-pound increase in automobile weight decreases a driver's injury risk by 23 percent but increases the probability of injury to the driver of the other car by 13 percent (see chapter 2).

The Effects of Safety Belts and Air Bags Differ by Crash Type

Safety belts greatly reduce the risk of driver injury in all crashes, but they are more effective in single-car crashes than in collisions with cars and light trucks. By comparison, air bags are effective only in frontal impacts, not in side impacts or rollovers. In addition, air bags offer additional protection to drivers already wearing lap and shoulder safety belts, reducing their risk of suffering a serious injury by about 10 percent. Safety belts alone are much more effective than air bags alone—that is, drivers wearing safety belts in cars without air bags are much less likely to be seriously injured than drivers not wearing belts in air bag-equipped cars (see chapter 2).

Women and Older Drivers Are More Likely to Be Injured

In equivalent crashes, women drivers and older drivers are more likely to be injured then men drivers and younger drivers. The relative risk of injury for women drivers compared to men drivers differs by the type of crash. More specifically, GAO estimates that women drivers have an injury risk approximately 50 percent greater than men drivers in statistically equivalent two-vehicle collisions but that the injury risk for women drivers and men drivers does not differ in one-car crashes. This is particularly important because women drivers are involved in more multivehicle collisions than one-car crashes, while men have more one-car than multivehicle crashes. Thus, women drivers are especially likely to be hurt in the type of crash that they experience most often. In addition, GAO found evidence that heavy automobiles and safety belts offer somewhat less protection for women drivers than for men drivers. In contrast, older drivers are more likely to be injured in a crash than younger drivers in almost all circumstances (see chapter 3).

Improving the Safety of Automobile Occupants

Increasing safety belt use and effectiveness would reduce injury risk for all automobile occupants. It is particularly important to increase safety belt use among drivers involved in serious crashes, because they use safety belts less than other drivers.

Women drivers and older drivers are in fewer crashes than men drivers and younger drivers, and, because they have more multivehicle than one-car crashes, the crashes that they are involved in are, on the average, less severe. Nonetheless, once a crash has occurred, women and, especially, older drivers are more likely to be injured than men and younger drivers. For this reason, women and older drivers would benefit substantially from improvements in automobile crashworthiness. Efforts to improve the protection of occupants of all sizes, and to improve protection in side-impact crashes, would be beneficial (see chapter 5).

Recommendations

This report contains no recommendations.

Agency Comments

In written comments on a draft of this report, the Department of Transportation (DOT) generally agreed with GAO's analytic methods and findings. In addition, DOT had several comments concerning the methods and findings of particular analyses. Those comments, and GAO's responses to them, are presented at the appropriate places in the report. A number of DOT's specific technical comments have been incorporated in the report where appropriate.

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Abbreviations

AIS	Abbreviated Injury Scale
DOT	Department of Transportation
FARS	Fatal Accident Reporting System
GAO	U.S. General Accounting Office
IIHS	Insurance Institute for Highway Safety
JAMA	Journal of the American Medical Association
NASS	National Accident Sampling System—Crashworthiness Data System
NHTSA	National Highway Traffic Safety Administration
SUDAAN	Survey Data Analysis

Introduction

Purpose

In recent years, automobiles have been associated with nearly 29,000 traffic fatalities annually in the United States, including the deaths of both automobile occupants and others involved in collisions with automobiles.[1] The National Highway Traffic Safety Administration (NHTSA), a unit of the Department of Transportation (DOT), has the lead role in federal government efforts to reduce the number of traffic crashes and to minimize their consequences. Some types of automobiles have higher fatality rates than others. (For example, small cars generally have higher rates than large cars.) In addition, some categories of drivers are more likely to be involved in serious crashes than others. (Young drivers, for example, have higher involvement rates than other drivers.) However, as we previously reported, one cannot conclude from differences in fatality rates that some types of cars, or some types of drivers, are in fact more dangerous than others, because driver and automobile characteristics are highly related (GAO, 1991). For example, since small cars have a disproportionate percentage of young drivers, do the high fatality rates for those cars stem from vehicle characteristics or the recklessness with which they are operated?

The goal of this report is to isolate the independent effects of important crash-related factors on the likelihood of injury in a collision. The report focuses on the most important predictors of occupant injury in a collision: crash type and crash severity, automobile size, safety belt use, and occupant age and gender. The report is concerned with both crashworthiness (protecting automobile occupants) and aggressivity (protecting other roadway users struck by automobiles). The report also considers prospects for improving the safety of automobile occupants.

This report is one of three GAO reports examining automobile safety. One of these, Highway Safety: Factors Affecting Involvement in Vehicle Crashes (GAO, 1994), examines the independent effects of driver characteristics and automobile size on crash involvement. Another, Highway Safety: Reliability and Validity of DOT Crash Tests (GAO/PEMD-95-5), looks at the extent to which results from the crash test programs conducted by NHTSA accurately predict injury in actual automobile crashes.

Background

Since the mid-1960's, both the number of traffic fatalities and the fatality rate per registered vehicle have sharply decreased in the United States.

[1]We use the terms "automobile," "auto," and "car" interchangeably in this report. We define automobiles as convertibles, sedans, hatchbacks, and station wagons. This definition specifically excludes other types of passenger vehicles, such as vans, minivans, multipurpose vehicles, and pickup trucks.

The fatality rate for automobile occupants has declined by 36 percent since 1975. The continued emphases on reducing drunk driving and increasing safety belt use, along with the introduction of antilock brakes, air bags, and other safety enhancing features, have increased the chances that this favorable trend will continue. Nonetheless, in 1991 automobiles were associated with nearly 29,000 traffic deaths in the United States.[2] About 22,000 of the automobile-related fatalities were automobile occupants (about 10,000 killed in single-car collisions and 12,000 in multiple-vehicle collisions), about 2,500 were occupants of other types of vehicles (for example, light trucks, vans, or motorcycles) involved in collisions with automobiles, and approximately 4,000 were pedestrians or cyclists hit by automobiles. (See table 1.1.)

Table 1.1: Roadway Fatalities Involving Automobiles, 1991

	Number of fatalities			
Crash type[a]	**Automobile occupants**	**Occupants of other vehicles**	**Pedestrians and cyclists**	**Total**
Single-car rollover	4,519	0	17	**4,536**
Single-car nonrollover	5,495	0	3,529	**9,024**
Two cars	4,638	0	170	**4,808**
Car and motorcycle	20	717	6	**743**
Car and light truck	3,466	955	124	**4,545**
Car and heavy truck	2,277	59	37	**2,373**
Car and other vehicle	72	60	19	**151**
Three or more vehicles	1,744	686	112	**2,542**
Total	**22,231**	**2,477**	**4,014**	**28,722**

[a]The crash type categories are mutually exclusive. We defined automobiles as Fatal Accident Reporting System (FARS) body type codes 1-9 (including convertibles, two- and four-door sedans, three- and five-door hatchbacks, and station wagons but not vans or minivans). Light trucks are FARS body type codes 10-39 (including auto-based pickups, vans, minivans, and utility vehicles). Heavy trucks are codes 40-79 and 93; motorcycles are codes 80-82, 88, and 89; and other vehicles are codes 90-92, 97, and 99 (including all-terrain vehicles, snowmobiles, and farm equipment).

Source: Our analysis of 1991 FARS data from National Highway Traffic Safety Administration, Fatal Accident Reporting System 1991, DOT-HS-807-954 (Washington, D.C.: 1993).

Different models of automobiles appear to make very different contributions to this fatality toll. For instance, the Insurance Institute for Highway Safety (IIHS) has reported that the most “dangerous” automobile models have occupant fatality rates more than nine times higher than the

[2]In 1991, the total number of U.S. traffic fatalities was 41,462 (including deaths not related to automobiles).

"safest" models.[3] Further, some of the automobile characteristics associated with this variation in fatality rates are well known. For instance, sports cars have higher fatality rates than station wagons, and small cars have higher fatality rates than large cars.[4]

However, this does not mean that types of automobiles with high fatality rates are necessarily more dangerous than those with low fatality rates. This is because different types of drivers prefer particular types of automobiles, affecting both the number of collisions involving particular autos and, perhaps, the probability of serious injury in the event of a collision. For example, young drivers are much more likely to be involved in fatal accidents than others—drivers age 16 to 20 are involved in fatal accidents at a rate three times higher than that for drivers age 45 to 54—thereby inflating the fatality rate for types of cars preferred by young drivers. Similarly, some types of automobile occupants are more likely to be seriously injured in a collision than others. For example, in collisions in which at least one vehicle was towed from the accident scene, NHTSA (1992a) recently estimated that women automobile occupants are about 36 percent more likely to be hurt than men occupants in similar collisions. This suggests that types of cars with a disproportionate number of women occupants may have higher fatality rates than other cars.

Injury Mechanisms

As automobiles abruptly stop or change direction in a collision, occupants continue moving in the original direction of travel. This independent movement of an occupant within a rigid vehicle that is decelerating more quickly than its occupant provides several opportunities for injury. First, some occupants are injured by being ejected (either partially or totally) from the vehicle. Ejection substantially increases the risk of serious injury—ejected occupants are three to four times more likely to be killed in a collision than occupants who do not leave the vehicle. Second, occupants can collide with the interior of the vehicle or other objects intruding into the passenger compartment. This "second collision" (following the "first collision" of the automobile striking an object) is understandably worse if it occurs at high speed, involves impact with a sharp or unyielding portion of the car's interior, or involves contact with part of another vehicle or a roadside object that has penetrated the passenger compartment. Finally, because different portions of an

[3]For example, IIHS (1991) reported that the automobile model with the highest fatality rate in the late 1980's was the Chevrolet Corvette Coupe, with 4.7 deaths per 10,000 registered vehicles. The Volvo 240 had the lowest fatality rate for that period at 0.5 deaths per 10,000 registered vehicles.

[4]For example, according to the IIHS (1991) report of fatality rates in the late 1980's, the fatality rate for midsize sports cars was 2.5 times that of midsize station wagons and vans. For four-door cars, the fatality rate for small cars was 40 percent greater than the rate for large cars.

occupant's body decelerate at different rates, internal injuries can be caused by the "third collision" of soft tissues against hard, bony structures. For example, in high-speed collisions, the skull decelerates more quickly than the brain, potentially causing injury to the brain as it strikes the hard skull.

Automobile Safety Design

Automobiles, and federal automobile safety regulations, are designed to protect their occupants from these dangers in several ways. One way is to attempt to reduce the deceleration forces acting on occupants. Deceleration forces can be reduced by designing the structure of a vehicle to absorb as much energy as possible before the crash forces are transmitted to the passenger compartment or by giving the occupant more time to slow down, thereby reducing the maximum force level the occupant is subjected to. The latter can be accomplished by starting the deceleration period more quickly (for example, by designing safety belts that begin holding back the occupant sooner) or by increasing the total deceleration period (for example, by lengthening the front end of the vehicle).

Another way cars may protect their occupants is by encasing them in a protective compartment that preserves a living space and prevents the intrusion into the passenger compartment of striking vehicles or other objects (such as light posts or trees) that a car hits. Third, automobiles are designed to keep their occupants both in the vehicle and away from interior surfaces. This is most obviously accomplished through the use of safety belts, but a number of other components are also intended to keep the occupant in the vehicle, including door latches and windshields that are reinforced to eliminate potential ejection routes. In addition, automobile interiors are designed to absorb energy from the occupant and to limit the occupant's movement rather than serve as a rigid barrier. Energy absorbing steering columns are one example.

There is little doubt that cars from recent model years, as a group, are safer than automobiles from past model years and that some of this improvement can be attributed to federal government safety regulations. For instance, in comparing the crash test results of cars from model years 1980 and 1991, NHTSA researchers found that one set of scores measuring injury potential had declined about 30 percent during the intervening years (Hackney, 1991). Similarly, Evans (1991b) estimated that the total effect of nine federal motor vehicle safety standards enacted by 1989 had been to reduce the occupant fatality rate by about 11 percent.

Objective, Scope, and Methodology

Objective

The objective of this report is to examine the independent effects of a number of factors—crash type, crash severity, automobile weight and size, safety belt use, and occupant age and gender—on the risk of injury in an automobile crash. We are concerned with both crashworthiness and aggressivity. Crashworthiness refers to the extent to which automobiles protect their occupants in a collision, and aggressivity refers to automobile characteristics that affect the safety of the occupants of the other vehicles in a collision.

Scope

We restricted the scope of the study in several ways in order to obtain a clear picture of the most important phenomena. First, we looked only at the safety of automobile occupants and the dangers automobiles pose to occupants of other vehicles. We were not directly concerned with factors affecting the safety of occupants of other types of passenger vehicles, such as pickup trucks, vans, minivans, and multipurpose vehicles; we considered these vehicles only as they affect the safety of automobile drivers in two-vehicle collisions. In our judgment, concerns about the safety of light trucks and other passenger vehicles differ significantly from that of automobiles. Light trucks and other passenger vehicles are less stable and thus roll over more frequently than automobiles, and they have been subject to less stringent safety regulations than automobiles.

Second, our statistical analysis focused on model year 1987 and later cars, because the safety experiences of those cars are more likely to apply to today's new cars than are the safety experiences of older ones. Finally, we considered in our analysis only the injury experiences of drivers, not those of automobile passengers or factors specifically affecting the safety of child occupants. (Roughly half of the automobiles on the road have no occupants other than the driver.)

Methodology

To meet our objective, we reviewed technical reports from NHTSA and other sources and consulted auto safety experts and representatives of automobile manufacturers. We also conducted our own statistical analyses of traffic safety databases obtained from NHTSA. Our primary data set was compiled from the National Accident Sampling System—Crashworthiness

Data System (NASS) for 1988 through 1991. NASS is a nationally representative probability sample of all police-reported crashes involving a passenger car, light truck, or van in which at least one vehicle was towed from the scene. In addition, all the automobiles included in NASS were towed from the crash site. Thus, the automobiles in NASS, as a whole, are much more likely to have injured occupants than are cars involved in typical crashes. Not only are police-reported crashes more severe than those not reported to the police, but tow-away crashes on the whole are also more severe than those not involving tow-aways. Indeed, almost all serious occupant injuries occur in police-reported tow-away collisions.[5]

For our analysis, we selected a subset of cases from the NASS data for 1988 through 1991. We included all one-car collisions involving a 1987 or newer model year automobile and all collisions between a model year 1987 or later automobile and any other car, van, pickup truck, or other light truck. These crash types, taken together, accounted for about 81 percent of all automobile occupant fatalities in 1991. The remaining 19 percent occurred in types of crashes that we did not include in our data set because of a lack of cases, principally collisions with medium and heavy trucks (about 10 percent of the 1991 total).

In our statistical analyses, we used logistic regression to look at the independent contributions of a variety of factors on the probability of driver injury.[6] Driver injury was indexed with a dichotomous outcome variable coded "1" if the driver was hospitalized or killed in the crash and "0" otherwise. The regression analysis allowed us to isolate the effects of one factor (for example, automobile weight) while statistically holding constant the other factors (for example, collision severity as well as driver age and gender). Regression analysis answers the question: If there were no differences among these drivers except for the factor of automobile weight, for example, how would that factor predict the probability of driver injury? (The data sets and analyses are described in appendix I.)

[5]For example, in a separate analysis not detailed here, we examined all police-reported crashes for model year 1987 to 1989 cars in North Carolina for calendar year 1990. Injuries to automobile drivers categorized as "serious" by North Carolina law enforcement personnel occurred about 39 times more often in crashes in which at least one vehicle was towed away than in other crashes, and 97 percent of all "serious" driver injuries were in tow-away crashes.

[6]For the logistic regressions, we used the Survey Data Analysis (SUDAAN) statistical package. SUDAAN takes into account the stratification and unequal selection probabilities inherent in the sampling design of NASS. Failure to consider the sampling design in the regressions is likely to produce artificially low standard errors, biasing the analysis in favor of finding relationships that appear to be statistically significant but that stem, in fact, from chance. For more information about the sampling plan for NASS, see NHTSA (1991c). For more information about SUDAAN, see Shah et al. (1992).

The studies that we reviewed from the traffic safety literature differed in several ways that increase the difficulty of comparing their results and of relating their conclusions to our own findings. For instance, some studies focused on injuries to automobile drivers, as we did, while others examined injuries to all automobile occupants, not just drivers. Similarly, different studies looked at slightly different sets of automobile crashes—at tow-away crashes (as we did) or at all police-reported crashes or only at crashes in which a fatality occurred. In addition, the studies employed different outcome measures. Our analysis concerned driver hospitalizations or deaths, while other studies looked only at fatalities or at injuries considered serious or worse or at injuries categorized as moderately severe or worse, for example. While these and other differences mean that the studies we cite rarely produced precisely equivalent findings, in most the findings were roughly the same. In particular, the direction of the findings was almost always the same (that is, whether a factor increases or decreases the risk of injury), and there was usually approximate agreement about the size of the effect (that is, whether a factor has a large effect on injury risk or only a minor influence).[7]

Our work was performed in accordance with generally accepted government auditing standards.

Organization of the Report

Chapter 2 looks at the effects of crash type and crash severity. It also discusses the effects of automobile size and safety belt use in three different configurations: one-car rollover crashes, one-car nonrollover crashes, and collisions between cars and other light vehicles. Chapter 3 examines the influence of driver age and gender on injury probability. Chapter 4 discusses the relative contributions of driver and automobile factors to driver injury. Chapter 5 discusses the potential for improving automobile safety. Appendix I describes our data set and statistical analyses.

[7]In general, because our data set included only very severe crashes, the effect sizes from our analyses were somewhat larger than those reported from analyses using a wider range of crashes. The reason for this is that almost all serious injuries occur in police-reported tow-away crashes, and data sets with a wider range of crashes thus necessarily include a high proportion of cases without serious injuries. Therefore, any statistical relationships are diluted by the presence of many cases in which there is little chance of injury regardless of the values of the independent variables.

The Effects of Automobile Weight, Automobile Size, Safety Belts, and Air Bags in Different Types of Crashes

This chapter discusses the safety consequences of crash characteristics, automobile weight and size, and safety belts and air bags. The chapter begins with a discussion of crash characteristics that are related to occupant injury, including the injury risk associated with one-car rollover crashes, one-car nonrollover crashes, and collisions with an automobile, a van, or a light truck. It then examines the safety consequences of automobile weight and size as well as of safety belt use in the different crashes. Each section summarizes relevant findings from the literature and then presents the results of our analyses of the NASS data. The chapter ends with a look at the effects of air bags.

Crash Characteristics

Previous Findings

The great majority of traffic crashes do not involve serious injury. A large proportion of all traffic crashes are not reported to the police (Evans, 1991b). And NHTSA has estimated that about one third of crashes reported to the police involve personal injury (two thirds having property damage only) and that just 6 percent involve a severe or fatal injury (NHTSA, 1991b).

Nonetheless, some crashes are much more likely to lead to serious injury than others. First, some types of crashes are more severe than others. Overall, single-car crashes are more likely to seriously injure occupants than are multiple-vehicle collisions. Single-vehicle crashes account for about 30 percent of police-reported crashes annually, yet in 1991 about 45 percent of all automobile occupant fatalities were in these collisions. Single-car rollover crashes are particularly dangerous, accounting for only about 2 percent of all police-reported accidents but about 20 percent of occupant fatalities (NHTSA, 1991b). A major reason for the relative severity of single-car crashes is that most crashes involving drunk drivers are single-car incidents, and crashes involving drunk drivers tend to be more severe than other collisions. For example, NHTSA reported that 53 percent of drivers killed in single-vehicle crashes in 1991 were intoxicated, compared with only 21 percent of the drivers killed in multiple-vehicle collisions (NHTSA, 1993b).

Second, for nonrollover crashes, some points of impact on the automobile are more dangerous than others. The preponderance of fatal crashes other than rollovers involve frontal impacts, followed at a distance by left- and right-side impacts. For example, table 2.1 indicates that 43 percent of all automobile occupant fatalities in 1991 occurred in frontal impacts, or more than half of all fatalities that did not occur in single-car rollovers.

Table 2.1: Automobile Occupant Fatalities by Rollover or Principal Impact Point, 1991

Type	Fatality
Nonrollover: principal impact point[a]	
Front	43%
Left side	16
Right side	15
Rear	3
Other	3
Single-car rollover	20
Total	**100%**

[a]Frontal impact points are clock positions 11:00, 12:00, and 1:00; left-side impact points are clock positions 8:00, 9:00, and 10:00; right-side, 2:00, 3:00, and 4:00; and rear, 5:00, 6:00, and 7:00.

Source: Our analysis of 1991 FARS data from National Highway Traffic Safety Administration, Fatal Accident Reporting System 1991, DOT-HS-807-954 (Washington, D.C.: 1993).

Third, crashes at high speeds are more dangerous than others. For example, Joksch (1993) estimated that the risk to drivers of fatal injury in two-car collisions was about 1 percent for a 20 mph collision, 10 percent for a 35 mph collision, and 44 percent for a collision involving a change in velocity of 50 mph.[1] NHTSA (1993e) recently reported similar findings for restrained vehicle occupants, noting, for instance, that the probability of fatal injury is about nine times as great in frontal collisions with a change of velocity of 40 mph as in those with a change of 30 mph. That the probability of death increases sharply with impact speed is one reason for the predominance of frontal impacts in fatal crashes, since frontal impacts are likely to involve cars that are moving forward.

The Results of Our Analysis of Crash Data

Here we report how injury risk and driver and automobile characteristics vary by crash type. Our data, from NASS, were for model year 1987 and later cars in three types of police-reported tow-away crashes in 1988-91: one-car rollovers, one-car nonrollovers, and collisions with other cars, vans, and light trucks.

[1]Change in velocity refers to the nearly instantaneous change in a vehicle's speed in a crash. For example, a vehicle that was abruptly stopped from a travel speed of 30 mph would have a change in velocity of 30 mph (from 30 to 0). In contrast, a parked vehicle struck from the rear and moved sharply forward at 10 mph would have a change in velocity of 10 mph (from 0 to 10).

The pattern of injury risk by crash type that we found in the NASS data set reflects the pattern described in the literature. As table 2.2 indicates, one-car crashes are more dangerous than multivehicle collisions. One-car rollover crashes, in particular, are much more dangerous than other crash types, with a rate of driver hospitalization or death that is double that of one-car nonrollover crashes and four times that of collisions with cars and light trucks.

Table 2.2: Driver Injury, Driver Characteristics, and Automobile Weight, by Crash Type

	Crash type[a]		
Item	**One-car rollover**	**One-car nonrollover**	**Collision with other cars or light trucks**
Driver characteristic			
Injury			
Hospitalized or killed	15.7%	7.0%	4.0%
Killed	3.0	0.7	0.2
Male	62.5	58.0	46.3
Age			
16-24	53.6	43.3	33.7
25-44	36.1	42.1	43.3
45-64	7.0	10.8	15.0
65+	3.3	3.8	8.0
Average automobile curb weight (lbs)[b]	2,502	2,688	2,669

[a]Percentages and means weighted by the National Inflation Factor to represent population values. The unweighted numbers of cases are 457 for one-car rollovers, 1,253 for one-car nonrollovers, and 4,393 for collisions with other cars or light trucks. The corresponding estimated population numbers of cases are 104,806, 422,056, and 1,510,653. (See appendix I.)

[b]Curb weight refers to the weight of an unoccupied automobile, including gasoline and other fluids. In the NASS data set, curb weight is recorded only to the nearest 100 pounds. Therefore, estimates of the average curb weight of any group of automobiles are less exact than they would be if curb weight were recorded more precisely.

Source: NASS 1988-91 data for model year 1987 and newer automobiles.

In addition to having a higher rate of driver injury, one-car crashes are disproportionately likely to involve men drivers and young drivers. (See table 2.2.) We found that about 60 percent of the drivers in one-car crashes were men, compared with approximately 46 percent in two-vehicle collisions. In addition, while close to half of the drivers in one-car crashes were 16 to 24 years of age, only about one third of the drivers in collisions with other cars or light trucks were that young. These findings are consistent with those of our companion report, Highway Safety: Factors Affecting Involvement in Vehicle Crashes (GAO, 1994), in which we found that driver age and gender are more strongly related to involvement in single-vehicle crashes than they are to involvement in two-vehicle collisions.

In addition, as table 2.2 indicates, the average curb weight of automobiles in one-car rollover crashes was somewhat lower than that of cars involved in other crashes. As we noted in Highway Safety: Factors Affecting Involvement in Vehicle Crashes, involvement in rollover crashes increases as automobile weight decreases.

Just as the literature suggests, we found that the risk of injury to drivers is significantly affected by impact point. In particular, we found that two-vehicle collisions involving head-on impacts between vehicles moving in opposite directions are much more dangerous than other two-vehicle crashes. The risk of driver injury or death is about five times as great in head-on collisions as in other two-vehicle collisions. For crashes other than head-on collisions, frontal impacts and left-side impacts had higher rates of driver hospitalization or death than others.

Finally, we found that high impact speeds are, not surprisingly, more dangerous than low impact speeds. Considering the three crash types together, we estimated that each increase of 10 mph in the change of velocity at impact increases the probability of driver hospitalization or death nearly sevenfold.

Automobile Weight and Size

Previous Findings

As we have previously reported, safety experts agree that, in general, heavier and larger cars are both more crashworthy and more aggressive than lighter and smaller automobiles (GAO, 1991). Thus, in the event of a collision, occupants are less likely to be hurt when they are in heavier and larger cars and when they are struck by lighter and smaller cars.

However, there is some disagreement in the literature about which is the more important dimension for occupant safety, weight or exterior size (that is, overall length and width).[2] Proponents of weight as the important dimension argue that automobile mass protects occupants from injury because it is aggressive—that is, heavier cars knock down objects and push other vehicles back, thereby transferring momentum and energy to the struck object, including other vehicles, that could otherwise affect occupants of the striking vehicle (see, for example, Evans and Frick, 1992). In contrast, proponents of exterior size as the more important dimension maintain that large vehicles protect their occupants by absorbing crash energy without increasing the injury risk of other roadway users (for example, see Robertson, 1991).

In most cases, this debate is of little practical significance now, since weight and exterior size are very highly correlated—that is, heavy cars are almost invariably also long and wide—but it has important implications for the design of future automobiles. If exterior size is the more important dimension, using lighter weight materials could make future automobiles lighter without decreasing exterior size, thus increasing fuel efficiency without exacting a safety cost. Conversely, using lighter weight materials would involve a safety cost if weight is the more important dimension.

In addition, estimates of the amount of additional protection offered by a given increase in automobile weight vary considerably. For example, consider the effects of a 500-pound increase in the weight of one automobile in a collision with another, assuming no change in the weight of the latter. Klein, Hertz, and Borener (1991) used data from two states to generate two different estimates of the decreased risk of serious driver injury from that automobile weight increase—13 percent and 20 percent. Other estimates are higher. For example, Evans (1982) concluded that this increase in automobile weight would reduce a driver's risk of fatal injury by about 29 percent.

Further, the protective effect of automobile size appears to differ by crash type. First, it is likely that this effect is somewhat less pronounced in one-car nonrollover crashes than in multivehicle collisions (Evans, 1991b). For example, in the 1991 paper by Klein and colleagues, NHTSA researchers estimated that a 500-pound increase in automobile weight reduces the risk of driver fatality by not quite 5 percent in one-car nonrollover crashes, somewhat less than the estimates of 13 percent and 20 percent for two-car collisions.

[2]Exterior size is measured by wheelbase—that is, the distance between the front and rear axles.

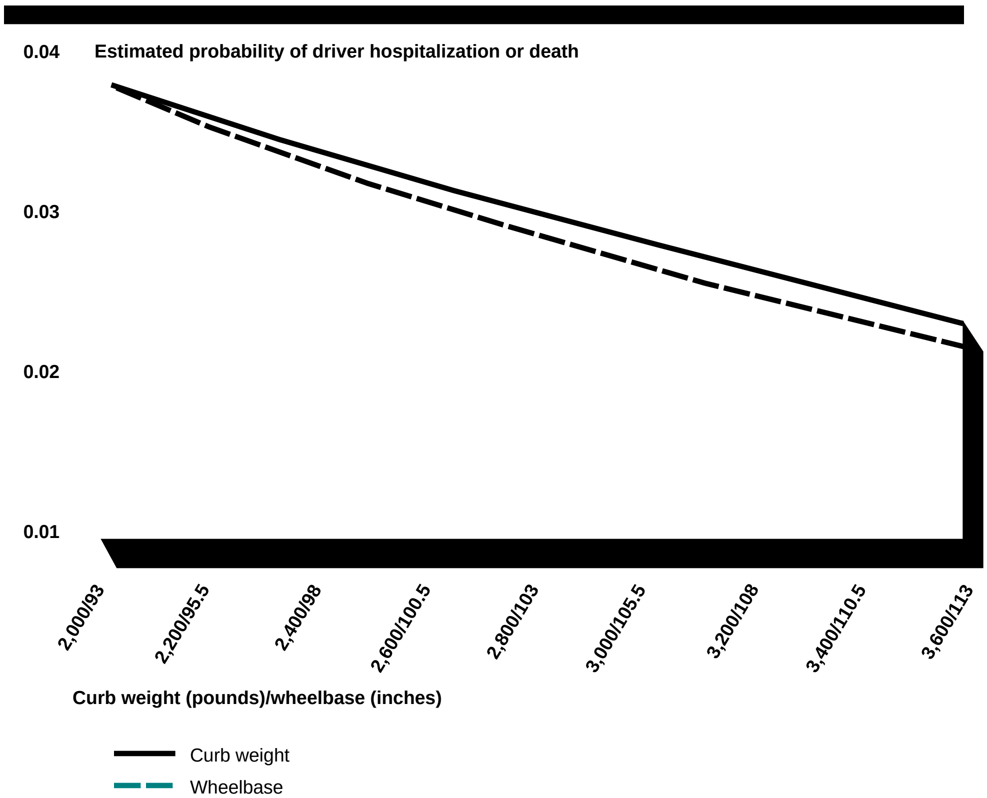
Second, although it is well documented that small cars are much more likely to be involved in one-car rollover crashes than are large cars (see, for example, GAO, 1994), the literature is less clear about the safety consequences of automobile size once a rollover has occurred. On the one hand, in examining the effects of reduced automobile weight and size on safety in rollover crashes, some researchers have focused on the increased number of rollover crashes among light and small cars (Evans, 1991b; Kahane, 1990; NHTSA, 1991a). The implication of these studies is that automobile weight and size do not affect crashworthiness in rollovers; otherwise, these researchers would have included weight and size as factors in their calculations. On the other hand, some direct studies of crashworthiness in rollovers have found that drivers of larger cars are more likely to be injured than drivers of smaller cars in rollovers (see, for example, Partyka and Boehly, 1989). One explanation for this finding is that it takes more energy to roll over a heavy automobile than a light one, meaning that the typical rollover crash involving heavy autos is more severe (that is, occurs at a higher speed) than the typical rollover involving light cars (see, for example, Terhune, 1991).

The Results of Our Analysis of Crash Data

The Effects of Automobile Weight and Size Vary by Crash Type

After combining all the crashes in our database (one-car rollovers, one-car nonrollovers, and collisions with cars and light trucks), we found that the risk of injury to drivers was significantly reduced as car weight and wheelbase increased in our sample. (See figure 2.1.) We estimated that the risk of driver hospitalization or death decreases about 14 percent for every additional 500 pounds of automobile weight and about 13 percent for each additional 5 inches of wheelbase. (See tables I.1 and I.2.)

Figure 2.1: Estimated Probability of Driver Hospitalization or Death in One-Car Crashes and Collisions With Other Cars or Light Trucks, by Automobile Weight and Wheelbase[a]



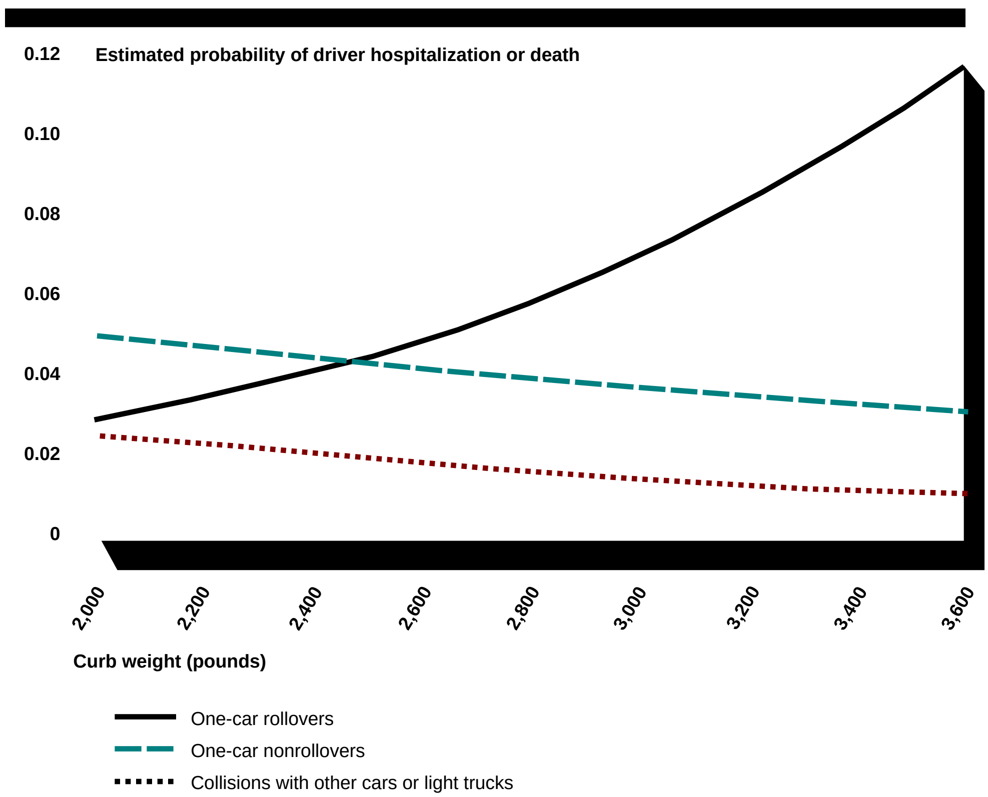
[a]Estimated probability of driver injury in an average crash for a typical driver: a 30-year-old man wearing manual lap and shoulder safety belts. Injury probability changes by 0.97 for each additional 100 pounds of automobile weight and by 0.973 for each additional inch of wheelbase.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Further, considering all crash types taken together, we could not statistically differentiate the injury reduction effects of curb weight and wheelbase. That is, the benefits of increasing weight and wheelbase were roughly equivalent in reducing injuries, and we were unable to establish that one had a stronger influence than the other. The nearly equivalent slopes of the lines for weight and wheelbase in figure 2.1 demonstrate this. The endpoints of the lines in figure 2.1 represent approximately the 5th and 95th percentiles of automobile weight and wheelbase in this data set. Thus, 2,000-pound cars are among the lightest and 3,600-pound cars are among the heaviest in this database of cars involved in serious crashes; similarly, cars with a wheelbase of 93 inches are among the shortest, 113 inches among the longest.[3] Figure 2.1 shows that, for all three crash types taken together, whether measured by weight or wheelbase, drivers in the heaviest and largest cars had a risk of hospitalization or death about 40 percent less than the drivers of the lightest and smallest cars.

However, these overall effects mask the fact that automobile weight and wheelbase have very different safety consequences in different types of crashes. Figure 2.2 shows the estimated effects of curb weight separately for the three crash types (see also tables I.3-I.5); figure 2.3, the estimated effects of wheelbase (see also tables I.6-I.8).

Figure 2.2: Estimated Probability of Driver Hospitalization or Death by Crash Type and Automobile Weight[a]

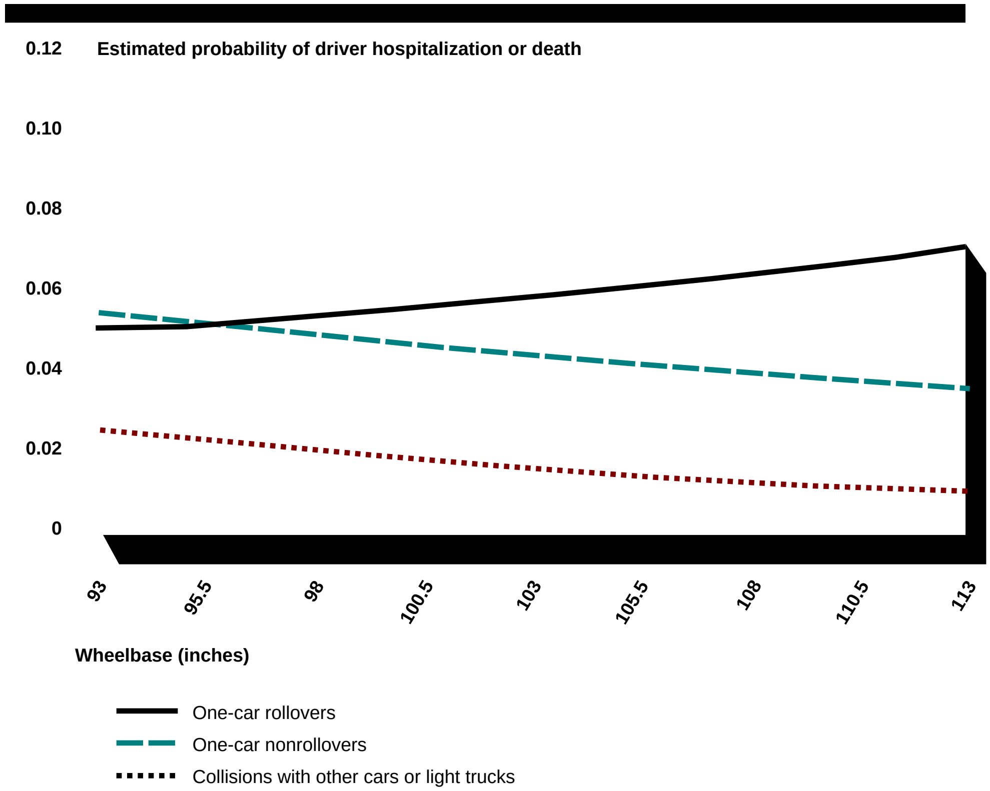


[a]Estimated probability of driver injury in an average crash for a typical driver: a 30-year-old man wearing manual lap and shoulder safety belts. Injury probability changes by 1.097 for each additional 100 pounds of automobile weight in one-car rollover crashes, by 0.968 in one-car nonrollover crashes, and by 0.948 in collisions with other cars or light trucks.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

[3]The heaviest cars in the data set weighed more than 4,400 pounds, the lightest less than 1,600 pounds. The longest cars had wheelbases of more than 120 inches, the shortest less than 84 inches.

Figure 2.3: Estimated Probability of Driver Hospitalization or Death by Crash Type and Automobile Wheelbase[a]



[a]Estimated probability of driver injury in an average crash for a typical driver: a 30-year-old man wearing manual lap and shoulder safety belts. Injury probability changes by 1.020 for each additional wheelbase inch in one-car rollover crashes, by 0.980 in one-car nonrollover crashes, and by 0.958 in collisions with other cars or light trucks.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Most importantly, although increasing weight and wheelbase reduces the risk of driver injury in one-car nonrollover crashes and in collisions with other cars or light trucks, drivers in heavier cars were much more likely to be hospitalized or killed in one-car rollover crashes than were drivers of lighter automobiles. For one-car rollover crashes, we estimated that each 500 pounds of additional automobile weight increases the risk of driver hospitalization or death by about 59 percent. This effect is solely a function of automobile weight, not of wheelbase; we found that the relationship between wheelbase and driver injury was not statistically significant in one-car rollovers. This finding agrees with the report of Partyka and Boehly (1989) that drivers of heavier and larger cars are more likely to be injured in rollovers than drivers of lighter and smaller cars. This finding is also consistent with the explanation that it takes more energy to roll over a heavy automobile than a light one, meaning that rollover crashes involving heavy autos occur at higher speeds than rollovers involving light cars. However, it is important to keep in mind that the rate of involvement in one-car rollover crashes is much greater for light cars than for heavy ones, so this finding does not necessarily mean that, considering both involvement and crashworthiness, drivers of heavy cars are more likely to suffer injuries in one-car rollovers.

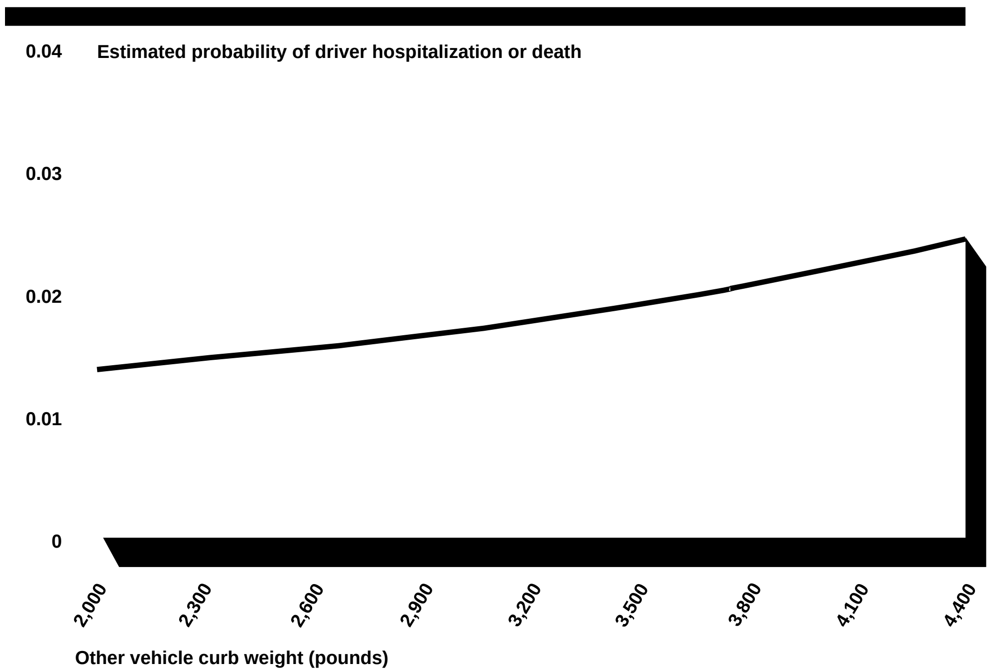
Figures 2.2 and 2.3 also show that we found a tendency for the risk of driver hospitalization or death to decrease with increasing car weight and size in one-car nonrollover crashes, but neither curb weight nor wheelbase was a statistically significant predictor of driver injury in those crashes. In contrast, we found that in collisions with other cars and light trucks, both automobile weight and wheelbase were statistically significant predictors of driver injury. In those crashes, we estimate that each additional 500 pounds of automobile weight decreased the risk of driver hospitalization or death by about 23 percent and each 5 inches of additional wheelbase lowered the risk of driver injury approximately 19 percent. These findings reflect the pattern, described in the literature, that the protective effects of automobile weight and wheelbase are somewhat greater in multivehicle collisions than in single-car nonrollover crashes.

Characteristics of the Other Vehicle Affect Injury Risk

In two-vehicle collisions, the injury risk of an automobile occupant is affected not only by the characteristics of his or her own automobile but also by the characteristics of the other vehicle. We looked at the effects of the weight and vehicle type of the other vehicle on the probability of injury for the first driver: both factors affect the aggressivity of the other vehicle.

First, not surprisingly, heavier vehicles pose more of a risk than lighter vehicles. (See figure 2.4.) In our analysis, each increase of 500 pounds in the weight of the other vehicle increased the probability of hospitalization or death by about 13 percent, holding other factors constant. (See table I.5.) It is important to note that the magnitude of this aggressive effect of vehicle weight is less than that of the protective effect of weight described earlier. (We estimated that each additional 500 pounds of automobile weight reduces the probability of injury by about 23 percent.) After statistically controlling for the influence of other factors, we found that this ratio of the protective effect to the aggressive effect of automobile weight of 1.77 to 1 is roughly consistent with the findings of other researchers. For example, Klein, Hertz, and Borener (1991), analyzing data from two different states, generated two estimates of the size of this ratio in two-car collisions: 1.54 to 1 and 1.30 to 1.

Figure 2.4: Estimated Probability of Driver Hospitalization or Death in Collisions With Other Cars or Light Trucks by Weight of the Other Vehicle[a]

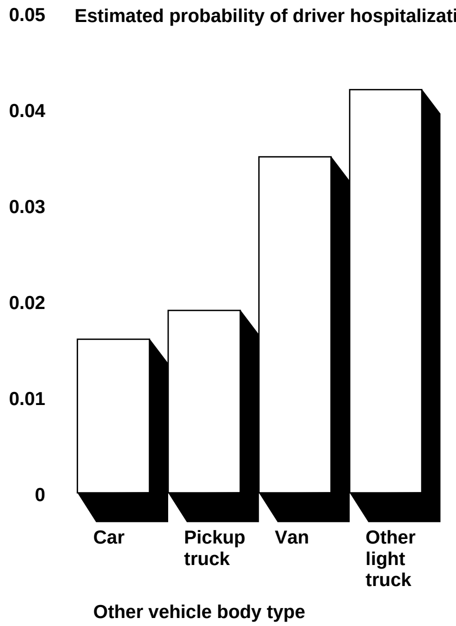


[a]Estimated probability of driver injury in an average crash for a typical driver: a 30-year-old man wearing manual lap and shoulder safety belts. Injury probability changes by 1.025 for each additional 100 pounds in the weight of the other vehicle.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Second, figure 2.5 shows that driver injury risk is strongly influenced by the body type of the other vehicle. We found that while pickup trucks do not pose more danger than automobiles, vans and other light trucks are more aggressive than automobiles. Indeed, statistically controlling for the weight of the driver's car and of the other vehicle, we estimate that the risk of hospitalization or death for the driver is more than twice as great in collisions with vans and light trucks than with other cars or light vehicles. (See also table I.5.) This finding reflects two characteristics of vans and light trucks. One is that because vans and light trucks can carry heavy cargo loads, these vehicles may be, in reality, heavier than the curb weight measurements available to us indicate. The second characteristic is that the structure and design of vans and other light trucks make those vehicles especially dangerous for automobile occupants in two-vehicle collisions (National Research Council, 1992; Terhune and Ranney, 1984).

Figure 2.5: Estimated Probability of Driver Hospitalization or Death in Collisions With Other Cars or Light Trucks by Type of the Other Vehicle[a]



[a]Estimated probability of driver injury in an average crash for a typical driver: a 30-year-old man wearing manual lap and shoulder safety belts.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Safety Belts

Previous Findings

Safety belts greatly reduce the risk of injury and death in roadway crashes. In a recent review of studies of safety belt effectiveness, we concluded that most studies show that belted vehicle occupants have a risk of serious injury or death that is approximately 50 to 75 percent less than that of unrestrained occupants (GAO, 1992). Other researchers have found safety belts to have slightly smaller effects. For example, NHTSA (1993d) estimated that when manual lap and shoulder safety belts are used in serious crashes, they reduce fatality risk by 45 percent. Similarly, Evans (1986) estimated that three-point lap and shoulder safety belts reduce a driver's risk of fatality by about 43 percent, with about half of that benefit the result of eliminating or attenuating impacts with the interior of the vehicle and about half the result of preventing occupant ejection.

There are three other important points about safety belt effectiveness. First, the effectiveness of safety belts varies by crash type. Belts are most effective in rollover crashes because they largely prevent occupant ejection (Evans, 1990; Partyka, 1988). They are also more effective in one-car crashes than in multivehicle collisions. For example, Evans and Frick (1986) estimated that safety belts reduce the risk of driver fatality in one-car crashes by 62 percent but by only 30 percent in two-car crashes. Second, belt effectiveness also varies by point of impact. Belts are most effective in frontal impacts and least effective in left-side impacts (Evans, 1990). Since one-car crashes are more likely to involve frontal impacts than are two-car collisions, this offers one possible explanation for the greater efficacy of safety belts in one-car crashes.

Third, it is likely that manual lap and shoulder belts are somewhat more effective than other safety belt configurations. For example, Evans (1991a) estimated that lap and shoulder belts reduce fatality risk in serious collisions by about 41 percent, compared with estimated risk reductions of 18 percent for lap belts only and 29 percent for shoulder belts only. Evans speculated that these two components have somewhat different functions, with lap belts primarily preventing ejection and shoulder belts mitigating contact with the interior of the vehicle. Comparing manual lap and shoulder belts to automatic belts, NHTSA (1993d) estimated that automatic safety belts, when used in serious crashes, reduce the risk of fatality by 42.5 percent, compared with an estimated fatality reduction of 45 percent for manual lap and shoulder belts.

The Results of Our Analysis of Crash Data

Considering all three crash types together, NASS researchers categorized 73 percent of the drivers in the NASS data set as using a safety belt at the time of collision, with those involved in one-car rollovers slightly less likely to be belted than others. This figure is higher than might be expected from the results of other estimates of safety belt use among the general driving population, particularly given that drivers involved in crashes are less likely to wear safety belts than others and that all the drivers included in our analysis had been involved in a crash. In one point of comparison, NHTSA estimated a 51-percent safety belt usage rate for all passenger cars in 1991 (NHTSA, 1992a). Further, it is well established that unbelted drivers are more reckless than belted drivers (Evans and Wasielewski, 1983; Evans, 1987; Preusser, Williams, and Lund, 1991; Stewart, 1993). As a result, unbelted drivers have much higher crash involvement rates than belted drivers: NHTSA (1992a) estimated that unbelted drivers have an involvement rate in potentially fatal crashes that is more than double that of belted drivers.[4]

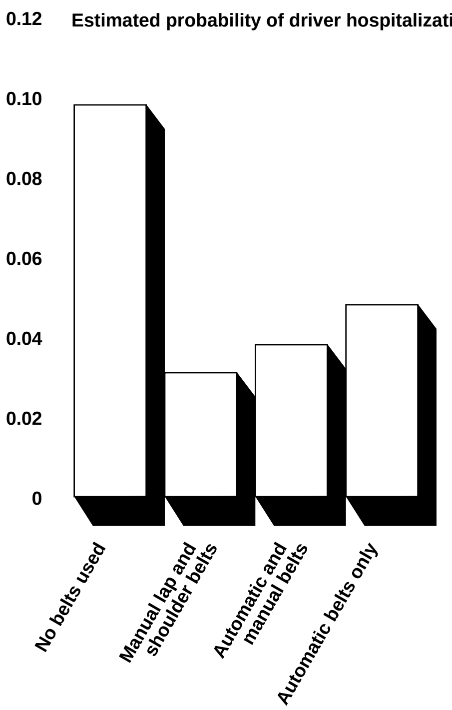
We cannot determine with certainty if, or to what degree, the safety belt use figures reported in NASS are incorrect, nor can we determine with certainty the extent to which any potential bias in those figures affected our analyses. For that reason, our results should be interpreted with caution. Nonetheless, because the results of our analyses concerning the relative effectiveness of different safety belt configurations in different types of crashes are consistent with the findings from the traffic safety literature, we believe that any potential bias has not seriously affected our findings.

For each of the three categories of crashes, we examined the performance of three safety belt configurations: (1) manual lap and shoulder belts, (2) automatic and manual belts combined (most commonly automatic shoulder belts and manual lap belts), and (3) automatic belts without manual components. Other safety belt configurations, including manual lap belts alone, had too few cases in the data set for us to estimate their effectiveness.

Statistically controlling for crash severity, driver characteristics, and other background factors, we found that, compared with unbelted drivers, drivers using any of the three safety belt configurations had greatly reduced risks of injury. We also found that, looking at the three types of crashes together, manual lap and shoulder belts were somewhat more effective in preventing driver injury than the other configurations. (See figure 2.6.) Compared with unbelted drivers, the estimated risk of hospitalization or death was reduced about 70 percent for those using manual lap and shoulder belts, about 63 percent for those using automatic and manual belts combined, and about 54 percent for those using automatic belts without manual components. (See also table I.1.)

[4]More specifically, NHTSA (1992a, pp. 20-21) estimated that an automobile fleet composed entirely of cars equipped with manual safety belts would have had a 48-percent belt usage rate in 1991 (with 52 percent of drivers unbelted) and that the manual belt use rate in “potentially fatal” crashes would have been 29.5 percent (with 70.5 percent of drivers unbelted). Therefore, by these estimates, the odds of drivers not using a belt in the general population would be 1.08 (52/48), the odds of drivers not using a belt in the crash-involved population would be 2.39 (70.5/29.5), and the relative risk of involvement in serious crashes of unbelted drivers would be 2.21 (2.39/1.08).

Figure 2.6: Estimated Probability of Driver Hospitalization or Death in One-Car Crashes and Collisions With Other Cars or Light Trucks by Safety Belt Use[a]



[a]Estimated probability of driver injury in an average crash for a 30-year-old man.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

We also found small variations in safety belt performance among the different types of crashes. Safety belts were somewhat less effective in collisions with other cars or light trucks than they were in single-car crashes. For example, in our analysis, manual lap and shoulder belts reduced the risk of driver hospitalization or death by 83 percent in one-car rollover crashes and by 80 percent in one-car nonrollover crashes but by only 64 percent in collisions with other cars or light trucks. (See tables I.3-I.5.)

Air Bags

Evaluations of the effectiveness of air bags are hampered by the relatively small number of cars now equipped with them (although all passenger cars, vans, and light trucks will be required to have both driver- and passenger-side air bags by the 1998 model year). There were too few automobiles with air bags in the NASS data set for us to conduct our own analysis of air bag effectiveness. Nonetheless, some of the characteristics of air bag performance have already been established. First, air bags are effective only in frontal impacts; they do not protect drivers in side impacts or other nonfrontal collisions (see, for example, Zador and Ciccone, 1993). While frontal impacts account for by far the greatest proportion of automobile occupant fatalities, more than half of occupant fatalities do not involve frontal impacts. (See table 2.1.)

Second, air bags offer additional protection to drivers already wearing safety belts. Researchers have found that belted drivers with air bags are about 10 percent less likely to be fatally injured than are belted drivers without air bags (Evans, 1991b; Zador and Ciccone, 1993). For example, NHTSA (1993d) estimated that lap and shoulder safety belts alone reduce automobile driver fatality risk by about 45 percent. In that paper, NHTSA also estimated that drivers with lap and shoulder belts and air bags are about 50 percent less likely to be killed than unbelted drivers, for a safety increment of close to 10 percent (50/45 = 1.11, or about 10 percent).

Finally, safety belts alone are much more effective than air bags alone. Estimates of the effectiveness of air bags for drivers who do not wear safety belts indicate that those drivers are approximately 20 to 30 percent less likely to be killed in a collision than are unbelted drivers without air bags (NHTSA, 1993d; Zador and Ciccone, 1993). In contrast, as noted previously, drivers wearing lap and shoulder safety belts are, by the most conservative estimate, 41 percent less likely to be killed than unbelted drivers.[5]

Summary

One-car crashes have higher injury rates than multivehicle collisions, and one-car rollover crashes are more dangerous than one-car nonrollover crashes. Further, automobile drivers are especially likely to suffer serious injury in crashes involving a frontal impact, and the probability of injury is greater at higher impact speeds.

[5]A potential concern about air bags that has not yet been thoroughly examined is that driver ejection rates may be somewhat higher in cars with air bags. NHTSA (1992a, pp. 50-51) reported that, in fatal accidents, drivers in vehicles with air bags are significantly more likely to be ejected from the vehicles than are drivers in cars with only manual safety belts. NHTSA appropriately noted that this result in a database containing only fatal accidents is suspect, since drivers "saved" by air bags are not included in the database unless another person in the crash was killed. However, the fact that a statistically significant relationship between air bags and ejection was found in a data set with a relatively small number of cases suggests that this may be a strong effect. At the least, this question deserves further investigation.

The protective effects of automobile weight and wheelbase differ by crash type. In one-car rollover crashes, drivers of heavier cars are more likely to be hospitalized or killed than drivers of lighter cars. Automobile wheelbase is not statistically related to injury risk in rollovers. In contrast, increasing both weight and wheelbase reduces the risk of driver injury in one-car nonrollover crashes and in collisions with other cars or light trucks, with a larger safety benefit in multivehicle collisions than in one-car nonrollover crashes.

Safety belts substantially reduce the risk of driver injury. Manual lap and shoulder belts are somewhat more effective than other belt configurations, and safety belts are more beneficial in one-car crashes than in multivehicle collisions. The traffic safety literature indicates that air bags offer a modest degree of additional protection to belted occupants and that safety belts without air bags are much more effective than air bags without safety belts.

Agency Comments and Our Evaluation

DOT had one general comment concerning the topics presented in this chapter: it maintained that the subset of the NASS data we used in the report is inappropriate for studying the effect of car size on safety and, more particularly, that the sample size is inadequate for assessing the consequences of changing the weight of both vehicles in a two-vehicle collision. We disagree. As the findings presented in this chapter demonstrate, the NASS data set we constructed clearly was adequate for uncovering a number of statistically significant relationships (the analyses are described in appendix I). In addition, our findings are similar to NHTSA's findings from statistical analyses of state accident databases (particularly concerning the effects of the weights of both vehicles in two-car collisions; see Klein, Hertz, and Borener, 1991) and to NHTSA's findings from statistical analyses of a slightly different NASS database (see table I.1 and NHTSA, 1992a, p. 72).

The Effects of Gender and Age on Driver Injury Risk

The Vulnerability of Women and Older Drivers

Previous Findings

Safety researchers have consistently found that women automobile occupants have a greater risk of injury in a collision than men and that the risk of injury increases with occupant age. For example, NHTSA (1992a) found that women vehicle occupants involved in tow-away crashes are 36 percent more likely than men to suffer an injury categorized as moderately severe or worse. NHTSA also found that the risk of moderate injury increases about 2 percent for each year of age, meaning that, compared with 20-year-olds, 30-year-olds have a 21-percent greater risk of injury and 60-year-olds are more than twice as likely to be injured. Similarly, Evans (1988b) reported that 30-year-old women have a fatality risk in traffic crashes about 31-percent higher than 30-year-old men and that the risk of fatality increases about 2 percent for each year of age.

The Results of Our Analysis of Crash Data

Our analysis of the NASS data set of police-reported tow-away crashes produced similar findings. For statistically equivalent crashes, we found that women drivers are about 29 percent more likely to be hospitalized or killed than men drivers. We also found that drivers 65 and older are about 4.5 times more likely to be seriously hurt than drivers 16 to 24 years old in equivalent crashes. (See table I.1.)

Possible Explanations

Previous Findings

One explanation for the greater vulnerability of women drivers and older drivers emphasizes their inherent physical frailty. This view postulates that the same degree of physical trauma is more likely to produce injury in women than in men and in older automobile occupants than in younger ones, because women and older people are physically less resilient than men and younger people. Indeed, there is some support for the view that women are physically more vulnerable than men (Evans, 1988b), and that older people are more fragile than younger ones is well documented (for example, Mackay, 1988; Pike, 1989). The implication of this view is that the greater vulnerability of women and older persons is not amenable to correction through automobile design changes, because weaker individuals will be hurt more often than stronger ones no matter what.

Other possible explanations have not been carefully developed in the literature, but they tend to involve speculation that some characteristic of the vulnerable group interacts with automobile design to cause a safety problem. For example, because women are shorter than men, on the average, they may sit closer to the steering wheel, causing them to hit the steering column more quickly in a crash. Similarly, the interaction of lower height and safety belts designed for average-sized drivers may oblige women, for reasons of comfort, to wear safety belts incorrectly more than men do, thereby increasing the injury risk of ostensibly belted women drivers relative to that of belted men drivers (see, for example, National Transportation Safety Board, 1988).

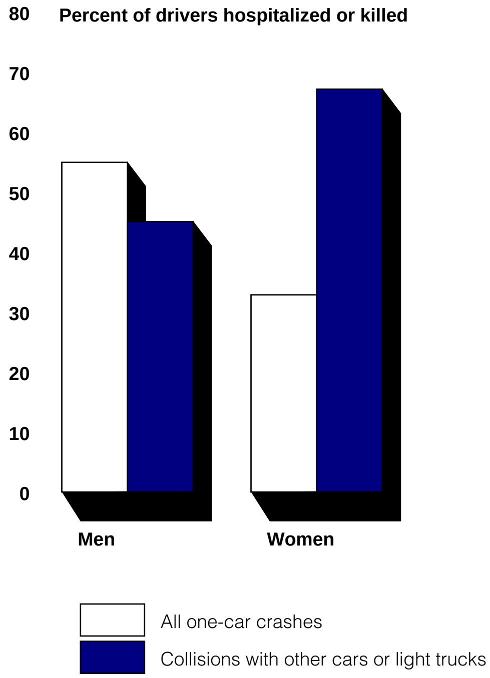
The Results of Our Analysis of Crash Data

Here, we discuss whether the factors we examined in chapter 2 differentially affect the probability of injury of women and men and of older and younger drivers. If the "inherent frailty" view is correct, women should be injured more than men, and older drivers more than younger drivers, regardless of crash type, automobile weight, or safety belt use. If any of these factors affect the relationship between gender or age and injury risk, the credibility of this view would be called into question, as this would mean that something other than frailty also makes an important difference. It would also indicate that the safety of women and older drivers could be at least somewhat improved by automobile design changes.

Factors Affecting Women Drivers

Crash Type. The pattern of injury by crash type varies for women drivers and men drivers. Multivehicle collisions are a greater source of injury for women than they are for men. Figure 3.1 shows our finding that 67 percent of the women drivers hospitalized or killed were injured in collisions with cars and light trucks, with only one third injured in one-car crashes (11 percent in rollovers, 22 percent in nonrollovers). In contrast, only 45 percent of the men drivers hospitalized or killed were injured in collisions with cars and light trucks; most of the men drivers were hurt in one-car crashes (20 percent of the total in rollovers, 35 percent in nonrollovers).

Figure 3.1: Distribution of Driver Hospitalization or Death by Crash Type and Gender[a]



[a]Driver injuries are weighted by the National Inflation Factor to produce population estimates. Columns sum to 100 percent separately for men and women.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

One reason for these differences in the pattern of injury is that men and women drivers tend to be involved in different types of crashes, as described in chapter 2. Men drivers are involved in one-car crashes more often than women drivers.[1] In our analysis, 69 percent of the crash involvements of men drivers were in collisions with cars and light trucks, with about 31 percent in one-car crashes. In contrast, about 79 percent of the crash involvements of women drivers were in collisions with cars and light trucks, with only about 21 percent in one-car crashes.

However, another reason is that women drivers are much more likely than men drivers to be hospitalized or killed in collisions with cars and light trucks. That is, women drivers are especially likely to be hurt in the type of

[1]See also Highway Safety: Factors Affecting Involvement in Vehicle Crashes (GAO, 1994). There, we found that men drivers are more frequently involved in single-vehicle crashes than women drivers but that men and women drivers do not differ in their involvement in two-vehicle collisions.

crash that they are also particularly likely to experience.[2] In statistically equivalent crashes, women drivers are 52 percent more likely than men drivers to be hospitalized or killed in collisions with other cars or light trucks, but injury risks for women drivers are roughly the same as those for men drivers in one-car crashes—4 percent higher in one-car rollovers and 6 percent lower in other one-car crashes.[3] (See tables I.3-1.5.)

Automobile Weight. In our data set, women drove lighter and smaller cars than men. The automobiles women drove had an average curb weight of 2,615 pounds and a mean wheelbase of 100.7 inches; for men drivers, the figures were 2,715 pounds and 101.5 inches.

We also found that the protective effect of increasing automobile weight was less evident for women drivers than for men drivers. Since increasing weight generally offers protection in a crash, the average automobile weight for drivers who were hospitalized or killed should be lower than the average weight for those who were not injured. This was true for men but not for women. The average curb weight of the cars driven by men who were hospitalized or killed was 2,626 pounds, compared with a greater average curb weight of 2,719 pounds for men who were not injured. In contrast, the average automobile curb weight for women drivers who were hospitalized or killed was 2,611 pounds, compared with an equivalent average curb weight of 2,615 pounds for women drivers who were not injured.[4]

Safety Belts. Each of the safety belt configurations that we examined (manual lap and shoulder belts, automatic and manual belts, and automatic belts only) significantly reduced the injury risk of both men and

[2]As noted at the begining of the chapter, combining the three types of crashes, our overall estimate is that women drivers are about 29 percent more likely to be hospitalized or killed in a collision than men drivers.

[3]These estimates were derived from logistic regression analyses that compared the injury experiences of women and men drivers in crashes that were statistically equivalent on a number of important dimensions, including crash severity, impact point, safety belt use, driver age, and automobile weight. This means that any differences that may exist between men and women drivers on these dimensions cannot account for the finding that women drivers are more likely than men drivers to be injured in collisions with cars and light trucks. Thus, whether or not women and men drivers differ on these dimensions, women drivers' increased injury risk in these crashes is not the result of, for example, women being involved in more severe crashes or of women more often driving smaller cars, among other possible explanations.

[4]Using the SUDAAN statistical software, we also conducted logistic regression analyses separately for men and women drivers. For men drivers, the coefficient for automobile curb weight (–0.043) has a p-value of less than 0.01; that coefficient translates to an odds ratio of 0.958. For women drivers, the coefficient for automobile curb weight (–0.012) was not statistically significant and translates to an odds ratio of 0.988.

women drivers.[5] However, we also uncovered evidence that, in this data set, safety belts were somewhat less effective for women drivers than for men drivers.

Table 3.1 compares men and women automobile drivers hospitalized as the result of a crash by safety belt use. For all three types of crashes, the table separates the percentage of drivers who were hospitalized or killed from those not hospitalized as well as separating men and women in each group. Safety belt use did not differ by gender for drivers who were not hospitalized: about three quarters of both the men and women drivers in that group were belted. If safety belts offered equivalent protection to men and women drivers, the belt use percentages among hospitalized or killed drivers should reflect the same pattern—in this case, rough equivalence for men and women. However, the table shows that among drivers who were hospitalized or killed, women were more likely to have been wearing safety belts than men. In particular, injured women drivers were about 50 percent more likely to have been wearing manual lap and shoulder belts than were injured men (36 percent to 24 percent).[6]

Table 3.1: Safety Belt Use by Driver's Injury Outcome and Gender[a]

	Injury outcome			
	Hospitalized or killed		Not hospitalized	
Safety belt configuration	**Men**	**Women**	**Men**	**Women**
Total belted	44%	55%	74%	75%
Manual lap and shoulder belts	24	36	48	52
Automatic and manual belts	6	9	12	12
Automatic belts	14	10	15	11
Total unbelted	56%	45%	26%	25%
Total	**100%**	**100%**	**100%**	**100%**

[a]The percentages are weighted by the National Inflation Factor to represent population values.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

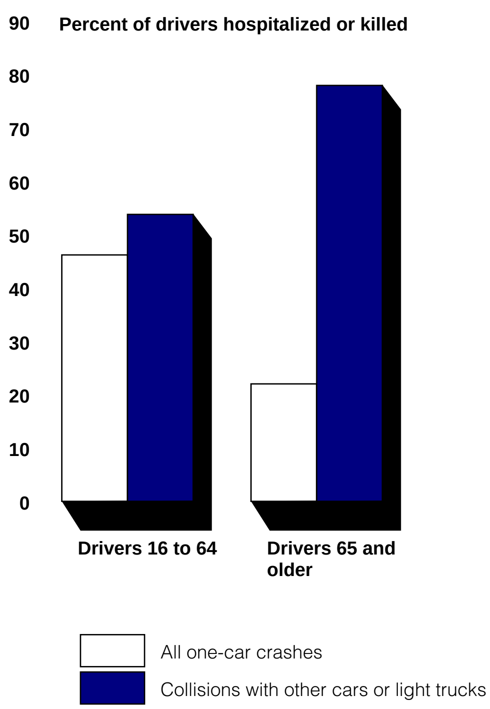
[5]As we discussed in chapter 2, the percentage of drivers coded as using safety belts in the NASS data set is higher than expected. While we do not believe that any potential bias in the data set has seriously affected our findings, these results should be interpreted with caution.

[6]Using the SUDAAN statistical software, we conducted logistic regression analyses to discriminate between men and women drivers. We did separate analyses for drivers who were hospitalized or killed and for those who were not injured, and we used our standard set of crash-related independent variables. For injured drivers, the only statistically significant safety belt factor was the variable for manual lap and shoulder belts. For drivers who were not injured, none of the safety belt variables was statistically significant.

Factors Affecting Older Drivers

Crash Type. The patterns of injury by crash type are very different for drivers 65 and older and for younger drivers.[7] Figure 3.2 shows that, in our analysis, nearly four fifths of the drivers 65 or older who were hospitalized or killed were injured in collisions with cars or light trucks, while only about one fifth were injured in one-car crashes (and almost none were hurt in one-car rollovers—just 3 percent). Conversely, just over half of the drivers 16 to 64 who were hospitalized or killed were injured in collisions with cars or light trucks, while about 29 percent were hurt in one-car nonrollovers and 17 percent were in one-car rollovers.

Figure 3.2: Distribution of Driver Hospitalization or Death by Crash Type and Driver Age[a]



[a]Driver injuries are weighted by the National Inflation Factor to produce population estimates. Columns sum to 100 percent separately for each age category.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

[7]We chose to compare drivers 65 and older with younger drivers in order to present the results of our analysis in a straightforward manner. However, any division of age categories is arbitrary. Driver age has many possible values and the relationship between driver age and injury risk is roughly linear—that is, for a given level of trauma, injury risk increases with each additional year of age.

The primary reason for this difference between the age categories is that drivers in the two groups are involved in different types of crashes. Drivers younger than 65 are involved in collisions with cars and light trucks less often, and in one-car crashes more often, than are drivers 65 and older.[8] In our analysis, 73 percent of the crash involvements of drivers 16 to 64 were in collisions with cars and light trucks, about 22 percent in one-car nonrollover crashes, and about 5 percent in one-car rollover crashes. In contrast, about 86 percent of the crash involvements of drivers 65 and older were collisions with cars and light trucks, with only about 11 percent one-car nonrollover crashes and just 3 percent one-car rollovers.

Older drivers are much more likely to be hurt in crashes than younger drivers in almost all circumstances. For one-car nonrollover crashes, we found that, in statistically equivalent crashes, drivers 65 and older were hospitalized or killed about 6.6 times more often than the youngest drivers, those 16 to 24. Similarly, for collisions with cars and light trucks, drivers 65 and older had a probability of injury more than four times as great as drivers 16 to 24.

Automobile Weight. Drivers 65 and older operated heavier and larger cars than younger drivers. The automobiles of drivers 65 and older had an average curb weight of 2,874 pounds and a mean wheelbase of 104.9 inches. The automobiles of drivers 16 to 64 had an average curb weight of 2,649 pounds and a mean wheelbase of 100.8 inches.

We also found that the protective effect of increasing automobile weight was only slightly less strong for drivers 65 and older than for younger drivers. Thus, the average curb weight of the cars driven by those 16 to 64 who were hospitalized or killed was 2,590 pounds, compared with a larger average curb weight of 2,652 pounds for those who were not hospitalized. The average automobile curb weight for drivers 65 and older who were hospitalized or killed was 2,836 pounds, compared with an average curb weight of 2,878 pounds for drivers who were not hospitalized.

Safety Belts. Although the safety belt use figures in the NASS data set may be inflated, as we discussed earlier, we found that safety belts reduced the risk of injury for drivers in both age categories. We also found that the effectiveness of safety belts was roughly equivalent for drivers 16 to 64 and for drivers 65 and older in this data set. For example, table 3.2 shows the

[8]See Highway Safety: Factors Affecting Involvement in Vehicle Crashes (GAO, 1994). There, we reported that younger drivers are particularly likely to be involved in one-car crashes but not multivehicle collisions; conversely, older drivers are less likely than others to be involved in one-car crashes but more likely to experience multivehicle collisions.

percentage of belted drivers separately for those hospitalized or killed and for those not hospitalized, as well as separating these categories by age. The table shows that drivers 65 and older used safety belts more often than drivers 16 to 64 and that this pattern holds both among those who were hospitalized or killed and among those who were not hospitalized. Thus, while older drivers use safety belts more frequently, this difference from younger drivers is found across the board, rather than only among the hospitalized and killed, as it was for the comparison between women drivers and men drivers.

Table 3.2: Safety Belt Use by Driver's Injury Outcome and Age[a]

	Injury outcome			
	Hospitalized or killed		Not hospitalized	
Safety belt configuration	Age 16-64	Age 65 and older	Age 16-64	Age 65 and older
Total belted	48%	66%	74%	82%
Manual lap and shoulder belts	29	39	49	55
Automatic and manual belts	8	8	12	8
Automatic belts	11	19	13	19
Total unbelted	52%	34%	26%	18%
Total	**100%**	**100%**	**100%**	**100%**

[a]The percentages are weighted by the National Inflation Factor to represent population values.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Conclusions and Implications

Taken as a whole, the evidence indicates that the "inherent frailty" hypothesis does not accurately describe the injury experience of women drivers in automobile crashes but is consistent with that of older drivers. This is because the relative injury risk of women drivers compared with men drivers differs as a function of crash type, automobile size, and safety belt use, while the relative injury risk of drivers 65 and older compared with younger drivers is largely unaffected by those three factors. Women drivers are more likely than men drivers to be hospitalized or killed in collisions with cars and light trucks but not in one-car crashes, and women drivers may be protected less well by heavier cars and by safety belts than are men drivers. In contrast, drivers 65 and older have a greater risk of hospitalization or death than younger drivers in one-car as well as multivehicle crashes, and they are afforded roughly the same degree of protection as drivers 16 to 64 by greater automobile weight and safety belt use.

The NASS data set did not allow us to pursue more specific explanations for differences stemming from gender and age. For example, men and women differ in many ways—on the average, women are shorter than men, weigh less than men, and have bones that are less strong than men's, among other potentially relevant differences. It is difficult to identify the key difference that accounts for women's greater injury risk. Our findings about the applicability of the inherent frailty hypothesis suggest that the concerns of women drivers are more likely to be ameliorated by automobile design changes than are those of older drivers. This means not that it is impossible to reduce the injury risk of drivers 65 and older but only that it may be difficult to close the gap between older and younger drivers. The implications of our findings for future automobile safety are discussed in chapter 5.

Three other points are worthy of mention. First, it is not surprising that the injury risk in one-car rollover crashes is similar both for women and men drivers and for drivers older and younger than 65. One-car rollover crashes are very severe events, meaning that differences between individual drivers are likely to be overwhelmed by the magnitude of the crash. Further, few of the drivers in one-car rollover crashes were either women or 65 or older.

Second, while our finding that safety belts may not protect women drivers as well as men drivers is far from definitive, other researchers examining data from other sources have also reported that the benefits of safety belts are not as great for women as they are for men. (See, for example, Hill, Mackay, and Morris, 1994; Mercier et al., 1993.)

Third, the types of crashes experienced by drivers 65 and older reduce the protective influence of automobile weight for them. Not only are older drivers much more likely to have multivehicle than one-car crashes; also, those multivehicle collisions occur disproportionately in intersections and, therefore, disproportionately involve side impacts. (See Viano et al., 1990.) Automobile weight offers less protection in side-impact collisions than in frontal impacts.

The Relative Importance of Crash Features, Driver Characteristics, Safety Belts, and Automobile Weight

As we demonstrated in chapters 2 and 3, crash severity, crash type, automobile weight and wheelbase, safety belt use, and driver age and gender, taken separately, each significantly influences the probability of driver hospitalization or death. For this chapter, we also assessed the relative importance of these factors simultaneously to see which ones are the most important predictors of injury in a crash and which ones have relatively little influence.

We found that crash severity is the most important predictor of driver hospitalization or death, followed by crash type, safety belt use, driver age and gender, and automobile weight. Crash severity refers to the speed of impact, while crash type refers to the number of vehicles in a crash, whether the car rolled over, and its points of impact. If information about only one of these several factors were available for predicting whether the driver would be seriously injured, having access to crash severity information would lead to the greatest number of accurate predictions. If crash severity information could not be obtained, information about the crash type would give the best chance of accurately predicting whether or not the driver would be injured. And so on down the list of factors.

Table 4.1 documents this finding. It shows a statistical measure of the "explanatory power" of each factor. The table shows that the largest value for this measure is for crash severity, followed by crash type, and then the other factors in the order previously noted. The "explanatory power" of automobile weight is substantially less than that of all the other factors.

Table 4.1: Relative Importance of Crash-Related Factors in Predicting Driver Hospitalization or Death[a]

Factor	Change in log likelihood	Degrees of freedom	Probability
Crash severity	110.70	3	0.01
Crash type	71.75	5	0.01
Safety belts	38.88	3	0.01
Driver age and gender	26.04	4	0.01
Automobile weight	2.36	1	0.03

[a]Larger change in log likelihood values indicates the more important explanatory factors. The probability column shows that all these factors are statistically significant. The change in log likelihood values was computed first by estimating the logistic regression equation without the variables representing each factor and then comparing the minus log likelihood values of those equations with the minus log likelihood from the full model. The minus log likelihood for the full equation is 1,020.13 (see table I.1). For crash severity, two variables measure change in velocity at impact and one measures the speed limit of the roadway section where the crash occurred. For crash type, five categorical variables represent a one- or two-vehicle crash, a vehicle rollover, a head-on crash, and front or left-side impact points. Three categorical variables measure driver age, and one indicates gender. Automobile weight is a continuous variable.

Source: GAO analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Another way to illustrate the great importance of the crash severity and crash type factors is presented in figure 4.1. Each column in the figure shows the estimated increment in risk of injury associated with a change in the associated crash-related factor, combining the three types of crashes in our analysis. Thus, the "crash severity" bar in the figure shows that crashes involving a change in velocity of 23 mph have an estimated risk of driver injury 25 times as great as crashes with a change in velocity of only 6 mph.[1] The bar for crash type shows our estimate that drivers involved in one-car rollover crashes are about nine times more likely to be hurt than drivers involved in collisions with cars and light trucks that are not head-on crashes.

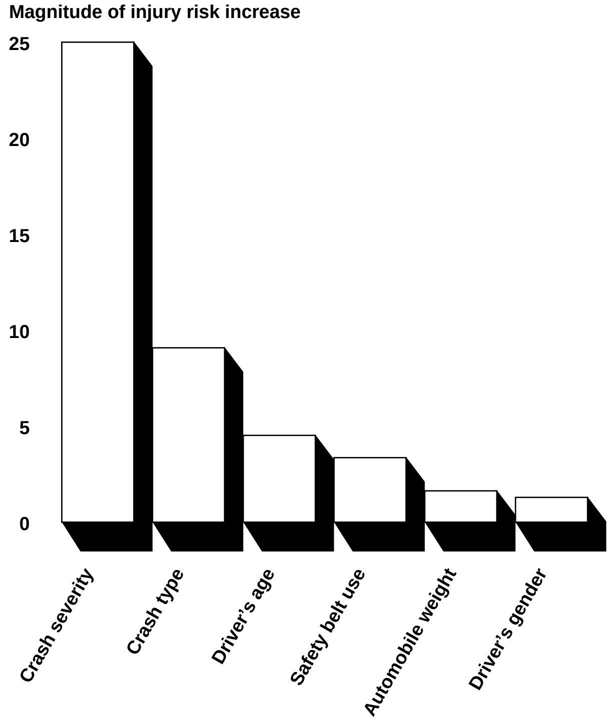
Similarly, figure 4.1 shows that drivers 65 and older are about 4.5 times more likely to be hospitalized or killed than drivers 16 to 24 and that unbelted drivers have an injury risk more than three times as great as drivers wearing manual lap and shoulder safety belts. Drivers of 2,000-pound automobiles have an estimated injury risk in a crash that is about 1.63 times (or 63 percent greater than) that of drivers of 3,600-pound cars.[2] Finally, the estimated injury risk for women drivers is about 1.29 times (or 29 percent greater than) that of men drivers.

[1]We used change in velocity values of 23 and 6 mph in this example because those values are near the endpoints of the change in velocity distribution. Twenty-three mph is the 95th percentile of the change in velocity distribution, while 6 mph is the 5th percentile.

[2]Two thousand pounds represents the 5th percentile of the distribution of automobile weights in this data set; 3,600 pounds is the 95th percentile.

It is important to note that this finding about the injury risks to individual drivers of automobiles of different weights does not mean that the overall "downsizing" of automobiles over the past 20 years has led to more total highway fatalities (see GAO, 1991).

Figure 4.1: Odds of Injury Associated With Changes in Crash-Related Factors[a]



[a]Estimates include all one-car crashes and collisions with cars and light trucks. Endpoints for each factor:

Crash severity: 23 mph change in velocity versus baseline 6 mph change in velocity.

Crash type: drivers in one-car rollovers versus baseline drivers in collisions with cars and light trucks that are not head-on.

Driver’s age: drivers 65+ versus baseline drivers 16-24.

Safety belt use: unbelted drivers versus baseline drivers wearing manual lap and shoulder safety belts.

Automobile weight: drivers of 2,000-lb cars versus baseline drivers of 3,600-lb cars.

Driver’s gender: women versus baseline men.

Source: Our analysis of NASS 1988-91 data for model year 1987 and newer automobiles.

Future Automobile Safety

Here we discuss the implications of our findings for future automobile safety. The first section below reviews the safety initiatives from NHTSA that have the greatest importance for automobile crashworthiness. The next section discusses ways to reduce the injury risk for particular categories of automobile drivers. The last section discusses the most effective uses of available safety technologies.

It is important to keep two points in mind when considering alternative approaches to automobile crashworthiness. First, crashworthy automobiles must offer as much protection as possible for a broad matrix of crash types, crash speeds, and occupant characteristics that pose very different occupant protection problems. For example, we found that one-car crashes, particularly rollovers, are much more dangerous than collisions with cars and light trucks. We also found that men drivers and young drivers are disproportionately involved in one-car crashes, while women drivers and older drivers are more likely to be involved in collisions with cars and light trucks. Protecting young men in severe one-car crashes is very different from protecting women and older drivers in multivehicle collisions. Second, individual safety features often affect only one portion of the matrix of crash types and occupant characteristics. For example, air bags clearly help protect occupants in frontal collisions, but they do not contribute to occupant safety in side-impact collisions or rollover crashes.

NHTSA Safety Initiatives

Recent Regulations

Frontal Impacts

Starting with the 1990 model year, all automobiles sold in the United States have had to demonstrate driver and right-front-seat passenger safety with passive restraints in a full-frontal crash at 30 mph into a rigid barrier.[1] “Passive restraint” means without the use of any safety device requiring actions by the driver or passenger, such as manual safety belts.[2] In model year 1987, the first year of the phase-in period for this regulation, all the automobiles NHTSA tested met this requirement with automatic

[1]See Highway Safety: Reliability and Validity of DOT Crash Tests (GAO/PEMD-95-5).

[2]Under this regulation, automobiles can be equipped with manual safety belts, but the safety standards of the compliance test must be met without benefit of the protection afforded by the manual belts.

safety belts. By 1993, almost all the tested cars fulfilled the passive restraint requirement with air bags rather than automatic belts alone, although many of the cars with air bags also had automatic safety belts.

NHTSA has announced major changes in this regulation.[3] All cars manufactured in September 1997 or later will be required to have both air bags and manual lap and shoulder safety belts for both drivers and right-front-seat passengers. Very importantly, the revised regulation prohibits automatic safety belts—not just for use in the compliance tests but as safety equipment. All cars will have to be equipped with manual safety belts.

Side Impacts

Beginning with the 1994 model year, NHTSA began phasing in a requirement for automobile occupant protection in side impacts. By model year 1997, all automobiles will have to meet safety standards in crash tests simulating the impact of a 3,000-pound vehicle hitting the target car in a side-impact collision at 33.5 mph. Unlike the frontal impact crash tests, active restraint systems, such as manual safety belts, must be used in these tests.

Other Activities

NHTSA is also undertaking a variety of efforts to deal with particular mechanisms of occupant injury rather than points of contact on the automobile. For example, to reduce head injuries, NHTSA is developing a regulation that would require energy-absorbing padding in the areas of automobile interiors that occupants' heads frequently strike in side-impact collisions. Also, NHTSA is studying ways to further reduce injuries in rollover crashes, primarily by reducing the risk of ejection, by improving door latches and increasing the strength of automobile windows other than windshields, as well as by considering tougher roof crush standards.

Other NHTSA activities are concerned with particular types of automobile occupants, especially children and elderly persons. It is important to note that NHTSA is seeking ways to improve protection for elderly drivers, although a major focus of NHTSA's work involves programs to improve their driving skills or otherwise reduce their likelihood of crash involvement. (See Transportation Research Board, 1992, and NHTSA, 1993a; see also NHTSA 1992b for its activities priority plan through 1994.)

[3] Federal Register, September 2, 1993 (49 C.F.R. 571-585).

Injury Reduction for Different Types of Drivers

Automobile manufacturers understand that different segments of the consumer market for automobiles prefer different types of cars. For example, young men are likely to prefer sports cars over station wagons, and older drivers disproportionately prefer large cars over smaller ones. In other words, in the marketplace for automobiles, one size does not fit all. Similarly, one size does not fit all when it comes to automobile safety: the crashworthiness problems of different types of drivers, and of drivers involved in different types of crashes, require a variety of different solutions. Here, we look at the differential safety concerns of segments of the safety "marketplace" that are defined by safety belt use and driver age and gender.

Unbelted and Belted Drivers

Drivers involved in traffic crashes, on the whole, operate their vehicles in a riskier manner than drivers who are not involved in crashes. For example, the rate of safety belt use for drivers involved in crashes is less than the use rate for the general driving population. Estimates of the degree to which drivers who do not wear safety belts are overinvolved in roadway crashes vary considerably. For example, NHTSA (1992a) estimated that unbelted drivers experience potentially fatal crashes 2.2 times more than belted drivers, while Hunter et al. (1993) found that unbelted drivers had a crash involvement rate 35 percent higher than belt users.

Unbelted and belted drivers have very different injury experiences in a crash. Unbelted drivers are more likely to suffer severe injuries, and their injuries are more likely to result from contact with the steering wheel or windshield (Danner, Langieder, and Hummel, 1987; Lestina et al., 1991). These differences are explained by the mechanisms of safety belt effectiveness. Safety belts tie the occupant to the car, helping the occupant decelerate over a relatively long period. In addition, by restricting movement, safety belts reduce the chances of the wearer's striking the interior of the vehicle and help make his or her course of motion within the car more predictable. In contrast, unbelted occupants keep moving within the automobile in the moments after collision, the direction of their movement within the vehicle is relatively unpredictable, and it is likely either that their rapid motion will be abruptly stopped by contact with a rigid surface within the vehicle or that they will be ejected from it.

Therefore, optimally safe vehicle interiors are conceptually dissimilar for belted and unbelted occupants (Mackay, 1993). For belted occupants, the more interior space the better, as increasing the space reduces the odds of contact with interior surfaces. Conversely, for unbelted occupants, the goal is to restrict movement and provide a soft place to land, so heavily padded interiors that minimize interior space are preferred.

How can crash protection be improved for unbelted and belted drivers? For unbelted drivers, the obvious answer is to put them in safety belts. In practical terms, the best way to do this is to increase the number of automobiles with automatic safety belts. As NHTSA (1992a) and Williams et al. (1992) have reported, automobiles equipped with automatic safety belts have much higher belt usage rates than those with manual belts. While experimental vehicles have been designed with substantial protection for unbelted occupants, we do not believe that any combination of interior padding, air bags, and other passive restraint systems will be able to rival the effectiveness of safety belts in production automobiles for the foreseeable future. One reason for this is that, as noted above, designing an optimally safe car for unrestrained drivers may require abandoning safety belts as the centerpiece of occupant protection strategies. And safety belts are extraordinarily effective; alone, they are much more effective at reducing serious injuries than are air bags alone.

For belted drivers, the prospects for dramatic improvements in crash protection are less obvious. On the one hand, promising efforts are under way to reduce much of the residual risk of injury confronting belted drivers. These include improvements in safety belt technology, the greater availability of air bags, and NHTSA's efforts to improve occupant protection in side impacts. On the other hand, the great success of recent occupant protection efforts means that further crashworthiness improvements are harder to achieve, primarily because the dwindling proportion of crashes that still cause serious injury and death to belted occupants are exceptionally severe events. For example, Mackay et al. (1992), reviewing a sample of crashes involving the death of restrained front-seat occupants in Britain, found that the deaths occurred in extremely severe crashes. Fifty percent of the deaths in frontal crashes were in collisions with large trucks, and 86 percent involved passenger compartments crushed so severely as to eliminate the space occupied by the fatally injured person before the crash. Similarly, Green et al. (1994) reported that most of the fatalities of restrained occupants that they examined involved severe intrusion into the passenger compartment and multiple injuries so severe that 90 percent of the victims died within an hour of the crash.

Driver Age and Gender

The "market segments" for automobile safety defined by driver age and gender require very different strategies for reducing fatalities. For men drivers and younger drivers, the problem is crash involvement, not crashworthiness. As we demonstrated in chapter 2, compared to women and older drivers, not only are men drivers and younger drivers involved in more automobile crashes but also the crashes they are particularly likely to be involved in have comparatively severe consequences—that is, single-car crashes have much higher driver injury rates than multivehicle crashes. However, as we saw in chapter 3, men drivers and younger drivers are significantly less likely to be hurt in a crash than women and older drivers. That is, men and younger drivers benefit from a degree of occupant protection that is not available to women and older drivers (we will discuss some of the reasons later). In summary, the surest way to improve the safety of men drivers and younger drivers is to attempt to reduce their crash involvement rates, particularly their rates of involvement in single-car crashes.

The situation is exactly the reverse for women and older drivers. The problem for them is crashworthiness, not crash involvement. Compared to men and younger drivers, women and older drivers are involved in fewer automobile crashes, and the crashes they are involved in are, on the average, less severe, since they are less likely to be involved in single-car crashes than in multivehicle collisions. However, once a crash has occurred, women and, especially, older drivers are more likely to be hospitalized or killed.

In our judgment, improving the crash protection offered by automobiles to women and older drivers so that it approaches the level enjoyed by men and younger drivers offers the greatest chance for reducing roadway injuries for them.[4] In the absence of compelling evidence for the inherent physical frailty of women compared to men, we are optimistic that crashworthiness for women can be substantially improved. In contrast, the evidence we have reviewed indicates that older drivers are, in fact, more fragile than young drivers. Nonetheless, we believe that older drivers can be afforded better protection by automobiles than they now receive (see subsequent discussion and Mackay, 1988). It is important that occupant protection for women drivers and older drivers be improved without

[4]This does not mean that efforts to reduce the crash involvement rates of women drivers and older drivers should not continue, but it does mean that the predominant focus should be on improving crashworthiness. This is particularly true for women drivers; notwithstanding recent calls to focus crash prevention programs on women drivers (for example, Centers for Disease Control, 1992), men drivers have much higher crash involvement rates than women drivers (GAO, 1994). In recent years, men drivers have been involved in more than three times as many fatal crashes as women drivers. For older drivers, efforts to understand, measure, and control the deterioration of physical and cognitive abilities that can impair driving skills are obviously important, but the crash involvement risk of older drivers is already reduced because they drive so many fewer miles than younger drivers (Evans, 1988a; “As Nation Grows Older,” 1992; NHTSA, 1993a).

compromising the crash protection of men drivers and younger drivers; design changes that merely shift injury risk from one group of drivers to another will not improve traffic safety in the aggregate.

One possible reason for the relatively high degree of crash protection enjoyed by men drivers and younger drivers is that efforts at improving automobile crashworthiness have concentrated on the crash types and occupant characteristics most often experienced by them. Current safety regulations and automobile safety designs emphasize protection in high-speed frontal collisions, and men drivers and younger drivers are more likely to be in single-car crashes, which disproportionately involve frontal impacts. The automobile crash tests NHTSA currently requires for all cars include full-frontal crashes into a rigid barrier at 30 mph (although the introduction of a requirement for side-impact tests is under way). Air bags reduce the risk of injury in frontal impacts only, not in side impacts. Similarly, safety belts are more effective in frontal than in side impacts (for example, Evans, 1990), and because of this, safety belts have a somewhat greater benefit in single-car crashes than in collisions with cars and light trucks.

A second possible reason for the crashworthiness deficit of women drivers compared with men drivers is that current NHTSA regulations require the use of only one size of crash test dummy—a dummy representing the 50th percentile of the male population, or 5 feet 9 inches tall, weighing 165 pounds. Maximizing the safety of persons with these characteristics may, in a relative sense, compromise the safety of others.

Another possible explanation for the greater injury risk for women drivers is that, on the average, women are shorter and lighter than men. Automobiles designed to accommodate taller and heavier men drivers may not accommodate women as well. For example, the Insurance Institute for Highway Safety (1993) recommends that drivers sit back as far as possible from the steering wheel and dashboard in order to minimize the risk of hitting those structures in a crash. Shorter drivers obviously cannot sit as far back as taller drivers if they hope to reach the accelerator and brake pedals, and this may expose them to more risk.

Making Effective Use of Available Safety Technologies

Enhanced Safety Belts

All safety belts are not equally effective. In particular, many cars on the market today have safety belts with automatic pretensioners or web locking devices that substantially improve their effectiveness (IIHS, 1993). Pretensioners work by reducing the amount of slack in the belts or by tightening them in a crash a fraction of a second sooner. They cause the belted occupant to begin decelerating sooner in a crash, thereby increasing the total deceleration period. In addition, they increase the chances that the occupant's forward motion will be stopped before he or she contacts the interior of the automobile.

To give an idea of the magnitude of the safety increment available from belts with these features, Viano (1988) compared the performance of several restraint mechanisms in frontal crash tests. Depending on the outcome measure used, lap and shoulder belts with pretensioners had injury scores about 15 to 40 percent below those of lap and shoulder belts without pretensioners.

NHTSA's Implementation of the Requirement for Air Bags

NHTSA has recently announced regulations that would implement the requirement in the Intermodal Surface Transportation Efficiency Act of 1991 that all passenger cars and light trucks be equipped with air bags and lap and shoulder safety belts. Beginning with all cars manufactured in September 1997, both drivers and right-front-seat passengers will have both air bags and manual lap and shoulder safety belts; automatic safety belts are prohibited.

We are concerned that NHTSA's implementation of the requirement for air bags may not achieve the greatest degree of improvement in the aggregate safety of the population of automobile occupants. Automobile occupants who travel in cars with air bags and who wear manual lap and shoulder safety belts will be well protected. However, because safety belts alone offer much more protection than air bags alone, occupants of air bag-equipped cars who do not wear lap and shoulder safety belts will be less well protected than if they were traveling in cars with automatic safety belts. This is important because cars with automatic safety belts have higher safety belt usage rates than cars with manual belts, and individuals involved in serious automobile crashes have lower safety belt use rates than others. If many automobile occupants in serious crashes do not wear manual safety belts, the aggregate safety of automobile occupants under NHTSA's proposal would be less than if, in addition to air bags, automatic safety belts were encouraged or required.

To examine this question, we compared the average amount of occupant protection available to all automobile occupants under three different safety-belt-use scenarios based on a recent NHTSA report (NHTSA, 1992a). In that report, NHTSA noted that cars equipped with manual lap and shoulder belts had a belt usage rate of 56 percent in 1991, while cars equipped with automatic safety belts had usage rates ranging from 64 to 97 percent, depending on the type of automatic belt.[5] If all cars had air bags and manual lap and shoulder belts and a belt usage rate of 56 percent, we estimate that fatality risk would fall 37.2 percent for the average automobile occupant compared with unprotected occupants.[6] If all cars had air bags and automatic safety belts and a belt usage rate of 64 percent, we estimate that the average automobile occupant would have a 37.7-percent reduction in fatality risk.[7] If all cars had air bags and automatic safety belts and a belt usage rate of 97 percent, we estimate that the total fatality risk reduction would be 46 percent.[8]

Thus, from the standpoint of maximizing the aggregate safety of all automobile occupants, the best proposal may be one that requires both air

[5]For the following calculations, we used figures reported by NHTSA. We assumed that unbelted drivers are 2.2 times more likely than belted drivers to be involved in serious crashes (NHTSA, 1992a, p. 21), that manual lap and shoulder belts reduce the risk of fatality by 45 percent (1993d, p. II-13), that automatic safety belts reduce fatality risk by 42.5 percent (1993d, p. II-13), that air bags alone reduce fatality risk by 30 percent, and that air bags with manual lap and shoulder belts reduce the risk of fatality by 50 percent (1993d, p. II-13). Assuming that air bags improve the lot of belted occupants by about 11 percent (as NHTSA estimates for manual lap and shoulder belts), we estimated for this analysis that air bags with automatic safety belts reduce fatality risk by 47 percent (42.5 x 1.11 = 47).

[6]If 56 percent of all drivers wore manual lap and shoulder safety belts, then about 37 percent of drivers in crashes would be belted. Those drivers would have a fatality risk reduction of 50 percent, while the remaining 63 percent of crash-involved drivers—that is, those not wearing safety belts—would have a fatality risk reduction of 30 percent, for an overall fatality risk reduction of 37.2 percent.

[7]If 64 percent of all drivers wore automatic lap and shoulder safety belts, then about 45 percent of drivers in crashes would be belted. Those drivers would have a fatality risk reduction of 47 percent, while the remaining 55 percent of crash-involved drivers—that is, those not wearing safety belts—would have a fatality risk reduction of 30 percent, for an overall fatality risk reduction of 37.7 percent.

[8]If 97 percent of all drivers wore automatic lap and shoulder safety belts, then about 94 percent of drivers in crashes would be belted. Those drivers would have a fatality risk reduction of 47 percent, while the remaining 6 percent of crash-involved drivers—that is, those not wearing safety belts—would have a fatality risk reduction of 30 percent, for an overall fatality risk reduction of 46.1 percent.

bags and automatic lap and shoulder safety belts. The magnitude of the fatality risk reduction arising from that configuration compared to NHTSA's regulation requiring manual lap and shoulder safety belts depends on the difference between the usage rates of automatic and manual safety belts for automobile occupants involved in serious crashes. As our estimates show, if that difference is small, the automatic safety belt alternative offers only a very slight aggregate safety improvement. Conversely, if the usage rate difference is high, placing air bags and automatic lap and shoulder safety belts in all cars would substantially improve the safety of automobile occupants in the aggregate.

Agency Comments and Our Evaluation

DOT had two comments regarding the implications of our finding that, holding constant crash characteristics and automobile weight, women are more likely than men to suffer serious injury in a crash. The first is that NHTSA plans to conduct crash tests with test dummies of different sizes rather than only the standard dummy that represents a 50th percentile man driver. The second is that NHTSA has recently made final a rule requiring improvements in the adjustability of safety belts that may increase the percentage of vehicle occupants using belts correctly. We applaud both these developments. Nonetheless, in our opinion, there is no definitive evidence that either size differences or patterns of safety belt use fully account for the differences in injury rates between men and women.

DOT also had two comments on our discussion of NHTSA's implementation of the requirement for air bags. First, it contended that the usage figures for automatic safety belts that we used in our example are unrealistically high. More specifically, DOT stated that the usage rates for complete automatic belt systems are much less than the 97-percent scenario we described, since some drivers use only one component but not the other (for example, using the shoulder belt but not the lap belt) and other drivers disconnect the automatic belt system entirely. Second, DOT disagreed with our conclusion that manual and automatic safety belts provide "a roughly equivalent degree of protection."

For the first point, we understand that it is extremely difficult to accurately measure safety belt use, especially the use of particular safety belt components (see chapter 2). However, NHTSA (1992a) has concluded that automatic safety belts are used more often than manual belts, and our 97-percent usage rate scenario was based on a NHTSA report, not on our own analysis. Further, our findings would not differ even if automatic safety belts had usage rates much less than 97 percent; thus, we found that the scenario with a 64-percent usage rate for automatic belts (NHTSA's lowest estimate) still provided slightly more total protection than the other scenario we considered, manual belts with a 56-percent usage rate. For the second point, our conclusion that manual and automatic safety belts provide approximately equivalent protection is based on NHTSA's work, not on our own analyses of automobile crash data. For example, NHTSA (1993d, p.II-13) estimated that, when used in a crash, manual lap and shoulder safety belts reduce fatality risk by 45 percent and automatic three-point belts reduce fatality risk by 42.5 percent. Similarly, NHTSA earlier reported that it was unable to find any statistically significant differences between several different configurations of manual and automatic safety belts (NHTSA, 1992a, p.66).

Most importantly, neither of DOT's comments about our discussion of NHTSA's implementation of the requirement for air bags addressed our main point—that drivers involved in serious crashes use safety belts much less than the general driving population. Our discussion is aimed at improving crash protection for drivers who have the greatest risk of involvement in serious crashes. A comprehensive evaluation of the best ways to increase safety belt use for those drivers is beyond the scope of this report. However, as our analysis demonstrates, NHTSA's decision to prohibit automatic safety belts may not achieve the best result from that perspective. At a minimum, NHTSA needs to continue to emphasize in its public education efforts the importance of wearing safety belts even in cars equipped with air bags.

Regression Analyses for Driver Injury

The Data Set

We compiled the data set for our analyses from the National Accident Sampling System—Crashworthiness Data System (NASS) for 1988 through 1991. NASS is a nationally representative probability sample of all police-reported crashes involving a passenger car, light truck, or van in which at least one vehicle was towed from the scene. For more information about NASS, including the sampling frame, sampling plan, and variable definitions, see NHTSA (1991c, 1991d).

For our data set, we selected the subset of cases from NASS that included all one-car crashes involving 1987 or later model year automobiles and all collisions between a model year 1987 or later automobile and any other car, van, pickup truck, or light truck. We discarded automobiles that had no valid curb weight information or no identifiable driver or a driver younger than 16 years of age. The final data set included 6,103 cases of eligible automobiles and their drivers: 457 in one-car rollover crashes, 1,253 in one-car nonrollover crashes, and 4,393 in collisions with other cars or light trucks.

The Outcome Variable

The outcome variable in our analyses was a dichotomous variable for driver injury coded "1" if the driver was hospitalized or killed in the crash and coded "0" otherwise. We chose this outcome measure because it is easy to understand and unambiguous. This variable was created from the "treatment" variable in the NASS file. In NASS, occupants were coded as hospitalized if they were admitted to a hospital for an overnight stay and coded as killed if they died within 30 days of the crash from injuries sustained in the crash.

To relate this measure of driver hospitalization or death to other measures of injury severity, our measure overlaps with injuries categorized as moderate to serious by the Abbreviated Injury Scale (AIS). (See Evans, 1991b.) Thus, we classified 19 percent of the drivers in this data set as hospitalized or killed. Had we used the AIS scheme, 24 percent of all drivers would have been classified as suffering a moderate or more severe injury (AIS 2-6) and 10 percent as suffering a serious or more severe injury (AIS 3-6).[1] For the drivers we coded as hospitalized or killed, 18 percent were killed, 33 percent had an injury listed as serious or critical on AIS (AIS 3-6), 33 percent had a moderate injury on AIS (AIS 2), and 16 percent had minor or no injuries according to the AIS scale.

[1]All the percentages in this paragraph are unweighted.

The Predictor Variables

For independent variables in the regressions, we used a number of factors measuring crash type, crash severity, automobile characteristics, driver safety belt use, and driver age and gender. All the independent variables are listed below. As the following regression tables show, not all these variables were used in all the regression analyses. The estimated population values for the variables are listed in the tables.

Crash Type

- One-car crash was coded “1” if only one car was involved in the crash and coded “0” if the crash was a two-vehicle collision.
- Rollover was coded “1” if the automobile rolled over (either as the primary crash event or as a secondary event) and coded “0” otherwise.
- Head-on collision was coded “1” if the crash was a two-vehicle collision between vehicles moving in opposite directions and coded “0” otherwise.
- Front area damage to the car was coded “1” if the crash was not head-on yet the car sustained frontal damage and coded “0” otherwise.
- Left side damage to the car was coded “1” if the crash was not head-on and the car sustained left-side damage and coded “0” otherwise.

Crash Severity

- Speed limit 40 mph or greater was coded “1” if the speed limit at the roadway location of the crash was 40 mph or greater and coded “0” otherwise.
- Has change in velocity value was coded “1” if the automobile had a valid change in velocity value in NASS and coded “0” otherwise. (Many automobiles had missing values for change in velocity in NASS; in particular, all the cars in one-car rollover crashes had missing values.)
- Change in velocity was measured in miles per hour. (Change in velocity refers to the nearly instantaneous change in a vehicle’s speed that occurs in a crash. For example, a vehicle that was abruptly stopped from a travel speed of 30 mph would have a change in velocity of 30 mph.) Automobiles coded “0” on the “has change in velocity value” variable were assigned the mean value of the change in velocity scores for each analysis.

Automobile Characteristics

- Model year was indexed by three categorical variables for model years 1987, 1988, and 1989. Cars from those model years were coded “1” for the appropriate year and “0” for the other years. Automobiles from the 1990 model year and later were coded “0” for all three variables.
- Curb weight was measured in 100-pound increments in NASS. Curb weight refers to the weight of the unoccupied automobile, including gasoline and other fluids.
- Wheelbase was measured in inches. (Wheelbase is a measure of automobile length that is one indication of the exterior size of a vehicle. Wheelbase refers to the distance between the front and rear axles.) Many

of the cars in the data set had missing wheelbase values in NASS. We were able to assign valid values to most of them by matching the missing cases to cars that had valid wheelbase values, based on model year, make, model, and body type. Nonetheless, slightly fewer cars had valid wheelbase values than had valid curb weight values in our final data set.

Driver Safety Belt Use

- Manual lap and shoulder belt use was coded "1" if the driver was noted by NASS researchers as wearing manual lap and shoulder safety belts (a "3-point belt") at the time of crash and coded "0" otherwise.
- Automatic belt use was coded "1" if the driver was noted by NASS researchers as wearing an automatic safety belt (a 3-point belt, a lap belt only, or a shoulder belt only) at the time of the crash and coded "0" otherwise.
- Both manual and automatic belt use was coded "1" if the driver was noted by NASS researchers as wearing both an automatic shoulder belt and a manual lap belt at the time of the crash and coded "0" otherwise.

Driver Age and Gender

- Driver age was indexed with four categorical variables representing ages 16 to 24 years, 25 to 44, 45 to 64, and 65 and older. Drivers were coded "1" for the appropriate age category and "0" for the other categories.
- Driver gender was coded "1" for men and "0" for women.

Results of the Regression Analyses

Tables I.1 through I.8 present the results of our regression analyses. The eight tables show the analyses for four sets of crashes (all crashes included in the data set, one-car rollover crashes, one-car nonrollover crashes, and collisions with cars and light trucks), using two measures of automobile size (curb weight and wheelbase).

Table I.1: One-Car Crashes and Collisions With Other Cars or Light Trucks: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Curb Weight

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	0.188	1.207	0.75	0.39	0.31
1988	–0.024	0.976	0.01	0.91	0.29
1989	0.205	1.227	0.71	0.40	0.21
Speed limit 40+ mph	0.459	1.582	9.76	0.01	0.50
One-car crash (versus two-vehicle crash)	0.915	2.497	38.37	0.01	0.26
Rollover	1.291	3.637	36.35	0.01	0.06
Head-on collision	1.159	3.188	24.65	0.01	0.03
Area of damage to the car (if not head-on collision)					
Front	0.521	1.684	8.45	0.01	0.60
Left side	0.690	1.994	17.38	0.01	0.21
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.216	0.297	51.77	0.01	0.49
Automatic belts	–0.769	0.464	17.14	0.01	0.13
Both manual and automatic belts	–1.002	0.367	20.48	0.01	0.11
Male driver	–0.251	0.778	4.18	0.04	0.50
Driver age in years (versus 16-24)					
25-44	0.542	1.720	9.19	0.01	0.43
45-64	0.940	2.559	33.72	0.01	0.14
65+	1.509	4.521	54.35	0.01	0.07
Collision severity: change in velocity					
Has change in velocity value	0.833	2.300	35.01	0.01	0.35
Change in velocity (mph)	0.191	1.211	116.89	0.01	14.55
Automobile weight (100s of pounds)	–0.030	0.970	6.98	0.01	26.64
Constant	–6.447				

(Table notes on next page)

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, “1” indicates that the driver was hospitalized or killed, “0” that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile weight by 100 pounds decreases the odds of hospitalization or death by a factor of 0.970, or 3 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 0.778 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, “Chi-Squared Tests for Contingency Tables,” in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.2: One-Car Crashes and Collisions With Other Cars or Light Trucks: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Wheelbase

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	0.210	1.233	0.90	0.34	0.31
1988	–0.029	0.971	0.02	0.89	0.29
1989	0.254	1.289	1.03	0.31	0.21
Speed limit 40+ mph	0.456	1.577	10.05	0.01	0.50
One-car crash (versus two-vehicle crash)	0.873	2.395	34.11	0.01	0.26
Rollover	1.306	3.693	33.75	0.01	0.06
Head-on collision	1.102	3.010	22.12	0.01	0.03
Area of damage to the car (if not head-on collision)					
Front	0.542	1.719	8.72	0.01	0.60
Left side	0.675	1.964	16.04	0.01	0.21
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.240	0.289	53.03	0.01	0.49
Automatic belts	–0.763	0.466	16.77	0.01	0.13
Both manual and automatic belts	–1.048	0.351	22.28	0.01	0.11
Male driver	–0.262	0.769	4.54	0.03	0.50
Driver age in years (versus 16-24)					
25-44	0.565	1.760	9.65	0.01	0.43

(continued)

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
45-64	0.966	2.627	34.93	0.01	0.14
65+	1.609	4.997	51.73	0.01	0.07
Collision severity: change in velocity					
Has change in velocity value	0.817	2.264	31.53	0.01	0.35
Change in velocity (mph)	0.192	1.212	115.64	0.01	14.55
Automobile wheelbase (inches)	–0.028	0.973	9.24	0.01	101.07
Constant	–4.456				

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, "1" indicates that the driver was hospitalized or killed, "0" that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile wheelbase by 1 inch decreases the odds of hospitalization or death by a factor of 0.973, not quite 3 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 0.769 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, "Chi-Squared Tests for Cotingency Tables," in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.) Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.3: One-Car Rollover Crashes: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Curb Weight

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	0.468	1.596	0.78	0.38	0.31
1988	–0.124	0.883	0.03	0.86	0.35
1989	0.458	1.581	0.55	0.46	0.18
Speed limit 40+ mph	1.111	3.038	8.50	0.01	0.75
Area of damage to the car					
Front	1.202	3.326	18.17	0.01	0.32
Left side	0.108	1.114	0.05	0.82	0.16
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.775	0.169	18.89	0.01	0.44
Automatic belts	–0.684	0.505	2.05	0.15	0.14
Both manual and automatic belts	–0.806	0.447	1.91	0.17	0.10
Male driver	–0.040	0.961	0.01	0.93	0.63
Driver age in years (versus 65+)					
16-24	0.114	1.121	0.02	0.89	0.54
25-44	0.350	1.419	0.17	0.68	0.36
45-64	0.920	2.508	1.15	0.29	0.07
Automobile weight (100s of pounds)	0.092	1.097	4.44	0.04	25.02
Constant	–5.110				

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, "1" indicates that the driver was hospitalized or killed, "0" that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile weight by 100 pounds increases the odds of hospitalization or death by a factor of 1.097, not quite 10 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 0.961 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, "Chi-Squared Tests for Contingency Tables," in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.4: One-Car Nonrollover Crashes: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Curb Weight

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	–0.220	0.803	0.34	0.56	0.32
1988	–0.366	0.694	0.57	0.45	0.31
1989	0.050	1.051	0.01	0.90	0.21
Speed limit 40+ mph	–0.006	0.994	0.00	0.98	0.59
Area of damage to the car					
Front	0.502	1.652	1.83	0.18	0.67
Left side	0.346	1.414	1.17	0.28	0.15
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.624	0.197	35.85	0.01	0.48
Automatic belts	–0.816	0.442	3.35	0.07	0.12
Both manual and automatic belts	–1.027	0.358	4.94	0.03	0.12
Male driver	0.059	1.060	0.04	0.85	0.58
Driver age in years (versus 16-24)					
25-44	0.777	2.174	7.56	0.01	0.42
45-64	0.609	1.839	3.03	0.08	0.11
65+	1.889	6.611	11.19	0.01	0.04
Automobile weight (100s of pounds)	–0.032	0.968	2.00	0.16	26.88
Collision severity: change in velocity					
Has change in velocity value	0.927	2.527	7.79	0.01	0.18
Change in velocity (mph)	0.200	1.221	23.24	0.01	13.98
Constant	–5.604				

(Table notes on next page)

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, "1" indicates that the driver was hospitalized or killed, "0" that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile weight by 100 pounds decreases the odds of hospitalization or death by a factor of 0.968, about 3 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 1.060 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, "Chi-Squared Tests for Contingency Tables," in C. J. Skinner, D. Holt, and T. M. F. Smith (eds), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.5: Collisions With Cars and Light Trucks: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Curb Weight

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	0.263	1.301	0.83	0.36	0.31
1988	0.021	1.021	0.01	0.93	0.28
1989	0.191	1.211	0.38	0.54	0.21
Speed limit 40+ mph	0.667	1.948	14.74	0.01	0.46
Head-on collision	1.642	5.166	22.30	0.01	0.05
Area of damage to the car (if not head-on collision)					
Front	0.273	1.314	1.27	0.26	0.55
Left side	0.874	2.396	9.90	0.01	0.23
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.029	0.357	23.48	0.01	0.49
Automatic belts	–0.654	0.520	8.24	0.01	0.13
Both manual and automatic belts	–0.989	0.372	10.27	0.01	0.11
Male driver	–0.419	0.658	6.07	0.01	0.46
Driver age in years (versus 16-24)					
25-44	0.365	1.441	2.31	0.13	0.43
45-64	0.920	2.509	23.02	0.01	0.15
65+	1.420	4.139	38.59	0.01	0.08

(continued)

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Collision severity: change in velocity					
Has change in velocity value	0.969	2.635	35.60	0.01	0.41
Change in velocity (mph)	0.195	1.215	95.11	0.01	13.94
Automobile weight (100s of pounds)	–0.054	0.948	12.85	0.01	26.69
Weight of other vehicle (100s of pounds)	0.025	1.025	3.47	0.06	30.60
Body type of other vehicle (versus automobiles)					
Pickup truck	0.166	1.181	0.62	0.43	0.13
Van	0.803	2.231	3.54	0.06	0.05
Other light vehicle	1.000	2.720	6.82	0.01	0.04
Constant	–6.784				

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, "1" indicates that the driver was hospitalized or killed, "0" that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile weight by 100 pounds decreases the odds of hospitalization or death by a factor of 0.948, about 5 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 0.658 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, "Chi-Squared Tests for Contingency Tables," in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.6: One-Car Rollover Crashes: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Wheelbase

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	0.365	1.440	0.52	0.47	0.31
1988	–0.182	0.833	0.07	0.79	0.35
1989	0.386	1.471	0.39	0.53	0.18
Speed limit 40+ mph	1.155	3.173	10.12	0.01	0.75
Area of damage to the car					
Front	1.247	3.480	17.72	0.01	0.32
Left side	0.142	1.152	0.09	0.76	0.16
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.795	0.166	15.93	0.01	0.44
Automatic belts	–0.683	0.505	2.11	0.15	0.14
Both manual and automatic belts	–0.915	0.400	2.91	0.09	0.10
Male driver	–0.017	0.983	0.00	0.97	0.63
Driver age in years (versus 65+)					
16-24	–0.315	0.730	0.14	0.70	0.54
25-44	0.071	1.073	0.01	0.93	0.36
45-64	0.707	2.027	0.74	0.39	0.07
Automobile wheelbase (inches)	0.020	1.020	0.34	0.56	98.83
Constant	–4.398				

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, “1” indicates that the driver was hospitalized or killed, “0” that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile wheelbase by 1 inch increases the odds of hospitalization or death by a factor of 1.020, or 2 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 0.983 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, “Chi-Squared Tests for Contingency Tables,” in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.7: One-Car Nonrollover Crashes: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Wheelbase

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	–0.147	0.863	0.15	0.70	0.32
1988	–0.298	0.743	0.39	0.53	0.31
1989	0.162	1.176	0.13	0.71	0.21
Speed limit 40+ mph	–0.020	0.980	0.00	0.95	0.59
Area of damage to the car					
Front	0.574	1.775	2.54	0.11	0.67
Left side	0.322	1.380	1.00	0.32	0.15
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.640	0.194	38.01	0.01	0.48
Automatic belts	–0.798	0.450	3.30	0.07	0.12
Both manual and automatic belts	–1.058	0.347	5.56	0.02	0.12
Male driver	0.025	1.025	0.01	0.93	0.58
Driver age in years (versus 16-24)					
25-44	0.830	2.293	9.19	0.01	0.42
45-64	0.661	1.938	3.78	0.05	0.11
65+	1.977	7.220	12.27	0.01	0.04
Automobile wheelbase (inches)	–0.020	0.980	1.38	0.24	100.53
Collision severity: change in velocity					
Has change in velocity value	0.907	2.475	7.31	0.01	0.18
Change in velocity (mph)	0.200	1.221	23.70	0.01	13.98
Constant	–4.588				

(Table notes on next page)

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, "1" indicates that the driver was hospitalized or killed, "0" that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile wheelbase by 1 inch decreases the odds of hospitalization or death by a factor of 0.980, or 2 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 1.025 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, "Chi-Squared Tests for Contingency Tables," in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

Table I.8: Collisions With Cars and Light Trucks: Logistic Regression Analysis Predicting Driver Hospitalization or Death, Model With Wheelbase

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Automobile model year (versus 1990 and newer)					
1987	0.284	1.329	1.01	0.31	0.31
1988	0.001	1.000	0.00	1.00	0.28
1989	0.242	1.273	0.59	0.44	0.21
Speed limit 40+ mph	0.653	1.921	13.97	0.01	0.46
Head-on collision	1.589	4.900	21.13	0.01	0.05
Area of damage to the car (if not head-on collision)					
Front	0.286	1.331	1.39	0.24	0.55
Left side	0.848	2.335	9.42	0.01	0.23
Safety belt use (versus unbelted)					
Manual lap and shoulder belts	–1.056	0.348	23.44	0.01	0.49
Automatic belts	–0.631	0.532	7.39	0.01	0.13
Both manual and automatic belts	–1.043	0.353	11.01	0.01	0.11
Male driver	–0.445	0.641	6.77	0.01	0.46
Driver age in years (versus 16 to 24)					
25-44	0.375	1.455	2.45	0.12	0.43
45-64	0.902	2.464	20.98	0.01	0.15
65+	1.499	4.476	37.71	0.01	0.08

(continued)

Variable	Coefficient[a]	Odds ratio[b]	Chi-square[c]	Probability level[d]	Population mean[e]
Collision severity: change in velocity					
Has change in velocity value	0.965	2.624	34.19	0.01	0.41
Change in velocity (mph)	0.196	1.217	93.85	0.01	13.94
Automobile wheelbase (inches)	–0.043	0.958	9.56	0.01	101.37
Weight of other vehicle (100s of pounds)	0.026	1.026	3.58	0.06	30.60
Body type of other vehicle (versus automobiles)					
Pickup truck	0.185	1.203	0.75	0.39	0.13
Van	0.845	2.327	4.05	0.04	0.05
Other light vehicle	0.957	2.603	6.16	0.01	0.04
Constant	–3.899				

[a]Coefficients are from logistic regression analyses conducted with the SUDAAN software package. The outcome variable is dichotomous—that is, “1” indicates that the driver was hospitalized or killed, “0” that the driver was neither hospitalized nor killed.

[b]The odds ratio is the exponentiated coefficient ($e^{coefficient}$). The odds ratio indicates the change in the odds of injury that occur with a change of one unit in the variable. For example, increasing automobile wheelbase by 1 inch decreases the odds of hospitalization or death by a factor of 0.958, just over 4 percent. The odds ratio for categorical variables indicates the change from the left-out group. For example, the injury odds for men drivers are 0.641 that of women drivers, the left-out group.

[c]The chi-square values test the statistical significance of the coefficients. The values are calculated from the Satterthwaite approximation to the chi-square distribution. This procedure reduces the chances of a Type I error. (See J. N. K. Rao and D. R. Thomas, “Chi-Squared Test for Contingency Tables,” in C. J. Skinner, D. Holt, and T. M. F. Smith (eds.), Analysis of Complex Surveys (New York: John Wiley and Sons, 1989).)

[d]Probability levels are from the Satterthwaite adjusted chi-square tests. Probability level refers to the chances that the coefficient equals zero in the population. By convention, coefficients with a probability level less than or equal to 5 percent (0.05) are regarded as statistically significant. In this table, 0.01 indicates a probability less than or equal to 0.01.

[e]The population means are the variable values in this sample weighted by the National Inflation Factor to approximate population values.

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