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# The Effectiveness of Head Restraints in Light Trucks

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16. Abstract


Federal Motor Vehicle Safety Standard 202 has required head restraints in front outboard positions for all cars manufactured January 1, 1969 and later, for sale in the United States. The National Highway Traffic Safety Administration extended the standard to include light trucks (pickup trucks, vans, and sport utility vehicles with Gross Vehicle Weight Rating less than 10,000 pounds) as of September 1, 1991.

NHTSA's 1982 evaluation of head restraints in passenger cars estimated a 13 percent overall reduction in injuries to drivers in rear impacts. The current evaluation, based on data from eight states (Florida, Indiana, Maryland, Missouri, North Carolina, Pennsylvania, Texas, and Utah) estimates that head restraints reduced overall injury risk in light trucks in rear impacts by a statistically significant 6 percent.


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## Executive Summary

Head restraints have been required at the driver's and right front passenger's seats on passenger cars manufactured January 1, 1969 and later, for sale in the United States, by Federal Motor Vehicle Safety Standard 202. The National Highway Traffic Safety Administration extended the standard to light trucks (pickup trucks, vans, and sport utility vehicles with Gross Vehicle Weight Rating less than 10,000 pounds) as of September 1, 1991.

The purpose of head restraints is to prevent excessive rearward motion of an occupant's head in rear impacts, with the goal of reducing the occurrence of "whiplash" injuries. This report examines the effectiveness, benefits, and costs of head restraints in light trucks, based on statistical analyses of state crash data from calendar years 1993 through 1998.

NHTSA's National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) was used to identify if vehicles were equipped with head restraints, by make-model and model year. Most vans and sport utility vehicles already had head restraints long before September 1, 1991. There are few, if any, comparable vehicles without head restraints on which to perform an analysis. Therefore, the present analysis was necessarily limited to pickup trucks; specifically, to seven high-sales make-models of pickup trucks that shifted from few or no head restraints in one model year to most or all head restraints in the next year, in 1990, 1991, or 1992. With some uncertainty, the effectiveness results for these seven make-models are also assumed to apply to other light trucks, such as vans and sport utility vehicles.

While NASS CDS is valuable for identifying what makes and models had head restraints, the number of rear-impact crashes is insufficient for statistically significant comparisons of injury rates in rear-impact crashes of selected make-models before and after the installation of head restraints. Only state crash data files can provide enough cases for those comparisons.

The evaluation was based on eight state files of calendar years 1993-98 - Florida, Indiana, Maryland, Missouri, North Carolina, Pennsylvania, Texas, and Utah - that are available for analysis at NHTSA, which indicate a vehicle's damage location (rear vs. other), and report the make-model or allow its identification via the VIN. The percent of front-seat occupants who had any type of injury in rear-impact crashes was compared for pickup trucks two model years before and after the installation of head restraints. This effectiveness estimate was adjusted for possible biases due to differences in vehicle age, and for the fact that a small percentage of the vehicles in the "Before" group had head restraints. The analysis comprised 93,954 cases of occupants involved in police-reported rear-impact crashes; of these, 23,807 were injured.

While head restraints are designed to reduce whiplash injury, this report examines the change in injury rate overall. This was done for several reasons. Whiplash can involve so many potential body regions that, when limiting whiplash to cases with only neck or back injury, many true whiplash victims are excluded. Conversely, injuries other than whiplash can occur in the neck and back regions, with similar coding descriptions. In addition, all eight State files analyzed in this evaluation code injuries according to their severity: A = "incapacitating injury," B = "other visible injury," C = "possible injury." Most of the symptoms associated with whiplash are not visible injuries, and they are usually, but not exclusively, coded AC.@ Only three of the state files, Indiana, Pennsylvania, and Utah, provide additional injury information: the body region of the occupant's most severe injury and the type of injury (laceration, fracture, complaint of pain, etc.). Since the principal analysis of the data must encompass all eight States, it will be based on comparing overall injury rates (A + B + C) before and after the installation of head restraints.

The principal finding of this study is that:

- Head restraints reduced overall injury risk in light trucks in rear-impact crashes by an estimated 6.08 percent. This reduction is statistically significant (confidence bounds: 3.49 to 8.65 percent).

Analyses also suggested that:

- Head restraints are more effective in pickup trucks with minor, non-towaway damage than in those trucks with towaway damage. Injury risk is reduced by an estimated 7.75 percent (confidence bounds: 2.59 to 12.84) in pickup trucks with minor damage, and by 0.33 percent (confidence bounds: -3.92 to 4.53) in pickup trucks with major (towaway) damage.

- In these data, the effectiveness of head restraints in reducing injury was about the same for:

  - Male and female occupants
  - Older and younger occupants
  - Centered and off-center rear impacts
  - Integral and adjustable head restraints
  - Pickup trucks with extended cabs and trucks with a cab that ends directly behind the front seat

If every light truck on the road (including all pickups, vans, and sport utility vehicles) had head restraints in 1999, a total of 14,882 injuries would have been prevented, relative to a fleet of light trucks with no head restraints (confidence bounds range from 8,341 to 21,694). Since 88.40 percent of light trucks were in fact equipped with head restraints by then, the actual number of injuries prevented in 1999 was 13,156 (confidence bounds range from 7,373 to 19,177).

# Chapter 1: Introduction and Background

The purpose of head restraints is to prevent excessive rearward motion of an occupant's head in rear impacts, with the goal of reducing the occurrence of "whiplash" injuries. Head restraints have been required on passenger cars manufactured since January 1, 1969 for sale in the United States, by Federal Motor Vehicle Safety Standard 202. The standard was extended to light trucks (pickup trucks, vans, and sport utility vehicles less than 10,000 pounds) as of September 1, 1991. An integral (fixed) head restraint must have a height of at least 27.5 inches and an adjustable head restraint, when adjusted to its highest position, must have a height of at least 27.5 inches. The height is measured along the seat back plane from approximately the hip level to the top of the head restraint.

## 1.1 Evaluation of Head Restraints

The Government Performance and Results Act (GPRA) of 1993[1] and Executive Order 12866 (October 1993) require that government agencies evaluate existing programs and regulations. The purpose of such an evaluation is to determine the actual benefits (such as injuries prevented and damage avoided) and costs of any additional equipment required on vehicles due to regulation.

Many safety standards that were originally applied only to passenger cars have been extended to light trucks. For situations in which passenger cars and light trucks become involved in similar types of crashes, it is plausible that safety measures effective in cars would also be effective in light trucks. However, there are design differences between cars and light trucks that could result in differing effectiveness of a safety measure for the two types of vehicles. In addition, light trucks tend to be driven in different manners and situations than are passenger cars, although this is less true today than in the past. Increasingly, light trucks (minivans and sport utility vehicles in particular) are purchased as a "family" or personal vehicle.

The NHTSA Final Regulatory Evaluation (FRE), *Extension of Head Restraint Requirements to Light Trucks, Buses, and Multipurpose Passenger Vehicles with Gross Vehicle Weight Rating of 10,000 Pounds or Less, Federal Motor Vehicle Safety Standard 202*[2] noted that in 1968, when FMVSS 202 was issued, light truck sales were a much smaller portion of the light vehicle market. In 1970, they made up 15.7 percent of the light vehicle (passenger cars and light trucks) market. By 1985, this was up to 28.7 percent. In 1999, they comprised 37 percent of light vehicles on the road and 49 percent of new vehicle sales. The increase in sales of light trucks, and their increased use as personal transportation, made it urgent to extend some safety standards, which originally applied only to passenger cars, to other vehicles.[3]

Passenger cars manufactured on or after January 1, 1969 are required to have head restraints. Since they had been found to successfully prevent injuries, NHTSA extended the requirement to light trucks. On September 25, 1989, a Final Rule was published in the Federal Register, extending FMVSS 202 to trucks, multipurpose vehicles, and buses with gross vehicle weight rating of 10,000 pounds or less.[4]

This report examines the effectiveness, benefits, and costs of head restraints in light trucks over calendar years 1993 through 1998. Prior to the September 1989 publication of the Final Rule, only a small portion of new domestic pickup trucks was equipped with head restraints. Head restraints were installed in many new pickup trucks between the 1989 publication and the September 1991 effective date. However, the majority of new vans and sport utility vehicles were already equipped with head restraints or high seat backs potentially meeting the height requirements of FMVSS 202 as early as model year 1983.

Two types of head restraints are used to meet the requirements of FMVSS 202. Integral head restraints usually consist of a seat back high enough to meet the height requirement of 27.5 inches, such as "captain's chairs" and high back bucket seats. An integral head restraint may also consist of a separate, padded metal frame attached to the seatback, with open areas that enable the driver to "see through." Adjustable head restraints use a separate pad, which is attached to the back of the seat by one or more sliding metal bars. The height of the pad is adjustable, but it must be at least 27.5 inches in the top position. Ideally, the occupant should adjust the head restraint to the top of the ears or higher. This allows the head's center of gravity to be captured in a rear impact, reducing the relative motion between the head and torso. Some adjustable head restraints have an angular rotation feature, which allows the occupant to move the restraint closer to the rear of the head.

## 1.2 Results of earlier studies

NHTSA's 1982 evaluation of head restraints[5] in passenger cars found that integral head restraints reduced the overall risk of injury to drivers in rear impacts by 17 percent. Adjustable restraints reduced the injury risk by 10 percent. It is important to note that adjustable restraints were not extended 75 percent of the time, and therefore did not achieve their full potential benefits. With the combination of integral and adjustable head restraints on the road, the average overall injury reduction was 13 percent, with confidence bounds of 7 to 19 percent. The result, had all passenger cars in 1979 been equipped with head restraints, would have been 64,000 injuries prevented.

Integral head restraints were found more effective in passenger cars than were adjustable head restraints. One factor which probably contributed to the result was that adjustable head restraints are frequently left in their lowest position. Other factors may have been at work, such as a lack of position locks, difference in backset position, and vehicle characteristics. The report also inferred from the limited available data in head restraint height that improved benefits could be realized with higher integral head restraints as well as requiring a minimum height requirement in the lowest position for adjustable head restraints.

Several recent studies[6,7,8] have reaffirmed the long held theory that female occupants to be at greater risk for whiplash injuries than are male occupants. There is uncertainty as to what the specific cause of this difference is, but it is presumably due to women having smaller neck bones and muscles for supporting heads of nearly the same size as men. The difference occurs in spite of the fact that men, on average, are taller than women, and therefore less likely to be adequately protected by an adjustable head restraint left in a low position. A study in the Rochester, New York area found that, accounting for age, vehicle damage severity, curb weight, and wheelbase, female drivers had 1.54 times the risk of neck pain compared to male drivers.[6] One study[7] found women to be at higher risk regardless of seat position, height, or age. However, another study[9] found that the higher risk for women appeared to be due to gender-based differences in height, and to a lesser extent occupant mass, head circumference, neck strength, and initial angle of the torso. Although females are at greater risk, head restraints have been found to offer greater reductions in "whiplash" injuries to females.[10]

Another recent study[8] found that neck injuries were more common for drivers whose car was hit in the rear center rather than a rear corner, as well as in crashes involving more severe damage. The location of the impact, as well as damage severity, may have both been related to change in velocity, which could not be directly measured.

Originally, whiplash was thought to be principally the result of extreme hyperextension of the neck muscles, tendons, or ligaments, causing them to tear or strain. Today the consensus of the biomedical community is that whiplash can occur within the normal range of motion. Whiplash injuries may have symptoms that last only a few days or weeks. More severe cases of whiplash, which result in longer lasting symptoms, are likely to involve neurological damage. However, the injury mechanism is not clearly established. One theory states that damage is due to the rapid changes that occur in spinal column pressure[10].

The height of the head restraint and the horizontal distance from the back of the head appear to be important factors in injury reduction. The Insurance Institute for Highway Safety (IIHS) published a report in 1999 on neck injuries in rear-impacts[11]. One observation made was that, in a rear impact, if the relative motion of the occupant's head and torso is minimized, it is unlikely that whiplash will occur. Therefore, the best head restraints are those that are positioned close to the occupant's head.

The Farmer, et al study[8] used the IIHS ratings in an analysis. Head restraints were rated as Good, Acceptable, Marginal, or Poor. Other factors, such as gender, age, direction of impact, crash location, repair cost, and damage severity, were also included in the analysis. It was found that in the very few models in which head restraints rated "Good," they were associated with less likelihood of neck injury than those rated "Poor," but the difference was only significant among women.

In 1995, NHTSA looked at the relative position of occupant's heads and head restraints for 282 vehicles[3]. The top of 59 percent of adjustable restraints were at or above the occupant's ear, while for integral restraints the value was 77 percent. Overall, a larger percentage of integral restraints were positioned in such a way as to decrease the potential of a whiplash injury. In addition, half of the adjustable head restraints were in their lowest position. (This is an improvement from the 75 percent observed in the 1982 study.) The likelihood of a whiplash injury could have been reduced in 75 percent of these cases by raising the head restraint.

Head restraint position and seat back stiffness were studied in rear impacts.[12] The authors believe that the whiplash injury mechanism is not fully understood, but the motions thought to be involved are:

> Ramping Up – the straightening of the spine and lifting upward of the head that occurs in the initial to middle period of the impact
> Head Retraction – the abrupt backward movement of the head relative to the torso, and
> Neck Extension – the hyperextension of the neck as the head moves backward.

In their study of head and neck motion, human volunteers were used to examine all three motions. In addition, dummies were used to examine neck extension in 25 km/h delta-v impacts. The seats used in the testing varied stiffness in the upper (torso) and lower (pelvic) area. One additional seat had a head restraint that moved both forward and upward in response to force from the occupant in the crash. A standard car seat was also included for comparison. The authors found that the Neck Injury Criterion (NIC) decreased as seatback stiffness was reduced, especially for the upper area.

However, previous research has shown that if a head restraint is not present or is poorly positioned, a weak or yielding seat back allows the torso and head to move rearward in unison, thus reducing the occurrence of whiplash.[13] Conversely, as a seat is made stiffer, head restraints become more effective because, as the seat back restrains the torso, the head restraint must be present to restrain the head.

Foret-Bruno[14], using an accident database containing 8,000 involved vehicles, concluded that as seat backs have become stiffer, head restraints have become more effective at reducing neck injuries. When seat backs are weak and bread upon rear impact, the head restraint may not become involved in altering occupant kinematics.

A report[15] by Maher reviewed earlier papers and examined head restraint measurements. It was found that, in some cases, the horizontal displacement increased as the vertical height of the head restraint increased. Maher recommends higher seat backs or head restraints.

Head restraint design varies a great deal, and clearly affects the ability of the restraint to reduce injury. In addition, the seat adjustment and stiffness also appear to be a factor in injury reduction. Height requirements, both for the highest as well as lowest position for adjustable restraints, could further reduce injuries. Research continues in an attempt to improve head restraints as well as the seats to which they are attached.

It is the consensus of the biomechanics community that whiplash injuries, due to rear impact crashes, occur because of the movement of the head and neck relative to the torso. Research has shown that reducing the gap between the occupant's head and the head restraint reduces the movement of the head relative to the torso, which would lower the rate of "whiplash" injuries.

As noted earlier, the FMVSS 202 currently requires the head restraint have a minimum height of 27.5 inches in the highest position. There is currently no US requirement for the lowest position. Integral head restraints, of course, have only one position. Adjustable head restraints are frequently left in the lowest position, effectively defeating the purpose of the standard. In contrast, requirements adopted in 1998 require European vehicles to be equipped with head restraints that are at least 29.5 inches in the *lowest* position – higher than the US requirement for the *highest* position.[6]

On January 4, 2001, NHTSA published a proposed rulemaking[16] to upgrade FMVSS 202. The proposed new standard would require head restraints to be higher, closer to the head, and available in rear as well as front outboard positions. Specifically, the proposed new rule would require:

- rear outboard head restraints.
- front seat head restraints in all passenger vehicles (passenger cars, pickups, vans, and utility vehicles) to be capable of achieving a height where the top of the head restraint is least 800 mm (31.5 inches) above the H-point (which represents the normally seated 50$^{th}$ male hip point).
- a lower limit on height - all required head restraints (both front and back seat) could not be less than 750 mm (29.5 inches) from the H-point.
- for front outboard seating positions, the distance between the back of the head form representing the position of a 50$^{th}$ percentile head, in a normally seated position, and the head restraint (defined as backset) be no farther than 50 mm (2 inches) in any adjustment position.

The height requirements are intended to prevent whiplash injuries by requiring that head restraints be high enough, and closer to the head, to limit the movement of the head and neck. Improvements made as a result of the upgraded standard would be expected to reduce injuries overall.

## Chapter 1 Footnotes


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13. Molino, Louis. *Determination of Moment-Deflection Characteristics of Automobile Seat Backs*. Light Duty Vehicle Division, Office of Crashworthiness Standards, National Highway Traffic Safety Administration, November 25, 1998.

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16. Preliminary Economic Assessment and Regulatory Flexibility Analysis: FMVSS No. 202 Head Restraints for Passenger Vehicles. National Highway Traffic Safety Administration, Plans and Policy, Office of Regulatory Analysis and Evaluation. December, 2000.

# Chapter 2: Injury Reduction and Effectiveness

Analyses of data from eight states indicate that head restraints in pickup trucks have reduced the frequency of injuries in rear-impact crashes. State data from 1993 through 1998, the six most recent years available, were examined. Overall, the introduction of head restraints in pickup trucks reduced injuries in rear-impact crashes by about six percent. This effectiveness estimate takes into account the age effect of vehicles, as well as the fact that some vehicles had head restraints before the requirement took effect.

## 2.1 Data Selection

### 2.1.1 Determination of Vehicles

FMVSS 202 required light trucks and vans less than 10,000 pounds to be equipped with head restraints as of September 1, 1991. While head restraints were required for model year 1992 and later light trucks (manufactured after September 1, 1991), many of these vehicles came equipped with head restraints as either standard or optional equipment in earlier years. It was necessary to determine the presence or absence of head restraints of each light truck by model year.

The National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) collects data on a sample of approximately 5,000 police-reported towaway crashes annually. Among the data collected are information on head restraint presence and type (integral or adjustable), and the Vehicle Identification Number (VIN). The CDS data collection manual states, "The head restraints can be of any design but must meet the requirements of FMVSS 202."[1] The VIN was used to determine the make, model, and model year of light trucks and vans in the CDS data for calendar years 1988 through 1999 (the most recent year currently available).

#### 2.1.1.1 NASS CDS Information

In order to evaluate the effectiveness of head restraints, it would be necessary to compare injury rates in vehicles with head restraints to the same make and model vehicles before having been equipped with head restraints. CDS data were used to determine which specific models went from having a small (no more than 25) to a large (at least 75) percent of head restraint equipped vehicles in successive years. In addition, it was required that there be at least two years of data for both the low and high percentage model years. Five vehicles, all domestic pickup trucks, met these criteria:

- Chevrolet C/K / GMC Sierra Series
- Chevrolet S/T / GMC Sonoma Series
- Dodge D/W
- Dodge Dakota
- Ford Ranger

In the CDS data, approximately five percent of the Chevrolet C/K and GMC Sierra trucks had head restraints in model years 1990 and 1991. The Chevrolet S/T and GMC Sonoma trucks were about 20 percent equipped in those years. All of these General Motors trucks were 100 percent head restraint equipped from model year 1992 on (as noted in the data as well as required by FMVSS 202).

Dodge Dakotas and D/W series trucks had no head restraints through 1989. From 1990 on, all Dakotas were equipped with head restraints. The Dodge D/W 100 series were also shown in the CDS data to be equipped 100% of the time from 1990 on. Data on the Dodge D/W 200/300 series, however, had only two observations for model year 1990 – one with a head restraint and one without. From 1991 on, all Dodge D/W series were equipped with head restraints. It was decided that, when the Dodge D/W 200/300 series trucks could be distinguished from other Dodge D/W trucks, model year 1990 would not be used. Instead, model years 1991 and 1992 date would be used as the "equipped" years. While this violated the requirement for using successive years, it was felt that it would be the best way to most accurately represent the data while permitting a larger set of data for analysis.

CDS data showed Ford Rangers having head restraints approximately 24 percent of the time for model years 1989 and 1990. The average for model years 1991 and 1992 was 94% equipped. Since FMVSS 202 required all vehicles built September 1, 1991 and later to be equipped with head restraints, the unequipped Rangers must have been model year 1991's or early 1992's.

All Chevrolet/GMC and Dodge pickups in the given model years were included in the analysis. Although involving different models (Chevrolet C/K and S/T, GMC Sierra and Sonoma, and Dodge D/W and Dakota), all pickup trucks by the respective manufacturers became predominately equipped with head restraints in the same model year. Ford Rangers are included in the present analysis, but the F150/250/350 Series pickups are not. Head restraints were introduced in the F-Series pickups more slowly, so that there is no clear transition year. Thus, we excluded them from the analysis.

Vans and sport utility vehicles are also considered "Light Trucks" and are covered under the revision of FMVSS 202. However, those vehicles that were in production in model year 1992 already had head restraints on most or all vehicles in all earlier years of production. There are no comparable vehicles without head restraints on which to perform an analysis. Therefore, the present analysis is necessarily limited to pickup trucks.

2.1.1.2 Manufacturer Information

Data on presence and type of head restraint by vehicle make and model year were requested from the domestic manufacturers (DaimlerChrysler, Ford, and General Motors). It was necessary to verify the data obtained from NASS CDS. It was also desirable to further investigate, particularly vehicles other than pickup trucks, for any possible additional with/without head restraint comparisons. The data from the manufacturers validated what had been concluded from the NASS CDS data.

### 2.1.2 State Data

The injury rate for each type of pickup would be determined using the two years of data before head restraints were installed, and compared to rate during the two years following installation. While NASS CDS is valuable for identifying what makes and models had head restraints, the number of rear-impact crashes is insufficient for statistically meaningful analysis of injury rates in this analysis. Because specific vehicles (rather than "all passenger vehicles") were used, a two-year span would not provide sufficient data for a reliable estimate of injury rate. Furthermore, in NASS CDS, only data on crashes involving at least one vehicle towed from the scene are collected. While this is useful for investigating more serious crashes, the majority of injuries in rear-impact crashes occur in non-towaway crashes. Using the NASS CDS data would require an adjustment to account for non-towaway crashes. State data are available as a more inclusive source to use in examining patterns of injuries in rear-impact crashes.

#### 2.1.2.1 Selection of States

In order to perform the analysis of injury rates in rear impact crashes, there were several requirements of the data. It would be necessary to determine make, model, and model year of vehicles. This could be done by either having those variables present on the file, or decoding the VIN if it were present. It would also be necessary to determine the impact location for the vehicle, in order to determine which vehicles sustained a rear impact.

NHTSA currently has data from 17 states available for analysis. Of these, California, Georgia, Illinois, New Mexico, Ohio, and Washington do not code a point of impact for the vehicle. Kansas did not code a vehicle impact point before 1997. Michigan and Virginia code neither a VIN nor the vehicle make or model. The remaining eight state files were used in the analysis: Florida, Indiana, Maryland, Missouri, North Carolina, Pennsylvania, Texas, and Utah. These states had a combined population of 73,512,899 as of July, 1999, about 27 percent of the total population of the United States. According to 1998 data, the most recent available, these eight states account for 9,452,980 registered pickup trucks, about 26 percent of the national total. State data from calendar years 1993 to 1998 were analyzed.

#### 2.1.2.2 Impact Location

Each state has its own way of coding data. For example, some states code impact location by clock point positions, while others use descriptions such as "front" or "left rear." The following table shows how rear impact was defined by each state. Also noted are the definitions used for "frontal impact," since these were used in the analysis as a control group.

| State | Rear Impact | Frontal Impact |
|---|---|---|
| Florida | Point of Impact 7, 8, 9 | Point of Impact 1, 2, 14 |
| Indiana | Initial Point of Impact 5, 6, 7 | Initial Point of Impact 1, 2, 3 |
| Maryland | Initial Impact and Vehicle Damage Area1 both 7-12, or one is blank and the other is 7-12 | Initial Impact and Vehicle Damage Area1 both 1-4,15,16, or one is blank and the other is 1-4, 15, 16 |
| Missouri | Vehicle Damage Area 7, 8, 9 | Vehicle Damage Area 1, 2, 14 |
| North Carolina | TAD1 10-13 | TAD1 1-4 |
| Pennsylvania | Initial Impact Point 5, 6, 7 | Initial Impact Point 1, 11, 12 |
| Texas | Damage Scale B--, LB-, RB- | Damage Scale F--, LF-, RF- |
| Utah | Damage Areas 1 and 2 both 7-9, or one is blank and the other 7-9 | Damage Areas 1 and 2 both 1-3, or one is blank and the other 1-3 |

Rear and frontal crashes were defined solely using the above criteria. Data were not limited to two vehicle crashes, so it is possible that some collisions involved impacts and/or damage to more than one area of a vehicle. The damage area coded on the state file is the one used for the analysis.

#### 2.1.2.3 Vehicle Information

Six of the eight state data files used in the analysis contain the VINs. This enables the make, model, and model year of the vehicle to be accurately determined based on a program developed by NHTSA staff. For five of these states (Florida, Maryland, North Carolina, Pennsylvania, and Utah), this was the sole method of determining vehicle information.

Missouri also includes the VIN on its data file. However, it is missing or invalid a large percentage of the time. Therefore, the Vehicle Type and Make variables on the Missouri file were used, in addition to the VIN, to select vehicles for inclusion in the analysis. For those cases where the VIN was not valid, vehicles with a Vehicle Type of 17 (Pickup Truck) and Make of Chevrolet, GMC, or Dodge were included. Recall that, except for Ford, all pickup trucks of a specific manufacturer in the selected model years were included in the analysis. Since there is no Model variable on the Missouri file, Fords could not be selected this way, since there was no way to distinguish between Rangers and the F-Series trucks.

Indiana and Texas files do not contain VIN. Vehicles in the Indiana file were selected using the variables Vehicle Type (2, Pickup Truck), Make, and Model. For Chevrolet, GMC, and Dodge, all vehicles of the appropriate Vehicle Type were included, even when the model was unknown. Vehicles in Texas were selected based on the Body Type (30, Pickup and 38, Pickup with Camper) and the Make/Model (MK_MDL) variables. Since make and model are combined in a single variable, this meant that a vehicle coded as Body Type "pickup truck" with, for example, "GMC Not Listed or unknown" or " Dodge Truck" as the Make/Model, were included in the analysis. However, only those coded specifically as "Ford Ranger" could be included.

#### 2.1.2.4 Seat Position and Gender

Five of the states collect data in such a way that permits analysis by both gender and seat position. That is, both drivers and right front passengers (occupants in seating positions that now require head restraints) are documented regardless of whether or not an injury occurred. Florida records right front passengers even when they are uninjured, but records gender for drivers only. Both Indiana and Missouri record data on right front passengers only when they are injured. This prohibits their use in determining injury rates.

Therefore, the data used in the present analysis contains drivers and right front passengers for all states except Indiana and Missouri, where only drivers are analyzed. The only exception is when gender is considered, at which time Florida right front passengers are excluded.

Another factor worth noting is that the analysis put no age or height requirements on the occupant data - all drivers and, where possible, right front passengers were included. Presumably, a head restraint would add protection only for those occupants whose head was above the actual seat back. Smaller stature occupants (including children) would not be affected by the addition of a head restraint, and consequently their injury rates would remain unchanged regardless of the presence of head restraints. For this reason, effectiveness estimates generated by this analysis can be considered conservative, since some proportion of the occupants should be unable to show improvement in terms of injury reduction. On the other hand, Indiana and Missouri could have relatively higher effectiveness rates than they would have if right front passengers were able to be included. Since the analysis in these states is drivers only, many of the younger, shorter occupants [viz., child passengers] are excluded, providing a larger proportion of occupants with injury reduction potential.

#### 2.1.2.5 Injury Information

Head restraints are designed to prevent "whiplash" injuries in rear impact collisions. Whiplash, however, is not in itself an injury, but a body motion that causes a group of symptoms difficult to define and even more difficult to encode in data files. The most direct symptoms of whiplash are neck pain and stiffness. Nevertheless, symptoms can occur in many other areas of the body due to spinal cord or nerve involvement. Therefore, headache, sight and hearing disturbances, pain or weakness in the arms and/or upper back, and concussion-like symptoms often accompany whiplash. Visible, superficial injuries due to contact with vehicle components, such as lacerations, contusions, and abrasions, are generally not called “whiplash.”

All eight State files analyzed in this evaluation code injuries according to their severity: A = “incapacitating injury,” B = “other visible injury,” C = “possible injury.” Most of the symptoms associated with whiplash are not visible injuries, and they are usually, but not exclusively, coded AC.@ Only three of the files, Indiana, Pennsylvania, and Utah, provide additional injury information: the body region of the occupant’s most severe injury and the type of injury (laceration, fracture, complaint of pain, etc.).

Since the principal analysis of the data must encompass all eight States, it will be based on comparing overall injury rates (A + B + C) before and after the installation of head restraints.

Whiplash can involve so many potential body regions that, when limiting whiplash to cases with only neck or back injury, many true whiplash victims are excluded. Conversely, injuries other than whiplash can occur in the neck and back regions, with similar coding descriptions. It is not possible to determine conclusively that all minor neck and/or back injuries indicate whiplash, while all other types of injury imply no whiplash.

Another complication with an analysis of whiplash injuries lies in how injury data tend to be coded. When the state data files include injury information, data on only a single injury is included for each occupant. Typically, this is the most serious injury. Head injuries, for example, are considered more serious than neck or back injuries. Therefore, if head restraints are indeed preventing and minimizing whiplash injuries, this could result in less severe injuries being coded where more severe injuries were being prevented. For example, a case of whiplash before the installation of head restraints might have involved a severe headache and a stiff neck, both common symptoms of whiplash. Conceivably, this same crash, once head restraints were installed, might have resulted only in the stiff neck. However, in the first case, a head injury would have been noted in the data file, while in the second, a neck injury. Thus, what in reality would be an occurrence of a head restraint reducing injury severity would look, in the data, as an increased rate of neck injury.

In addition, NHTSA’s state data are obtained from the police accident report. Medical or hospital records are not examined. Whiplash injuries could potentially be overlooked due to a delayed onset of symptoms. Because of these limitations of data coding, the preferred method is to focus on overall injury rate, rather than trying to determine specific cases of whiplash.

The data extracted from each state, for the selected pickup trucks, are presented in Exhibit 2-1. Shown are the numbers of uninjured and injured occupants for the two model years before the vehicles were equipped with head restraints, labeled “Before, Uninjured” and Before, Injured,” respectively. Also shown are the (uninjured and injured) occupants for the two years after the vehicles were equipped with head restraints, labeled “After, Uninjured” and “After, Injured,” respectively. Data for both rear and frontal impacts are shown. The final column shows the total number of occupants, by head restraint, crash type, and injury status, in all of the eight states included in the analysis.

**Exhibit 2-1: Number of Occupants in Selected Pickup Trucks, 2 Model Years Before and 2 Model Years After Head Restraint Installation, by Injury Status and Crash Type, by State (State Data, Calendar Years 1993 - 1998)**

| | Florida | Indiana | Mary-land | Miss-ouri | North Carolina | Pennsyl-vania | Texas | Utah | Total of all Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Rear Impact** | | | | | | | | | |
| Before, Uninjured | 3,335 | 5,248 | 674 | 4,170 | 3,022 | 1,743 | 12,909 | 919 | 32,020 |
| Before, Injured | 1,628 | 638 | 221 | 693 | 1,000 | 883 | 6,253 | 184 | 11,500 |
| Before, Total N | 4,963 | 5,886 | 895 | 4,863 | 4,022 | 2,626 | 19,162 | 1,103 | 43,520 |
| | | | | | | | | | |
| After,Uninjured | 4,460 | 5,369 | 741 | 4,841 | 3,635 | 1,743 | 16,345 | 993 | 38,127 |
| After,Injured | 1,975 | 533 | 201 | 719 | 1,036 | 791 | 6,859 | 193 | 12,307 |
| After,Total N | 6,435 | 5,902 | 942 | 5,560 | 4,671 | 2,534 | 23,204 | 1,186 | 50,434 |
| | | | | | | | | | |
| **Frontal Impact** | | | | | | | | | |
| Before, Uninjured | 7,390 | 11,406 | 1,654 | 9,483 | 6,619 | 5,883 | 30,427 | 2,098 | 74,960 |
| Before, Injured | 3,051 | 1,863 | 512 | 1,902 | 1,683 | 2,552 | 11,614 | 404 | 23,581 |
| Before, Total N | 10,441 | 13,269 | 2,166 | 11,385 | 8,302 | 8,435 | 42,041 | 2,502 | 98,541 |
| | | | | | | | | | |
| After,Uninjured | 9,147 | 10,703 | 1,673 | 9,612 | 7,848 | 5,414 | 35,115 | 2,274 | 82,786 |
| After,Injured | 3,482 | 1,488 | 545 | 1,834 | 1,835 | 2,299 | 12,676 | 472 | 24,631 |
| After,Total N | 12,629 | 12,191 | 2,218 | 11,446 | 9,683 | 7,713 | 47,791 | 2,746 | 106,417 |

## 2.2 Changes in Rear Impact Injury Rates in Pickup Trucks

In order to estimate the effectiveness of head restraints in preventing injuries in rear impact crashes, it was necessary to compute injury rates both before and after installation. The injury rates are calculated by dividing the number of injured occupants by the total number of occupants in the appropriate group (e.g. occupants in rear impact crashes in Florida) as shown here:

$$\text{“Before” Injury Rate} = \frac{1{,}628}{(1{,}628 + 3{,}335)} = 0.3280$$

The injury rates for rear impacts, both before and after being equipped with head restraints, are presented (as percentages) for each state in Exhibit 2-2.

**Exhibit 2-2: Injury Rates Before and After Vehicles were Equipped with Head Restraints, Rear Impacts, in Selected Pickup Trucks (State Data)**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah | Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Rear** | | | | | | | | | |
| Before | 32.80 | 10.84 | 24.69 | 14.25 | 24.86 | 33.63 | 32.63 | 16.68 | 26.42 |
| After | 30.69 | 9.03 | 21.34 | 12.93 | 22.18 | 31.22 | 29.56 | 16.27 | 24.40 |
| % reduction | 6.44 | 16.68 | 13.59 | 9.25 | 10.79 | 7.17 | 9.42 | 2.45 | 7.65 |

The effectiveness, measured as the reduction in injury rate, is also shown, with a positive number indicating an improvement (a decrease in the injury rate). This is calculated by taking the difference between the two rates, and dividing by the earlier rate:

$$\text{Effectiveness (E)} = \frac{p_1 - p_2}{p_1}$$

where $p_i$ = the percent of injured occupants as:

i=1 for the group without head restraints ("Before") and
i=2 for the group with head restraints ("After")

Note that this is mathematically equivalent to:

$$E = 1 - \frac{p_2}{p_1} \qquad (1)$$

So, for example, in Florida, the effectiveness is determined as:

$$E = 1 - \left(\frac{0.3069}{0.3280}\right) = 0.0644$$

Thus, in Florida, a reduction of 6.44 percent is seen in rear impacts after the introduction of head restraints.

The rates for the combined total for the eight states are shown in the final column. These were computed by summing the data for all states, by impact type, head restraint and injury status, and calculating the injury rates as above.

Note that the injury rates are presented as rounded to two decimal places. The percent change has been calculated using the original data, without rounding, so that calculations using the presented rounded data might give slightly different results. This will be true throughout this report – values presented in any formula will be rounded, for convenience, but results will have been computed using unrounded data, and therefore may differ slightly from calculations made using values in the formula.

The initial step in evaluating the effectiveness of head restraints in reducing injuries in rear impact crashes is to examine the change in injury rate as a result of having head restraints. One method would be to look at the combined state data. As shown in the last column of Exhibit 2-2, injuries in rear impact crashes were 7.65 percent lower after the vehicles were equipped with head restraints.

Looking at the combined state data, while providing useful information, has several flaws. In examining the data for each state, it can be seen that the injury rates vary widely from state to state. For example, in rear impact crashes before the installation of head restraints, Pennsylvania has an injury rate of 33.63 percent, more than three times that of Indiana's rate of 10.84 percent. It is important to note that each state has its own reporting threshold for police-reported crashes. Some require a certain dollar amount of damage, which varies from state to state. In the states used for this analysis, this amount ranges from $250 in Texas to $750 in Indiana. Some states (Pennsylvania and Utah in the current analysis) require that one of the vehicles be towed from the accident scene, regardless of the dollar amount involved.

These differing thresholds result in very different injury rates across states, and also contribute (along with state population differences) to very different raw counts of injured and involved occupants. These differences can be out of proportion to the actual differences in the "sizes" of the states. For example, in rear impact crashes before head restraints were installed, Texas had over 6,000 injured occupants, while Maryland and Utah had about 200 each (see Exhibit 2-1), even though Texas is not 30 times as "large" as Maryland in term of population, Vehicle Miles Traveled (VMT), number of registered pickup trucks, etc. As another example, Maryland with a 1998 population of 5.17 million and Missouri with a population of 5.47 million are similar in "size," but Missouri has more than five times the number of occupants in the data shown in Exhibit 2-1. Clearly, the states with lower counts (regardless of the reason) will wind up contributing far less to any estimate calculated by simply summing the data across states.

An alternative process would be to consider each state as an estimate of head restraint effectiveness. The percent reduction for each state, as noted in Exhibit 2-2, would be used as each state's effectiveness estimate. When the simple arithmetic average of these is taken, we find a 9.19 percent decrease in the injury rate in rear impact crashes. This method, however, gives equal weight to each of the states. This is undesirable, since the states differ greatly in size.

States vary in countless ways. Clearly there are size differences, but also worth considering are the differences found in the data. States with less variable data give a more precise picture of whatever factor is being examined. Therefore, a more statistically sound method of determining a single estimate using the data from these eight states would be to combine them in such a way as to give greater weight to those states with 'better,' more accurate estimates.

A variance for each injury rate is first calculated as:

$$s_p^2 = \frac{p \times (1 - p)}{N}$$

where p=percent of occupants injured
N= number of occupants involved

Therefore, in Florida, where 4,963 occupants (see Exhibit 2-1) were involved in rear impacts before head restraints were installed, and 32.80 percent of them were injured, the variance of this statistic would be computed as:

$$\frac{0.3280 \times (1 - 0.3280)}{4963} = 0.000044412$$

Exhibit 2-3 presents the variances for the eight state states, for the injury rates both before ($p_1$) and after ($p_2$) the installation of head restraints, in rear impacts.

**Exhibit 2-3: Variance of Injury Rates and Effectiveness Estimates, and Coefficients for Determining Variance based Estimate, Rear Impacts**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah |
|---|---|---|---|---|---|---|---|---|
| **Rear** | | | | | | | | |
| Variance $p_1$ | 0.000044 | 0.000016 | 0.000208 | 0.000025 | 0.000046 | 0.000085 | 0.000011 | 0.000126 |
| Variance $p_2$ | 0.000033 | 0.000014 | 0.000178 | 0.000020 | 0.000037 | 0.000085 | 0.000009 | 0.000115 |
| Variance E | 0.0007 | 0.0022 | 0.0055 | 0.0020 | 0.0012 | 0.0014 | 0.0002 | 0.0084 |
| 1/Var(E) | 1495.78 | 464.08 | 182.92 | 496.00 | 836.36 | 715.70 | 5791.39 | 118.52 |
| Coefficient | 0.1481 | 0.0459 | 0.0181 | 0.0491 | 0.0828 | 0.0709 | 0.5734 | 0.0117 |

Recall that effectiveness was calculated as:

$$E = 1 - \frac{p_2}{p_1}$$

The variance of the effectiveness is equivilent to the variance of $p_2/p_1$, or (1 - effectiveness). The linear approximation of the variance of the ratio $p_2/p_1$ is calculated, separately for each state, as:

$$s_E^2 = \frac{p_2^2 \times s_{p_1}^2}{p_1^4} + \frac{s_{p_2}^2}{p_1^2} \qquad (2)$$

where $\sigma^2_E$=the variance of the effectiveness estimate
$p_1$=injury rate before installation of head restraints
$p_2$=injury rate after installation of head restraints
$\sigma^2_{pi}$=variance of the injury rate (percent injured)

The variance for each state's effectiveness estimates, for rear impacts, are included in Exhibit 2-3. Also presented is the inverse of the variance ($1/\sigma^2$) for each state. If these inverses are summed, and the inverse of the total taken, a constant is obtained. A coefficient for each state is then derived, by dividing this constant by the variance of the effectiveness, for each state. Note that these coefficients would sum to one. It can be shown mathematically that using coefficients that are inversely proportional to the variances results in the linear combination of a set of estimates with minimum variance. These coefficients are presented in Exhibit 2-3 as well.

Weighting each effectiveness estimate by its respective coefficient, and summing across states, gives an overall estimate of head restraint effectiveness, emphasizing the states with less variable data. Using this method, head restraints are estimated to be 9.25 percent effective in rear impacts.

To determine the significance of this, a z-score is computed as:

$$z = \frac{E}{s_E}$$

First the variance of the overall effectiveness estimate, which has been weighted by the coefficients, must be determined as:

$$s_E^2 = \sum_{i=1}^{8} c_i^2 \times s_i^2$$

where $c_i$=coefficient for state$_i$

$\sigma_i^2$=variance of the estimate for state$_{i,}$

Since the coefficient is equal to the constant divided by the variance for each state, this is equal to:

$$\sum_{i=1}^{8} \left( \frac{K^2}{s_i^4} \right) s_i^2$$

where K=constant

This simplifies to

$$K^2 \sum_{i=1}^{8} \frac{1}{s_i^2}$$

Since the constant is the inverse of the sum of the inverses of the variances across states, this is actually equal to the constant. Therefore, the z-score is calculated as:

$$z = \frac{E}{\sqrt{K}}$$

where E=Effectiveness estimate
K=constant

For rear impacts, this would be calculated as:

$$z = \frac{0.0925}{\sqrt{0.0000990026}} = 9.30$$

which is statistically significant.

The eight states differ greatly in size and population, which logically should be reflected in calculating an effectiveness estimate. Since the data involve pickup trucks, weighting each state's change in injury rate by the number of registered pickup trucks in the state would be advisable. This information for 1998 (the most recent year available) is presented in Exhibit 2-4.

**Exhibit 2-4: Number of Registered Pickup Trucks, by State, 1998**

| | |
|---|---:|
| Florida | 1,425,339 |
| Indiana | 1,025,244 |
| Maryland | 435,292 |
| Missouri | 943,717 |
| North Carolina | 1,168,132 |
| Pennsylvania | 1,010,419 |
| Texas | 3,120,226 |
| Utah | 324,611 |

When each state's change in injury rate is weighted by registered pickup trucks in that state, the average decrease in injuries in rear impact crashes is 9.62 percent, calculated as:

$$\text{E} = \frac{\sum n_i p_i}{N} \qquad (3)$$

where $n_i$ = number of registered pickup trucks in state i
$p_i$ = percent change from before head restraints installed to after, in state i
N = total number of registered pickup trucks in the eight states in the analysis

Therefore,

$$\frac{\begin{pmatrix}(1{,}425{,}339\times 6.44)+(1{,}025{,}244\times 16.68)+(435{,}244\times 13.59)+(943{,}717\times 9.25)+\\(1{,}168{,}132\times 10.79)+(1{,}010{,}419\times 7.17)+(3{,}120{,}226\times 9.42)+(324{,}611\times 2.45)\end{pmatrix}}{1{,}425{,}339+1{,}025{,}244+435{,}244+943{,}717+1{,}168{,}132+1{,}010{,}419+3{,}120{,}226+324{,}611}$$

= 9.62 percent

This is a statistically significant reduction, with a t-score of 8.01. The value of the t-score is obtained using a SAS computer program[2]. The numbers of injured and uninjured occupants in rear impact crashes, both before and after the installation of head restraints, were input, along with the number of registered pickups, for each state. The rate of injury before and after head restraint installation, and the change (decrease) in the injury rate, were calculated from these data. Then a PROC MEANS was performed, with output including the mean (9.62), t-score (8.01), and standard error of the estimate (1.20). The mean reported by this SAS program is identical to the decrease in the injury rate as calculated above.

With 7 degrees of freedom (using eight states, n – 1 = 7), a t-score larger than 1.895 indicates a significant reduction at the two-sided 90 % (or one-sided 95 %) confidence level; larger than 2.365, significance at the two-sided 95 % level; larger than 2.998, significant at the one-sided 99 % level.

Notice that the effectiveness estimate determined by weighting the data by the number of registered pickup trucks (9.62) is very close to the value arrived at when the data are weighted according to the variance (9.25).

### 2.3 <u>Comparison of Rear vs Frontal Impacts in Pickup Trucks</u>

For various reasons, there is a tendency to report crashes involving older vehicles only when they are more serious, such as when an injury is involved. Because of this, a larger proportion of crashes in the "earlier" or "before head restraint" years would tend to involve injuries for any given model year. Left unchecked, this "vehicle age effect" would tend to show a decrease in injury rates regardless of any additional safety benefits that were present.[3]

Therefore, it is necessary to have a control group for comparison, so it can be stated with confidence that any observed improvements are actually due to the presence of head restraints rather than an artifact of the data. In this analysis, frontal impacts are used as the control group. These pickup trucks did not get air bags or, as far as we know, any other modification that would have significantly improved frontal crashworthiness during the model years considered in this study. While the number of frontal impacts is larger than rear impacts, and tend to be more serious, the rate of injury would be expected to change in a similar manner regardless of type of crash, if there were no outside factors influencing only one crash type. If the injury rates change in different ways, particularly if they do so consistently across a set of several states, it can be said that these differences are due to some outside factor. In this case, we assume that factor to be the presence of head restraints.

Important to notice in Exhibit 2-2 is that, in every state, injuries in rear impacts occurred less frequently in vehicles after head restraints were installed. Certainly, this is not unexpected, since the equipped vehicles are also newer vehicles. As mentioned earlier, crashes involving older vehicles tend to be reported only when there are injuries, which often results in a lower injury rate for newer vehicles for no other reason than the age of the vehicle.

The equivalent data for frontal impacts are shown in Exhibit 2-5. These data are based on the frontal crash counts shown in Exhibit 2-1. Note that two of the eight states show an *increased* injury rate in frontal impacts. Rear impacts consistently showed a decrease in injury rate, even when the rate in frontal impacts increase. Additionally, in every state in which frontal impacts showed a decreased injury rate, rear impacts showed a larger decrease. This definitely suggests that head restraints may very well be effective in lowering the rate of injury in rear impact crashes.

**Exhibit 2-5: Injury Rates Before and After Vehicles were Equipped with Head Restraints, Frontal Impacts, and Effectiveness Estimates, in Selected Pickup Trucks, by State (State Data)**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah | Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Frontal** | | | | | | | | | |
| Before | 29.22 | 14.04 | 23.64 | 16.71 | 20.27 | 30.25 | 27.63 | 16.15 | 23.93 |
| After | 27.57 | 12.21 | 24.57 | 16.02 | 18.95 | 29.81 | 26.52 | 17.19 | 23.15 |
| % reduction | 5.65 | 13.07 | -3.95 | 4.09 | 6.52 | 1.48 | 3.99 | -6.45 | 3.28 |

In order to quantify this effectiveness more accurately, changes in frontal impacts were compared to those calculated for rear impacts. When the data for the eight states are combined using Formula 1, there is a 3.28 percent decrease in the injury rate in frontal crashes after head restraints are installed. Using the same calculation methods as shown earlier on rear impact crashes, a z-test on these data results in a value of 4.18. Recall that, in rear impacts, there was a 7.65 percent decrease in the injury rate. Observation of the data showed that rear impacts experienced a greater improvement in injury rate than did frontal impacts. The effectiveness estimates permit a comparison of those differences.

Calculations could also be done using the method which combines individual state estimates based on the variance of the estimate. As was done for rear impacts in Section 2.2, the variance is calculated for the injury rates before ($p_1$) and after ($p_2$), as well as for the effectiveness estimate, for each state. These are shown in Exhibit 2-6 for frontal impacts. Also shown, and used in the calculations, are the value for the inverse of the effectiveness estimate and the coefficient used for combining the data across states.

**Exhibit 2-6: Variance of Injury Rates and Effectiveness Estimates, and Coefficients for Determining Variance based Estimate, Frontal Impacts**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah |
|---|---|---|---|---|---|---|---|---|
| **Frontal** | | | | | | | | |
| Variance $p_1$ | 0.000020 | 0.000009 | 0.000083 | 0.000012 | 0.000019 | 0.000025 | 0.000005 | 0.000054 |
| Variance $p_2$ | 0.000016 | 0.000009 | 0.000084 | 0.000012 | 0.000016 | 0.000027 | 0.000004 | 0.000052 |
| Variance E | 0.0004 | 0.0008 | 0.0031 | 0.0008 | 0.0008 | 0.0006 | 0.0001 | 0.0043 |
| 1/Var(E) | 2552.90 | 1258.48 | 321.85 | 1213.51 | 1250.07 | 1780.61 | 9018.76 | 230.41 |
| Coefficient | 0.1448 | 0.0714 | 0.0183 | 0.0688 | 0.0709 | 0.1010 | 0.5117 | 0.0131 |

Using this method, the effectiveness estimate for frontal impacts is 4.53 percent. The z-score is determined as:

$$z = \frac{0.0453}{\sqrt{0.0000567325}} = 6.01$$

The third method used to determine effectiveness weights the data by the number of registered pickup trucks in the state. When this method is employed, using Formula 3, the effectiveness estimate is 4.55 percent. The resulting t-score is 2.91.

Notice that, again, the result obtained by weighting the data by registered pickup trucks is very similar to the estimate when data are weighted according to their variances.

There is no intuitive reason to expect head restraints to reduce injuries by more than a small amount, if any, in frontal crashes. It is possible that, in some frontal crashes, the occupant could rebound and derive some benefit from the head restraint. In addition, a vehicle can be involved in both a frontal and a rear impact in the same crash. The impact location could be coded as ‘Frontal Impact,’ but the head restraint would provide protection at least during the rear-impact portion of the crash. Nevertheless, any protection head restraints provide in vehicles determined to be in frontal crashes would be, at best, a second order effect.

As evidenced by the significant results for both methods above, however, clearly something is going on. The most likely cause is the age of the vehicle and its impact on reporting a crash to the authorities. In order to determine a valid measure of effectiveness of head restraints, this age effect needs to be eliminated. Using frontal impacts as a control group for the rear impacts, a more accurate measure of the effectiveness of head restraints can be determined. Since the purpose of head restraints is to prevent whiplash and related injury in rear impact crashes, frontal crashes are an appropriate control.

The effectiveness of head restraints, as measured by injury reduction in rear impacts controlled for by frontal impacts, is calculated for the eight states combined as:

$$E = 1 - \left[ \left( \frac{p_{12}}{p_{11}} \right) \Big/ \left( \frac{p_{22}}{p_{21}} \right) \right] \quad (4)$$

Where $p_{ij}$ = percent of injured occupants (injury rate)
i = impact location (1=rear, 2=front)
j = status of head restraint installation (1=before, 2=after)

Combining the eight states into a single estimate gives:

$$E = 1 - \left[ \left( \frac{24.40}{26.42} \right) \Big/ \left( \frac{23.15}{23.93} \right) \right] = 4.52 \text{ percent}$$

Therefore, when the data from the eight states are combined, it is estimated that head restraints reduce injuries in rear impact crashes (when controlled for frontal crashed) by 4.52 percent.

The z-score for this is 3.29, which is significant, is calculated as follows:

$$z = \frac{E}{s}$$

where:

$$s = \sqrt{\frac{1-p_{11}}{n_1 p_{11}} + \frac{1-p_{12}}{n_1 p_{12}} + \frac{1-p_{21}}{n_1 p_{21}} + \frac{1-p_{22}}{n_1 p_{22}}}$$

$$= \sqrt{\frac{(1-0.2642)}{43{,}520 \times 0.2642} + \frac{(1-0.2440)}{50{,}434 \times 0.2440} + \frac{(1-0.2393)}{98{,}541 \times 0.2393} + \frac{(1-0.2315)}{106{,}417 \times 0.2315}}$$

$$\sqrt{0.000189} = 0.01374$$

Therefore:

$$z = \frac{0.0452}{0.01374} = 3.29$$

In order to derive an effectiveness estimate based on the variances of the estimates, Formula 2, as introduced in section 2-2, is used.

$$s_E^2 = \frac{p_2^2 \times s_{p_1}^2}{p_1^4} + \frac{s_{p_2}^2}{p_1^2}$$

In this case, however, $p_{FA}/p_{FB}$ (percent in the "After" group injured in frontal crashes divided by the percent in the "Before" group injured in frontal crashes) would be substituted for $p_1$ in the formula. Similarly for the rear impacts, as $p_2$. The variances for these are equivalent to the variances for the respective effectiveness estimates, which have already been calculated and presented in Exhibits 2-3 and 2-6. The effectiveness for each state is calculated using the same method as was used for the combined state data above, using Formula 4:

$$E_i = 1 - \left[ \left( \frac{p_{12}}{p_{11}} \right) \Big/ \left( \frac{p_{22}}{p_{21}} \right) \right]$$

The eight states' individual effectiveness estimates, and the values used for their calculation, are presented in Exhibit 2-7. The front and rear effectiveness data have been presented earlier, in Exhibits 2-2 and 2-5, but are repeated here together for reference.

**Exhibit 2-7: Injury Rates Before and After Vehicles were Equipped with Head Restraints, Rear and Frontal Impacts, and Effectiveness Estimates, in Selected Pickup Trucks, by State (State Data)**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah | Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Rear** | | | | | | | | | |
| Before | 32.80 | 10.84 | 24.69 | 14.25 | 24.86 | 33.63 | 32.63 | 16.68 | 26.42 |
| After | 30.69 | 9.03 | 21.34 | 12.93 | 22.18 | 31.22 | 29.56 | 16.27 | 24.40 |
| % reduction | 6.44 | 16.68 | 13.59 | 9.25 | 10.79 | 7.17 | 9.42 | 2.45 | 7.65 |
| **Frontal** | | | | | | | | | |
| Before | 29.22 | 14.04 | 23.64 | 16.71 | 20.27 | 30.25 | 27.63 | 16.15 | 23.93 |
| After | 27.57 | 12.21 | 24.57 | 16.02 | 18.95 | 29.81 | 26.52 | 17.19 | 23.15 |
| % reduction | 5.65 | 13.07 | -3.95 | 4.09 | 6.52 | 1.48 | 3.99 | -6.45 | 3.28 |
| E | 0.84 | 4.16 | 16.67 | 5.39 | 4.57 | 5.77 | 5.65 | 8.36 | 4.52 |

Using this methodology, the effectiveness estimate of head restraints in rear impacts, controlled for by frontal impacts, is 5.14 percent, with a z-score of 3.99.

The effectiveness estimate determined by weighting the data by registered pickup trucks is calculated as:

$$E = \frac{\sum n_i E_i}{N} \qquad (5)$$

where $n_i$ = number of registered pickup trucks in state i
$E_i$ = Effectiveness estimate in state i
N = total number of registered pickup trucks in the eight states in the analysis

So that:

$$\frac{\begin{pmatrix}(1{,}425{,}339\times 0.84)+(1{,}025{,}244\times 4.16)+(435{,}244\times 16.87)+(943{,}717\times 5.39)+\\(1{,}168{,}132\times 4.57)+(1{,}010{,}419\times 5.77)+(3{,}120{,}226\times 5.65)+(324{,}611\times 8.36)\end{pmatrix}}{1{,}425{,}339+1{,}025{,}244+435{,}244+943{,}717+1{,}168{,}132+1{,}010{,}419+3{,}120{,}226+324{,}611}$$

$$= 5.23 \text{ percent}$$

Calculated using the SAS procedure as described above, the standard error is 1.18. The t-score is calculated as

$$t = \frac{E}{s} = \frac{5.23}{1.18} = 4.43$$

and is statistically significant.

In summary, it was shown that the injury rates in both rear and frontal impacts were lower in the two years following the installation of head restraints in pickup trucks. While the decrease in the rate for rear impact injures was expected, because of head restraints, and larger than the decrease in frontal impacts, both were significant. Thus, in order to determine the actual effectiveness of head restraints in rear impact crashes, controlling for the decrease in injury rate in frontal impacts would be necessary. While this process of calculating an effectiveness estimate is the most complex thus far, it is also the one that best accounts for the needs of the data.

This was done using three alternative methods - combining all state data into a single estimate, weighting estimates based on the variance of the data, and weighting based on the number of registered pickup trucks. All three methods gave similar results (4.52, 5.14, and 5.23, respectively).

The estimate of the effectiveness derived from combining the data across states has the same shortcomings as the earlier ones calculated using this method. The estimates based on treating each state as an individual estimate, and weighting according to the variances of those estimates, are statistically sound but intuitively lacking. The final method uses an estimate for each state, weighting each of these sample values by the state's number of registered pickup trucks. This minimizes the effect of differing reporting thresholds in each state, while providing a means for those states with larger numbers of pickup trucks to have a greater impact on the estimate.

The two methods that weight the estimate for each state (by variance or by registered pickup trucks) result in extremely similar estimates overall. There is little practical difference in selecting one over the other. Therefore, the method which weights the data by registered pickup truck counts will be considered the preferred one, since it simpler as well as being more straightforward to comprehending the meaning of the final estimates.

For the remainder of this report, the variance weighted estimates will not be presented. Because they provide a simple but flawed alternative, the estimates based on combining all the data into a single estimate will be calculated, but significance testing will not be performed. It is important in any research report to establish the selection of method, including whatever procedure is used to determine estimates, early in the analysis. Otherwise, if numerous procedures are performed, statistically significant results would, at some point, be expected by chance alone. To avoid this, it is important to logically establish a single method of determining the estimates. Therefore, weighting data by the number of registered pickup trucks will be considered the preferred method.

## 2.4 Changes in Injury Rates in Passenger Cars

The previous estimate controls for the vehicle age effect by using frontal crashes of pickup trucks as a control group. However, the results could still be biased if the vehicle age effect exhibited in frontal crashes is not the same as the one that occurs in rear impacts. It might be better to derive a vehicle age effect specifically for rear impacts, by considering passenger cars. Cars, unlike the pickup trucks, already had head restraints by model year 1969. They did not significantly modify their head restraints or other components that affect rear-impact crashworthiness during the model years considered in our study, 1988-93. (Although the maximum and minimum heights of head restraints in passenger cars have increased since the standard initially took effect, there is no evidence that there was a noteworthy change in the height of passenger car head restraints during this time frame.) In other words, if the injury rates in rear impacts of passenger cars, measured the same way as in pickup trucks, show any important reductions for later vs. earlier cars, this is due to the age effect, and it can be deducted from the observed injury reduction in pickup trucks in order to obtain the true effect of head restraints.

Recall that pickup truck manufacturers introduced head restraints in different years. Therefore, the “Before” and “After” model years, in this analysis, vary by manufacturer. The “After” years for Dodge are 1990 and 1991; for Ford Rangers, 1991 and 1992; and for Chevy and GMC pickups, 1992 and 1993. In each case, the “Before” model years are the two model years proceeding the “After” years. In order to account for any possible changes in passenger car injury rates, it would be necessary to examine the changes over the same sets of model years. Accordingly, injury rates in passenger cars were determined for the same pairs of years as had been done for the pickup trucks, by state and type of crash (rear or frontal).

Note that the data involving pickup trucks were designated as “Before” or “After” regarding head restraint installation (based on manufacturer), and then combined into “Before” and “After” groups. Passenger cars, as a comparison group, do not belong to a “Before” or “After” groups based on head restraint status, but are classified according to model year only.

Let us define three overlapping cohorts of passenger cars:

- The “Dodge truck comparison group” consists of all passenger cars (of any manufacturer) of model years 1988-91, with MY 1988-89 considered as the “Before” group and MY 1990-91 counted as “After. ”

- The “Ford Ranger comparison group” consists of all passenger cars of model years 1989-92, with MY 1989-90 considered as the “Before” group and MY 1991-92 counted as “After.”

- The “GM truck comparison group” consists of all passenger cars of model years 1990-93, with MY 1990-91 considered as the “Before” group and MY 1992-93 counted as “After.”

Injury rates for passenger cars, by state and crash type, for each set of “Before” and “After” years (in each of the three comparison groups), are presented in Exhibit 2-8. Note that the pair of “After” years in the first group, 1990-91, is the same set of years in the “Before” group in the last set of data. Also, the data as presented here are not mutually exclusive, so that the data for model year 1990 passenger cars, for example, are incorporated as part of the “After” data in the first set, and in the “Before” data in the remaining two sets. In most cases, the cars had some “After” vs. “Before” reduction in the reported injury rate (a “vehicle age effect”), although the reductions were typically smaller than for the trucks in the rear impacts (Exhibit 2-2).

Simply looking at the injury rates in passenger cars, however, is not appropriate. The car data need to be combined and weighted so they will have the same model-year mix as the truck data in Exhibits 2-1, 2-2, and 2-5. That will make the vehicle-age effect exhibited by the cars directly analogous to the vehicle age effect that is presumably hidden in the truck injury rates of Exhibits 2-1, 2-2, and 2-5. In other words, the cases for the three comparison groups of cars must be weighted so that they will make the same contribution to the total as the three make-model groups of trucks did in Exhibits 2-1, 2-2, and 2-5. Specifically, since the number of Dodge truck cases in our study was small, the car cases in the Dodge truck comparison group will have low case-weight factors. Since the number of GM truck cases was large, the cars in the GM truck comparison group will have higher case weights.

### 2.4.1 Weighting Passenger Car Counts

First, the raw counts of front outboard passenger car occupants for the Dodge truck, Ford Ranger, and GM truck comparison groups, by injury status (injured or uninjured), impact location (rear or frontal), “Before/After” status, and state were obtained. These data, which are the basis for the injury rates shown in Exhibit 2-8, are presented in Exhibit 2-9. Rear and frontal impacts for these crashes were then combined, and are shown in Exhibit 2-10 for both cars and trucks. The purpose of weighting the passenger car counts is to obtain comparable weights based on the model year of the vehicle. Combining the rear and frontal impacts allows for a more robust procedure. While the raw data for passenger cars are the same as in Exhibit 2-9, later calculations performed on the data are more easily followed when the car data are presented both separated by injury status as well as combined.

The next step was to form a ratio of the number of trucks to the number of cars, for each state and manufacturer (for pickup trucks) or its comparison group (for passenger cars), by “Before” or “After” head restraint status. These ratios were then multiplied by the appropriate corresponding data, as presented in Exhibit 2-9. The calculations were performed as follows:

$$N_{Wijk} = \left(\frac{N_{Ti}}{N_{Ci}}\right) \times N_{Cijk}$$

where $N_W$ = Weighted number of passenger car cases
$N_T$ = Number of trucks
$N_C$ = Number of cars
i = model year grouping (before, after)
j = impact location (rear, frontal)
k = injury status (injured, uninjured)

For example, in Florida, there were 2,058 Dodge pickup trucks in the "Before" groups, and 265,346 passenger cars in the "Before" portion of the Dodge comparison group. The ratio for this cell would be 2,058/265,346 = 0.00776. If each passenger car case in the Florida "Before" Dodge truck comparison group is weighted by 0.00776, the weighted number of cars will be exactly the same as the actual number of trucks: 2,058. So every passenger car count in the 1988/90 vs 1990/91 "Before" group would be multiplied by the ratio described above. Four values, then, would be multiplied by each ratio – both injured and uninjured occupants, rear and frontal impacts, in the proper grouping for that state. In the present example, these calculations, for the Dodge comparison group in the state of Florida, are:

| | |
|---|---|
| Before, Rear Impact, Uninjured: | 49,209 x 0.00776 = 382 |
| Before, Rear Impact, Injured: | 32,746 x 0.00776 = 254 |
| Before, Frontal Impact, Uninjured: | 120,758 x 0.00776 = 937 |
| Before, Frontal Impact, Injured: | 62,633 x 0.00776 = 486 |

Cells were then summed across model year combinations – the "Before, Rear Impact, Uninjured" are totaled for the three "Before/After" time periods, which coincide with the "Before/After" model years for the three manufacturer groups of pickup trucks. The results of this weighting are presented in Exhibit 2-11. Notice that this results in the same total number of weighted car cases as was seen for corresponding totals of pickup trucks. The overall model-year mix of the weighted car cases is exactly the same, in each state, as the model-year mix of the actual truck cases.

**Exhibit 2-8: Injury Rates and Percent Changes in Passenger Cars, by Sets of "Before" and "After" Model Years for each Pickup Manufacturer, by State**

| | *Florida* | *Indiana* | *Maryland* | *Missouri* | *North Carolina* | *Pennsyl-vania* | *Texas* | *Utah* |
|---|---|---|---|---|---|---|---|---|
| | **Any Injury, Dodge Truck Comparison Group** | | | | | | | |
| **Rear Impact** | | | | | | | | |
| 1988-1989 | 39.96 | 17.50 | 40.63 | 20.90 | 30.52 | 45.29 | 44.41 | 23.60 |
| 1990-1991 | 38.41 | 16.93 | 38.07 | 20.13 | 28.99 | 44.18 | 43.96 | 22.80 |
| Percent reduction | 3.88 | 3.26 | 6.30 | 3.68 | 5.01 | 2.45 | 1.01 | 3.39 |
| **Frontal Impact** | | | | | | | | |
| 1988-1989 | 34.15 | 13.82 | 26.94 | 19.35 | 24.49 | 38.55 | 34.56 | 20.57 |
| 1990-1991 | 33.28 | 12.81 | 26.17 | 18.46 | 23.66 | 37.49 | 34.85 | 20.33 |
| Percent reduction | 2.55 | 7.31 | 2.86 | 4.60 | 3.39 | 2.75 | -0.84 | 1.17 |
| | **Any Injury, Ford Ranger Comparison Group** | | | | | | | |
| **Rear Impact** | | | | | | | | |
| 1989-1990 | 39.19 | 17.15 | 39.38 | 20.78 | 29.91 | 45.06 | 44.33 | 23.28 |
| 1991-1992 | 38.20 | 16.86 | 37.53 | 19.46 | 28.35 | 43.65 | 43.99 | 23.23 |
| Percent reduction | 2.53 | 1.69 | 4.70 | 6.35 | 5.22 | 3.13 | 0.77 | 0.21 |
| **Frontal Impact** | | | | | | | | |
| 1989-1990 | 33.57 | 13.31 | 26.56 | 18.76 | 23.94 | 37.88 | 34.57 | 20.29 |
| 1991-1992 | 33.25 | 12.24 | 26.53 | 18.36 | 23.36 | 36.80 | 34.87 | 20.49 |
| Percent reduction | 0.95 | 8.04 | 0.11 | 2.13 | 2.42 | 2.85 | -0.87 | -0.99 |
| | **Any Injury, GM Truck Comparison Group** | | | | | | | |
| **Rear Impact** | | | | | | | | |
| 1990-1991 | 38.41 | 16.93 | 38.07 | 20.13 | 28.99 | 44.18 | 43.96 | 22.80 |
| 1992-1993 | 37.82 | 16.57 | 38.06 | 19.24 | 28.07 | 43.76 | 44.42 | 24.02 |
| Percent reduction | 1.54 | 2.13 | 0.03 | 4.42 | 3.17 | 0.95 | -1.05 | -5.35 |
| **Frontal Impact** | | | | | | | | |
| 1990-1991 | 33.28 | 12.81 | 26.17 | 18.46 | 23.66 | 37.49 | 34.85 | 20.33 |
| 1992-1993 | 33.30 | 11.77 | 26.58 | 18.61 | 23.14 | 36.55 | 35.70 | 20.87 |
| Percent reduction | -0.06 | 8.12 | -1.57 | -0.81 | 2.20 | 2.51 | -2.44 | -2.66 |

**Exhibit 2-9a: Number of Front Outboard Occupants in Passenger Cars, by Model Year, Injury Status, and Crash Type, Dodge Truck Comparison Group, by State (State Data, Calendar Year 1993 – 1998)**

| **1988/89 vs 1990/91** | *Florida* | *Indiana* | *Maryland* | *Missouri* | *North Carolina* | *Pennsyl-vania* | *Texas* | *Utah* |
|---|---|---|---|---|---|---|---|---|
| **Rear Impact** | | | | | | | | |
| Before,Uninjured | 49,209 | 28,327 | 10,827 | 26,962 | 56,386 | 20,908 | 51,577 | 9,111 |
| Before,Injured | 32,746 | 6,010 | 5,718 | 7,123 | 24,770 | 17,311 | 41,196 | 2,815 |
| After,Total N | 81,955 | 34,377 | 16,545 | 34,085 | 81,156 | 38,219 | 92,773 | 11,926 |
| After,Uninjured | 47,039 | 25,710 | 10,847 | 27,237 | 50,847 | 19,595 | 53,030 | 9,393 |
| After,Injured | 29,330 | 5,239 | 5,357 | 6,863 | 20,757 | 15,507 | 41,604 | 2,774 |
| After,Total N | 76,369 | 30,949 | 16,204 | 34,100 | 71,604 | 35,102 | 94,634 | 12,167 |
| **Frontal Impact** | | | | | | | | |
| Before,Uninjured | 120,758 | 48,799 | 32,528 | 70,204 | 150,297 | 75,489 | 149,732 | 27,582 |
| Before,Injured | 62,633 | 7,827 | 14,318 | 16,840 | 48,755 | 47,363 | 79,093 | 7,146 |
| Before,Total N | 183,391 | 56,626 | 46,846 | 87,044 | 199,052 | 122,852 | 228,825 | 34,728 |
| After,Uninjured | 106,247 | 40,748 | 30,882 | 64,778 | 127,125 | 65,665 | 149,841 | 27,183 |
| After,Injured | 52,991 | 5,985 | 13,451 | 14,661 | 39,409 | 39,378 | 80,143 | 6,938 |
| After,Total N | 159,238 | 46,733 | 44,333 | 79,439 | 166,534 | 105,043 | 229,984 | 34,121 |

**Exhibit 2-9b: Number of Front Outboard Occupants in Passenger Cars, by Model Year, Injury Status, and Crash Type, Ford Ranger Comparison Group, by State (State Data, Calendar Year 1993 – 1998)**

| **1989/90 vs 1991/92** | *Florida* | *Indiana* | *Maryland* | *Missouri* | *North Carolina* | *Pennsyl-vania* | *Texas* | *Utah* |
|---|---|---|---|---|---|---|---|---|
| **Rear Impact** | | | | | | | | |
| Before, Uninjured | 47,614 | 26,814 | 10,902 | 26,865 | 53,209 | 20,425 | 52,263 | 9,295 |
| Before, Injured | 30,689 | 5,551 | 5,570 | 7,049 | 22,701 | 16,753 | 41,625 | 2,820 |
| Before, Total N | 78,303 | 32,365 | 16,472 | 33,914 | 75,910 | 37,178 | 93,888 | 12,115 |
| After,Uninjured | 50,906 | 26,260 | 10,797 | 28,378 | 54,966 | 19,370 | 53,517 | 9,227 |
| After,Injured | 31,469 | 5,326 | 5,222 | 6,858 | 21,751 | 15,007 | 42,026 | 2,792 |
| After,Total N | 82,375 | 31,586 | 16,019 | 35,236 | 76,717 | 34,377 | 95,543 | 12,019 |
| **Frontal Impact** | | | | | | | | |
| Before, Uninjured | 111,616 | 44,347 | 31,628 | 67,295 | 137,928 | 70,832 | 150,558 | 27,805 |
| Before, Injured | 56,405 | 6,811 | 13,918 | 15,540 | 43,405 | 43,199 | 79,547 | 7,078 |
| Before, Total N | 168,021 | 51,158 | 45,546 | 82,835 | 181,333 | 114,031 | 230,105 | 34,883 |
| After Uninjured | 110,248 | 39,671 | 29,664 | 62,324 | 131,035 | 62,122 | 145,433 | 25,676 |
| After Injured | 54,912 | 5,531 | 13,044 | 14,014 | 39,942 | 36,165 | 77,855 | 6,618 |
| After,Total N | 165,160 | 45,202 | 42,708 | 76,338 | 170,977 | 98,287 | 223,288 | 32,294 |

**Exhibit 2-9c: Number of Front Outboard Occupants in Passenger Cars, by Model Year, Injury Status, and Crash Type, GM Truck Comparison Group, by State (State Data, Calendar Year 1993 – 1998)**

| 1990/91 vs 1992/93 | *Florida* | *Indiana* | *Maryland* | *Missouri* | *North Carolina* | *Pennsyl-vania* | *Texas* | *Utah* |
|---|---|---|---|---|---|---|---|---|
| **Rear Impact** | | | | | | | | |
| Before,Uninjured | 47,039 | 25,710 | 10,847 | 27,237 | 50,847 | 19,595 | 53,030 | 9,393 |
| Before,Injured | 29,330 | 5,239 | 5,357 | 6,863 | 20,757 | 15,507 | 41,604 | 2,774 |
| Before,Total N | 76,369 | 30,949 | 16,204 | 34,100 | 71,604 | 35,102 | 94,634 | 12,167 |
| After,Uninjured | 60,023 | 26,487 | 11,383 | 29,074 | 61,940 | 19,576 | 54,294 | 9,261 |
| After,Injured | 36,502 | 5,259 | 5,600 | 6,925 | 24,167 | 15,231 | 43,400 | 2,928 |
| After,Total N | 96,525 | 31,746 | 16,983 | 35,999 | 86,107 | 34,807 | 97,694 | 12,189 |
| **Frontal Impact** | | | | | | | | |
| Before,Uninjured | 106,247 | 40,748 | 30,882 | 64,778 | 127,125 | 65,665 | 149,841 | 27,183 |
| Before,Injured | 52,991 | 5,985 | 13,451 | 14,661 | 39,409 | 39,378 | 80,143 | 6,938 |
| Before,Total N | 159,238 | 46,733 | 44,333 | 79,439 | 166,534 | 105,043 | 229,984 | 34,121 |
| After,Uninjured | 123,284 | 37,775 | 29,757 | 59,312 | 141,807 | 60,445 | 140,487 | 24,715 |
| After,Injured | 61,561 | 5,037 | 13,325 | 13,564 | 42,697 | 34,813 | 77,986 | 6,518 |
| After,Total N | 184,845 | 42,812 | 43,082 | 72,876 | 184,504 | 95,258 | 218,473 | 31,233 |

**Exhibit 2-10: Number of Front Outboard Occupants in Pickup Trucks by Manufacturer, and Passenger Cars by Model Year; by Head Restraint Status and State (State Data, Calendar Year 1993 – 1998)**
**[To determine weighting factors for Cars]**

**Raw Counts, Pickup Truck Front Outboard Occupants**

| | Florida | Indiana | Mary-land | Missouri | North Carolina | Pennsyl-vania | Texas | Utah |
|---|---|---|---|---|---|---|---|---|
| **Dodge** | | | | | | | | |
| Before | 2,058 | 2,544 | 466 | 2,377 | 1,496 | 1,806 | 6,665 | 399 |
| After | 1,591 | 2,003 | 442 | 2,186 | 1,240 | 1,358 | 6,248 | 533 |
| **Ford** | | | | | | | | |
| Before | 4,444 | 1,463 | 812 | 2,915 | 3,461 | 2,581 | 9,008 | 959 |
| After | 5,321 | 1,557 | 932 | 3,823 | 3,849 | 2,499 | 12,803 | 963 |
| **Chevy/GMC** | | | | | | | | |
| Before | 8,902 | 15,148 | 1,783 | 10,956 | 7,367 | 6,674 | 45,530 | 2,247 |
| After | 12,152 | 14,533 | 1,786 | 10,997 | 9,265 | 6,390 | 51,944 | 2,436 |

**Raw Counts, Passenger Car Front Outboard Occupants**

| | Florida | Indiana | Mary-land | Missouri | North Carolina | Pennsyl-vania | Texas | Utah |
|---|---|---|---|---|---|---|---|---|
| **1988/89 vs 1990/91** | | | | | | | | |
| Before | 265,346 | 90,963 | 63,391 | 121,129 | 280,208 | 161,071 | 321,598 | 46,659 |
| After | 235,607 | 77,682 | 60,537 | 113,539 | 238,138 | 140,145 | 324,618 | 46,288 |
| **1989/90 vs 1991/92** | | | | | | | | |
| Before | 246,324 | 83,523 | 62,018 | 116,749 | 257,243 | 151,209 | 323,993 | 46,998 |
| After | 247,535 | 76,788 | 58,727 | 111,574 | 247,694 | 132,664 | 318,831 | 44,313 |
| **1990/91 vs 1992/93** | | | | | | | | |
| Before | 235,607 | 77,682 | 60,537 | 113,539 | 238,138 | 140,145 | 324,618 | 46,288 |
| After | 281,370 | 74,558 | 60,065 | 108,875 | 270,611 | 130,065 | 316,167 | 43,422 |

**Exhibit 2-11: Weighted Passenger Car Cases**

| | Florida | Indiana | Mary-land | Missouri | North Carolina | Pennsyl-vania | Texas | Utah | Total of Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Rear Impact** | | | | | | | | | |
| Before | | | | | | | | | |
| Uninjured | 3,018 | 6,275 | 542 | 3,828 | 2,590 | 1,516 | 9,960 | 724 | 28,459 |
| Injured | 1,916 | 1,287 | 273 | 978 | 1,080 | 1,219 | 7,846 | 216 | 14,816 |
| After | | | | | | | | | |
| Uninjured | 4,004 | 6,358 | 589 | 4,433 | 3,240 | 1,517 | 12,090 | 828 | 33,066 |
| Injured | 2,451 | 1,268 | 288 | 1,067 | 1,273 | 1,181 | 9,619 | 257 | 17,407 |
| **Frontal Impact** | | | | | | | | | |
| Before | | | | | | | | | |
| Uninjured | 6,965 | 10,087 | 1,563 | 9,309 | 6,591 | 5,183 | 28,305 | 2,123 | 70,143 |
| Injured | 3,506 | 1,505 | 684 | 2,133 | 2,063 | 3,144 | 15,091 | 542 | 28,673 |
| After | | | | | | | | | |
| Uninjured | 8,412 | 9,218 | 1,581 | 9,374 | 7,553 | 4,776 | 31,805 | 2,258 | 74,996 |
| Injured | 4,197 | 1,248 | 701 | 2,132 | 2,288 | 2,773 | 17,481 | 589 | 31,416 |
| **Total** | 34,468 | 37,248 | 6,221 | 33,254 | 26,678 | 21,308 | 132,198 | 7,537 | 298,976 |

### 2.4.2 Changes in Rear Impact Injury Rates in Passenger Cars

As was done for pickup trucks, the initial step in determining what has occurred in injury rates in passenger cars is examining the changes over time. Exhibit 2-12 presents, by state, the injury rates in rear impact crashes, in the "Before" and "After" model years, based on the weighted data detailed in the previous section. The last column shows the data for the eight states combined, as had been done for pickup trucks. Again, positive values in the "% reduction" row indicate an improvement, which is a decrease in the injury rate.

**Exhibit 2-12: Weighted Injury Rates in Passenger Cars, Rear Impacts, in the "Before" and "After" Model Years (State Data)**

| | **Florida** | **Indiana** | **Maryland** | **Missouri** | **North Carolina** | **Pennsyl-vania** | **Texas** | **Utah** | **Eight States** |
|---|---|---|---|---|---|---|---|---|---|
| Before | 38.83 | 17.02 | 33.48 | 20.35 | 29.42 | 44.56 | 44.07 | 23.01 | 34.24 |
| After | 37.97 | 16.63 | 32.88 | 19.39 | 28.22 | 43.79 | 44.31 | 23.67 | 34.49 |
| % reduction | 2.22 | 2.29 | 1.81 | 4.70 | 4.10 | 1.73 | -0.55 | -2.87 | -0.73 |

Analogous data for pickup trucks were presented in Exhibit 2-2, and some comparisons are notable. Observe that, while pickup trucks showed a decrease in the injury rate in every state, for passenger cars two of the states actually have higher injury rates in the later years. This is reflected in the negative percent reduction shown for Texas and Utah in Exhibit 2-12. Furthermore, not only is there always a lower injury rate in the “After” years for the pickup trucks, the percent reduction is always greater than is seen in passenger cars, state for state. One of the states with a higher injury rate in the “After” years is Texas, which contributes a large proportion of the total data. Thus, when the data for the eight states are combined using Formula 1, there is an increase in the injury rate (an effectiveness estimate of *negative* 0.73 percent) in the “After” years. This is shown in the last column in Exhibit 2-12.

When the data in Exhibit 2-12 are weighted by each state’s number of registered pickup trucks, the overall injury reduction in passenger car rear impacts is 1.55 % (using Formula 3 detailed in section 2.2). Notice that, using this method, a positive effectiveness results, whereas when the unweighted data are combined there is a negative effectiveness. This is explained by the differing proportions contributed by each state, between the raw data counts and the data weighted by number of registered pickups. For example, Texas is one of the two states with a higher injury rate in the “After” group. Texas contributes 44% of the data when they are simply totaled for all states, but only 33% when weighted by registered pickups. Conversely, three states with a lower rate in the “After” group contribute a notably larger proportion when the registration-weighted data are used: Maryland (2% of the raw data, to 5% of that weighted by registered pickups), Florida (12% raw data, 15% weighted), and North Carolina, with a relatively high reduction in injury rate (9% raw data, 12% weighted).

This particular example shows why the data weighted by the number of registered pickup trucks in the state is the preferred method to use. Simply summing the data into a single estimate depends too heavily on the amount of data provided by a given state. As discussed previously, this is based on various factors (such as police reporting criteria), not all of which are relevant to measuring the effectiveness of head restraints in pickup trucks. The change in the distribution, which is a more accurate reflection of ‘real world’ data, causes the effectiveness estimate to switch from an increase in the injury rate (using the unweighted data) to a decrease. Thus, the effectiveness estimate of a 1.55 % reduction in the injury rate in passenger cars would be considered the ‘better’ estimate of the “vehicle age effect” in rear impacts of passenger cars.

The t-score for this estimate is 2.03, which is just significant at the 90% level. Since it is significant, however, it would be appropriate to take it into account. Rear impacts in passenger cars show a decreased injury rate from the ‘”Before” years to the “After” years. Whatever the reason, this general tendency for lower injury rates in later model year vehicles should be taken into consideration when determining a final effectiveness estimate for head restraints in pickup trucks.

Recall that the effectiveness estimate for head restraints in pickup truck rear impact crashes was 9.62 (based on the registration-weighted average of eight states, as described in Section 2.2). When controlled for the reduction in injury in frontal crashes for pickup trucks, the estimate was 5.23 (as derived in Section 2.3). Now, rather than using frontal impact pickup crashes as the control, rear impact passenger car crashes will be used instead. Data for rear impact crashes, for both pickup trucks and passengers cars, are presented in Exhibit 2-13. Although both sets of data have appeared previously, they are presented here again for ease of comprehension.

**Exhibit 2-13: Injury Rates in Pickup Trucks and Weighted Injury Rates in Passenger Cars, Rear Impacts, and Effectiveness Estimates, in the "Before" and "After" Model Years, by State (State Data)**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah | Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Pickup Trucks, Rear Impact** | | | | | | | | | |
| Before | 32.80 | 10.84 | 24.69 | 14.25 | 24.86 | 33.63 | 32.63 | 16.68 | 26.42 |
| After | 30.69 | 9.03 | 21.34 | 12.93 | 22.18 | 31.22 | 29.56 | 16.27 | 24.40 |
| % reduction | 6.44 | 16.68 | 13.59 | 9.25 | 10.79 | 7.17 | 9.42 | 2.45 | 7.65 |
| **Passenger Cars, Rear Impact** | | | | | | | | | |
| Before | 38.83 | 17.02 | 33.48 | 20.35 | 29.42 | 44.56 | 44.07 | 23.01 | 34.24 |
| After | 37.97 | 16.63 | 32.88 | 19.39 | 28.22 | 43.79 | 44.31 | 23.67 | 34.49 |
| % reduction | 2.22 | 2.29 | 1.81 | 4.70 | 4.10 | 1.73 | -0.55 | -2.87 | -0.73 |
| E | 4.31 | 14.73 | 11.99 | 4.78 | 6.98 | 5.53 | 9.91 | 5.17 | 8.32 |

The final row of Exhibit 2-13 presents new information – the effectiveness estimate for each state, as well as for the unweighted combined data, using passenger car rear impacts as the control group. These are calculated using the same formula as was used for the effectiveness of head restraints in rear impact pickup truck crashes when controlled for by pickup frontal impacts, presented in Section 2.3. Formula 4, shown here again for convenience, is:

$$E = 1 - \left[ \left( \frac{p_{12}}{p_{11}} \right) \Big/ \left( \frac{p_{22}}{p_{21}} \right) \right]$$

Note that, in the current calculation, it is the vehicle type rather than the impact location that varies. Therefore, in this occurrence:

i=vehicle type (1=truck, 2= passenger car).

The final entry shows that, when state data are combined into a single estimate, the installation of head restraints results in an 8.32 percent reduction in the injury rate in rear impact crashes in pickup trucks, when controlled for by rear impacts in passenger cars. This was calculated as:

$$E = 1 - \left[ \left( \frac{24.40}{26.42} \right) \Big/ \left( \frac{34.49}{34.24} \right) \right] = 8.32 \text{ percent}$$

Using Formula 5 for registration-weighted data detailed in section 2.3, and substituting car/rear impact data for pickup truck/frontal, we obtain:

$$\frac{\begin{pmatrix}(1{,}425{,}339 \times 4.31) + (1{,}025{,}244 \times 14.73) + (435{,}244 \times 11.99) + (943{,}717 \times 4.78) + \\ (1{,}168{,}132 \times 6.98) + (1{,}010{,}419 \times 5.53) + (3{,}120{,}226 \times 9.91) + (324{,}611 \times 5.17)\end{pmatrix}}{1{,}425{,}339 + 1{,}025{,}244 + 435{,}244 + 943{,}717 + 1{,}168{,}132 + 1{,}010{,}419 + 3{,}120{,}226 + 324{,}611}$$

$$= 8.18 \text{ percent}$$

Thus, when the data are weighted by the number of registered pickup trucks per state, there is an 8.18 percent reduction in the injury rate in pickup truck rear impact crashes, when controlled for by passenger car rear impact crashes.

## 2.5 Comparison of Rear vs Frontal, Passenger Cars vs Pickup Trucks

Two groupings of estimates previously calculated use controls to adjust the effectiveness estimate for pickup trucks in rear impact crashes. One used truck frontal crashes as the control group (Section 2.3), while the other used rear impacts in passenger cars as a control (Section 2.4.2). An additional estimate will be determined, which utilizes both of these methods of control.

It has been shown that, over time, injury rates tend to decrease for reasons other than the presence of head restraints, a development that must be taken into account. Thus far, both frontal impacts in pickup trucks and rear impacts in passenger cars have been used as controls for rear impact crashes in pickup trucks. A final estimate will be determined, in which rear impacts in pickup trucks will be controlled for by frontal impacts in pickups, which in turn will be controlled for by passenger car rear impacts controlled for by passenger car frontal impacts.

A simpler way to think of this estimate is as the combination of two similar estimates. Remember that head restraints were designed to reduce injury in rear impacts. Therefore, when pickup trucks with head restraints are compared to those without them, a decreased injury rate in rear impacts would be expected, while no change in frontal impacts would be anticipated. Any change in frontal impacts would be attributed to something other than the installation of head restraints, and assumed to affect rear as well as frontal impacts, and thus could serve as a control for whatever changes occur to injury rates over time.

The data for rear and frontal impacts, for both pickup trucks and passenger cars, are presented in Exhibit 2-14. In Section 2.3, it was determined that when rear impacts in pickup trucks were controlled for by frontal impacts, the effectiveness rate is 4.52 percent when the data from the eight states are simply combined, as shown in Exhibit 2-14, or 5.23 using Formula 5, with registered pickup weighted data. The same procedure could be performed on passenger cars (which were equipped with head restraints throughout the time frame of our data). The row in Exhibit 2-14 labeled “Rear vs Frontal” in the Passenger Car section presents the effectiveness estimates for rear impacts controlled for by frontal in passenger cars. When the eight states are combined, this estimate is a nonsignificant 1.00. The estimate when the states are weighted by registered pickup trucks is 0.62, which also is not significant (t-score=0.59). Since these calculations are of interest only as intermediary steps, they will not be discussed in further detail.

**Exhibit 2-14: Injury Rates Before and After Pickup Trucks were Equipped with Head Restraints, and Weighted Injury Rates in Passenger Cars in the "Before" and "After" Model Years. Rear and Frontal Impacts, and Effectiveness Estimates, in Selected Pickup Trucks, by State (State Data)**

| | Florida | Indiana | Maryland | Missouri | North Carolina | Pennsyl-vania | Texas | Utah | Eight States |
|---|---|---|---|---|---|---|---|---|---|
| **Pickup Trucks** | | | | | | | | | |
| **Rear** | | | | | | | | | |
| Before | 32.80 | 10.84 | 24.69 | 14.25 | 24.86 | 33.63 | 32.63 | 16.68 | 26.42 |
| After | 30.69 | 9.03 | 21.34 | 12.93 | 22.18 | 31.22 | 29.56 | 16.27 | 24.40 |
| % reduction | 6.44 | 16.68 | 13.59 | 9.25 | 10.79 | 7.17 | 9.42 | 2.45 | 7.65 |
| Frontal | | | | | | | | | |
| Before | 29.22 | 14.04 | 23.64 | 16.71 | 20.27 | 30.25 | 27.63 | 16.15 | 23.93 |
| After | 27.57 | 12.21 | 24.57 | 16.02 | 18.95 | 29.81 | 26.52 | 17.19 | 23.15 |
| % reduction | 5.65 | 13.07 | -3.95 | 4.09 | 6.52 | 1.48 | 3.99 | -6.45 | 3.28 |
| **Rear vs Frontal** | 0.84 | 4.16 | 16.67 | 5.39 | 4.57 | 5.77 | 5.65 | 8.36 | 4.52 |
| **Passenger Cars** | | | | | | | | | |
| Rear | | | | | | | | | |
| Before | 38.83 | 17.02 | 33.48 | 20.35 | 29.42 | 44.56 | 44.07 | 23.01 | 34.24 |
| After | 37.97 | 16.63 | 32.88 | 19.39 | 28.22 | 43.79 | 44.31 | 23.67 | 34.49 |
| % reduction | 2.22 | 2.29 | 1.81 | 4.70 | 4.10 | 1.73 | -0.55 | -2.87 | -0.73 |
| **Frontal** | | | | | | | | | |
| Before | 33.48 | 12.98 | 30.43 | 18.64 | 23.84 | 37.76 | 34.78 | 20.35 | 29.02 |
| After | 33.29 | 11.93 | 30.73 | 18.53 | 23.25 | 36.73 | 35.47 | 20.70 | 29.52 |
| % reduction | 0.58 | 8.15 | -0.98 | 0.59 | 2.50 | 2.71 | -1.99 | -1.74 | -1.74 |
| Rear vs Frontal | 1.65 | -6.38 | 2.77 | 4.14 | 1.64 | -1.00 | 1.41 | -1.12 | 1.00 |
| E | -0.82 | 9.91 | 14.51 | 1.30 | 2.98 | 6.71 | 4.30 | 9.37 | 3.56 |

The final effectiveness estimate calculated will be a combination of these two estimates – rear impacts controlled for frontal impacts in pickup trucks, in turn controlled for by rear impacts controlled for by frontal impact in passenger cars. This is shown as "E" in the last row of Exhibit 2-14.

Extending Formula 4, this effectiveness estimate would be determined using the formula:

$$E = 1 - \frac{\left[\left(\frac{p_{211}}{p_{111}}\right) \Big/ \left(\frac{p_{221}}{p_{121}}\right)\right]}{\left[\left(\frac{p_{212}}{p_{112}}\right) \Big/ \left(\frac{p_{222}}{p_{122}}\right)\right]} \qquad (6)$$

Where $p_{ijk}$ = percent of injured occupants (injury rate)
i = status of head restraint installation (1=before, 2=after)
j = impact location (1=rear, 2=front)
k= vehicle type (1=pickup truck, 2=passenger car)

So that effectiveness when the eight states are combined into one set of data would be calculated as:

$$E = 1 - \frac{\left[\left(\frac{24.40}{26.42}\right) \Big/ \left(\frac{23.15}{23.93}\right)\right]}{\left[\left(\frac{34.49}{34.24}\right) \Big/ \left(\frac{29.52}{29.02}\right)\right]} = 3.56 \text{ percent}$$

Thus, when the eight states are combined into one set of data, it is estimated that there is a 3.56 percent reduction in the injury rate in rear impact crashes in pickup trucks, when they are controlled for by frontal impacts, in turn controlled for by rear impacts in passenger cars controlled for by frontal impacts in passenger cars.

The final row of Exhibit 2-14 presents the effectiveness estimates, calculated using Formula 6 above, for each state. When these are combined using Formula 5, weighting each state by its respective number of registered pickup trucks, as:

$$\frac{\begin{pmatrix} -(1{,}425{,}339 \times 0.82) + (1{,}025{,}244 \times 9.91) + (435{,}244 \times 14.51) + (943{,}717 \times 1.30) + \\ (1{,}168{,}132 \times 2.98) + (1{,}010{,}419 \times 6.71) + (3{,}120{,}226 \times 4.30) + (324{,}611 \times 9.37) \end{pmatrix}}{1{,}425{,}339 + 1{,}025{,}244 + 435{,}244 + 943{,}717 + 1{,}168{,}132 + 1{,}010{,}419 + 3{,}120{,}226 + 324{,}611}$$

= 4.58 percent

Therefore, when the effectiveness estimates are weighted by the number of registered pickup trucks in each state, the result is an overall estimate of 4.58 percent. The t-score is significant at 2.98.

Exhibit 2-15 summarizes all effectiveness estimates of head restraints in pickup trucks that have been calculated in previous sections, with significance tests provided where determined. Recall that, at the 0.10 significance level, a t-score of 1.895 or greater, or a z-score of 1.645 or greater, indicates significance. Thus, all t-scores and z-scores presented are significant.

**Exhibit 2-15: Point Estimates of Overall Injury Reduction by Head Restraints**

| **Mean of Eight States, Weighted by Number of Registered Pickup Trucks** | **Effectiveness Estimate** | **t-score** |
|---|---|---|
| Truck Rear | 9.62 | 8.01 |
| Truck Rear, controlled for Truck Frontal | 5.23 | 4.43 |
| Truck Rear, controlled for Car Rear | 8.18 | 6.54 |
| Truck Rear, controlled for Truck Frontal, controlled for Car Rear, controlled for Car Frontal | 4.58 | 2.98 |
| **Mean of Eight States, Weighting based on variance** | **Effectiveness Estimate** | **z-score** |
| Truck Rear | 9.25 | 9.30 |
| Truck Rear, controlled for Truck Frontal | 5.14 | 3.99 |
| **Eight States Combined, Unweighted** | **Effectiveness Estimate** | **z-score** |
| Truck Rear | 7.65 | 7.11 |
| Truck Rear, controlled for Truck Frontal | 4.52 | 3.29 |
| Truck Rear, controlled for Car Rear | 8.32 | |
| Truck Rear, controlled for Truck Frontal, controlled for Car Rear, controlled for Car Frontal | 3.56 | |

The numerical value of this most recently determined estimate, which uses passenger cars to control for pickup trucks, as well as frontal impacts to control for rear, is very close to the simpler “Truck Rear controlled for Truck Frontal” (4.58 vs 5.23) in the top section of Exhibit 2-15.

## 2.6 Computation of Effectiveness Estimates in a 0% to 100% Head Restraint Equipped Fleet

All of the estimates of effectiveness so far have been calculated using pickup truck data available in the real world. There is no direct way to determine which individual vehicles did or did not have head restraints from the data. This information is not coded in the VIN, nor is it perfectly consistent across any model or styling group. Based on the State crash data, it was only possible to classify the trucks by make-model and model years.

Recall that it was required for this analysis that make-models in the "Before" model years have no more than 25% equipped with head restraints, while the "After" group needed to be at least 75% equipped. While this permitted an examination of the change from a small to a large percent of head restraints, the intent of this evaluation is to estimate the effectiveness when head restraints are installed in vehicles that were previously unequipped. The goal is to measure what happens when the change is from 0% to 100% equipped. No group of vehicles went from not having head restraints at all to a totally equipped fleet. However, if the percent of vehicles with head restraints is known, the effectiveness estimates obtained can be adjusted to account this.

As discussed earlier in Section 2.1.1.1, data from NASS-CDS was used to determine the percentage of vehicles, by manufacturer and/or model, that were equipped with head restraints. This information was also verified by the vehicle manufacturers. Exhibit 2-16 presents the percentage of vehicles equipped with head restraints. The different lines of Chevrolet/GMC pickup trucks are treated separately here since they differ in the percent equipped in the "Before" model years.

**Exhibit 2-16: Percent of Pickup Trucks Equipped with Head Restraints in "Before" and "After" Model Years, by Manufacturer/Model**

| | Before | After |
|---|---|---|
| Dodge Pickups | 0 | 100 |
| Chevrolet C/K, GMC Sierra | 5 | 100 |
| Chevrolet S/T, GMC Sonoma | 20 | 100 |
| Ford Ranger | 24 | 94 |

This information shows the presence of head restraints in each of these vehicles in nationwide registration data. What is required is a method of combining them in a way that reflects the appropriate relative proportion of each vehicle in state crash data.

The first step in this process was to determine the percentage of each manufacturer (and, in the case of GM, model) in the crash data, based on the six VIN states where the actual make-model could be identified: Florida, Maryland, Missouri, North Carolina, Pennsylvania and Utah. All impact locations were included. Indiana and Texas do not include VIN on their state data file, and are not included in these counts.

The counts by manufacturer (and GM model) are presented in Exhibit 2-17, and the percent of each manufacturer's presence by state is presented in Exhibit 2-18.

**Exhibit 2-17: Number of Pickup Trucks by Manufacturer in Each State, All Impact Locations**

| | Florida | Maryland | Missouri | North Carolina | Pennsyl-vania | Utah |
|---|---|---|---|---|---|---|
| **Before** | | | | | | |
| Dodge | 2725 | 585 | 2191 | 2400 | 2209 | 573 |
| GM C/K | 7063 | 1250 | 6097 | 6668 | 4408 | 2282 |
| GM S/T | 4606 | 962 | 4741 | 4722 | 3665 | 922 |
| Ford Ranger | 5894 | 1029 | 3958 | 5606 | 3189 | 1394 |
| *Total* | *20288* | *3826* | *16987* | *19396* | *13471* | *5171* |
| **After** | | | | | | |
| Dodge | 2095 | 537 | 2179 | 1841 | 1689 | 788 |
| GM C/K | 9533 | 1251 | 7432 | 7553 | 4266 | 2751 |
| GM S/T | 6473 | 922 | 3879 | 6569 | 3364 | 710 |
| Ford Ranger | 7003 | 1146 | 5075 | 6086 | 3049 | 1320 |
| *Total* | *25104* | *3856* | *18565* | *22049* | *12368* | *5569* |

**Exhibit 2-18: Percent of Pickup Trucks by Manufacturer in Each State, all Impact Locations**

| | Florida | Maryland | Missouri | North Carolina | Pennsyl-vania | Utah |
|---|---|---|---|---|---|---|
| **Before** | | | | | | |
| Dodge | 13.43% | 15.29% | 12.90% | 12.37% | 16.40% | 11.08% |
| GM C/K | 34.81% | 32.67% | 35.89% | 34.38% | 32.72% | 44.13% |
| GM S/T | 22.70% | 25.14% | 27.91% | 24.35% | 27.21% | 17.83% |
| Ford Ranger | 29.05% | 26.89% | 23.30% | 28.90% | 23.67% | 26.96% |
| **After** | | | | | | |
| Dodge | 8.35% | 13.93% | 11.74% | 8.35% | 13.66% | 14.15% |
| GM C/K | 37.97% | 32.44% | 40.03% | 34.26% | 34.49% | 49.40% |
| GM S/T | 25.78% | 23.91% | 20.89% | 29.79% | 27.20% | 12.75% |
| Ford Ranger | 27.90% | 29.72% | 27.34% | 27.60% | 24.65% | 23.70% |

These percentages were then combined to form a weighted average, using registered pickup trucks per state, which were presented in Exhibit 2-4. The overall percents by manufacturer, before and after the installation of head restraints, are presented in Exhibit 2-19.

**Exhibit 2-19: Percent of Pickup Trucks by Manufacturer, Across Six States, Weighted by Number of Registered Pickup Trucks per State**

| | **Before** | **After** |
|---|---|---|
| Dodge | 13.68% | 10.77% |
| Chevy C/K | 34.91% | 37.10% |
| Chevy S/T | 24.75% | 25.12% |
| Ford Ranger | 26.67% | 27.01% |

These values were then multiplied by the percent of each type of vehicle equipped with head restraints (from Exhibit 2-16), and summed to obtain an overall “Before” and an “After” percent of vehicles equipped with head restraints, as follows:

$$\text{Before: } (13.68\times 0)+(34.91\times .05)+(24.75\times .2)+(26.67\times .24)=13.10\%$$

$$\text{After: } (10.77\times 1)+(37.10\times 1)+(25.12\times 1)+(27.01\times .94)=98.38\%$$

Overall, 13.10 percent of pickup trucks were equipped with head restraints in the “Before” model years, and 98.38 percent in the “After” years (recall that the “Before” and “After” years varied by manufacturer). Consequently, what has actually been measured is $E_1$, the reduction in injuries in rear impacts in a fleet that is 98.38 percent equipped with head restraints relative to a fleet that is 13.10 percent equipped. The actual measurement needed is $E_2$, the reduction for a 100 percent head restraint equipped fleet relative to one without any head restraints. Since

$$1-E_1=\frac{(1-p_A)+p_A(1-E_2)}{(1-p_B)+p_B(1-E_2)} \tag{7}$$

where $p_A$ = percent of fleet equipped with head restraints in the “After” model years
$p_B$ = percent of fleet equipped with head restraints in the “Before” model years.

Substituting 0.1310 for $p_B$ and 0.9838 for $p_A$, and solving for $E_2$,

$$E_2=\frac{E_1}{0.8528+(0.1310\times E_1)} \tag{8}$$

So, for each effectiveness estimate $E_1$ that has been determined, a new value, $E_2$, that adjusts the estimate to measure the change from a fleet with no head restraints to one that is 100 percent equipped, can be calculated. These adjusted measures are presented in Exhibit 2-20 for the effectiveness estimates of head restraints in pickup truck rear impacts.

**Exhibit 2-20: Point Estimates of Overall Injury Reduction by Head Restraints, adjusted for 0 Percent to 100 Percent Head Restraint Equipped Fleet.**

| **Mean of Eight States, Weighted by Number of Registered Pickup Trucks** | **Effectiveness Estimate** |
|---|---|
| Truck Rear | 11.12 |
| Truck Rear, controlled for Truck Frontal | 6.08 |
| Truck Rear, controlled for Car Rear | 9.47 |
| Truck Rear, controlled for Truck Frontal, controlled for Car Rear, controlled for Car Frontal | 5.33 |
| **Eight States Combined, Unweighted** | **Effectiveness Estimate** |
| Truck Rear | 8.87 |
| Truck Rear, controlled for Truck Frontal | 5.27 |
| Truck Rear, controlled for Car Rear | 9.64 |
| Truck Rear, controlled for Truck Frontal, controlled for Car Rear, controlled for Car Frontal | 4.15 |

The argument could be made to adjust the individual state effectiveness estimates and then combine them, rather than adjust the already combined estimates. If this were done, however, it would be more appropriate to use each individual state's distribution of vehicles by manufacturer. However, because accurate distributions could not be determined for Indiana and Texas, no estimates could be used for these states. Using the overall percent equipped and applying that to each state could also be done, but the final difference in obtained estimates is trivial. For example, the largest effectiveness estimate is obtained for "Pickup Trucks in Rear Impacts" without using any controls and weighting the data by registered pickups. The estimate adjusted for a zero to 100 percent equipped fleet using the aggregated state data (and shown in Exhibit 2-20) is 11.12. If the "Before" percent of 13.10 and "After" of 98.38 are used to adjust each state before combining and weighting by registered pickup trucks, the effectiveness estimate is 11.10. The t-score increases from the originally calculated 8.01 (for the unadjusted effectiveness estimate of 9.62) to 8.06. Given the uncertainty of having to use combined state data to adjust individual state estimates, the method of adjusting the final estimate seems preferable.

## 2.7 <u>Selection of the Best Estimate of Effectiveness of Head Restraints in Pickup Trucks</u>

Exhibit 2-20 presents the eight effectiveness estimates of head restraint injury reduction in pickup trucks that have been determined. These range from 4.15 to 11.12 percent. It remains to discuss which of these estimates best represents what head restraints have done to improve passenger safety.

Recall the two basic methods used to determine effectiveness estimates, by combining all the data into a single 'eight state estimate,' or by weighting each estimate by the number of registered pickup trucks in that state. In Section 2.2 it was discussed that the amount of data provided per state was not proportional to the 'sizes' of the states, on whatever metric they might be measured. Combining each state's effectiveness estimate and computing the average gives equal weight to each state, which is equally unsound. Alternatively, each state's estimate was weighted by its number of registered pickup trucks. This gave an overall estimate that reflected each state's contribution appropriately. Consequently, the 'best' estimate would be selected from those that were calculated using registered pickup trucks.

Of the four such estimates, the estimate derived from pickup truck rear impact data alone is not particularly useful. Since there is no control for whatever changes took place, anything affecting the injury rate would be attributed to the installation of head restraints. This would include the "vehicle age" factor discussed earlier. The estimate of injury reduction in pickup truck frontal impacts was also significant, demonstrating that some reduction in the measured injury rate was taking place that could not be attributed to the installation of head restraints.

The "Rear Controlled for Frontal" comparison for pickup trucks (5.23, calculated in Section 2.3) was significant, while that for passenger cars (0.62, Section 2.5) was not. In addition, the change in injury rate in frontal crashes was significant in pickup trucks, but not in passenger cars. Clearly, cars and trucks differ with respect to the changes occurring in injury rates over these model years. This suggests that using frontal impacts in pickup trucks is a preferred control to rear impacts in passenger cars. In addition, the "Truck Rear controlled for Truck Frontal" is a more conservative estimate than "Truck Rear controlled for Car Rear". This prevents overstating obtained benefits.

The final calculated estimate, in which pickup truck rear impacts were controlled for by pickup truck frontal impacts, which in turn were controlled for by passenger car rear impacts controlled for by car frontal impacts, likely provides more control than is needed. The "Passenger Car Rear controlled for Frontal" portion is not significant, meaning that there is no real difference, between frontal and rear impact, in the change in injury rates in passenger cars in the model years examined. Therefore, it isn't necessary to control for these differences, as they don't add any substantive benefit to the estimate.

The conclusion, then, is that the adjusted estimate of 6.08, in which pickup truck rear impacts are controlled for by pickup truck frontal impacts, is the estimate of choice. Since this is being used as the best estimate of head restraint effectiveness, confidence limits need to be determined. The 90 percent confidence bounds for the estimate of injury reduction are first calculated on the original estimate. Then the values are adjusted for a fleet with no head restraints compared to a one with all vehicles equipped. Calculated using the same SAS procedure as described earlier, the standard error for this estimate is 1.18.

$$\text{Original Estimate} \pm [1.895 \times \text{standard error}]$$

$$5.23 \pm (1.895 \times 1.18) = [2.99, 7.46]$$

By applying Formula 8 to the upper and lower limits, the confidence interval for this estimate, which ranges from 3.49 to 8.65, is obtained.

## Chapter 2 Footnotes

1. *National Automotive Sampling System 1997 Crashworthiness Data System Data Collection, Coding, And Editing Manual*. US Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, January, 1997.

2. *SAS: Procedures Guide, Version 6, Third Edition,* SAS Institute Inc., Cary, NC, 1990, pp 365-387.

3. Kahane, Charles J. *An Evaluation of Head Restraints*, NHTSA Publication No. DOT HS 806 108, Washington, DC, 1982, pp. 154-160 and 181-197.

# Chapter 3: Effectiveness in Rear Impacts, for Specific Populations and Situations

The previous chapter discussed the overall effectiveness of head restraints in rear impacts. There are some circumstances, however, in which head restraints may offer greater protection to certain groups of people, in particular types of crashes, or with specific characteristics of vehicles.

Analyses of data from the eight states indicate that head restraints are more effective in rear impacts for pickup trucks with minor, nontowaway damage than in trucks with towaway damage. Adjustable head restraints seem to be at least as effective as integral head restraints, although it is not possible to clearly distinguish between the two types. Head restraint effectiveness is about the same for younger and older, as well as for male and female drivers. Effectiveness was about the same regardless of whether the rear impact was to the rear center of the vehicle or off to one side. The presence or absence of a back seat was also not a factor in how effective head restraints were in preventing injuries.

The effectiveness estimates in this chapter are presented as a way of exploring and demonstrating general trends in the data. Unless there appears to be a possible significant difference, the estimates are not controlled for age affects or other influencing factors. In most instances, they are not corrected to represent a fleet changing from no head restraints to one that is fully equipped. To put them in perspective, they would be comparable to the "Truck Rear" estimates of 7.65% for combined state data, and 9.62% for data weighted by registered pickup trucks, presented in Chapter 2 (see Exhibit 2-15). If the analysis on rear impacts showed no significant difference between groups, further analyses were not performed. In the two cases where initial data suggest significance, further analyses were done.

### 3.1 <u>Male vs. Female</u>

Gender differences have been noted in several of the studies discussed in Chapter 1. Women have a higher probability of whiplash injury, given a rear impact, than do men. Since the experience of a rear impact differs for men and women, it is reasonable to speculate that head restraints, which were designed to prevent whiplash injuries in rear impacts, would perform differently for women than for men.

Data from the combined eight states in the current analysis are presented by gender in Exhibit 3-1. Note that the totals in the "Before" as well as the "After" groups differ from combined state totals presented in Chapter 2. This will be the case generally for all specific groups and situations, since these data require a known condition for an additional variable. Specifically in this case, all occupants with non-reported gender were necessarily excluded from the analysis. Additionally, Florida records gender information for drivers only, so the right front passengers present in other analyses are excluded here.

As reported earlier, some researchers have found injury rates in rear impacts are substantially higher for females than males. However, the overwhelming majority of all pickup truck occupants, and even of the injured occupants, are males.

**Exhibit 3-1: Injury Status by Gender for Eight States Combined, Before and After Installation of Head Restraints, Rear Impacts**

| | Male | | Female | |
|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** |
| **Injured** | 7,599 | 7,929 | 3,414 | 3,797 |
| **Uninjured** | 24,640 | 28,810 | 5,891 | 7,653 |
| **Injury Rate** | 23.57 | 21.58 | 36.69 | 33.16 |

Effectiveness estimates were determined for each state individually, as well as for the combined state data, using Formula 1 covered in Section 2-2. These results are presented in Exhibit 3-2.

**Exhibit 3-2: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Gender**

| | **Male** | **Female** |
|---|---|---|
| Florida | 6.14 | **12.33** |
| Indiana | 14.43 | **25.26** |
| Maryland | 12.98 | **13.28** |
| Missouri | 9.21 | **29.85** |
| North Carolina | **12.64** | 7.58 |
| Pennsylvania | **9.18** | -0.35 |
| Texas | 9.85 | **10.01** |
| Utah | -3.29 | **2.12** |
| **Eight States Combined** | **8.44** | **9.62** |
| **Eight States Weighted** | **9.69** | **12.47** |

For each state, the higher effectiveness estimate is in bold. Note that, although the estimates for the combined states are relatively close (8.44 for males and 9.62 for females), six of the eight individual states had higher effectiveness estimates for females than for males. This is not a statistically significant advantage for females, but only suggest the results are slightly in their favor. By an exact binomial test, at least seven of the eight states would have to have higher effectiveness for females to indicate a significant trend.

The data from each state were also weighted by the number of registered pickups in the respective state, using Formula 3 as shown in Section 2-2. Effectiveness for males was 9.69%, and for females, 12.47%. These estimates, using the preferred method of weighting the data, show a more pronounced advantage for females using head restraints.

Because the data suggest that there may be a real difference between the benefits for males and females, the data were examined further. As an additional check, effectiveness of head restraints for males and for females in rear impacts, using frontal impacts as a control, were determined. Calculations were performed as shown in Formula 5 for combined state data and in Exhibit 2-8 and Formula 6 for data weighted by number of registered pickup trucks. Using the combined data, the effectiveness for males was 5.13% (confidence bounds 2.46 and 7.80, z=3.00). For females, the effectiveness was almost identical, 5.01% (confidence bounds 1.25 and 8.76, z=2.08). Using the data weighted by registered pickup trucks gave similar results. Effectiveness for males was 5.70% (confidence bounds 3.02 and 8.38, t=4.03) while for females it was 5.88% (confidence bounds 0.27 and 9.74, t=2.35).

Adjusting the data to reflect a fleet going from no head restraints to one in which all vehicles are equipped gives similar results. For the combined state data, effectiveness for males in rear impacts, controlled by frontal impacts, was 5.97 (confidence bounds 2.87 and 9.04) and for females was 5.82 (confidence bounds 1.46 and 10.14). Using the data weighted by registered pickups, effectiveness for males was 6.63 (confidence bounds 3.53 and 9.71) and for females was 6.84 (confidence bounds 0.31 and 11.26).

Therefore, upon further investigation, the data show no significant difference between males and females in the benefit of head restraints in rear impact crashes. The small difference seen earlier when looking only at rear impacts disappears when using frontal impacts as a control.

## 3.2 Older vs. Younger

Age differences have been reported in some earlier studies on head restraints. For the present study, a frequency distribution of injured pickup occupant ages was produced, and the median age determined, for each state. These are presented in Exhibit 3-3.

**Exhibit 3-3: Median Age of Injured Occupants, by State**

| State | Median Age |
|---|---|
| Florida | 33 |
| Indiana | 33 |
| Maryland | 34 |
| Missouri | 32 |
| North Carolina | 35 |
| Pennsylvania | 33 |
| Texas | 31 |
| Utah | 28 |

The median age of all injured occupants in all states combined was 32. To simplify the analysis, occupants were placed in one of two age groups – those through age 30 were in the "younger" group, those age 31 and above in the "older" group (30 being the decade closest to the median age).

Data from the combined eight states are presented by age group in Exhibit 3-4. Younger occupants had slightly lower injury rates than the older occupants. Note also that both the older and younger group saw lower injury rates in rear impacts after head restraints were installed.

**Exhibit 3-4: Injury Status by Age Group, for Eight States Combined, Before and After Installation of Head Restraints, Rear Impact**

| | Younger | | Older | |
|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** |
| **Injured** | 4,227 | 4,641 | 7,122 | 7,515 |
| **Uninjured** | 12,773 | 15,395 | 18,253 | 21,741 |
| **Injury Rate** | 24.86 | 23.16 | 28.07 | 25.69 |

Effectiveness estimates were determined for each state, for the combined state data, using Formula 1, as well as the data weighted by registered pickups, using Formula 3. The results are presented in Exhibit 3-5. Again, for each state, the higher effectiveness estimate is noted with bold type.

**Exhibit 3-5: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Age Group**

| | **Younger** | **Older** |
|---|---|---|
| Florida | 3.53 | **7.28** |
| Indiana | -1.80 | **25.00** |
| Maryland | **30.36** | 6.27 |
| Missouri | **14.45** | 14.09 |
| North Carolina | **15.24** | 6.64 |
| Pennsylvania | **9.50** | 6.07 |
| Texas | 9.22 | **9.43** |
| Utah | -22.23 | **16.43** |
| **Eight States Combined** | **6.84** | **8.48** |
| **Eight States Weighted** | **8.36** | **10.65** |

Four of the states show a greater benefit for older occupants, while the other four show more benefit for younger occupants. In addition, in both Missouri and Texas, the two effectiveness estimates are extremely close in value. Both the combined and weighted state data show a slightly larger benefit for older occupants. Overall, neither age group appears to benefit more in rear impacts from the installation of head restraints in pickup trucks. There is not a significant difference between the two groups.

### 3.3 Vehicle Damage Severity

As stated earlier, the majority of injuries in rear impact crashes occur in low-speed crashes, such as those involving vehicles that have not been towed from the scene. As with any safety device, it is possible that head restraint effectiveness could vary with crash severity. An analysis was done to compare head restraint effectiveness for vehicles having minor/non-towaway damage as compared to those with major/towaway damage. For this analysis, rear-impacted vehicles with minor damage were compared with rear-impacted vehicles that were towed and/or sustained major damage.

Since the concern of this report is injury reduction as a result of installing head restraints in light trucks (specifically, for the analysis, pickup trucks), it was important to use a consistent standard of damage for the vehicle of interest. There could be many cases where, for example, a passenger car and pickup truck collide. If the passenger car sustained more severe damage and required towing from the scene, while the pickup truck remained drivable, this should not be considered "major damage" for the pickup truck. A measure of damage to the vehicle, rather than accident severity, was required. Utah's state data codes accident severity, which is based on injuries rather than vehicle damage, but has no damage indicator for individual vehicles. Therefore, Utah was excluded from the vehicle damage severity portion of the analysis.

States vary in how they determine and record vehicle damage. Several of the state data files used in this analysis record whether the vehicle was towed from the scene. When available, this measure was used, as it is an objective measure of vehicle damage. Indiana, Missouri, North Carolina, and Pennsylvania record tow status of each vehicle in the crash.

Florida and Maryland state data files both contain a "Vehicle Damage Severity" variable. In the Florida data, severity is coded as "Disabling", "Functional", or "No Damage." In Maryland, the options are "Not Applicable", "No Damage", "Minor", "Functional", "Disabling", "Destroyed", "Other", and "Unknown." In each case, Disabling damage refers to damage to the motor vehicle such that it can not be driven. In other words, the vehicle would need to be towed from the scene. For Maryland data, "Destroyed" was also included in the "Major Damage" category.

Texas has no variable that is equivalent to tow status. It does, however, have a Damage Scale variable that records the extent of damage to the vehicle. The scale ranges from 1 to 7, with 1 being "Minor Damage" and 7 being "Vehicle Totally Damaged." Minor damage is coded as 1 or 2, Moderate as 3 or 4, and Severe as 5 or 6, with 7 being a totaled vehicle. A frequency distribution of the damage scale on light trucks in the Texas state data showed that about 18 percent of the vehicles were coded as having a damage scale of 4 or greater, and about 39 percent as having 3 or greater. Including vehicles recorded as having a damage scale of 3 and above provided a similar percentage of more severely damaged vehicles to those selected using the tow status variables of the other states. Therefore, vehicles in the Texas data file with a Damage Scale of 3 through 7 were considered as having major damage for the purpose of this analysis.

Exhibit 3-6 shows the relevant variable in each state, the values used, and the percent of light trucks considered as having major damage. Note that for most of the states, 30 to 40 percent of the vehicles experienced major damage. Pennsylvania, however, has a much higher 57 percent of vehicles with major damage. Recall, as stated in Section 2.2, that Pennsylvania requires that one of the vehicles be towed from the accident scene, regardless of the dollar amount involved, in order to file a police report. Therefore, it would be expected that a larger proportion of vehicles in the data file would have been towed.

**Exhibit 3-6: Vehicle Damage Severity Data in State Files, and Percent of Trucks**

| State | Variable Name | Values Included as Major Damage | Percent of Light Trucks with Major Damage |
|---|---|---|---|
| Florida | Vehicle Damage Severity | Disabling | 32% |
| Indiana | Towaway | Towed | 29% |
| Maryland | Vehicle Damage Severity | Disabling, Destroyed | 36% |
| Missouri | Towaway | Towed | 27% |
| North Carolina | Towaway | Not Driveable | 30% |
| Pennsylvania | Towaway | Towed | 57% |
| Texas | Damage Scale | 3-7 (Moderate and above) | 39% |

Vehicles that were towed from scene, not driveable, disabled, or totaled were considered as having major damage. Vehicles with lesser types of known damage were considered as having minor damage. Those vehicles for which the extent of damage was unknown were excluded from this portion of the analysis.

Exhibit 3-7 presents the number of occupants in the total of the seven states, grouped by damage severity, presence or absence of any type of injury, and head restraint status. As would be expected, the injury rates are much higher in vehicles experiencing major damage. The number of occupants in vehicles with minor damage, however, is much higher, and close to 75 percent of the injured occupants were in the vehicles with minor damage.

**Exhibit 3-7: Injury Status by Damage Severity, for Seven States Combined, Before and After Installation of Head Restraints, Rear Impact**

| | Minor Damage | | Major Damage | |
|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** |
| **Injured** | 8,065 | 8,637 | 2,907 | 3,091 |
| **Uninjured** | 26,001 | 31,068 | 3,225 | 3,712 |
| **Injury Rate** | 23.67 | 21.75 | 47.41 | 45.44 |

The estimates of head restraint effectiveness in reducing overall injury risk are presented for each state in Exhibit 3-8. Important to note is that, in each of the seven states included in the analysis, head restraints are more effective in vehicles with minor damage than those with major damage. By an exact binomial test, all seven of the states would have to have higher effectiveness for vehicles with minor damage in order to indicate a significant trend. In fewer than 99% of the cases would such an occurrence happen by chance without some real underlying difference existing. Thus, it can be stated that head restraints are significantly more effective in reducing overall injury risk in vehicles sustaining minor damage than those having major damage.

**Exhibit 3-8: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Damage Severity**

| | Minor Damage | Major Damage |
|---|---|---|
| Florida | **7.10** | 3.99 |
| Indiana | **13.11** | 12.90 |
| Maryland | **12.66** | 4.17 |
| Missouri | **16.03** | -0.89 |
| North Carolina | **12.87** | -3.37 |
| Pennsylvania | **8.18** | 6.95 |
| Texas | **10.02** | 5.00 |
| **Seven States Combined** | **8.12** | **4.16** |
| **Seven States Weighted** | **10.82** | **4.23** |

For the seven states of combined data, effectiveness is estimated to be 8.12% in vehicles with minor damage and 4.16% in those with major damage. When the data are weighted by registered pickup trucks in each state, the estimate in vehicles with minor damage is 10.82%, and in those with major damage, 4.23%. Note that the estimates in vehicles with minor damage are relatively close to the overall estimates obtained for rear impacts (7.65% for combined data, 9.62% for weighted data). This should be no surprise, since the majority of occupants are in vehicles experiencing minor damage.

Since benefits do appear to be different in crashes with major and minor damage, further examination is warranted. Effectiveness in rear impacts by crash severity will be determined using frontal impacts as a control. Combining the state data (for the seven states usable for analysis of damage severity) as in Formula 4 results in an effectiveness in crashes with minor (nontowaway) damage of 7.17% (confidence bounds of 3.68 and 10.67, z=3.14). The effectiveness in crashes with major (towaway) damage is 1.07%, with a confidence interval ranging from –2.29 to 4.42, and a z-score of 0.52. For the data weighted by registered pickup trucks, effectiveness in crashes with minor damage is 6.68% (confidence bounds of 2.21 and 11.14, t=2.91) and in crashes with major damage is 0.28% (confidence bounds of –3.32 and 3.89, t=0.15).

Adjusting these data for a fleet going from no vehicles having head restraints to one in which all vehicles are equipped shows the same pattern. For the combined state data, effectiveness in minor damage crashes is 8.32% (confidence bounds of 4.29 and 12.31, z=3.14) and in major damage crashes is 1.25% (confidence bounds of –2.70 and 5.15, z=0.52). Using the data weighted by registered pickup trucks, effectiveness in crashes with minor damage is 7.75% (confidence interval ranging from 2.59 to 12.84, t=2.91) and in crashes with major damage is 0.33% (confidence bounds of –3.92 and 4.53, t=0.15).

These results strengthen the earlier conclusion that head restraints are in fact more effective in reducing injuries in vehicles receiving minor damage than for those with major damage.  In fact, the data show that head restraints are significantly effective in vehicles sustaining minor damage, and do not have a significant benefit in vehicles sustaining major damage.  The effectiveness estimates of 7.75% for vehicles with minor damage and 0.33% for those with major damage are directly comparable to the overall estimate of 6.08% for registered pickup truck weighted data for the unequipped to fully equipped fleet.  Again, since the vast majority of crashes do not involve any vehicles with towaway damage, it is not surprising that the effectiveness for minor damage vehicles is so similar to the overall rate.  In addition, a much larger number of occupants is involved in these lower severity crashes.

It is not obvious why head restraints should be more effective in vehicles with minor damage.  One factor, however, is that the analysis is based on overall injury risk.  The more severe crashes are more likely to involve multiple injuries, including non-whiplash injuries, that head restraints are unlikely to reduce to "no injury."  As discussed in Section 2.1.2.5, these data do not realistically permit a separate analysis of whiplash injuries.

### 3.4 Rear Impact Location – Center vs Off-Center

Rear impacts have been the focus of injury reduction due to head restraints.  To better understand how head restraints reduce injury, an analysis was done comparing centered rear impacts to off-centered ones.  Different impact location schemes are used by various states, and an attempt was made to standardize the criterion for inclusion as a center or off-center impact.

The following table presents the variables used in each state, and the values used to determine a rear center impact.  All other values were considered off-center.  Also shown is the percent of vehicles in the dataset (of rear impacts) that were considered as having a centered rear impact.  Since only rear impact crashes were used, there were no cases with unknown impact location.

| State | Rear Center Impact | Percent of Rear Impacts with Center Impact |
|---|---|---|
| Florida | Point of Impact is 8 | 76% |
| Indiana | Initial Point of Impact is 6 | 48% |
| Maryland | Either Initial Impact or Vehicle Damage Area1 is 9,10 | 71% |
| Missouri | Vehicle Damage Area is 8 | 63% |
| North Carolina | TAD1 is 11,12 | 68% |
| Pennsylvania | Initial Impact Point is 6 | 77% |
| Texas | Damage Scale is BC, BD | 56% |
| Utah | Damage Areas 1 or 2 is 8 | 8% |

The percent of vehicles having a rear center impact in the Utah file is much smaller than that in the other states.  Utah's codes for rear impact are 7 (Left Back), 8 (Middle Back), and 9 (Right Back).  Of the 2,289 vehicles in the Utah state data file used for the analysis, there were 67 with Damage Area 1 reported as Middle Back, 125 with Damage Area 2 reported as Middle Back, and none with both Damage Areas 1 and 2 as Middle Back.

About half the cases (1135) list no second damage area. Clearly, since the percentage of rear impacts that are center impacts is much lower in Utah than the other states, Utah state data reports or records centered vs off-centered crashes differently than do the other states. Therefore, Utah was excluded from this portion of the analysis.

Data from the combined seven states are presented by rear impact location in Exhibit 3-19. Injury rates are higher for center crashes than for those off-center. Both types of crashes experienced lower injury rates in the later years, when head restraints were present.

**Exhibit 3-9: Injury Status by Rear Impact Location, for Seven States Combined, Before and After Installation of Head Restraints, Rear Impact**

| | **Off-Center** | | **Center** | |
|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** |
| **Injured** | 3,041 | 3,226 | 8,188 | 8,810 |
| **Uninjured** | 13,423 | 15,599 | 17,027 | 20,929 |
| **Injury Rate** | 18.47 | 17.14 | 32.47 | 29.62 |

Effectiveness estimates were determined for each of the seven states in the analysis, as well as for the combined state data. The results are presented in Exhibit 3-10. Again, the higher effectiveness estimate is noted with bold type. For location of rear impact, the data are mixed. Three of the states show greater effectiveness for off-center rear impacts, while the remaining four states show greater effectiveness for centered rear impacts. The combined data shows a slightly greater benefit in centered rear impact crashes, but the data weighted by registered pickup trucks shows the opposite.

**Exhibit 3-10: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Impact Location (Percent Fatality Reduction)**

| | **Off-Center** | **Center** |
|---|---|---|
| Florida | **21.33** | 3.00 |
| Indiana | **32.68** | 8.50 |
| Maryland | 2.79 | **14.73** |
| Missouri | 11.70 | **16.96** |
| North Carolina | 1.95 | **12.06** |
| Pennsylvania | **15.61** | 3.17 |
| Texas | 5.69 | **11.41** |
| **Seven States Combined** | **7.22** | **8.77** |
| **Seven States Weighted** | **12.26** | **9.67** |

There is no evidence of any strong effect for head restraints being more effective in either rear center or off-center crashes. There are not enough data to draw a definitive conclusion. The varying types of data and definitions used for “rear center impact” likely contribute to this lack of observable effect. Overall, although head restraint protection depends on the direction of impact, it doesn’t depend on the location of the (rear) impact. Head restraints cushion the head and neck of the occupant in either type of impact.

### 3.5 Integral vs. Adjustable Head Restraints

The 1982 evaluation[1] of head restraints in passenger cars found integral restraints to reduce the overall injury risk to occupants in rear impacts by 17 percent, and adjustable restraints by 10 percent. It is of interest to compare the performance of these types of head restraints in pickup trucks. The first step is to determine the type of head restraint found in each type of vehicle, in each of the "After" years. There were two possible sources of data available to determine the type of head restraint in the various makes and models of pickup trucks. Where available, data from the manufacturer were used, as this provided a definitive census of the make-up of head restraints available in each vehicle. Where manufacturer information was unavailable, the Crashworthiness Data System (CDS) data were used. Recall that CDS is a sample of crashes in the United States, and isn't an exact measure of how the types of head restraints were distributed. However, it's the best information available in the absence of manufacturer provided data.

The pickup trucks used in the present study vary with respect to the composition of the type of head restraints found in them. About 80 percent of the Ford Rangers in the CDS in 1991 (the first year with at least 75 percent having head restraints) were equipped with integral head restraints. The remaining 20 percent were evenly split between adjustable and no head restraints. In 1992, 90 percent of the Ford Rangers in CDS had integral head restraints, and the remaining 10 percent had adjustable. Data from the manufacturer confirm that 91 percent of Rangers manufactured in 1992 (the earliest year for which data were available) had integral head restraints, and the remainder had adjustable ones.

Dodge pickup trucks were more frequently equipped with adjustable head restraints. According to the manufacturer, all Dodge D/Ws in 1990 and 91 were equipped with them. In 1990, 84 percent of Dodge Dakotas were equipped with adjustable head restraints. In 1991, 89 percent of Dakotas had adjustable head restraints. In both years, the remaining vehicles had integral head restraints.

CDS data show that 82 percent of C/K pickups, and 65 percent of S/T pickups, had adjustable head restraints in 1992. In 1993, 73 percent of the C/K pickup trucks and 57 percent of the S/Ts were equipped with adjustable head restraints. For all these GM vehicles, the remaining trucks were equipped with integral head restraints.

Recall, as discussed in Section 2.6, that there is no direct way to determine which individual vehicles did or did not have head restraints from the data. Similarly, unless a specific make of vehicle was equipped with only one type of head restraint, it is impossible to determine the type of head restraint present in a particular vehicle. Therefore, the best solution is to look at the type of head restraint found most frequently in a particular type of vehicle, and assign all such trucks to that group. For the present analysis, Ford Rangers were most frequently equipped with integral head restraints when a head restraint was present. The Dodge and GM pickup trucks most often had adjustable head restraints. Therefore, this section will compare the effectiveness of Ford Ranger head restraints as compared to those in Dodge and GM pickups. The separation is far from clean, however, particularly with the General Motors S/T line.

Exhibit 3-11 presents data from the combined eight states grouped by manufacturer according to the type of head restraint that predominated in the vehicles. In general, occupants in GM and Dodge pickup trucks had lower injury rates than those in Ford Rangers. All vehicles saw a decrease in injury rates in the "After" years.

**Exhibit 3-11: Injury Status by Predominant Type of Head Restraint, for Eight States Combined, Before and After Installation of Head Restraints, Rear Impact**

| | GM/Dodge (Adjustable) | | Ford Ranger (Integral) | |
|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** |
| **Injured** | 9,081 | 9,280 | 2,332 | 2,951 |
| **Uninjured** | 25,814 | 29,911 | 5,562 | 7,601 |
| **Injury Rate** | 26.02 | 23.68 | 29.54 | 27.97 |

The effectiveness estimates for each state are presented in Exhibit 3-12. Also presented are the estimates for the combined and weighted state data. Bold type highlights the higher effectiveness estimate in each state.

**Exhibit 3-12: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Predominant Type of Head Restraint (Percent Fatality Reduction)**

| | GM/Dodge (Adjustable) | Ford Ranger (Integral) |
|---|---|---|
| Florida | **6.99** | 5.28 |
| Indiana | **17.29** | 14.43 |
| Maryland | **19.29** | -1.59 |
| Missouri | **17.20** | 8.77 |
| North Carolina | **12.39** | 5.67 |
| Pennsylvania | **8.90** | -1.61 |
| Texas | **10.03** | 7.80 |
| Utah | -3.02 | **12.54** |
| **Eight States Combined** | **9.01** | **5.33** |
| **Eight States Weighted** | **11.22** | **6.70** |

Note that seven of the eight states show a higher effectiveness estimate for the "Mostly Adjustable" group, which would indicate a significant trend according to an Exact Binomial Test. This is contrary to what was observed in passenger cars. The combined as well as the weighted data also favor adjustable restraints.

All the data used in the analysis are confounded by the fact that the fleets do not go from being zero to 100 percent head restraint equipped. A method of correcting for this was discussed and used in Section 2.6. The data examined in the present section, however, are further confounded by not being separable into purely "Integral" and "Adjustable" groups. Therefore, it was decided that, for this set of data, the correction for adjusting to a zero to 100 percent equipped fleet would be used to at least partially adjust the estimates.

The adjustments for the GM/Dodge and Ford Ranger groups would have to be done separately. The first step is to determine the makeup of each group by vehicle make. The same process used in Section 2.6 were applied to the data here. As noted in Section 2.6, Indiana and Texas are excluded from the portion of the analysis that derives the formulae for adjustment, since these states do not provide the VIN on their data files. Once derived, however, the adjustments can of course be used on the Indiana and Texas estimates. Data for the correction for the GM/Dodge vehicles are presented in Exhibit 3-13. These are the same data presented in Exhibit 2-17, excluding the Ford Rangers.

**Exhibit 3-13: Number of Pickup Trucks by Manufacturer in Each State, All Impact Locations, Mainly Adjustable Head Restraint Vehicles**

| | Florida | Maryland | Missouri | North Carolina | Pennsyl-vania | Utah |
|---|---|---|---|---|---|---|
| **Before** | | | | | | |
| Dodge | 2725 | 585 | 2191 | 2400 | 2209 | 573 |
| GM C/K | 7063 | 1250 | 6097 | 6668 | 4408 | 2282 |
| GM S/T | 4606 | 962 | 4741 | 4722 | 3665 | 922 |
| *Total* | *20288* | *3826* | *16987* | *19396* | *13471* | *5171* |
| **After** | | | | | | |
| Dodge | 2095 | 537 | 2179 | 1841 | 1689 | 788 |
| GM C/K | 9533 | 1251 | 7432 | 7553 | 4266 | 2751 |
| GM S/T | 6473 | 922 | 3879 | 6569 | 3364 | 710 |
| *Total* | *25104* | *3856* | *18565* | *22049* | *12368* | *5569* |

Exhibit 3-14 shows the percent of pickup trucks by manufacturer in each state, using the data from Exhibit 3-13. These percentages reflect the fact that Ford Rangers are not included in them. Therefore, while the counts in Exhibit 3-13 are the same as in 2-14, these percentages differ from those in Exhibit 2-18.

**Exhibit 3-14: Percent of Pickup Trucks by Manufacturer in Each State, all Impact Locations, Mainly Adjustable Head Restraint Vehicles**

| | Florida | Maryland | Missouri | North Carolina | Pennsyl-vania | Utah |
|---|---|---|---|---|---|---|
| **Before** | | | | | | |
| Dodge | 18.93% | 20.92% | 16.82% | 17.40% | 21.48% | 15.17% |
| GM C/K | 49.07% | 44.69% | 46.80% | 48.35% | 42.87% | 60.42% |
| GM S/T | 32.00% | 34.39% | 36.39% | 34.24% | 35.64% | 24.41% |
| **After** | | | | | | |
| Dodge | 11.57% | 19.82% | 16.15% | 11.53% | 18.12% | 18.55% |
| GM C/K | 52.67% | 46.16% | 55.09% | 47.32% | 45.78% | 64.74% |
| GM S/T | 35.76% | 34.02% | 28.75% | 41.15% | 36.10% | 16.71% |

These percentages were then combined to form a weighted average, using registered pickup trucks per state, originally presented in Exhibit 2-4. The overall percents by manufacturer for vehicles in the "Mainly Adjustable Head Restraint" group, before and after the installation of head restraints, are presented in Exhibit 3-15.

**Exhibit 3-15: Percent of Pickup Trucks by Manufacturer, Across Six States, Weighted by Number of Registered Pickup Trucks per State**

| | **Before** | **After** |
|---|---|---|
| Dodge | 18.64 | 14.73 |
| Chevy C/K | 47.66 | 50.81 |
| Chevy S/T | 33.70 | 34.46 |

These values were then multiplied by the percent of each type of vehicle equipped with head restraints (from Exhibit 2-16), and summed to obtain an overall "Before" and an "After" percent of vehicles equipped with head restraints, as follows:

$$\text{Before: } (18.64 \times 0) + (47.66 \times .05) + (33.70 \times .2) = 9.12\%$$

$$\text{After: } (14.73 \times 1) + (50.81 \times 1) + (34.46 \times 1) = 100$$

Since Ford Rangers were the only vehicle make with any unequipped vehicles in the "After" years (and are excluded here), the "After" group for the "Mostly Adjustable" group is 100 percent equipped. Overall, 9.12 percent of pickup trucks were equipped with head restraints in the "Before" model years. Consequently, what has actually been measured is $E_1$, the reduction in injuries in rear impacts in a fleet that is 100 percent equipped with head restraints relative to a fleet that is 9.12 percent equipped. The actual measurement needed is $E_2$, the reduction for a 100 percent head restraint equipped fleet relative to one without any head restraints. Using Formula 7 (repeated here for convenience),

$$1 - E_1 = \frac{(1 - p_A) + p_A(1 - E_2)}{(1 - p_B) + p_B(1 - E_2)}$$

where $p_A$ = percent of fleet equipped with head restraints in the "After" model years
$p_B$ = percent of fleet equipped with head restraints in the "Before" model years.

Substituting 0.0912 for $p_B$ and 1 for $p_A$, and solving for $E_2$,

$$E_2 = \frac{E_1}{0.9088 + (0.0912 \times E_1)}$$

Each estimate for the "Mostly Adjustable" group would be adjusted using this formula.

The process for Ford Rangers is easier, since it involved only one type of vehicle. As shown in Exhibit 2-16, 24 percent of Ford Rangers in the "Before" group and 94 percent in the "After" group were equipped with head restraints. Thus, in Formula 7, 0.24 is substituted for $p_B$ and 0.94 for $p_A$. Solving for $E_2$ it becomes:

$$E_2 = \frac{E_1}{0.7 + (0.24 \times E_1)}$$

The adjusted effectiveness estimates for the "Mostly Adjustable" (GM/Dodge pickup trucks) and the "Mostly Integral" (Ford Rangers) using the correction formulas derived above are shown in Exhibit 3-16.

**Exhibit 3-16: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Predominant Type of Head Restraint (Percent Fatality Reduction), adjusted for 0 Percent to 100 Percent Head Restraint Equipped Fleet.**

| | **GM/Dodge (Adjustable)** | **Ford Ranger (Integral)** |
|---|---|---|
| Florida | **7.64** | 7.40 |
| Indiana | 18.70 | **19.64** |
| Maryland | **20.82** | -2.29 |
| Missouri | **18.61** | 12.16 |
| North Carolina | **13.47** | 7.95 |
| Pennsylvania | **9.70** | -2.31 |
| Texas | **10.92** | 10.85 |
| Utah | -3.34 | **17.18** |
| **Eight States Combined** | **9.83** | **7.48** |
| **Eight States Weighted** | **12.21** | **9.35** |

Comparing Exhibits 3-12 and 3-16, it is notable that the Ford Ranger effective estimates change to a greater degree than do the GM/Dodge estimates. The Rangers were adjusted from a fleet that actually went from 24 to 94 percent equipped to one going from zero to 100 percent. The GM/Dodge vehicles needed less correction, adjusting only from a fleet actually 9.12 to 100 percent equipped. Because of this, note that in Indiana, the adjusted estimate for Ford Rangers is higher than that for GM/Dodge, where the opposite was true of the unadjusted estimates. Six of the eight states are not enough to indicate significance using the Exact Binomial Test. In addition, observe that the adjusted combined state estimates, as well as the adjusted weighted ones, while still higher for the "Mostly Adjustable" group, are much closer in magnitude than the unadjusted estimates were.

Adjustable head restraints seem to be at least as effective as integral head restraints. Unlike the 1982 evaluation of passenger cars, the data do not show an advantage for integral head restraints in light trucks. At the same time, they do not show a statistically significant advantage for adjustable head restraints. However, the analysis of light trucks is hampered by the fact that it is not possible to clearly distinguish between the two types.

In addition, the assumption is made that the "before" seats in vehicles that eventually had integral head restraints installed were equivalent to those that eventually had adjustable ones. This might not be a valid assumption if one vehicle had a seat more amenable (for whatever reason) to introducing integral rather than adjustable head restraints, or vice versa. Overall, these data do not show a difference between integral and adjustable head restraints.

### 3.6 Pickup Trucks with Back Seats vs. Pickup Trucks without Back Seats

Pickup trucks without back seats have a window directly behind the (front-seat) occupants. It is possible that this window offered some measure of support to the head in a rear impact before head restraints were installed; thus, head restraints were less essential and would have lower effectiveness. Conversely, it is conceivable that the window and its frame presented an extra hazard to occupants; in that case, the head restraint would be all the more beneficial. Therefore, it would be of interest to compare the changes in injury rates between pickup trucks with and without back seats. Using the VIN, it is possible to distinguish which vehicles had back seats from those that did not.

The Ford Ranger Supercab produced in model years 1989 through 1992 (the model years of interest for Ford Rangers) was manufactured with a back seat. Other Ford Rangers in these model years did not have a back seat, and therefore had the rear window closer to the front-seat occupants' heads.

The model years of interest for General Motors pickup trucks are 1990 through 1993. During these model years, vehicles designated as "Maxicab," "Extended Cab," or "Crew Cab," as well as the four door pickups, had back seats. Other General Motors pickup trucks did not.

During model years 1988 through 1991, Dodge D/W Club Cab Pickup Trucks had back seats, while other models of D/W pickup trucks did not. Over the same model years, Dodge Dakota Club Cabs, other than the Short Bed model, had back seats. Other Dodge Dakotas, including the Club Cab Short Bed, had no rear seat. All of the back seat models, however, were produced during model years 1990 and later only. Since there were no "Before" Dodge vehicles having back seats, no comparison could be made for them. Therefore, Dodge vehicles were excluded from this portion of the analysis. In addition, since presence or absence of a back seat was determined from the VIN, Texas and Indiana, which do not contain the VIN on their state data files, were excluded from this portion of the analysis.

Data from the combined remaining six states (Florida, Maryland, Missouri, North Carolina, Pennsylvania, and Utah) are presented by presence or absence of back seat in Exhibit 3-17. Note that both types of vehicles saw a decrease in the injury rate in the later years.

**Exhibit 3-17: Injury Status by Presence/Absence of Back Seat, for Six States Combined, Before and After Installation of Head Restraints, Rear Impact**

| | No Back Seat | | Back Seat | |
|---|---|---|---|---|
| | **Before** | **After** | **Before** | **After** |
| **Injured** | 3,088 | 3,202 | 808 | 1,178 |
| **Uninjured** | 8,667 | 10,022 | 2,536 | 4,067 |
| **Injury Rate** | 26.27 | 24.21 | 24.16 | 22.42 |

Effectiveness estimates were determined for each of the six states, for the combined state data, and the data weighted by the number of registered pickup trucks. These are presented in Exhibit 3-18.

**Exhibit 3-18: Estimates of Effectiveness of Head Restraints in Rear Impacts, by State and Presence/Absence of Back Seat (Percent Fatality Reduction)**

| | No Back Seat | Back Seat |
|---|---|---|
| Florida | **6.31** | 5.00 |
| Maryland | **17.77** | 0.37 |
| Missouri | 13.83 | **18.90** |
| North Carolina | **10.20** | 3.95 |
| Pennsylvania | 6.14 | **9.38** |
| Utah | -5.57 | **-0.11** |
| **Six States Combined** | **7.83** | **7.21** |
| **Six States Weighted** | **8.69** | **7.38** |

Worth noting is that the Utah data showed a worsening in performance over time in both types of vehicles. (Utah's overall rear impact improvement was the lowest of the eight states in the analysis (Exhibit 2-2).) Notice that three of the six states saw greater improvement in pickup trucks without a back seat. Two states saw a larger improvement, and Utah saw less worsening, in vehicles with back seats. While both the combined and weighted state data saw greater improvement in vehicles with no back seats, the differences are quite small. It would appear that neither vehicle configuration, either those with back seats or those without, benefit more in rear impacts from the installation of head restraints in pickup trucks.

# Chapter 4: Benefits and Costs

In 1999, head restraints in light trucks prevented an estimated 13,156 injuries. If all light trucks had head restraints, a total of 14,882 injuries could have been prevented. The total cost of head restraints was $35.41 per vehicle. Given the number of light trucks sold in the United States during the preceding 15 years (1985-1999), this resulted in an average annual cost of $186,846,000, or $12,555 per injury prevented.

## 4.1 Injuries Prevented by Head Restraints in Light Trucks

### 4.1.1 National Estimates of Injured Occupants

Most of the information presented thus far has been based on eight states for which NHTSA has relevant data files (Florida, Indiana, Maryland, Missouri, North Carolina, Pennsylvania, Texas, and Utah). In order to determine estimates of injuries prevented nationwide, the effectiveness estimate determined in Chapter 2 would need to be applied to a national estimate of injured front outboard occupants in light trucks experiencing a rear impact. Two possible ways to determine national estimates would be to use NHTSA's General Estimates System (GES) data, or to base an estimate on the eight states used previously in the analysis. Both approaches are presented below.

#### 4.1.1.1 General Estimates System

The GES is a probability sample of police-reported traffic crashes in the United States. National estimates are obtained by weighting the data with the "WEIGHT" variable on the data file.[1] For some variables, GES provides either univariate or hot-deck imputed variables, which assign a value when one is unknown.[2]

The Hot-Deck Imputed Body Type variable was used to determine which vehicles were light trucks. For 1992 and later, these were coded in GES as Utility Vehicles (Body Type values 14,15,16, and 19), Van-Based Light Trucks (values 20-29), Light Conventional Trucks (values 30-39), and Other Light Trucks (values 40 through 48).

Unknown seat position was distributed using univariates. In 1998, for example, there were an estimated 118,806 drivers and 41,435 right front passengers in rear impacts in light trucks. There were an additional 3,647 front seat occupants with known seating, and 240 with unknown seating. The 118,806 drivers were 72.49 percent of the known seated position front occupants (a total of 163,888 occupants; 118,806 drivers + 41,435 right front passengers + 3,647 other front occupants), so 72.49% of the 240 unknown seat position front occupants would be counted among the drivers. Right front passengers were distributed using the same method.

After distributing the front seat occupants, the remaining 2,320 occupants with completely unknown seating position were distributed. This resulted in final estimates of 120,484 drivers and 42,020 right front passengers, for a total of 162,504 injured front outboard occupants in light trucks involved in rear impact crashes. Performing similar calculations on the 1999 GES data results in a total of 182,004 injured front outboard occupants in light trucks involved in rear impact crashes.

4.1.1.2 State Data

The first step in using the state data for a national estimate of injured occupants is to determine the number of injured front outboard occupants in rear impacts. As stated in Section 2.1.2.4, Indiana and Missouri record data on right front passengers only when they are injured. This prohibited their use in determining injury rates, but does not prevent their being used in this portion of the analysis. The total number of injured front outboard occupants in the eight states for 1998 (the most recent year of data available) was 40,794.

This number of front outboard occupants can be used to calculate a national estimate. The 9,452,370 pickup trucks registered in these eight states are 26.11% of the 36,203,980 registered nationwide. Using the formula

$$40{,}794 / 0.2611 = 156{,}234$$

estimates that a total of 156,234 injured front outboard occupants in light trucks were involved in rear impact collisions. This is very close to the 1998 GES estimate of 162,504.

Light trucks are becoming a larger portion of the vehicle fleet annually. Therefore, it is beneficial to use the most current year of data available for the most accurate estimate. As of December 2000, state data files of calendar year 1999 are not available for analysis within NHTSA, but GES data are available for 1999. Since the estimates for both data systems were very similar for 1998, it was decided to use the 1999 GES estimate to determine the number of injuries prevented by head restraints in light trucks.

### 4.1.2 Injuries Prevented

According to NHTSA's economic cost report[3], in 1994 there were 4,130,606 police-reported injured persons, and 1,126,001 unreported injured persons, for a total of 5,256,607 injured. If the assumption is made that the ratio of reported to non-reported crashes for rear impacts is the same as for overall crashes, this data can be used to determine injuries prevented in both reported and unreported crashes. The ratio:

$$\frac{5{,}256{,}607}{4{,}130{,}606} = 1.2726$$

gives a multiplier that can be used on reported crashes to determine the total number of crashes, including unreported ones. So the number of injured front outboard occupants in 1999, in rear impacts, would be

$$182{,}004 \times 1.2726 = 231{,}618$$

using the 1999 GES estimate.

This correction is most likely to be conservative. Unreported crashes would naturally tend to have less severe injuries than reported crashes. The “whiplash” injuries that head restraints were designed to prevent would typically be recorded as less serious or minor injuries. So the estimates obtained using these data could be viewed as a lower bound to the actual number of injuries prevented.

The final step in determining the number of injuries that head restraints have prevented in light trucks is to apply the effectiveness estimate of 6.08 percent to the number of injured occupants. Recall that this estimate was derived using pickup truck data only. The assumption will be made that head restraints have a similar effect in all light trucks. This assumption introduces some uncertainty but it is necessary because head-restraint effectiveness could not be evaluated in vans or SUVs: there were no high-sales make-models that shifted from 0-25 percent to 75-100 percent head-restraint-equipped from one model year to the next one. Vans and to a lesser extent SUVs in a few ways resemble cars (where head restraint effectiveness is 13 percent) more closely than pickup trucks: they may be more often used as personal, urban transportation and have a higher proportion of female drivers than pickup trucks. But on the whole, the mass, height and rigidity of vans and SUVs makes them more similar to pickup trucks than cars. SUVs in particular are often derivatives of pickup-truck designs. Therefore, the effectiveness found for pickup trucks could be used to determine injuries prevented in vans and sport utility vehicles as well.

According to the CDS, the percent of light trucks having head restraints in calendar year 1999 was 88.40 percent. The number of potential injured occupants if no light trucks at all had been equipped with head restraints is determined using the formula:

$$\frac{231{,}618}{1-(0.0608\times 0.8840)} = 244{,}774$$

where 231,618 is the actual number of injured front outboard occupants in light trucks in rear impacts in 1999, and 0.0608 is the effectiveness estimate determined previously.

If every light truck on the road had head restraints in 1999, the injuries prevented would have been:

$$244{,}774 \times 0.0608 = 14{,}882$$

The actual number of injuries prevented in 1999, however, was:

$$244{,}774 \times 0.0608 \times 0.8840 = 13{,}156$$

Using the upper limit of 3.49 percent and the lower limit of 8.65 percent, previously calculated for the estimate of effectiveness (Exhibit 2-20), the confidence bounds around the estimates of injuries prevented can be determined. First, the upper and lower bounds for potential injuries are determined:

$$\text{Lower Limit: } \frac{231{,}618}{1-(0.0349\times 0.8840)} = 238{,}991$$

$$\text{Upper Limit: } \frac{231{,}618}{1-(0.0865\times 0.8840)} = 250{,}795$$

Using these values, the limits for the number of injuries that would have been prevented if all light trucks had been equipped with head restraints are:

$$\text{Lower Limit: } 238{,}991\times 0.0349 = 8{,}341$$
$$\text{Upper Limit: } 250{,}795\times 0.0865 = 21{,}694$$

The confidence bounds for the estimate of actual injuries prevented (given that not all light trucks were equipped with head restraints) are calculated as:

$$\text{Lower Limit: } 238{,}991\times 0.0349\times 0.8840 = 7{,}373$$
$$\text{Upper Limit: } 250{,}795\times 0.0865\times 0.8840 = 19{,}177$$

In sum, if every light truck on the road had head restraints in 1999, a total of 14,882 injuries would have been prevented, relative to a fleet of light trucks with no head restraints (confidence bounds range from 8,341 to 21,694). Since 88.40 percent of light trucks were in fact equipped with head restraints by then, the actual number of injuries prevented in 1999 was 13,156 (confidence bounds range from 7,373 to 19,177). Note that these estimates are based on the effectiveness value calculated on pickup truck at the time head restraints were first installed in these vehicles. If head restraints in vans and sport utility vehicles were either more or less effective, this would of course change the number of injuries prevented. In addition, if head restraints had changed configuration in such a way as to have become more effective in recent years, this would also alter the number of injuries prevented. It is known that head restraints in passenger cars are higher today than when they were first installed. If this is also true for light trucks, then the number of injuries prevented would correspondingly increase.

NHTSA's Evaluation of Head Restraints in Passenger Cars[4] found that head restraints in passenger cars were going to prevent 64,000 injuries per year when they were in every car on the road. There are various reasons for the 4 to 1 difference between injuries prevented by head restraints in cars and in light trucks.

Although light truck sales have greatly increased over the last decade, they currently make up only 37% of the light vehicle fleet. This means there are twice as many cars as light trucks on the road. In addition, given that a rear impact occurs, there is less risk of injury for occupants in a light truck than for those in a passenger car. One reason for this discrepancy is gender difference. Women tend to be more prone to "whiplash" type injuries than are men. A larger proportion of men drives light trucks than do women, particularly pickup trucks. This combination of factors results in fewer "whiplash" injuries in rear impacts in light trucks than cars.

Finally, the effectiveness of head restraints in light trucks was determined to be 6.08%. Head restraints are more than twice as effective in passenger cars, about 13% for the mix of adjustable and integral head restraints. Note that the current fleet of passenger cars is equipped with head restraints that are higher the minimum required[5], and effectiveness may have increased since this initial evaluation was performed. It is unknown why head restraints are more effective in cars. Perhaps the large mass and extensive rear structure of light trucks, especially pickup trucks, offers a degree of protection in rear impacts that makes it less beneficial to have head restraints.

Overall, the in rear impacts in passenger cars is more than twice the number injured in light trucks. This, combined with the lower effectiveness of head restraints in light trucks, results in one-fourth as many injuries prevented by head restraints in light trucks as in passenger cars.

### 4.2 <u>Cost of Head Restraints in Light Trucks</u>

NHTSA is preparing a report[6] on cost estimates for the increase in the purchase price and weight associated with head restraints as well as other safety standards. It was determined that, on average, head restraints added $31.03 (in 1998 dollars) to the purchase price and 3.85 pounds to the weight of a light truck. Since the injuries prevented reflect 1999 data, the costs must also be indexed to 1999. The initial cost of the head restraint is multiplied by the factor of 104.77/103.22 (the ratio of the Implicit Price Deflator[7] for 1999 relative to that of 1998). This is calculated as:

$$\frac{104.77}{103.22} \times \$31.03 = \$31.50$$

resulting in a cost of $31.50 in 1999 dollars.

The consumer cost of head restraints over the life of a light truck is the sum of the purchase price increase and any additional operating costs. The additional weight of the head restraints will result in a slight increase in fuel consumption over the life of the vehicle. At 3.85 pounds, this results in an additional 5.38 gallons of fuel[8] over the lifetime of the light truck. A 2000 price per gallon of $1.53 was used, adjusted by weighted average yearly mileage over a span of 25 years, as well as a discount factor of 7 percent for net present value of future gasoline purchasing. This resulted in a lifetime fuel consumption having net present value $3.91 due to the weight increase of the front-seat head restraints. Since the head restraints are inside the passenger compartment, they do not add to aerodynamic drag, so there is no fuel penalty other than that due to the weight increase.

The lifetime consumer cost per light truck is the sum of the purchase price increase and the fuel penalty:

$$\$31.50 + \$3.91 = \$35.41 \text{ per light truck}$$

An average of 5,276,636 light trucks has been sold annually in the United States during the past 15 years (1985-1999).  Since fifteen years is approximately the average lifespan of a light truck in the United States, this is a suitable period of time over which to determine the average annual cost, calculated as:

$$5{,}276{,}636 \times \$35.41 = \$186{,}845{,}678.40$$

The average annual cost of head restraints in light trucks is approximately $186,846,000. Given that a year's output of head restraints will prevent 14,882 injuries over the lifetime of these vehicles, the cost per injury prevented is $12,555.

## Chapter 4 Footnotes

1. National Estimates, *National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1988-1999.* Washington, DC: U.S. Department of Transportation; National Highway Traffic Safety Administration; National Center for Statistics and Analysis, Dec, 2000, pp. 9-10.

2. Understanding the GES Imputation Process, *National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1988-1999.* Washington, DC: U.S. Department of Transportation; National Highway Traffic Safety Administration; National Center for Statistics and Analysis, Dec, 2000, pp. 7-8.

3. Blinoe, Lawrence J. *The Economic Cost of Motor Vehicle Crashes, 1994*. DOT HS 808 425. Washington, DC. U.S. Department of Transportation; National Highway Traffic Safety Administration, July 1996, p. 9.

4. Kahane, Charles J. *An Evaluation of Head Restraints: Federal Motor Vehicle Safety Standard 202.* Technical Report No. DOT HS 806 108. Washington" National Highway Traffic Safety Administration, 1982.

5. Preliminary Economic Assessment and Regulatory Flexibility Analysis: FMVSS No. 202 Head Restraints for Passenger Vehicles. National Highway Traffic Safety Administration, Plans and Policy, Office of Regulatory Analysis and Evaluation. December, 2000.

6. Rymarz, Greg. *The Cost and Weight of the Federal Motor Vehicle Safety Standards for Passenger Cars and Light Trucks*. Washington, DC. U.S. Department of Transportation; National Highway Traffic Safety Administration, to be published.

7. Bureau of Economic Analysis Data. Internet Address: http://www.bea.doc.gov/bea/dn/nipaweb/AllTables.asp. Washington: Bureau of Economic Analysis, 2001.

8. *FMVSS No. 208 Mandatory Air Bag Installation.* Washington, Office of Regulatory Analysis, Plans and Policy, June 1993.
   Page III-9 of the above report gives this formula for computing increased fuel consumption:

$$\left[\left(\frac{W_2}{W_1}\right)^{.8}-1\right]\left[\frac{LifetimeVMT}{FuelEconomy, mpg}\right]$$

   where the values used in the present report are:

   $W_1$=Original vehicle weight (4169, average in-use weight of light truck in the U.S.)
   $W_2$=Vehicle Weight after increase due to head restraints (4169 + 3.85 = 4172.85)

Lifetime VMT=128,195
Actual Fuel Economy, MPG=17.6=85% of CAFÉ

Pages III-9 to III-12 of the same report compute the net present value of a gallon of fuel consumed over the life of the truck.