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# IDENTIFYING PRIORITIES FOR IMPROVING REAR SEAT OCCUPANT PROTECTION

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16. Abstract
This project helped to identify priorities for improving the safety of rear seat occupants through a literature review and NASS-CDS injury analysis. The literature review covers injury patterns of rear seat occupants, new safety technologies intended for the rear seat, studies of rear seat belt and seat geometry, and methods for assessing belt fit; key points follow. Most rear-seat cushion lengths exceed the recommended length of 440 mm intended for accommodating adults. Since children make up 70% of rear seat occupants, built-in booster seats with shorter cushion lengths designed to accommodate children aged 5-8 would be beneficial. Front seats tend to have steeper outboard lap-belt angles, more forward shoulder belt anchors, and narrower spacing between lap belt anchorages than in the rear seat; target lap belt angles in the rear seat should range from 45 to 70 degrees. Booster seats are potentially more effective at mitigating poor lap belt geometry than poor shoulder belt geometry, so improving shoulder belt geometry in the rear seat should have higher priority. Load limiters, seatbelt pretensioners, and inflatable belt systems are potential countermeasures for reducing thoracic injury for rear seat occupants. If load limiters are installed in rear seats, the amount of available space for occupant displacement would be more important to consider in the rear seat than in the front seat.
The NASS-CDS database was first used to identify rear-row occupant seating patterns. In the second row, adults tend to sit on the right side, but this is not true for children. Vans are the only vehicle type with substantial numbers of 3rd row seating. The ages of rear seat occupant vary substantially with driver age. Drivers aged 16-25 most likely have other 16-25YO or 0-4YO occupants in the rear seat. For drivers aged 26-50, 85% of their rear seat occupants are under aged 16. Drivers over age 50 have the greatest proportion of passengers over age 50 in the rear seat.
From the injury analysis, seating in the rear seat is protective in terms of fatality and injury reduction, regardless of restraint use, except for rear impacts. The back of the front seat is a common injury contact point for rear-seat occupants. Studies of belt restraints have seldom found a difference in effectiveness between the front and rear seat. Most common injury contact points in side impact for belted children are on the lower rear quarter of the rear window. The presence of other occupants in the rear seat provides some benefit in injury reduction for children involved in side impacts, possibly by limiting lateral movement. Pediatric abdominal injury patterns indicate that the rear seats of minivans provide an environment with lower risk of abdomen injury compared to the back seats of passenger cars and SUVs. Pediatric injury rates are similar for children riding in SUVs and passenger cars, as potential benefits of a heavier vehicle are offset by a greater tendency to be in rollovers. Presence of a three-point belt rather than a lap-only belt reduces pediatric risk of AIS2+ injury by 81%. The presence of a shoulder belt in the center rear seating position usually only affects seating practices when there is a single child occupant in the rear seat.

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# EXECUTIVE SUMMARY

The purpose of this project was to identify priorities for improving the safety of rear seat occupants. The two tasks to achieve this goal were a review of the literature regarding rear seat occupants, and an analysis of the NASS database to compare injury risk for belted rear seat occupants to that of frontal occupants in frontal and near-side crashes.

The first part of the literature review covers publications discussing injury patters of rear and front seat occupants. Most studies find that rear seat occupants are at lower risk of injury or fatality than front seat occupants, and that restraint systems are equally effective in the front and rear seat. One study noted that the benefits provided by rear seating diminish with vehicle model year, with the hypothesis that improved safety in the front seat due to new front-seat safety features is the cause of this change, rather than a decrease in rear-seat safety. In studies that reviewed crashes with injured rear seat occupants, the back of the front seatback is the most common contact point associated with injury. Another study of children involved in side impacts indicated that the presence of another child in the rear seat can be protective, suggesting that limiting lateral motion in side impacts is a possible countermeasure for improving protection.

The second part of the literature review addresses new safety technologies intended for rear seat occupants. When evaluating advanced technologies such as pretensioners and load limiters for rear seat occupants, some researchers noted that the amount of available room for head excursion may be a more important factor in determining allowable spoolout than it is in the front seat. In addition, if rear seat belt geometry is improved to reduce submarining, it will likely lead to greater thoracic loading. One study suggested that the geometry of belts in the rear seat should be more like that of the front seat, particularly with respect to lap belt angle and fore-aft D-ring location.

The literature review includes more detailed discussion of several recent UMTRI studies that examine the geometry of the rear seat and belts. One study compares the belt geometry of the rear and front seat in 55 vehicles, finding that the lateral spacing between the lap belt anchors tends to be narrower in the front seat. In the rear seat, the D-ring is relatively further rearward compared to the front seat. The front outboard anchor is lower and more rearward than the rear lap belt anchorage or the front inboard anchorage. Another UMTRI study of rear seat cushion length in 55 vehicles finds that only 5% of rear seat cushions meet the recommended length of 440 mm, and that the median length of rear seat cushions is longer than 24% of adult buttock-popliteal lengths (BPL) and 83% of child BPL. Shorter cushion lengths would reduce slouching and therefore submarining in rear-seat passengers who are not in boosters.

Several other UMTRI programs have performed static testing with volunteers and dynamic testing with ATDs to examine belt fit on children. These efforts have resulted in a new seating procedure recommended for use with the Hybrid III 6YO and 10YO ATDs that positions the heads and hips of the ATDs in a realistic position compared to child volunteer postures. In addition, a procedure has been developed to assess belt fit relative to landmarks on the child ATDs' pelvis and thorax. Testing with the ATDs has shown that use of HIC to evaluate booster seats encourages more outboard belt placement that leads to the dummy rolling out of the shoulder belt. Because field data indicate that pediatric head injury rarely occurs without head contact, high HIC values without head contact seen in dummy testing may not be predictive of real-world head injury patterns. Instead, use of a static shoulder belt fit test coupled with a reasonable head excursion limit has been proposed for assessing booster seats. Additional testing with booster seats demonstrated that a booster seat with well-designed lap belt guides can reroute poor belt geometry and prevent submarining dynamically, but this is not the case for shoulder belt guides. As a result, it would be a higher priority to improve the fit of shoulder belt geometry for children in the rear seat instead of lap belt geometry.

The NASS analysis portion of the project used crash years 1998-2007, and only front and near-side impacts were analyzed. Occupants were classified into the following age groups: 0-4, 5-8, 9-12, 13-15, 16-25, 26-50, and >50. Occupants aged 5 and above were considered restrained if they were using a three-point belt, while those aged 0-8 were considered restrained if they were using a child restraint system. Vehicle model years were limited to 1986 and later.

The initial analysis reviewed where restrained occupants involved in towaway crashes sit. For adults, almost 20% of those aged 16-25 sit in the rear, while less than 5% of adults over aged 50 sit in the rear. In the second row, adults more frequently choose to sit on the right side rather than the left, although this preference is not true for children. Among children, the right-front position is seldom used until age 9. Although all children under 13 are most often seating in the 2$^{nd}$ row outboard, children aged 0-4 are the age group most often seated in the center of the second row, and children aged 5-12 are the group most likely to be in the 3$^{rd}$ row. Analysis of rear seating patterns by vehicle type indicated that vans are the only types of vehicle with substantial numbers of 3$^{rd}$ row occupants and are more likely to have rear seat passengers compared to other vehicle types. Seating distributions in passenger cars and SUVs were very similar.

Although rear seat occupant distribution does not vary with vehicle type, it does vary with the age of the driver. Drivers aged 16-25 are most likely to have rear seat occupants in the same age group (16-25) or children under age 4. For drivers aged 26-50, 85% of rear seat passengers are aged 15 and under, and over 40% of their rear seat occupants are booster-seat aged. Drivers over 50 are most likely to have adults in the rear seat, seldom transport children under age 5, and are the only driver age group with a substantial number of rear seat occupants over age 50.

Risk of AIS2+ injury for children in frontal impacts is generally lower in the back seat for all age groups and model years. However, for many age groups, risk is higher in model year (MY) 02-08 vehicles than the MY86-97 vehicles. For adults, the most notable thing is the large jump in injury risk for adults > 50 in the rear seat and right-front in MY98-01 vehicles. Other than this anomaly, rear seat occupant risk is lower than that of the driver and usually lower than in the right-front passenger position, and the rear seat risk is lower or similar for MY02-08 compared to MY86-97 years. We hypothesize that the high risk to rear seat occupants over 50 for MY98-01 is because these were the first vehicles with depowered airbags, which were tested in the unbelted condition using a generic sled pulse. Advanced restraint systems were effective at protecting drivers, but stiffer vehicles (possibly driven by the desire to perform well in IIHS testing) resulted in an injurious rear seat environment for older adults. The insight from this finding is that among vehicles likely to be driven by someone over age 50, those with the stiffest vehicle pulses should have countermeasures to prevent thorax and spine injury in the rear seat.

When body regions were analyzed separately, the highest risk of AIS2+ injury to a particular body region for a particular age group ranges from 0.5% to 2%, all relatively low. To help prioritize safety measures for rear seat occupants, MY02-08 values of risk and exposure (based on rear occupancy seating patterns by driver age, and driver involvement in frontal crashes) were combined to estimate the annual number of restrained, injured rear seat occupants. Based on these numbers, children aged 0-4 make up 35% of the restrained, injured, rear seat population. They travel with drivers under age 50 and sustain lower extremity and head/face injuries from contact with the back of the front seat back. Adults aged 16-25 make up 26% of the population; they tend to sustain upper extremity injuries and travel with drivers aged 16-25. Children aged 5-8 make up 11% of the rear-seat injured population. They are most likely sustain abdomen injuries from poor belt geometry/long cushion lengths and travel with drivers aged 26-50. Although older passengers make up only 7% of the rear seat injury problem, for vehicles with drivers over age 50, the numbers are larger, and it is a priority to prevent thoracic injury from belt loading in passengers over age 50, since thorax injuries to older adults are generally considered a more serious outcome than upper extremity injuries to younger adults.

Risk to children in near-side impacts is generally lower in the back seat for all age groups and model years, and risk for MY02-08 vehicles is lower than for MY86-97. For adults in near-side impacts, there are big improvements in the rear seat in recent model years compared to MY86-97, and the rear seat risk is similar to or lower than the driver and right-front passenger (RFP) in MY02-08.

A similar analysis to combine MY02-08 risk and exposure was performed to identify who is getting hurt in the rear seat in near-side impacts. When looking at the distribution of restrained, injured rear occupants in near-side impacts, 38% of the problem is head injuries from interior contact to children aged 0-4, who most often ride with drivers under age 50. Adults who sustain thorax, spine and head injury from loading by the interior side door make up 55% of the near-side impact injury problem in the rear seat. Older children are not an issue in the rear seat during near-side impacts.

In summary, both the literature review and NASS analysis demonstrated that the rear seat is safer than the front seat for most restrained occupants. However, improving rear seat belt geometry, shortening cushion lengths, and reducing injury potential from contact with the front seatback are proposed countermeasures for improving rear seat occupant protection. Specific injury/age groups that predominate in the rear seat for frontal crashes are head/face/lower extremity injuries to 0-4-year-olds, upper extremity injuries to 16-25-year-olds, abdomen injuries to 5-8-year-olds, and thorax injuries to >50-year-olds.

# LITERATURE REVIEW

## Introduction

The literature review portion of the project focused on two main areas. The first includes studies on injury or fatality patterns as a function of front vs. rear seating position, or as a function of different safety technologies. Review of these studies provided guidance for structuring the NASS analysis portion of the project. The second area includes reports of new safety technologies, as well as comparison testing of different safety features.

For each part of the literature review, summaries of each paper are grouped by topic. A summary of key points from the literature is included at the end of each section.

For reference, Table 1 lists a timeline of when different safety features were required and when different consumer testing programs began. Green text relates to belt restraints, blue to airbags, red to side-impact requirements, light blue to head interior protection, and orange to consumer testing information programs.

Table 1. Timeline of safety requirements

| | |
|---|---|
| <1985 | Lap belts required in rear seating positions and 3PB in front positions<br>Frontal NCAP tests being performed |
| 1986 | |
| 1987 | |
| 1988 | |
| 1989 | passive restraints required for drivers |
| 1989 | 3PB required in outboard rear seating positions |
| 1990 | |
| 1991 | |
| 1992 | passive restraints required for right-front passengers |
| 1993 | |
| 1994 | |
| 1995 | passive restraints required for LTV |
| 1995 | IIHS begins frontal offset testing |
| 1996 | Side impact testing required as part of FMVSS 214 |
| 1997 | Begin phase-in of updated 201 requirements<br>Side-impact NCAP testing begins |
| 1998 | Airbags must meet depowered test requirements |
| 1999 | |
| 2000 | |
| 2001 | |
| 2002 | IIHS begins side-impact testing |
| 2003 | Begin phase-in of smart airbags |

| | |
|---|---|
| 2004 | |
| 2005 | |
| 2006 | Complete phase-in of updated 201 requirements |
| 2007 | |
| 2008 | 3PB required in all rear seating positions |
| 2009 | |
| 2010 | Begin phase-in of updated 214 requirements |
| 2010 | Complete phase-in of smart airbags |
| 2011 | |
| 2012 | |
| 2013 | |
| 2015 | complete phase-in of updated 214 requirements |

## Analysis of Injury/Fatality Patterns

*Front vs. Rear Seat Injury/Fatality Patterns*

Viano and Parenteau (2008a) reviewed 1996-2005 FARS to estimate fatality risk by seating row and PDOF. Vehicle model years were limited to 1990+. NASS-CDS was used to estimate exposure. They did not consider occupant restraint. 9.6% of fatalities were to 2$^{nd}$ row occupants, who represent about 12.3% of occupants in towaway crashes. Less than 1% of fatalities are to 3$^{rd}$ row occupants, with 61% of those in rollovers. 3$^{rd}$ row occupants represent 0.7% of occupants in towaway crashes. Rear occupant fatality risk is highest in near-side impacts. They estimate fatality risk by occupant row and crash type according to Table 2. For all occupants, the greatest fatality risk is in rollovers. Fatality risk for 2$^{nd}$ row occupants is less than that for front-row occupants except in rear impacts. Fatality risk of 3$^{rd}$ row occupants is always less than that of 2$^{nd}$ row occupants, even in rear impacts. Data on 4$^{th}$ row occupants appear to be distorted by the small number of occupants in that seating row.

Table 2. Fatality risk by occupant row and crash type (Viano and Parenteau 2008)

| Row | Front 11-12-1 | Right 2-3-4 | Rear 5-6-7 | Left 8-9-10 | Rollover | Other/? | Total |
|---|---|---|---|---|---|---|---|
| Front | .63% | 1.19% | 0.31% | 1.32% | 3.05% | 0.21% | 0.93% |
| 2$^{nd}$ | .36% | 0.91% | 0.53% | 0.77% | 2.52% | 0.20% | 0.70% |
| 3$^{rd}$ | .20% | 0.35% | 0.22% | 0.37% | 2.01% | 0.23% | 0.52% |
| 4$^{th}$ | .34% | 14.63% | | 0.36% | 2.06% | | 1.70% |
| Total | .59% | 1.14% | 0.34% | 1.24% | 2.97% | 0.21% | 0.89% |

Viano and Parenteau (2008b) reviewed 1991-2005 NASS-CDS for crashes involving 0-7-year-old children seated in the second row. Vehicles were limited to model years 1990 and later, and restraint use was not considered. Side impacts and front impacts led to almost equal proportions of MAIS3+ injury (31% vs. 30% respectively), followed by rollovers at 24% and rear crashes at 15%. 75% of injured children were in passenger vehicles. In SUVs, rollovers caused 61% of the serious injury to children. They also reviewed specific cases of front and rear impact to identify injury mechanisms for pediatric second-row occupants. In injurious rear impacts, over 2/3 involved intrusion levels greater than 12", but only one child out of 16 was injured by rearward rotation of the front-row seatback. In frontal impacts, the most common sources of injury were the front seatback or B-pillar and the child restraint.

Winston et al. (2007) compared injury risk for restrained children in the rear seat to injury risk of restrained drivers over time, classifying vehicle model years into 4-year groupings beginning with 1990. They analyzed crashes occurring from 2003-3005 using the Partners for Child Passenger Safety dataset, which collects data on crashes involving children from 15 different states. They estimated risk of AIS2+ injury, comparing children in the rear seat to the driver in each vehicle to account for other crash factors. Children were grouped into three categories: aged 0-8 in CRS, aged 4-8 in 3-point belts, and aged 9-12 in 3-point belts. While the risk of AIS2+ injury is always lower for any child category compared to the driver category, the difference in risk generally becomes lower over time. The authors suggest that this results from the installation of more safety features for first row occupants than for second row occupants over the last 20 years.

Kuppa et al. (2005) analyzed NASS and FARS data to examine the effect of rear vs. front seating in frontal crashes. FARS data for years 1993-2003 were analyzed, limiting vehicle model year to 1991 and beyond. A double-paired comparison study was conducted to determine the relative risk of outboard rear seat occupants to right-front occupants, using the driver as the control. For restrained occupants, the rear seat is safer than the front seat for all occupant age groups up to age 50. Beyond that, the front seat is more protective in reducing fatalities for restrained occupants. For unrestrained occupants, the rear seat is safer. Airbags available in the front seat appear to be particularly effective for older occupants.

For the NASS-CDS analysis, frontal crashes from 1993 to 2003 were reviewed, excluding rollovers and model years prior to 1992. 90% of rear occupants are in the second row, with 78% in outboard seats and 18% in center seats. 64% are belt-restrained. 64% of rear seat occupants in frontal crashes are less than 12 years old. Risk of AIS 3+ injury is 5.2% for restrained front seat occupants and only 1.6% for restrained rear seat occupants. Injury risk is higher for restrained rear seat occupants over age 25 than under age 25. For older occupants, the thorax is the most frequently injured body region.

Smith and Cummings (2004) compared risk of death and serious injury for front vs. rear seat passengers using 1993-2000 NASS-CDS. Both fatalities and serious injury risks were lower for rear seat occupants, with risk ratios of 0.61 and 0.67, respectively. They did not find a substantial variation in restraint effectiveness in the front vs. rear seat. They did not limit vehicle model year, and excluded light trucks because they seldom had a complete rear seat. Drivers were also excluded because the authors were interested in the relative risk to passengers.

Parenteau and Viano (2003b) reviewed 1991-1999 NASS-CDS to compare injury patterns for children in first and second rows. In their sample, 54% of children aged 4-12 were sitting in the 2$^{nd}$ row and 41% were in the front row. In this analysis, use of booster seats by children in this age group was negligible. Injury rates for children in this age group were similar in the front and back seat. The head, upper extremities, and lower extremities were the most commonly injured body regions for 3-point-belted children, with contact with the seatback the most common injury source. For lap-belted children, abdomen and lower extremity injuries caused by belt contact are the most frequent injuries. This analysis also reviewed 0-3-year-old children, but the limited number of injured children in this age range prevented statistically significant analysis of front vs. rear seat effects. The authors suggest extending the range of vehicle components covered by FMVSS 201 to the seatback and interior surfaces below the beltline.

Parenteau and Viano (2003a) reviewed NASS-CDS (years 1991-1998), GES (1992-1998), and FARS (1988-1996) to analyze injury patterns of adults and teenagers (13 and older) who are seated in the rear seats of vehicles. Less than 25% of crashes involve a rear seat occupant of any age. In FARS, about 63% of rear occupants were unbelted, while only 40% were unbelted in NASS. Fatality risk is lower in the second row for all crash types but rear impacts. Lap/shoulder belted occupants have lower injury risk in the 2$^{nd}$ or 3$^{rd}$ row relative to the front row occupants. The most common body region injured in 2$^{nd}$ row occupants was the thorax, resulting from seatbelt loading.

Brown and Cline (2001) analyzed motor-vehicle crashes with a rear-seat occupant that occurred during 1988 and 1989 in a primarily rural county served by one hospital. The dataset included 346 crashes involving 1273 occupants. Overall seat belt use was 67%, with 46% in the rear seat and 85% in the front seat. Mean ISS for unbelted occupants was 1.87, compared to 0.51 for belted occupants. Only one fatality was restrained. Rear seat occupants had lower mean ISS than front seat occupants (0.85 vs. 1.04). Sitting in the rear sat had a protective effect.

Berg et al. (2000) analyzed crash records in Utah from 1992 to 1996 to identify effects of seating position and restraint use on children under age 15 involved in crashes. Restraint use was classified as optimal, suboptimal, or none, although they did not consider booster seat use as a requirement for optimal restraint for children over age 4. Rear seat occupancy was protective (odds ratio front-to-rear 1.7), as was restraint use (OR 2.7).

Braver et al. (1997) analyzed 1988-1995 FARS data to estimate risk of death for children under age 13 in the front and rear seats. For vehicles without front passenger airbags, fatality risk was 35% lower for children in the rear seat. The fatality risk was 50% lower in the rear seat in vehicles with front passenger airbags. They showed that sitting in the rear seat reduces fatality risks for both restrained and unrestrained children, and that the center rear seating position reduces fatality risk by 10-20% compared to outboard positions.

Huelke and Compton (1994) reviewed NASS case years 1980-1991 for frontal crashes with at least one rear seat passenger. Airbag-equipped cars were excluded. Pairwise comparisons were made between unbelted front and rear seat occupants or 3-point-belted front and lap-belted rear seat occupants. The authors conclude that the rear seat is safer than the front seat.

*Side-impacts with rear seat occupants*

Maltese et al. (2007) reviewed injury causation scenarios for side-impact crashes involving children aged 4 to 15 years seated on the struck side of the vehicle in the rear seat. Twenty-four cases from the PCPS and CIREN datasets were analyzed. The most frequent head injury contact point was the lower rear quarter of the rear window. The most common cause of abdomen and thorax injury was the side door interior, particularly protruding components such as the armrest.

Maltese et al. (2005) analyzed the PCPS dataset to look at the outcomes of restrained children aged 4 to 15 by their rear seating position: struck-side, center, and non-struck-side. Risk of AIS 2+ injury is highest to those on the struck-side (2.6%) and lowest on the non-struck side 1.4%. Risk to the center rear position was 3.0%, but because of the small sample of children in the center position, this was not shown to be statistically different from either the near- or far-side risk. The authors noted that center occupants having the highest risk in side impact seemed counterintuitive, but they said the lack of torso restraint in most center-rear positions may be a contributing factor. In addition, most prior studies of side-impact injury patterns grouped center-occupants with the far-side occupants. As a continuation to this study, Maltese et al. (2005) analyzed the risk of belted, rear-seat occupants in side impacts involving passenger cars by the presence of other occupants in the row. Occupants were classified as alone, another-between (at least one other occupant between the case the occupant and the struck side), and case-between (the case occupant was between at least one other occupant and the struck side). Being seated alone in the rear seat resulted in higher risk (3.5%) than the “another-between” (1.2%) or “case-between” occupants (1.8%). The authors suggest that the presence of other occupants help to reduce lateral motion.

*Injury variation with vehicle type*

Daly et al. (2006) used the PCPS dataset (2000-2003) to analyze injury rates in children riding in SUVs compared to those riding in passenger cars. Injury rates are similar for children riding in both vehicle types. The potential benefits of a heavier vehicle are offset by their greater tendency to be in rollover crashes. Unrestrained children in rollover crashes had particularly high injury rates.

*Restraint Effects*

Nichols et al. (2005) analyzed trends in fatalities among children aged 0-3, compared to children aged 4-12, for time periods of 1992-1996 and 1996-2003. The time periods were selected based on the implementation of a 1996 campaign to encourage rear seating for child occupants. They analyzed the FARS dataset. Compared to baseline data in 1992, they found an increase in the number of rear seat and restrained deaths, likely because of an increased population of child occupants who were seated in the rear seat and restrained. After 2001, the total number of child fatalities is reduced compared to 1992 rates.

Arbogast et al. (2004) used data from the PCPS study (1998-2002) to estimate benefits of providing 3-point-belts in all rear seating positions. They note that having a shoulder belt in the center rear seating position generally affects seating practices only when there is a single child occupant (usually under age 9) in the vehicle. They estimate that use of a 3-point-belt rather than only a lap belt reduces risk of AIS2+ injury by 81%.

Ray (2000) conducted analysis of FARS data to estimate effectiveness of lap/shoulder belts in rear seats vs. lap belt only in rear seats. They used FARS data from 1986- 1997. They limited data to matched pairs of vehicle makes and models before and after 3-point-belts were installed in the rear seat without other significant platform changes. They only included airbag-equipped vehicles if the airbag was available in both the rear lap-belt-only and rear lap/shoulder belt vehicles. They concluded that lap/shoulder belts and lap belts were equally effective at preventing fatalities for outboard rear-seat occupants. These results do not agree with Morgan (1999) who estimated greater fatality risk reduction for lap/shoulder belts in outboard rear seating positions than that achieved by lap belts alone.

Mayrose et al. (1999) analyzed 1995-2001 FARS data to identify the risk to drivers of unbelted rear passengers. Crashes were limited to those involving one or two vehicles and did not include any crashes with missing information about restraint use, seat position, death, or point of impact. Only passenger vehicles with belted drivers were included. In frontal crashes with PDOF of 12 o'clock, odds of death for a belted driver are 2.27 higher for those seated in front of unbelted rear passengers than those seated in front of belted rear passengers. Unbelted rear-seat passengers have 2.71 greater odds of death than belted rear-seat passengers. The belt restraint status of a rear seat occupant does not affect the status of drivers in 9 o'clock PDOF impacts. The analysis is limited by its focus only on head-on and 90 degree lateral near-side impacts, as well as by only studying drivers and rear passengers in the left-rear seating position.

Morgan (1999) analyzed 1988-1997 FARS data to estimate effectiveness of lap belts vs. lap/shoulder belts for occupants seated in rear seats. She used a double paired comparison technique that compared back seat fatalities to front seat fatalities. She found that rear lap belts are 32% effective at fatality reduction, while rear lap/shoulder belts are 44% effective. Rates for passenger vans and SUVs are 63% and 73%. Presence of lap/shoulder belts in the rear seats increases belt use rates by rear occupants from 7-10%.

Padmanaban et al. (1998) analyzed 1987-1996 FARS data to compare fatality rates of occupants using 2-point and 3-point belts. They found similar fatality rates for both types of belts. However, they did not account for the possibility that rates were the same because fewer users of 3-point belts may be in FARS because they are more effective.

*Specific Injury Types*

Arbogast et al. (2004) studied abdominal injury patterns of children using the PCPS dataset. Children aged 4-8 years were most likely to sustain abdominal injury, compared to children aged 0-3 or 9-15 years. In addition, risk for this age group was lowest in minivans compared to passenger cars or SUVs. The authors suggest that the presence of captain's chairs, more upright seatbacks, less horizontal seat cushions, shorter cushion lengths, and lap belts anchored to the seat structure may contribute to the lower risk of abdominal injury in minivans. Their results suggested a trade-off between head and abdominal injury among child occupants.

Arbogast et al. (2002) performed in-depth crash investigations involving 15 children who sustained facial fractures. The back of the front seat was the most common injury contact point for children in the rear seat, while the instrument panel was most common for children in the front seat. Seven of the children with facial fractures were not using the available shoulder belt.

*Summary of Key Points*

- Seating in the rear seat is protective in terms of fatality and injury reduction, regardless of restraint use, except for rear impacts.
- The back of the front seat is a common injury contact point for rear-seat occupants.
- Studies of belt restraints have seldom found a difference in effectiveness between the front and rear seat.
- Vehicles likely to have rear seat occupants over age 50 would benefit from measures to reduce thoracic injury.
- Most common injury contact points in side impact for belted children are on the lower rear quarter of the rear window.
- The presence of other occupants in the rear seat provides some benefit in injury reduction for children involved in side impacts, possibly by limiting lateral movement.
- Pediatric abdominal injury patterns indicate that the rear seats of minivans provide an environment with lower risk of abdomen injury compared to the back seats of passenger cars and SUVs.
- Pediatric injury rates are similar for children riding in SUVs and passenger cars, as potential benefits of a heavier vehicle are offset by a greater tendency to be in rollovers.
- Presence of a three-point belt rather than a lap-only belt reduces pediatric risk of AIS2+ injury by 81%.
- The presence of a shoulder belt in the center rear seating position usually only affects seating practices when there is a single child occupant in the rear seat.

## Rear Seat Technologies

*Rear Seat Geometry*

Huang and Reed (2006) compared the buttock-popliteal length (BPL) of children to seat cushion length of late-model vehicle rear seats. The recommended cushion length for vehicle seats for an adult population is 440 mm or less, based on the 5$^{th}$ percentile female buttock-popliteal length. Seat cushion length (SCL) was measured in the second and third rows of 56 late-model vehicles. The population of occupants sitting in rear seats was determined using NASS-GES from 1999-2002. The distribution of BPL for the distribution of rear seat occupants was calculated. As shown in Figure 1, distribution of rear SCL was compared to distributions of BPL for children, adults, all rear seat occupants, and children above and below 145 cm. About 5% of rear seats meet the recommended SCL of 440 mm or less. The median SCL of 455 mm was longer than the BPL of 24% of adult rear-seat occupants and 83% of child rear seat occupants. The authors recommend shortening rear SCL to accommodate a wider range of rear seat occupants, and consider using adjustable seat cushion lengths to accommodate more children who sit in the rear seat.

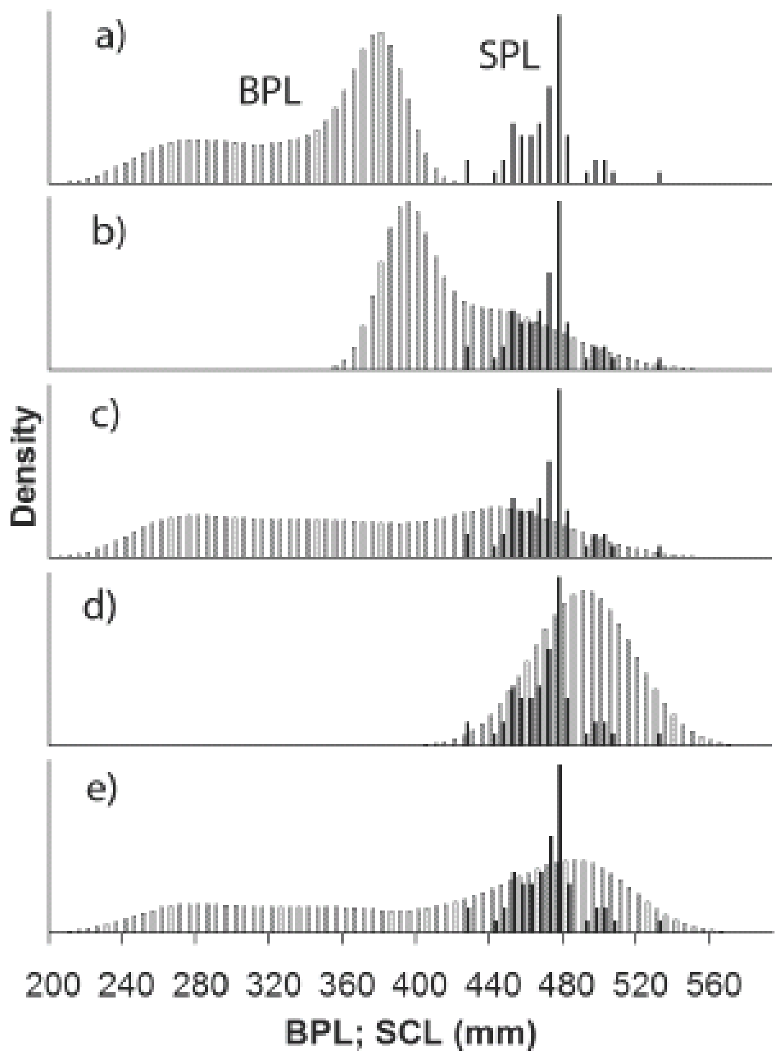



Figure 1. Distribution of rear seat cushion length (dark) and buttock-popliteal length (light). a) children under 145 cm, b) children over 145 cm, c) all children, d) all adults, e) all.

Bilston and Sagar (2007) measured the geometry of vehicle rear seats and child restraints and compared them to anthropometric measures of children who would use them. Fifty vehicle rear seats were measured. They found that all rear seat cushion lengths were too long to accommodate children smaller than an average 11.5-year-old child, and half of vehicle seat cushions were too long to accommodate an average 15-year-old. Approximately one-third of vehicles had shoulder belt geometry that could accommodate the average 6 to 8-year-old child.

*Belt Geometry*

Ebert-Hamilton et al. (submitted) measured the belt anchorage geometry in the front and rear seats of 55 different vehicles using a FARO arm 3D coordinate measurement system. Distribution of anchorage locations are shown in Figure 2, and mean values of anchorage locations are provided Table 3. The mean location of the inboard lower anchorage is significantly further inboard from the H-point in the front seat than in the rear seat. The outboard anchorage in the front seat is significantly lower and more rearward than any other lower anchorage position relative to H-point. On average, the D-ring anchorage is located further rearward in the rear seat when compared to the front seat.

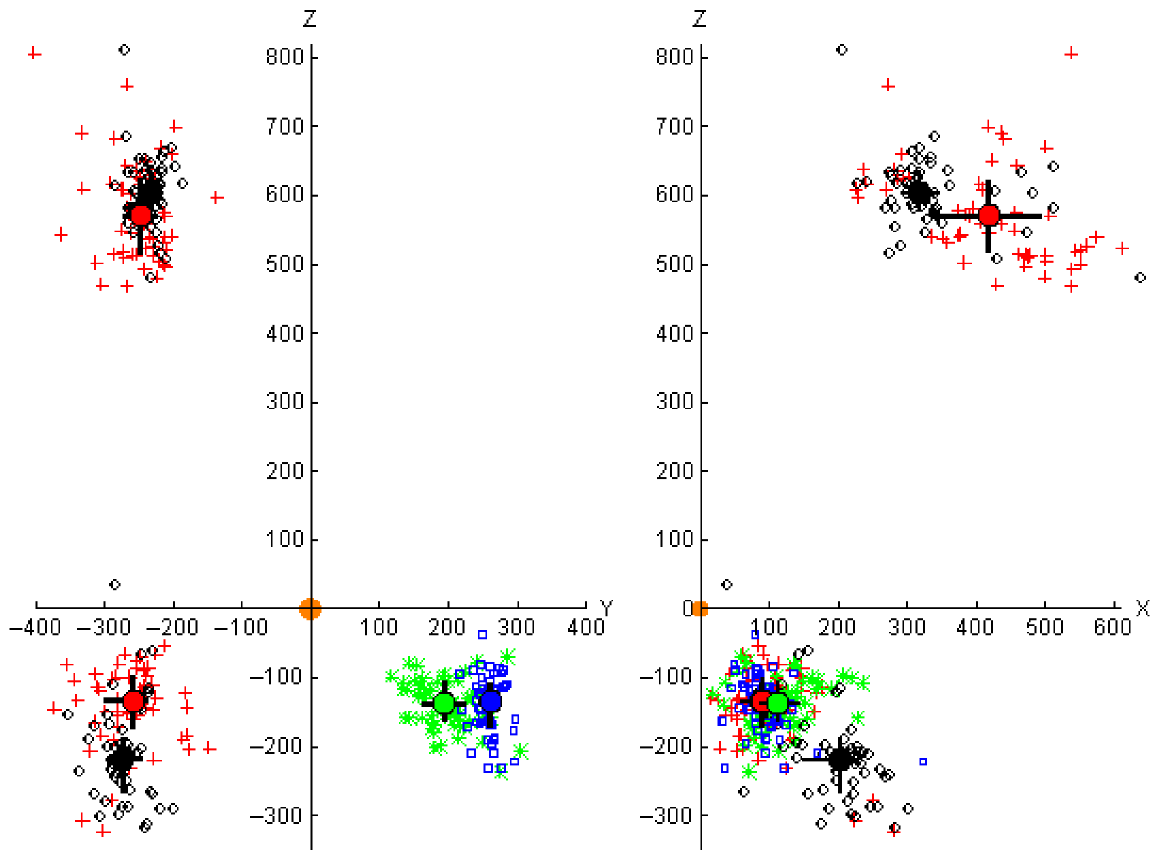



Figure 2. Distribution of safety belt anchorage locations relative to H-point (0,0) in the front seat set to predicted 50th percentile male position at mid height adjustment. Closed shapes=front seat with black=outboard and blue =inboard, crosses=rear seat with red=outboard and green = inboard. YZ (viewed from behind seat) on the left and XZ

(viewed from let side of vehicle) on the right. Colored lines represent +/- standard deviations with the intersection at the mean location.

Table 3. Locations of anchorages (front seat set to 50th percentile male position); median values and inner quartile ranges of the distances (mm) between anchorages and H-point along each axis and inner quartile range

| | | **X** axis | | **Y** axis | | **Z** axis | |
|---|---|---|---|---|---|---|---|
| Anchorages | Position | Med | IQR | Med | IQR | Med | IQR |
| Upper | Front | 317 | 298 - 342 | 233 | 220 - 249 | 605 | 581 - -633 |
| | Rear | 417 | 338 - 493 | 248 | 225 - 271 | 570 | 519 - 612 |
| Outboard | Front | 202 | 150 - 227 | 273 | 249 - 287 | -218 | -264 - -190 |
| | Rear | 91 | 62 - 125 | 259 | 239 - 297 | -134 | -170 - -101 |
| Inboard | Front | 88 | 73 - 106 | 260 | 246 - 269 | -135 | -170 - -111 |
| | Rear | 113 | 88 - 141 | 194 | 164 - 223 | -137 | -160 - -107 |

X and Y axis measures given as absolute values

Reed et al. (2005, 2006) performed a laboratory study of seatbelt fit, seated posture, and body dimensions on 62 children with masses ranging from 18 to 45 kg. Measurements were taken with the children seated in three vehicle seats with and without each of three belt-positioning boosters. In addition to standard anthropometric measurements, three-dimensional body landmark locations were recorded with a coordinate digitizer in sitter-selected and standardized postures. The database quantifies the vehicle-seated postures of children and demonstrates how belt-positioning boosters can improve belt fit. In addition, analysis of the data allowed quantification of hip and head locations and pelvis and head angles for both sitter-selected and standardized postures. Results indicate that in the sitter-selected posture, children sit with their hips further forward and with more reclined pelvis orientations than in the standardized posture. The hip locations of the 6YO and 10YO ATDs, when seated using the standardized posture, are positioned further rearward than the sitter-selected postures of children by 20 mm in boosters and 40 mm on the vehicle seat. The head positions of the dummies are 20 mm higher on boosters and 40 mm higher on vehicle seats than the head positions of children of comparable size. The 10YO head position is also forward of the head locations of children. Raising the child up on a booster seat both improves their posture, as well as increasing the angle of the lap belt to a more favorable orientation. Pelvis angles with both dummies are within the range seen with children. The papers report on development of a seating procedure that positions the crash dummy heads and hips in more realistic positions.

Reed et al. (2008) performed a laboratory study to quantify the effects of belt-positioning boosters on lap and shoulder belt fit. Postures and belt fit were measured for forty-four boys and girls ages 5 to 11 in four highback boosters, one backless booster, and on a vehicle seat without a booster. Belt anchorage locations were varied over a wide range, while seat cushion angle, seat back angle, and seat cushion length were varied in the no-booster conditions. All boosters produced better mean lap belt fit than was observed in the no-booster condition, but the differences among boosters were relatively large. With one midrange belt configuration, the lap belt was not fully below the anterior-superior iliac spine (ASIS) landmark on the front of the pelvis for 89% of children in one booster, and 75% of children failed to achieve that level of belt fit in another. In contrast, the lap belt was fully below the ASIS for all but two children in the best-performing booster.

Child body size had a statistically significant but relatively small effect on lap belt fit. The largest children sitting without a booster had approximately the same lap belt fit as the smallest children experienced in the worst-performing booster. Increasing lap belt angle relative to horizontal produced significantly better lap belt fit in the no-booster condition, but the boosters isolated the children from the effects of lap belt angles. Reducing seat cushion length in the no-booster condition improved lap belt fit but changing cushion angle did not.

In this study, belt upper anchorage (D-ring) location had a strong effect on shoulder belt fit in conditions without shoulder belt routing from the booster. Unexpectedly, the worst average shoulder belt fit was observed in one highback booster with a poorly positioned shoulder belt routing clip. The shoulder belt was routed more outboard, on average, with a backless booster than without a booster, but raising the child also amplified the effect of D-ring location, such that children were more likely to experience poor shoulder belt fit due to outboard and forward D-ring locations when sitting on the booster. Taller children experienced more-outboard shoulder belt fit in conditions without shoulder belt routing by the booster and in the one booster with poor shoulder belt routing. Adjustable shoulder belt routing on three of the highback boosters effectively eliminated stature effects, providing approximately the same shoulder belt fit for all children. Seat back angle did not have a significant effect on shoulder belt fit. The belt fit was measured in each test condition using the 6YO and 10YO Hybrid-III ATDs relative to landmarks on the ATD pelvis and thorax (Figure 3). ATD belt fit was strongly correlated with child belt fit across test conditions, but offsets between the ATD and child belt fit scores were observed due to anatomical and postural differences between the ATDs and children.

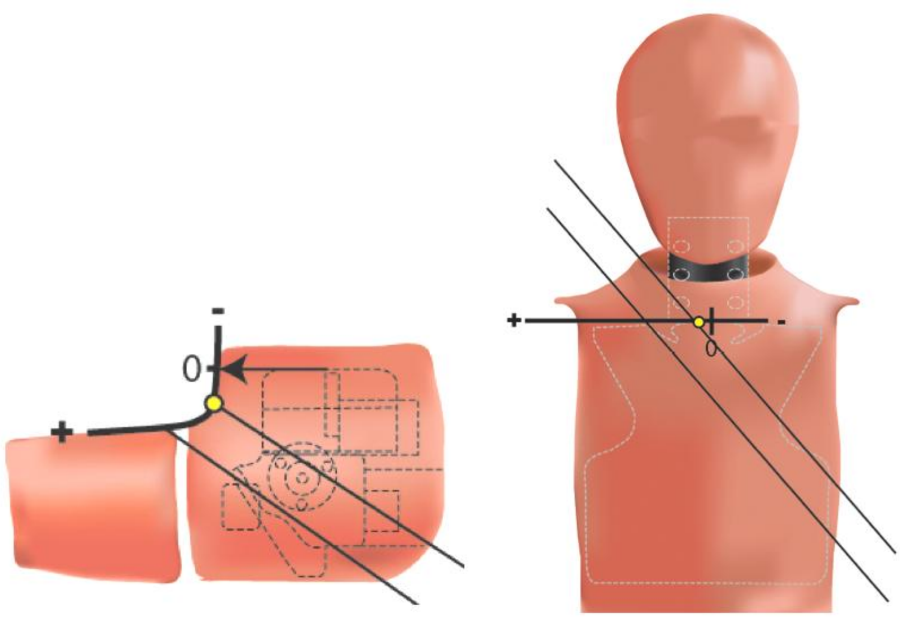



Figure 3. Methods for assessing child belt fit relative to landmarks on the ATD pelvis and thorax.

Klinich et al. (2008) report on 49 dynamic sled tests that were performed with the Hybrid III 10YO to examine issues relating to child belt fit. The goals of these tests were to evaluate ATD response to realistic belt geometries and belt fit, develop methods for accurate, repeatable evaluation of restraint conditions for older children, identify dependent measures that differentiate between good and poor restraint performance, and relate ATD performance to static belt fit with children. The first series of tests examined the effects of lap belt tension, belt configuration, and seating procedure on dynamic responses. The second series of tests examined how different designs of booster seat lap belt guides and shoulder belt guides affect performance. In addition, the dummy's response to different shoulder belt and lap belt geometries was evaluated.

With regard to test procedures, use of a lap/shoulder belt with a sliding latchplate produces similar results to using a lap/shoulder belt with fixed anchorages. Use of a production retractor reduces shoulder belt load, as well as head, neck, and chest measures. Reducing lap belt tension to a more realistic 2 lb (rather than 15 lb) did not have a pronounced effect on kinematics with two different booster seats. The UMTRI seating procedure, which produces ATD postures closer to those measured in real children, also prevents the lap belt from being trapped in the gap between the pelvis and the thigh. Use of the UMTRI seating procedure produces more reclined initial postures and more pronounced chin-to-chest contact.

A well-designed booster lap belt guide can maintain good belt position dynamically, even with poor lap belt geometry. Shoulder belt guide designs affect ATD kinematics. However, preventing the shoulder belt from coming out of the shoulder belt guide does not necessarily produce better restraint performance, because the belt can still leave the ATD shoulder during the event, and stiffening booster seats does not necessarily produce better routing of the shoulder belt dynamically. Shoulder belt scores of less than 70 mm produce good torso kinematics with the 10YO ATD, but as shown in Figure 4, use of HIC as an injury criterion tends to discourage booster seat designs that produce good belt fit on the 10YO ATD. Lap belt angle affects torso kinematics, with shallower lap belt angles leading to submarining and more vertical lap belt angles leading to rollout. Wider spacing of lap belt angles leads to submarining, while narrowing spacing leads to rollout. Both upper and lower belt anchorage locations have a strong effect on ATD kinematics. Although good booster designs can apparently mitigate the consequences of poor lap belt geometry, boosters do not appear to always be able to overcome poor shoulder belt geometry to keep the belt on the ATD shoulder, even when they are able to create good static belt fit. This finding suggests that more attention should be focused on the effects of the wide variability in vehicle D-ring locations on belt restraint performance for children. Also, because HIC scores are decreased when the torso belt fit is degraded, use of HIC as an injury criterion for booster testing may lead to worse rather than better booster designs. Because field data indicate that it is rare for children to have head injury without contact, shoulder belt fit is considered more important than HIC measured under FMVSS 213 conditions where head contact does not occur.

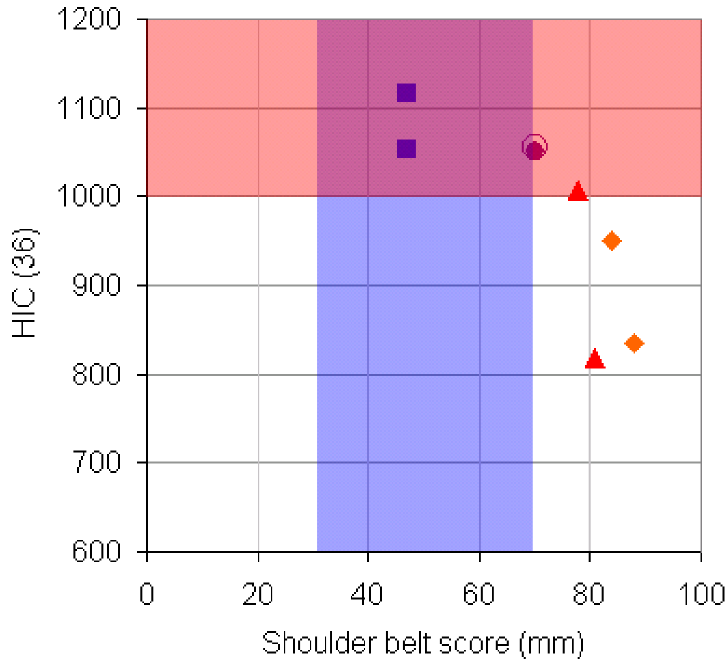



Figure 4. HIC (36) vs. shoulder belt score, with blue zone indicating good shoulder belt fit and red zone indicating HIC values that exceed recommended criteria.

Tylko and Dalmotas (2005) performed a series of full frontal rigid barrier tests and offset frontal deformable barrier tests with the 6YO, 10YO, and small female Hybrid III ATDs seated in the rear seats restrained by three-point belts, with or without belt-positioning booster seats. Acceptable ATD torso kinematics were associated with high shoulder belt loads and substantial chest displacements. Many belt geometries allowed the belt to slip off the shoulder, which resulted in extreme torso flexion, head contact, and high neck loads. Booster seats seemed effective at keeping lap belts in favorable locations for restraining the ATDs, but did not have a substantial effect on shoulder belt routing. For the small female, chest measures were generally higher in the rear seat compared to the front seat, and the ATD showed a greater tendency to submarine in the rear seat. For the 6YO, the shoulder belt either slipped off the shoulder or moved inboard to load the neck. Use of a 5-point-harness restraint with the 6YO generally improved head and chest measures but not neck forces. Use of a booster seat that was tethered and LATCHed to the vehicle improved response in some but not all tests.

Bidez et al. (2005) performed oblique sled tests with delta V of 35 kph using Hybrid III 6YO and small female ATDs in simulated SUV rear seats. The belt geometry matched that of the vehicle. Test angle was varied from 0 to 60 degrees in 15 degree increments. Both dummies submarined with the standard belt geometry at all test angles. They found that the rollout threshold for both ATDs began at impact angles of 15 and 30 degrees, with the shoulder belts offering no torso restraint at oblique impact angles of 45 degrees. In contrast, the Hybrid III average male ATD has been reported to be retained by the shoulder belt at oblique impact angles of 45 degrees. Head excursions increased with sled buck test angle as the shoulder belt offered less restraint at each angle. Use of a pretensioner improved shoulder belt restraint with the 6YO and lowered neck tension levels. However, preventing submarining of the small female ATD required modification of the rear-seat belt geometry. An adjustable shoulder belt anchorage was insufficient for providing shoulder good belt geometry. The authors did not report the exact configurations of the belt geometry used during testing, and most conditions were only tested once. The authors noted issues with the biofidelity of the 6YO ATD, with the shoulder belt being wedged in the shoulder structure in multiple tests and the abdominal insert being overly stiff.

Kuppa et al. (2005) report results of 10 frontal barrier crash tests with ATDs in both the front and rear seats. Average normalized HIC values and neck tension values are higher for dummies in the rear seat than in the front seat. Kinematics of the ATDs in rear seats with integrated belts showed excessive seatback rotation that allowed the ATD head to contact the front seatback, console, or its knees.

Malott et al. (2004) conducted a series of frontal, oblique, and side impact sled tests with the Hybrid III 6YO. They used the ECE R16 buck with generic seatback and cushion pads to simulate a captain's chair type of seat. The three-point belt was configured to represent an average minivan geometry or a belt-integrated seat geometry. They used a 30 mph pulse in the frontal tests and a 25 mph pulse in the oblique and side impact tests. In addition to baseline tests with the two different 3-point belt configurations, they used highback and backless boosters, as well as seat-mounted shoulder belt guides and lap/shoulder belt guides constructed of steel loops. They did not identify any restraint configuration as clearly the best, and many of their results contradicted field-based evidence showing that boosters reduce the incidence of head injury. Evaluations of side impact results may be limited by the use of an extremely severe side impact pulse.

Zelmer, Lurs, and Bruggemann (1998) performed sled testing and MADYMO modeling to optimize parameters for 3-point belts in the rear seat. They suggest using a load limiter to reduce chest injuries resulting from excessive displacement and a pretensioner to reduce viscous thoracic injuries. They note that rear-seat occupants frequently sustain injuries to the thorax and abdomen. The geometry of seat belt restraints in the rear seat typically provides shallower lap belt angles than seen in the front seat, as well as shoulder belt anchorages that are positioned further rearward relative to the occupant. Both of these differences can promote greater likelihood of submarining. They performed sled tests using a Hybrid III 50$^{th}$ percentile male ATD with a relatively stiff pulse, and using typical rear seat belt geometry, tested a conventional belt system, a belt system with a retractor pretensioner, and a belt system with both retractor pretensioner and 5.5 kN load limiter. MADYMO models of the tests were reconstructed and used to optimize restraint parameters. To reduce submarining, they suggest that the shoulder anchor point should be as close to the occupant shoulder as possible, that lap belt anchors points should be as far below the occupant as possible, seat cushion angle should be steeper, and load limiting in the retractor should be implemented. They mention that greatest reduction in chest load is produced by belt geometries that have the greatest likelihood of submarining. They also state that in the rear seat, amount of space available for occupant displacement before contact may be a more important factor in setting load limiter levels than it is in the front seat.

Haberl (1987) et al. describe the design of a "reverse" three-point belt system for use in the rear seat. The system was designed so the buckles are outboard, such that the shoulder belts cross the occupant from the inboard shoulder to the outboard hip. This design offers improved ease-of-use because the buckle is installed in the seat such that only one hand is required for buckling, and it is no longer possible to confuse which buckle goes with which seatbelt. In addition, the outboard buckle location allows a more upright lap belt angle that does not interfere with passenger comfort.

*Advanced Belt Systems*

Bidez et al. (2005) performed sled tests to simulate oblique 45 degree impacts with delta V of 35 km/hr using the Hybrid III 6YO, small female, and large male ATDs in a simulated rear seat of an SUV. The production restraint system was tested, as well as a retrofit pretensioner system. Use of a pretensioner seemed to improve kinematics for the 6YO and small female ATDs. Both of the smaller dummies rolled out of the shoulder belt in these oblique tests, which was not true for the large male ATD.

Kawaguchi et al. (2003) performed MADYMO modeling to optimize a restraint system for a range of occupant sizes in the rear seat with the intent of reducing neck injuries. In Japan, crash statistics indicate that children and adult females should have highest priority with respect to rear seat occupants. The goal is to reduce the relative velocity between the head and chest. When considering occupants from the 6YO through the large male, they found that a load limiter threshold of 3.5 kN, together with an initial spoolout of 50 mm and a secondary spoolout of 0-200 mm provided the best restraint conditions for protecting a range of rear seat occupant sizes.

*Inflatable Restraint Systems*

Heudorfer et al. (2005) present development of a roofbag to reduce head and neck loading during rollovers. The roofbag would deploy from the top of a seatback. It protects by placing a cushion between the occupant's head and the roof, as well as by placing the occupant's neck into flexion, where it has a higher tolerance to loading than in an extension posture. Use of a roofbag has an advantage over padding in that it avoids "pocketing" of the head which can increase injury risk. Testing showed substantial reductions in neck load and acceptable levels of risk to out-of-position occupants.

Karigiri et al. (1999) present sled test results for an inflatable shoulder belt. When deployed, the device is a 6" diameter tube along the length of the shoulder belt. In sled tests performed with small female, mid-sized male, and large male Hybrid III ATDs, none of the ATD measures exceeded recommended values. In addition, when compared to ATD measures from an NCAP test using a conventional belt system, use of the inflatable belt reduced almost all injury measures, and the few that increased were within allowable limits.

Narita (1993) reports on Nissan's development of a frontal-impact airbag for rear seat passengers. The airbag is contained within the upper part of the front passenger's seat. The front seat's reclining feature and available fore-aft adjustment range have been reduced. The airbag designs are such that only two airbags can be installed in the vehicle at once, and the intent would be for use in vehicles used as limousines.

*Vehicle Crash Pulse*

Hong et al. (2008) analyzed results of 28 NCAP tests in which the Hybrid III 10YO ATD was seated in the rear seat. They developed a 5-star rating system for the Hybrid III 10YO ATD using HIC15 and 3-ms chest clip measures. For the nine vehicles tested, most of which received 4- or 5-star ratings for the driver and front passenger, only two received a four-star rating for the 10YO seated in the rear seat; the rest ranged from 1- to 3-stars. In these nine tests, the dummy was seated in a booster in all but one test, which received a 1-star rating. Vehicles with poorer performance in the rear seat had a relatively high peak vehicle pulse between 30-100 ms compared to better performing vehicles. The two vehicles with better performance generally produced lower peak shoulder belt loads. In reviewing 10YO rear seat performance in four SUVS, the vehicle with a pretensioner produced the best results. 10YO results in minivans were generally better than in passenger cars and the SUVs without pretensioners. For three pickup trucks, ratings ranged from 1 to 3 stars. The authors note that for rear seat occupants, usually without advanced belt systems and airbags, the peak value of vehicle crash pulse is correlated with peak head acceleration. High values of vehicle crash pulse between 30 and 100 ms produce high HIC values. The peak value of relative velocity between the chest and vehicle, as well as the slope of this relative velocity, are good indicators of chest acceleration. Most vehicles with good rear seat performance had lower shoulder belt loads.

*Built-in Booster Seats*

Lundell et al. (1993) describes development of a built-in booster seat for the Volvo 800 and 900 series. The integrated "child cushion" folds out like a foldable armrest, and has a seat cushion and a backrest. When the backrest is folded down, it acts as a normal armrest. The booster can be used by children aged 3 to 10 years of age. Crash testing with the P-series of child ATDs showed that performance was as good as or better than with normal booster seats, although they identified some repeatability issues with these dummies.

*Summary of Key Points*

- Most rear-seat cushion lengths exceed the recommended length of 440 mm intended for accommodating adults.
- Since children make up 70% of rear seat occupants, built-in booster seats with shorter cushion lengths designed to accommodate children aged 5-8 would be beneficial.

- Front seats tend to have steeper outboard lap-belt angles, more forward shoulder belt anchors, and narrower spacing between lap belt anchorages than in the rear seat.
- Target lap belt angles in the rear seat should range from 45 to 70 degrees.
- A seating procedure has been developed for use with Hybrid III 6YO and 10YO ATD's that positions their heads and hips in more realistic positions when compared to child volunteer data.
- Booster seats are potentially more effective at mitigating poor lap belt geometry than poor shoulder belt geometry, so improving shoulder belt geometry in the rear seat should have higher priority.
- When the 10YO ATD is used to evaluate belt restraint system, use of HIC promotes more outboard belt geometries that produce less desirable kinematics.
- Modifying lap belt geometry to reduce submarining may lead to increased thoracic loading.
- Load limiters, seatbelt pretensioners, and inflatable belt systems are potential countermeasures for reducing thoracic injury for rear seat occupants.
- If load limiters are installed in rear seats, the amount of available space for occupant displacement would be more important to consider in the rear seat than in the front seat.
- Vehicles with poor performance with a 10YO ATD seated in the rear seats of NCAP tests generally had a relatively high peak vehicle pulse between 30 and 100 ms.

# NASS ANALYSIS

## Approach to NASS Analysis

The analysis used the NASS dataset, selecting case years 1998-2007. Selected crash types include frontal and side impacts. Vehicle model years were limited to 1986 and later, and classified into 1986-1997, 1998-2001, and 2002-2008 groupings.

Adult occupants were grouped by age as 16-25, 26-50, and 51+. Child occupants were classified as age 0-4, 5-8, 9-12, and 13-15. Restraint categories were 3-point-belt (3PB) and child restraint system (CRS). For children in the youngest age group, a restrained occupant was considered one in a CRS without gross misuse. For the 5-8YO age group, use of either a three-point belt or CRS was considered acceptably restrained.

The analysis included the following areas:

- Definition of the restrained population
- Distribution of occupant seating position by age group and vehicle model year group.
- Variation in occupant seating patterns with vehicle type and driver age.
- Distribution of body region injured by crash type, occupant age, seating row, and vehicle model year grouping.
- Risk of AIS2+ and AIS3+ injury by crash type, occupant age, seating position, and vehicle model year grouping
- Risk of AIS2+ injury to different body regions by occupant age and vehicle model year grouping for frontal impacts
- Risk ratios of different occupant ages and seating positions compared to the driver by vehicle model year for AIS2+ and AIS3+ risks
- Risk ratios for different occupant ages between MY02-08 and MY86-97 vehicles.
- Analysis of rear seat injury scope by occupant age group using both risk and exposure

## Occupant Population

*Restrained occupants*

The proportion of properly restrained occupants in the dataset is shown in Figure 5 by age group and occupant position. For drivers, belt use increases with the age of the driver. Belt use by right-front occupants is the most consistent among the age groups. One exception is 0-4YO, of which only 34% are properly restrained in a child restraint system (CRS) in the right-front seating position. Since it is strongly recommended that children in this age group do not use this seating position, it is consistent that caregivers who ignore this recommendation also do not secure their children in a CRS. In the rear seat, children aged 0-12 and adults over 50 have a belt use rate near 80%. However, occupants aged 13-50 have a substantially lower belt use rate in the rear seat compared their belt use in the front seat.

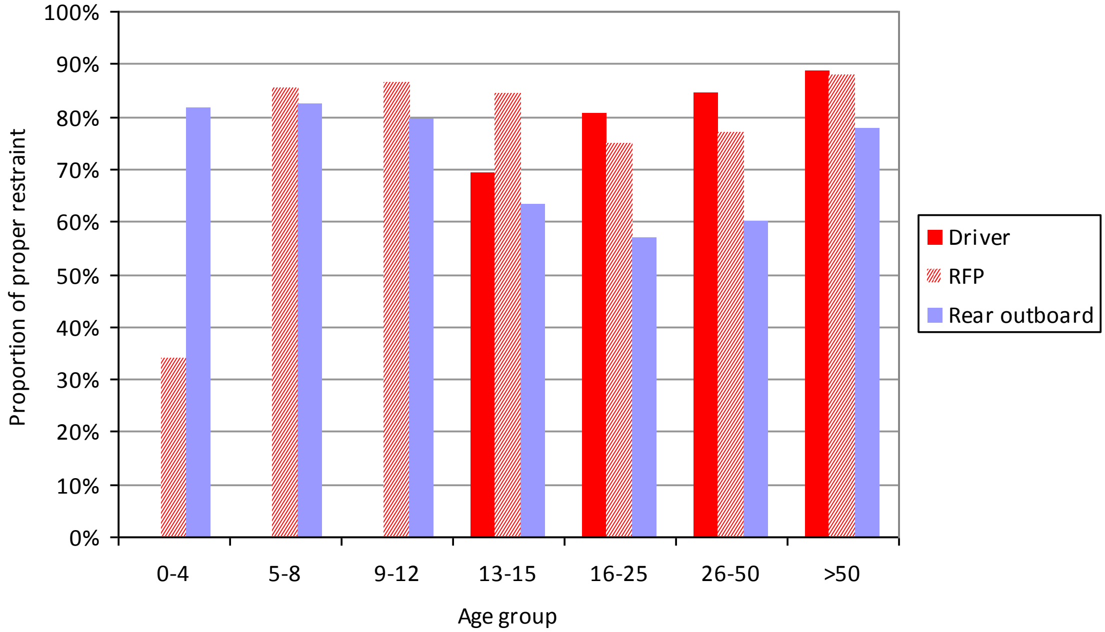



Figure 5. Proportion of properly restrained occupants by age group and seating position.

For 5-8YO, proper constraint was considered to be 3PB or a CRS. Figure 6 shows the distribution of CRS use among 5-8YO by crash year. Overall CRS usage is 15% for this age group in the crashes selected, but CRS use increased substantially in 2006 and 2007, presumably because of booster-seat laws in some states.

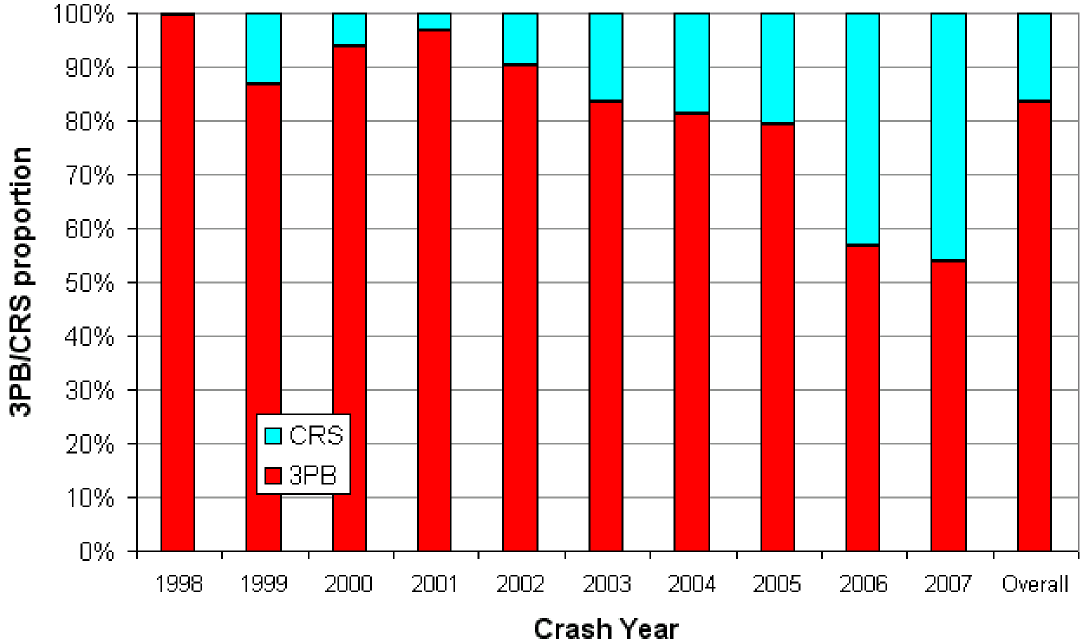



Figure 6. Distribution of 3PB/CRS use among restrained 5-8 year-olds by crash year.

*Seating Position*

Initial analyses reviewed seating trends using weighted NASS data. Figure 7 shows the distribution of occupant seating position by vehicle model year. This plot also shows that for NASS case years 1998-2007, vehicle model years 1994-1997 were most common, with 1986-1989 least frequent. Figure 8 shows the same data expressed as a proportion, showing minimal variation in occupant seating position with vehicle model year. There is a slight increase in the proportion of drivers with vehicle model year grouping.

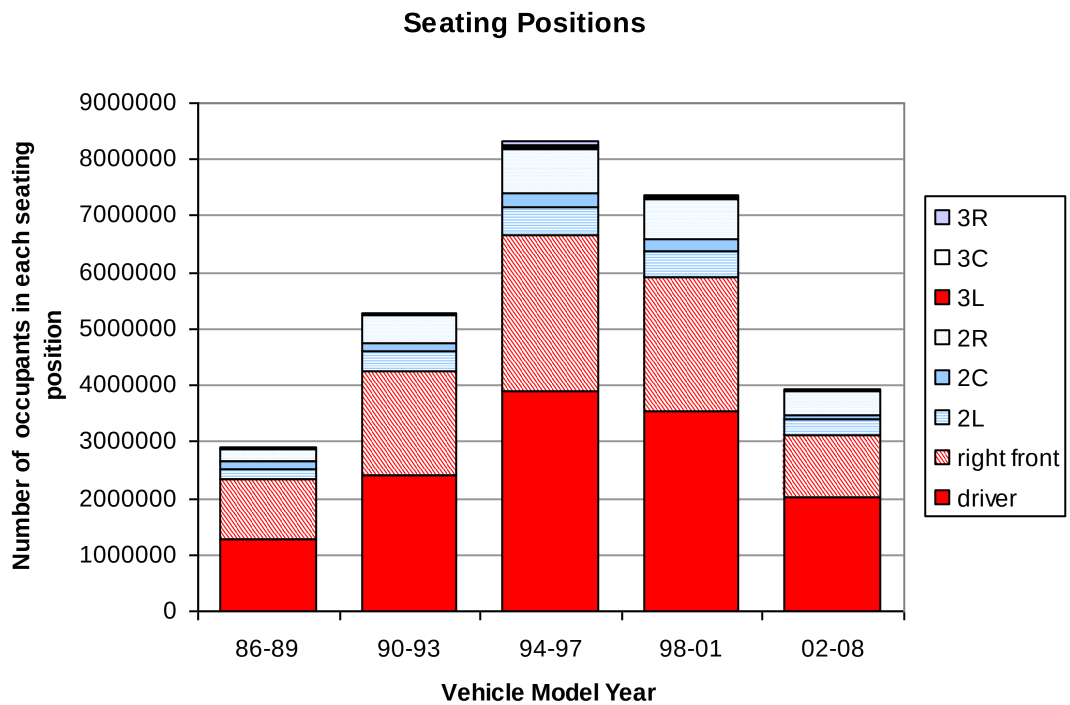



Figure 7. Number of occupants by vehicle model year and seating position.

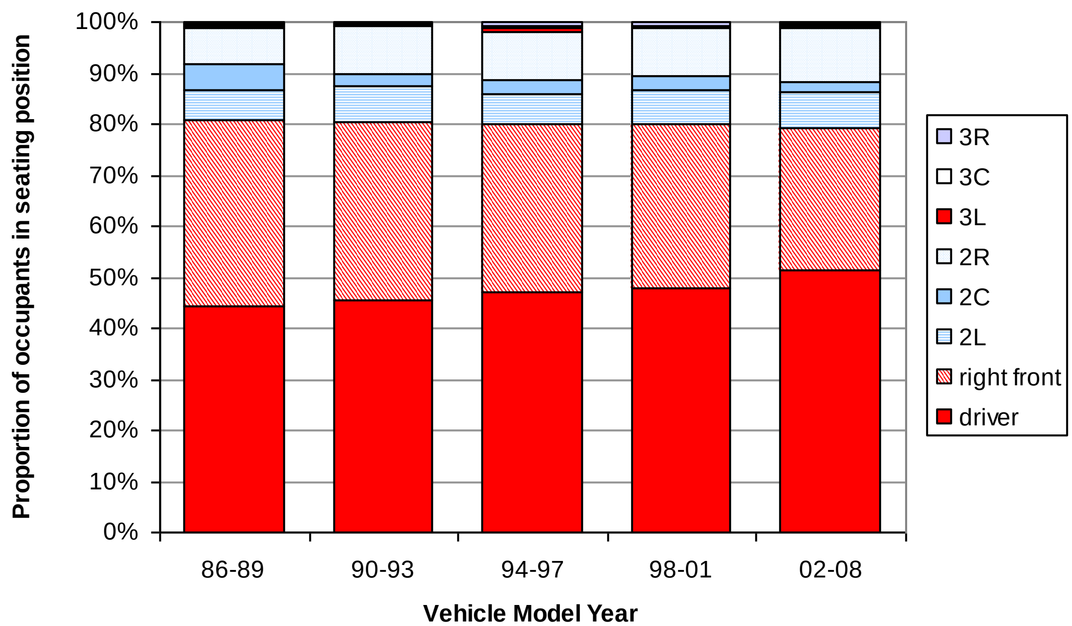



Figure 8. Proportion of occupants by vehicle model year and seating position.

Figure 9 allows better visualization of where people sit in the rear seats of vehicles, by removing the front-row passengers from the data presented in Figure 8. The most notable differences are in the 1986-1989 model years, with a higher proportion of occupants seated in the second center row. This trend likely reflects the requirement beginning in 1989 that rear outboard seating positions be equipped with 3PB, which seems to have encouraged a migration from the center position to outboard positions.

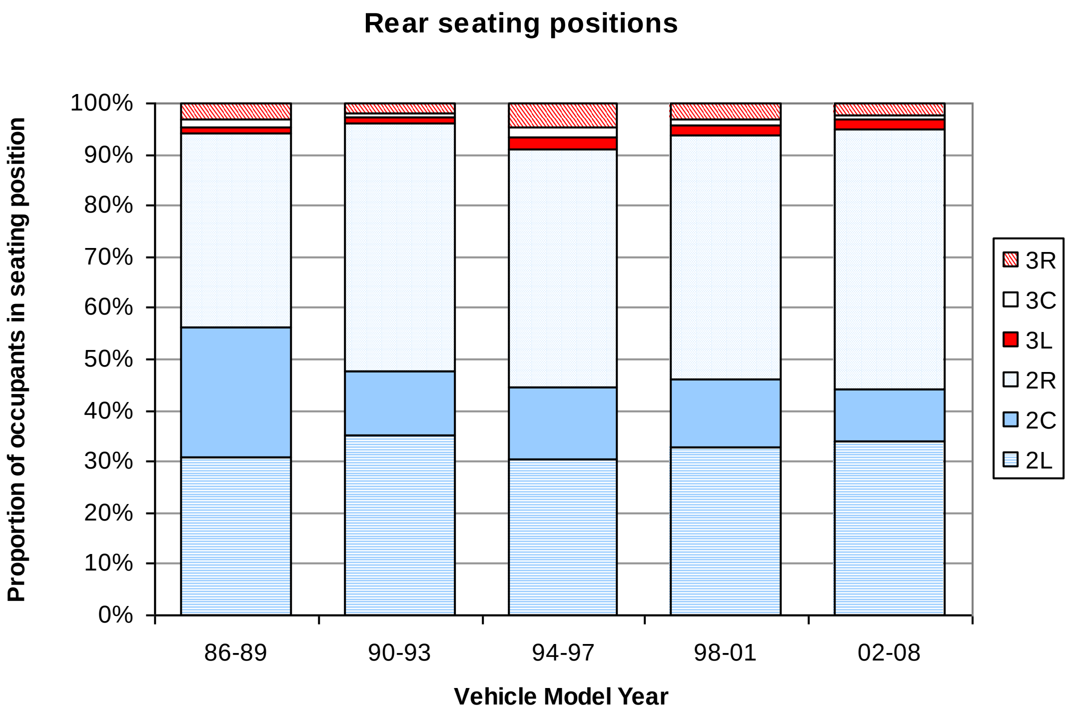



Figure 9. Proportional distribution of rear-seat occupants by vehicle model year and seating position.

*Occupant Age*

The distribution of occupant age by vehicle model year is shown in Figure 10. The distributions are generally the same with vehicle model year grouping, with a slight increase in the proportion of the oldest occupants in the more recent vehicle model year groups. Just over 10% of all occupants are children.

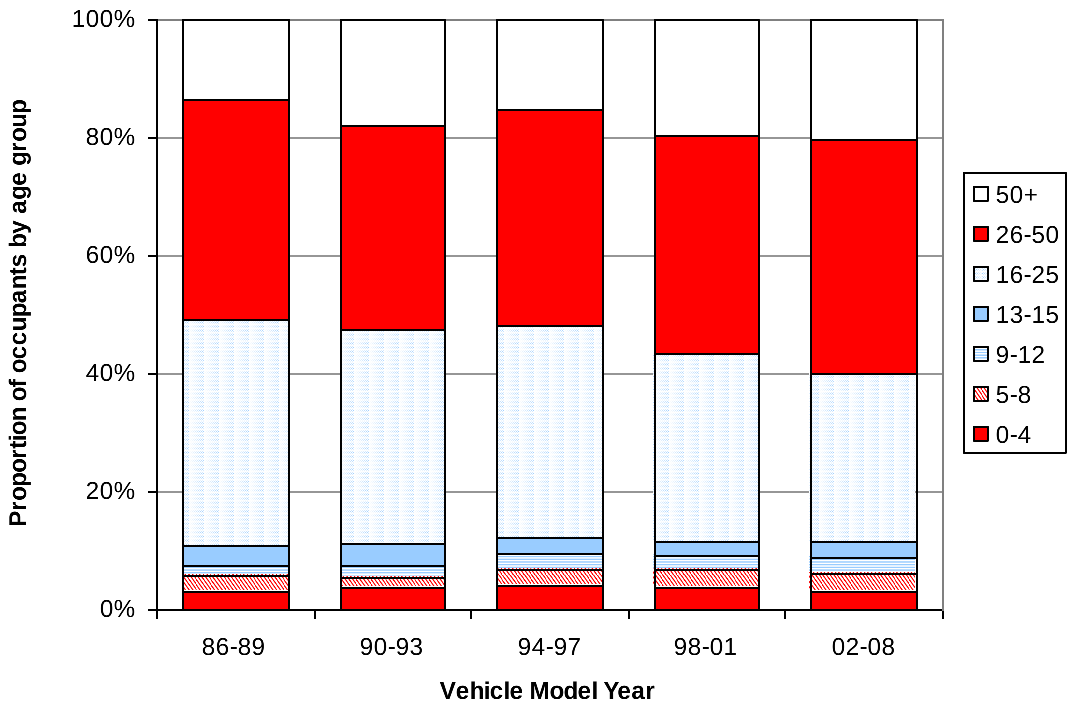



Figure 10. Proportion of occupants by vehicle model year and age group.

*Seating position by age*

The distribution of seating position for adult occupants is shown in Figure 11. The proportion of adult occupants who sit in the rear seat decreases from almost 20% for those aged 16-25 to less than 5% for those over age 50. There are no substantial changes in distribution with vehicle model year, but there is a small but steady increase in the proportion of drivers with vehicle model year for all age groups except the oldest.

Figure 12 shows the distribution of adults occupants seated in the rear seat. For all model years 1990 and later, and all occupant age groups, there is a distinct preference for adults in the second row to choose a seat on the right. One possible cause is that there may be more occupant space available in the second row right if taller drivers require a more rearward position of their seat. Another factor may be increased ease of a passenger entering and exiting from the right side of the vehicle if they are being picked up or dropped off on a roadway. The oldest adults are least likely to sit in the center of the second row. The youngest adults are the only age group with a visible shift from the center position to outboard positions for vehicle model years 1990 and later. With regard to third-row seating, the youngest adults rarely sit in the third row, and adults aged 26-50 are the adults who most frequently choose the rear seat.

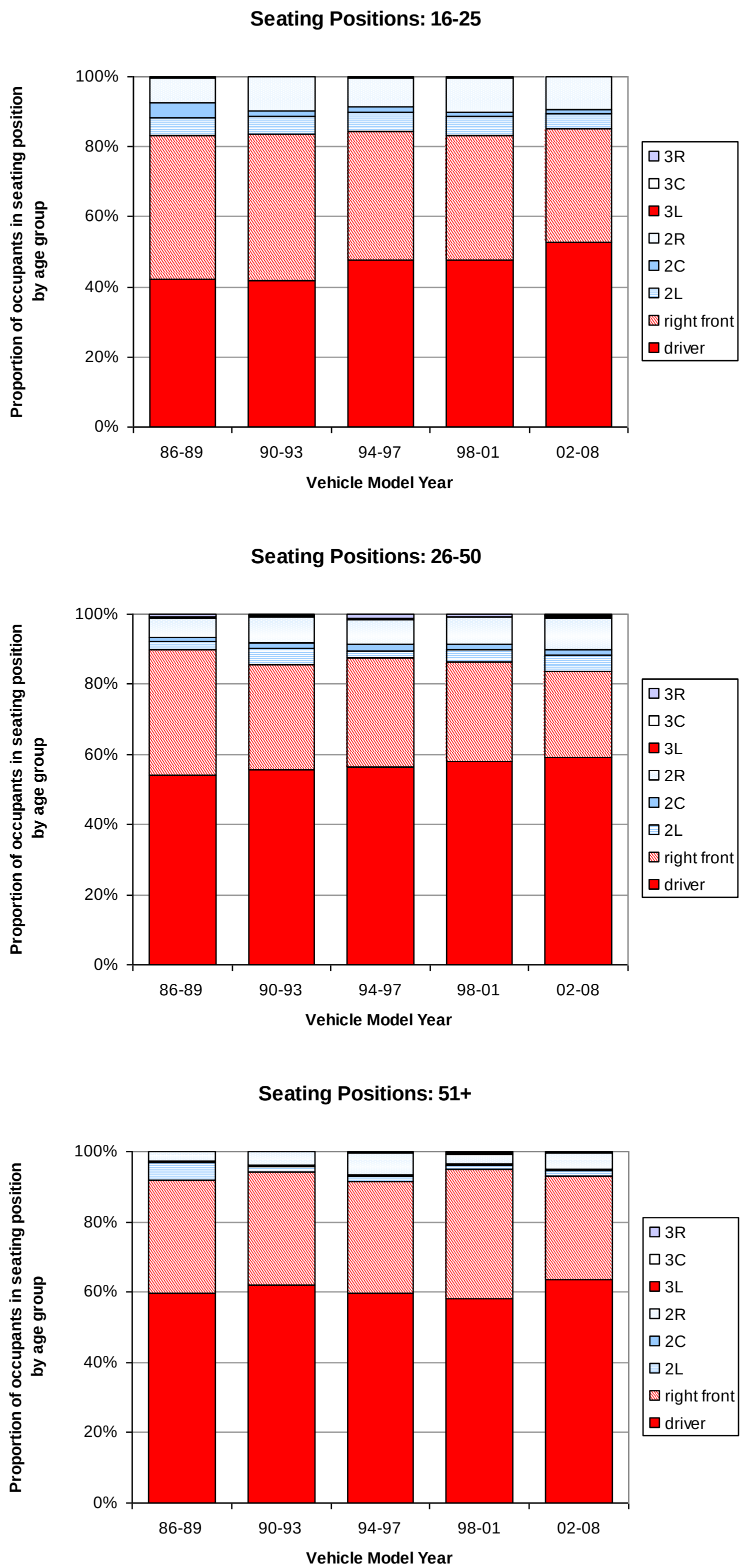



Figure 11. Proportion of adult occupants by vehicle model year, seating position, and age group.

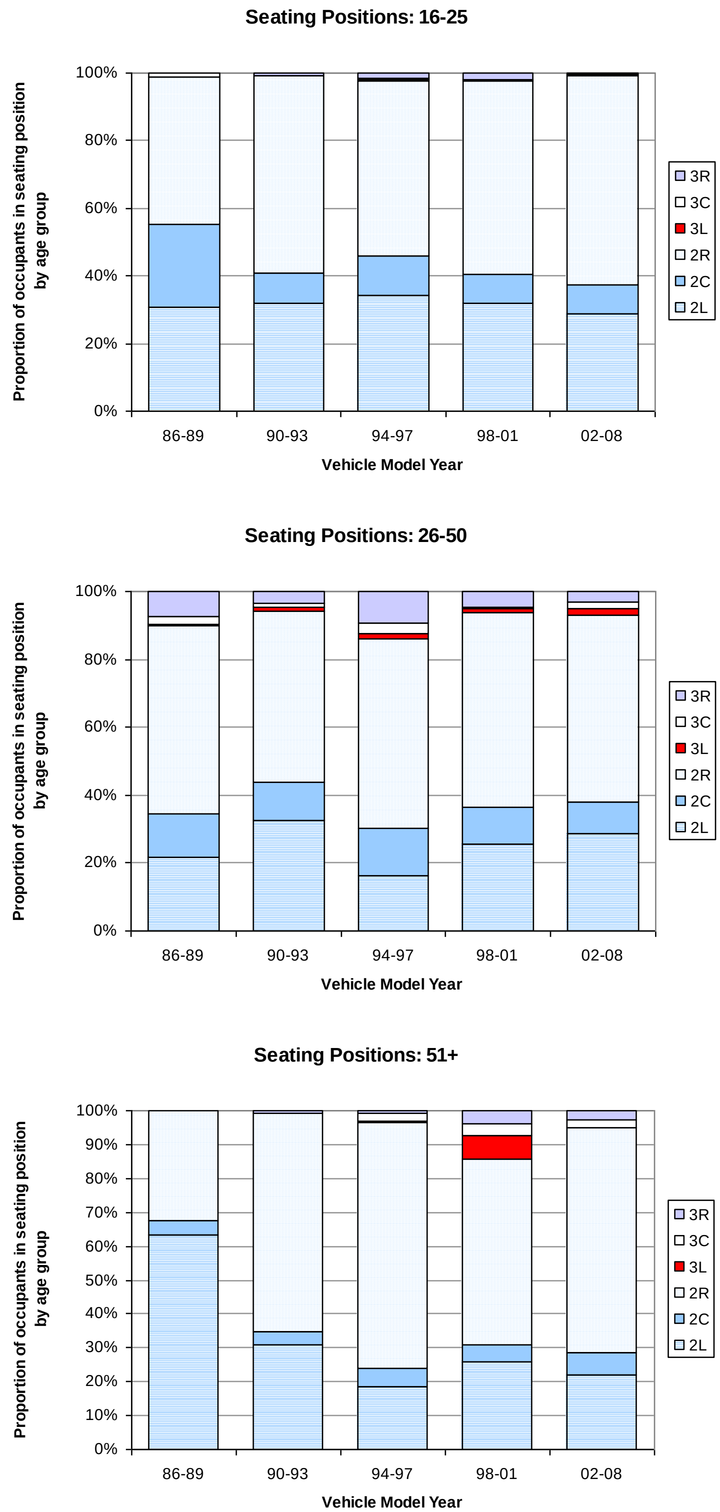



Figure 12. Proportion of adult rear-seat occupants by vehicle model year, seating position, and age group.

The distribution of child occupants by vehicle model year, seating position, and age group is shown in Figure 13. The proportion of children sitting in the right-front increases with age group. Among children aged 0-4, those in the newest model years are least likely to be in the right-front position.

Children aged 0-4 are most likely to be in the second-row center position for two reasons. One is that children of this age should be in CRS, which can be secured with only a lap belt that is often present in this seating position. Second, the center second row seating position is recommended to parents as the safest position in the vehicle, so families with only one child would be encouraged to choose this location. Children in the two youngest age groups show a decrease in second-row center seating position in 1990 and later vehicles, once rear outboard positions were required to have 3PB. Children aged 13-15 are least likely to be seated in the center second row.

For the second row outboard positions, there does not seem to be a consistent trend with left vs. right seating for children aged 0-8. There is a slight preference for the right side vs. the left side in age groups 9-15 for most vehicle model year groups, but it is not as prevalent as the right-side seating preference seen with adults.

For third row seating, the 13-15 and the 0-4 age groups rarely sit in the third row. Children aged 5-12 use the third row most frequently, as they can generally buckle themselves in and the use of the front seat by these age groups is not recommended.

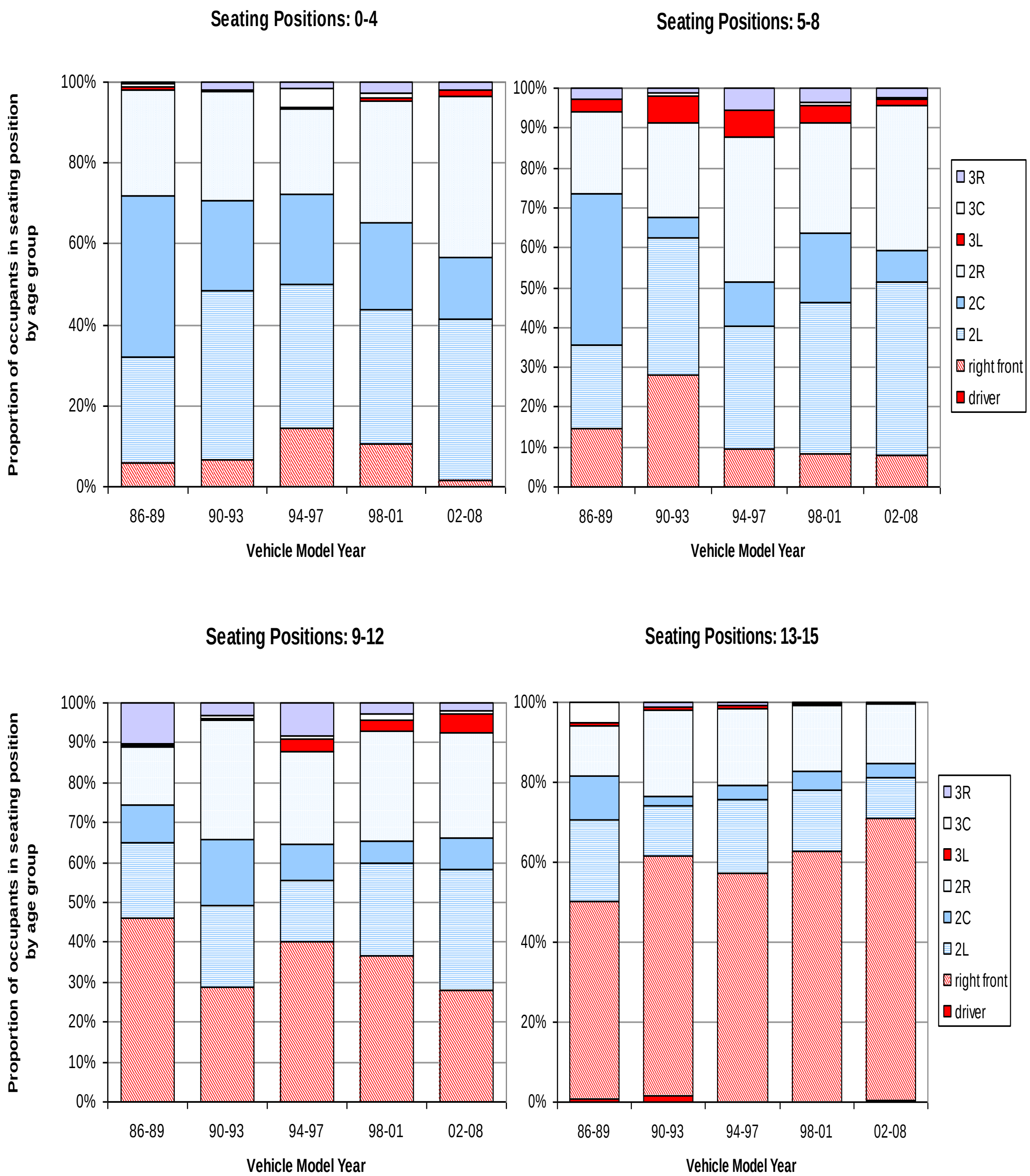



Figure 13. Proportion of child occupants by vehicle model year, seating position, and age group.

*Vehicle Type*

Figure 14 shows the variation in row occupancy with vehicle type. Vans are most likely to have rear seat occupants, while light trucks are least likely to have rear seat occupants. Passenger cars and SUVs have similar rates of second row occupancy. Vans are the only vehicle type with a substantial number of 3rd row occupants.

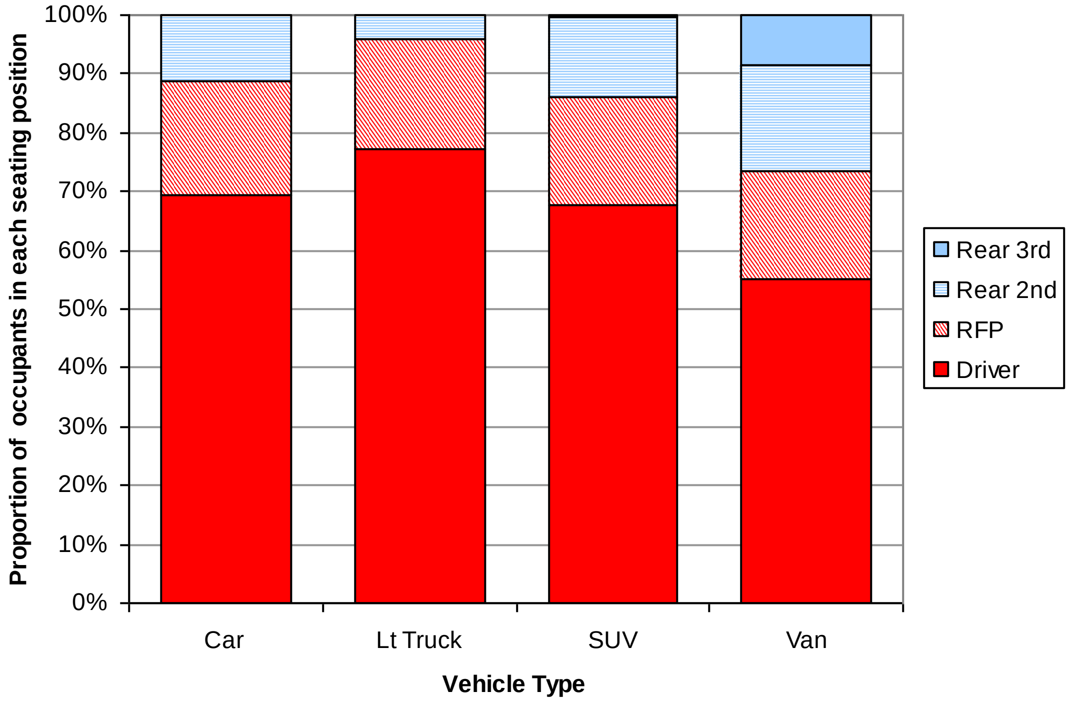



Figure 14. Distribution of occupant seating position by vehicle type.

Figure 15 shows the distribution of adults in the second-row by different vehicle types. In all vehicle types, just under 40% of adults choose the left second row. SUVs and vans are more likely to have a second row center occupant, possibly because many of these vehicles have a bench seat that may be offset towards the left.

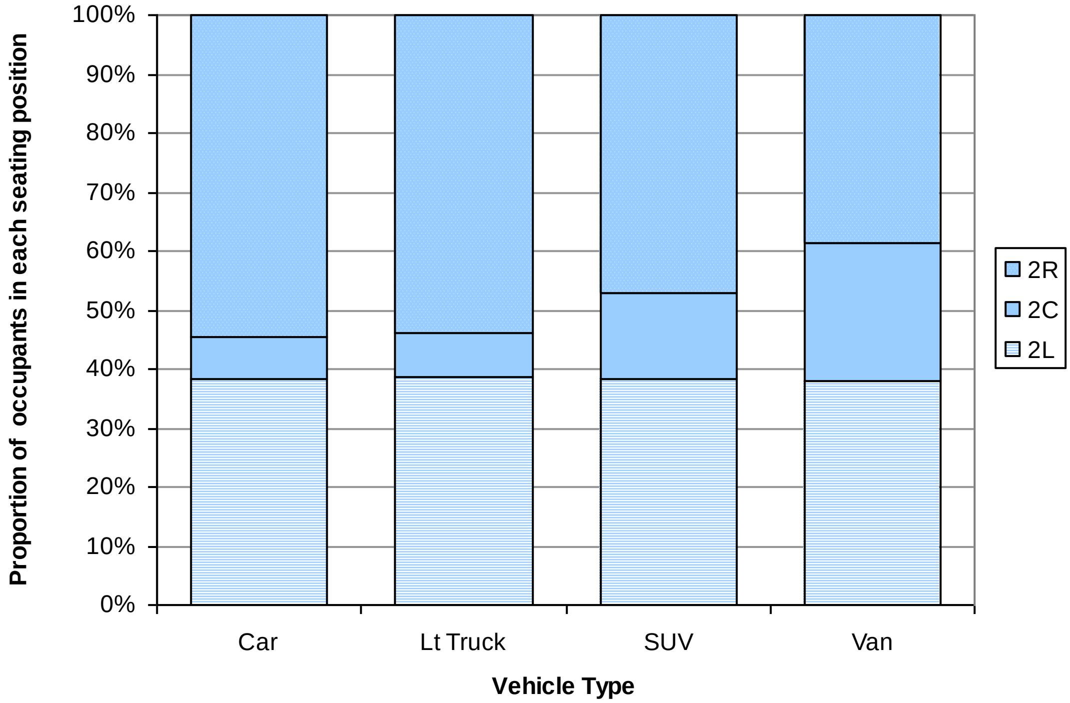



Figure 15. Distribution of adult second-row seating positions by vehicle type.

Figure 16 through Figure 18 show the distribution of rear seating by age group and vehicle type. Figure 16 shows this information for the second-row outboard positions, Figure 17 for the second-row center positions, and Figure 18 for all third row positions. There are a few differences between left and right second row seating choices with age group. In passenger cars and SUVs, more children aged 0-4 are seated in the left outboard position than the right. In vans, more 9-12YO children are seated on the left than on the right. For second row center seating, cars and light trucks show similar distribution with age, while SUVs have the greatest proportion of 16-25YO sitting in that position. Vans have the lowest proportion of 0-4YO and the highest proportion of >50YO in this position. For third row seating, 5-8YO most commonly sit in this row in passenger cars and SUVs, while for vans, third row seating is fairly evenly distributed among 0-4YO, 5-8YO, and 9-12YO. Vans also have the highest proportion of adults seated in the 3rd row.

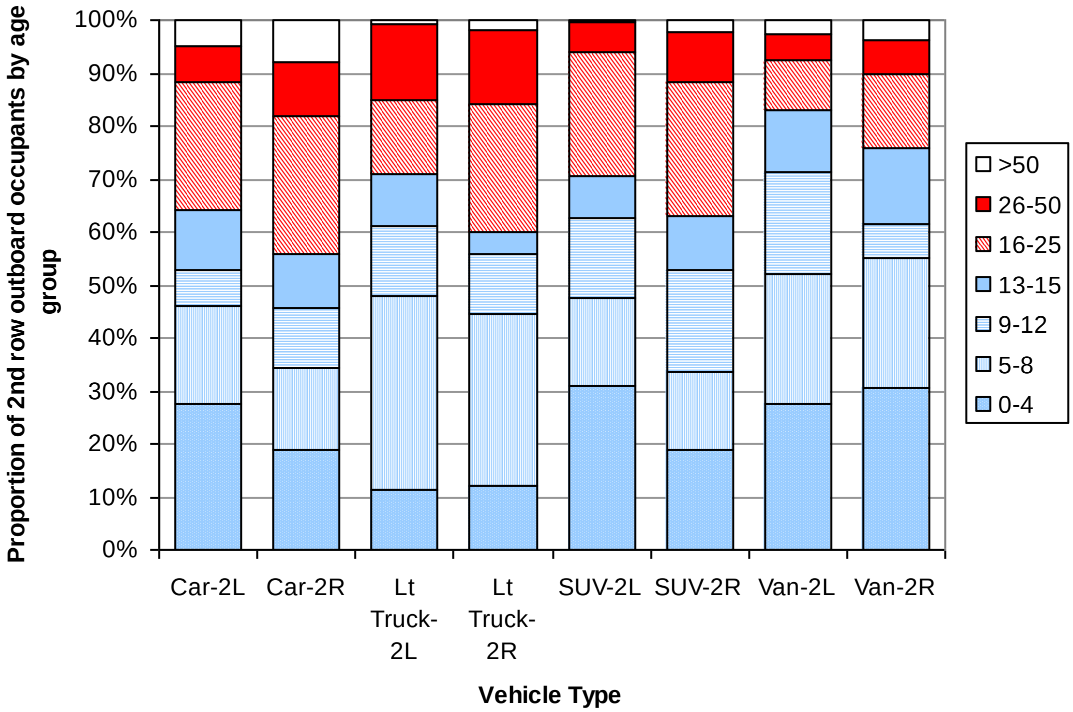



Figure 16. Distribution of outboard second-row seating positions by occupant age vehicle type, and side of the vehicle.

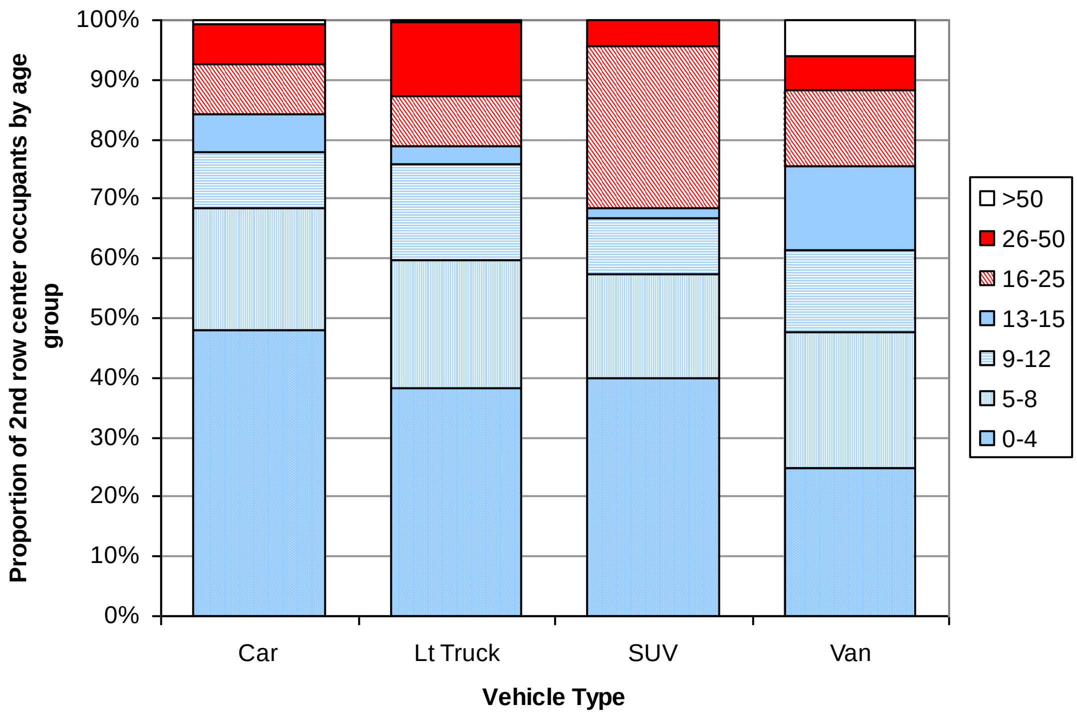



Figure 17. Distribution of second-row center seating positions by occupant age and vehicle type.

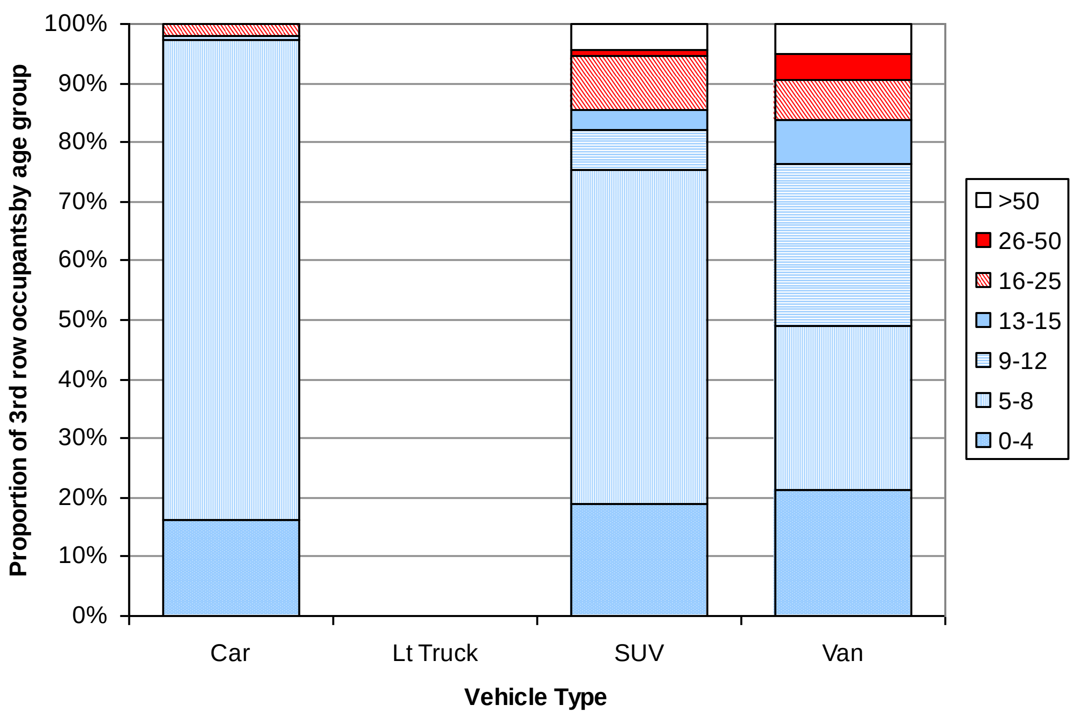



Figure 18. Distribution of 3[rd] row seating by occupant age and vehicle type.

*Rear Seat Occupants by Driver Age Group*

Another approach for determining how to improve safety for rear-seat occupants in different vehicles is to examine how the rear seat population changes with the age of the driver. Figure 19 shows the distribution of ages of rear seat occupants for three different age groups of drivers. For drivers aged 16-25, their rear seat occupants are most likely to be in the same age group or slightly younger (51.5% of their total rear seat population). The next most frequent age group is children aged 0-4, at about 30%. Children aged 5-12 make up less than 10% of the rear seat population, as parents in this age group would not usually be old enough to have children in this age range. The other 10% of their rear seat occupants are adults aged 26 and older.

For drivers aged 26-50, 85% of their rear seat occupants are 15 years old or younger, and 79% are aged 12 and younger. Only 15% of their rear seat occupants are other adults. For drivers aged over 50, over half of their rear seat occupants are adults, with about 35% of their rear seat occupants aged over 50. Less than 5% of their rear seat occupants are under age 4, and about 30% are aged 5-12.

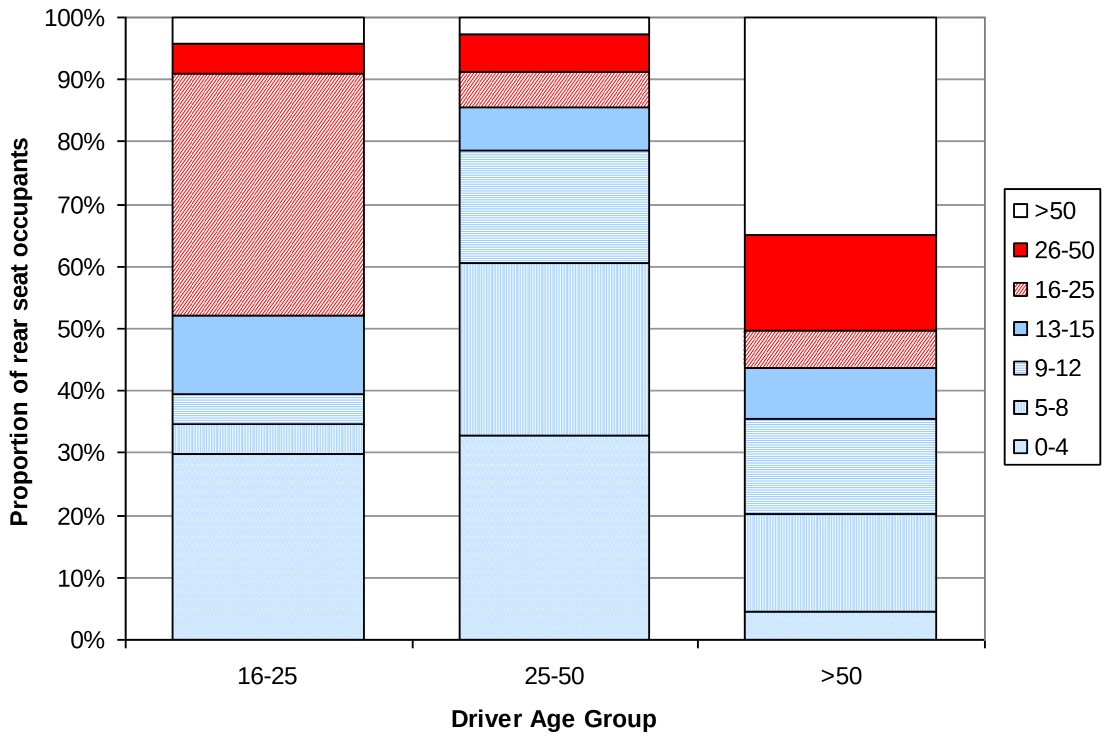



Figure 19. Distribution of rear seat occupant ages by driver age group.

*Key Points*

- In the second row, adults tend to sit on the right side, but this is not true for children.
- Vans are the only vehicle type with substantial numbers of 3rd row seating.

- The ages of rear seat occupant vary substantially with driver age. Drivers aged 16-25 most likely have other 16-25YO or 0-4YO occupants in the rear seat. For drivers aged 26-50, 85% of their rear seat occupants are under aged 16. Drivers over age 50 have the greatest proportion of passengers over age 50 in the rear seat.
- Occupant seating patterns do not vary substantially with vehicle model year.

## Injury distribution by body region

*Frontal impacts*

The distributions of AIS2+ injuries to restrained occupants by body region and age group are shown in Figure 20 for front seat occupants and rear seat occupants. All occupants are using 3-point belts, except children aged 0-4, who are in child restraints, and children aged 5-8, who are either in child restraints or 3-point belts.

For adult occupants in the front seat, injury distributions in the front seat are similar for the three age groups, except that adults over age 50 have a higher proportion of thorax injuries, and adults under 25 have a higher proportion of head injuries. Lower extremity injuries are the most common injury to adults in the front seat.

For restrained children in the front seat, head injury is the most frequently injured body region. The proportion of lower extremity injury increases with child age. Children aged 5-8 have the highest proportion of abdomen injury among all age groups. Booster seat use is recommended for this age group to position the child appropriately relative to the vehicle belt geometry, and they are particularly effective at reducing abdomen injury frequency. To check this hypothesis, we looked at rates of abdomen injury for 5-8 year-olds in the rear seat as a function of restraint type. In frontals, 5-8-year-olds in belts had a risk of abdomen injury of 0.76%, compared to 0.19% for those in boosters. This result is consistent with the study by Arbogast et al. (2004) and supports the hypothesis that the high rate of abdomen injury seen in Figure 20 is from young children using belts rather than booster seats in the rear.

Unlike the front seat, the injury distributions vary substantially with age for restrained adults in the rear seat in frontal impacts, but this is most likely because of smaller sample sizes in the rear seat. Adults over age 50 are most likely to sustain thorax or spine injuries in the rear seat. The proportion of thoracic injury increases with age group for adults. Lower extremity injuries are less frequent among all ages of adult rear-seat passengers compared to the front seat. The youngest adults have the highest proportion of upper extremity injuries in the rear seat.

For children in the rear seat, head injury is the most common body region injured for all age groups except for 5-8 year-olds, where the abdomen is most frequently injured. Children aged 0-4, who are seated in child restraints, have the highest proportion of injuries to the lower extremities. A greater proportion of their lower extremities may be closer to the front row seat back because of their higher position relative to the vehicle seat and their shorter leg lengths. While abdomen injuries are most prevalent in the 5-8 year old group, the proportion of abdomen injuries for 9-15 year-olds is higher in the rear seat than in the front seat for this age range. Injuries to the spine make up a notable proportion of injuries to rear-seated 9-12-year-olds as well.

Appendix A contains plots of injured body region by age group and vehicle model year grouping for rear outboard and front seat occupants.

Similar results are shown in Figure 21 for AIS3+ injuries with the following exceptions. For the oldest adults in the front seat, thoracic injuries are more prevalent than lower extremity injuries. Head injury is less frequent and upper extremity injury more frequent for 9-12YO children compared to other pediatric age groups. In the rear seat, adults aged 26-50YO have the highest proportion of AIS3+ upper extremity injuries.

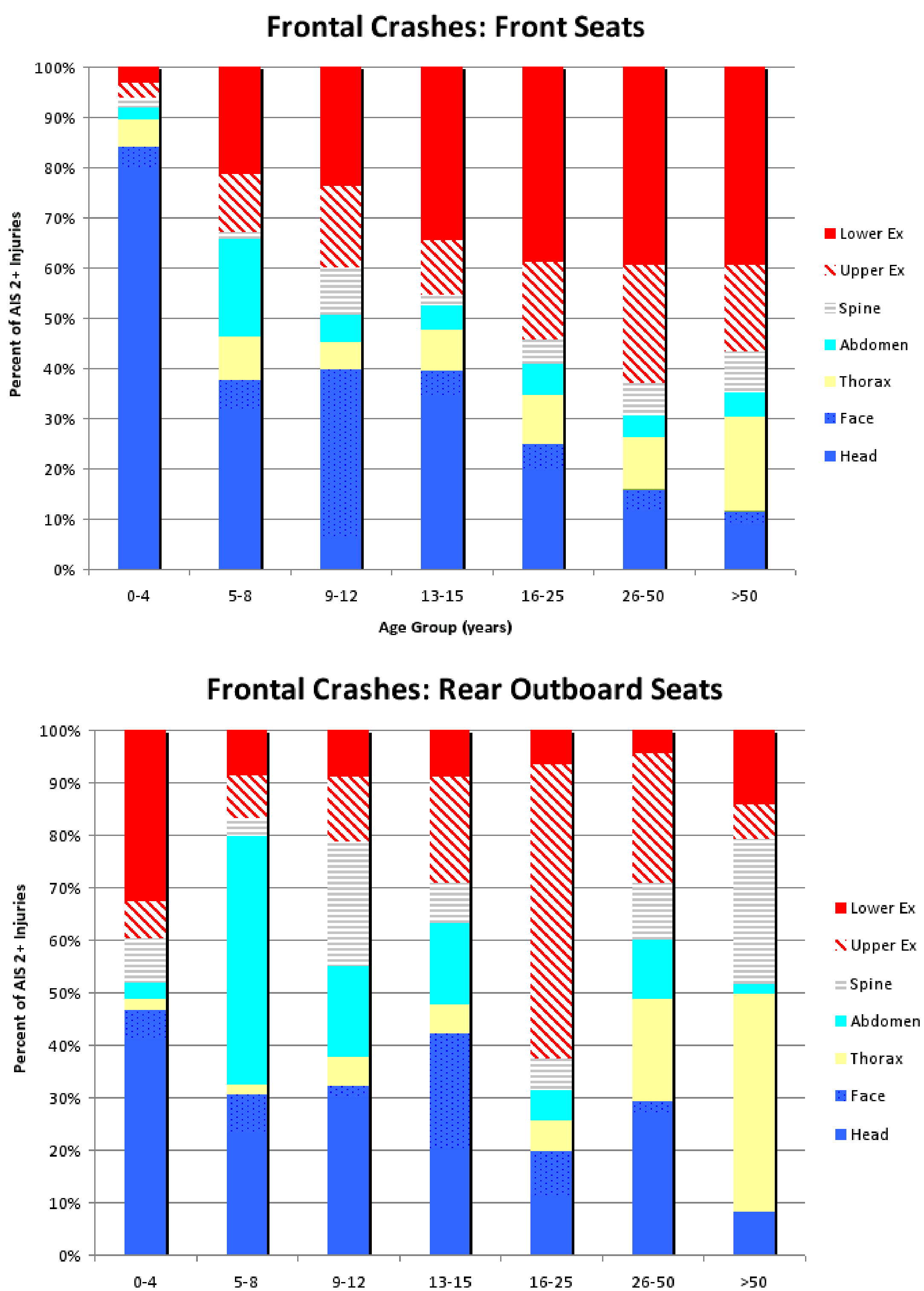
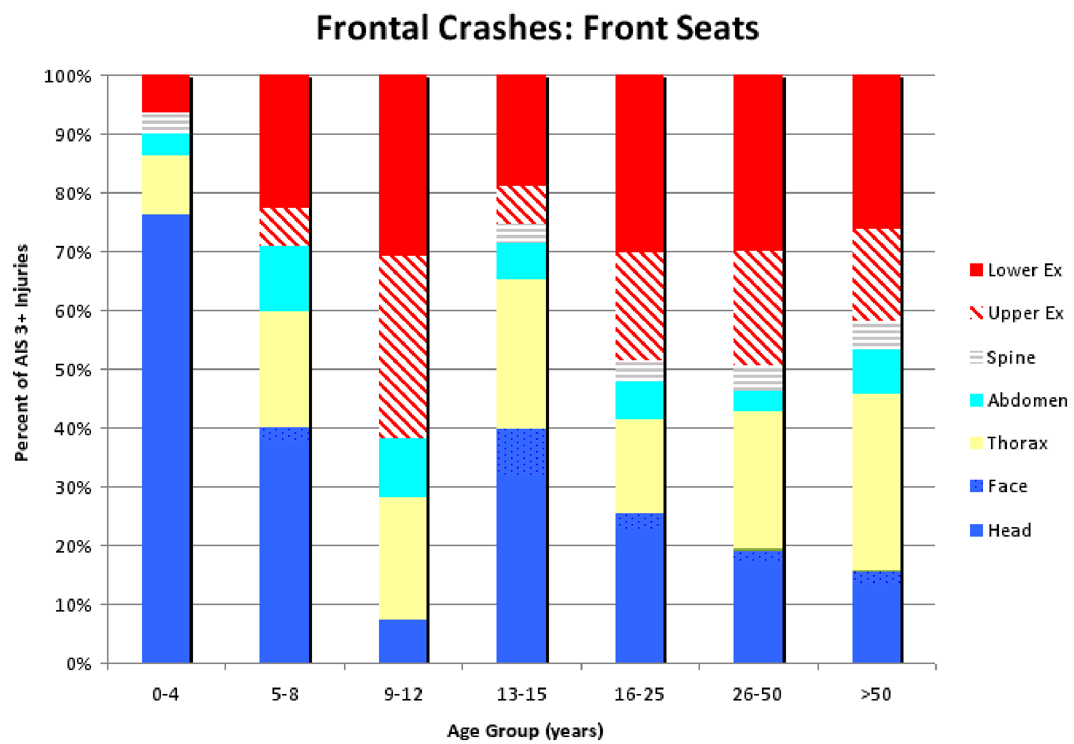



Figure 20. Distribution of AIS2+ injuries by age group and body region for front seat occupants (top) and rear outboard occupants (bottom) in frontal crashes.



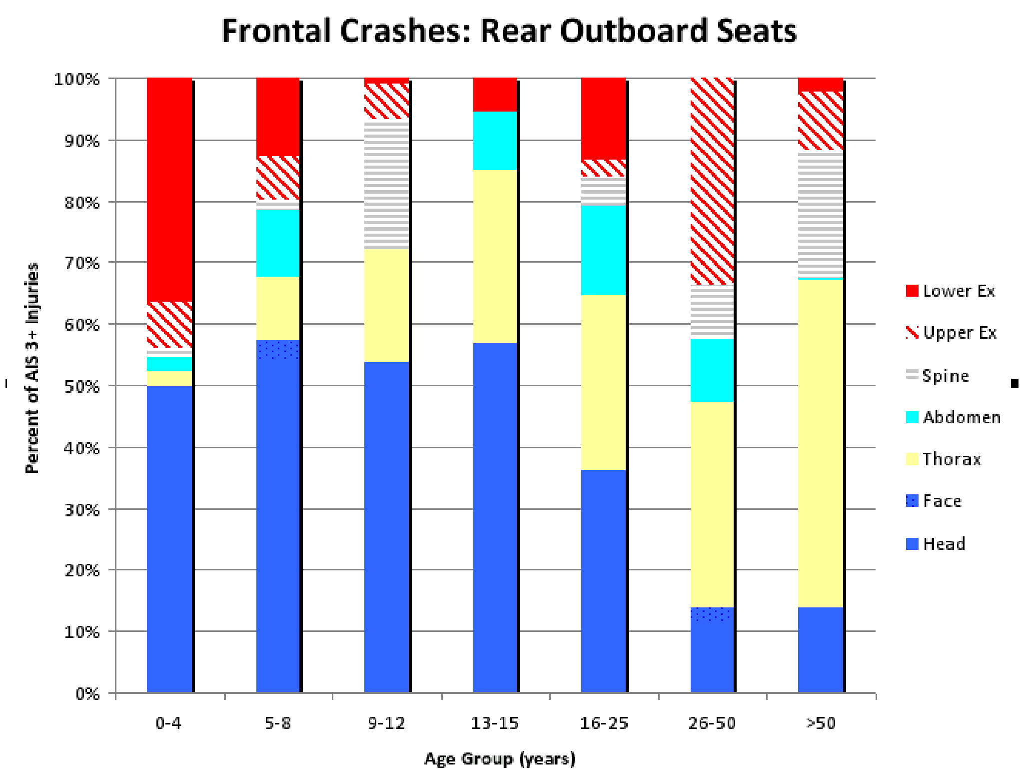




Figure 21. Distribution of AIS3+ injuries by age group and body region for front seat occupants (top) and rear outboard occupants (bottom) in frontal crashes.

*Near-side impacts*

The distributions of AIS2+ injuries for occupants in near-side impacts by body region and age group are shown in Figure 22 for front and rear seat occupants. For adults in the front seat, the most commonly injured body regions are the head and lower extremity with only slight variations in body region distributions with age group. For restrained children through age 12 in the right-front seat, head and upper extremity are the most commonly injured body regions.

For rear seat occupants in near-side crashes, head injuries are most frequent for adults aged 16-25, thoracic injuries are most frequent for adults aged 26-50, and spine injuries are most frequent for adults over age 50. Among children, head and extremity injuries are most frequent in the rear seat in near-side impacts.

Similar injury distributions are presented in Figure 23 for AIS3+ injuries. Front seat injury patterns are similar to those for AIS2+ injuries. For 26-50YO adults in the rear seat, AIS3+ thoracic injury is less prevalent than AIS2+ thoracic injury. Abdomen injuries make up a greater proportion of AIS3+ injuries to 0-4 and 9-12YO children in the rear seat who are involved in near-side impacts.

Because the number of injured occupants in each age category/vehicle model year grouping is low for rear seat occupants, distributions of injured body region are not presented as a function of these variables.

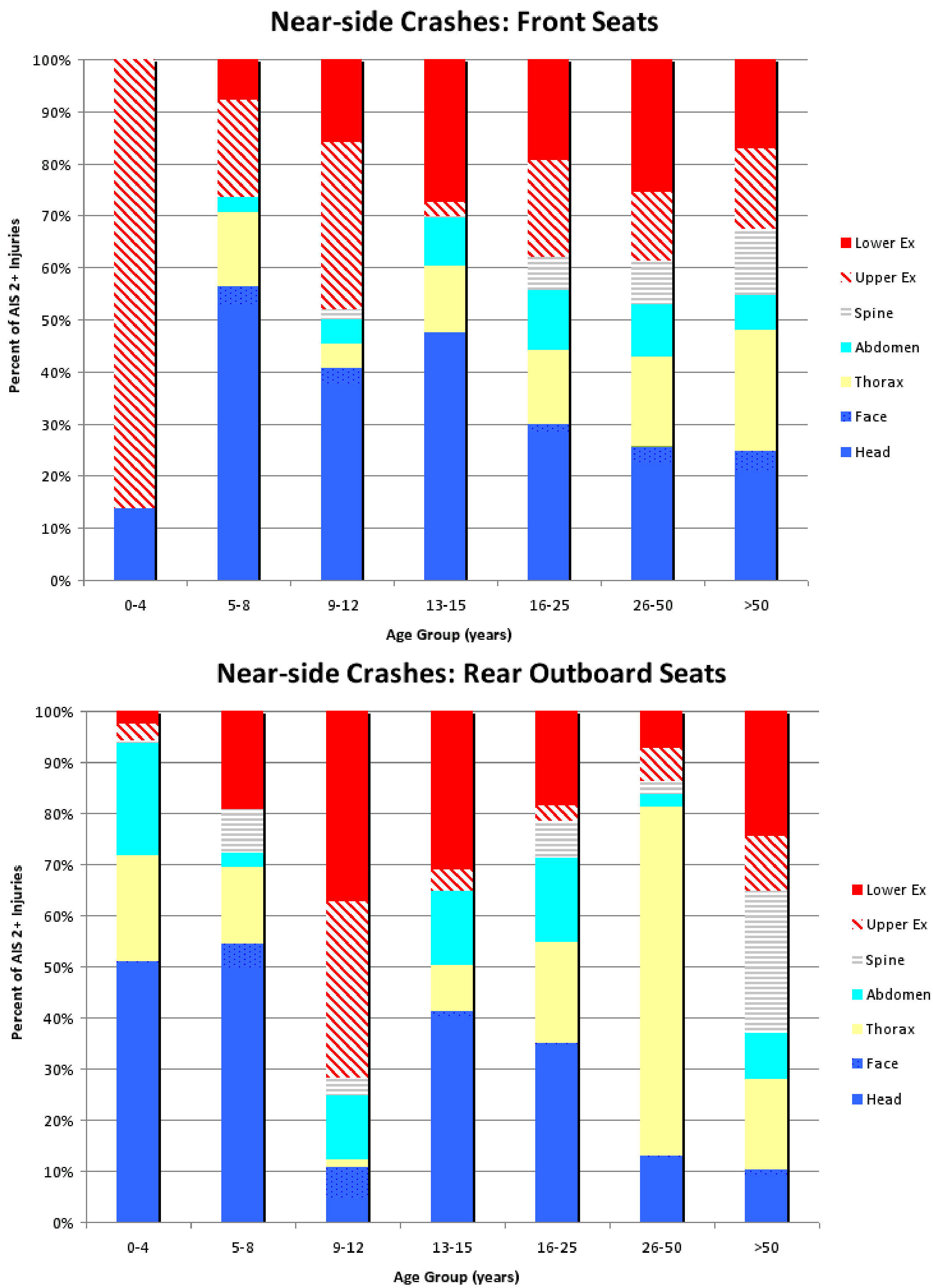
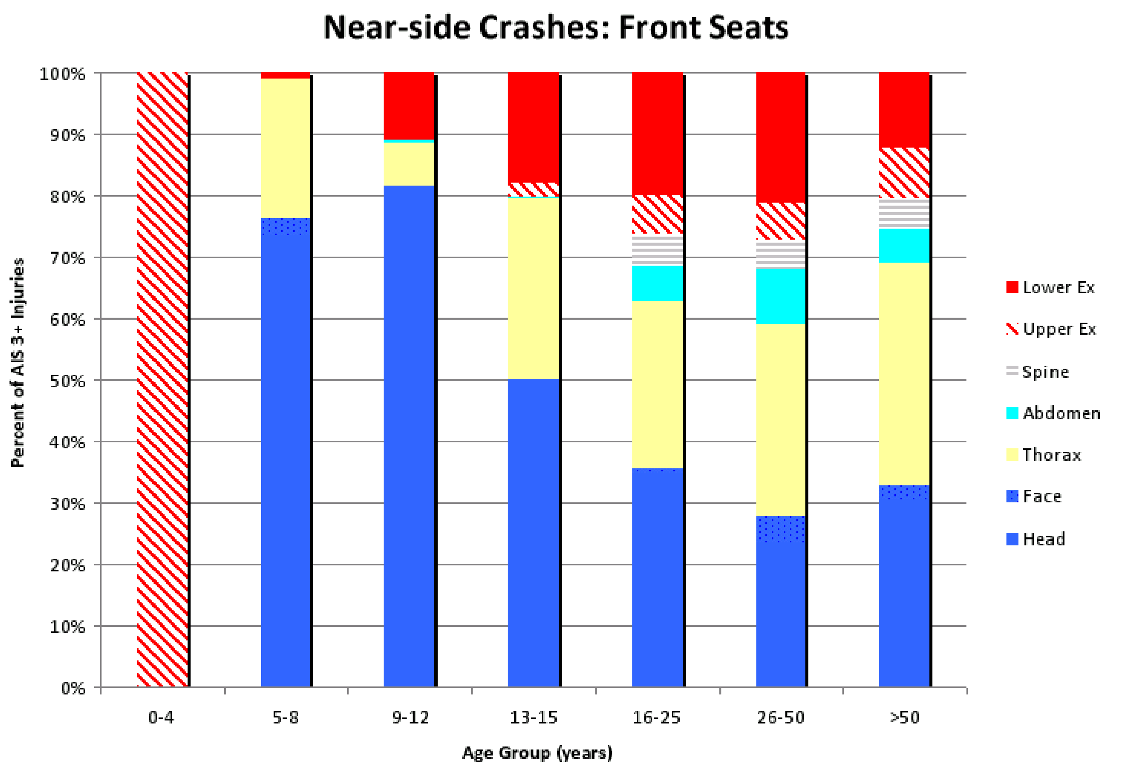



Figure 22. Distribution of AIS2+ injuries by age group and body region for front seat occupants (top) and rear outboard occupants (bottom) in near-side impacts.



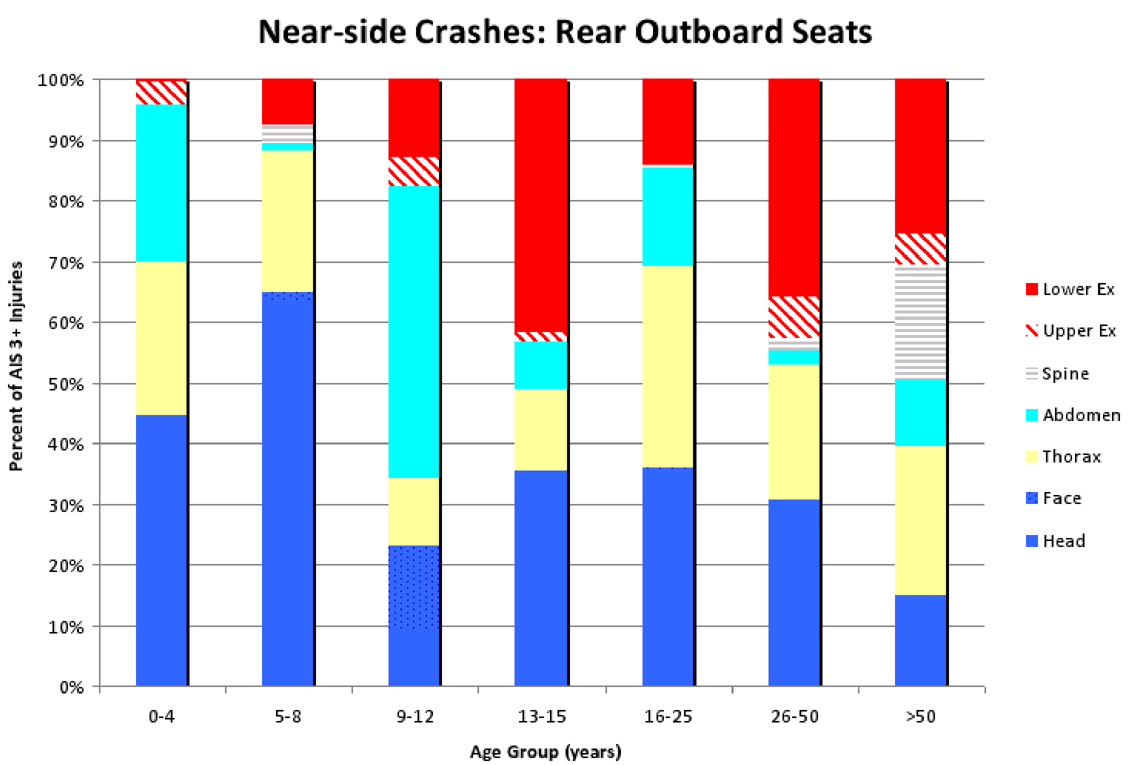




Figure 23. Distribution of AIS3+ injuries by age group and body region for front seat occupants (top) and rear outboard occupants (bottom) in near-side impacts.

## Injury Risk Analysis

*Confidence in analysis*

Although all of the NASS analysis uses weighted data, the ability to make meaningful assessments of injury risk depends on the number of occupants in each age group and the number of injured occupants in each age group. When the number of occupants and injuries is low, the effect of one occupant or injury on the distribution can be substantial. The wide variation in distribution of body region injured for rear seat occupants, compared to the fairly even distribution for adult front seat occupants, results in part from the much smaller sample size of rear seat occupants.

Table 4 contains the number of occupants in each age group, seating position, and vehicle model year grouping for each type of crash. Using the overall AIS2+ injury risk for each population, the numbers are color-coded according to confidence levels we have in the analysis based on the data. Green is high, orange is medium, red is low, and black is weak. Thus we have high confidence in the analysis based on adults in the front row for different crash types and vehicle model years, but weak confidence in the analysis of side impacts for rear seat occupants.

Table 4. Unweighted number of occupants in each crash type, vehicle model year, age group, and seating position category

| | | Frontal | | Near-side | |
|---|---|---|---|---|---|
| Vehicle model year | Age group | Front | Rear outboard | Front | Rear outboard |
| 86-97 | 0-4 | 73 | 429 | 12 | 113 |
| 86-97 | 5-8 | 103 | 237 | 32 | 62 |
| 86-97 | 9-12 | 169 | 163 | 36 | 42 |
| 86-97 | 13-15 | 287 | 113 | 82 | 39 |
| 86-97 | 16-25 | 5028 | 264 | 1275 | 77 |
| 86-97 | 26-50 | 6087 | 113 | 1467 | 30 |
| 86-97 | >50 | 3158 | 81 | 956 | 17 |
| 98-01 | 0-4 | 14 | 281 | 3 | 66 |
| 98-01 | 5-8 | 39 | 198 | 3 | 47 |
| 98-01 | 9-12 | 87 | 128 | 19 | 44 |
| 98-01 | 13-15 | 143 | 74 | 37 | 24 |
| 98-01 | 16-25 | 2393 | 161 | 607 | 52 |
| 98-01 | 26-50 | 3376 | 84 | 865 | 30 |
| 98-01 | >50 | 1722 | 45 | 538 | 18 |
| 02-08 | 0-4 | 2 | 176 | 1 | 45 |
| 02-08 | 5-8 | 24 | 146 | 7 | 26 |
| 02-08 | 9-12 | 55 | 109 | 13 | 30 |
| 02-08 | 13-15 | 81 | 58 | 21 | 18 |
| 02-08 | 16-25 | 1523 | 120 | 408 | 34 |
| 02-08 | 26-50 | 2536 | 67 | 675 | 19 |
| 02-08 | >50 | 1340 | 51 | 402 | 17 |

Confidence level: green= high, orange=medium, red=low, black=weak

*Injury risk values*

Overall risks of AIS2+ and AIS3+ injury in frontal crashes were calculated for each age group, passenger seating position (driver or right-front or rear outboard), and model year grouping. Center row seating was not evaluated because of the small number of injured occupants in that seating position. Risks for child age groups are shown in Figure 24 (AIS2+ risk) and Figure 25 (AIS3+) and for adults in Figure 26 (AIS2+) and Figure 27 (AIS3+ risk).

For AIS2+ injury risk in children, risk is generally lower in the rear outboard seat than in the right-front seat, except for 0-4YO children, because they rarely sit in the right-front seat. For most age groups, risk is higher in MY02-08 vehicles than in MY96-97 vehicles.

Highest risks in recent vehicle model years are to 9-15YO children in the front seat, followed by 13-15 and 0-4YO children in the rear seat. Risk of AIS3+ injury is less than 2% for all child age groups/model year/seating positions except for 13-15YO in the right-front of MY02-08 vehicles, and 0-4YO in the rear outboard of MY98-01 vehicles.

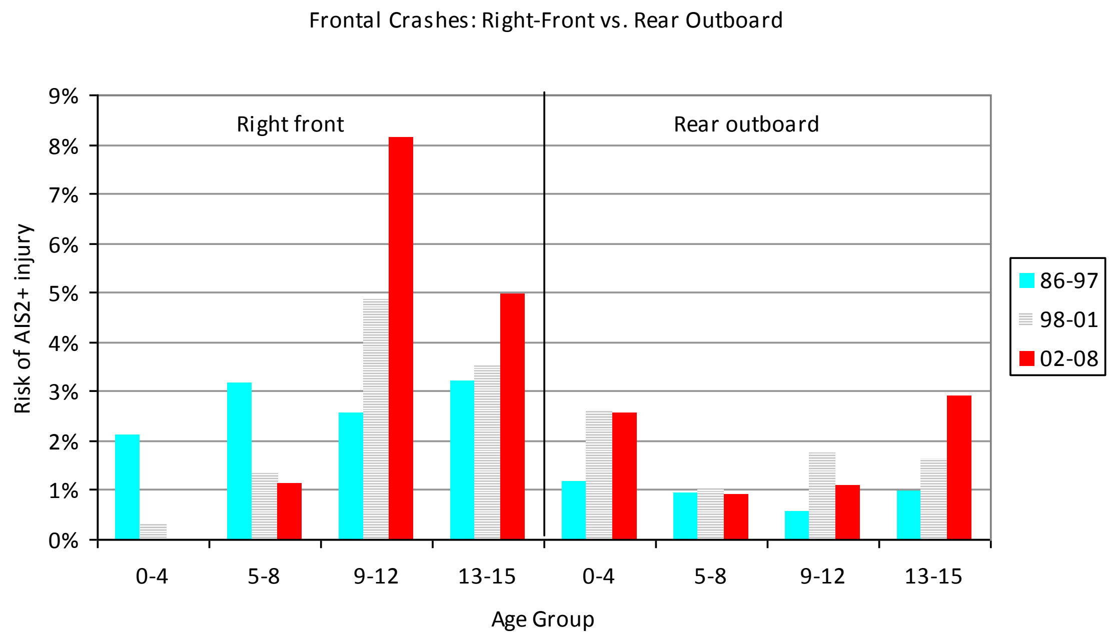



Figure 24. Risk of AIS2+ injury for children by age group and vehicle model year in the front and rear seat in frontal impacts.

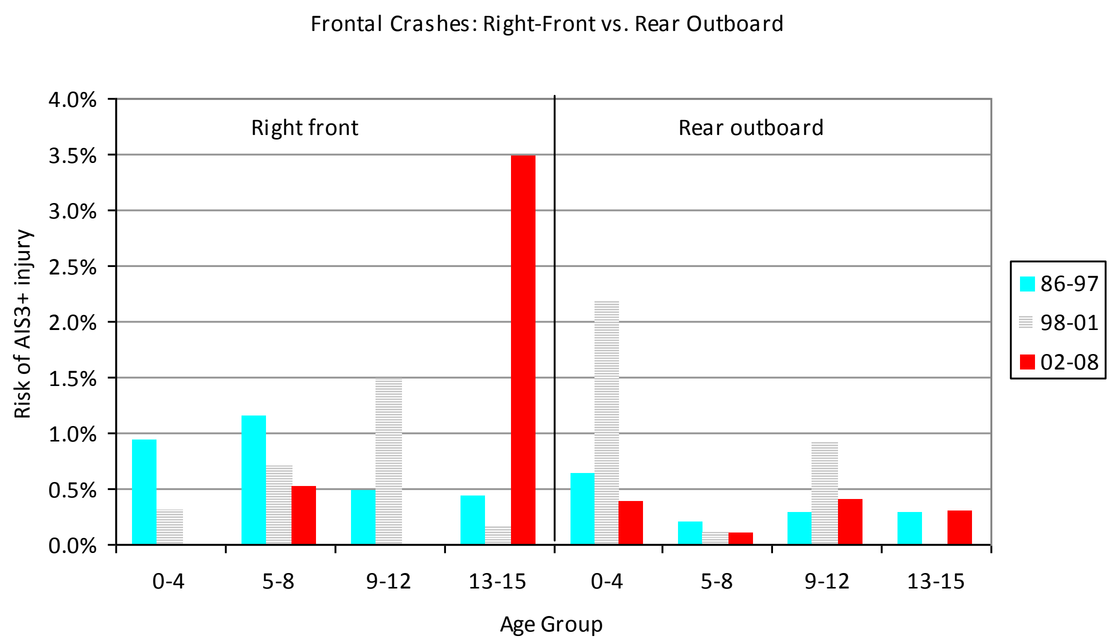



Figure 25. Risk of AIS3+ injury for children by age group and vehicle model year in the front and rear seat in frontal impacts.

For adult occupants, risks are generally lower for rear seat occupants than for drivers or right-front occupants. The exception is rear seat occupants over age 50 in MY98-01 vehicles. With regard to AIS3+ injury risk, rear seat occupants aged 26 and higher have substantially higher risks than all other rear seat occupant age/model year combinations. The next highest risks of AIS3+ injury are to those over 50 in the right-front seat.

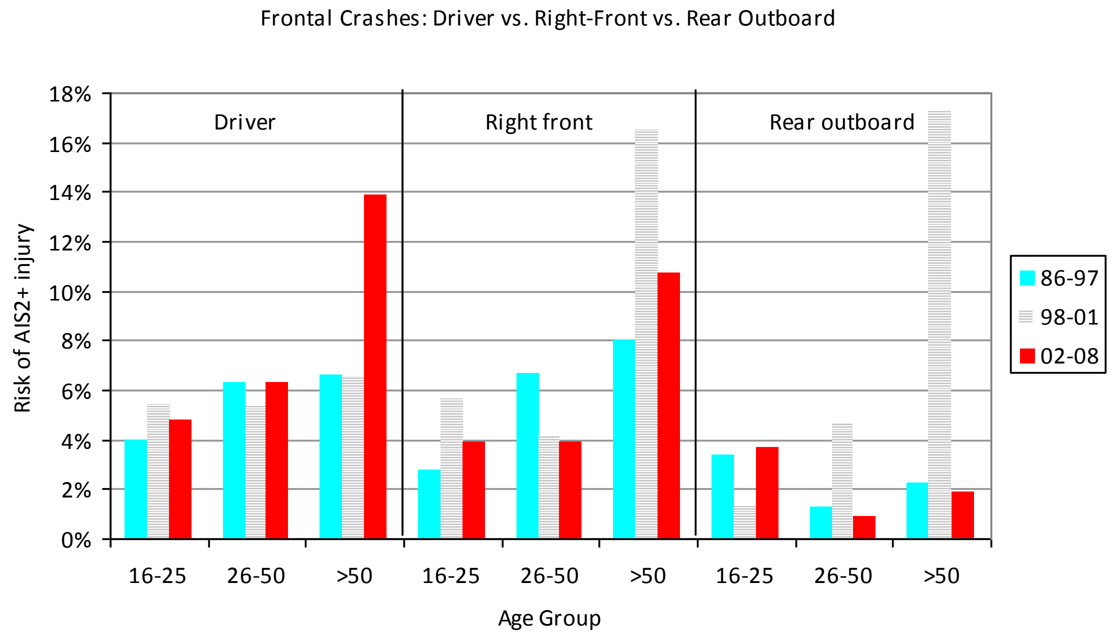



Figure 26. Risk of AIS2+ injury for adults by age group and vehicle model year for each seating position in frontal impacts.

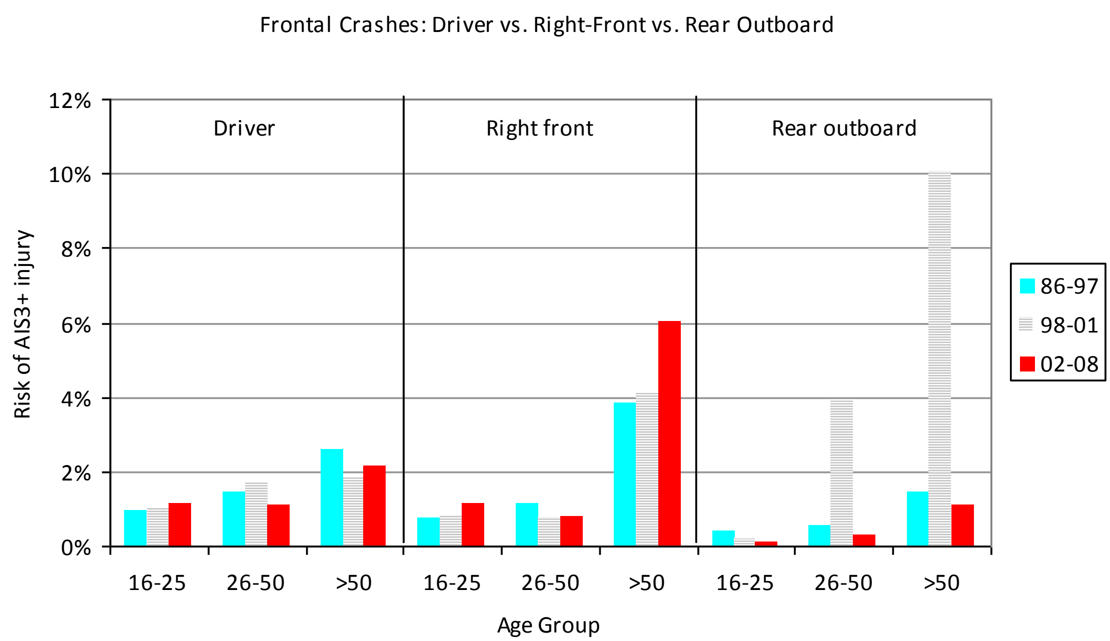



Figure 27. Risk of AIS3+ injury for adults by age group and vehicle model year for each seating position in frontal impacts.

The AIS2+ injury risks in near-side crashes are shown in Figure 28 for children and Figure 29 for adults. AIS3+ injury risks were not calculated because of the small number of rear seat occupants injured at this level. For children, risk of AIS2+ injury in near-side impacts is generally lower in the rear seat than in the front seat. One exception is children aged 0-4 after 1998 vehicle model years because they rarely sit in the front seat. The other exception is 9-12YO in MY98-01 vehicles, where rear seat risk is higher than front seat risk. However, this may partly result from small numbers of belted injured occupants of these ages in the rear seat.

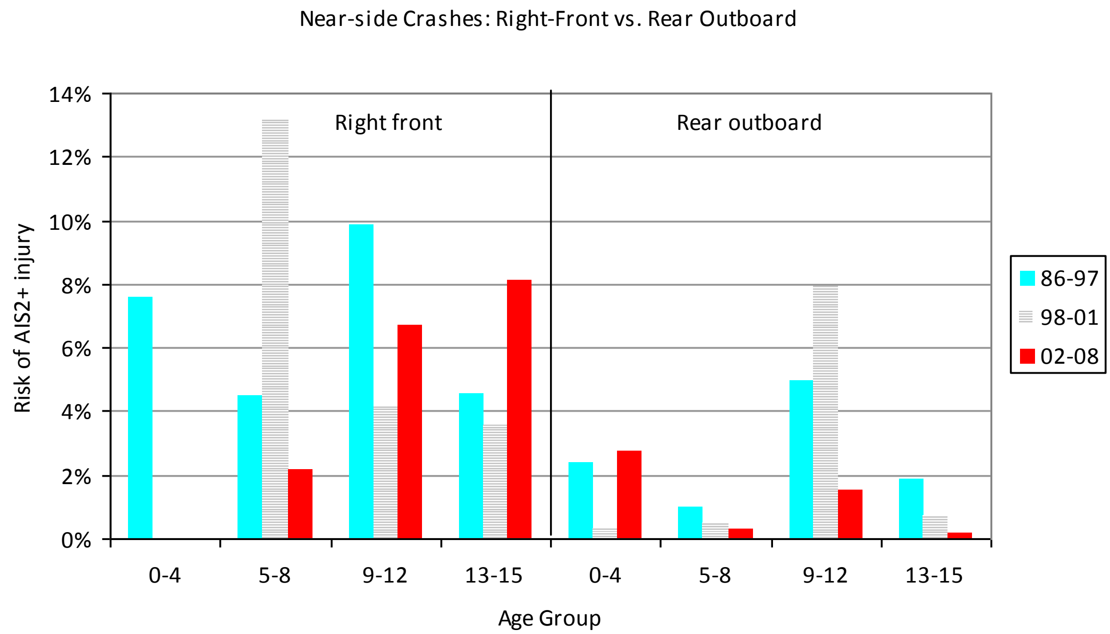



Figure 28. Risk of AIS2+ injury for children by age group and vehicle model year in the front and rear seat in side impacts.

For adults in near-side impacts, the highest risks are generally to rear passengers in older vehicles. This seems reasonable, as regulatory side impact tests were not required until 1996. The other group with high risk in near-side impacts are right-front occupants over age 50 in MY02-08 vehicles. Further investigation indicates that most of these injuries are to the lower extremity and thorax, and three quarters of the injuries are MAIS3 and higher. Besides these highest risk groups, the risk in AIS2+ injury in near-side impacts varies with age group and each seating position. Occupants aged 16-25 have the lowest risk in the rear seat, followed by the right-front position which is similar to the driver. Occupants aged 26-50 have the lowest risk in the right-front seat, followed by the driver position, and the highest risk in the rear seat. Occupants over 50 have the most difference in risk with vehicle model year. Most recently, they have similar risk levels in the driver and rear seating positions, and the highest risk in the right-front seat.

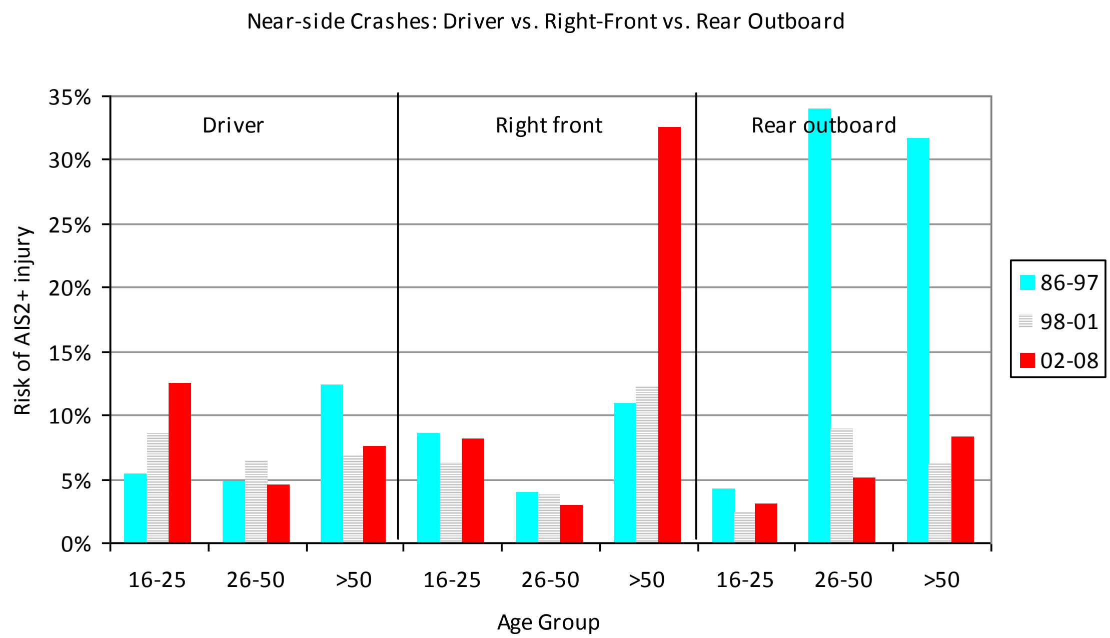



Figure 29. Risk of AIS2+ injury for adults by age group and vehicle model year in the front and rear seat in side impacts.

Appendix B contains plots of the risk of AIS2+ injury for each body region by age group, vehicle model year grouping, and seating row in frontal impacts. Because of the small number of injured occupants in each age group/vehicle model year category in side impacts, similar distributions are not presented for side impacts.

The most interesting finding of the analysis is the high rate of injury risk to occupants over age 50 in the rear seats for vehicle model years 1998-2001. This jump in injury risk is not seen for drivers of these vehicles for this age group, although there is an also elevated risk of AIS2+ injuries to right-front passengers. We hypothesize that vehicles from these model years may be stiffer than those vehicles produced before or after this time period. More detailed review of the model years within this grouping indicates that 1998 and 1999 model years are responsible for most of the increased injury risk.

Figure 30 shows the risk of AIS2+ injury to adult right-front and rear seat occupants by body region for the MY98-01 vehicles. The substantial risks of thorax and spine injuries to those over age 50 in the rear seat, as well as lower extremity injuries, are the main contributions to the high risk of AIS2+ injury for this age/seating group. For the right-front position, thorax and lower extremity are the most commonly injured body regions.

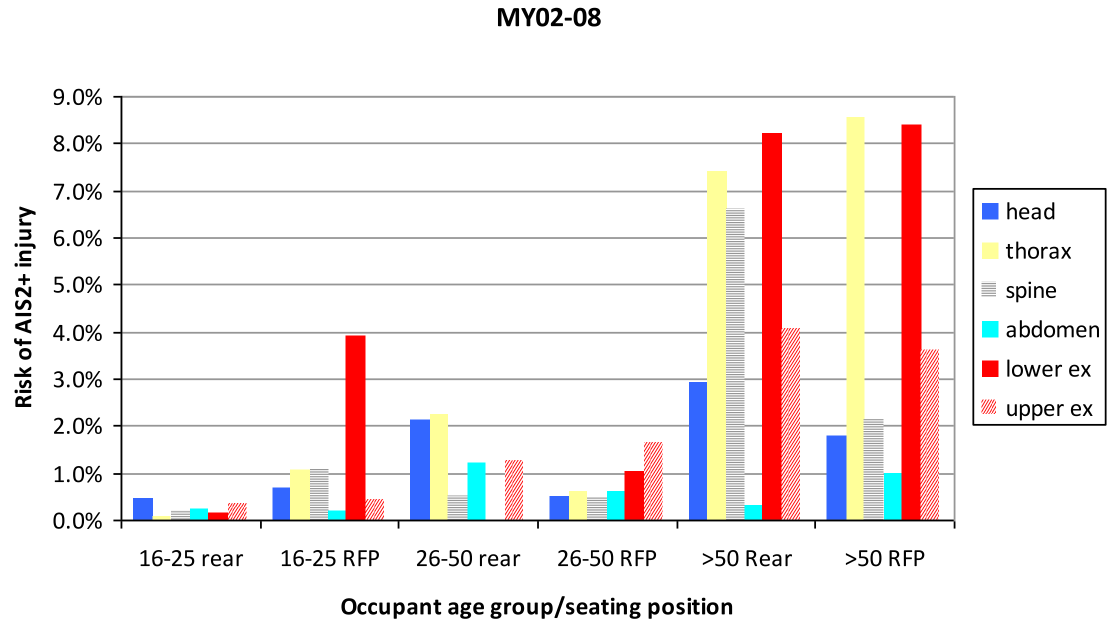



Figure 30. Risk of AIS2+ injury by occupant age group and seating row by body region for MY98-01 vehicles.

Our initial hypothesis for the increased stiffness of these vehicle model years was the high influx of SUVs into the U.S. vehicle fleet at this time. However, analysis by vehicle type indicates that the injury rate is actually worse for passenger cars than SUVs or minivans. Our revised hypothesis was that these vehicles make up the initial fleet of vehicles with depowered airbags, which were exempt from passing a 30-mph barrier test with unbelted ATDs, and used a sled test with a generic sled pulse instead of a barrier test to evaluate unbelted ATDs. Vehicle manufacturers were able to meet requirements for drivers in a 35-mph belted test using advanced belt and airbag systems even if their vehicles were stiffer. For some reason, the right-front restraint systems were not as effective for the older population as the driver restraints. A possible motivation for making vehicles stiffer may have been to obtain better performance in IIHS offset frontal testing, which places high value on maintaining passenger compartment integrity that can be partly achieved with a stiffer vehicle. The IIHS began publicizing their tests in the mid 1990's, so these may be the first set of vehicle model years designed with the IIHS test in mind.

The more recent vehicle model years do not exhibit this elevated injury risk for older adults in the rear seat, and showed some improvement in the right-front position, so manufacturers appear to have resolved the issues either by reducing vehicle stiffness or improving rear seat and right-front restraint systems for older occupants. The lesson to be learned from these data regarding future product development efforts is that vehicles likely to have rear-seat occupants over age 50 with the stiffest vehicle pulses should be the first candidates for improved restraint systems designed to reduce thorax and spine injuries.

For MY02-08 vehicles, the current NASS analysis calculated a lower risk of AIS2+ injury for occupants over 50 in the rear seat compared to those in the front seat for 02-08 vehicles. This differs from the results of Kuppa et al. (2005), who identified the front seat as a safer position for occupants over 50 because of high risk of thoracic injury to belted adults over 50 in the rear seat. The primary reason for these different findings is that the Kuppa et al. analysis included vehicle years 1992-2003, and is likely dominated by the high risk of injury to older rear seat occupants identified for model years 1998-2001 shown in the current study. For more recent vehicle model years, the rear seat is safer for occupants of this age group.

*Comparison of rear seat and front seat injury risks for MY02-08*

Using overall risk of AIS2+ or AIS3+ injury in frontal crashes, risk ratios were calculated for all occupant age groups relative to the risk of a 26-50-year old driver. This group's risk was selected as the denominator because the average driver age for all age groups falls within this range, except for occupants over age 50. Values below 1.0 indicate that the occupant age/seating position/model year group has lower risk than the driver.

The risk ratios for children are in Figure 31 for the right-front position and in Figure 32 for the rear outboard positions. In the right-front position, all child age groups have lower risk than the driver for all vehicle model year groupings, except for 9-12YO AIS2+ injury risk in MY02-08 and 13-15YO AIS3+ injury risk in MY02-08. In the rear seat, all child age groups have lower risk than the driver except for 0-4YO children in the MY98-01 grouping.

Figure 33 and Figure 34 show the risk ratios for adults in the right front and rear outboard positions, respectively. Adult right-front passengers aged 50 and younger have lower injury risk than the driver, while those over 50 have higher injury risk than the driver, particularly with respect to AIS3+ injury. Most adults in the rear seat have lower injury risk than the driver, except for adults over 50 in MY98-01 vehicles, and AIS3+ injured adults from 26-50 in MY98-01 vehicles.

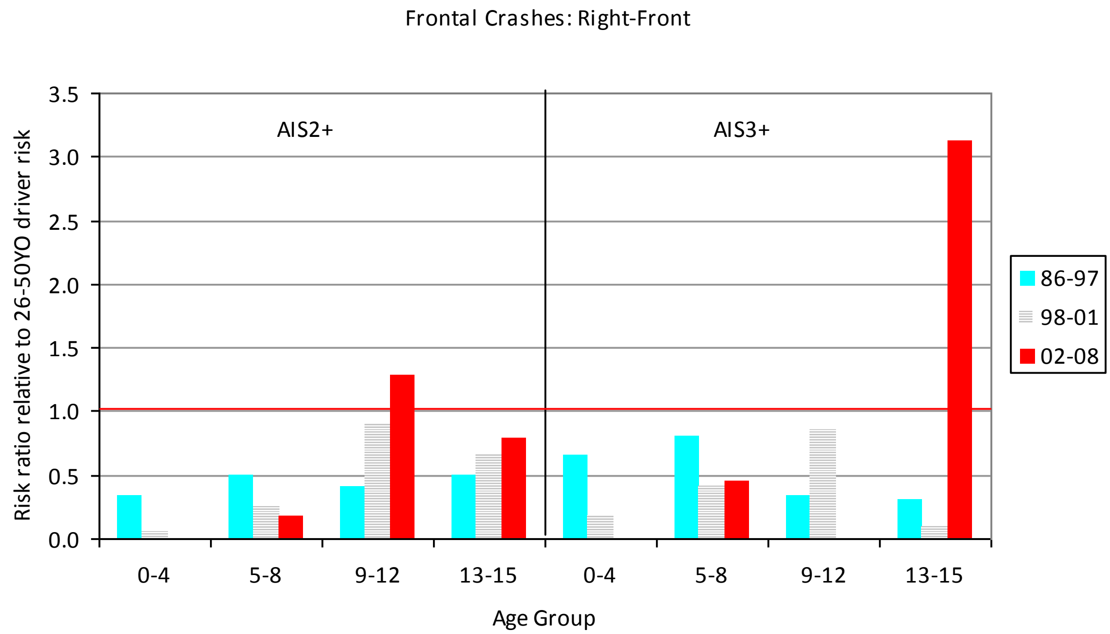



Figure 31. AIS2+ and AIS3+ risk ratios relative to 26-50YO drivers for child right-front occupants.

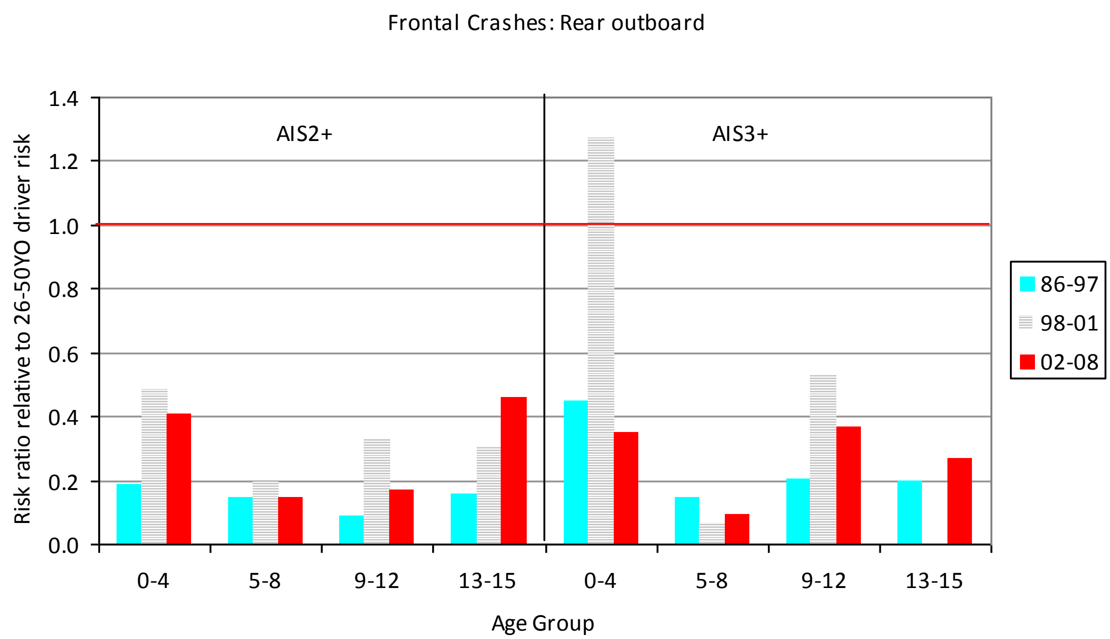



Figure 32. AIS2+ and AIS3+ risk ratios relative to 26-50YO drivers for child rear outboard occupants.

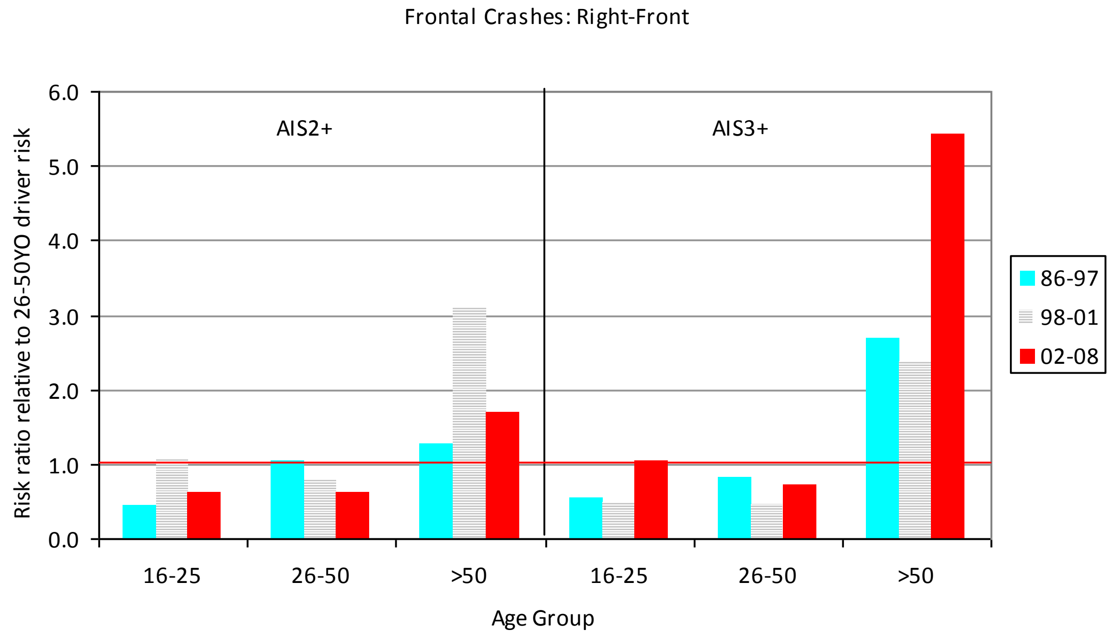



Figure 33. AIS2+ and AIS3+ risk ratios relative to 26-50YO drivers for adult right-front occupants

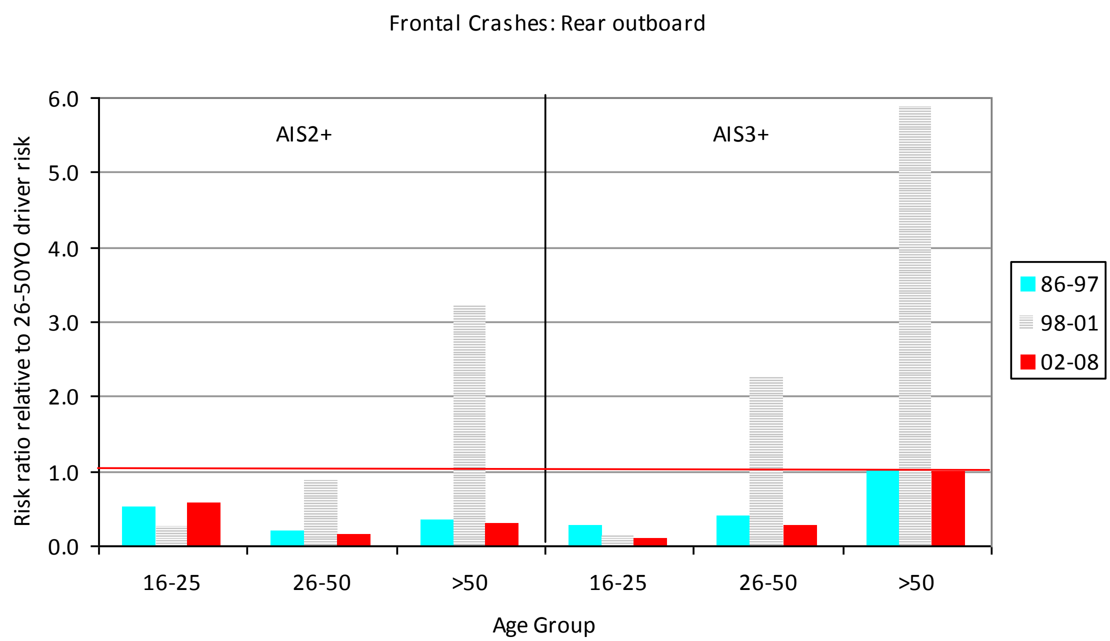



Figure 34. AIS2+ and AIS3+ risk ratios relative to 26-50YO drivers for adult rear outboard occupants

For many of the groups in the preceding graphs, the risk ratio relative to the driver has become less advantageous when comparing the most recent model years (02-08) to the earliest model years (86-97). This could partly result from improvements in driver protection, but would only affect ratios of AIS3+ injury, which changed from 1.4% to

1.1% for the 26-50YO driver between these model years, as risk of AIS2+ injury for 26-50YO drivers is the same for MY86-97 and MY02-08 vehicles. This trend agrees with the results of Winston et al. (2007), who showed that the advantages of rear seating for children decreased with newer vehicle model years.

To clarify changes in risk with model year, a risk ratio was calculated for each age group/seating position to compare the risk for MY02-08 to that of MY86-97 for AIS2+ and AIS3+ injuries. These risk ratios are shown for front seat occupants in Figure 35 and rear outboard occupants in Figure 36. For the fourteen different age group/seating positions, eight of them have higher risk of AIS2+ injury in more recent model year vehicles than they did in the earliest model year vehicles. Five age group/seating positions have higher risk of AIS3+ injury in more recent model year vehicles than in the earlier model year vehicles. Because of small sample sizes for some of these occupant groups, risk ratios greater than 1.5 would be of greatest concern.

A possible reason for increase in risk of AIS2+ injuries is a reduction in risk of AIS3+ injuries. For 9-12YO in the right-front and 0-4YO in the rear seat, an increase in AIS2+ injuries may be partly due to a reduction in AIS3+ injuries. However, relative risk of both AIS2+ and AIS3+ injuries are substantially higher in MY02-08 than MY86-97 for 13-15 in the front seat, as well as 9-12YO and 13-15YO in the rear seat.

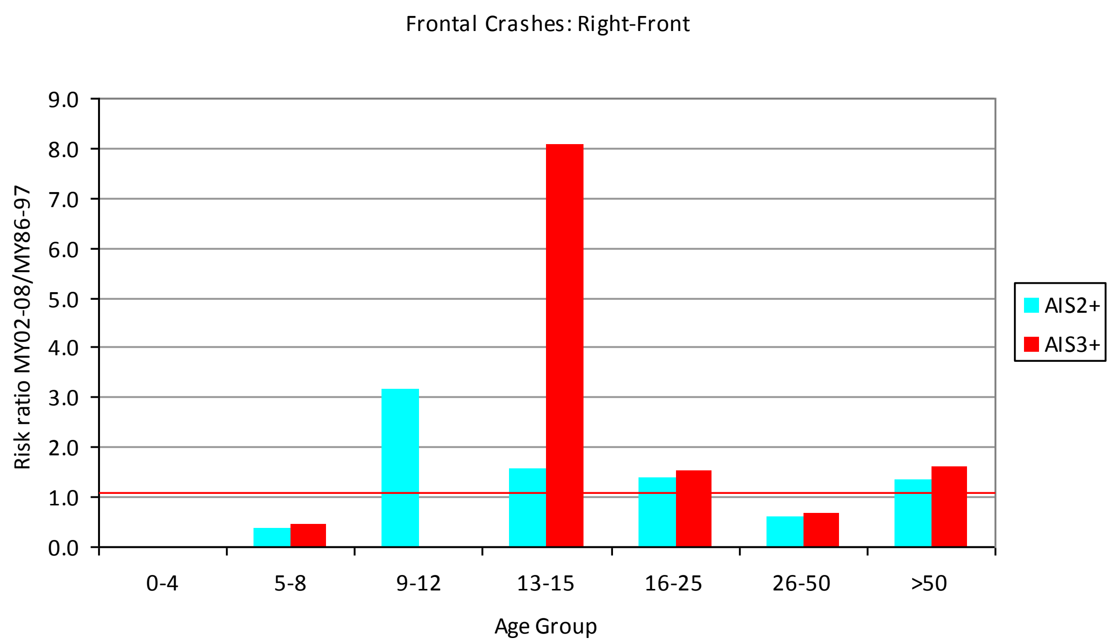



Figure 35. Risk ratios between MY02-08 occupants and MY86-97 occupants by age group and injury severity level for right-front occupants.

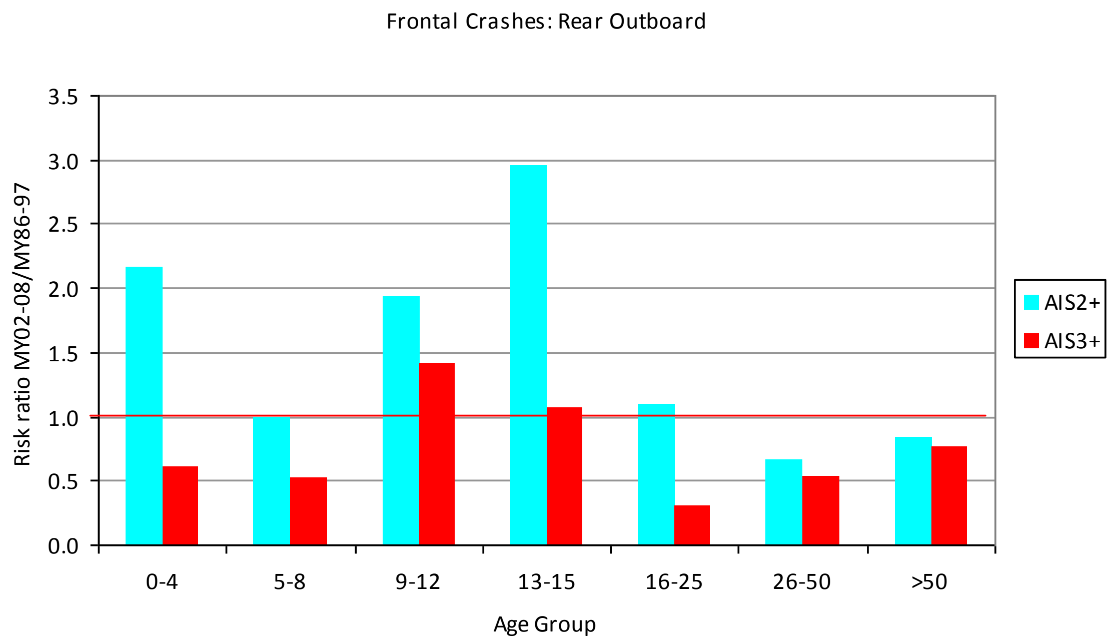



Figure 36. Risk ratios between MY02-08 occupants and MY86-97 occupants by age group and injury severity level for rear outboard occupants.

The AIS2+ risk ratios for children in near-side impacts are shown in Figure 37. Risk is almost always lower for children in the rear seat relative to the driver. In addition, the rear seat risk ratio is either similar or reduced with later vehicle model year, suggesting no decrease in safety relative to the driver over time. For children in the right-front position, some age group/model year combinations have higher risk than the driver. Of most concern are the 9-15YO children in MY02-08 vehicles, which are higher than the preceding model year groupings.

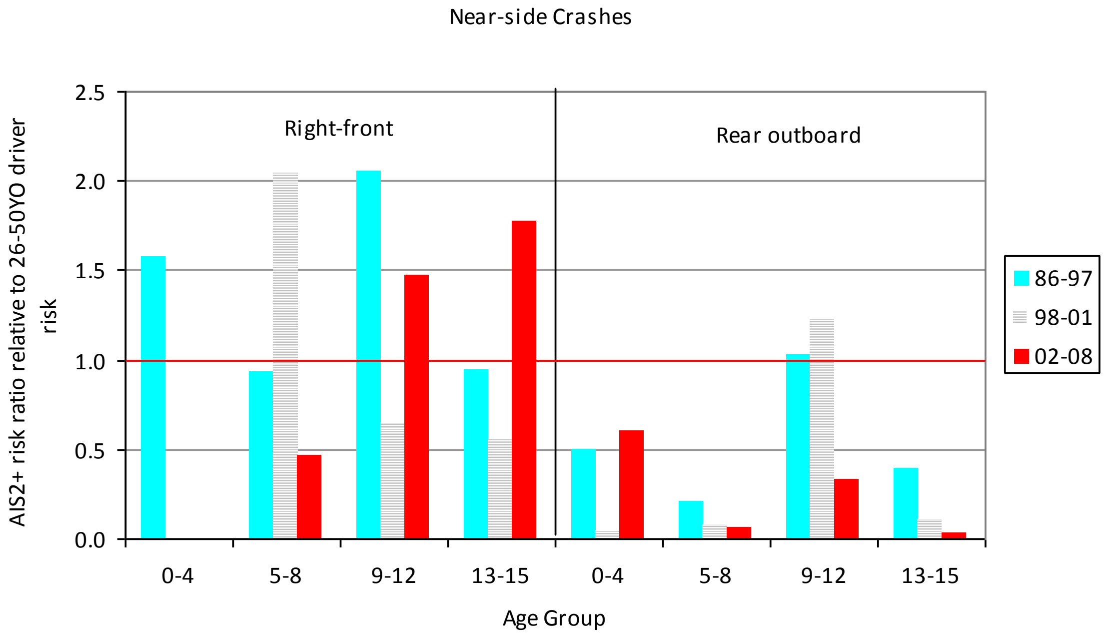



Figure 37. AIS2+ risk ratios relative to 26-50YO drivers for child occupants.

The AIS2+ risk ratios in near-side crashes for adults relative to the 26-50YO driver are shown in Figure 38. Older adults in the right-front seat for MY02-08, as well as rear seat occupants in MY96-97 vehicles, have substantially higher risks than drivers in near-side impacts. The rear seat risk ratios indicate that most other rear seat passengers have lower risk than the driver, except for MY02-08 rear seat occupants over age 50. For the right-front position, occupants aged 26-50 have lower risk than the driver, but adults younger and older than this age generally have higher risk than the driver for most vehicle model years.

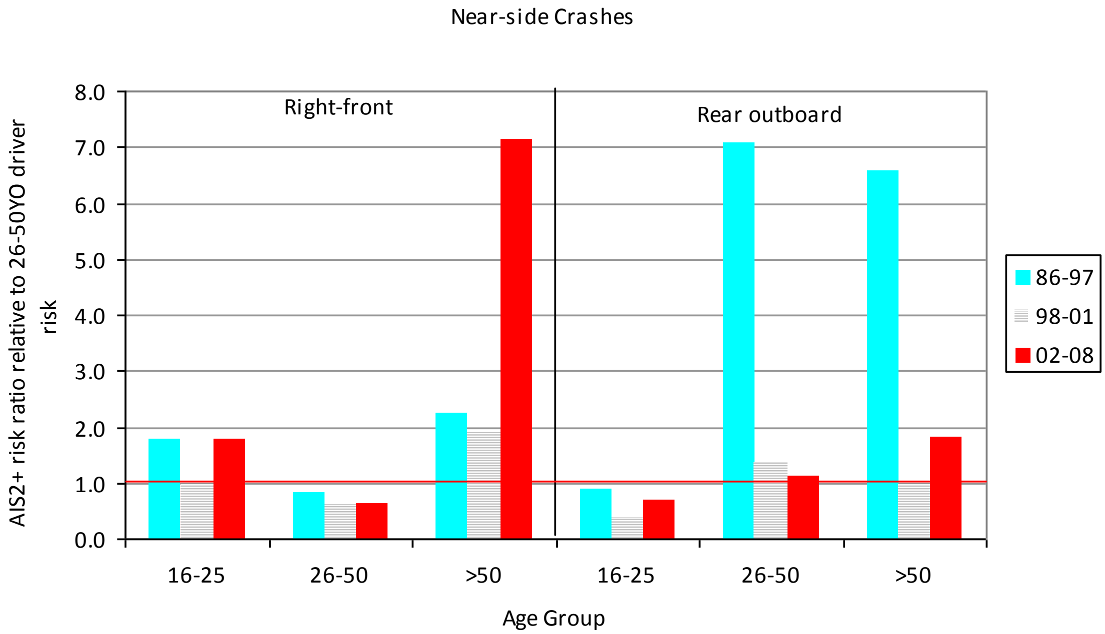



Figure 38. AIS2+ risk ratios relative to 26-50YO drivers for adult occupants.

*Prioritizing countermeasures in the rear seat for frontal crashes*

Appendix C contains plots comparing the risk of AIS2+ injury in frontal crashes to each body region for front and rear seat occupants by age group using risk values from MY02-08 vehicles. Based on these plots, Table 5 lists the body regions with the highest risk of AIS2+ injury for restrained, rear outboard occupants in frontal crashes for MY02-08 vehicles. All of the risk values are less than 2%. However, some of these risk values for occupants in the rear seat are higher than for occupants in the front seat, indicating that implementing safety countermeasures in the rear seat may address injuries to these body regions.

Table 5. Body regions with highest risk of AIS2+ injury in frontal crashes in the rear seat by age group for MY02-08 vehicles

| Age Group | Body region | Risk |
|---|---|---|
| 0-4 | Lower extremity<br>Face | 1.2%<br>0.9% |
| 5-8 | Abdomen* | 0.5% |
| 9-12 | Upper extremity* | 1.0% |
| 13-15 | Upper extremity*<br>Head | 2.0%<br>1.2% |
| 16-25 | Upper extremity*<br>Face* | 2.0%<br>1.0% |
| 26-50 | Upper extremity | 0.6% |
| >50 | Thorax<br>Abdomen* | 1.4%<br>0.8% |

* Risk in rear seat is higher than in front seat

Unfortunately, upper extremity is frequently the body region with the highest risk, and there are few countermeasures available that directly reduce injury to the upper extremities. An injury countermeasure frequently mentioned in the literature is additional padding of the rear of the front seat backs, which would likely reduce lower extremity and head/face injury in 0-4YO children, head injury in 13-15YO, and face injury in 16-25YO, as well as provide some benefit with regard to upper extremity injury.

Although risk of abdomen injury for 5-8 year-olds is only 0.5%, it is higher in the rear seat than in the front seat, and has increased in MY02-08 vehicles compared to MY86-97 vehicles. Feasible countermeasures for reducing abdomen injury are available, since use of a booster seat has been demonstrated to practically eliminate abdomen injuries for children in this range. Thus implementation of a built-in booster seat, or shorter vehicle cushion length coupled with improved lap belt geometry, would offer a means of reducing abdomen injury in restrained 5-8YO children.

For older adults in the rear seat, thoracic injury presents the greatest risk, followed by abdomen injury. Efforts to mitigate abdominal injury such as improved lap belt geometry may lead to increased thoracic loading as likelihood of submarining is reduced. Thus efforts to reduce abdominal injury risk should be accompanied by measures to reduce thoracic loading such as seatbelt load limiters, particularly in vehicles where older adults are likely to sit in the rear seat.

Another strategy for prioritizing rear-seat occupant countermeasures is to see which age groups show the largest decrease in rear seat safety between MY02-08 and MY86-97 as indicated in Figure 36. This would give highest priority to protecting occupants aged 13-15 and 9-12. However, the number of injured restrained rear occupants in these age groups is small for both of these model year groupings, so this may have led to the larger risk ratios between newer and older vehicles.

Figure 39 shows the distributions of AIS2+ injury for rear seat occupants according to driver age group. Since vehicle purchases vary with age of the driver, these distributions may help provide input on what rear seat injury prevention measures should be targeted for vehicles with different driver demographics. Thus head and face impact protection is of greater concern for vehicles with drivers under age 50, while thorax and abdomen are the body regions of highest concern for vehicles with drivers over age 50.

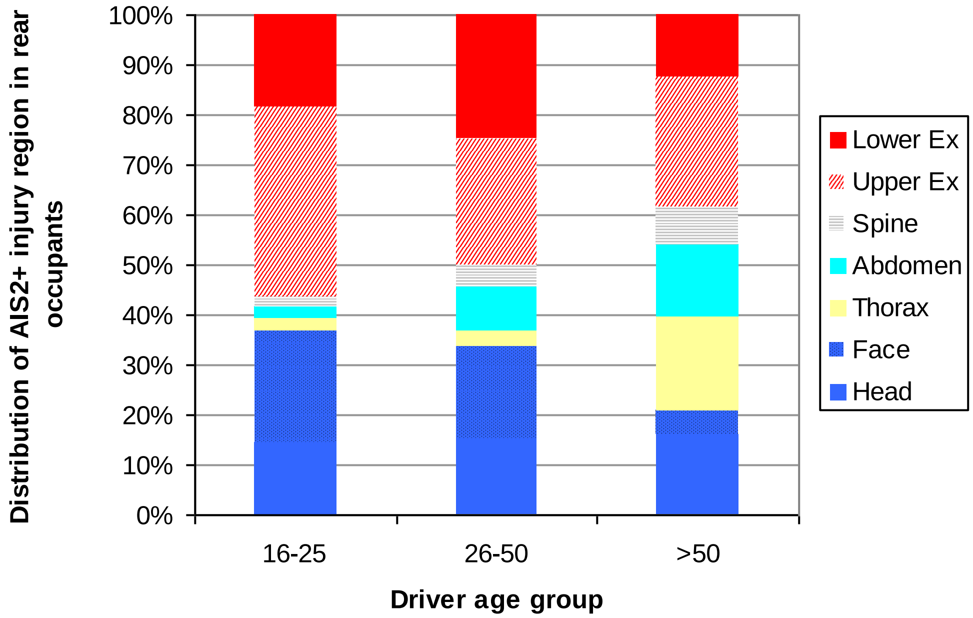



Figure 39. Distribution of AIS2+ injury regions for rear occupants by driver age groups.

While the preceding analyses detail the risks for different rear seat occupants, prioritizing occupant protection for rear seats should also consider exposure. For example, a certain age group may have a high risk of injury to a particular body region, but they may travel less than other age groups or travel with safer drivers, which lowers their exposure to crashes and the importance of that particular injury. Figure 40 shows the estimated number of rear seat occupants in each age group with AIS2+ injuries in frontal crashes, based on the risk of injury to the age group and the crash exposure of drivers of different ages. The risk values and rear occupant seating patterns used are those from MY02-08 vehicles. To estimate an annual number of injured rear seat occupants, the numbers were adjusted to the expected number of injuries if MY02-08 vehicles made up the entire fleet.

Based on this analysis, rear seat occupants over age 50, even though they usually have higher injury risks than other adults, do not comprise a very big portion of injured rear seat occupants, simply because they travel less. Because adults aged 16-25YO most frequently travel with the most unsafe drivers (those 16-25YO), injuries to these occupants in the rear seat is the largest problem for adults even though they usually have lower risk of injury than other adults. Although children aged 0-4 in CRS have the most effective restraints of all age groups, their frequent travel with drivers in the two younger adult age groups makes them a substantial part of the rear seat occupant injury problem. The 0-4YO age group receives more injuries than other child age groups because they more frequently travel in passenger vehicles; older children likely have more limited exposure because they are in school and travel by school bus.

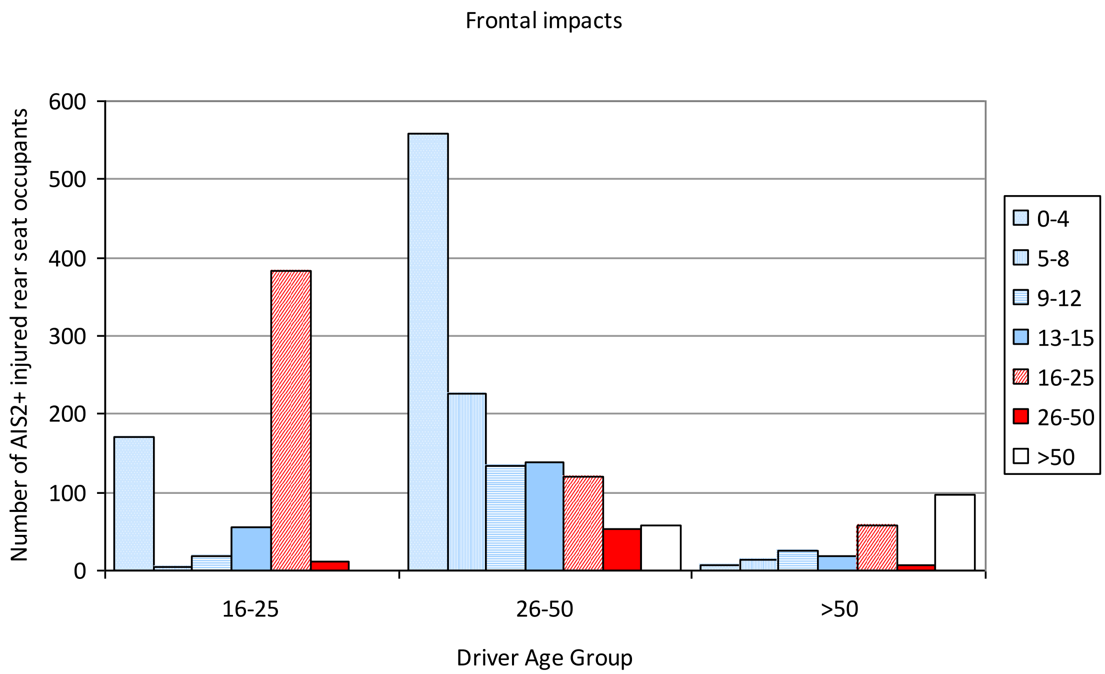



Figure 40. Distribution of AIS2+ injured rear occupants by age and driver age group based on risk and exposure in frontal crashes.

Figure 41 shows the proportion of AIS2+ injured rear seat occupants by age group, obtained by summing results in the previous graphs across driver age. Adults, who make up approximately 30% of rear seat occupants, make up approximately 36% of the injured rear seat occupants. Children aged 0-4 make up the largest percentage of AIS2+ injured rear seat occupants.

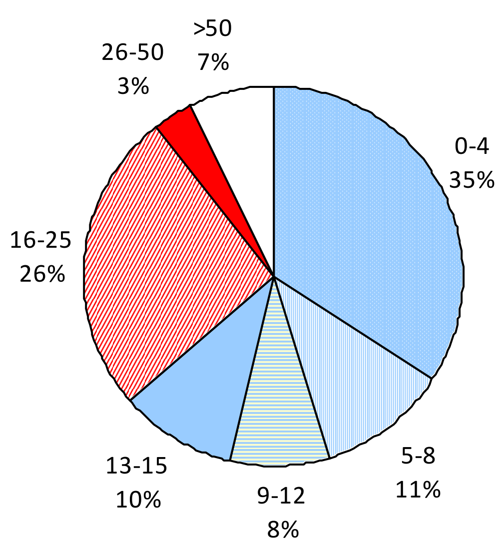



Figure 41. Proportion of AIS2+ injured rear seat occupants by age group in frontal crashes.

*Prioritizing countermeasures in the rear seat for side impacts*

Table 6 lists the risk of AIS2+ injury by age group for near-side impacts in MY02-08 vehicles. Because of the limited numbers of injured rear seat occupants, detailed analysis of risk by body region is not possible. Adults have higher risks in the rear seat than children, and their risk increases with age. However, among children, the youngest children have the highest risk in near-side impacts in the rear seat.

Table 6. Risk of AIS2+ injury in near-side occupants in the rear outboard seating position for MY02-08 vehicles

| Age Group | Risk |
|---|---|
| 0-4 | 2.8% |
| 5-8 | 0.3% |
| 9-12 | 1.5% |
| 13-15 | 0.2% |
| 16-25 | 3.1% |
| 26-50* | 5.1% |
| >50 | 8.3% |

* Risk in rear seat is higher than in front seat

Another approach for prioritizing rear seat safety needs in near-side impact is to identify which age groups have experienced a decrement in safety with vehicle model year using the risk values in Figure 37 and Figure 38. Only 0-4YO have a higher risk ratio relative to the driver in MY02-08 vehicles compared to MY86-97 vehicles.

The risks of AIS2+ injury to rear seat occupants in near-side crashes were used together with rear seating distribution patterns for different driver age groups to estimate the annual number of rear seat occupants who sustain AIS2+ injuries. Risks and seating patterns were based on MY02-08 vehicles and adjusted to provide an estimate if these vehicles made up the entire fleet. These estimates are shown in Figure 42. Children aged 0-4 are most frequently injured in near-side impacts because of their higher injury risk compared to other child age groups and because of their higher exposure to crashes. For adults, those aged 16-25 are most frequently injured because they most frequently ride with the most unsafe drivers (those age 16-25).

The distribution by age group of rear seat occupants injured in near-side crashes is shown in Figure 43. In near-side impacts, adults comprise 54% of the injured rear seat population even though they make up only 30% of rear seat occupants. Children aged 0-4 make up 38% of the injured rear seat population for this crash mode.

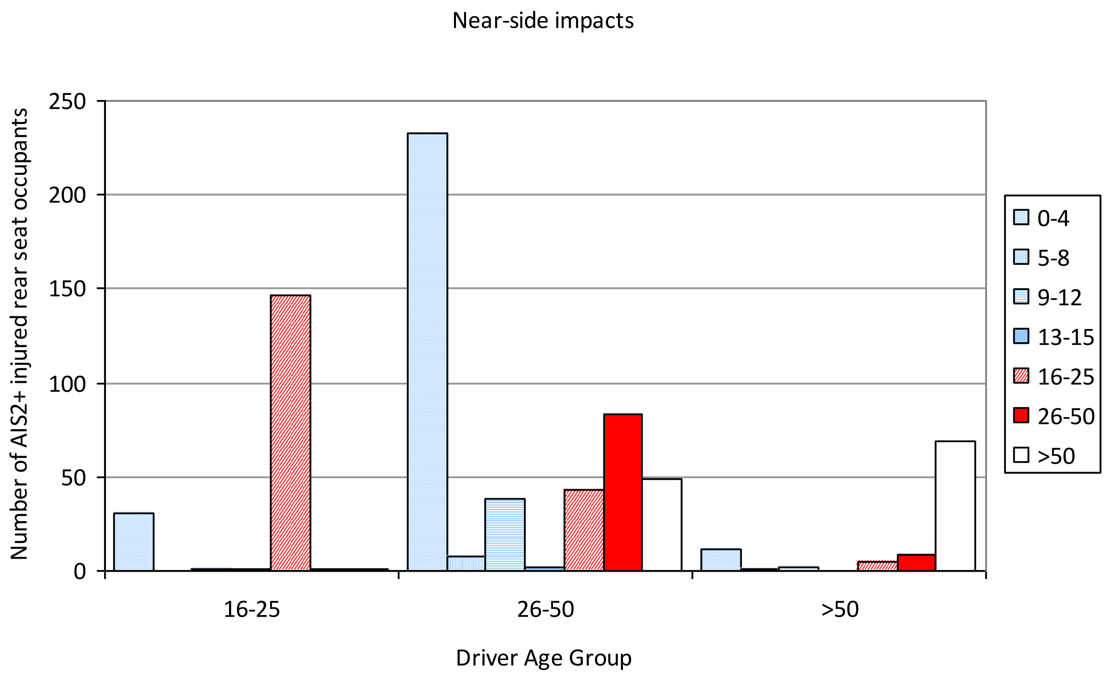



Figure 42. Distribution of AIS2+ injured rear occupants by age and driver age group based on risk and exposure in near-side crashes.

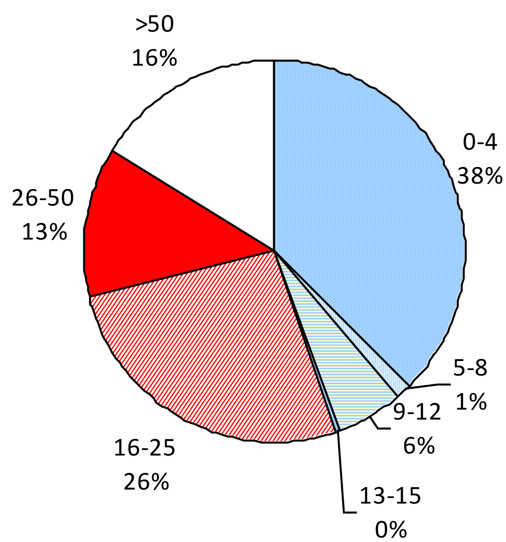



Figure 43. Proportion of AIS2+ injured rear seat occupants by age group in near-side crashes.

## Key Points from NASS Injury Analysis

- Body region injured varies with occupant age. Among rear seat occupants in frontal crashes, 5-8YO have the greatest proportion of abdomen injuries, 16-25YO have the greatest proportion of upper extremity injuries, and >50YO have the greatest proportions of spine and thorax injury.
- Analysis of rear seat injury patterns is limited by the small number of injured rear seat occupants, particularly in side impacts.
- In frontal and near-side crashes, children have lower risk of injury in the rear seat than in the right-front seat.
- In frontal crashes, adults have lower injury risk in the rear seat with the exception of adults >50YO in MY98-01 vehicles.
- In near-side crashes, only adults aged 16-25 in the rear seat have consistently lower risk levels than those in the front seat.
- Vehicle model years 1998-2001 have high risk levels for adults over 50 in the rear and right-front seat. It is hypothesized that requirements to allow depowered airbags led to stiffer vehicles that were particularly injurious to these occupants.
- When comparing risk ratios relative to the driver in frontal crashes, values for children (but not adults) in MY02-08 vehicles are frequently higher than those for in MY86-97 vehicles, indicating decrements decreases in safety over time. These changes may partly result from a decrease in AIS3+ injury risk resulting in an increase of AIS2+ injury risk.
- For frontal crashes, rear occupants aged 9-12 in MY02-08 vehicles show increases in both AIS2+ and AIS3+ risk relative to MY86-97 vehicles.
- For near-side impacts, risk ratios for children in the rear seat relative to the driver are generally better for more recent vehicle model years.
- Based on highest risk levels for each age group seated in the rear seat, preventing upper extremity injuries, lower extremity injuries in occupants aged 0-4YO, and thorax injuries in occupants over age 50 would be the highest priority.
- Using a combination of risk and exposure based on different ages of drivers in MY02-08 vehicles, occupants aged 0-4 comprise 35% of the AIS2+ injured rear seat occupant population. Adults aged 16-25YO make up 26% of this population.
- In frontal crashes, the highest rear seat protection priorities should be preventing lower extremity and head/face injuries in 0-4YO, who travel with drivers aged 16-50. The next highest priority is preventing upper extremity injuries in 16-25YO, who travel with other 16-25YO. The third highest priority is preventing abdomen injury in 5-8YO, caused by poor belt geometry and long seat cushion lengths. In vehicles driven by adults over age 50, countermeasures to reduce thoracic loading in the rear seat are high priority.
- In near-side impacts, adults have higher injury risks than children and they increase with occupant age. Among children, those aged 0-4 have the highest risk level in near-side impacts.
- Based on a combination of risk and exposure in near-side impacts, adults make up approximately 30% of the occupants in the rear seat but are 54% of the injured rear seat population.

- Children aged 0-4 make up 38% of the injured rear seat occupants in near-side impacts.
- In near-side impacts, preventing head injuries in 0-4YO should have highest priority, followed by preventing thorax, spine, and head injuries in adults caused by loading from the vehicle interior.

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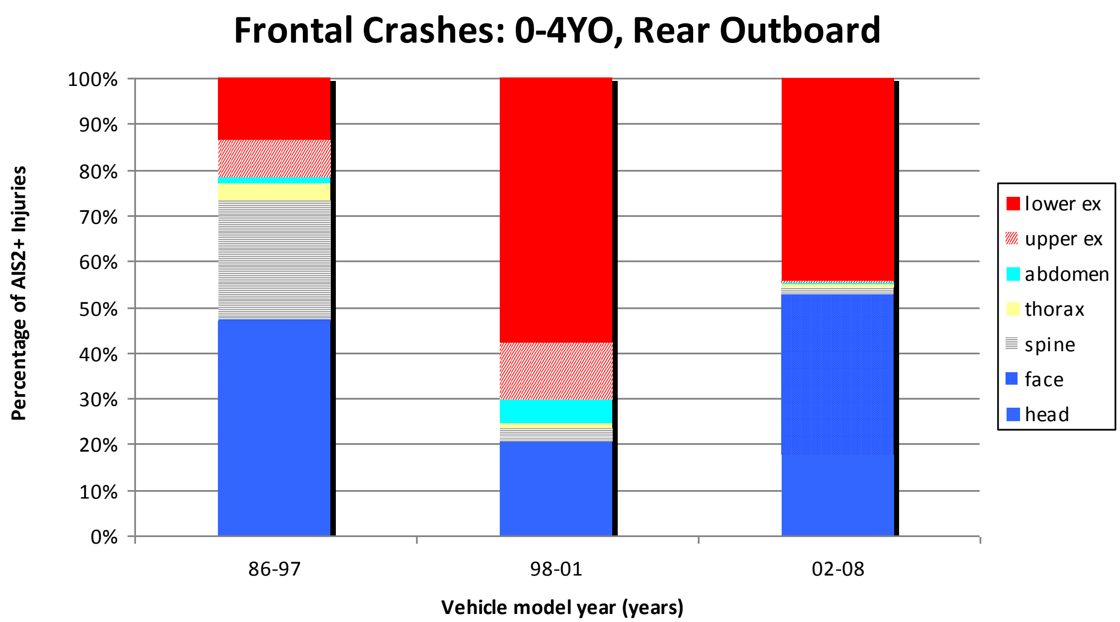
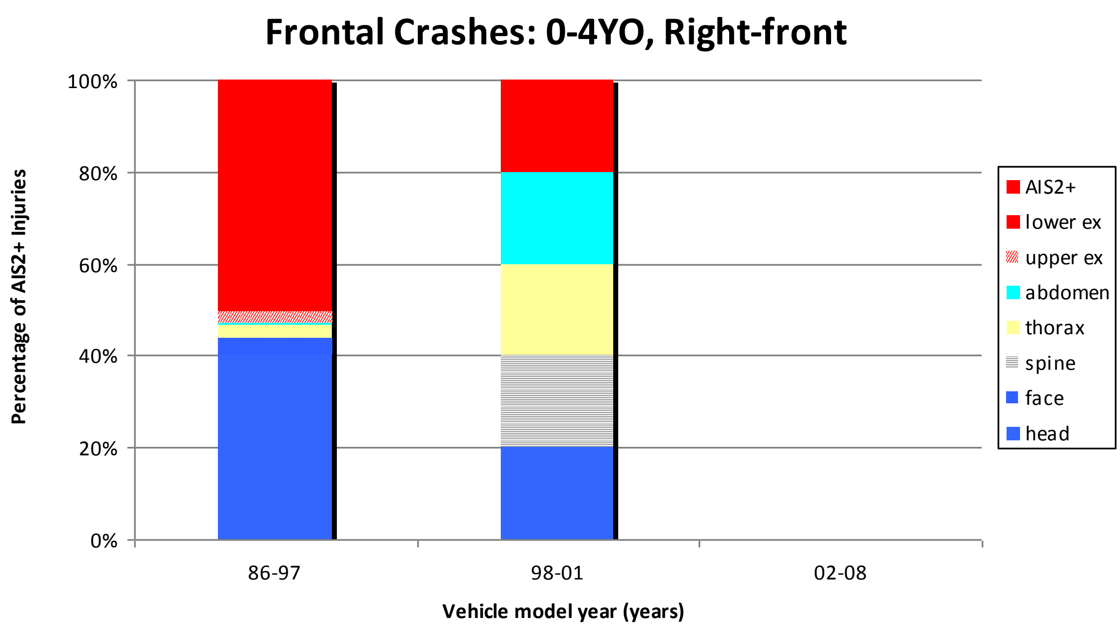
# APPENDIX A

Distribution of AIS2+ injury by body region for frontal impacts by age group, seating row, and vehicle model year grouping

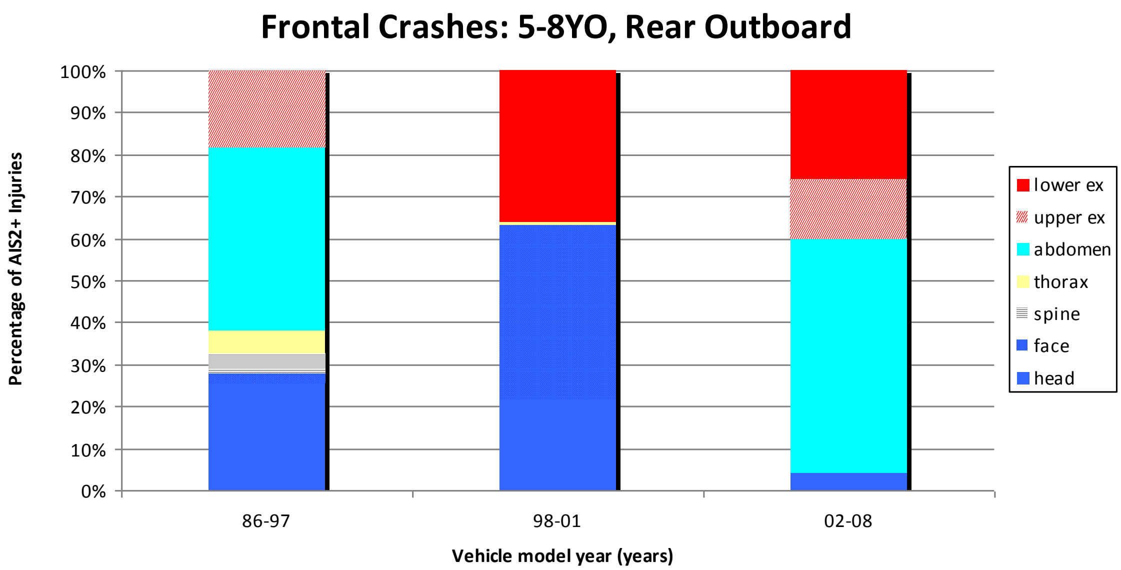
Note: scale on risk plots varies with age group

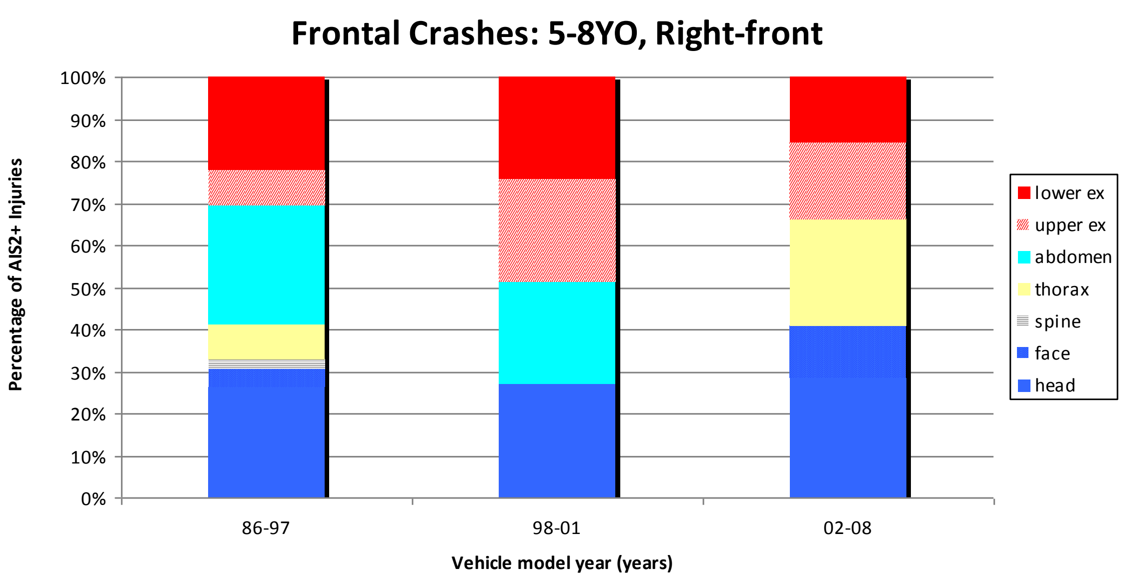


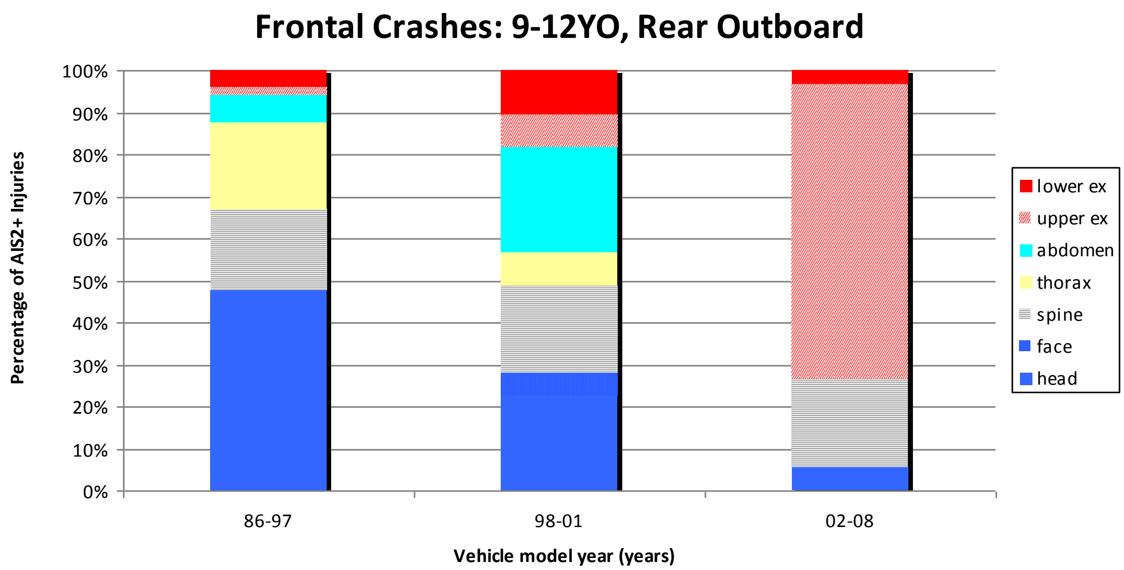
Frontal Crashes: 0-4YO, Rear Outboard
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

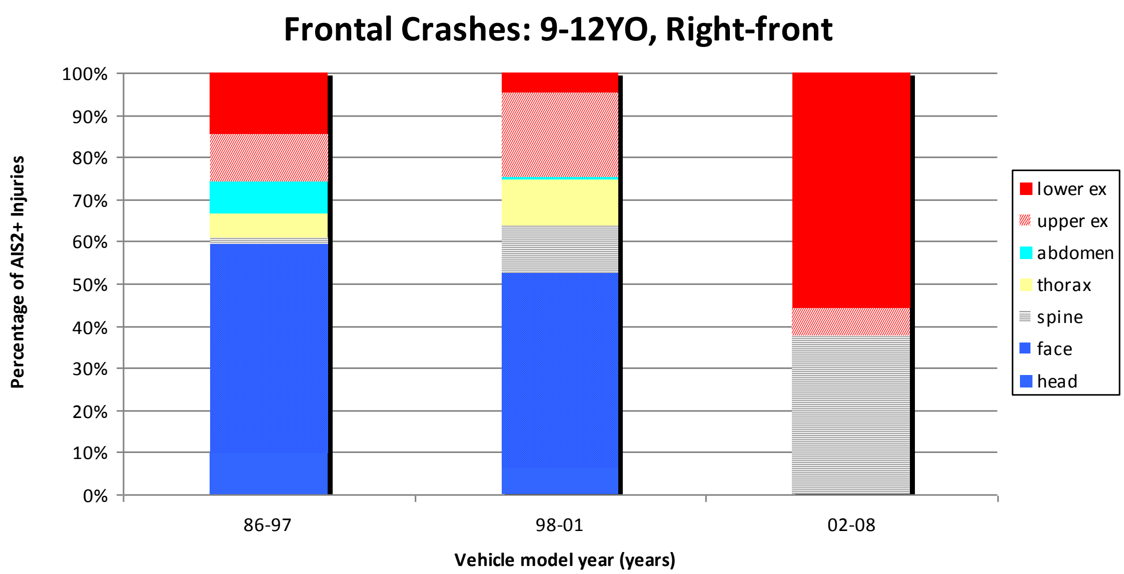



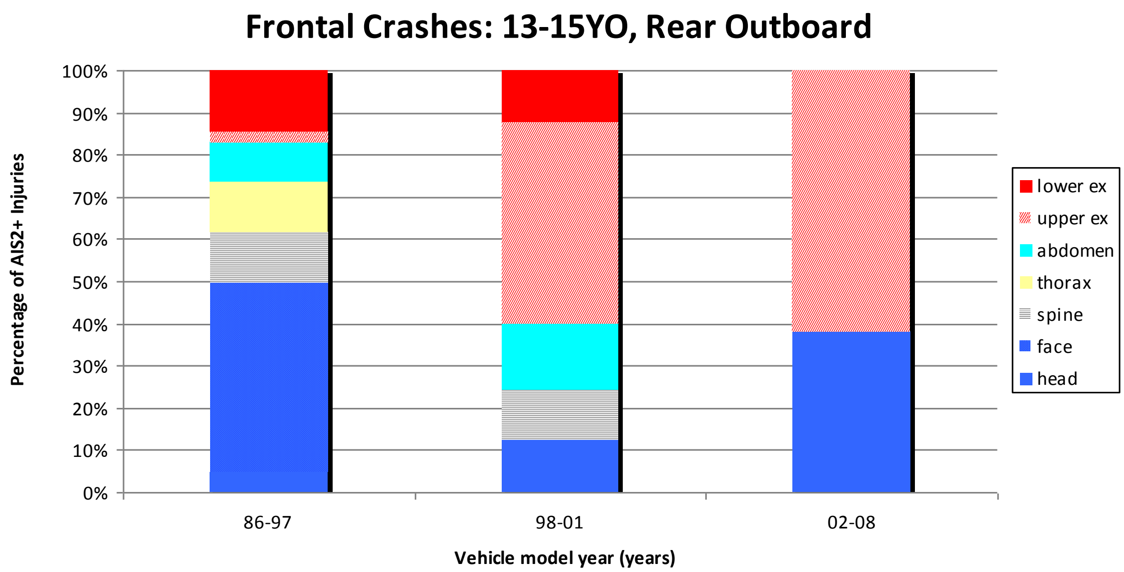
Frontal Crashes: 0-4YO, Right-front
100%
80%
60%
40%
20%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
AIS2+
lower ex
upper ex
abdomen
thorax
spine
face
head

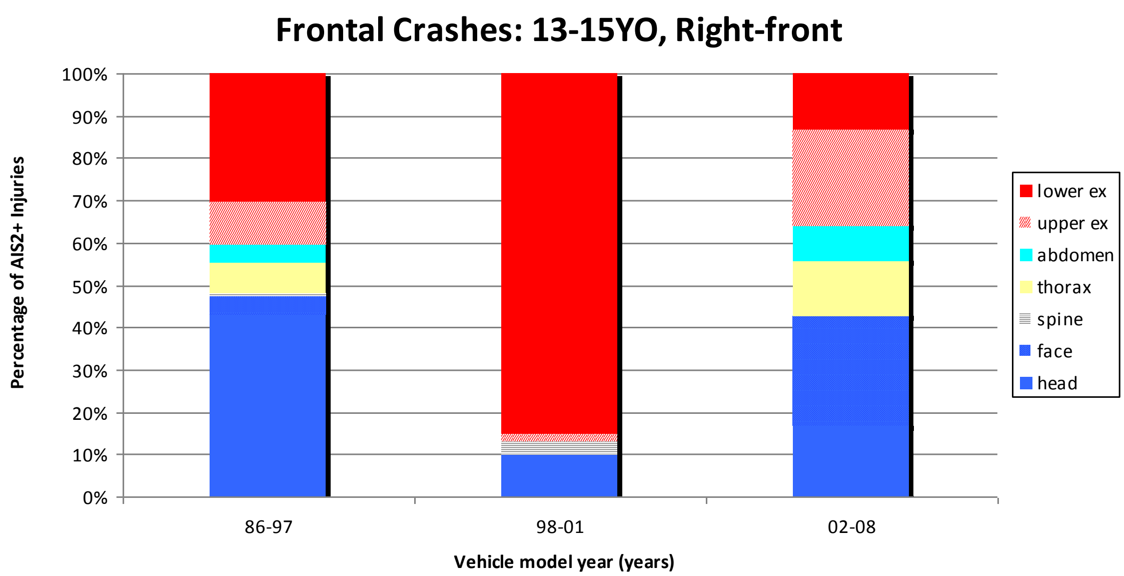

Frontal Crashes: 5-8YO, Rear Outboard
Percentage of AIS2+ Injuries
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

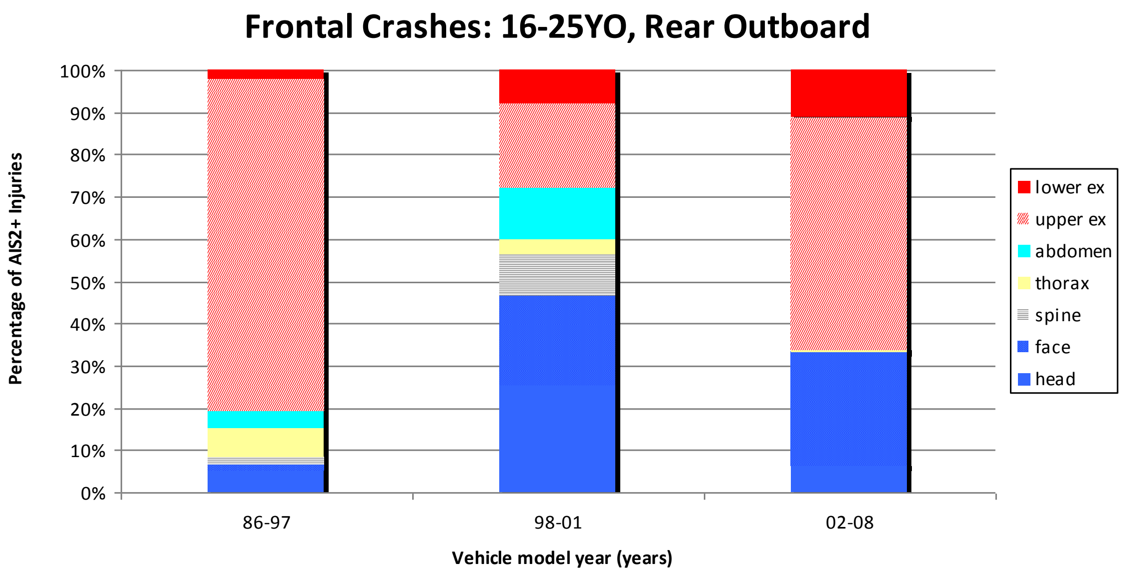

Frontal Crashes: 5-8YO, Right-front
Percentage of AIS2+ Injuries
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

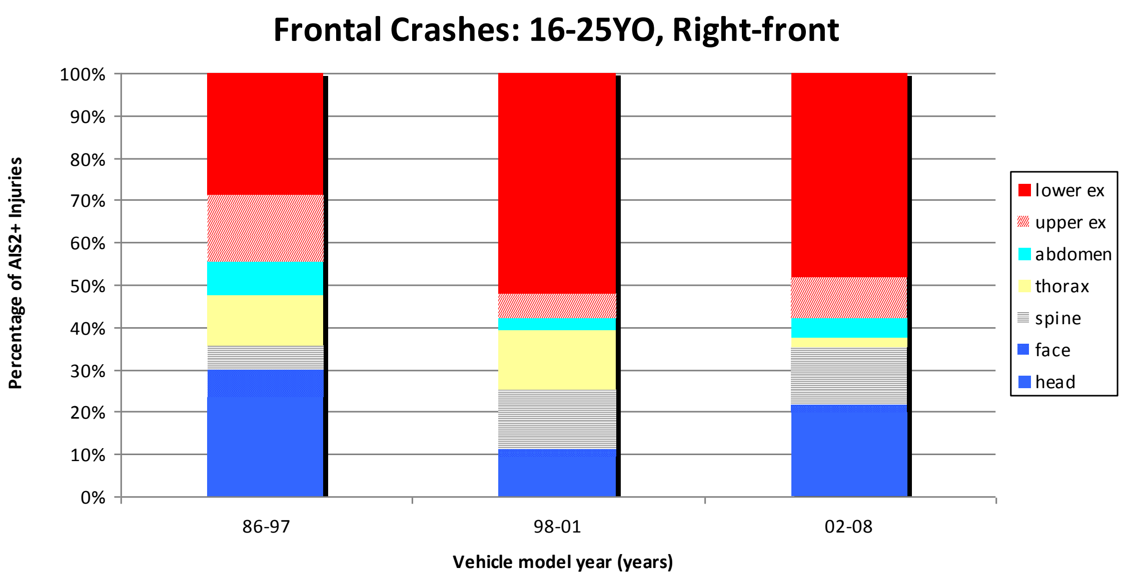

Frontal Crashes: 9-12YO, Rear Outboard
Percentage of AIS2+ Injuries
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

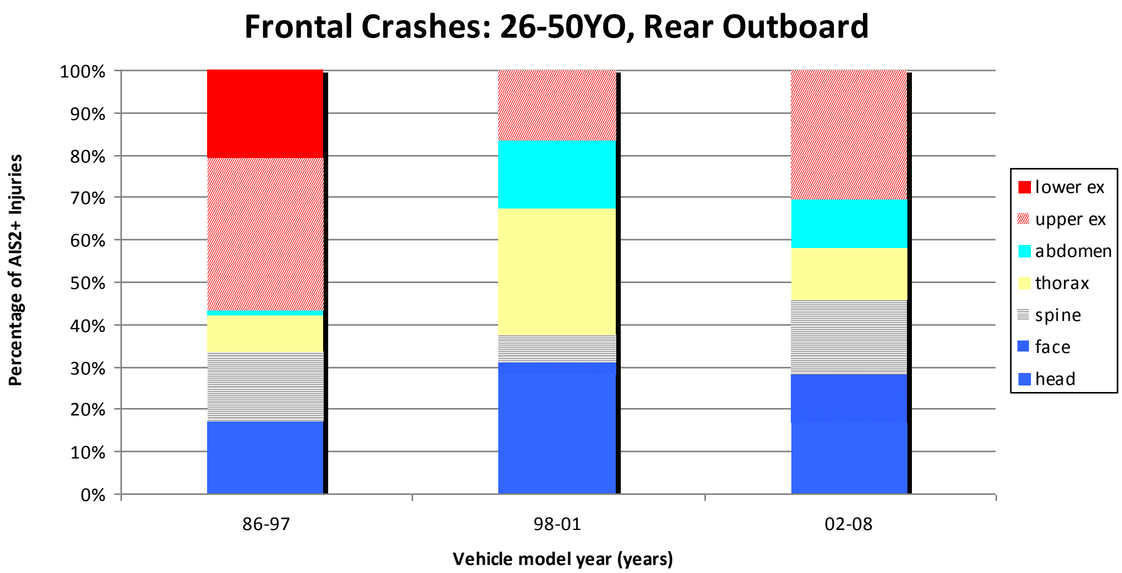

Frontal Crashes: 9-12YO, Right-front
Percentage of AIS2+ Injuries
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

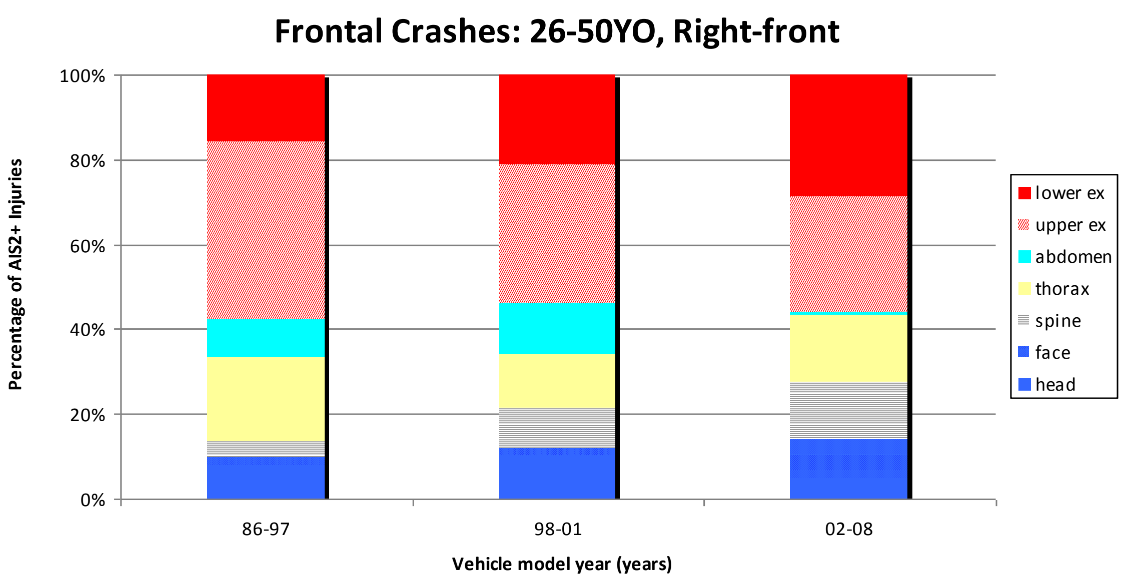

Frontal Crashes: 13-15YO, Rear Outboard
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

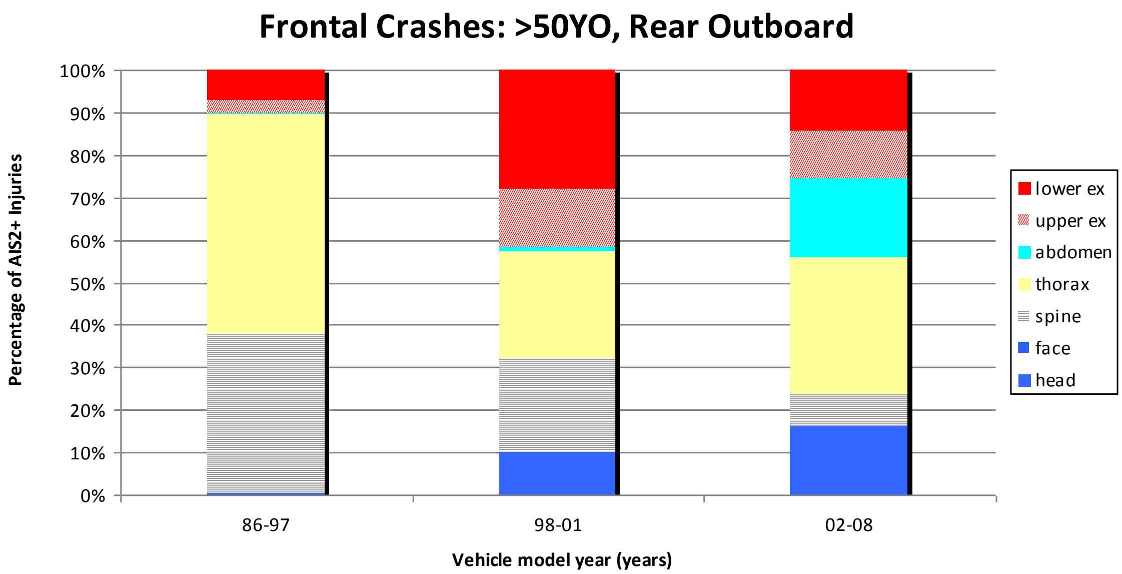

Frontal Crashes: 13-15YO, Right-front
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

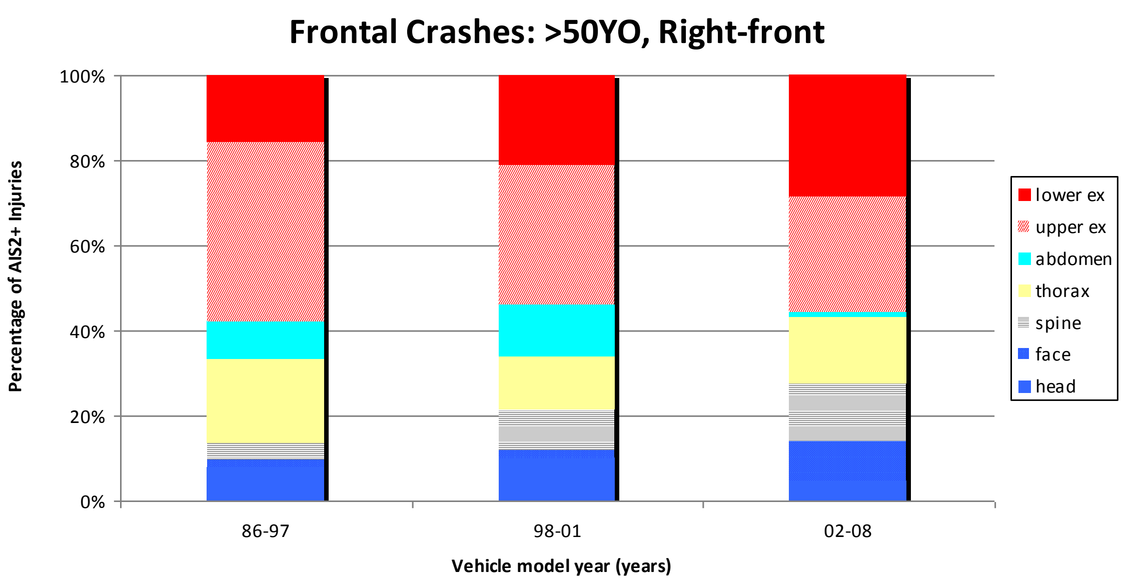

Frontal Crashes: 16-25YO, Rear Outboard
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head


Frontal Crashes: 16-25YO, Right-front
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head


Frontal Crashes: 26-50YO, Rear Outboard
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head


Frontal Crashes: 26-50YO, Right-front
100%
80%
60%
40%
20%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

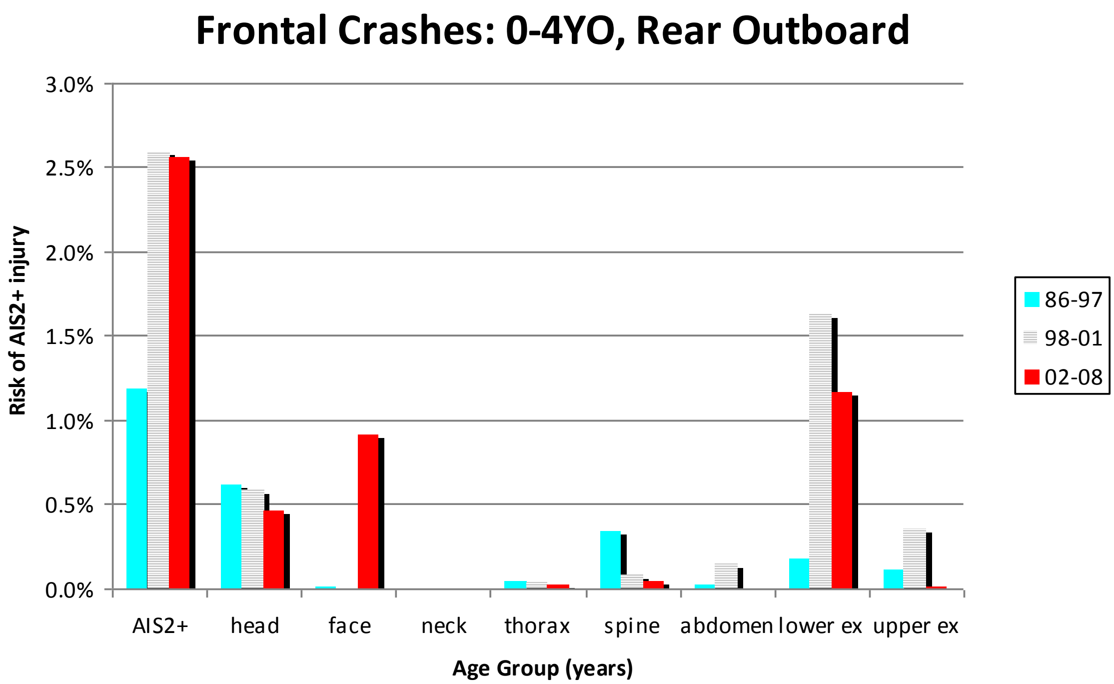

Frontal Crashes: >50YO, Rear Outboard
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head


Frontal Crashes: >50YO, Right-front
100%
80%
60%
40%
20%
0%
Percentage of AIS2+ Injuries
86-97
98-01
02-08
Vehicle model year (years)
lower ex
upper ex
abdomen
thorax
spine
face
head

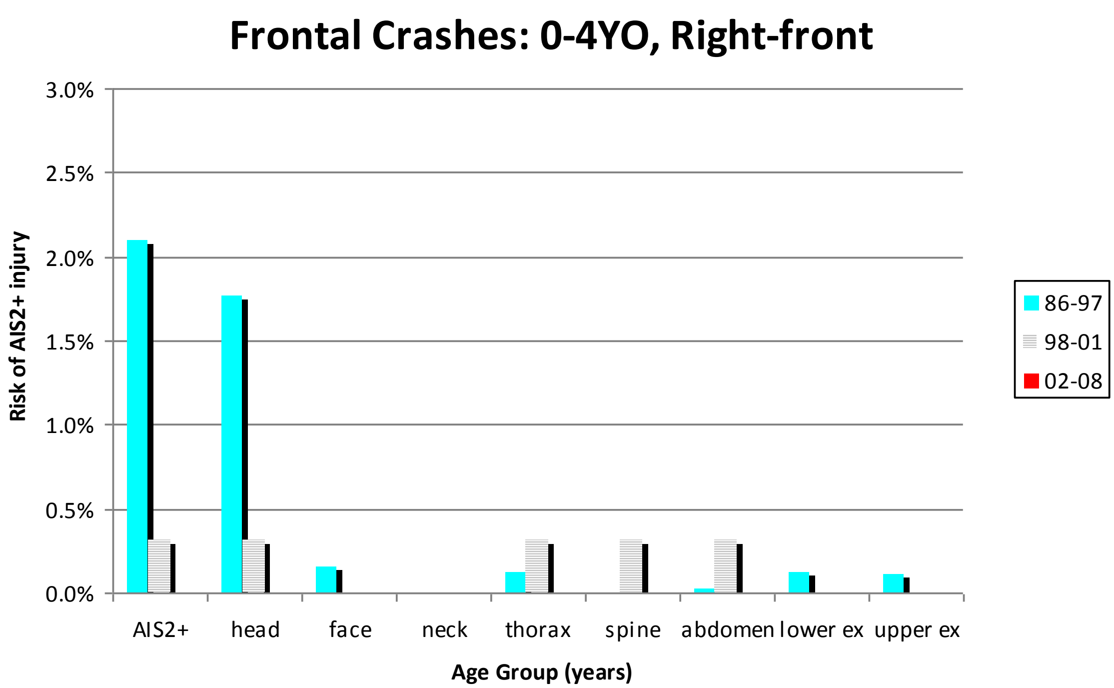
# APPENDIX B

Risk of AIS2+ injury by body region in frontal impacts by occupant age, vehicle model year, and seating row

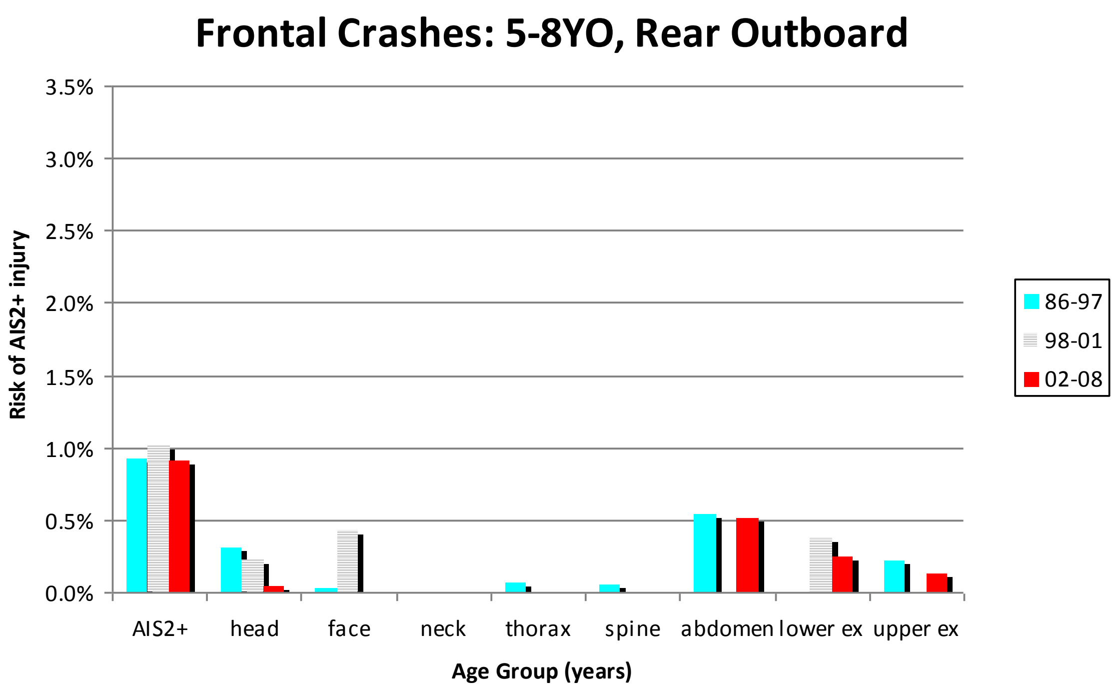
Note: scales vary with plots for each age group



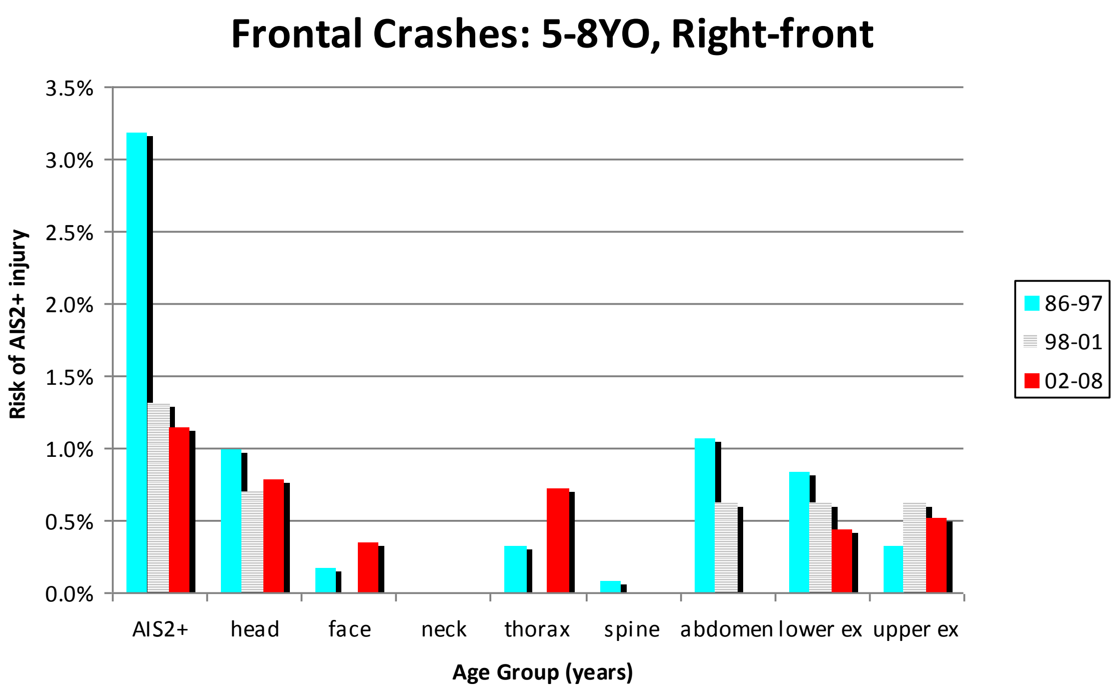
Frontal Crashes: 0-4YO, Rear Outboard
Risk of AIS2+ injury
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

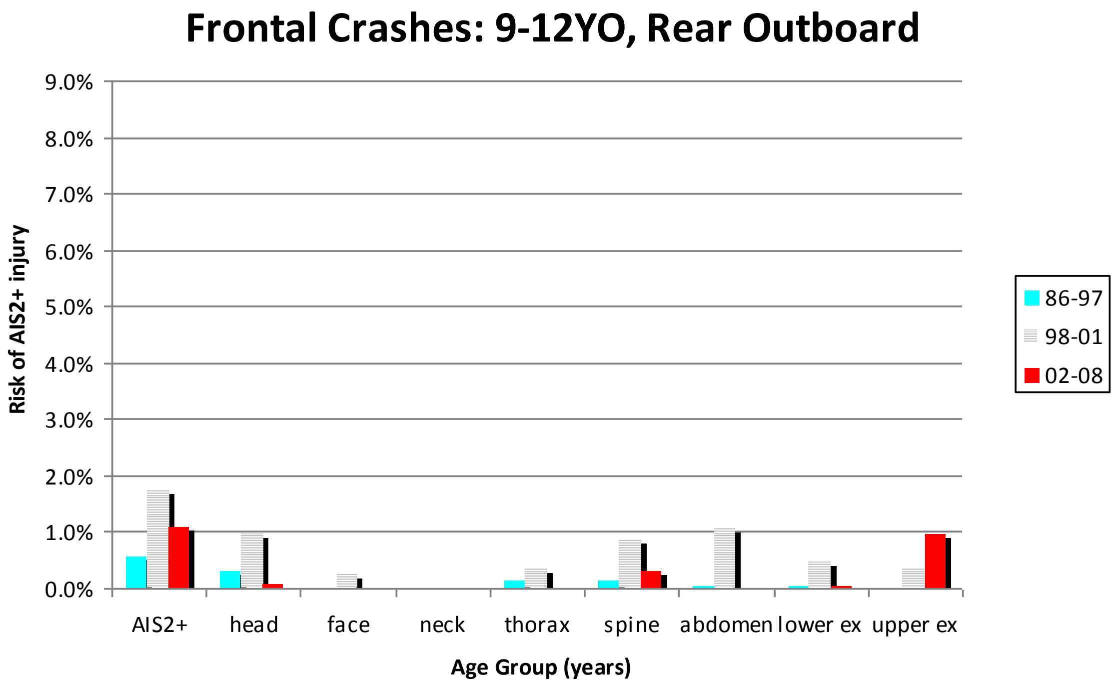
Frontal Crashes: 0-4YO, Right-front
Risk of AIS2+ injury
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08



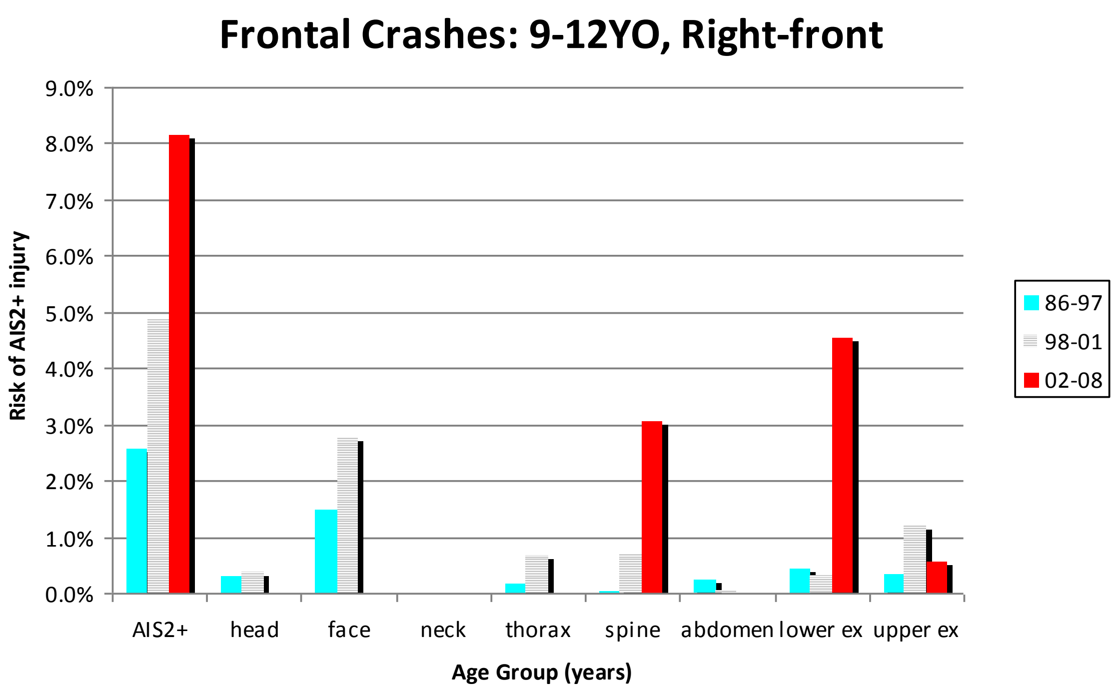
Frontal Crashes: 5-8YO, Rear Outboard
Risk of AIS2+ injury
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

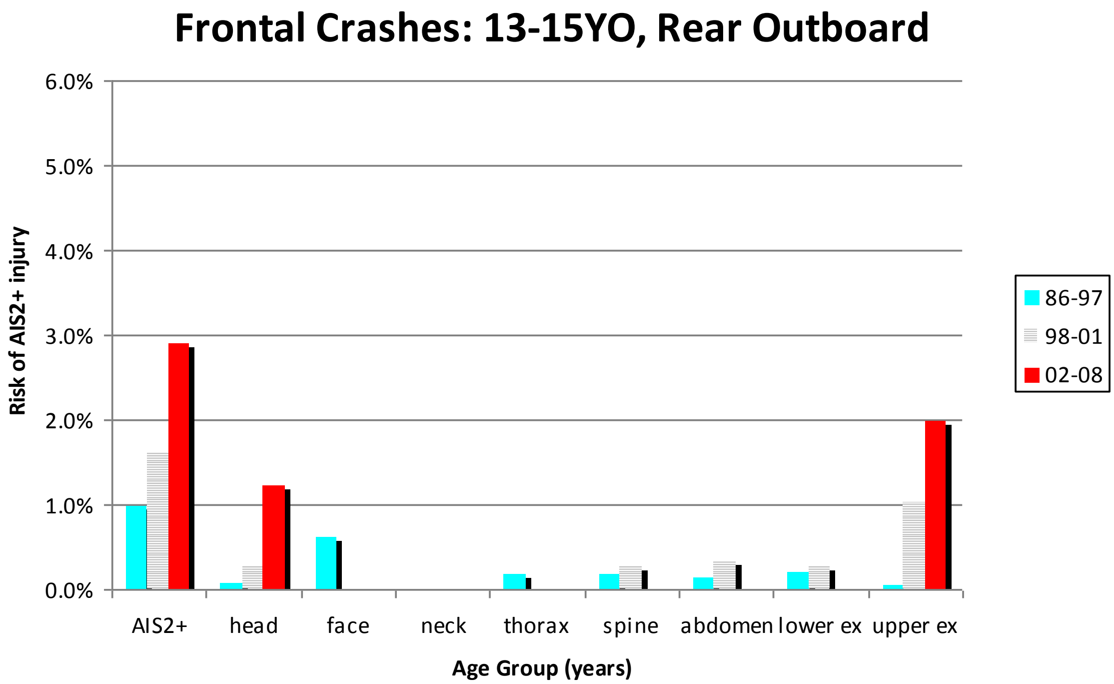
Frontal Crashes: 5-8YO, Right-front
Risk of AIS2+ injury
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08



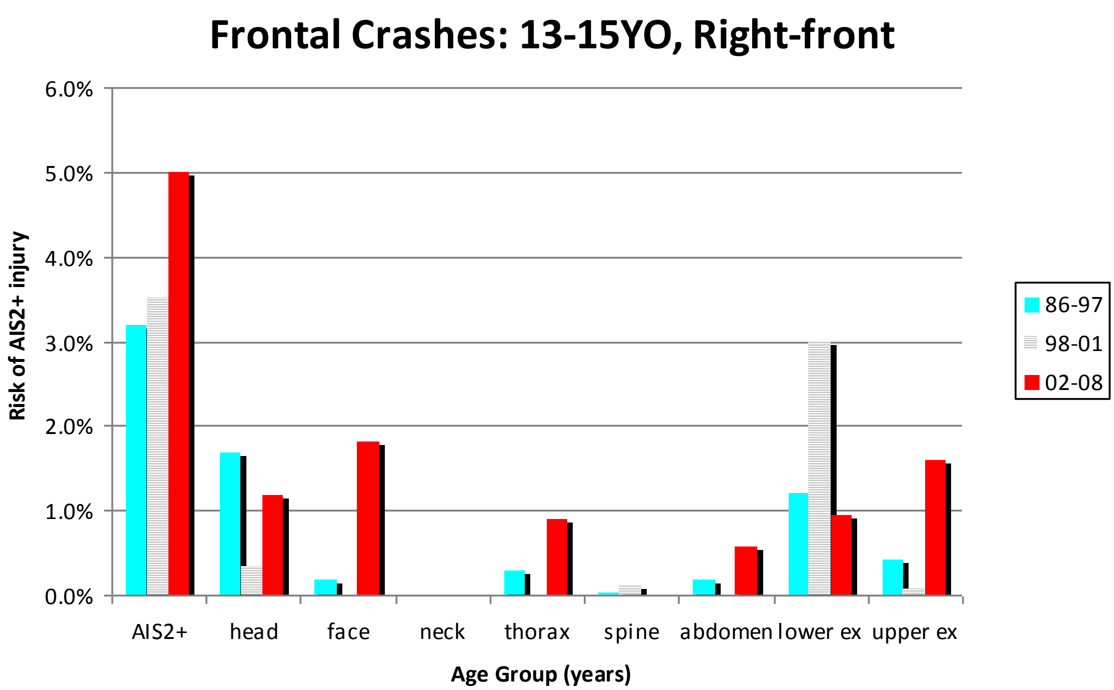
Frontal Crashes: 9-12YO, Rear Outboard
9.0%
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

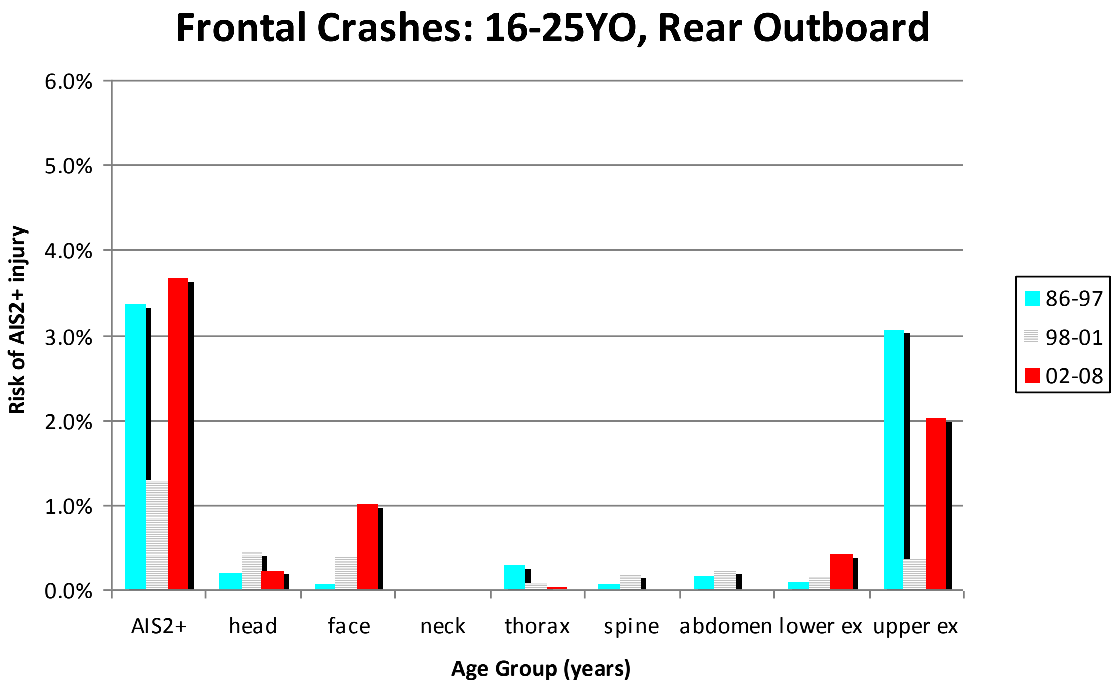
Frontal Crashes: 9-12YO, Right-front
9.0%
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

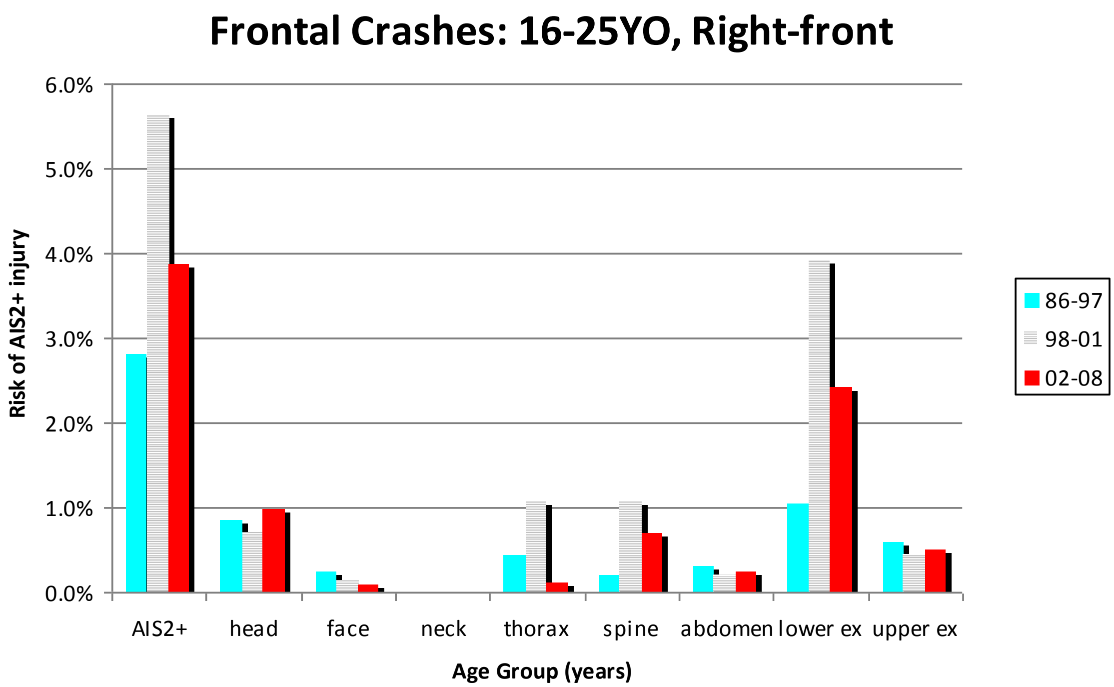


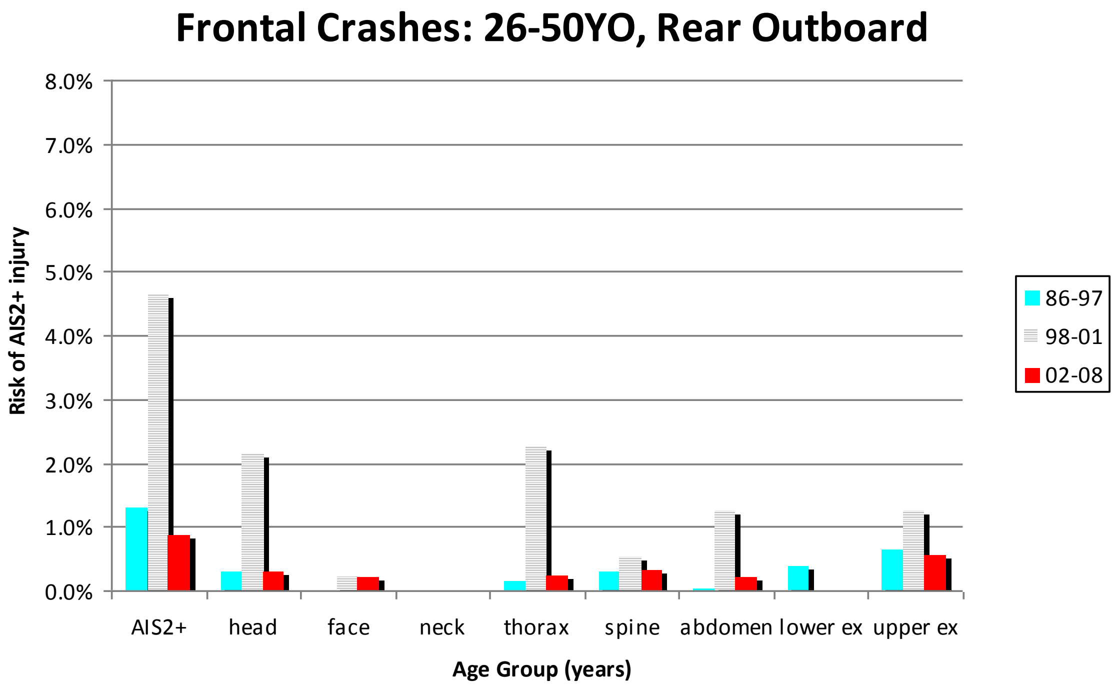
Frontal Crashes: 13-15YO, Rear Outboard
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

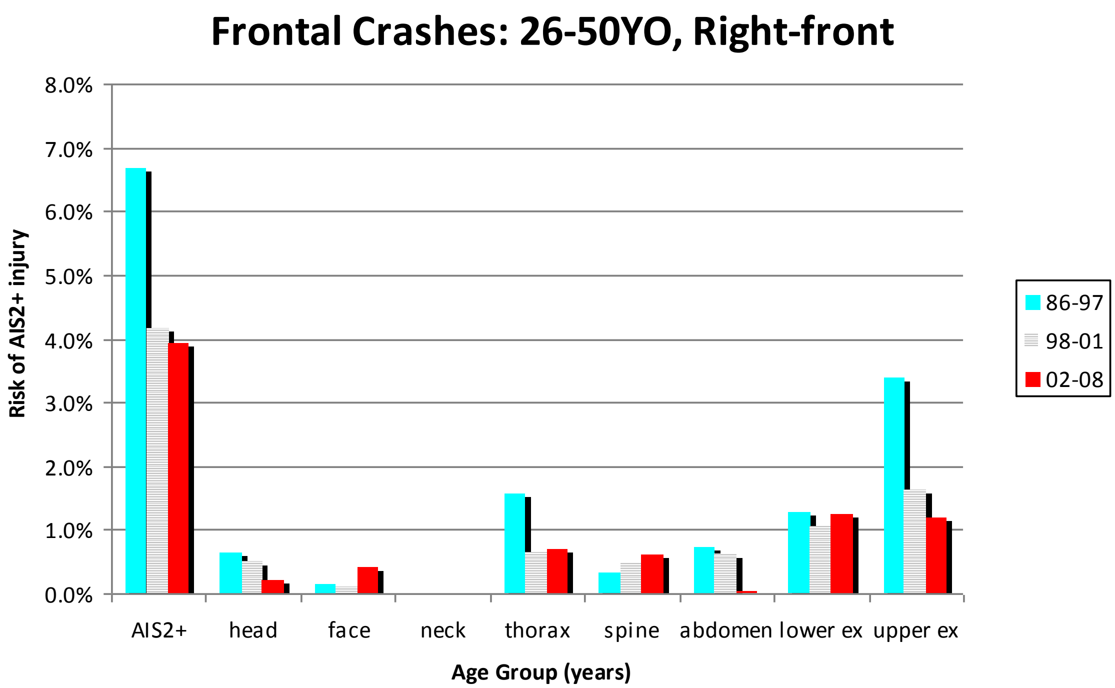



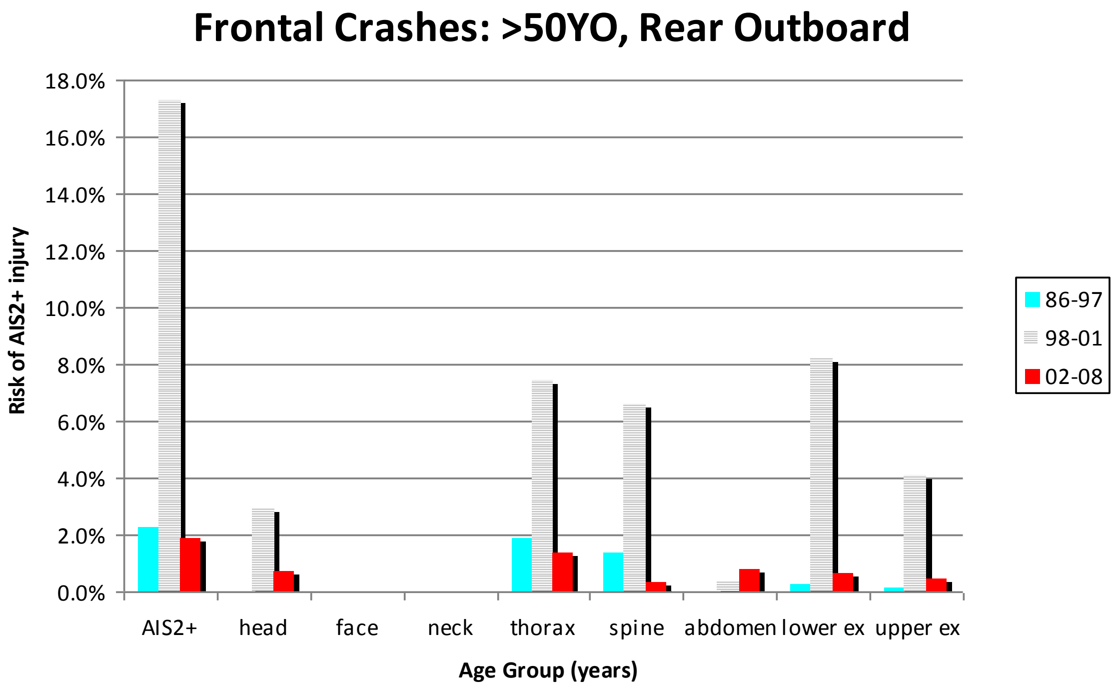
Frontal Crashes: 13-15YO, Right-front
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

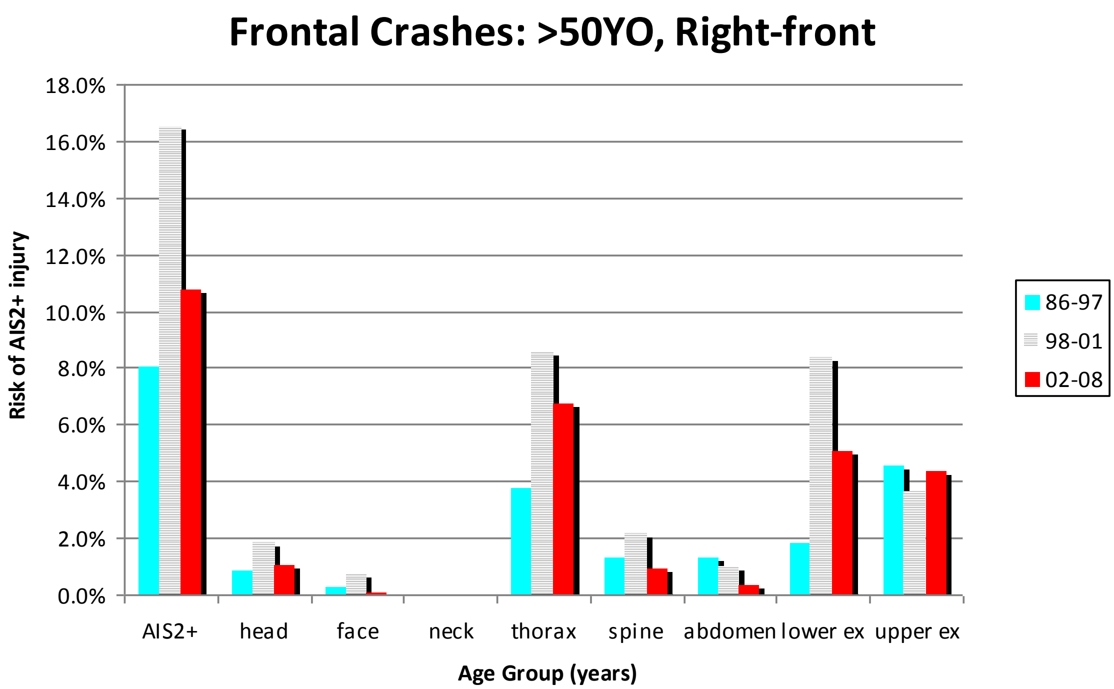

Frontal Crashes: 16-25YO, Rear Outboard
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08


Frontal Crashes: 16-25YO, Right-front
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08


Frontal Crashes: 26-50YO, Rear Outboard
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08


Frontal Crashes: 26-50YO, Right-front
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

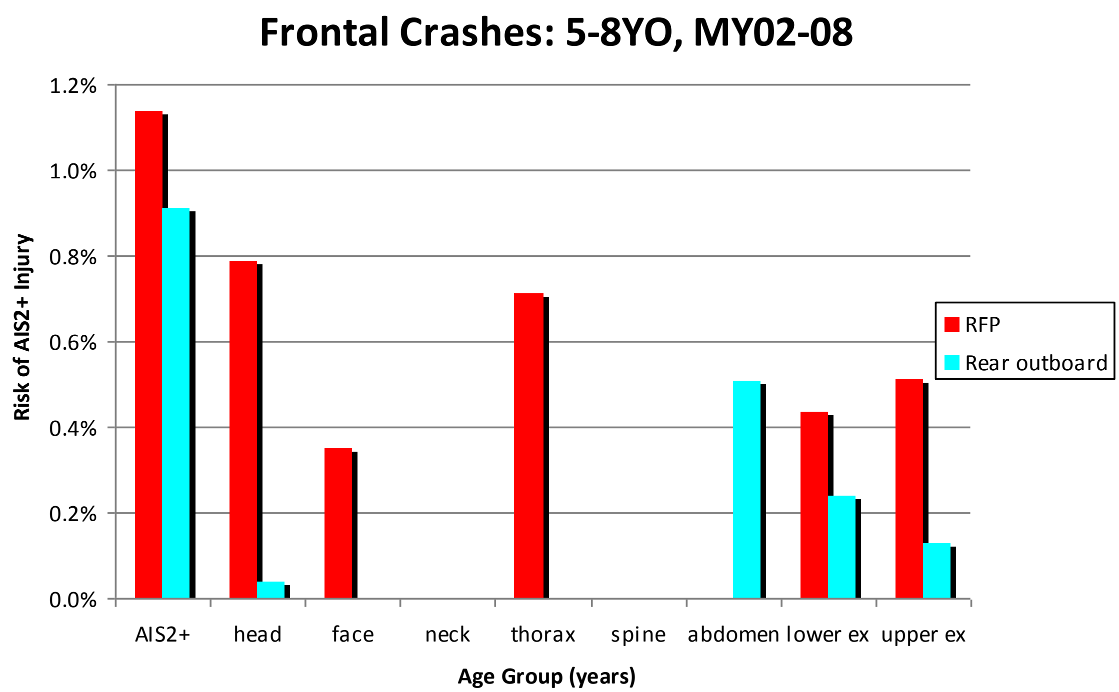

Frontal Crashes: >50YO, Rear Outboard
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

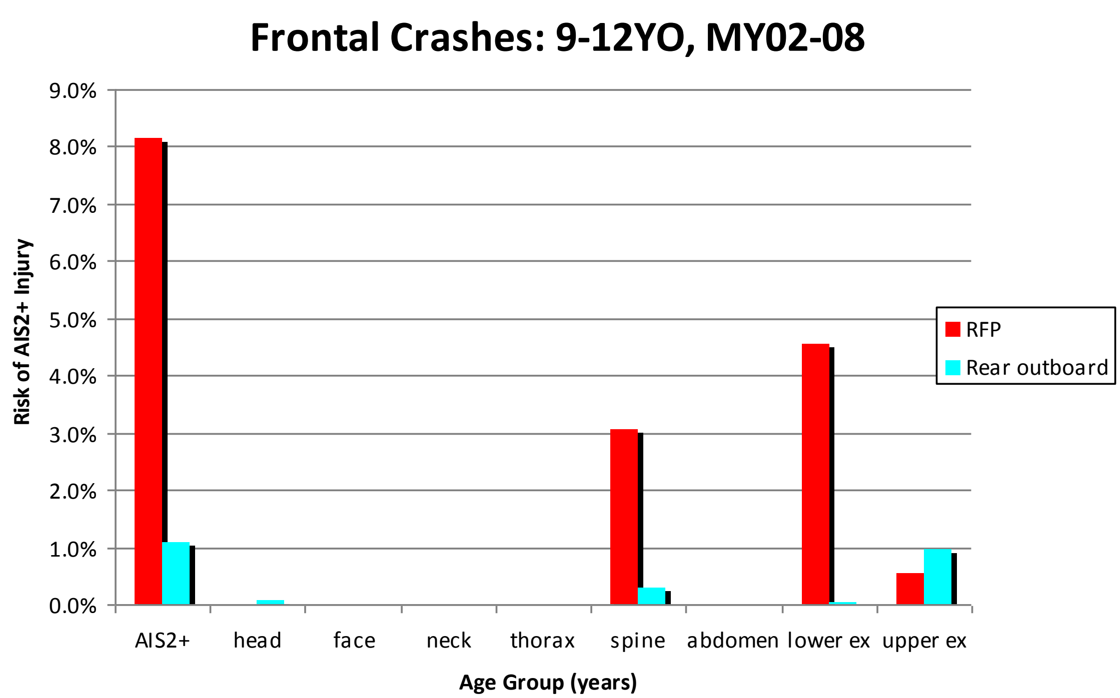

Frontal Crashes: >50YO, Right-front
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
Risk of AIS2+ injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
86-97
98-01
02-08

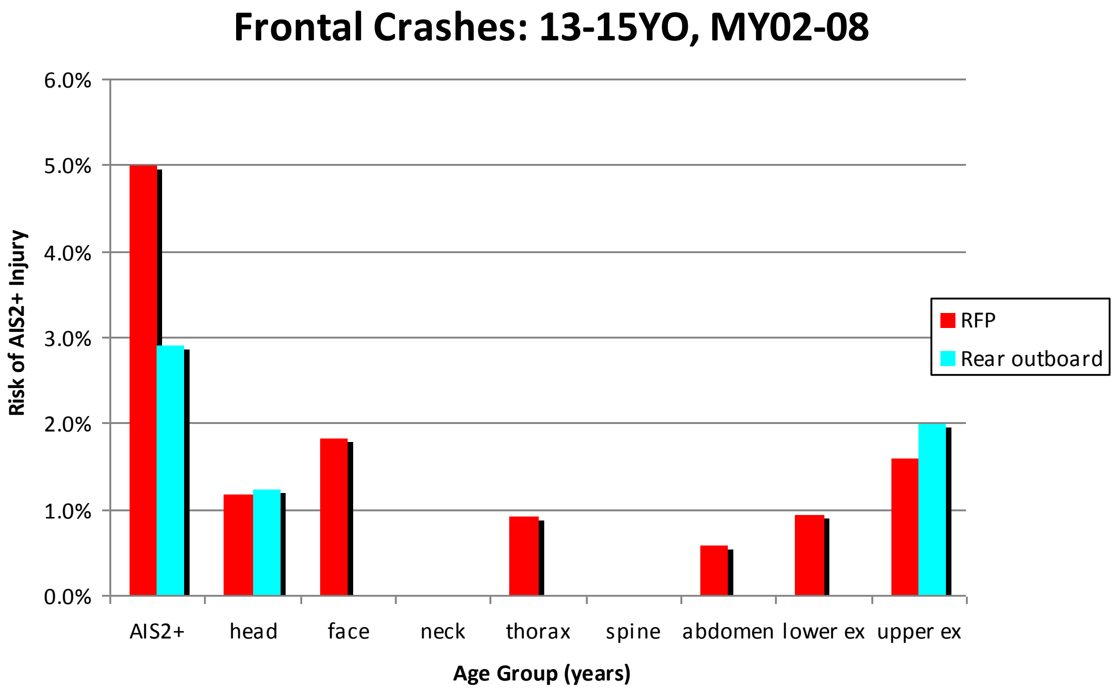
# APPENDIX C

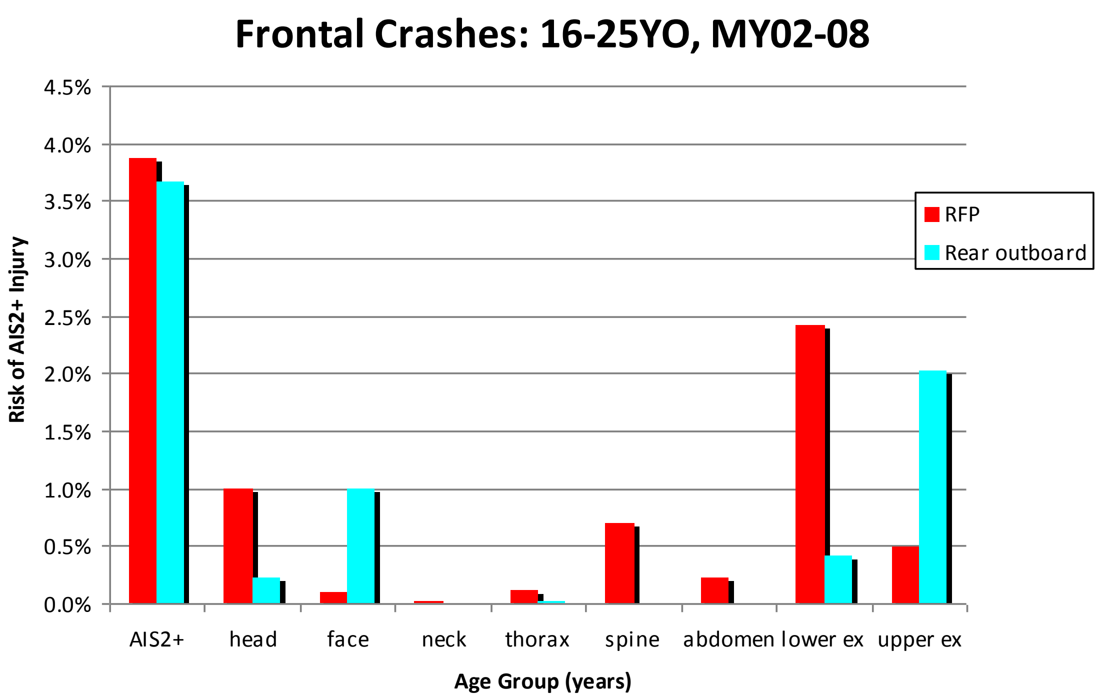
Comparison of rear seat to front seat risk of AIS2+ injury by age group for MY02-08 vehicles

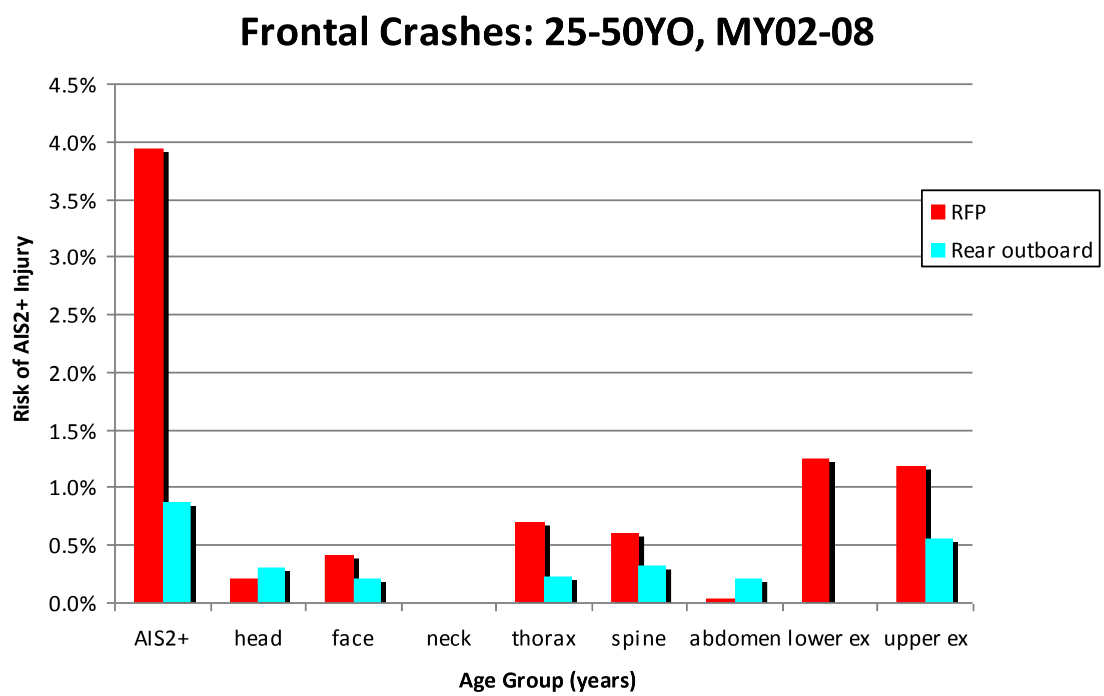
Note: 0-4 age group is not included because there were no injured occupants in front seats for this age group and model year group

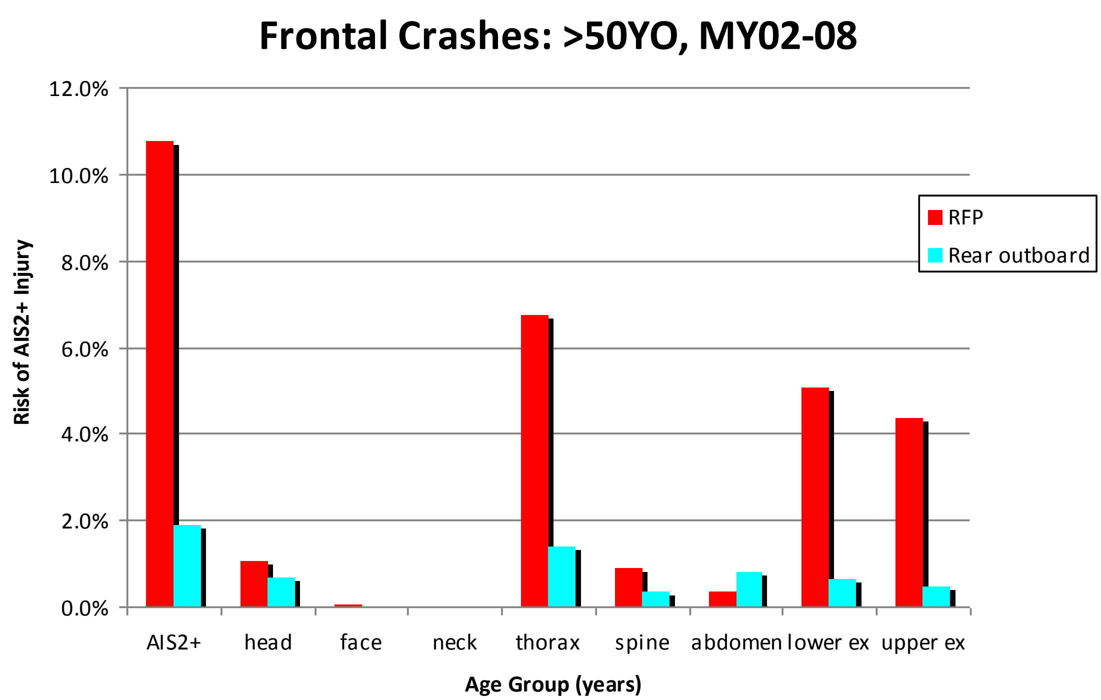

Frontal Crashes: 5-8YO, MY02-08
1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
Risk of AIS2+ Injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
RFP
Rear outboard


Frontal Crashes: 9-12YO, MY02-08
9.0%
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of AIS2+ Injury
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
RFP
Rear outboard


Frontal Crashes: 13-15YO, MY02-08
Risk of AIS2+ Injury
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
RFP
Rear outboard


Frontal Crashes: 16-25YO, MY02-08
Risk of AIS2+ Injury
4.5%
4.0%
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)
RFP
Rear outboard


Frontal Crashes: 25-50YO, MY02-08
Risk of AIS2+ Injury
4.5%
4.0%
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
RFP
Rear outboard
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)


Frontal Crashes: >50YO, MY02-08
Risk of AIS2+ Injury
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
RFP
Rear outboard
AIS2+
head
face
neck
thorax
spine
abdomen
lower ex
upper ex
Age Group (years)