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Effect of vehicle and crash factors on older occupants

Rory A. Austin*, Barbara M. Faigin

National Highway Traffic Safety Administration, U.S. Department of Transportation, Room 5320, 400 7th Street, Southwest, Washington, DC 20590, USA

Abstract

Problem: The expected substantial increase in people aged 65 or older is important for those concerned about transportation injuries. However, much of the previous research concentrates on older drivers and overlooks the fact that vehicle and crash factors may provide significant explanations of older occupant injury rates. *Method*: Differences across age groups are explored using two nationwide travel surveys, crash involvement, fatalities, and injuries from crash databases and an ordered probit model of injury severity. *Results and Discussion*: Two noticeable differences that help explain injury risk are that older people are more likely to travel in passenger cars than younger people who frequently use light trucks, and that seriously injured older occupants are more likely to be involved in side-impact crashes than their younger counterparts. *Impact*: Increased attention to vehicle engagement in side-impact crashes and to vehicle technologies that can help drivers avoid side collisions would be particularly helpful for older occupants.

Keywords: Age; Motor vehicle; Exposure; Traffic crashes; Injury risk

1. Introduction

According to a recent study by the U.S. Census Bureau, the world's population of age 65 or older grew by more than 795,000 people each month during 2000. This rate is expected to increase so that the older population will grow by more than 847,000 a month during 2010. By 2030, more than 60 nations are expected to have more than 2 million people aged 65 or older, which is twice the number of nations reaching this benchmark in 2000 (Kinsella & Velkoff, 2001). In the United States alone, the number of people 65 or older was 35 million in 2000. By 2030, this number is expected to double to over 70 million (U.S. Census Bureau, 2000). A significant number of the older population will continue to drive, and those who do not are likely to be passengers. Unfortunately, the existing literature does not provide enough information regarding older occupants, their travel patterns, or their crash involvement to guide future research and policy.

2. Problem

The projected increase in the number of older road users has spurred public debate as well as scholarly research. When examining U.S. occupant fatality rates per 100,000 population, people aged 65–74 have rates similar to those aged 35–44. Although the fatality rate increases for those 75 and older, it is still below the rate for people aged 16 to 24. Occupant injury rates per 100,000 population appear to diminish with age. For people over 75, the rate is about half of its value for those 35–44 and one-quarter for people aged 16–24 (National Highway Traffic Safety Administration [NHTSA], 2002). While these numbers are informative, many traffic safety researchers argue that these statistics may be misleading because they do not account for exposure. In other words, older people may have a lower fatality and injury rate per person because they do not travel as often or as far as younger people. One frequently used approach to control for differences in exposure is to examine driver fatality rates per 100 million vehicle miles traveled. This type of analysis produces a U-shaped curve where the highest fatality rates are for the youngest and oldest drivers (Insurance Institute for Highway Safety, 2001). However, this approach does not fully capture exposure either because it focuses on drivers rather than all occupants. Previous research has shown that people over 65, especially women, have a higher proportion of miles traveled as nondrivers than all younger adults except teenagers (Federal Highway Administration, 1997).

Although a significant amount of vehicle travel by older occupants occurs as a passenger, the existing literature mainly focuses on the fatality risk of older drivers. One line of research aims to explain why the fatality rate per mile is higher for older drivers. Two possible explanations are higher

* Corresponding author. Tel.: +1-202-493-2631; fax: +1-202-493-2290.
E-mail address: raustin@nhtsa.dot.gov (R.A. Austin).

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crash involvement and higher fragility. Higher crash involvement means greater potential for injury caused by a crash, and higher fragility means greater chance of injury given that a crash occurred. While crash involvement per vehicle miles traveled does increase appreciably after age 70, research indicates that fragility is a more important explanation (Li, Braver, & Chen, 2001; Lyman, Ferguson, Braver, & Williams, 2002). This conclusion fits with research showing that older occupants have a higher fatality risk from similar impacts than younger occupants (Evans, 2001). It also is supported by studies from Canada (Zhang, Lindsay, Clarke, Robbins, & Mao, 2000) and the United States (Khattak, Pawlovich, Souleyrette, & Hallmark, 2002) showing that age is an important predictor of older driver injury severity even when controlling for vehicle and crash characteristics. A related analysis demonstrated that fatal crash rates per 100,000 population still differ by age after controlling for urban versus rural status through population density (Clark, 2001). Fatality rates, along with assumptions about changes in population, licensure rates, and annual miles traveled, have also been used to make future projections. One such study claims that by 2030 drivers 65 and older will account for 25% of driver fatalities compared to the 14% in 1999 (Li et al., 2001).

Another set of studies compares crash scenarios across age groups. This type of analysis helps provide information regarding how crash situations involving older drivers differ from those involving younger drivers and offers suggestions for improving safety for older drivers. Overall, older drivers are a relatively safe group. They are less likely to have crashes involving alcohol or high speeds than younger drivers (McGwin & Brown, 1999). However, studies of crashes in both Finland (Hakamies-Blomqvist, 1993) and the United States (McGwin & Brown, 1999) have shown that older drivers are overrepresented in crashes at intersections, particularly in collisions with crossing vehicles, and are more likely to be at fault in these crashes. A close examination of intersection crashes revealed that uncontrolled and stop-sign-controlled intersections represent the highest fatality risk for older drivers relative to younger drivers (Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998). Research also has found that older drivers are more likely to be involved in collisions while making turns, particularly left-hand turns (McGwin & Brown, 1999; NHTSA, 2001). The most frequent policy recommendation from this line of research is light-controlled intersections with protected left-turn signals.

While all of these previous studies help us to understand the interaction between age and crash factors, there is more that can be learned. The focus on drivers, for example, tends to overlook the frequency with which older people, especially women, are passengers. The objective of this article is to further our understanding of the effect of vehicle and crash factors on older occupants by accounting for variables that have been rarely researched. These potentially important factors include the types of vehicles used for travel by older occupants, the types of vehicles involved in crashes, and the crash circumstances, such as the number of vehicles involved and the manner of collision.

3. Methods

This article uses a variety of methods and data sets to understand the relationship between age and important crash characteristics. The analysis seeks to provide information on the factors that influence vehicle safety outcomes for the oldest segment of the population and to gauge their relative importance. The methods cover the issues of travel exposure, crash involvement, occupant fatalities and incapacitating injuries, and injury severity.

3.1. Travel exposure

Travel exposure was explored through the analysis of the preliminary release of the 2001 National Household Travel Survey (NHTS) and the most recent version of the 1995 Nationwide Personal Transportation Survey (NPTS). Over 26,000 households reported their travel behavior via telephone interview from April 2001 to May 2002 for the 2001 NHTS. The 1995 NPTS includes reported travel behavior from over 42,000 households. The travel data presented are for day trips, defined as "any time the respondent went from one address to another" in a designated 24-hour period, completed in privately owned motor vehicles (Bureau of Transportation Statistics & Federal Highway Administration, 2003).

The private vehicles category in these surveys includes cars, vans, sport utility vehicles, pickup trucks, motorcycles, large trucks, and motor homes, but it does not differentiate between light and large vehicles using vehicle weight. These surveys also contain weighting factors to produce national travel estimates. The age groups used are 25–44, 45–64, 65–74, and 75 and older. The decision to focus on occupants 25 and older should make the comparison groups more appropriate by excluding the most inexperienced drivers. Older occupants also are split into two categories (65–74 and 75+) to distinguish between the younger old and the rapidly growing group of the oldest occupants. This approach will provide evidence of how exposure patterns, measured by estimated annual miles traveled, are affected by age and temporal trends.

3.2. Crash involvement

Crash involvement is captured using the five most recent years of the National Automotive Sampling System—General Estimates System (NASS-GES or GES 1997–2001). GES is based on a nationally representative sample of about 57,000 police-reported crashes per year. GES crashes must have a police accident report, which is the basis for all coded values, must "involve at least one motor vehicle traveling on a trafficway," and "must result in property damage, injury, or death" (NHTSA, 2002). GES also contains a weighting factor to produce annual estimates of the characteristics of police-reported crashes. This approach will enable us to address the effect of crash exposure for explaining differences in injury patterns across age groups.

3.3. Fatalities in crashes

Occupant fatalities were classified using the most recent 5 years of the Fatality Analysis Reporting System (FARS 1997–2001). FARS is a census of all crashes involving a motor vehicle on a public roadway that resulted in at least one fatality within 30 days of the incident. While FARS contains information on nonmotorist fatalities, this analysis focuses on vehicle occupant deaths. Because FARS is a census, the results reflect national totals and do not require a weighting factor.

3.4. Incapacitating injuries in crashes

Similar to the approach using FARS for fatalities, incapacitating injuries are explored using police-reported crashes from GES. Injury severity in GES is measured on a police-reported injury scale with values of none, possible, non-incapacitating, incapacitating, and fatal. While police-reported injury severity serves some purposes, there are potential measurement issues because police-reported severity may not reflect real injuries, especially at lower levels of severity. Police-reported severity is likely to be more accurate for incapacitating and fatal injuries. Our GES analysis of serious injuries focuses on incapacitating injuries because they should accurately represent the most serious nonfatal injuries and does not examine fatal injuries because they are covered by FARS. It should be noted, however, that incapacitating injuries from police-reported injury severity are not necessarily the same as serious injuries from the Abbreviated Injury Scale (AIS) discussed in the next section, which is not available in GES. Because GES is a sample of crashes, we used the weighting factor to produce national estimates.

3.5. Modeling injury severity

The National Automotive Sampling System—Crashworthiness Data System (NASS-CDS 1997–2001) was used to describe the relationship between the degree of injury severity and the change in velocity (ΔV), the occupant's age, and other important factors. NASS-CDS is a probability sample of police-reported crashes involving at least one towed light vehicle and either property damage or personal injury. Light vehicles are defined by the NHTSA as vehicles having a gross vehicle weight rating (GVWR) of less than 10,000 lb and include passenger cars, utility vehicles, light vans, and most pickup trucks. Selected crashes are investigated by a NASS team. The focus on more severe crashes and the detailed scrutiny of crash sites, vehicles, and medical records leads to the investigation of about 4,000 crashes per year. While the sample is smaller, NASS-CDS contains two important variables for modeling injury severity that are not included in GES. NASS-CDS measures injury severity using the AIS and contains a variable for the maximum known AIS for towed vehicle occupants. The NASS-CDS also contains the total change in velocity (total ΔV) for investigated vehicles, which is often strongly correlated with occupant injury severity.

The technique used to model the effects of age, ΔV, and other factors on injury severity is ordered probit. Ordered probit is an extension of the more common dichotomous probit and closely related logit analyses (Greene, 1993). In dichotomous probit, the variable that the researcher is trying to explain takes two possible values (such as yes or no, success or failure, etc.). The explanatory variables are then used to estimate the unobserved probability of an observation taking a particular value (such as the probability of a respondent answering yes). Because the approach is multivariate, a researcher can isolate the effect of one variable on the estimated probability while controlling for other explanatory variables.

Ordered probit is used when the variable that the researcher wants to explain takes more than two ordered categorical values. Consider the case of the effect of age on injury severity. If injury severity were measured with two values such as no injury versus injury, then dichotomous probit would produce the estimated effect of age on the probability of an occupant injury. Now suppose that injury severity is measured by the maximum injury on a scale such as none, minor, moderate, serious, and severe. These five categories have order because they represent increasing injury severity, and ordered probit would be an appropriate tool for analyzing the effect of age on injury severity. Ordered probit would produce estimates of the effect of age on the probability of an occupant suffering a maximum injury of each severity level. Thus, ordered probit would produce five estimated probabilities, one for each severity level, and these estimated probabilities would sum to one because they cover all possible outcomes. It is highly unlikely that age would be the only factor affecting injury severity, and our analysis contains other important control variables, such as ΔV, to isolate the effect of age on injury severity. We also use an appropriate weighting factor to reflect national estimates of the distribution of crash scenarios, occupant characteristics, and injuries.

4. Results

The results are divided into five sections. The first section explores how exposure, in terms of miles traveled, differs by age groups and how it has changed over time. The second section explores how crash involvement exposure patterns differ by age groups. The third section examines how fatal injuries vary by age and crash characteristics. The fourth section presents incapacitating injuries in a similar fashion. The fifth section demonstrates the relationship between the severity of injury, the age of the occupant, and the change in velocity (ΔV) in various crash modes.

4.1. Travel exposure

We measure exposure both in terms of miles traveled and crash involvement. The results for miles traveled are based on early results from the 2001 NHTS, in which over 26,000 households reported their travel behavior via telephone interview. As previously discussed, the preliminary release includes information on travel day trips, defined as "any time the respondent went from one address to another" in a designated 24-hour period, by various transportation modes including private motor vehicles. Travel day trips aim to capture everyday travel patterns in the United States and the designated days assigned to respondents cover an entire year. Using a weighting factor, the survey responses can be used to produce national travel estimates. These estimates are then used by researchers to compute the total number of miles traveled as well as the number of miles per person. Table 1 provides an overview of the changes in these statistics from 1995 to 2001.

While person miles per person for day trips increased for all age groups, there have been striking differences—from less than 1% for 25- to 44-year-olds to 20% for the 75 and older population. The differences in total day trip miles are even more dramatic, with total miles traveled by the oldest Americans increasing by over 50%. The difference between the increase in total miles traveled and in miles traveled per person reflects that changes are occurring both in the size of older population as well as in their behavior. These results are a more inclusive picture of changes in exposure than previous work based exclusively on driving behavior (Hu, Jones, Reuscher, Schmoyer, & Truett, 2000; Li et al., 2001).

Table 1
Changes in total person miles traveled in privately owned vehicles by age (1995 NPTS and 2001 NHTS day trips)

Age	1995	2001	Percent change (1995–2001)
Total person miles (billions)			
25–44	1352	1360	1
45–64	764	931	22
65–74	191	211	10
75+	66	100	51
Person miles per person			
25–44	15,780	15,856	<1
45–64	14,854	15,312	3
65–74	9796	11,312	15
75+	5659	6772	20

Sample sizes for number of people in youngest to oldest age group.
1995 unweighted: 32,533, 23,227, 8014, and 4677; weighted (in millions): 85.7, 51.4, 19.5, and 11.7.
2000 unweighted: 16,080, 16,533, 5313, and 4139; weighted (millions): 85.8, 60.8, 18.7, and 14.8.

Table 2
Distribution of person miles traveled by age and other factors (1995 NPTS and 2001 NHTS day trips)

Survey year	1995				2001			
Age group	25–44	45–64	65–74	75+	25–44	45–64	65–74	75+
Gender/driver role								
Male: driver	48	50	46	36	48	50	47	41
Male: passenger	7	7	8	13	6	6	6	10
Female: driver	31	26	24	23	31	28	22	21
Female: passenger	14	17	22	28	14	16	26	28
Total (%)	100	100	100	100	100	100	100	100
Vehicle type (all occupants)								
Car	59	62	73	84	52	55	71	77
Van	11	10	8	4	13	11	9	10
Utility vehicle	9	8	4	3	16	13	5	3
Pick-up	16	16	14	7	17	18	14	7
Other	4	4	1	1	3	3	1	3
Total (%)	100	100	100	100	100	100	100	100

Sample sizes for number of people in each age group same as Table 1.

However, the results are similar in that they reflect the importance of the increasing population size on future older driver target population estimates. Table 2 further explores these changes by presenting the percentage distribution of the miles traveled by gender, driver status, and vehicle type across the various age groups.

There was little change between 1995 and 2001 in the driver versus passenger shares of total person miles traveled by age groups, except for some shift from miles by male passengers to male drivers in the 75 and older age group. If this pattern continues, it suggests a growing need for crash avoidance countermeasures for older drivers. However, on the crashworthiness side, there has been some shift in miles traveled by the oldest population from passenger cars into vans. This shift works in a positive direction with regard to vehicle compatibility issues because vans have a lower vulnerability metric, defined as deaths in struck vehicles per 1,000 police reported crashes, than passenger cars in side-impact crashes (Hollowell, Summers, & Prasad, 2002). The changes indicated by these early results from the 2001 NHTS survey detailed in Tables 1 and 2 provide evidence that mobility for older people of current and future generations of older people (i.e., baby boomers and beyond) may be significantly different than for previous generations, which underscores the need for increased attention to older occupant safety.

Although exposure in terms of miles traveled has increased most rapidly for the oldest segment of the population, the number of light vehicle (car, utility vehicle, pick-up, and van) occupant fatalities among those aged 65 and older has decreased every year from 1997 to 2001. There are at least two possible explanations. One is that temporal improvements in traffic safety have made traveling by light vehicle safer for all occupants. One method for evaluating this hypothesis is to compare the change in occupant fatality rates across age groups and over time. The results indicate that overall improvements in traffic safety account for part of the explanation. From 1997 to 2001, the fatality rate per 100,000 population for those aged 25–44 fell by about 3.6%. However, the fatality rates for those 65–74 and for the 75 and older population fell by a much greater amount (12.8% for each group). Another possibility is that improvements in medical care of the injured or improvements in the general physical status of the older population have shifted many of the oldest occupant fatalities to injuries. This hypothesis also does not appear to offer a complete explanation. While light vehicle occupant injury rates per 100,000 population for ages 65–74 fell fairly consistently from 1997 to 2001 (overall 13.5% decrease), the 75 and older age group shows no consistent pattern, with some increases and some decreases throughout the period, and an overall decrease of 8.6%. However, because of the sampling error in GES, it is unclear whether the changes in injury rates among the oldest occupants reflect a new downward trend or are due to random sampling. The results suggest that overall improvements in traffic safety from 1997 to 2001 for light vehicle occupants have had a larger effect on older than younger occupants, but more work needs to be done to understand the dynamics of this change.

4.2. Crash involvement exposure

Another common way of addressing exposure is to examine driver involvement in crashes by age. Crash involvement is computed as the number of drivers in a certain age category per 100,000 licensed drivers. These numbers are contained in Table 3.

While crash involvement rates per licensed driver in all crashes are lower for the oldest drivers than for any other age group, they do not fall as dramatically as driver exposure, based on annual person miles per person. This comparison is incomplete because the NHTS preliminary release did not include information on longer trips; however, Table 3 indicates that there are some crash incidence factors, as well as "survivability" factors, at work. While driver involvement rates in property damage only (PDO) and injury-producing crashes also follow this consistent downward trend by age, the driver involvement rate in fatal crashes for the oldest age group is over 40% higher than the next oldest group. Along with the results for occupant crash involvement by severity (see next section), this speaks to the strong influence of higher crash consequences for the oldest population group.

Another way to address age differences in exposure is to analyze the crash scenario to which an occupant is exposed given a crash. This analysis uses the GES estimates of all police-reported crashes for the most recent 5 years (1997–2001). Table 4 summarizes these results by presenting percentages within each age category to facilitate comparison across the columns. As discussed above, light vehicles have a GVWR of less than 10,000 lb and include passenger cars, utility vehicles, light vans, and most pickup trucks. Large vehicles have a GVWR greater than 10,000 lb and include trucks, buses, and large vans. The table focuses on light vehicle occupant crashes but also contains the percentage for other vehicle types.

Table 4 demonstrates that older occupants involved in a crash are more likely to be in a light vehicle than a large vehicle. Even more telling, older occupants are much more likely to be in a car than a light truck or van (abbreviated as LTV). This result agrees with exposure by vehicle type based on miles traveled from the NHTS and NPTS. The results also indicate that older occupants have a higher exposure to side-impact crashes, particularly side impacts where they are in the struck vehicle, than younger occupants.

These findings further confirm the continued overinvolvement of older occupants, particularly drivers, in side impact collisions at intersections and while making turns. Interestingly, exposure to rear-end crashes appears to diminish with age. This change would work against lower fatality rates for older occupants because rear-end crashes rarely produce fatalities.

4.3. Fatally injured vehicle occupants

This section examines whether fatality patterns differ across age groups. Table 5 contains the distribution of fatal

Table 3
Exposure measured by driver crash involvement and annual miles traveled (2001)

Driver age	PDO crashes per 100,000 licensed drivers	Injury crashes per 100,000 licensed drivers	Fatal crashes per 100,000 licensed drivers	All crashes per 100,000 licensed drivers	Annual person miles per person (day trips)
25–44	3,923	1,928	29	5,880	15,856
45–64	2,874	1,352	22	4,248	15,312
65–74	2,094	1,056	20	3,170	11,312
75+	1,844	1,056	28	2,928	5,659
Exposure change from					
25–44 to 45–64	26.7% ↓	29.9% ↓	26.6% ↓	27.8% ↓	3.4% ↓
45–64 to 65–74	27.1% ↓	21.8% ↓	8.2% ↓	25.4% ↓	26.1% ↓
65–74 to 75+	12.0% ↓	0.0% ↓	42.4% ↑	7.6% ↓	40.1% ↓

Licensed drivers from Federal Highway Administration (2002), PDO, and injury crash estimates from GES 2001, fatal crashes from FARS 2001, and person miles from NHTS 2001.

Table 4
Occupants in police-reported crashes by vehicle and crash type (GES 1997–2001)

Type of occupant and crash mode	Percent of all crash occupants by age group			
	25–44	45–64	65–74	75+
Light vehicle occupants				
Single-vehicle crash				
Rollover	2	1	1	1
Fixed object collision	5	6	6	6
Other and unknowns	6	4	4	4
Single-vehicle subtotal	13	11	10	11
Two-vehicle crash				
Rollover vehicle	< 1	< 1	< 1	< 1
Two light vehicles				
Frontal	2	2	3	3
Side: struck	11	12	17	20
Side: striking	12	11	14	16
Rear-end	26	25	23	18
Other and unknowns	12	12	14	14
With large vehicle	2	3	3	3
With other type	2	2	2	3
Two vehicle subtotal	68	69	75	78
Three or more vehicle crash	11	12	11	9
Car subtotal	57	57	70	82
Light truck or van subtotal	35	35	27	16
Light vehicle occupants	93	92	97	98
Large vehicle occupants	4	5	1	< 1
Motorcycle occupants	1	1	< 1	< 1
Other and unknown	2	3	2	2
Total (%)	100	100	100	100

Sample sizes for youngest to oldest age group: unweighted: 247,158, 121,541, 25,834, and 18,145; weighted (in millions): 27.2, 13.4, 3.1, and 2.2.
Light vehicles include cars, light trucks (pick-ups and utility vehicles), and vans.

injuries to vehicle occupants recorded in FARS from 1997 to 2001 by age and by occupant type and crash mode.

As expected, there is a strong relationship between age and occupant type. For the 25–44 age group, 84% of the vehicle fatalities occurred in light vehicles. This number rises to 98% for the 75 and over age group. The higher percentage of light vehicle fatalities for older occupants reflects the substantial drop in the proportion of motorcycle fatalities and, to a lesser extent, large vehicle occupant fatalities after 65.

Age is also strongly related to the crash mode for light vehicle occupant fatalities. The proportion of fatalities in single-vehicle crashes drops from 45% for the youngest group to 22% for the oldest group. When examining only light vehicle fatalities, the drop is from over one-half for the youngest group to under one-quarter for oldest group. This drop occurs mainly because single-vehicle rollovers appear to be a young person's crash. This crash mode accounts for one-quarter of the vehicle occupant fatalities for those aged 25–44. By comparison, it only accounts for 7% for those 75 and older. The proportion of fatalities occurring in single-vehicle fixed object collisions also diminishes with age, but the drop is not as substantial as for rollovers.

As the role of single-vehicle crashes in explaining fatalities decreases with age, the importance of crashes involving two or more vehicles increases. Two-vehicle crashes account for one-third of the fatalities for the youngest group and almost two-thirds for the oldest. This increase is reflected in the large proportions of older occupant fatalities in light vehicles stuck in the side by the front of another light vehicle and in frontal crashes involving two light vehicles. Where single-vehicle rollovers can be described as a young person's crash, side impact appears to be an old person's crash. Fatalities occurring in light vehicles struck in the side account for over one-quarter of the total occupant fatalities for those 75 and older, but only 7% for those 25 to 44. The proportion of fatalities from a frontal crash involving two light vehicles also increases with age from 10% for the youngest group to 17% for the oldest. The proportion of light vehicle fatalities occurring in crashes involving a large vehicle or three or more vehicles also increases with age.

Table 5 demonstrated that light vehicle occupant fatalities in two-vehicle crashes accounted for a majority of the fatalities for those 65 and older. Furthermore, one reason that side impact may be particularly important for explaining older occupant fatalities may be that the type of light vehicle differs by occupant age. Using the FARS 2001, the ratio of driver fatalities in striking versus struck vehicles in side impact collisions is 1:8 for a car striking another car but

Table 5
Occupant fatalities by age and crash mode (FARS: 1997–2001)

Type of occupant and crash mode	Percent of all occupant fatalities by age group			
	25–44	45–64	65–74	75+
Light vehicle occupants				
Single-vehicle crash				
Rollover	25	19	12	7
Fixed object collision	17	14	14	13
Other and unknowns	3	3	2	2
Single-vehicle subtotal	45	36	29	22
Two-vehicle crash				
Rollover vehicle	4	5	4	3
Two light vehicles				
Frontal	10	13	16	17
Side: struck	7	10	18	27
Side: striking	1	2	2	3
Other and unknowns	2	2	3	4
With large vehicle	7	8	11	11
With other type	1	1	1	1
Two-vehicle subtotal	33	41	55	65
Three or more vehicle crash	7	9	11	11
Light vehicle occupants	84	86	95	98
Large vehicle occupants	3	4	1	< 1
Motorcycle occupants	12	8	2	< 1
Other and unknown	1	1	1	1
Total (%)	100	100	100	100

Total fatalities for youngest to oldest age group: 59,369, 34,234, 12,592, and 16,753.
Light vehicles include cars, light trucks (pick-ups and utility vehicles), and vans.

1:29 for an LTV striking a car. The term *light truck or van*, which is abbreviated LTV, refers to pick-up trucks, utility vehicles, and vans that have a GVWR less then 10,000 lb.

Given the importance of light vehicles overall and of the distinction between passenger car and LTV occupants, Table 6 provides more detailed information regarding light vehicle fatalities in nonrollover crashes. For all age groups, car occupant fatalities outnumber LTV occupant fatalities. However, the proportion increases from 69% for the 45–64 group to 85% for the 75 and older group. Correspondingly, the proportion of LTV occupant fatalities decreases with age in almost every crash scenario. The other significant difference occurs in the proportion of fatalities from side impact. From the youngest to the oldest age group, the proportion of fatalities involving a car striking a car in the side increases by 8% and those involving an LTV striking a car in the side increases by 10%. For those 75 and older, almost one in four occupant fatalities occur when an LTV strikes the side of a car.

Table 6
Light vehicle occupant fatalities in two-vehicle nonrollover crashes by age and crash mode (FARS 1997–2001)

Type of light vehicle occupant and crash mode	Percent of all occupant fatalities by age group			
	25–44	45–64	65–74	75+
Car occupants				
Frontal with car	12	12	13	12
Side struck by car	8	9	12	16
Striking side of car	1	2	1	2
All other with car	2	2	2	2
Car with car subtotal	24	25	28	33
Frontal with light truck or van	14	12	12	10
Side struck by light truck or van	13	15	18	23
Striking side of light truck or van	1	1	2	2
All other with light truck or van	3	2	3	2
Car with light truck or van subtotal	31	30	35	37
Car with large truck	16	14	14	13
Car with other body type	1	1	2	2
Car occupants	72	69	78	85
Light truck or van occupants				
Frontal with car	3	4	3	2
Side struck by car	1	2	2	1
Striking side of car	1	1	1	< 1
All other with car	1	1	1	< 1
Light truck or van with car subtotal	5	7	5	4
Frontal with light truck or van	7	7	4	2
Side struck by light truck or van	3	3	3	3
Striking side of light truck or van	1	1	1	< 1
All other with light truck or van	1	1	1	1
Light truck or van with light truck or van subtotal	11	13	9	6
Light truck or van with large truck	10	10	7	4
Light truck or van with other body type	1	1	1	< 1
Light truck or van occupants	27	30	22	14
Total (%)	100	100	100	100

Total fatalities for youngest to oldest age group: 16,956, 12,432, 6461, and 10,400.
Light vehicles include cars, light trucks (pick-ups and utility vehicles), and vans.

Table 7
Vehicle occupants with incapacitating injuries by age and crash mode (weighted GES 1997–2001)

Type of occupant and crash mode	Percent of all incapacitating injuries by age group			
	25–44	45–64	65–74	75+
Light vehicle occupants				
Single-vehicle crash				
Rollover	12	7	6	3
Fixed object collision	15	11	9	14
Other and unknowns	2	1	2	1
Single-vehicle subtotal	28	20	17	18
Two-vehicle crash				
Rollover vehicle	3	2	3	2
Two light vehicles				
Frontal	7	7	8	7
Side: struck	14	16	20	28
Side: striking	11	12	14	12
Other and unknowns	14	16	16	14
With large vehicle	3	4	4	3
With other type	1	1	1	1
Two-vehicle subtotal	52	58	66	67
Three or more vehicle crash	10	13	14	13
Light vehicle occupants	91	90	97	99
Large vehicle occupants	2	2	< 1	< 1
Motorcycle occupants	6	6	1	< 1
Other and unknown	1	2	1	1
Total (%)	100	100	100	100

Sample sizes for youngest to oldest age group: unweighted: 9968, 5158, 1163, and 1038; weighted: 639,862, 322,811, 82,106, and 72,890.
Light vehicles include cars, light trucks (pick-ups and utility vehicles), and vans.

4.4. Vehicle occupants with incapacitating injuries

This section examines incapacitating injuries in a manner similar to the previous section. As discussed in the Methods section, this analysis uses police-reported incapacitating injuries for the five most recent years of GES (1997–2001). Table 7 presents the results for all vehicle occupants, and Table 8 presents the results for light vehicle occupants in two-vehicle nonrollover crashes.

For the most part, the results in Table 7 are similar to those for fatalities. The proportion of incapacitating injuries from single-vehicle crashes diminishes with age. There appears to

Table 8
Light vehicle occupants with incapacitating injuries in two-vehicle nonrollover crashes by age and crash mode (weighted GES 1997–2001)

Type of light vehicle occupant and crash mode	Percent of all incapacitating injuries by age group			
	25–44	45–64	65–74	75+
Car occupants				
Frontal with car	6	6	6	6
Side struck by car	13	13	17	23
Striking side of car	11	9	13	9
All other with car	12	11	11	8
Car with car subtotal	41	38	47	47
Frontal with light truck or van	3	3	3	3
Side struck by light truck or van	9	9	12	15
Striking side of light truck or van	5	5	5	5
All other with light truck or van	9	10	9	9
Car with light truck or van subtotal	26	27	29	32
Car with large truck	5	5	4	3
Car with other body type	1	2	< 1	2
Car occupants	73	72	81	84
Light truck or van occupants				
Frontal with car	2	2	3	1
Side struck by car	3	4	2	4
Striking side of car	4	4	2	1
All other with car	5	4	3	2
Light truck or van with car subtotal	14	14	10	8
Frontal with light truck or van	2	2	1	1
Side struck by light truck or van	3	3	1	1
Striking side of light truck or van	3	3	3	3
All other with light truck or van	3	4	2	2
Light truck or van with light truck or van subtotal	10	11	7	6
Light truck or van with large truck	2	2	1	1
Light truck or van with other body type	< 1	1	1	< 1
Light truck or van occupants	27	28	19	16
Total (%)	100	100	100	100

Sample sizes for youngest to oldest age group: unweighted: 4807, 2693, 719, and 692; weighted: 317,512, 178,074, 51,775, and 47,843.
Light vehicles include cars, light trucks (pick-ups and utility vehicles), and vans.

be an increase in incapacitating injuries from fixed object collisions in the oldest age group, but more work needs to be done to determine if this result is substantive or mainly sampling error. The likelihood of an incapacitating injury resulting from a two light vehicle frontal crash is almost the same across age groups. However, the likelihood of an incapacitating injury for light vehicle occupants struck in the side increases substantially with age.

Table 8 presents a closer look at incapacitating injuries for light vehicle occupants involved in two-vehicle nonrollover crashes. Similar to the case for fatalities, there is a substantial increase in the proportion of light vehicle occupant incapacitating injuries in cars struck by other cars and LTVs as occupant age increases. Another similarity between Tables 6 and 8 is that car and LTV subtotals reflect the exposure data where older occupants are more likely to travel in cars than LTVs. Finally, the proportion of light vehicle collisions with large trucks is lower for all age groups when compared to fatalities.

4.5. Severity of injury in crashes

This section uses the ordered probit method, discussed in the Methods section, to estimate the effect of ΔV, age, gender, belt use, and the type of other light vehicle on the probability of a particular maximum AIS for each car occupant. The data are weighted by the national inflation factor, which has been normalized to reflect the actual number of cases. While this approach does not capture all of the complexity of the NASS multistage sampling design when computing standard errors, it does provide a good first approximation of the hypothesized relationships. The restriction to car occupants makes modeling simpler because it restricts the vehicle type combinations and reflects the fact that few older occupants travel in LTVs. Given the exposure data, these results will reflect the injury risk faced by most older occupants.

Two particular occupant crash scenarios are examined using data from the NASS-CDS 1997–2001: Two-vehicle frontal crashes involving a car and another light vehicle and nearside-impact crashes where the front of the striking light vehicle hits the side of a car on which the occupant is seated. Belt use was dropped from the nearside impact analysis because it did not achieve statistical significance in the expected direction. This may reflect the fact that safety belts are more effective in frontal than side impacts. A variable attempting to capture problems with vehicle compatibility was also tried by including an indicator variable when the other vehicle was an LTV. This measure is included in the model of nearside injury severity because it achieved statistical significance in the expected direction, but it was dropped from the analysis of frontal crashes. Finally, the handful of cases with values of ΔV greater than 100 km/h were dropped to prevent overly influential outliers.

Tables 9 and 10 summarize the effect of age at various levels of ΔV on the predicted probability of each injury severity. The results in Table 9 also control for gender differences (women are more likely to have a higher maximum AIS than men) and safety belt use (occupants not using a safety belt are more likely to have higher maximum AIS than those who do use a safety belt.) The results in Table 10 control for gender differences and whether the other vehicle is an LTV. The middle two sets of results in Table 10 further illustrate that car occupants struck by LTVs are more likely to have higher maximum AIS than car occupants struck by another car. The complete results, including probit coefficients and statistical significance, are contained in Appendix A.

Rather than present probit model coefficients, Tables 9 and 10 provide the predicted probabilities of injury levels for particular scenarios. To illustrate interpretation, consider the top subtable within Table 9. The predicted probabilities are for a 30-year-old belted female car occupant in a frontal crash with another light vehicle with a total ΔV of 20 km/h. As one moves across the columns, the only assumption that changes is the age of the car occupant. As one moves down the column to the second subtable, the only assumption that changes is that total ΔV increases to 35 km/h. One could construct other tables for males or unbelted occupants, but the effect of age would stay essentially the same because the model explicitly controls for these two factors. Looking again at the first subtable in Table 9, the column for the 30-year-old says that the probability of no injury in this crash scenario is .46 (46%). However, the most likely outcome is a minor injury, which has an estimated probability of .48. For the 70-year-old occupant, the probability of no injury drops to .22. Instead, the probability of injury at all levels increases. The probability of an injury rated moderate or more severe rises from about .07 for the 30-year-old to .19 for the 70-year-old.

Table 9 indicates that in the relevant frontal crashes, both ΔV and age have an effect on the occupant's maximum known AIS. However, the largest effect occurs in crashes involving a relatively low ΔV. Frontal crashes at a ΔV of 50 km/h look similar for the three ages in that they are likely to produce injuries at a moderate or higher level. This result is different from that found in Table 10. In Table 10, the effect of age is strong at all three levels of ΔV, but it becomes stronger as ΔV increases. The biggest effect of age can be seen when ΔV equals 45 km/h. In this case, the probability of a serious or higher injury is .13 for the 30-year-old but .55 for the 70-year-old. Table 10 also shows the higher predicted injury when a car is struck in the side by an LTV than by a car. The probability of minor injuries and less decreases and the probabilities of moderate or greater injuries increases when comparing the middle two subtables in Table 10.

Table 9
Predicted probabilities of maximum injury severity to car occupants by age and ΔV in nonrollover two-light vehicle frontal crashes (NASS-CDS 1997–2001): Belted female

Probability of maximum AIS	30-year-old	55-year-old	70-year-old
Total ΔV of 20 km/h			
None (0)	0.46	0.33	0.22
Minor (1)	0.48	0.55	0.58
Moderate (2)	0.05	0.08	0.11
Serious (3)	0.02	0.03	0.06
Severe (4+)	0.00	0.01	0.02
Total ΔV of 35 km/h			
None (0)	0.18	0.13	0.10
Minor (1)	0.58	0.56	0.53
Moderate (2)	0.13	0.16	0.18
Serious (3)	0.08	0.10	0.13
Severe (4+)	0.03	0.04	0.06
Total ΔV of 50 km/h			
None (0)	0.04	0.04	0.03
Minor (1)	0.42	0.40	0.38
Moderate (2)	0.21	0.21	0.21
Serious (3)	0.20	0.21	0.22
Severe (4+)	0.13	0.14	0.16

Predicted probabilities based on probit results in Appendix A.

Table 10
Predicted probabilities of maximum injury severity to car occupants by age, ΔV, and other vehicle type in nonrollover two-light vehicle nearside crashes (NASS-CDS 1997–2001): Female

Probability of maximum AIS	30-year-old	55-year-old	70-year-old
Total ΔV of 25 km/h (other vehicle car)			
None (0)	0.26	0.20	0.15
Minor (1)	0.61	0.62	0.62
Moderate (2)	0.07	0.09	0.11
Serious (3)	0.05	0.07	0.09
Severe (4+)	0.01	0.02	0.04
Total ΔV of 35 km/h (other vehicle car)			
None (0)	0.12	0.05	0.02
Minor (1)	0.60	0.51	0.38
Moderate (2)	0.12	0.16	0.17
Serious (3)	0.11	0.17	0.23
Severe (4+)	0.05	0.10	0.20
Total ΔV of 35 km/h (other vehicle LTV)			
None (0)	0.08	0.03	0.01
Minor (1)	0.56	0.44	0.30
Moderate (2)	0.15	0.17	0.16
Serious (3)	0.14	0.21	0.25
Severe (4+)	0.08	0.16	0.27
Total ΔV of 45 km/h (other vehicle car)			
None (0)	0.04	0.01	0.00
Minor (1)	0.48	0.27	0.11
Moderate (2)	0.16	0.16	0.10
Serious (3)	0.19	0.25	0.23
Severe (4+)	0.13	0.31	0.55

Predicted probabilities based on probit results in Appendix A.

5. Discussion

Taking into account important factors for the safety of older occupants—growth in population, increasing travel exposure, crash involvement rates, and fragility—there are clear warning signs for the future safety of the oldest segment of the traveling public. This article documents at least two important and related areas where the growth in the older population, their travel patterns, and their typical crash situations could lead to substantial increases in affected populations.

The first is that a significantly larger share of travel (in day trips) by the oldest occupants is by passenger car versus other types of vehicles. This passenger car concentration is also indicated by overall crash involvement rates. The fatality risk for passenger car drivers is greater than the risk for light truck and van drivers in two-vehicle frontal crashes. The fatality risk for car drivers struck in the side by a light truck or van is also substantially greater than the fatality risk for car drivers struck in the side by another car. These numbers are particularly meaningful for older occupants because they are more likely to crash with another light vehicle and less likely to be in single-vehicle crashes than younger occupants. This study also shows that the predicted maximum injury level is higher for a car occupant struck by a light truck or van than another car even when controlling for age, gender, and change in velocity. The small shift in the 75 and older group into vans from passenger cars would help to diminish this particular effect on target population projections, but a strong relationship between the percent of light vehicle miles traveled in car and the age of the occupant still exists.

The second factor is the importance of crash mode, particularly side-impact crashes, in explaining injuries for older occupants. Side-impact crashes, both from a crash involvement and survivability standpoint, are of the greatest concern. The review of previous literature suggested that older drivers are more likely to be involved in side-impact crashes than younger drivers, and occupant involvement rates examined in the current study demonstrate that older occupants are more likely to be in side-impact crashes than younger occupants. The increase in crash involvement explains some of the increase in the proportion of fatalities and serious injuries in struck side-impact crashes, but survivability and frailty also play important roles.

Although not as important as side-impact crashes, frontal crashes also play a role in explaining age differences. Involvement in two light-vehicle frontal crashes increases slightly with age, and the proportion of serious injuries from frontal crashes is about the same across age groups. However, the proportion of fatalities from frontal crashes increases substantially with age. Because there is little change in crash exposure, the explanation could be one of frailty. This argument is supported by the ordered probit results where the probability of a maximum AIS of 4 or greater increases with age, but age still does not have as strong an effect as it does in side-impact crashes.

Interestingly, an increase in the proportion of miles traveled by older occupants compared to younger occupants also suggests that some issues may not be as important in the future. For example, a larger proportion of older occupants would probably result in a smaller proportion of miles traveled by motorcycle. It also appears that single-vehicle rollovers diminish in importance as a cause of fatalities and incapacitating injuries as age increases. Therefore, a larger proportion of miles traveled by older occupants could result in fewer rollover fatalities and injuries per mile traveled. In addition, as more older individuals move from pedestrians to vehicle occupants, pedestrian fatalities among the oldest population may fall. This change may help explain why total pedestrian fatalities decreased among those aged 70 and above between 1991 and 2001, although the population increased substantially (NHTSA, 2001).

6. Summary

Results from 1995 and 2001 nationwide travel surveys indicate that while annual person miles per person for day trips increased for all age groups, the percentage increases for people 65 and older have increased more than five times the rate of increase for the population 25–64. The differences in total day trip miles are even more dramatic, with total miles traveled by the oldest Americans increasing by over 50%. These differences reflect changes in the size of the older population as well as in their behavior.

Results for exposure based on crash involvement rates per licensed driver indicate that while crash involvement in all crashes is lower for the oldest drivers than for any other age group, the rate does not fall as dramatically as does driver exposure based on annual person miles per person. There are some crash incidence factors, as well as survivability factors, at work. While driver involvement rates in PDO and injury-producing crashes also follow this downward trend by age, the driver involvement rate in fatal crashes for the oldest age group is over 30% higher than the next oldest group. Along with the results for occupant crash involvement by severity, this speaks to the strong influence of higher crash consequences for the oldest population group.

Another important finding is that vehicle travel and crash involvement by the oldest motorists are more concentrated in passenger cars than other vehicles, such as light trucks and utility vehicles, compared to younger ages. As a result, increases in the population and vehicle travel by older occupants could exacerbate the compatibility problem related to the vehicle mix on the road. In frontal impact crashes involving two light vehicles, the fact that older occupants are more likely to be in cars than LTVs increases their fatality risk. Using the FARS 2001, the ratio of driver fatalities in cars involved in frontal crashes with light trucks and vans is 4:1. The analysis also points to the importance and concern for the oldest vehicle occupants in side-impact crashes. For those 25–44, struck side-impact crashes account for 11% of occupants involved in crashes, 7% of occupant fatalities, and 14% of seriously injured occupants. For those aged 75 and above, struck side-impact crashes increase to 20% of occupants involved in crashes, 27% of fatalities, and 28% of those seriously injured. Furthermore, the results demonstrate that the expected maximum injury severity in side-impact crashes where the car is struck on the occupant's side of the vehicle increases greatly with age, especially in crashes involving relatively high values of ΔV. This effect holds even when controlling for whether the other vehicle is an LTV.

Several factors work together to increase the compatibility problem for older drivers in side-impact crashes. The increase in older drivers will likely lead to an increase in side impact collisions. Also, the fact that older occupants involved in a side impact collision are more likely than younger occupants to be in struck cars, particularly cars struck by LTVs, increases the fatality and injury risk for older occupants. As discussed previously, the ratio of driver fatalities in striking versus side struck passenger cars using the FARS 2001 is 1:8 when the other vehicle is a car and 1:29 when the other vehicle is a light truck or van. These results suggest that the problem is best addressed in terms of both crash avoidance and crash-worthiness countermeasures.

7. Impact on research, practice, and policy

Based on the results of this analysis, vehicle safety issues for the oldest segment of the population should be carefully examined over the next several years. While programs aimed at reducing driving exposure should be continued and strengthened, it is likely that the oldest population will continue to have an expectation and level of mobility that is different from their parents and grandparents. The issues involve nondrivers as well as drivers because growth will continue in older passenger exposure even if all driving ended. As a result, greater attention to vehicle safety issues, as well as behavior change, is needed.

While occupant protection in crashes presents significant challenges due to physiological issues in the oldest population and crash dynamics, solutions can be sought to ameliorate the degree of injury they will sustain in a crash. These could include new occupant protection technologies as well as increased side impact protection. These results also echo the concerns of researchers regarding the crash compatibility of vehicles on the road and show that increased attention to vehicle engagement in side-impact crashes would be particularly helpful for older occupants. In addition, a greater body of research is needed on vehicle technologies that can help older drivers avoid collisions. Research aimed at crash avoidance while making turns and while navigating intersections would help older occupants by reducing side-impact crashes.

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Appendix A. Complete order probit results for predicting AIS injury severity

Variable	Frontal crashes			Side-impact crashes		
	Coefficient	Standard error	Pr > chi-square	Coefficient	Standard error	Pr > chi-square
Intercept 1	− 1.8884	0.1912	< .0001	− 0.3473	0.2142	.1049
Intercept 2	− 1.6279	0.0496	< .0001	− 1.7691	0.0610	< .0001
Intercept 3	− 2.1709	0.0620	< .0001	− 2.1972	0.0759	< .0001
Intercept 4	− 2.8618	0.0893	< .0001	− 2.8549	0.1116	< .0001
Age	0.0248	0.0034	< .0001	− 0.0165	0.0047	.0004
Sex (0 = male, 1 = female)	0.5290	0.0592	< .0001	0.1310	0.0639	.0404
ΔV	0.0666	0.0066	< .0001	0.0221	0.0107	.0380
Belt use (0 = no, 1 = yes)	− 0.3462	0.0680	< .0001			
Striking vehicle LTV (0 = no, 1 = yes)				0.2418	0.0705	.0006
Age × ΔV	0.0004	0.0001	.0002	0.0011	0.0002	< .0001
	N = 1648			N = 1350		

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Rory A. Austin is a mathematical statistician with the National Highway Traffic Safety Administration (NHTSA). Prior to joining NHTSA in 2002, he taught research methods as an assistant professor of political science at the George Washington University. He received his PhD in political science from the University of Rochester in 1998.

Barbara M. Faigin is division leader of the Planning and Analysis Division, Office of Rulemaking, NHTSA. Prior to her current position, she directed NHTSA's Strategic Planning Program, developed agency injury cost data, and performed benefit cost analyses on several of the agency's vehicle safety standards. After 2 years at the Syracuse University/Maxwell School, she received her undergraduate degree in economics from George Washington University, followed by graduate work in economics and computer science.