PERGAMON

Accident Analysis and Prevention 35 (2003) 227–235

ACCIDENT ANALYSIS & PREVENTION

www.elsevier.com/locate/aap

Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers

Guohua Li [a,b,*], Elisa R. Braver [c], Li-Hui Chen [b]

[a] Department of Emergency Medicine, Johns Hopkins University School of Medicine, 1830 East Monument Street, Suite 6-100, Baltimore, MD 21205, USA
[b] Center for Injury Research and Policy, Johns Hopkins University Bloomberg School of Hygiene and Public Health, Baltimore, MD 21205, USA
[c] Insurance Institute for Highway Safety, Arlington, VA 22201, USA

Received 20 July 2001; received in revised form 15 November 2001; accepted 26 November 2001

Abstract

Using multiple national data systems, the roles of fragility (susceptibility to injury) versus excessive crash involvement in the increased fatality risk of older drivers per vehicle-mile of travel (VMT) were estimated. For each age and gender group, deaths per driver involved in a crash (a marker of fragility) and drivers involved in crashes per VMT (a marker of excessive crash involvement) were computed. Compared with drivers ages 30–59, those younger than 20 and those 75 or older both had much higher driver death rates per VMT. The highest death rates per mile driven, 13-fold increases, were observed among drivers age 80 or older, who also had the highest death rates per crash. Fragility began to increase at ages 60–64 and increased steadily with advancing age, accounting for about 60–95% of the excess death rates per VMT in older drivers, depending on age group and gender. Among older drivers, marked excesses in crash involvement did not begin until age 75, but explained no more than about 30–45% of the elevated risk in this group of drivers; excessive crashes explained less of the risk among drivers ages 60–74. In contrast, crash over-involvement was the major factor contributing to the high risk of death among drivers younger than 20, accounting for more than 95% of their elevated death rates per VMT. Although both fragility and crash over-involvement contributed to the excess death rates among older drivers per VMT, fragility appeared to be of over-riding importance. These findings suggest that measures to improve the protection of older vehicle occupants in crashes should be vigorously pursued.

Keywords: Aging; Traffic safety; Epidemiologic methods; Older drivers; Elderly drivers

1. Introduction

Personal mobility plays a pivotal role in normal daily living and social functions for people of all ages. In the United States, driving is the primary means of personal mobility, accounting for 92% of all daily person-miles of travel (FHWA, 1997a). For the elderly, the ability to drive a car is a significant predictor of quality of life, functional independence, and physical and mental health.

Because physiological functions, such as vision and reaction time, decline with increasing age and cognitive functions also may decrease, safety performance in older drivers has been a cause of public concern (Marottoli et al., 1994; Foley et al., 1995; McGwin et al., 2000; Lyman et al., 2001; Janke, 2001; Teed, 1996). The prevalence of dementia has been reported as about 30% among 85-year-olds (Skoog et al., 1993); however, the prevalence of dementia among drivers in their 80 s is unknown because many older people with dementia are likely to have stopped driving. Public concern also is related to the increasing percentage of the elderly in the United States population and the consequent increase in the number of older drivers, who are driving more than older people in earlier decades (FHWA, 1997b). In addition, age-related declines in physical health can increase the likelihood of poor outcomes among older vehicle occupants involved in crashes. Older people are at higher risk of fractures and chest injuries (Augenstein, 2001; Cavanaugh and Koh, 2001; Wang, 2001; Zhou et al., 1996; Hall and Owings, 2000) and are more prone to injuries related to seat belts (Augenstein, 2001; Cavanaugh and Koh, 2001; Zhou et al., 1996). Moreover, injuries among older occupants have a poorer prognosis (Barancik et al., 1986; Waller et al., 1986; Evans, 1988; Evans and Gerrish, 2001; Kim et al., 1995). Despite extensive research on aging and driving safety, it is unclear to what extent fragility and crash over-involvement separately contribute to the excess fatal crash rates among older drivers. Past research focused on either one or the other factor, but not their joint effects. The objective of this study was to examine age-related differ-

* Corresponding author. Tel.: +1-410-614-5229; fax: +1-410-502-8881.
E-mail address: ghli@jhmi.edu (G. Li).

0001-4575/02/$ – see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0001-4575(01)00107-5

ences in the relative contributions of fragility and excessive crash involvement to fatal crash risk, while controlling for the quantity of exposure to vehicle travel.

The effects of gender in combination with age also were of interest because women have been described as having a greater risk of injury in crashes of equivalent severity (Evans and Gerrish, 2001). The role of fragility and crash over-involvement in relation to age was examined by vehicle impact point because of research reporting that older drivers have high involvement rates in side impact crashes (Cooper, 1990; Insurance Institute for Highway Safety, 2000; McGwin and Brown, 1999; Preusser et al., 1998; Zhang et al., 1998).

2. Methods

Older drivers (ages 60 or older) and young drivers (ages 16–19 and 20–29) were compared with drivers ages 30–59, the age group with the lowest death rate per mile driven.

2.1. Data sources

Data for this study came from three federal sources: the 1993–1997 Fatality Analysis Reporting System (FARS), the 1993–1997 General Estimates System (GES), and the 1995 Nationwide Personal Transportation Survey (NPTS).

Driver fatality data were obtained from FARS, a census of crashes that occur on public roads in the United States in which a death results within 30 days of the crash (NHTSA, 1997a). FARS records information on each driver and vehicle involved in a fatal crash.

GES, a nationally representative probability sample of all police-reported traffic crashes that result in property damage, personal injury, or death (NHTSA, 1997b), provided weighted estimates of drivers involved in police-reported crashes for this analysis. Each year, GES randomly selects about 54,000 police-reported crashes from approximately 400 police jurisdictions across the United States. A weight is assigned to each sampled crash to generate national estimates.

Exposure-to-driving data came from the 1995 NPTS, which provides information about the characteristics of daily personal travel in the United States (FHWA, 1997a). Based on a stratified sample that considered seasonal and day-of-week variations in travel patterns, the 1995 NPTS conducted a telephone survey of 97,881 respondents from a nationally representative sample of 42,033 households. A total of 27,577 male drivers and 26,123 female drivers ages 16 and older provided travel data for NPTS. Both travel diaries and odometers were used to obtain information about the respondent's trips on a pre-assigned travel day and vehicle-mileage during a specific time period (ranging from 2 to 6 months). NPTS supplied estimates of annual vehicle-miles of travel (VMT) by age and gender for 1995, which were multiplied by 5 to obtain estimates of travel quantities during 1993–1997. This procedure enabled calculation of deaths and crash involvements per VMT during 1993–1997. It was reasonable because travel grew linearly from 1993 through 1997 so that the degree of underestimation of travel during 1996–1997 was counterbalanced by overestimation of travel during 1993–1994 (FHWA, 1996, 1997b, 1998, 1999), assuming no age-related deviations from the linear increase.

This study was limited to driver deaths, police-reported crashes, and vehicle-mileage involving passenger vehicles. Vehicles that were not passenger vehicles, such as trucks and motorcycles, were excluded. For the remainder of this paper, the term "drivers" will refer only to passenger vehicle drivers.

2.2. Statistical analysis

Using data from FARS, GES, and NPTS, and the decomposition method explained below, age and gender differences were examined for three outcome measures: (1) driver deaths per VMT, (2) drivers involved in police-reported crashes per VMT, and (3) driver deaths per driver involved in a police-reported crash. These indices are interrelated and measure different aspects of driving safety. Numerically, the first outcome measure, driver deaths per VMT, is a death rate per unit of exposure and is the product of the latter two outcome measures. Eq. (1) describes the relationship among the three outcome measures:

$$\text{driver death rate per VMT} = \frac{\text{driver deaths}}{\text{VMT}} = \frac{\text{driver deaths}}{\text{drivers involved in crashes}} \times \frac{\text{drivers involved in crashes}}{\text{VMT}} \tag{1}$$

The second outcome measure, driver involvements in police-reported crashes per mile driven, reflects the tendency of drivers to be involved in crashes that come to the attention of police agencies. Such crashes tend to be those that involve injured occupants or have substantial property damage (Braver et al., 2002). The third measure, driver deaths per driver involved in a crash, represents the risk of dying given involvement in a crash. This measure reflects human susceptibility to injury (fragility), assuming that vehicle and crash characteristics are constant. These outcome measurements were calculated by driver age, gender, and vehicle impact point (front, side, or rear). Of primary interest were age differences in driver death rates per mile driven and the relative contributions of fragility and excessive crash involvement to these differences. The decomposition method used in this study is described in detail elsewhere and is a technique for separating the individual components contributing to overall death rates (Li and Baker, 1996; Li et al., 1998). Briefly, the differences in driver death rates per unit of travel between two age groups are expressed as the ratio of the rates for the two age groups. This ratio equals the ratio of driver deaths per all drivers involved in police-reported crashes for the two age groups multiplied by the ratio of drivers involved in police-reported crashes per VMT for the same two age groups, as described in Eq. (2):

$$\text{death rate ratio} = \frac{\text{driver deaths}_1/\text{VMT}_1}{\text{driver deaths}_2/\text{VMT}_2} = \underbrace{\frac{\text{driver deaths}_1/\text{drivers involved in crashes}_1}{\text{driver deaths}_2/\text{drivers involved in crashes}_2}}_{(\text{ratio}_1)} \times \underbrace{\frac{\text{drivers involved in crashes}_1/\text{VMT}_1}{\text{drivers involved in crashes}_2/\text{VMT}_2}}_{(\text{ratio}_2)} \qquad (2)$$

The relative contribution (RC) partitions the influence of the indicators of fragility and crash over-involvement on fatality risk per unit of travel using the following formula. This formula does not consider any other variables:

$$\text{relative contribution estimate for individual marker (fragility or excessive crash involvement)} = \text{RC}_i = \frac{|\ln(\text{ratio}_i)|}{\sum_{i=1}^{2}|\ln(\text{ratio}_i)|} \times 100\% \qquad (3)$$

A high relative contribution does not necessarily mean that drivers in a particular age group are more fragile or more likely to be involved in a crash; rather, a high relative contribution simply indicates that the overall driver death rate per unit of travel is more heavily influenced by either death rates per crash-involved driver or crash rates per unit of travel. Having a very low crash rate per unit of travel may be associated with a high relative contribution for that rate if it is much lower than that of the comparison group.

Accordingly, estimates of relative contributions generated by the above equations must be interpreted in conjunction with the rate ratios for death rates per driver in a crash and crash rates per VMT. For example, if the ratio of deaths per driver involvement is above 1.0 and its relative contribution is above 50%, then this indicates that drivers in an age group of interest have higher death rates per crash, and these higher rates may explain more than half of their overall death rates per unit of travel. Yet if the death rate ratio is below 1.0, but the relative contribution exceeds 50%, this indicates that their lower death rates per crash explain a large portion of the group's overall death rate per unit of travel.

3. Results

3.1. Age and gender

3.1.1. Driver death rates per VMT

Driver death rates per unit of travel among both genders were much higher for the youngest and oldest age groups (Table 1). During 1993–1997, there were 11,801 driver deaths among 16–19-year-old, who drove about 420 billion miles during this period, and 10,318 driver deaths among those age 75 or older, who drove about 193 billion miles. For both male and female drivers, death rates per VMT were at their lowest during ages 30–59, started rising by ages 65–69, and then rose sharply after age 74. Men had substantially higher death rates per unit of travel than women when they were younger than 30 and at age 80 or older.

Among men, death rates per VMT were not greatly elevated until ages 70–74, at which time they more than doubled (rate ratio = 2.2) relative to men ages 30–59 (Table 2). Among women, rate ratios for deaths per VMT became markedly elevated earlier than for men, starting at ages 60–64 (rate ratio = 1.8, relative to ages 30–59). Extremely high death rates per mile driven occurred among men and women age 80 or older, whose rates were 13 times as high as those for drivers ages 30–59 (Table 2).

3.1.2. Driver deaths per driver involved in a crash (fragility indicator)

Driver deaths per crash involvement, the marker of fragility, remained fairly stable and then started increasing steadily at age 60 among men and women, with a steep increase at age 80 or older (Fig. 1, Table 1). The death rates per crash for male drivers in each age group were higher than those for female drivers. In addition, there were gender differences in the extent to which fragility rose by age. Older women had a greater increase in rate ratios relative to women ages 30–59 than men of the same age groups compared with 30–59-year-old male drivers (Table 2).

3.1.3. Drivers involved in crashes per VMT (crash over-involvement indicator)

Rates of drivers involved in crashes per unit of travel, the marker for excessive crash involvement, were highest among the youngest drivers, chiefly those ages 16–19 (Fig. 2, Table 1). There were an estimated 7 million police-reported crashes involving 16–19-year-old drivers and about 1.6 million crashes involving drivers age 75 or older during 1993–1997 (Table 1). The risk of crash involvement was constant from ages 30–69, before rising at ages 70–74 and then continuing to increase with age. Crash involvement rates more than tripled for drivers age 80 or older compared with drivers ages 65–69. Until age 80, female drivers had, on average, a 10% greater risk of crash involvement than their male counterparts (Table 1).

3.1.4. Relative contributions of indicators of fragility and excessive crash involvement

Table 2 presents the decomposition of age disparities in VMT-based driver death rates by gender. Because this study attempted to explain increased fatality risks among different age groups, the following summary of results includes relative contribution estimates only for age-gender groups in which the overall death rates per VMT were elevated.

Among older drivers, deaths per crash, the measure of fragility, increased at younger ages (60–64) and explained higher proportions of overall deaths per unit of travel than crashes per VMT, the measure of excessive crash

Table 1
Passenger vehicle driver deaths per 1000 drivers involved in police-reported crashes and per 100 million vehicle-miles of travel (VMT) by driver age and sex, united states, 1993–1997

Age group	Passenger vehicle driver deaths[a]	Drivers involved in police-reported crashes[b]		Respondents to NPTS (unweighted)[c]	Vehicle-miles of travel (in millions)[c]	Driver deaths per 1000 driver involvements	Drivers in crashes per 100 million VMT	Driver deaths per 100 million VMT
		Unweighted	Weighted					
Male								
16–19	8231	32432	4115910	1211	248891	2.00	1654	3.31
20–29	19302	67554	8343040	3816	1132965	2.31	736	1.70
30–59	31091	114067	14410660	17153	3856974	2.16	374	0.81
60–64	2766	7468	955120	1655	306841	2.90	311	0.90
65–69	2784	6619	838480	1478	260288	3.32	322	1.07
70–74	2970	5568	708830	1197	171052	4.19	414	1.74
75–79	2844	4030	509300	683	79801	5.58	638	3.56
80+	4015	3432	432880	384	38432	9.28	1126	10.45
Female								
16–19	3570	22743	2930310	1078	171602	1.22	1708	2.08
20–29	6582	45786	5798460	4031	758919	1.14	764	0.87
30–59	13226	81247	10494730	16798	2482976	1.26	423	0.53
60–64	1290	4458	575850	1315	138599	2.24	415	0.93
65–69	1406	4165	533480	1135	140114	2.64	381	1.00
70–74	1579	3667	471740	887	86218	3.35	547	1.83
75–79	1562	2753	353280	555	49109	4.42	719	3.18
80+	1897	2278	288750	324	26134	6.57	1105	7.26

[a] Fatality Analysis Reporting System.
[b] General Estimates System.
[c] Nationwide Personal Transportation Survey.

Table 2
Age disparities in driver deaths per vehicle-mile of travel (VMT): death rate ratios and relative contributions (RC) of measures of fragility[a] and excessive crash involvement[b] by driver age and sex

Age group	Driver deaths per VMT: rate ratio	Driver deaths per 1000 driver involvements		Drivers in crashes per 100 million VMT	
		Rate ratio	RC (%)	Rate ratio	RC (%)
Male					
16–19	4.1	0.9	5	4.4	95
20–29	2.1	1.1	9	2.0	91
30–59[c]	1.0	1.0	–	1.0	–
60–64	1.1	1.3	62	0.8	38
65–69	1.3	1.5	74	0.9	26
70–74	2.2	1.9	87	1.1	13
75–79	4.4	2.6	64	1.7	36
80+	13.0	4.3	57	3.0	43
Female					
16–19	3.9	1.0	2	4.0	98
20–29	1.6	0.9	15	1.8	85
30–59[c]	1.0	1.0	–	1.0	–
60–64	1.8	1.8	97	1.0	3
65–69	1.9	2.1	88	0.9	12
70–74	3.4	2.7	79	1.3	21
75–79	6.0	3.5	70	1.7	30
80+	13.6	5.2	63	2.6	37

[a] Fragility as indicated by driver deaths per 1000 drivers involved in police-reported crashes.
[b] Excessive crash involvement as indicated by driver involvements in police-reported crashes per 100 million VMT.
[c] Reference group.

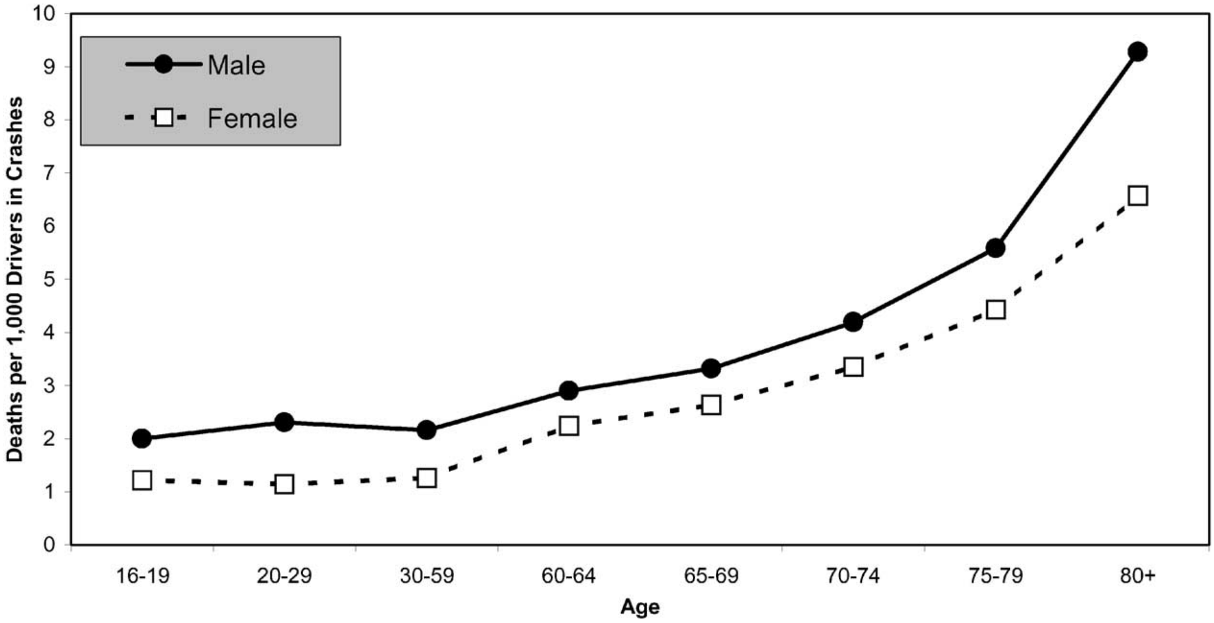

Fig. 1. Passenger vehicle driver deaths per 1000 drivers in police-reported crashes by age and gender, United States, 1993–1997: marker for fragility.

involvement. Unlike older drivers, the excess death rates per mile for adolescent and 20–29-year-old drivers of both genders were due almost entirely to increased crash involvements per VMT, with relative contributions exceeding 85%.

At the ages at which older driver death rates per VMT became greatly elevated, 70–74 for men and 60–64 for women, fragility was estimated as contributing to 87% of the death rate per mile among men and 97% among women. Rate

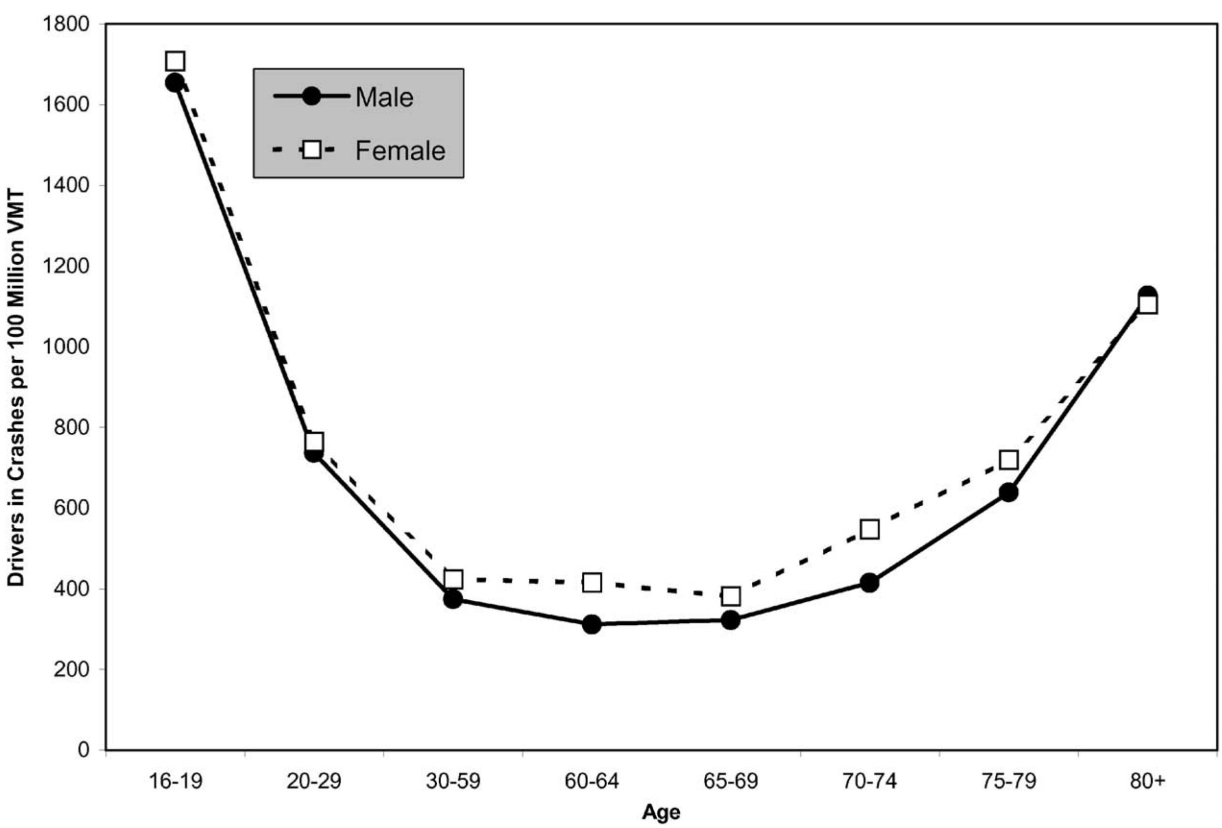

Fig. 2. Passenger vehicle drivers in police-reported crashes per 100 million VMT by age and gender, United states, 1993–1997: marker for crash over-involvement.

Table 3
Passenger vehicle driver deaths per 1000 drivers involved in police-reported crashes by driver age and vehicle impact point, united states, 1993–1997

Age group	Passenger vehicle driver deaths[a]	Drivers involved in police-reported crashes[b]		Vehicle-miles of travel[c] (in millions)	Driver deaths per 1000 driver involvements	Drivers in crashes per 100 million VMT	Driver deaths per 100 million VMT
		(Unweighted)	(Weighted)				
Front impact point							
16–19	6024	28789	3586310	420493	1.68	853	1.43
20–29	14596	54848	6559300	1891884	2.23	347	0.77
30–59	26070	84694	10301160	6339951	2.53	162	0.41
60–74	7441	13415	1606720	1103112	4.63	146	0.67
75+	5364	5628	686080	193477	7.82	355	2.77
Side impact point							
16–19	3534	17039	2194970	420493	1.61	522	0.84
20–29	6491	34955	4421550	1891884	1.47	234	0.34
30–59	10457	61538	7927190	6339951	1.32	125	0.16
60–74	3997	11544	1515470	1103112	2.64	137	0.36
75+	4234	5087	651570	193477	6.50	337	2.19
Rear impact point							
16–19	353	6531	964920	420493	0.37	229	0.08
20–29	862	18791	2638580	1891884	0.33	139	0.05
30–59	1615	42279	5905780	6339951	0.27	93	0.03
60–74	480	6135	856590	1103112	0.56	78	0.04
75+	301	1495	213110	193477	1.41	110	0.16

[a] Fatality Analysis Reporting System.
[b] General Estimates System.
[c] Nationwide Personal Transportation Survey.

ratios for driver deaths per crash continued to climb with each successive age group, indicating drivers were becoming more fragile as they aged.

At the age at which driver crash involvements per VMT started to increase among older drivers, 70–74, relative contributions for crash rates per mile were about 15–20%. At age 75 or older, the higher crash involvement rates resulted in higher estimated relative contributions, 30–43%, among male and female drivers. Relative contribution estimates for fragility decreased with increasing age, simply reflecting the role of crash over-involvement among the oldest drivers.

Men and women age 80 or older were the most fragile (rate ratios for deaths per crash were 4.3 among men and 5.2 among women). Among older drivers, those age 80 or older also were the most over-involved in crashes (rate ratios for crashes per VMT were 3.0 among men and 2.6 among women).

3.2. Age and vehicle impact point

Driver age differences in fatality risk also were examined in relation to the vehicle impact point. Older drivers were divided into two age groups (60–74 and 75 or older) to ensure adequate sample size for impact point analyses.

3.2.1. Driver death rates per VMT

For all ages, the highest death rates per unit of travel were observed in frontal impacts, followed by side impacts (Table 3). Death rates per 100 million VMT among occupants in vehicles sustaining rear impacts were less than one-tenth those of frontal impacts.

For frontal, side, and rear impacts, age patterns with respect to driver deaths per unit of travel were similar to those previously described for all types of crashes. The most striking finding by age was the increased death rates among older drivers in side impact crashes per VMT: drivers age 75 or older were 13 times more likely to die than drivers ages 30–59 (Table 3). By comparison, the oldest drivers were about 6–7 times more likely to die in frontal or rear impact crashes per VMT than 30–59-year-old drivers.

3.2.2. Driver deaths per driver involved in a crash (fragility indicator)

As was observed for all impact points combined, fragility increased with age for each impact point (Table 3). The risk of dying per side impact crash, relative to ages 30–59, among drivers age 75 or older was moderately higher than for frontal impacts (rate ratios of 4.9 and 3.1, respectively).

3.2.3. Drivers involved in crashes per VMT (crash over-involvement indicator)

Similar to findings for all crashes, excessive crash involvements per VMT were highest among teenage drivers for each impact point and were present to a lesser extent among drivers age 75 or older (Table 3). Teenagers (ages 16–19) had rate ratios of 5.3 for frontal and 4.2 for side impacts compared with 30–59-year-old drivers. The involvement rate ratios were 2.7 for side impacts and 2.2 for frontal impacts among drivers age 75 or older.

3.2.4. Relative contributions of indicators of fragility and excessive crash involvement

Relative contribution estimates for individual vehicle impact points resembled those for all impact points combined in that fragility explained more of the death rates per VMT among older drivers than excessive crash involvement. Decomposition analysis (not shown) suggested that about 80–85% of the deaths per VMT in frontal, side, and rear impacts among drivers ages 60–74 could be explained by fragility. Among the oldest drivers, relative contribution estimates for the role of fragility were about 60% for frontal and side impacts and about 90% for rear impacts. In contrast, among drivers younger than 30, the elevated risk of dying per VMT in frontal, side, and rear impacts was strongly related to excessive crash involvements per mile driven, with relative contributions of about 70–90%.

4. Discussion

In this study, the decomposition method was used to explore the age variations in different outcome measures of driving safety. Fragility, as measured by risk of death when involved in a crash, appeared to be of over-riding importance in explaining the increased fatality risk per unit of travel among older drivers. Fragility started increasing at ages 60–64 and continued to rise with advancing age; its estimated relative contribution exceeded that of excessive crash involvement even among the oldest drivers. Marked excesses in crash involvement, as measured by drivers involved in crashes per unit of travel, were not apparent among older drivers until ages 75–79. In contrast, excessive crash involvement was the major factor explaining the elevated risk of dying per unit of travel among drivers younger than 30, particularly drivers ages 16–19, who had the highest crash rates per mile. In addition to drivers age 80 or older, females were the other group of older drivers with high fragility. By ages 60–64, female drivers had nearly double the death rate per crash of 30–59-year-old women, whereas male drivers' death rates per crash did not double until ages 70–74. Paradoxically, male drivers had a higher death rate per crash than female drivers at all ages, although males are not more fragile than females (Evans, 2001; Evans and Gerrish, 2001). Risk-taking behaviors such as speeding, failure to use seat belts, and alcohol-impaired driving are more common among men and may explain why crashes were more lethal for men (NHTSA, 1997; NHTSA, 1998; NHTSA, 2000).

The findings for front, side, and rear vehicle impact points strongly resemble the findings for all crashes in that increased crash involvement explained the excess fatality risk per mile driven among drivers younger than 30, whereas increased fragility largely explained the excess risk among older drivers. Some researchers have attributed increased older driver fatalities in intersection crashes to factors relating to crash over-involvement, such as the increased cognitive burden associated with making left turns or the higher prevalence of visual field problems among older drivers (Ball et al., 1990; Teed, 1996). Although this study did not examine intersection crashes separately, its findings suggest that the excessive older driver deaths in intersection crashes may be more related to their fragility in side impact crashes than to their tendency to get into side impact crashes.

The estimates of the relative contributions of fragility and excessive crash involvement should be interpreted with caution because of the limitations inherent in the national databases relied on by this study, especially NPTS and GES, which are subject to sampling variation. NPTS is designed to be a national sample of travel, and its estimates of travel for each age-gender grouping are reasonable, but not necessarily statistically stable (FHWA, 1997). Another potential problem is that as a sample of police-reported crashes, GES is subject to regional variations in the reporting of crashes to police agencies, in addition to the greater likelihood of reporting more serious crashes to authorities (Braver et al., 2002). How this affects computed rates of crashes per mile driven and death rates per crash by age and gender is unknown; however, age differences in crash and fatality risk undoubtedly are real even if the estimates are imprecise.

Other limitations stem from shortcomings of the outcome measures used for the analysis. VMT-based driver death and crash involvement rates could not account for older drivers' different travel patterns, including travel under lower risk conditions (Chipman et al., 1993; Evans, 1993; Janke, 1991; Hakamies-Blomqvist et al., 1995; Li et al., 1998). This study underestimated the fatality risks among older drivers relative to younger drivers by some unknown quantity because older drivers have higher belt use rates, tend to obey speed limits more frequently, drive bigger passenger vehicles, travel at lower speeds, and are less likely to have elevated blood alcohol concentrations while driving (NHTSA, 1998; NHTSA, 2000; unpublished data from 1999 FARS and 1995 NPTS).

One factor that could have led to overestimation of crash risks among older drivers was that the occurrence of injuries may have influenced whether a crash was reported to police. Because older drivers are more susceptible to injury, crashes that otherwise may have been unreported could have been included in the GES data used to compute crash rates per unit of travel.

The proxy measure of fragility, driver death rates per crash involvement, is a useful, but imperfect indicator of fragility because of its inability to adjust for other factors that affect crash outcomes. These factors include seat belt use, car size, and travel speeds.

4.1. Implications for highway safety

The findings of this study suggest that countermeasures to reduce the vulnerability of older drivers to injury should be vigorously pursued. Increased fragility not only is a stronger risk factor for occupant deaths than crash over-involvement, but it affects more elderly drivers because it begins earlier, at ages 60–64.

Reducing traffic speeds and improving seat belt use rates are already known to be effective methods of reducing the crash forces acting on vehicle occupants of any age. Future developments in vehicle design may improve the protection of older vehicle occupants, but are not yet ready for adoption. These include modifications to occupant seat belts that would distribute restraining forces better, such as making them wider, inflatable, or having four points of attachment to the vehicle instead of the current three-point lap/shoulder belts (Kent, 2001; Vala, 2001; Wang, 2001). Also, crash forces could be reduced if the crush zones of passenger vehicles were lengthened in conjunction with reducing the stiffness of vehicle front ends. Any potential changes to vehicles or restraint systems need thorough testing and would need to be acceptable to vehicle owners.

Other features to augment crashworthiness already are in some vehicles, such as side impact airbags and frontal airbags that tailor inflation and deployment to both crash severity and occupant characteristics, including seat belt use and seat location (Vala, 2001; Kent, 2001). Whether side impact airbags and advanced airbag systems are beneficial to older people involved in real-world crashes has not yet been established.

Programs that seek to reduce crash involvements among older drivers have limited effects on the problem of fragility, including special training programs for older drivers (AARP, 2001). Much research has been directed toward identifying older drivers at high risk of making hazardous driving errors (Janke, 2001; Janke and Eberhard, 1998). If such screening programs were implemented, any older driver subject to driving restrictions would continue to be at increased risk of injury when traveling as a passenger.

Much of the public concern about older drivers has to do with perceptions that older drivers are imperiling not only themselves but other people. This concern is not substantiated by this study, which found that crash over-involvement was a minor problem except among the oldest drivers. Furthermore, other data shows that older drivers hit few pedestrians and when older drivers do collide with other vehicles, they are far more likely to die than the occupants of the other vehicles (Evans, 2000; NHTSA, 2000; unpublished data from FARS).

The death rate per VMT for drivers is a function of crash incidence density and crash fatality rate. The results of this study indicate that the heightened death rates per VMT among older drivers resulted predominantly from increased fragility, whereas excessive crash involvement was mainly responsible for the high death rates per VMT among adolescent drivers. These findings suggest that preventive strategies for older drivers could emphasize occupant protection. Research to devise modifications of vehicles and restraint systems so as to reduce the injury susceptibility of older vehicle occupants is urgently needed.

Acknowledgements

We would like to thank the following colleagues at the Insurance Institute for Highway Safety: Susan A. Ferguson for providing helpful comments on this paper and Robert Tabor and Kristi W. Lowe for providing editorial assistance. This research was supported primarily by the Insurance Institute for Highway Safety and in part by grants R01AG13642 and R01AA09963 from the National Institutes of Health and grant CCR302486 from the Centers for Disease Control and Prevention. The opinions, findings, and conclusions expressed in this publication are those of the authors and do not necessarily reflect the views of the funding organizations.

References

AARP, 2001. AARP 55 Alive Driver Safety Course. Washington, DC, 2001. Available at http://www.aarp.org/55alive/about.html (accessed 7 November 2001).

Augenstein, J., 2001. Differences in clinical response between the young and elderly. In: Proceedings of the Presentation at Aging and Driving Symposium, Southfield, MI, 19–20 February 2001. Association for the Advancement of Automotive Medicine, Des Plaines, IL.

Ball, K., Owsley, C., Beard, B., 1990. Clinical visual perimetry underestimates peripheral field problems in older adults. Clin. Visual Sci. 5, 113–125.

Barancik, J.I., Chatterjee, B.F., Greene-Cradden, Y.C., Michenzi, E.M., Kramer, C.F., Thode Jr., H.C., Fife, D., 1986. Motor vehicle trauma in northeastern Ohio. Part I. Incidence and outcome by age, sex, and road-use category. Am. J. Epidemiol. 123, 846–861.

Braver, E.R., Solomon, M.G., Preusser, D.F., 2002. Commercial and passenger motor vehicle crashes on toll roads. Accident Anal. Prev. 34, 293–303.

Cavanaugh, J., Koh, S.W., 2001. Thoracic injury tolerance in older occupants. In: Proceedings of the Presentation at Aging and Driving Symposium, Southfield, MI, 19–20 February 2001. Association for the Advancement of Automotive Medicine, Des Plaines, IL.

Chipman, M.L., MacGregor, C.G., Smiley, A.M., Lee-Gosselin, M., 1993. The role of exposure in comparisons of crash risk among different drivers and driving environments. Accident Anal. Prev. 25, 207–211.

Cooper, P.J., 1990. Differences in accident characteristics among elderly drivers and between elderly and mid-aged drivers. Accident Anal. Prev. 22, 499–508.

Evans, L., 1988. Older driver involvement in fatal and severe traffic crashes. J. Gerontol. 43, S186–S193.

Evans, L., 1993. How safe were today's older drivers when they were younger? Am. J. Epidemiol. 137, 769–775.

Evans, L., 2000. Risks older drivers face themselves and threats they pose to other road users. Int. J. Epidemiol. 29, 315–322.

Evans, L., 2001. Female compared to male fatality risk from similar physical impacts. J. Trauma 50, 1–25.

Evans, L., Gerrish, P.H., 2001. Gender and age influence on fatality risk from the same physical impact determined using two-car crashes. Society of Automotive Engineers, Paper 011174.

Federal Highway Administration, 1996. Highway Statistics Summary to 1995. US Department of Transportation, Washington, DC.

Federal Highway Administration, 1997a. 1995 Nationwide Personal Transportation Survey. US Department of Transportation, Washington, DC.

Federal Highway Administration, 1997b. Highway Statistics 1996. US Department of Transportation, Washington, DC.

Federal Highway Administration, 1998. Highway Statistics 1997. US Department of Transportation, Washington, DC.

Federal Highway Administration, 1999. Highway Statistics 1998. US Department of Transportation, Washington, DC.

Foley, D.J., Wallace, R.B., Eberhard, J., 1995. Risk factors for motor vehicle crashes among older drivers in a rural community. J. Am. Geriatric Soc. 43, 776–781.

Hakamies-Blomqvist, L., Johansson, K., Lundberg, C., 1995. Driver's licenses as a measure of older drivers' exposure: a methodological note. Accident Anal. Prev. 27, 853–857.

Hall, M.J., Owings, M.F., 2000. Hospitalizations for injury: United States, 1996. Advance Data 2000, no. 318. National Center for Health Statistics, Hyattsville, MD.

Insurance Institute for Highway Safety, 2000. Fatality Facts: Elderly. Arlington, VA. Available at http://www.highwaysafety.org (accessed 30 November 2000).

Janke, M.K., 1991. Accidents, mileage, and the exaggeration of risk. Accident Anal. Prev. 23, 183–188.

Janke, M.K., 2001. Assessing older drivers: two studies. J. Safety Res. 32, 43–74.

Janke, M.K., Eberhard, J.W., 1998. Assessing medically impaired older drivers in a licensing agency setting. Accident Anal. Prev. 30, 347–361.

Kent, R., Restraint system optimization for an older occupant population. In: Proceedings of the Presentation at Aging and Driving Symposium, Southfield, MI, 19–20 February 2001. Association for the Advancement of Automotive Medicine, Des Plaines, IL.

Kim, K., Nitz, L., Richardson, J., Li, L., 1995. Personal and behavioral predictors of automobile crash and injury severity. Accident Anal. Prev. 27, 469–481.

Li, G., Baker, S.P., 1996. Exploring the male-female discrepancy in death rates from bicycling injury: the decomposition method. Accident Anal. Prev. 28, 537–540.

Li, G., Baker, S.P., Langlois, J.A., Kelen, G.D., 1998. Are female drivers safer? An application of the decomposition method. Epidemiology 9, 379–384.

Lyman, J.M., McGwin Jr., G., Sims, R.V., 2001. Factors related to driving difficulty and habits in older drivers. Accident Anal. Prev. 33, 413–421.

Marottoli, R.A., Cooney, L.M., Wagner, R., Doucette, J., Tinetti, M.E., 1994. Predictors of automobile crashes and moving violations among elderly drivers. Ann. Int. Med. 121, 842–846.

McGwin Jr., G., Brown, D.B., 1999. Characteristics of traffic crashes among young, middle-aged, and older drivers. Accident Anal. Prev. 31, 181–198.

McGwin Jr., G., Sims, R.V., Pulley, L., Roseman, J.M., 2000. Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case–control study. Am. J. Epidemiol. 152, 424–431.

National Highway Traffic Safety Administration, 1997. National Occupant Use Survey—1996: Controlled Intersection Study. Research Note (National Center for Statistics and Analysis). US Department of Transportation, Washington, DC. Available at http://www.nhtsa.dot.gov/people/ncsa/pdf/Nopusci2.pdf (accessed 12 July 2001).

National Highway Traffic Safety Administration, 1997a. Fatality Analysis Reporting System: 1993–1997. US Department of Transportation, Washington, DC.

National Highway Traffic Safety Administration, 1997b. General Estimates System: 1993–1997. US Department of Transportation, Washington, DC.

National Highway Traffic Safety Administration, 1998. National Survey of Speeding and Other Unsafe Driving Actions. Vol. II. Driver Attitudes and Behavior. US Department of Transportation, Washington, DC. Available at http://www.nhtsa.dot.gov/people/injury/aggressive/unsafe/att-beh/Chapt1-2.html (accessed 12 July 2001).

National Highway Traffic Safety Administration, 2000. Traffic Safety Facts 1999. DOT HS 809-100. US Department of Transportation, Washington, DC. Available at http://www.nhtsa.dot.gov/people/ncsa/809-100.pdf (accessed 12 July 2001).

National Highway Traffic Safety Administration, 2000. Fatality Analysis Reporting System 1999. US Department of Transportation, Washington, DC.

Preusser, D.F., Williams, A.F., Ferguson, S.A., Ulmer, R.G., Weinstein, H.B., 1998. Fatal crash risk for older drivers at intersections. Accident Anal. Prev. 30, 151–159.

Skoog, I., Nilsson, L., Palmertz, B., Andreasson, L.-H., Svanborg, A., 1993. A population-based study of dementia in 85-year-olds. N. Engl. J. Med. 328, 153–158.

Teed, N.J., Visual Field Deficits and Motor Vehicle Crashes. Insurance Institute for Highway Safety, Arlington, VA.

Vala, M., 2001. Designing vehicle interiors for the mature driver. In: Proceedings of the Presentation at Aging and Driving Symposium, Southfield, MI, 19–20 February 2001. Association for the Advancement of Automotive Medicine, Des Plaines, IL.

Waller, P.F., Stewart, J.R., Hansen, A.R., Stutts, J.C., Popkin, C.L., Rodgman, E.A., 1986. The potentiating effects of alcohol on driver injury. J. Am. Med. Assoc. 256, 1461–1466.

Wang, S.C., 2001. An Aging Population: Fragile, Handle with Care. National Highway Traffic Safety Administration, Washington, DC. Available at http://www.nhtsa.dot.gov/departments/nrd-50/ciren/um_fragile.html (accessed 27 July 2001).

Zhang, J., Fraser, S., Lindsay, J., Clarke, K., Mao, Y., 1998. Age-specific patterns of factors related to fatal motor vehicle traffic crashes: focus on young and elderly drivers. Public Health 112, 289–295.

Zhou, Q., Rouhana, S.W., Melvin, J.W., 1996. Age effects on thoracic injury tolerance. In: Proceedings of the 40th Stapp Car Crash Conference, Alburquerque, NM, 4–6 November 1996. SAE Paper 962421.