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The independent contribution of driver, crash, and vehicle characteristics to driver fatalities

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Abstract

Several driver, crash, and vehicle characteristics may affect the fatality risk of drivers involved in crashes. To determine the independent contribution of these variables to drivers' fatality risk, we used data from single-vehicle crashes with fixed objects contained in the US Fatal Accident Reporting System. A multivariate logistic regression revealed that the odds ratio (OR) of a fatal injury increased with age, reaching 4.98 (99% confidence interval (CI) = 2.01–12.37) for drivers aged 80 + compared with drivers aged 40–49 years. Female gender (OR = 1.54, 99% CI = 1.35–1.76) and blood alcohol concentration greater than 0.30 (OR = 3.16, 99% CI = 1.96–5.09) were also associated with higher fatality odds. In comparison with front impacts, driver-side impacts doubled the odds of a fatality (OR = 2.26, 99% CI = 1.92–2.65), and speeds in excess of 111 kilometers per hour (kph; 69 mph) prior to or at impact were related to higher fatality odds (OR = 2.64, 99% CI = 1.82–3.83) compared with speeds of less than 56 kph (35 mph). Three-point seatbelts were protective against fatal injuries (OR = 0.46, 99% CI = 0.39–0.53 compared with no belt). These data suggest that increasing seatbelt use, reducing speed, and reducing the number and severity of driver-side impacts may prevent fatalities. The importance of age and gender suggests that the specific safety needs of older drivers and female drivers may need to be addressed separately from those of men and younger drivers.

Keywords: Determinants; Fatalities; Drivers; Crashes; Vehicles; Age

1. Introduction

Several variables may affect the risk of a driver fatality in the event of a crash. These include driver characteristics such as age, gender and behavior (e.g. alcohol and seatbelt use), crash characteristics (e.g. direction of impact, vehicle speed at impact), and vehicle characteristics (e.g. weight, length, model year, air bags). However, it has been difficult for researchers to assess the independent contribution of these variables. Such analyses require data on a substantial number of variables, and a large sample size to control for numerous potential confounders and to provide accurate risk estimates.

Few databases contain sufficient information to perform meaningful analyses and are readily available to most researchers. One such database is the Fatal Accident Reporting System (FARS) database collected by the US Department of Transportation. For every traffic fatality in the US, information about crash situations, drivers and passengers, and about the vehicles involved is added to the database. The FARS database contains data from 1975 onward. Many variables contained in FARS are not available in other national databases (Fife, 1989), making this database the most comprehensive tool to study fatal crashes. Although there are some biases in the reporting of the information, the quantity of information coded in the database, and number of crashes recorded allows for the control of many potential confounders, and for the calculation of crash estimates more easily generalizable to the general

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population (Barr et al., 1993). Further investigation of the relationship between these variables and fatal injuries may suggest strategies to minimize the number of fatal crashes.

In addition to data on potential confounders, the FARS database also allows the detailed examination of age as a fatality risk factor. Presently, most fatally injured drivers are younger drivers (< 30 years). Although fewer older drivers are fatally injured every year compared with other age groups (Graca, 1986), this number is increasing steadily (Bédard et al., 2001a). One possible reason is that older vehicle occupants are a greater risk of a fatal injury than younger occupants (Dulisse, 1997; Evans, 1986a; McCoy et al., 1989; Zhang et al., 2000). A detailed analysis of the contribution of age to driver fatalities could provide additional information to safety analysts and planners.

Consequently, the first aim of this study was to identify the independent contribution of driver, crash, and vehicle characteristics to fatal injuries sustained by drivers. Furthermore, the analyses were stratified according to age to better understand its contribution. We hope that this information will be useful to safety planners and policy-makers.

2. Methods

2.1. Data

The FARS database contains comprehensive data about crash situations, drivers and passengers, and vehicles, involved in US traffic fatalities from 1975 onward (analyses used 1975–1998 data). It has built-in quality control mechanisms, and allows for the control of many confounders. For further details on the FARS database, visit their website (http://www-fars.nhtsa.dot.gov/).

The analyses presented were based on driver fatalities only to factor out the effect of seating position. Seating position affects the risk of a fatal injury, with rear center seats as the safest location in a vehicle (Evans and Frick, 1988, 1989). Also, in multiple vehicle crashes, the risk of fatality is dependent on the characteristics of the other vehicle(s) (Evans, 1985, 1992b, 1993; Evans and Frick, 1994). Therefore, to maximize the interpretability of findings, a model focusing on driver fatalities involving single-vehicle crashes with fixed objects was chosen. Focusing on drivers removed the confounding impact of seating position, and focusing on single-vehicle crashes removed the effect of other vehicle characteristics.

Because crashes are included in FARS only if a fatality ensued, all drivers of single-vehicle crashes in which they were the sole occupants were killed, effectively removing any variability, and possibly biasing the results of the analyses. Including single-occupant crashes in the analyses would have led to a sample of 85% fatalities. To alleviate this difficulty, analyses were performed on crashes where at least two vehicle occupants were present. In all cases, the crash was sufficiently serious to kill at least one occupant, but not necessarily the driver. A total of 110 813 drivers were available for the analyses, and approximately 50% of all drivers were fatally injured. However, because of missing data, the analyses did not include all 110 813 drivers.

Driver characteristics studied included age category (< 20, 20–29, 30–39, 40–49, 50–64, 65–79, 80 + years), gender, blood alcohol concentration (BAC) (0, 0.01–0.04, 0.05–0.09, 0.10–0.14, 0.15–0.19, 0.20–0.29, 0.30 +), and seatbelt use (none, lap only, shoulder only, lap + shoulder). Crash characteristics included impact direction based on the four quadrants (front, right side, rear, left side), vehicle deformity (severe, less severe), and vehicle speed immediately before or at impact (< 56 kilometers per hour (kph) (35 mph), 56–95 kph (35–59 mph), 96–111 kph (60–69 mph), 112 + kph (70 mph)). Vehicle characteristics included air bags (deployed, not), weight (kg), wheelbase length (cm), model year, and vehicle age. Injury severity was dichotomized as ‘fatal’ or ‘non-fatal’.

2.2. Statistical analyses

Descriptive data were compiled by age category for driver and crash characteristics. To determine whether driver, crash, and vehicle characteristics were associated with fatalities, the odds ratio (OR) along with 99% confidence interval (99% CI) of a fatal injury were calculated for each variable with univariate statistics (unadjusted OR), followed by a multivariate logistic regression using backward variable selection to control for driver, crash, and vehicle characteristics (adjusted OR). Statistical significance was concluded when the 99% CI did not include unity ($P < 0.01$).

3. Results

3.1. Age and gender

The majority of fatalities reported were among male drivers younger than 30 years. However, larger proportions of older adults were fatally injured compared with younger adults. And, although there appeared to be no difference across gender for young drivers, a larger proportion of older male drivers were fatally injured compared with older female drivers (Table 1).

3.2. Alcohol use and fatal injuries

The number of fatalities by age and BAC are presented in Table 2 (only data for drivers who were tested are presented). The proportion of sober drivers fatally injured increased from 64.2% for drivers younger than 20 years to 88.5% for drivers aged 80 years and more. However, the relationship between BAC and fatality risk was 'U'-shaped. Fatality risk initially decreased with increasing BAC, reaching the lowest point at a BAC of 0.05–0.09. It then increased with BAC to reach its maximum at a BAC of 0.30 or greater. Using the age category 40–49 years as an example, the ratio of fatally injured drivers to non-fatally injured drivers was 2.79 at a BAC of zero. At a BAC of 0.05–0.09, the ratio was 1.52. Yet, at a BAC of 0.30 or more, the ratio was 7.06. This pattern was consistent for the other age groups, although little data were available for older drivers.

Table 1
Fatalities by age category and gender

Gender	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
Men								
Non-fatal	13801 (54.9)	18994 (51.5)	5845 (49.0)	2427 (47.4)	1903 (46.3)	1549 (47.5)	377 (46.6)	44896 (51.5)
Fatal	11318 (45.1)	17878 (48.5)	6091 (51.0)	2689 (52.6)	2211 (53.7)	1713 (52.5)	432 (53.4)	42332 (48.5)
Women								
Non-fatal	3311 (54.4)	3779 (52.7)	1945 (50.9)	994 (49.5)	966 (52.0)	749 (53.4)	130 (49.4)	11874 (52.5)
Fatal	2774 (45.6)	3386 (47.3)	1877 (49.1)	1016 (50.5)	892 (48.0)	653 (46.6)	133 (50.6)	10731 (47.5)
Total[a]								
Non-fatal	17112 (54.8)	22773 (51.7)	7791 (49.4)	3422 (48.0)	2869 (48.0)	2298 (49.3)	507 (47.3)	56772 (51.7)
Fatal	14092 (45.2)	21265 (48.3)	7969 (50.6)	3705 (52.0)	3103 (52.0)	2366 (50.7)	565 (52.7)	53065 (48.3)

[a] Total number of cases are slightly higher than men and women data together as gender data were missing for approximately 200 cases.

Table 2
Fatalities by blood alcohol concentration (BAC) and age group

BAC	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
0								
Non-fatal	1882 (35.8)	1308 (34.6)	456 (27.6)	279 (26.4)	248 (19.9)	218 (16.9)	31 (11.5)	4422 (30.4)
Fatal	3381 (64.2)	2469 (65.4)	1194 (72.4)	778 (73.6)	996 (80.1)	1071 (83.1)	238 (88.5)	10127 (69.6)
0.01–0.04								
Non-fatal	544 (50.0)	607 (52.7)	122 (42.1)	40 (32.8)	20 (22.5)	16 (27.6)	3 (25.0)	1352 (48.1)
Fatal	543 (50.0)	544 (47.3)	168 (57.9)	82 (67.2)	69 (77.5)	42 (72.4)	9 (75.0)	1457 (51.9)
0.05–0.09								
Non-fatal	1016 (50.1)	1506 (53.6)	353 (54.3)	81 (39.7)	36 (36.0)	5 (13.9)	2 (28.6)	2999 (51.4)
Fatal	1012 (49.9)	1302 (46.4)	297 (45.7)	123 (60.3)	64 (64.0)	31 (86.1)	5 (71.4)	2834 (48.6)
0.10–0.14								
Non-fatal	1301 (45.6)	2345 (46.9)	590 (47.0)	178 (42.0)	70 (34.0)	13 (27.7)	0 (0.0)	4497 (45.9)
Fatal	1553 (54.4)	2654 (53.1)	665 (53.0)	246 (58.0)	136 (66.0)	34 (72.3)	4 (100)	5292 (54.1)
0.15–0.19								
Non-fatal	813 (35.8)	2154 (39.0)	701 (37.6)	213 (36.0)	85 (32.1)	17 (27.9)	1 (25.0)	3984 (37.6)
Fatal	1460 (64.2)	3371 (61.0)	1162 (62.4)	378 (64.0)	180 (67.9)	44 (72.1)	3 (75.0)	6598 (62.4)
0.20–0.29								
Non-fatal	301 (23.0)	1303 (26.0)	626 (27.2)	196 (21.6)	92 (22.4)	19 (23.5)	0 (0.0)	2537 (25.3)
Fatal	1005 (77.0)	3717 (74.0)	1678 (72.8)	710 (78.4)	319 (77.6)	62 (76.5)	1 (100)	7492 (74.7)
0.30+								
Non-fatal	15 (12.2)	83 (15.3)	59 (13.9)	28 (12.4)	10 (9.4)	4 (28.6)	0 (0.0)	199 (13.9)
Fatal	108 (87.8)	458 (84.7)	365 (86.1)	197 (87.6)	96 (90.6)	10 (71.4)	2 (100)	1236 (86.1)

Table 3
Fatalities by direction of impact and age group

Impact	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
Front impact								
Non-fatal	8371 (54.8)	11883 (51.9)	4428 (49.8)	2118 (48.9)	1903 (48.9)	1683 (49.2)	418 (48.1)	30804 (51.7)
Fatal	6893 (45.2)	10992 (48.1)	4464 (50.2)	2214 (51.1)	1990 (51.1)	1736 (50.8)	451 (51.9)	28740 (48.3)
Right-side impact								
Non-fatal	3813 (72.2)	4669 (69.3)	1319 (63.8)	488 (62.1)	365 (61.0)	234 (64.3)	35 (57.4)	10923 (68.7)
Fatal	1471 (27.8)	2064 (30.7)	749 (36.2)	298 (37.9)	233 (39.0)	130 (35.7)	26 (42.6)	4971 (31.3)
Rear impact								
Non-fatal	623 (63.8)	754 (58.7)	284 (61.1)	146 (67.6)	97 (64.2)	65 (65.0)	4 (33.3)	1973 (61.6)
Fatal	354 (36.2)	530 (41.3)	181 (38.9)	70 (32.4)	54 (35.8)	35 (35.0)	8 (66.7)	1232 (38.4)
Left-side impact								
Non-fatal	1316 (33.1)	1565 (30.7)	555 (32.3)	212 (29.8)	155 (32.4)	92 (32.2)	14 (27.5)	3909 (31.7)
Fatal	2665 (66.9)	3535 (69.3)	1164 (67.7)	499 (70.2)	323 (67.6)	194 (67.8)	37 (72.5)	8417 (68.3)

Table 4
Fatalities by restraint use and age group

Restraint	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
No seatbelt								
Non-fatal	11766 (52.2)	15431 (48.7)	4925 (44.8)	1923 (41.1)	1531 (40.9)	1054 (43.4)	240 (42.5)	36870 (48.1)
Fatal	10771 (47.8)	16277 (51.3)	6057 (55.2)	2754 (58.9)	2212 (59.1)	1373 (56.6)	325 (57.5)	39769 (51.9)
Shoulder only								
Non-fatal	76 (55.5)	94 (54.3)	25 (48.1)	10 (35.7)	13 (46.4)	16 (57.1)	3 (42.9)	237 (53.2)
Fatal	61 (44.5)	79 (45.7)	27 (51.9)	18 (64.3)	15 (53.6)	12 (42.9)	4 (57.1)	216 (47.7)
Lap only								
Non-fatal	201 (63.4)	253 (65.2)	122 (62.6)	55 (63.9)	69 (63.9)	52 (51.5)	11 (64.7)	763 (63.2)
Fatal	116 (36.6)	135 (34.8)	73 (37.4)	26 (32.1)	39 (36.1)	49 (48.5)	6 (35.3)	444 (36.8)
Shoulder and lap								
Non-fatal	2092 (68.7)	2661 (66.6)	1318 (67.9)	799 (69.5)	732 (64.7)	760 (59.6)	160 (55.4)	8522 (66.4)
Fatal	954 (31.3)	1336 (33.4)	624 (32.1)	351 (30.5)	400 (35.3)	515 (40.4)	129 (44.6)	4309 (33.6)

3.3. Direction of impact

Roughly 65% of all crashes where data were available involved front impacts, representing the largest source of fatalities. Right-side impacts were the next most frequent occurrence at 17.5%, followed by left-side (driver-side) impacts at 13.5%, and finally rear-end impacts in 3.5% of all cases. At best, one-third of drivers survived left-side impacts, irrespective of age (Table 3). Rear-end and right-side impacts were fatal for smaller proportions of drivers. Whereas the proportion of fatalities following left-side and rear impacts was not dependent on age, it progressed with age for front and right-side impacts.

3.4. Restraint use

Approximately 84% of drivers with restraint data were not wearing a seatbelt at the time of the crash. Of the remaining 16%, most were wearing a three-point belt (shoulder and lap). Data for restraint use are presented in Table 4; the following analyses emphasize three-point belt use versus no belts.

The proportion of fatally injured drivers not wearing seatbelts ranged from a low of 47.8% for drivers younger than 20 years to a high of 59.1% for drivers aged 50–64. On the other hand, the proportion of fatally injured drivers wearing belts ranged from a low of 30.5% for drivers aged 40–49 years to a high of 44.6% for drivers aged 80 and over.

The difference between proportions of fatally injured drivers without belts and with three-point belts varied with age according to an inverted ‘U’-shaped curve. Thirty-five percent fewer drivers younger than 30 years died wearing belts compared with those not wearing belts. This proportion increased to 42% for drivers aged 30–39 and to 48% for drivers aged 40–49 years. From then onward, the belt advantage decreased to 40% for drivers aged 50–64, and 29 and 22% for drivers aged 65–74 and 80+ years, respectively.

3.5. Air bags

Although air bag data were missing for 65% of the cases available, these data are not as supportive as seatbelt data. As shown in Table 5, air bags did not appear to have a protective effect on drivers younger than 40 years, appeared beneficial to drivers aged 40–64, but may have been detrimental to older drivers. Although these data also suggested an inverted 'U'-shaped curve as found with seatbelts, the overall benefit of air bags without controlling for other variables such as the direction of impact is uncertain.

3.6. Vehicle deformity

Data on vehicle deformity attested to the severity of the impacts. Vehicle deformity was ranked by investigating officers on a four-point scale; severe deformity was one extreme. Data were dichotomized as severe deformity or less severe. Approximately 94% of all vehicles were severely deformed following the crash. Consistently, proportionally more fatalities were found among drivers of severely deformed vehicles (Table 6). Among drivers of severely deformed vehicles, smaller proportions of drivers younger than 30 years were fatally injured compared with other age groups.

The proportion of severely deformed vehicles also varied according to age. The ratio of severely deformed vehicles to less deformed vehicles decreased steadily with age. Specifically, among drivers younger than 20 years, the number of crashes resulting in severe deformity was 15.22 times that of crashes resulting in less severe deformity. This contrasts with a ratio of 10.57 for drivers aged 30–39, and 7.09 for those aged 80+.

3.7. Vehicle speed

Higher speeds were associated with more fatalities irrespective of age group (Table 7). Overall, the youngest drivers fared better than other drivers, and the oldest fared worst. Whereas only 25% of drivers younger than 20 years were fatally injured in crashes at speeds of less than 56 kph (35 mph), 49% of drivers aged 80+ were fatally injured. The differential across age groups continued for other speed categories.

As shown with vehicle deformity, the proportion of crashes at different speed categories varied by age groups. For drivers younger than 30 years, the largest proportion of crashes occurred at speeds of 112 kph (70 mph) or more. However, for all other age categories the

Table 5
Fatalities by air bag deployment and age group

Air bag status	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
Bag not deployed								
Non-fatal	5263 (55.9)	7067 (52.1)	3043 (50.4)	1435 (49.1)	975 (48.9)	899 (50.6)	242 (48.8)	18924 (52.3)
Fatal	4160 (44.1)	6490 (47.9)	2998 (49.6)	1485 (50.9)	1020 (51.1)	879 (49.4)	254 (51.2)	17286 (47.7)
Bag deployed								
Non-fatal	355 (56.3)	489 (53.7)	211 (49.9)	118 (51.5)	110 (55.6)	115 (47.3)	22 (44.9)	1420 (52.9)
Fatal	276 (43.7)	422 (46.3)	212 (50.1)	111 (48.5)	88 (44.4)	128 (52.7)	27 (55.1)	1264 (47.1)

Table 6
Fatalities by vehicle deformity and age group

Vehicle deformity	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
Severe								
Non-fatal	15723 (54.2)	20674 (50.9)	6818 (47.8)	2927 (46.1)	2445 (46.1)	1996 (48.4)	431 (46.4)	51014 (50.7)
Fatal	13281 (45.8)	19962 (49.1)	7434 (52.2)	3423 (53.9)	2862 (53.9)	2127 (51.6)	498 (53.6)	49587 (49.3)
Less severe								
Non-fatal	1205 (63.2)	1885 (62.7)	884 (65.6)	458 (64.2)	401 (65.4)	271 (56.9)	72 (55.0)	5176 (63.2)
Fatal	701 (36.8)	1122 (37.3)	464 (34.4)	255 (35.8)	212 (34.6)	205 (43.1)	59 (45.0)	3018 (36.8)

Table 7
Fatalities by vehicle speed and age group

Vehicle speed in kph (mph)	Age (years)							
	<20	20–29	30–39	40–49	50–64	65–79	80+	Overall
<56 (35)								
Non-fatal	207 (75.5)	279 (72.3)	183 (71.8)	124 (71.3)	114 (62.0)	129 (62.0)	34 (50.7)	1070 (69.1)
Fatal	67 (24.5)	107 (27.7)	72 (28.2)	50 (28.7)	70 (38.0)	79 (38.0)	33 (49.3)	478 (30.9)
56–95 (35–59)								
Non-fatal	2734 (62.4)	3659 (59.9)	1587 (56.5)	805 (55.0)	781 (53.4)	650 (51.6)	121 (49.2)	10337 (58.3)
Fatal	1648 (37.6)	2451 (40.1)	1222 (43.5)	658 (45.0)	682 (46.6)	610 (48.4)	125 (50.8)	7396 (41.7)
96–111 (60–69)								
Non-fatal	1582 (57.7)	2094 (54.2)	814 (52.5)	338 (50.2)	248 (46.4)	201 (51.8)	24 (39.3)	5301 (54.0)
Fatal	1162 (42.3)	1772 (45.8)	736 (47.5)	335 (49.8)	286 (53.6)	187 (48.2)	37 (60.7)	4515 (46.0)
112+ (70)								
Non-fatal	2431 (47.6)	3115 (44.2)	799 (38.1)	257 (33.6)	111 (32.8)	52 (37.1)	2 (13.3)	6767 (43.7)
Fatal	2674 (52.4)	3925 (55.8)	1299 (61.9)	508 (66.4)	227 (67.2)	88 (62.9)	13 (86.7)	8734 (56.3)

largest number of crashes occurred at speeds of 56–95 kph (35–59 mph).

3.8. Vehicle attributes

Vehicle attributes examined included weight, wheelbase, model year, and age. Weight, wheelbase and model year were extracted directly from the FARS database. Vehicle age was obtained by subtracting the vehicle model year from the crash year. Descriptive statistics for these variables are presented in Table 8.

Given the practice of automakers to release new model year vehicles midway in the previous year, a number of vehicles had an age of -1. All vehicle variables were considered normally distributed with the exception of vehicle age, which was positively skewed. Vehicle age was transformed using the natural logarithm (Howell, 1987) of vehicle age $+2$ (it is impossible to obtain a natural logarithm for a value of zero or less) and plotted. The distribution of the transformed variable approached normality. Multivariate models were tested with both the untransformed and transformed vehicle age data.

3.9. Independent predictors of fatal injuries

We conducted a multivariate logistic regression to examine the independent contribution of driver, crash, and vehicle characteristics to fatal injuries. Age category, gender, BAC, impact direction, restraint use, air bag deployment, traveling speed, vehicle model year, vehicle wheelbase, and the natural logarithm of the vehicle age (repeated with the untransformed data) were entered and sequentially removed if not statistically significantly associated with fatal injuries using a $P < 0.01$ cut-off. To index the severity of the impact, vehicle speed was chosen over deformity because it provided more variability than the latter, which was severe in 94% of all cases. Vehicle wheelbase and weight were highly correlated ($r = 0.82$), hence only wheelbase was entered; wheelbase was chosen because information was available for about 1000 additional cases (a further regression with weight yielded a similar model but less precise estimates).

In the initial regression ($n = 6811$), the air bag variable was not statistically associated with fatal injuries (OR = 1.04; 99% CI = 0.78–1.40; $P = 0.72$). Because air bag data were missing for 65% of all cases, a final regression was conducted to obtain more precise estimates by excluding the air bag variable, thus increasing the sample size to 12 325. Vehicle age (transformed or not) was not statistically significant and was removed from the model.

Results of the final multivariate regression model are presented in Table 9 (the reference categories have OR = 1.0). For comparison, unadjusted OR obtained with univariate regressions for each variable are also presented. The model correctly classified 69% of the observations. Increasing driver age was associated with fatal injuries. Younger drivers had lower odds of a fatal injury than drivers aged 40–49 and older drivers had higher odds. Overall, women were 54% more at odds of

Table 8
Descriptive statistics for vehicle attributes

Variable	Mean	S.D.	Minimum	Maximum
Weight (kg)	1361.13	310.70	492	2659
Wheelbase (cm)	270.10	24.92	200	428
Model year	1979.07	8.45	1900	1999
Age	7.17	5.56	-1	84

Table 9
Results of the univariate logistic regressions (unadjusted) and multivariate logistic regression (adjusted) with driver fatality ($N = 12\,325$) as the dependent variable (OR and 99% CI)

Variable	Unadjusted OR	99% CI	Adjusted OR	99% CI
Age (years)				
<20	0.73	0.59–0.90	0.78	0.62–0.99
20–29	0.71	0.57–0.87	0.76	0.60–0.95
30–39	0.83	0.66–1.05	0.84	0.66–1.07
40–49	1.00	1.00–1.00	1.00	1.00–1.00
50–64	1.48	1.07–2.04	1.73	1.23–2.44
65–79	1.68	1.16–2.42	2.33	1.58–3.43
80+	3.35	1.38–8.15	4.98	2.01–12.37
Gender				
Male	1.00	1.00–1.00	1.00	1.00–1.00
Female	1.48	1.31–1.67	1.54	1.35–1.76
BAC				
0	1.00	1.00–1.00	1.00	1.00–1.00
0.01–0.04	0.49	0.39–0.61	0.49	0.39–0.62
0.05–0.09	0.46	0.39–0.55	0.49	0.41–0.58
0.10–0.14	0.53	0.46–0.61	0.54	0.46–0.64
0.15–0.19	0.78	0.68–0.90	0.80	0.68–0.94
0.20–0.29	1.39	1.18–1.64	1.37	1.14–1.64
≥0.30	3.15	1.99–5.00	3.16	1.96–5.09
Impact				
Front	1.00	1.00–1.00	1.00	1.00–1.00
Right side	0.47	0.41–0.53	0.48	0.42–0.55
Rear end	0.72	0.56–0.91	0.72	0.56–0.93
Left side	2.11	1.81–2.46	2.26	1.92–2.65
Restraint use				
None	1.00	1.00–1.00	1.00	1.00–1.00
Shoulder belt	0.82	0.47–1.45	0.66	0.36–1.21
Lap belt	0.79	0.49–1.26	0.82	0.50–1.36
Shoulder and lap belt	0.58	0.51–0.65	0.46	0.39–0.53
Traveling speed (kph)				
<56	1.00	1.00–1.00	1.00	1.00–1.00
56–95	1.19	0.84–1.67	1.36	0.94–1.96
96–111	1.32	0.94–1.87	1.68	1.15–2.45
112+	1.84	1.31–2.58	2.64	1.82–3.83
Model year				
5-year increment	1.02	0.99–1.05	1.05	1.01–1.09
Wheelbase				
25-cm increment	0.96	0.92–1.02	0.90	0.85–0.95

a fatal injury than men. A protective effect of alcohol was found at lower levels of BAC, but an injurious effect was found at higher concentrations. In comparison with front-impact crashes, crashes on the right side and rear were associated with lower odds of fatal injuries. However, crashes on the drivers' side had OR more than twice that of front-impact crashes. The OR of drivers wearing shoulder and lap seatbelts was 54% less than those of non-belted drivers. Drivers traveling at speeds of 112 kph or more were nearly three times more at odds to be fatally injured than those traveling at speeds of less than 56 kph. The size of the vehicle (indexed either with wheelbase or weight) provided protection against fatalities. A 25 cm (10 inches) increase in wheelbase translated into a 10% reduction in the fatality risk. A 5-year increase in model year translated into a 5% increase in the odds of fatality.

3.10. Seatbelt use and fatality estimates

Several researchers have suggested that seatbelt use is over-reported because of the legal implications of not wearing seatbelts in some US jurisdictions (Levine et al., 1999; Li et al., 1999; Malliaris et al., 1996; Stewart, 1993; Streff and Wagenaar, 1989). Over-reporting may be especially prevalent with survivors, who may otherwise suffer legal consequences. From a statistical perspective, this may result in the potential misclassification of survivors as belt wearers, and the overestimation of the effectiveness of belts in preventing fatalities. American researchers proposed that seatbelt use should be discounted by 12% to reflect actual use (Streff and Wagenaar, 1989). Australian data showed that police-reported belt use overestimated actual use by 9% in crashes resulting in injuries (Li et al., 1999).

Therefore, we re-examined the regression model by discounting belt use. To achieve this goal, we randomly selected surviving drivers in 5% increments, and recoded those reported as wearing a three-point belt as non-belt users. Multivariate regressions were computed with recoded data until belt use was no longer statistically significantly associated with a lower fatality OR (Table 10). This occurred when 17% of crash survivors originally coded as belt users were recoded into non-users (OR = 0.92, 99% CI = 0.78–1.08). At 14%, the OR of a fatality was 0.77 (99% CI = 0.66–0.90).

Table 10
Results of the multivariate logistic regression with driver fatality as the dependent variable (OR and 99% CI) after recoding of survivors with lap/shoulder belt into non-belt wearers

Actual % recoded	OR	99% CI
0	0.46	0.39–0.53
4	0.52	0.45–0.61
9	0.64	0.55–0.75
14	0.77	0.66–0.90
17	0.92	0.78–1.08

4. Discussion

The data presented here confirmed that older drivers are more vulnerable to the traumatic effects of crashes. We found a positive relationship between age and fatal injuries, after controlling for gender, BAC, restraint use, crash direction, traveling speed, and vehicle wheelbase and model year. Whereas the odds of a fatal injury among young drivers (< 30 years) were less than 80% that of reference drivers aged 40–49, the odds of a fatal injury for an 80 + driver were five times that of drivers aged 40–49. These results confirmed and expanded on the findings of others (Evans, 1986a; Levine et al., 1999; McCoy et al., 1989; Zhang et al., 2000) by controlling for driver, crash, and vehicle characteristics.

Wisconsin data showed that adults aged 85 years and over were at three times greater risk to be hospitalized or fatally injured in a crash compared with adults aged 16–64 (Dulisse, 1997). Our unadjusted OR for drivers aged 80 + was similar at 3.35, but it climbed to 4.98 after controlling for other variables. This difference attests to the importance of controlling for confounding variables. These statistics are alarming given that increasing numbers of older adults will be driving in coming years (Eberhard, 1996).

Consistently with others (Levine et al., 1999), data on gender showed an overall 50% increased risk for fatal injuries in women compared with men. However, in both this study and a previous one (Evans, 1988b), this effect appeared mostly limited to younger women. Proportionally fewer women among older age groups in this study were fatally injured compared with men of the same age, results once again consistent with the literature (Zhang et al., 2000). The reasons for this age by gender interaction are not clear as our findings were obtained after controlling for driver and important crash and vehicle characteristics. Possibly, overall health, which cannot be determined with the FARS database, may explain gender differences. As women typically live 6 years longer than men, it is possible that older men are less healthy than women of the same age.

Anecdotally, alcohol is believed to exert a protective effect against fatalities (Waller et al., 1986); higher fatality rates among intoxicated drivers compared to sober ones are often attributed to the reckless driving behavior of drunk drivers (Andersen et al., 1990; Waller et al., 1997). However, intoxicated drivers and passengers may be at increased risk of fatal injuries because of adverse physiological effects of alcohol on the body (Evans, 1992a, 1993; Waller et al., 1986).

Our analyses on BAC and fatalities revealed a 'U'-shaped relationship, supporting both possibilities. The odds of a fatal injury were 50% lower among drivers with alcohol concentrations at or below the typical legal limits (< 0.10) than among sober drivers. Hence, anecdotal support for a protective effect of alcohol may be real. However, at higher BAC (> 0.19) alcohol had a detrimental effect on fatality risk. At a BAC of 0.30 or greater, drivers were three times more at risk of a fatal injury than sober drivers. Because the analyses controlled for other driver behavior and crash variables, the lethal effect of high alcohol concentrations possibly represents a weakened physiological response to the crash trauma as suggested by others (Evans, 1992a; Stein et al., 1988). However, not all drivers were tested for alcohol. Survivors who did not appear impaired may not have been tested, thus possibly biasing these results.

Waller et al. (1986) also studied the impact of BAC on fatality risk. Using three categories (BAC = 0.10–0.14, 0.15–0.19, and ≥ 0.20), they found the lowest injury rates for the 0.15–0.19 category, higher rates for the 0.10–0.14 category, and much higher rates for the ≥ 0.20 category. Further epidemiological studies (Evans, 1993; Waller et al., 1986), and studies using animal models are desirable to understand the physiological mechanism underlying the effect of alcohol on the human body's ability to survive serious trauma.

In spite of the results presented here, alcohol use continues to be a great source of excess traffic fatalities. Although drivers with low BAC may be less at risk to die in a crash, once it has occurred they are more at risk of committing driving errors that may lead to fatal crashes. We found in a recent study that a BAC greater than zero but less than 0.05 was associated with a 45% increased OR of making a driving error compared with sober drivers (Bédard et al., 2001b). When the BAC exceeded 0.20, the OR of a driving error increased by more than 700%. Thus, alcohol consumption is not protective. A high BAC is doubly lethal because both the risk of a driving error and fatal injury are highly elevated compared with sober drivers.

Restraint use (manual and automatic seatbelts), has been promoted as the most important behavior to prevent fatalities (Robertson, 1996). Evans proposed that more than 40% of all fatalities incurred by non-belted drivers and passengers could be avoided with seatbelts (Evans, 1986b, 1987). At the very least, researchers estimated that we could expect a reduction of 15% in all severe and fatal injuries if all drivers and passengers were belted, even after controlling for age and vehicle deformity (Evans, 1988a; Nash, 1989; Streff, 1995).

Consistently with other reports (Evans, 1986b, 1987, 1988a; Nash, 1989; Robertson, 1996; Streff, 1995), our analyses on restraint data showed an unequivocal protective effect of three-point belts. Wearing a seatbelt halved the risk of a fatal injuries in the dataset analyzed. Two-point belts had OR in the expected direction but sample sizes were too small to provide precise estimates. However, most vehicles on the roads at the present time are equipped with three-point belts.

Given the strength of the association between restraint use and non-fatal injuries, a causal link is highly probable. Furthermore, there was a gradient (dose-related response) between restraint use and fatal injuries, such that the risk of a fatal injury decreased from no restraint to two-point restraints to three-point restraints. These facts reinforce the belief that seatbelts save lives. Even assuming a 14% over-reporting of belt use among survivors, the odds of a fatality would have been 23% lower among our sample of belted drivers compared with non-belted drivers. However, the protective effect of belts may not generalize well to all crash conditions outside those studied here. The majority of the crashes studied involved front impacts, for which belts are best suited (Levine et al., 1999); seatbelts are reportedly less effective in struck vehicles than striking vehicles (Evans and Frick, 1986).

This problem is especially relevant for older drivers because they are more likely to be struck by incoming vehicles at intersections than other age groups (Hakamies-Blomqvist, 1993). The fatality risk of struck drivers is five times that of the striking drivers when hit on the right side, and ten times more when struck on the left side (Evans, 1993). However, our data did not support such a difference across points of impacts. Drivers hitting a fixed object on the left side had twice the odds of a fatal injury compared with drivers who experienced front impacts. However, our reliance on single-vehicle crashes and control for variables such as age may explain this difference.

Air bag data did not show a protective effect using the current paradigm. This result is surprising given that air bags are expected to perform well in front impacts (Evans, 1990, 1991; Zador and Ciccone, 1993). Other researchers reported reductions in fatalities ranging between 16 and 28% (Lund and Ferguson, 1995; Zador and Ciccone, 1993). However, their analyses provided less control for driver, crash, and vehicle characteristics, and early models equipped with air bags may have been luxurious, large vehicles. It is also unclear what additional benefit, if any, air bags provided to seatbelts, and whether specific groups of drivers may have been adversely affected by air bags; some data point to a fatality risk for shorter drivers (Perez and Palmatier, 1996). Nonetheless, air bag data were available for fewer observations than other variables, warranting caution in the interpretation of this finding. Further studies are required to evaluate the effect of air bags.

Data on speed as a fatality risk factor are less contentious. According to a Canadian study (Zhang et al., 2000), the odds of a fatality in crashes that occurred in 70–90 kph zones were almost six times those of crashes occurring in zones with slower posted speed limits. Although these data did not rely on the speed of vehicles, it is unlikely that this limitation would have biased the effect considerably. In our regression model, traveling at a speed of 112 kph (70 mph) or more was independently associated with a 164% increase in the odds of a fatality compared with speeds of less than 56 kph (35 mph). Although our results are not as dramatic as those presented by Zhang and colleagues, they attest to the safety issue related to speed. Dischinger et al. (1998) found that larger decelerations (i.e. larger traveling speeds at impact) were associated with more post-injury medical complications, independent of age and injury severity. Because the impact of speed may be related to trauma sustained with the sudden deceleration experienced (Viano, 1988), future research would benefit from the inclusion of traveling speed indices.

Possibly the vehicle attribute most closely related to injury severity is size. Although weight and length are highly correlated, weight is the most studied characteristic. Evans reported that in any two-vehicle crash, the passengers of the heavier vehicle fared better than those of the lighter vehicle (Evans, 1985, 1992b, 1993; Evans and Frick, 1994). Yet, drivers of two 900 kg (2000 lbs) vehicles were at twice the risk of fatal injuries compared with drivers of two 1800 kg (4000 lbs) vehicles (Evans and Wasielewski, 1987). Levine et al. (1999) reported that every 454 kg (1000 lbs) increase in vehicle weight was equivalent to the driver's ability to withstand front impact crashes of 10 more kph (6 mph) before being fatally injured. Using wheelbase length, we substantiated these findings after controlling for other critical variables. A 25 cm (10 inches) increase in wheelbase translated into a 10% reduction in the odds of a fatality. This finding supports the protective value of larger vehicles independent of their drivers.

On the other hand, our findings regarding model year are not consistent with others. We found that recent model year vehicles were associated with an increased risk of fatalities of 5% for each 5 years. Others reported that recent models were safer (Levine et al., 1999) and others that there was no relationship (Robertson, 1996). Furthermore, whereas the present analyses did not find an association between vehicle age and fatalities, others reported such an association (Robertson, 1996). Discrepancies between these studies are likely explained by crucial methodological differences and samples. Nonetheless, the model year effect we reported was extremely small. We suggest caution in the interpretation of this finding.

Possibly the main limitation of this study is its generalizability to all types of crashes. To answer our research question, we focused the analyses on a very controlled set of observations. Although we believe this strengthens inferences that can be made, these are limited to the type of crashes studied. Further studies will be required to determine whether our findings also apply to other crash situations (e.g. multi-vehicle crashes).

Notwithstanding this limitation, in situations where vehicles collide with fixed objects, older drivers are at much greater risk of fatal injuries compared with younger drivers. Similarly, women are at a disadvantage compared with men. These data point to potentially different safety needs for older drivers and women. Possibly the best safety provision for all drivers is to wear seatbelts, avoid traveling at high speeds, and drive sober. Furthermore, reductions in the number and severity of driver-side impacts are desirable. Finally, larger vehicles continue to afford more protection to their drivers than smaller vehicles. Their public health benefits need to be weighted against the societal benefits of smaller cars.

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