Journal of Traffic Medicine 29(1-2): 10-19, 2001

Age and Fatality Risk from Similar Severity Impacts

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ABSTRACT

Objective: To estimate how risk of death from the same physical impact changes as people age.

Method: Fatality risks are estimated using data for 252,564 people killed when traveling in cars, light trucks, or motorcycles containing at least two occupants. Combinations of safety-belt use, helmet use, and seating location lead to 16 male and 14 female occupant categories.

Results: Relationships between fatality risk and age are similar for the 16 male occupant categories and for the 14 female occupant categories, but are different for males and females. Because details of injury mechanism differ between the occupant categories, such agreement suggests that the results apply to blunt trauma in general (for example, due to falls) and not just to the traffic "laboratory" that provided the data.

Conclusions: After age 20, the risk of death from the same impact increases at compound rates of

- (2.52 ± 0.08)% per year for males
- (2.16 ± 0.10)% per year for females.

Risk at age 70 exceeds risk at age 20 by 250% for males and 190% for females.

INTRODUCTION

It is common knowledge that as people age they are more likely to sustain serious injury, including fatal injury, from the same physical impact (or blunt trauma insult). However, quantification of the effect proves elusive because there are few cases in which it can be reliably concluded that persons differing in age were subjected to similar physical insults.

This study obtains quantitative estimates of how the risk of death from the same physical insult depends on age for males and females by using traffic fatality data and a method to make the required inferences from such data.

Received 12/7/2000
Accepted: 1/3/2001
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METHOD

Data

The Fatality Analysis Reporting System, or FARS (National Highway Traffic Safety Administration 2000) documents all vehicles and people involved since 1975 in US traffic crashes in which anyone was killed. The present study uses data for 1975 through 1998. During this 24-year period, over a million fatalities are documented, 252,564 of which are used in this study.

The FARS data do not immediately answer the question "How does fatality risk depend on age?" To illustrate, consider that the most common type of US fatal crash involves only one person, a lone vehicle driver. Examining such crashes for younger drivers shows that 100% of them were killed; if they were not killed, the case would not be in FARS. The corresponding older driver case similarly shows 100% killed. Such a comparison shows many more deaths to younger than to older drivers, but cannot provide any information on how age affects outcome, given that a crash occurs.

The Double Pair Comparison Method

The double pair comparison method (Evans 1986) was devised specifically to make inferences from FARS data. The method effectively isolates the influence of a particular factor of interest (in the present case, age) from the multitude of other influences that affect fatality risk in a crash. The best accepted values of many quantities, particularly effectiveness of occupant protection devices such as safety belts, were obtained using the double pair comparison method, as is documented in Appendix A. The only prior quantitative estimate of how age affects fatality risk was obtained using the same method (Evans 1988), but at a time when vastly fewer data were available. The method has recently been applied to examine how gender affects the risk of death in a crash (Evans 2000a), other factors being the same, also using 1975-1998 FARS data.

While the method is formulated in mathematical terms that facilitate formal addressing of many questions, it can be described more simply. It uses vehicles containing two specific occupants, at least one being killed. We refer to one as the subject occupant, and aim to discover how some characteristic affects the subject's fatality risk. The other, the control occupant, serves to standardize conditions in order to estimate risk to the subject. The method permits a wide choice of control and subject occupants. It is explained below in terms of a specific example using male occupants (who far outnumber female occupants in fatal crashes). Initially we select 20-year-old car passengers seated in the right-front seat as controls. We use this control occupant to compare risks to 20-year-old and 25-year-old subject car drivers.

Two sets of crashes are selected. The first contains cars each containing a 25-year-old driver and a 20-year-old passenger, at least one being killed. This first set of crashes provides

$$r_1 = A/B \tag{1}$$

where

A=Number of 25-year-old drivers killed traveling with 20-year-old passengers, and

B=Number of 20-year-old passengers killed traveling with 25-year-old drivers.

It might seem that r_1 immediately measures how risk depends on age. As driver and passenger are involved in the same crash, factors such as impact speed, or type and properties of object struck (tree, vehicle, etc.), apply equally to both occupants. Changing numerator and denominator by similar proportions does not change r_1. Factors that influence the risk of crashing, such as driver behavior, change sample sizes but should not systematically affect r_1. A factor that does contribute to differences in risk between 25-year-old drivers and 20-year-old passengers is that different risks are associated with different vehicle seats (Evans and Frick 1988). To correct for this, a second set of crashes uses 20-year-old driver subjects accompanied by 20-year-old control passengers, at least one being killed. The subject's age is 20, not 25 as in the first set of crashes, but the control's age is the same. The second set of crashes gives

$$r_2 = C/D \tag{2}$$

where

C=Number of 20-year-old drivers killed traveling with 20-year-old passengers, and

D=Number of 20-year-old passengers killed traveling with 20-year-old drivers.

Based on assumptions that are likely to be more than adequately satisfied (Evans 1986) the quantity

$$r = r_1/r_2 \tag{3}$$

estimates the risk to 25-year-old drivers compared to the risk to 20-year-old drivers. The crash conditions are effectively standardized because the 20- and 25-year-old drivers experience their impacts in mixes of crashes that posed similar risks to accompanying 20-year-old male passengers.

The control occupant does not enter directly into the result. Because of this, many separate estimates can be calculated using various control occupants. This helps diminish confounding influences due to interactions between subject and control occupant. The basic assumptions of the method require that the probability of a passenger death should not depend (in the present example) on the age of the driver. This assumption would be violated if, for example, the same physical impact was more likely to kill a passenger traveling with an older driver than one traveling with a younger driver. This is indeed the case, because older drivers are more likely to be accompanied by older passengers.

The potentially biasing influences of such confounding interactions can be reduced by disaggregating control subjects into gender and age categories, thus insuring that passengers of similar age and the same gender accompany the younger and older drivers (of the same gender) being compared. As occupant restraint (safety belt or helmet) use affects fatality risk, the control occupant should have the same restraint use in the first and second set of crashes. The method does not require the subject and control occupants to have the same belt use; belted controls could be used to examine unbelted subjects. In practice, belt use is so highly correlated among the occupants of a vehicle that the analysis was confined to cases in which the restraint use of subject and control were the same. Exceptions were the analysis for unbelted truck rear passengers and belted truck front occupants, where controls were included regardless of belt use in order to produce usable sample sizes. Right-front passengers were controls for car and truck drivers, and motorcycle passengers were controls for motorcycle drivers. Drivers acted as controls for all the other cases. Injuries in crashes in which airbags deploy differ from other crash injuries because airbags provide their own source of energy, which generates age and gender effects (Dalmotas et al. 1996) different in nature from those studied here. Accordingly, cases in which airbags deployed were excluded (about 2% reduction in sample sizes).

A Specific Example: The calculations are described below in more detail, starting with the specific example of comparing risks to unbelted car drivers aged 23-27 to risks to unbelted car drivers aged 18-22 using, to begin with, unbelted male passengers aged 16-24 (Table 1). We refer to occupants in these age groups as 25-year olds and 20-year olds, so this case is the same as the earlier illustrative case.

The 1975-1998 FARS give that the number of 25-year old male drivers killed traveling with 20-year-old male passengers is 3,365, while the number of 20-year-old male passengers killed traveling with 25-year-old male drivers is 2,928, leading to

$$r_1 = 3365/2928 = 1.149 \quad . \tag{4}$$

For the second comparison in which driver and passenger are both age 20, we have 9,842 driver fatalities compared to 9,649 passenger fatalities, giving $r_2 = 1.020$. Substituting these values into Eqn 3 gives r = 1.127. The estimate based on 20-year-old male passengers gives the result that the risk of death to 25-year-old male drivers is 12.7% greater than the risk to 20-year-old male drivers in similar severity crashes.

RESULTS

Males

The above example provides the first of eight estimates, each using a different set of control occupants (Table 1). The weighted average of the eight estimates for male car drivers in Table 1 leads to the conclusion that, in the same set of crash experiences, the risk of male-driver death is (12.7 ± 0.037)% higher at age 25 than at age 20. (The closeness of this value to the value using 20-year-old male passengers as controls is fortuitous). All errors are standard errors. The error and weighting calculations are based on applying material in Fleiss (1973), Schlesselman (1982) and Young (1962) as described in Evans (1988, 1991).

Table 1. Fatality risk to 25-year olds* compared to risk to 20-year olds** for unbelted male car drivers. (Data: FARS 1975-1998).

Control Occupant Characteristics	Fatalities A	Fatalities B	Fatalities C	Fatalities D	Ratios r_1 =A/B	Ratios r_2 =C/D	Ratios $r = r_1/r_2$	Ratios $\Delta r^{\dagger}$
Male passenger 16-24	3365	2928	9842	9649	1.149	1.020	1.127	0.065
Male passenger 25-34	1968	2016	1133	1243	0.976	0.912	1.071	0.077
Male passenger 35-54	354	562	236	425	0.630	0.555	1.134	0.133
Male passenger 55+	57	176	42	129	0.324	0.326	0.995	0.238
Female passenger 16-24	1723	1874	3083	3733	0.919	0.826	1.113	0.072
Female passenger 25-34	738	957	233	369	0.771	0.631	1.221	0.133
Female passenger 35-54	141	258	90	222	0.547	0.405	1.348	0.230
Female passenger 55+	31	114	18	88	0.272	0.205	1.329	0.442
					Weighted Average		**1.127**‡	**0.037**

* 25-year-old drivers are those aged 23, 24, 25, 26, or 27.
** 20-year-old drivers are those aged 18, 19, 20, 21, or 22, and similarly for other ages.
A = Number of 25-year-old drivers killed in cars with control passengers (with characteristics listed in first column)
B = Number of control passengers killed in cars with 25-year-old drivers
C = Number of 20-year-old drivers killed in cars with control passengers
D = Number of control passengers killed in cars with 20-year-old drivers
† Δr is the standard error in r. For small Δr, there is a 68% chance that the actual value lies between $r-\Delta r$ and $r+\Delta r$.
‡ The weighted average indicates that, for unbelted male car drivers, a 25-year old is 12.7% more likely to die than is a 20-year old.

Risks to 30- and 25-year olds are compared in the same way, and so on for the five-year age increments shown in Table 2. Note how each five-year increment for ages above 20 is associated with an increase in risk of about 13% (except for the age 80 case, which is based on small samples). By multiplying the individual r values, an estimate of the risk, R, at any age relative to the risk at 20 is obtained.

Table 2. Risk, R, at different ages relative to risk at age 20 for male car drivers (Data: FARS 1975-1998).

Age_1	Age_2	$r^{\dagger}$	Δr	Age_3	$R^{\ddagger}$	ΔR
16	20	0.958	0.040	16	0.958	0.040
				20	1*	-*
25	20	1.127	0.037	25	1.127	0.037
30	25	1.131	0.039	30	1.274	0.060
35	30	1.160	0.046	35	1.478	0.092
40	35	1.181	0.055	40	1.745	0.135
45	40	1.116	0.061	45	1.948	0.185
50	45	1.155	0.069	50	2.249	0.252
55	50	1.092	0.068	55	2.455	0.315
60	55	1.178	0.076	60	2.891	0.416
65	60	1.066	0.069	65	3.083	0.486
70	65	1.055	0.069	70	3.253	0.555
75	70	1.019	0.070	75	3.314	0.609
80	75	0.991	0.072	80	3.284	0.649
85	80	1.008	0.089	85	3.311	0.716
90	85	1.118	0.153	90	3.703	0.947

† r is risk at Age_1 compared to risk at Age_2

‡ R is risk at Age_3 compared to risk at Age = 20

*Male risk at age 20 is defined to be unity.

For two reasons the above process is adopted rather than comparing directly, say, 70-year-old drivers with 20-year-old drivers. First, there are relatively few cases in which 70-year-old drivers travel with passengers who are the same age as the passengers who travel with 20-year-old drivers. Most commonly, drivers travel with passengers of similar age and different gender, a tendency which facilitated the examination of the influence of gender on risk (Evans 1988, 2000a) but hampers the examination of the influence of age. Second, the crashes in which a 20-year-old driver and a 70-year-old driver are accompanied by, say, a 20 year-old passenger may be sufficiently different in other characteristics to compromise the assumptions of the method. Evans (1988) provides additional discussion of this topic.

The unbelted male car driver analysis summarized in Table 2 is based on 47,989 subject (driver) fatalities. The subject sample sizes for all other cases examined are given in Table 3. The present study uses 252,564 fatalities in 30 occupant categories compared to under 100,000 fatalities in 18 occupant categories used by Evans (1988). Because of their broad importance to blunt trauma, it is important to examine how robust, repeatable and general are the results of Evans (1988), and to achieve higher levels of precision. Additional occupant categories solidify the interpretation.

Table 3. Distribution of 252,564 fatally injured subject occupants by occupant category and gender (Data: FARS 1975-1998).

Vehicle	Subject Occu-pant	Belt, Helmet Use	Male	Female	Total
Car	Driver	No	47,989	14,873	62,862
	Rfp*	No	37,663	34,695	72,358
	Driver	Yes	8,967	4,755	13,722
	Rfp	Yes	6,392	12,301	18,693
	Lrp	No	5,460	3,961	9,421
	Rrp	No	6,265	4,481	10,746
Light truck	Driver	No	17,403	2,362	19,765
	Rfp	No	13,478	7,544	21,022
	Driver	Yes	2,705	712	3,417
	Rfp	Yes	1,702	2,308	4,010
	Lrp	No	819	737	1,556
	Rrp	No	930	781	1,711
Motor-cycle	Driver	No	3,871	-	3,871
	Psngr	No	1,647	2,213	3,860
	Driver	Yes	2,857	-	2,857
	Psngr	Yes	1,027	1,666	2,693
		Total	**159,175**	**93,389**	**252,564**

*R = Right, L = Left; f = Front, r = Rear; p = Passenger

Occupants in Each of the Three Vehicles

The top left graph in Fig. 1 shows the values of R in Table 2, plotted on a logarithmic scale, versus age. The solid diamond denotes the defined point R = 1 at age = 20. For ages between 20 and 83 data were fitted to

$$Ln(R) = \beta \times (Age - 20), \quad (5)$$

where Ln(R) is the natural logarithm (to base e) of R. As the relationship is constrained to pass the point

R = 1, Age = 20, a weighted least squares regression estimates the one parameter, the slope β. This parameter represents the fractional increase in risk for each additional year of aging. Values of β?are shown on the figures multiplied by 100, so that, for example, the top left graph in Fig. 1 implies that the risk of death from the same physical impact increases by (2.47 ± 0.13)% per year. The error limits were computed by a simulation which provided estimates that depended in appropriate ways not only on the weighted-least squares regression fit to the data, but also the error limits of individual values.

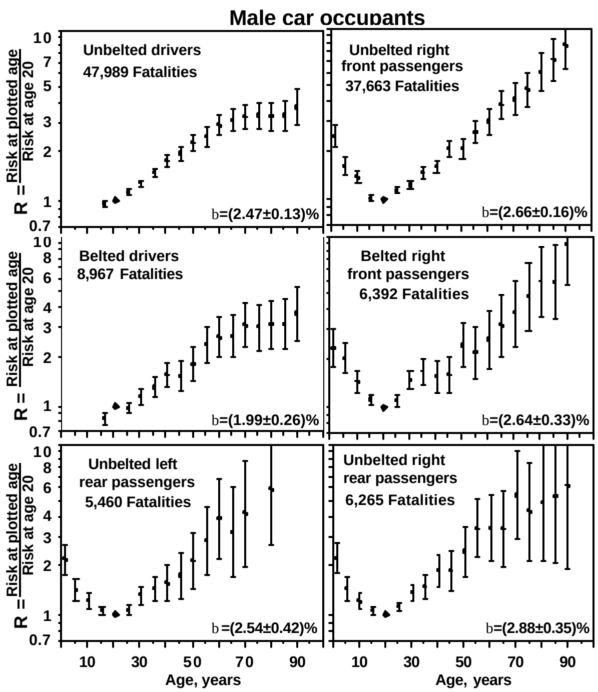

Figure 1. Risk of male fatality at specific ages compared to risk at age 20 for male occupants of cars involved in fatal crashes. The solid diamond indicates R = 1 at age 20. The point immediately to the right of this in the top-left graph is R = 1.127 ± 0.037, as derived in Table 1. The value β = 2.35% (in the top left graph) means that each additional year of aging increases risk by 2.35%. This and all subsequent figures are derived using FARS data 1975-1998.

Figs. 2 and 3 show results for occupants of light trucks, as defined in Kahane (1997), and for motorcyclists. The data for drivers in Figs 1-3 show no values at ages below the age of licensure (Evans 2000b) , because the numbers of driver fatalities at younger ages are too few for this study.

None of the individual graphs in Fig. 1 departs systematically from their collective trend (except for lower than trend values at older ages for drivers). It is therefore appropriate to combine all these data to obtain a best estimate for car occupants (top graph in Fig. 4). The other two graphs in Fig. 4 show corresponding information for light trucks and motorcycles.

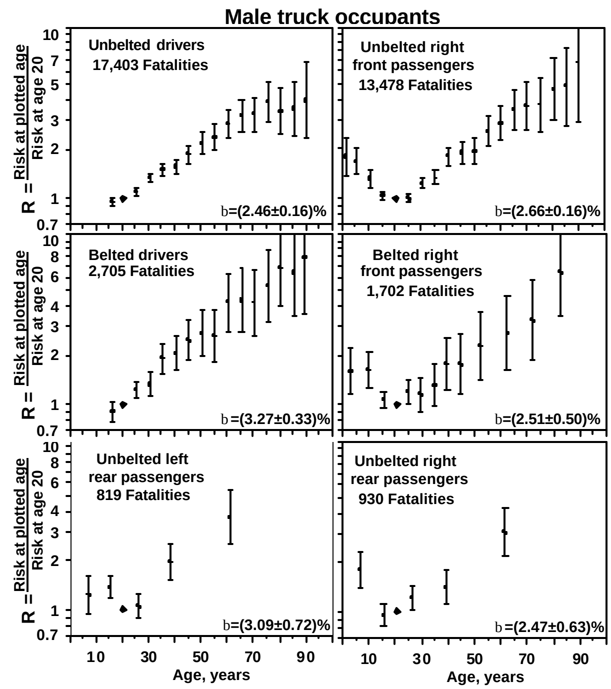

Figure 2. Risk of fatality at specific ages compared to risk at age 20 for male occupants of light trucks involved in fatal crashes.

Average Over All Vehicles

As results for individual vehicles do not depart systematically from the collective trend, it is appropriate to combine all the data. Fig. 5, based on 159,175 male subject fatalities, represents the summary findings for males. The risk to a male of specified age compared to the risk to a 20-year-old male is given by

$$R_{Male}\,(\text{Age}) = \exp[\,0.0252\,(\text{Age} - 20)\,] \qquad (6)$$

(for Age between 20 and 80)

Eqn 6 estimates that 25-year-old males are 1.134 times as likely to die as are 20-year-old males, in close agreement with the example in Table 1. Seventy-year-old males are 3.52 times as likely to die as are 20 year-old males. Eqn 6 means that for each additional year a male ages after age 20, his risk of death from the same physical impact increases at a compound rate of (2.52 ± 0.08)% per year.

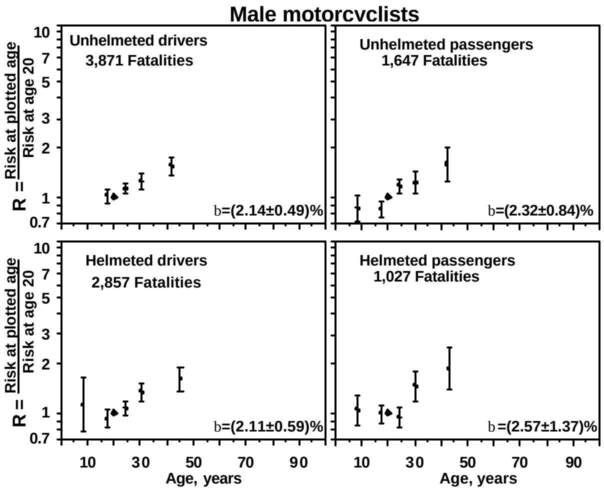

Figure 3. Risk of fatality at specific ages compared to risk at age 20 for male motorcyclists involved in fatal crashes.

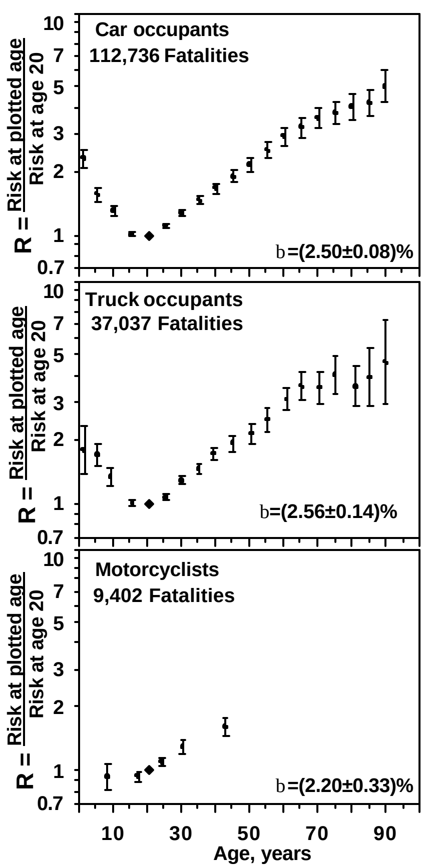

Figure 4. Average values for male occupants of cars, trucks and motorcycles obtained by taking weighted averages over all graphs in each of the Figs 1-3.

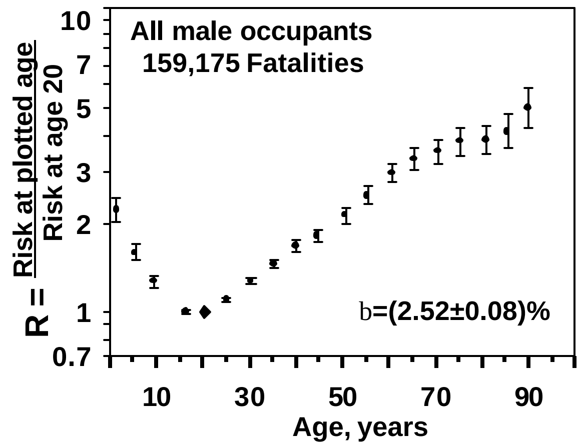

Figure 5. Average over all male occupants. Each point is the weighted average of the three values, one for each vehicle from Fig. 4, or the mathematically identical weighted average of the 16 values for all categories in Figs 1-3.

Females

The main difference between the analysis for females compared to that for males arises because the reference for all risks reported in this study is the risk to a 20-year-old male. Measuring all risks using the same metric facilitates comparisons between populations differing in both age and gender. Earlier research established that females were at higher risk of death from the same physical impact (Evans 1988, 2000a). Therefore, instead of a defined point at age 20, each female graph will have an empirically determined value of the risk of death to a 20-year-old female relative to that of a 20-year-old male.

A weighted linear regression

$$\mathrm{Ln}(R) = a + \beta(\mathrm{Age} - 20) \qquad (7)$$

was fitted to the data at ages from 20 to 83. The parameter β has the same interpretation as in the male case. The risk to 20-year-old females compared to the risk to 20-year-old males is exp(a). The quantity $\alpha = 100[1 - \exp(a)]$ estimates the percent difference between female and male fatality risk. For example, for the top left graph in Fig. 6, the parameter $a = 0.302$ derived from the regression fit implies that the 20-year-old female risk is 35.3% higher than the 20-year-old male risk. Values of α and β are given on the graphs (Figs 6-10).

Note that the values of α for all 14 graphs in Figs 6-8 consistently indicate higher risk to 20-year-old females than to 20-year-old males. Each of these estimates is based on fitting data for all ages between 20 and 83, rather than the direct comparison involving only subject occupants of the same age. The findings therefore provide additional quantitative evidence on higher female risk (although the data are the same here as used by Evans (2000a) for the specific gender comparison). The final summary graph for females, Fig. 10, shows that at age 20, female risk is 31% greater than male risk, compared to 28% reported by Evans (2000a).

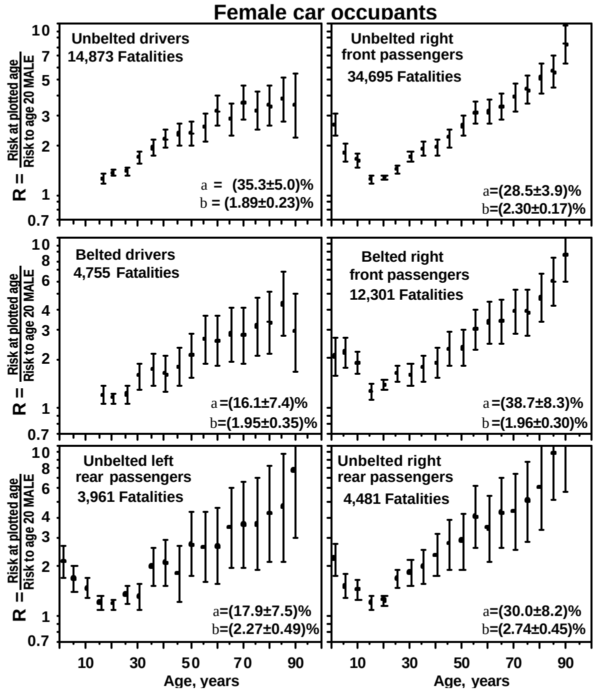

Figure 6. Risk of female fatality at specific ages compared to risk for 20-year-old males when each is involved in comparable severity fatal crashes while traveling in cars. The interpretation of the parameters (for the top left graph) is that at age 20, female risk is 30.6% higher than male risk, and female risk increases at 1.82% per year.

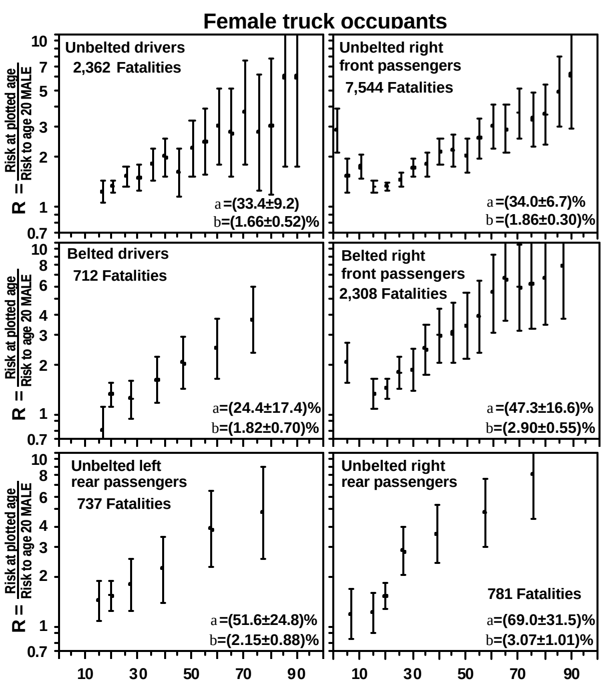

Figure 7. Risk of female fatality at specific ages compared to risk for 20-year old males when each is involved in comparable severity fatal crashes while traveling in light trucks.

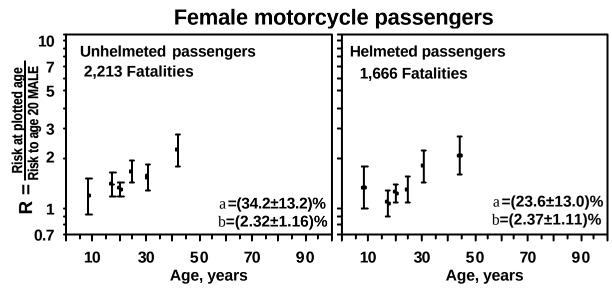

Figure 8. Risk of female fatality at specific ages compared to risk for 20-year-old males when each is involved in comparable severity fatal crashes as motorcycle passengers.

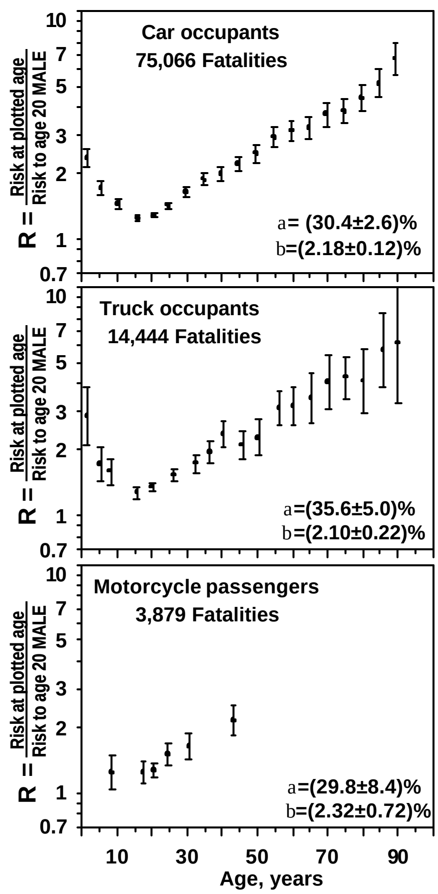

Figure 9. Average values for female occupants of cars, trucks and motorcycles obtained by taking weighted averages over all graphs in each of the Figs 6-8.

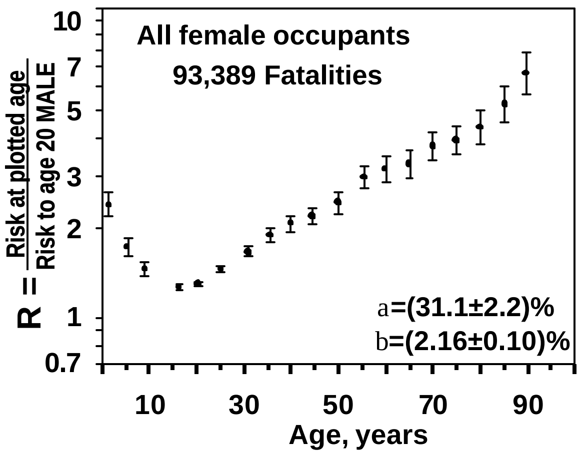

Figure 10. Average over all female occupants. Each point is the weighted average of the three values, one for each vehicle from Fig. 9, or the mathematically identical weighted average of the 14 values for all categories in Figs 6-8.

Fig. 10, based on 93,389 subject fatalities, leads to the equation

$$R_{Female}(Age) = 1.311 \exp[\, 0.0216\,(Age - 20)\,] \qquad (8)$$
(for Age between 20 and 80)

where R is the risk at a given age compared to the risk to a 20-year-old male. For example, 70-year-old females are 3.86 times as likely to die as 20-year-old males (or 2.95 times as likely to die as 20-year-old females). Eqn 8 means that for each additional year a female ages after age 20, her risk of death from the same physical impact increases at a compound rate of $(2.16 \pm 0.10)\%$ per year. Comparing this to the male rate of $(2.53 \pm 0.08)\%$ per year shows a lower rate of increase in risk of death with each year of aging for females compared to males.

Relevance to Interpreting Traffic Fatality Rates

If hypothetical equal-sized populations of drivers experienced identical mixes of crashes, the populations would not have equal numbers of fatalities if the drivers differed in age or gender, as shown in the illustrative values in Table 4 computed using Eqns 6 and 8.

Differences in observed fatalities have often been inappropriately attributed exclusively to differences in crash involvement rates. Table 4 illustrates that a large component of any observed increases in fatalities as drivers age is due to the increased risk of death in the same crash. Equations 7 and 8 can be used to decompose such observed rates into the two conceptually distinct components, one due to changes in vulnerability in a given crash, and the other due to changes in crash involvement rates.

Table 4. Comparison of number of fatalities in two populations of drivers identical in numbers and crash rates.

Driver-Population A	Driver-Population B	Fatality Comparison
70-year-old males	20-year-old males	253% more in population A
70-year-old females	20-year-old females	194% more in population A
70-year-old females	20-year-old males	286% more in population A

DISCUSSION

Male subjects in the 16 categories (Figs. 1-3) and female subjects in 14 categories (Figs 6-8) are killed by a wide variety of impact mechanisms. For example, car occupant fatalities usually result from impacting the car interior, while motorcyclist fatalities result from impacting objects other than the motorcycle. The absence or presence of steering wheels, safety belts, helmets, cushioning effects of occupants in front, car interiors compared to truck interiors, etc. all affect injury mechanisms. Yet the relationships obtained for the different occupant categories are fairly similar. There are suggestions of some difference dependent on vehicle or subject category. It would be unreasonable to not expect the specifics of the crash to exercise some influence on the dependence on age of the ratio of the risks. However, the degree of similarity suggests that the relationships are measuring a general response to impact, with the details of the particular crash or occupant category exercising no more than a secondary role. That is, the general trends in the results originate from fundamental changes in susceptibility to injury from blunt impact as people age.

For expository convenience comparisons are described in terms of differences in risk when two individuals receive identical physical impacts. The results in fact reflect averaging over the mix of physical impacts that occur in traffic crashes. If an impact is of such great severity as to certainly kill a 20-year old, then it cannot pose a greater risk to anyone older, yielding R = 1. Similarly, an impact which poses zero risk to a 20-year-old may pose a non-zero risk to anyone older, thus implying an infinite value of R. This situation parallels exactly that of safety belts, which are zero percent effective at very high severity, and 100% effective in a low severity range (see p. 222-226 of Evans 1991). The useful measure of safety belt effectiveness is the reduction in risk averaged over the mix of crashes that occur. This mix has the general structure that for a fixed increase in severity, the number of crashes decreases by a fixed proportion (Evans 1996). It is because of this underlying pattern that the relative fatality risk relationships are not distinguishably different between belted truck occupants and unhelmeted motorcyclists (Figs 2 and 3, and Figs 7 and 8), even though these occupants are at greatly different risks of death in similar-severity crashes. (Similarly, safety belt effectiveness is not distinguishably different for urban and rural crashes, even though rural crashes are more severe). A similar pattern is likely to apply to other sources of blunt trauma. Many people fall from small heights, but the number who fall from a given height decreases steeply as the height increases. The results here are therefore expected to apply to any source of blunt trauma that has declining frequencies of occurrence as severity increases.

Traffic crash data and the method used provided a "laboratory" to investigate the relative fatality risk from similar blunt trauma insults as people age. The results are interpreted to apply beyond that laboratory, so that Figs. 5 and 10, and associated equations 6 and 8, represent how fatality risk changes with age for any life-threatening blunt trauma insult.

CONCLUSIONS

After age 20, risk of death from the same severity blunt trauma impact increases by:-

- (2.52 ± 0.08)% per year for males
- (2.16 ± 0.10)% per year for females.

While traffic crashes provided the "laboratory" for this study, the findings are interpreted to apply to blunt trauma from more general sources, such as falling from a roof or down stairs. The results imply that if populations of 70-year-old males and 20-year-old males are subjected to identical mixes of blunt-trauma insults, the population of older males will sustain 250% more fatalities. A population of 70 year-old females will sustain 190% more fatalities than a population 20-year-old females (290% more than a population of 20-year-old males).

ACKNOWLEDGEMENTS

The major portion of this research was financed by General Motors pursuant to an agreement between GM and the U.S. Department of Transportation. The data analyses were completed while the author was employed by GM. The large number of tabulations from the FARS data were produced with great skill and enthusiasm by Peter H. Gerrish of Nesa and Associates, Inc.

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APPENDIX A

Papers Addressing or Using the Double Pair Comparison Method

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