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Gender And Age Influence On Fatality Risk From The Same Physical Impact Determined Using Two-Car Crashes

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ABSTRACT

Studies using the double-pair-comparison method found that fatality risk from the same physical impact is (28 ± 3)% greater for females than for males, and increases with age after age 20 at compound annual rates of (2.52 ± 0.08)% for males and (2.16 ± 0.10)% for females. The purpose of the present study is to investigate fatality risk from the same physical impact versus gender and age using a dfferent method and data distinct from those in the other studies. Female to male fatality risk was estimated using two-car crashes in which the gender of the two drivers differed. Fatality risk from the same impact is found to be (22 ± 9)% greater for females than for males, and to increase annually after age 20 by (2.86 ± 0.32)% for males and (2.66 ± 0.37)% for females. The relatively close quantitative agreement between the present and double-pair-comparison estimates increases confidence in the validity of double-pair-comparison methods and the present method.

INTRODUCTION

Recent studies showed that when subjected to similar physical impacts, young women were (28 ± 3)% more likely to die than men of the same age [1], and that for each additional year of life after age 20 years, fatality risk increases at compound rates of (2.52 ± 0.08)% per year for men and (2.16 ± 0.10)% per year for women [2]. These recent studies built upon findings of earlier investigations [3,4]. The results [1-4] were interpreted to reflect basic physiological differences in response to blunt trauma as functions of gender and age. The findings were interpreted to apply in general, and not just to the crash situations that provided the "laboratory" used to investigate them. Such a fundamental interpretation invites examining if similar effects are observable using different methods and data.

All of the results [1-4] were obtained using the double-pair-comparison method [5] which uses vehicles containing a pair of occupants, at least one being killed. While the method has been applied widely [6-24] and appears to effectively correct for known large biases, the fundamental interpretation of the conclusions makes it desirable to investigate the phenomena using unrelated methods.

To examine gender effects we here estimate female to male risk by examining two-car crashes in which one car has a female driver and the other a male driver of similar age, in both cases the drivers traveling alone. So, not only is the method conceptually unrelated to the double-pair-comparison method, but the data we use contain no crashes in common with double-pair-comparison studies which use only vehicles with at least two occupants.

METHODS AND MATERIALS

DATA The Fatality Analysis Reporting System (FARS) [25] 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, a 24-year period during which over a million fatalities occurred. Including only vehicles with unaccompanied unbelted drivers who were involved in two-car crashes in which at least one driver was killed produced the sample sizes given in Table 1. The average number of deaths per fatal two-car crash is 1.08, somewhat lower than the corresponding ratio for all crashes because only two occupants are at risk in the crashes for this study, and any appreciable disparity in car mass places one at substantially lower risk than the other. The 1998 FARS document, 41,471 people killed in 37,081 fatal crashes, for an average of 1.12 deaths per fatal crash.

TABLE 1. *The numbers of drivers killed in the two-car crashes used in the study. The gender study includes only crashes for which both drivers were in the same age category. The male versus age study includes only crashes between male drivers aged 16-24 and male drivers older than 25. The female versus age study includes only crashes between male drivers aged 16-24 and female drivers of any age.*

Analysis	Fatalities			No. of crashes
	Male	Female	Total	
Gender	1078	1484	2562	2391
Male risk versus age	4020	0	4020	3713
Female risk versus age	903	1966	2869	2678

APPROACH We focus on the ratio of the number of drivers of one type (say, females) to the number of another type (say, males) killed when cars with female drivers crash into cars with male drivers. If all other factors were equal, this would immediately provide the sought after risk ratio. However, other factors are rarely equal. Two factors that have a large influence on fatality risk in a crash are the use of safety belts [4,6,11] and the masses of the involved cars [26, 27]. Influences from safety belts are removed by confining the study to unbelted drivers (airbag-deployment cases are also excluded). This does not seriously diminish sample sizes because there are few two-car fatal crashes in which both drivers are belted. It also avoids addressing whether some surviving drivers were miscoded as belted when they were in fact unbelted (drivers coded as unbelted are very likely to be unbelted). While prior studies [1,2] used car, truck and motorcycle data, the present study is confined to cars because masses are not coded for the other vehicles. Vehicle mass has a large effect on outcome [26,27]. If one car in a two car crash is 20% heavier than the other (a typical mass disparity), then the driver in the lighter car is 100% more likely to be killed than the driver in the heavier car [26, 27]. It is infeasible to confine the study to crashes between cars of closely similar mass because there are too few such crashes. Instead, the analysis relies heavily on the study [27] summarized below.

INFERRING RISK RATIOS WHEN CARS ARE OF UNEQUAL MASS From a formal perspective, each car involved in a two-car crash can be considered to play a symmetrical role -- they crash into each other. For every crash between two cars (call them car_a and car_b) of known mass, we can define a mass ratio, μ, as

$$\mu = (\text{Mass of } car_b)/(\text{Mass of } car_a) \qquad (1)$$

and a driver fatality risk ratio, R, as

$$R = \frac{\text{Probability of driver fatality in } car_a}{\text{Probability of driver fatality in } car_b} \qquad (2)$$

It is found [27] that

$$R = \mu^u \qquad (3)$$

fits well data for many categories of two-car crashes. Equation 3 applies to cars which are not differentiated by any attribute other than mass, so, by definition, R=1 when μ =1. The relationship is thus constrained to pass through the point μ=1, R=1. Fitting data to Equation 3 yields one parameter, u.

If the cars are differentiated by some attribute other than mass, say car_a is driven by a female driver and car_b is driven by a male driver, then the value of R when μ=1 in Equation 3 measures the influence of driver gender on fatality risk. The earlier study [27] found that the relationship

$$R = A \mu^u \qquad (4)$$

fitted well such cases. The parameter A estimates the influence of the attribute when the masses are equal. In this way, data for cases of unequal mass contribute to estimating R when the masses are equal, thus enabling us to infer the female to male risk ratio controlling for the mass effect.

In order to produce each of the data points presented later, data were first ordered by increasing μ values. Intervals containing selected sample sizes of data were then formed. The value of mass ratio plotted is the mean, weighted by the number of crashes, of this interval.

RESULTS

AN EXAMPLE - COMPUTING FEMALE TO MALE RISK FOR 20-YEAR-OLD DRIVERS. The specific case of comparing female to male risk for drivers aged 16-24 (refer to them as 'age 20 drivers') is shown in Figure 1. To illustrate the process, focus on the point closest to the μ = 1 axis, plotted at μ = 1.02. This value is the average of 51 crashes with μ in the range 0.988 and 1.053. In these crashes, 37 female and 21 male drivers died, giving the plotted risk ratio R = 1.76. As it is arbitrary whether we compare female to male risk, or male to female risk, the natural logarithm of R is used for all analyses. The standard error in Log(R) is given by v(1/37 + 1/21) = 0.273 [28,29], leading to Log(R)= 0.566 ± 0.273. (in the present and double-pair-comparison papers [1-4], all errors are standard errors). Because errors are most strongly affected by the smaller fatality count, larger sample sizes are required as R departs further from 1. For example, the point plotted at μ = 1.68 reflects 216 crashes with mass ratios between 1.37 and 2.88. These crashes killed 201 female and 18 male drivers, giving R = 11.2, and a standard error in Log(R) = 0.246, similar to the error in the earlier case. The mass ratio ranges were chosen to produce similar errors for each point. Note that the number of drivers killed per fatal crash trends downwards as mass ratios depart from one. In the above examples, 1.137 deaths per fatal crash at μ = 1.02 compared to 1.014 deaths per crash at μ = 1.68.

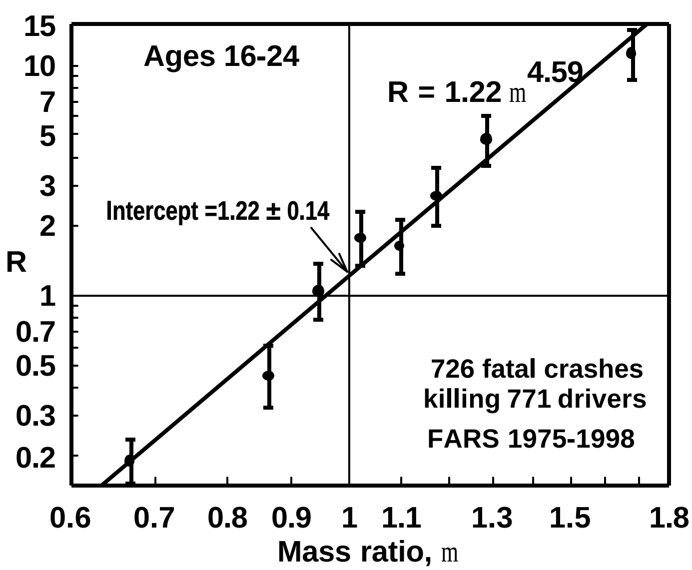

FIGURE 1. *Risk of death to female drivers compared to risk of death to male drivers, R, when the mass of the male driver's car is m times the mass of the female driver's car.*

The line in Figure 1 is a weighted least squares fit to

$$\text{Log}(R) = \text{Log}(A) + u\ \text{Log}(\mu), \qquad (5)$$

the natural logarithm transformation of Equation 4. The fit gives u = 4.59 ± 0.40, and, more central to the present study, A = 1.22 ± 0.14. The error limits were computed by a simulation which provided results 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. For expository convenience results are presented as A = 1.22 ± 0.14; which is a useful approximation to the more formally correct expression exp(0.199 ± 0.115) used in all calculations.

It is convenient to discuss risks, R, in terms of ?R = 100*(A-1)/R, the percent change from the R = 1 value denoting no difference in risk dependent on gender. So Figure 1, which is based on 726 fatal crashes killing 771 drivers (476 female and 295 male) leads to the conclusion that females are (22 ± 14)% more likely than are males to die from similar crash forces. The simple ratio of female to male deaths, 476/295 = 1.61 (or 61% higher for females) is so different because, on average, females drive lighter cars.

The mass ratio that generates equal male and female risks is 0.958, equivalent to the female's car being 4% heavier than the male's. This 4% difference in mass cancels the 22% higher risk to females when other factors are equal.

GENDER INFLUENCE ON FATALITY RISK The value of A from Figure 1 provides the female to male ratio plotted at age 20 in Figure 2; a corresponding process

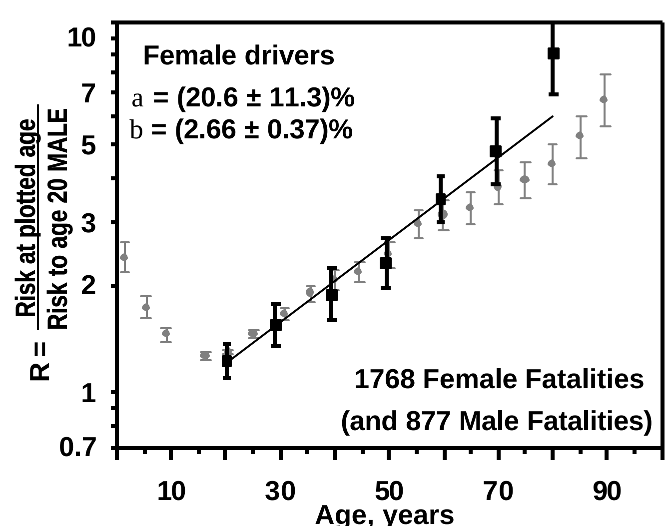

FIGURE 2. *Risk of female fatality compared to the risk of male fatality versus age. The bold black symbols are*

results from the present study; the gray symbols are results from [1].

provides all the other values plotted in this and subsequent figures (black symbols). At ages 20, 30 and 45 we find that female risk exceeds male risk by (22 ± 14)%, (23 ± 19)% and (21 ± 14)%, respectively. The weighted mean of these values, (22 ± 9)%, provides definitive evidence that in the same crash experience, females older than 20 but not older than the mid fifties (the 45 year old category was 37 to 55) are about 20% more likely to die than are males of the same age. The present finding of about a 20% higher risk for females than for males corroborates the double-pair-comparison findings [1], shown in gray symbols in Figure 2. The point plotted at age 70 includes the range 56-97. The suggestion that at ages above the mid fifties, female risk becomes less than male risk corroborates the more detailed findings [1].

As the present study is confined to drivers, it produces no estimates that can be compared to the pre-licensure ages obtained in [1,2].

MALE AGE INFLUENCE ON FATALITY RISK. Here we examine fatality ratios when cars driven by 20-year-old male drivers (drivers in the 16-24 year category) are involved in crashes involving cars driven by male drivers in older age categories. In parallel with the gender case, a weighted regression of Log(R) on m produced the estimates plotted in Figure 3 for the case when the cars are of equal mass. Except for ages above about 80, the present results agree well with the double-pair-comparison findings. Because all the comparisons are to 20-year-old males, the risk at age 20 is defined to be one, as indicated by the diamond shaped symbol.

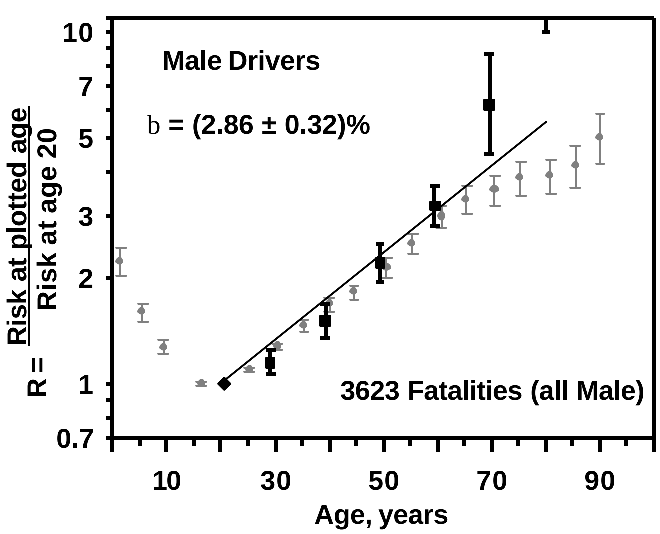

FIGURE 3 *The risk, R, of death at the indicated age compared to the risk of death at age 20 for males. By definition, at age 20 R=1, as indicated by the diamond, a point through which the fitted line is constrained to pass.*

The bold black symbols are results from the present study; the gray symbols are results from the study [2].

For ages between 20 and 80 the data were fitted, using a weighted least-squares regression, to

$$\mathrm{Log}(R) = b\,(\mathrm{Age} - 20). \tag{6}$$

Equation 6 has only one parameter, b, because, by definition, at age 20, R=1. The data in Figure 3 lead to b = (0.0286 ± 0.0032). It is convenient to express values of b as percents, so that the slope becomes (2.86 ± 0.32)%. The interpretation is that, for each additional year a male ages after age 20, his risk of dying from the same physical impact increases at a compound rate of (2.86 ± 0.32)% per year. This value is in good agreement with of (2.52 ± 0.08)% from [2]obtained using the double-pair-comparison method.

FEMALE AGE INFLUENCE ON FATALITY RISK. Here we examine fatality ratios when crashes occur between cars driven by 20-year-old male drivers and cars driven by female drivers in various age categories (Figure 4). As in [2-4], both male and female age analyses use the same reference value, the risk to 20 year old males. An additional compelling reason to use male drivers as the reference is that crashes involving one male and one female driver outnumber crashes involving two female drivers by a factor of about three.

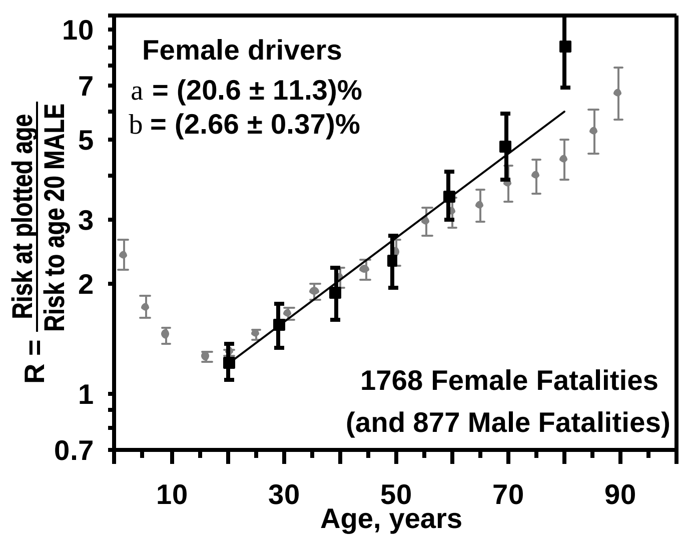

FIGURE 4 *The risk, R, of death for a female of the indicated age compared to the risk of death to a 20-year-old male. The bold black symbols are results from the present study; the gray symbols are results from the study [2].*

For ages between 20 and 80 the data were fitted, using a weighted least-squares regression, to

$$\mathrm{Log}(R) = K + b\,(\mathrm{Age} - 20), \tag{7}$$

where K measures the difference in risk between female and male drivers in the same 16-24 age category. The data in Figure 4 give K= (0.1874 ± 0.0938) leading to R=exp(K) = (1.206 ± 0.113)%. This implies that at age 20, female risk exceeds male risk by (21 ± 11)%. In comparing this to the value (22 ± 14)% inferred from Figure 1, note that this same value from Figure 1 is common to both the gender analysis (Figure 2) and Figure 4.

Equation 7 yields b = 0.0266 ± 0.0037, meaning that for each additional year of life after age 20, female risk of death from the same impact increases at a compound rate of (2.66 ± 0.37)% per year. As in the double-pair-comparison studies [1,3,4], the female risk increases at (in this case a nominally) lower rate than the male rate.

DISCUSSION

The present results are in general agreement with the double-pair-comparison results. There are, however, indications of some departures. For ages above 80, R values are larger in the present than in the double-pair-comparison studies [2,3-4]. This may reflect changing types of two-car crashes with increasing age. For example, given involvement in a fatal two car crash, side impact is more likely for an older driver [30], and fatality risk is far higher for drivers whose vehicles are struck in the side compared to being struck in front [27]. It would be surprising if the specifics of the crash did not exercise some influence on risk ratios. The present study compared risks faced by two lone drivers in cars crashing into each other, whereas the double-pair-comparison studies compared risks faced by a pair of occupants traveling in the same vehicle involved in crashes of any type in which at least one of them was killed.

For expository convenience we have described the comparisons in terms of differences in risk when two individuals receive identical physical impacts. The results in fact reflect averaging over the distribution of physical impacts that occur in traffic crashes. If an impact is of such great severity as to certainly kill any 20-year-old male, 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 small but non-zero risk to someone older, thus implying that R is infinite. This situation parallels exactly that for safety belts, which are zero percent effective at very high severity, and 100% effective in a low severity range (see p. 222-226 of Ref. 4).

The overall average risk of death in a set of crashes does not systematically affect estimates of gender and age dependence [1,2] (or of belt effectiveness [13]). Relationships derived for belted drivers are not materially different from those for unbelted drivers (or motorcyclists) [2]. What does affect estimates is how the probability of a given severity crash decreases with increasing severity. If this probability decreases at a fixed exponential rate as severity increases, as is supported by empirical data [11,31], then average severity should not affect estimates. The degree of agreement between the present and other [1-4] results, and between the many relationships in the other studies (14 in the gender study [1] and 30 in the age study [2]) supports the interpretation that the distribution of crashes by severity does indeed follow such a pattern.

CONCLUSIONS

The present analysis finds that, from about age 20 to 45, fatality risk from the same impact is (22 ± 9)% greater for female drivers than for male drivers, and that after age 20, risk increases each year by (2.86 ± 0.32)% for males and (2.66 ± 0.37)% for females. The relatively close quantitative agreement between the present and higher precision double-pair-comparison estimates increases confidence in the validity of both methods. The present study is confined to unbelted drivers of cars and can therefore address directly only unbelted drivers of cars. The other studies[1-4] produced estimates for 16 categories of occupants, including belted and unbelted right-front-passengers of cars and light trucks, rear-seat passengers of cars and light trucks, and motorcyclists with and without helmets. No distinguishable differences were found among the results for the different occupant categories, showing that the effects were not due to the specifics of the occupants environment. The agreement between the double-pair-comparison results for unbelted car drivers and for other occupants precludes the possibility that the effects are due to the specifics of the driver's environment, such as the presence of the steering wheel. This suggests that the present results are likewise not due to such characteristics as the presence of the steering wheel. The possibility the results could arise simply due to differences in stature is likewise largely precluded by the similarity of effects for motorcyclists and car occupants, and by the analysis presented in [1]. The results in the [1-4] are interpreted to reflect fundamental physiological differences in response to blunt trauma in general, not just to injuries sustained in traffic crashes. The car-driver results of the present paper cannot lead to such a broad conclusion. However, the quantitative agreement between the present results for those in the double-pair-comparison studies based on many categories of occupants adds support to the interpretation in the other studies.

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