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Female Compared with Male Fatality Risk from Similar Physical Impacts

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Objective: If a female and a male suffer similar potentially lethal physical impacts, which of them (other factors being equal) is more likely to die? This question is addressed using 245,836 traffic fatalities.

Methods: Fatality risk ratios were estimated using crash data for cars, light trucks, and motorcycles with two occupants, at least one being killed. Combinations of seat belt use, helmet use, and seating location led to 14 occupant categories.

Results: Relationships between fatality risk and gender are similar for all 14 occupant categories. Female fatality risk exceeds male risk from preteens to late 50s. For ages from about 20 to about 35, female risk exceeds male risk by (28 ± 3)%.

Conclusion: Whereas specific injury mechanisms differ greatly between the 14 occupant categories, the effect of gender on fatality risk does not, thus implying that the relationships reflect fundamental gender-dependent differences.

Key Words: Gender differences, Sex differences, Blunt trauma, Fatality risk, Trauma insult, Injury risk, Traffic fatalities, Traffic crashes.

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If a female and a male suffer similar potentially lethal physical impacts, which of them (other factors being equal) is more likely to die? This question cannot be answered by standard epidemiologic methods because adequate samples of sufficiently similar cases are unavailable.

Note that risk of death from the same physical impact should not be confused with risk of death after the same severity injury, or after admission to a trauma unit. Being more vulnerable to fatality risk increases the risk of severe injury, and of being hospitalized. The question of risk from similar impact is addressed here using traffic fatality data[1] and a method[2] to make the required inferences from such data.

MATERIALS AND METHODS

Data

The Fatality Analysis Reporting System (FARS)[1] documents all vehicles and people involved in U.S. traffic crashes (since 1975) in which anyone was killed. The present study uses data for 1975 through 1998. During this 24-year period, over 1 million fatalities are documented, 245,836 of which meet the selection criteria for inclusion in this study.

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

Double Pair Comparison Method

The double pair comparison[2] method 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, gender) from the multitude of other influences that affect fatality risk in a crash. This method has been applied to many problems,[3–23] including the current question,[7] but at a time when only about one third as many data were available. A more detailed description of the method, including computation details, are in my earlier study,[7] the only prior study to address quantitatively how gender influences fatality risk from the same blunt trauma insult.

The method focuses on 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 that occupant's fatality risk. The other, the control occupant, serves to standardize conditions to estimate risk to the subject occupant.

For expository convenience, the method is described below for the specific case in which the subject occupant is a car driver and the control occupant is a male passenger seated in the right-front seat. The aim is to determine how driver gender influences driver fatality risk.

Two sets of crashes are selected. The first contains cars with a female driver and a male passenger, at least one being

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killed. From these crashes the following quantities are calculated:

$$\mathbf{A} = \text{Number of female drivers killed in cars with male passengers} \quad (1)$$

$$\mathbf{B} = \text{Number of male passengers killed in cars with female drivers.} \quad (2)$$

These lead to a female driver to male passenger ratio, $\mathbf{r_1} = \mathbf{A/B}$.

The second set of crashes consists of cars in which subject and control are both male. That is, the subject gender is different from the first set of crashes, but the control characteristics are the same. These crashes provide

$$\mathbf{C} = \text{Number of male drivers killed in cars with male passengers} \quad (3)$$

$$\mathbf{D} = \text{Number of male passengers killed in cars with male drivers,} \quad (4)$$

leading to a male driver to male passenger ratio, $\mathbf{r_2} = \mathbf{C/D}$.

Dividing these two ratios gives

$$\mathbf{R} = \mathbf{r_1/r_2} = \mathbf{AD/(BC)} \quad (5)$$

Subject to assumptions that are likely to be more than adequately satisfied,[2] the quantity **R** measures the risk of death to a female driver compared with the risk of death to a male driver, other factors being essentially the same. The crash conditions are effectively standardized because the female and male drivers experienced their injuries in a mix of crashes that posed similar risks to accompanying male passengers. The quantity $\mathbf{r_1}$ alone does not estimate relative fatality risk to females compared with males because of possible other differences, such as different risks in driver compared with passenger seats.[24]

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 potential confounding because of differences that may exist between subject and control occupant with regard to such factors as age, seat belt use, and seating position. The basic assumptions of the method require that the probability of a passenger death should not depend (in the present example) on the gender of the driver. This assumption would be violated if, for example, the same physical impact was less likely to kill a passenger traveling with a male driver than one traveling with a female driver. Departures from this assumption could arise if, for example, passengers traveling with male drivers tended to be younger than those traveling with female drivers. The biasing influences of such potential confounding can be reduced by disaggregating control subjects into gender and age categories, thus ensuring that passengers of similar age and gender accompany the female and male drivers being compared. As occupant-protection device (seat belt or helmet) use affects fatality risk, the control occupant should have the same use in the first and second set of crashes.

A Specific Example

The calculations are described below in more detail using the specific example of comparing unbelted car driver fatality risk for females aged 38 to 42 with that for males in the same age interval (call them 40-year-old drivers). For the control occupant, we first chose unbelted male right-front passengers aged 16 to 24, hereafter referred to as 20-year-old male passengers. The 1975 to 1998 FARS data give $\mathbf{A} = 90$ female drivers aged 40 were killed while traveling with 20-year-old male passengers, and $\mathbf{B} = 36$ male passengers aged 20 were killed while traveling with female drivers aged 40. These give a 40-year-old female driver to 20-year-old male passenger fatality risk ratio of $\mathbf{r_1} = 2.500$. This departs so substantially from unity because fatality risk from the same impact depends so strongly on age.[3,7] For the second set of crashes, $\mathbf{C} = 244$ and $\mathbf{D} = 133$, giving $\mathbf{r_2} = 1.835$. The ratio of $\mathbf{r_1}$ to $\mathbf{r_2}$ gives $\mathbf{R} = 1.363$, so, in this specific subject and control case, females are estimated to be 36% more likely to die than males from the same physical impact.

RESULTS

The above specific example provides the first of the eight estimates for 40-year-old subject drivers shown in Table 1. This table contains data for all crashes by cars in 1975 to 1998 FARS containing unbelted 40-year old-drivers and unbelted right-front passengers of any known age in which one of these occupants was killed. Summing the appropriate columns in Table 1 shows 4,920 such crashes killing 3,038 drivers (930 female and 2,108 male drivers) and 2,870 right-front passengers. The conclusion from Table 1 is that 40-year-old female car drivers are $(19.9 \pm 8.6)\%$ more likely to be killed than male drivers in similar severity crashes. This value provides the point plotted at age 40 in the top left plot of Figure 1. Each of the other points plotted is determined on the basis of extracting data in the same form as Table 1 for other driver ages. Summing data over all driver ages gives 62,862 driver fatalities (14,873 female and 47,989 male drivers), as shown as the first row of Table 2, which gives corresponding sample sizes for each of the 14 occupant categories.

Figures 1 to 3 show 185 estimates of **R** plotted for 14 categories of occupants in three types of vehicles. Summing the sample sizes for each of the 14 occupant categories gives a total sample size of 245,836 subject fatalities, compared with 81,994 in eight occupant categories in the earlier study.[7] Because of the fundamental interpretation of the effects reported, it is important to examine how robust, repeatable, and general the earlier[7] results are. Additional occupant catego-

Table 1 Comparison of Female with Male Fatality Risk to 40-Year-Old[a] Unbelted Car Drivers

Control Occupant Characteristics, Age	Fatalities A	Fatalities B	Fatalities C	Fatalities D	Ratios $r_1 = A/B$	Ratios $r_2 = C/D$	$R = r_1/r_2$	ΔR[b]
Male passenger, 16–24	90	36	244	133	2.500	1.835		0.314
Male passenger, 25–34	93	49	359	230	1.898	1.561		0.246
Male passenger, 35–54	243	206	439	448	1.180	0.980		0.152
Male passenger, 55+	33	76	76	158	0.434	0.481		0.231
Female passenger, 16–24	169	77	116	61	2.195	1.902		0.249
Female passenger, 25–34	73	51	303	297	1.431	1.020		0.289
Female passenger, 35–54	144	133	532	597	1.083	0.891		0.174
Female passenger, 55+	85	214	39	104	0.397	0.375		0.247
						Weighted average		0.078

A = Number of 40-year-old female drivers killed traveling with control passengers (with characteristics indicated in column 1).
B = Number of control passengers killed traveling with 40-year-old female drivers.
C = Number of 40-year-old male drivers killed traveling with control passengers.
D = Number of control passengers killed traveling with 40-year-old male drivers.
[a] Drivers aged 38, 39, 40, 41, or 42 years.
[b] **ΔR** is the standard error in **R** (for calculation of errors and weights, see references 2, 7, 27–29). For small **ΔR**, there is a 68% chance that the actual value lies between **R–ΔR** and **R** + **ΔR**.
[c] The weighted average indicates that 40-year-old female unbelted drivers are 19.9% more likely to be killed than 40-year-old males from the same impact.

ries, and substantially increased numbers of belted occupants, solidify the interpretation.

Occupants in Each of the Three Vehicles

The data for drivers in Figures 1 and 2 show no values at ages below the age of licensure, because driver fatalities at younger ages[25,26] are insufficient for this study. For small sample sizes, categories of age wider than the mainly 5-year intervals are adopted, as is apparent in the graphs (each point is still the weighted average of eight values in parallel with Table 1). There are insufficient female motorcycle driver fatalities to analyze the effect of gender on motorcycle-driver risk. All errors quoted and plotted are one SE, with the approximate interpretation that there is a 68% probability that the true value is within the indicated error range, and a 16% probability that it is higher and a 16% probability that it is lower. The computation of errors and weights[2,7,27–29] is illustrated with a specific example, including complete numerical details, in the earlier study.[7]

If there were no systematic differences between male and female risk, then all the data in Figures 1 to 3 would distribute randomly around the value **R** = 1.0 (marked by a dashed line in all graphs). Instead, clear systematic departures are apparent in each graph, with the departures being similar from graph to graph. This can be further illustrated by focusing on the numerical values at a specific age. We choose age 20 because each of the 14 graphs contains a point plotted close to age 20. The numerical values plotted for each graph are given in Table 3. For all 14 comparisons, female risk exceeds male risk by, typically, more than 2 SE. The 14 individual values are generally in good agreement, with the overall weighted average female risk being (27.9 ± 2.3)% higher than male risk.

None of the individual graphs in Figure 1 departs systematically from their collective trend. It is therefore appropriate to combine all these data to obtain a best estimate for car occupants (top graph in Fig. 4). The values plotted are the

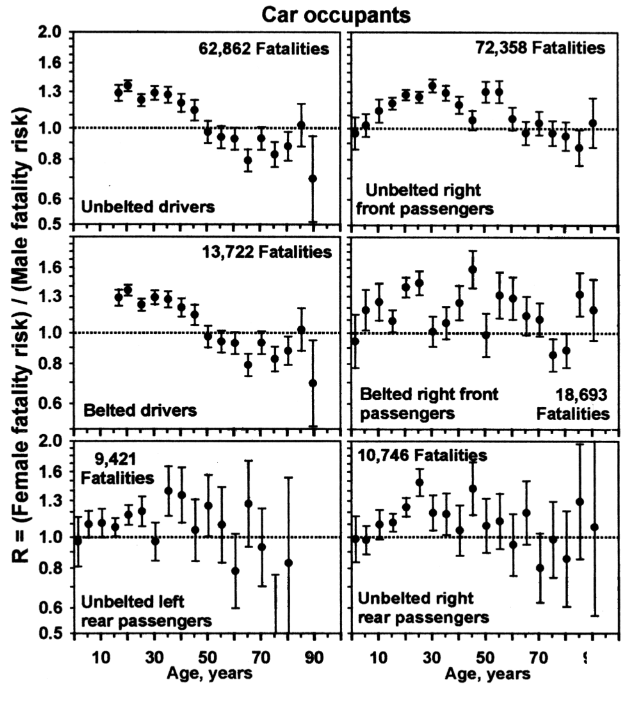

Fig. 1. *Female to male fatality risk, **R**, from similar physical impacts, estimated using car occupants. The weighted averages over the six occupants produce the top plot in Figure 4. Risk was determined on the basis of 187,802 subject fatalities (75,066 female and 112,736 male fatalities). In the top left graph, the point at age 40 (sixth point from left) is **R** = 1.199 ± 0.078, as calculated in Table 1.*

Table 2 Distribution of 245,836 Fatally Injured Subject Occupants by Occupant Category and Sex[a]

Vehicle	Subject Occupant	Restraint Use	Female Fatalities	Male Fatalities	Total
Car	Driver	Unbelted			62,862
	Right-front passenger	Unbelted			72,358
	Driver	Belted			13,722
	Right-front passenger	Belted			18,693
	Left-rear passenger	Unbelted			9,421
	Right-rear passenger	Unbelted			10,746
Light truck[b]	Driver	Unbelted			19,765
	Right-front passenger	Unbelted			21,022
	Driver	Belted			3,417
	Right-front passenger	Belted			4,010
	Left-rear passenger	Unbelted			1,556
	Right-rear passenger	Unbelted			1,711
Motorcycle	Passenger	Unhelmeted			3,860
	Passenger	Helmeted			2,693
Totals					245,836

[a] Values obtained from the Fatality Analysis Reporting System (FARS), 1975–1998.
[b] As defined by Kahane, 1997.[30]

weighted averages of the six (or fewer) values plotted at the indicated ages in Figure 1.

The other two graphs in Figure 4 show corresponding information for light trucks[30] and motorcycles. Weighted average values of **R** at, say, age 20 are 1.285 ± 0.027 for cars, 1.241 ± 0.052 for light trucks, and 1.312 ± 0.078 for motorcycle passengers. For all vehicles, female risk exceeds male risk by amounts that are not systematically different depending on which of the three vehicles provides the data. The **R** values for occupants of each of the three vehicle types are, to within their error limits, consistent with the weighted average of 1.279 ± 0.023.

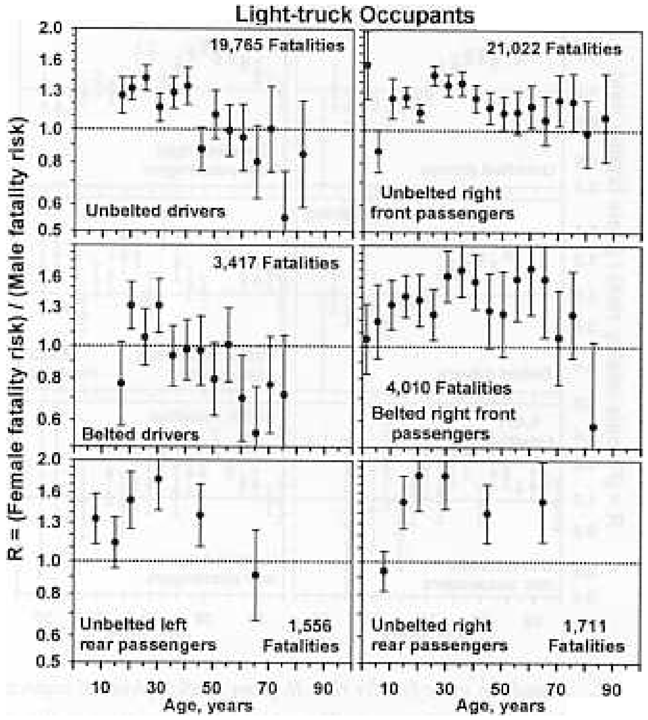

Fig. 2. *Female to male fatality risk, **R**, from similar physical impacts, estimated using occupants of light trucks.[30] Risk was determined on the basis of 51,481 subject fatalities (14,444 female and 37,037 male fatalities).*

Average over Occupants in the Three Vehicle Categories

As results for individual vehicle categories do not depart systematically from their collective trend, it is appropriate to combine the data in Figure 4 to produce Figure 5. The main findings of this investigation are summarized in Figure 5. Each point plotted can be considered the weighted average of the up to 14 values from the 14 occupant categories, or the mathematically identical weighted average of the values from each of the three vehicle categories.

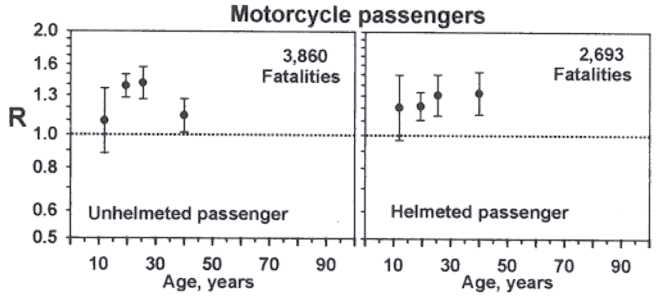

Fig. 3. *Female to male fatality risk, **R**, from similar physical impacts, estimated using 6,553 motorcycle passenger fatalities (3,879 female and 2,674 male fatalities). There are no plots for motorcycle drivers because of too few (139) female motorcycle driver fatalities.*

Table 3 Values of the Ratio, R, of the Fatality Risk to 20-Year-Old Females to the Risk to 20-Year-Old Males for All Subject Occupants Studied

Vehicle	Subject Occupant	Restraint Use	R	ΔR	R[a]	ΔR[a]
Car	Driver	Unbelted	1.357			
	Right-front passenger	Unbelted	1.274			
	Driver	Belted	1.150			
	Right-front passenger	Belted	1.391			
	Left-rear passenger	Unbelted	1.173			
	Right-rear passenger	Unbelted	1.242			
	Weighted average for cars				1.285	
Light truck	Driver	Unbelted	1.323	0.103		
	Right-front passenger	Unbelted	1.131	0.065		
	Driver	Belted	1.318	0.215		
	Right-front passenger	Belted	1.373	0.246		
	Left-rear passenger	Unbelted	1.517	0.296		
	Right-rear passenger	Unbelted	1.800	0.437		
	Weighted average for light trucks				1.241	
Motorcycle	Passenger	Unhelmeted	1.385	0.108		
	Passenger	Helmeted	1.215	0.112		
	Weighted average for motorcycle passengers				1.312	0.078
	Weighted averages of 14 values				1.279	0.023
	Weighted averages of three vehicle values				1.279	0.023

[a] These columns contain composite estimates for each of the three vehicles.

The values plotted at ages 20, 25, 30, and 35 are 1.279 ± 0.023, 1.301 ± 0.028, 1.291 ± 0.033, and 1.287 ± 0.038. These values show consistently that, between ages 20 and 35, female risk exceeds male risk by (28 ± 3)%. From about age 10 to the late 50s, female risk exceeds male risk by amounts that depend on age. For ages below 10 or above 60, the study provides no indication of clear differences, although there is a weak suggestion that older men might be more vulnerable than older women.

DISCUSSION

Interpretation

Subjects in the 14 categories (Figs. 1–3) are killed by a wide variety of impact mechanisms. For example, car occupant fatalities usually result from impacting the car interior, whereas motorcyclist fatalities result from impacts into objects external to the motorcycle. The absence or presence of steering wheels, seat belts, helmets, cushioning effects of occupants in front, car interiors compared with truck interiors, etc., all affect injury mechanisms. Nevertheless, the results obtained for the 14 occupant categories are similar. In particular, for ages 20 to 35, female risk exceeds male risk by the same (28 ± 3)% for occupants of cars, trucks, or motorcycles.

Further evidence supporting how robust the findings are is provided by a study[11] focused on examining whether the relationships found in the earlier study,[7] which used 1975 to 1983 data, were similarly revealed in data independent of those used in the earlier study, namely, 1984 to 1996 data. No distinguishable differences were found dependent on which of the independent data sets was used. This supports that the effects are not changing in time, and apply for different vintage vehicles. This justifies pooling all available data

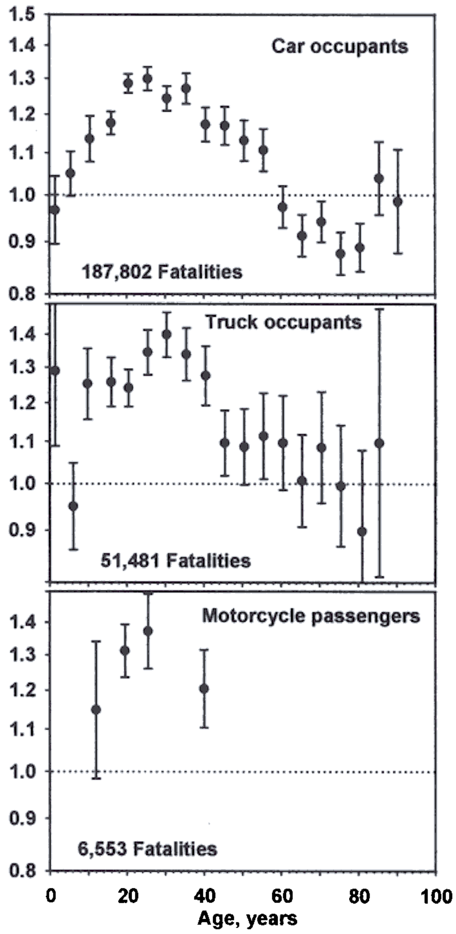

Fig. 4. *Female to male fatality risk, **R**, from similar physical impacts derived using data for specific vehicle categories. The weighted average of the values for the three vehicle categories produces Figure 5.*

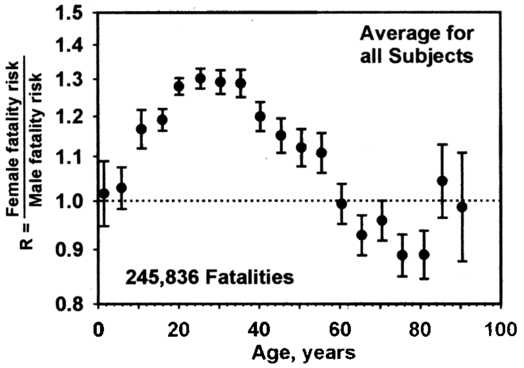

Fig. 5. *Female to male fatality risk, **R**, from similar physical impacts. The points plotted are the weighted averages for the three vehicle categories (Fig. 4), or the mathematically identical weighted average over data for all 14 occupant categories (Figs. 1–3).*

(those used by Evans,[7,11] plus data for 1997 and 1998) to obtain the highest precision estimate of the effects, a purpose of the present article.

The finding that female risk exceeds male risk by amounts that do not appear different for different time periods, different types or vintages of vehicles, seating positions, or occupant restraint use supports the interpretation that females are intrinsically more likely to die from physical impacts in general. This is a generality somewhat parallel to the data-based findings that females live longer than males, and are more likely to survive infancy. In each case, the generalities are phenomenologic in nature—they state what is found to happen without offering explanations of why it happens. However, all three effects likely reflect basic physiologic differences between males and females.

The difference in the risk to females and males is quantified in Figure 5. Although traffic crash data and the method used provided a laboratory to discover and quantify gender-dependent differences, these are interpreted to apply beyond that laboratory. Thus, Figure 5 is interpreted to apply to injuries not just from traffic crashes, but from other sources such as falling from a roof or down stairs.

I gave this same interpretation to the results of the earlier study,[7] which was derived from less than one third as many subject fatalities from 1975 to 1983 data in eight occupant categories. The present results for the same eight occupant categories are all consistent with the prior estimates, but are more precise because of larger sample sizes. Increasing the number of occupant categories from 8 to 14 further strengthened the interpretation because of the similarity of the effect for all 14 categories. Such similarity strengthens generalizing the findings to physical impacts in general.

This interpretation is consistent with cadaver tests using fixed impacts[31] that find that females have a 20% greater risk of injury to the thorax than males. The interpretation finds additional support in a recent study[32] using single-occupancy two-car crashes and a method unrelated to that used here, which finds that women from about age 20 to 35 are at (22 ± 9)% higher fatality risk. This[32] and another recent paper[33] provide additional information on the influence of age on fatality risk from the same physical impact.

The age range in which female risk from blunt trauma exceeds male risk (preteens to late 50s) is similar to the childbearing years, thus inviting the speculation that biologic factors associated with the potential to have children could increase risk from physical impacts.

Inferring Involvement Rates from Fatality Data

The Table 1 example for 20-year-old drivers is derived from 14,677 male fatalities and 3,532 female fatalities, for a male to female fatality ratio of 4.2. Such ratios are often interpreted to mean that males are 4.2 times as likely as females to be involved in severe crashes. The results here show that this interpretation should be modified. If 20-year-old males and females had equal involvement rates, females would experience 28% more deaths. The ratio should be multiplied by 1.28 to take account of the different risk from the same impact, so a 20-year-old man is 5.4 times, not 4.2 times, as likely to be involved in a severe crash.

One of the most firmly established results in injury research is that male fatalities exceed female fatalities by large amounts for all activities involving discretionary risk taking.[3,34,35] The results here show that male involvement risk exceeds female involvement risk by even larger amounts than previously thought.

Possible Biases, Alternate Explanations

Essentially all estimates of differences between male and female fatality risk from the same physical impact are from the double pair comparison method. It is therefore appropriate to examine whether the findings could be attributable to biases in the method or data, or whether the effect could be interpreted differently from above.

The fact that male drivers have higher crash involvement rates does not systematically affect **R** for drivers. Higher crash rates generate additional crashes, which increase subject and control fatalities by similar proportions, but do not change ratios systematically. The data show no systematic differences in estimates of **R** for passengers dependent on whether the driver is a man or a woman (male controls provide about three times as many data).

Let us assume that males not only have more crashes than females, but when they do crash they also have crashes of higher severity. Formal mathematical reasoning[2] shows that plausibly different distributions by severity can have, at most, only small influences on **R**. This result is more immediately apparent from the following data-based examples.

Seat belts reduce driver fatality risk by 42%,[3,5] and by a similar amount for right-front passengers, yet values of **R** are not systematically different for belted and unbelted occupants (compare rows 1 and 2 in Figs. 1 and 2). Could incorrect coding of belt use bias results? Perhaps about 10% of surviving occupants coded as belted were unbelted. This is a major problem in estimating belt effectiveness, just as miscoding surviving males as females would be for this study. If **R** does not much depend on belt use, which appears to be the case in Figures 1 and 2, then males and females being miscoded in similar proportions will not systematically affect **R**. Plausible departures from these assumptions could lead to no more than small changes in **R**. It is widely accepted that when occupants are coded as unbelted, they are very likely unbelted. Cases with unknown belt use were excluded.

Rear-seat unbelted occupants have fatality risks 26% lower than unbelted front-seat occupants,[3,24] yet **R** values for rear-seat occupants do not differ systematically from those for front-seat occupants (compare rows 1 and 3 in Figs. 1 and 2). Motorcycle helmets reduce passenger fatality risk by 28%, yet values of **R** do not systematically depend on helmet use (Fig. 3). Fatality risk differs between cars, trucks and, particularly, motorcycles, yet values of **R** do not systematically differ (compare the 3 graphs in Fig. 4).

The study was replicated using only rural, and then using only urban, crashes. About two thirds of fatalities and about one third of crashes occur in rural areas. A typical rural crash is about four times as likely to be fatal as a typical urban crash. Despite such a large difference in severity, the rural and urban replications produced values of **R** that are in good agreement with each other and with Figure 5.

Could the results reflect differences in stature? One could certainly speculate that risk might be greater for smaller drivers because of differences in the details of their interaction with the steering wheel during a crash. However, it seems implausible that the same explanation could apply to occupants whether or not they were belted, as belts alter the mix of injury mechanisms. Rear-seat occupants impact different structures from those struck by front-seat occupants. There does not seem to be any plausible mechanism that would favor taller individuals in all seats by amounts approaching the 28% found here. As motorcyclists are typically killed by striking objects external to the motorcycle, characteristics of the interaction between occupant and vehicle can have little bearing on outcome.

When injuries result from airbag deployments, they are of a different nature from other crash injuries in that the device provides its own source of energy. Whereas airbags reduce risk to males, they increase risk to females.[36] Accordingly, cases in which airbags deployed were excluded (about 2% reduction in sample sizes). The greater risk of female death from the same physical impact reported here could be a contributory factor to deaths from airbag deployments in low-severity crashes being predominantly to females.

An additional reason why the effects cannot plausibly be attributed to differences in stature is because at older ages female risk is, if anything, less than male risk (Fig. 5), yet females remain about the same percentage shorter than males at all ages. International anthropometric data[37,38] show consistently that 20-year-old women are 7.5% shorter than 20-year-old men, compared with 7.4% shorter for 70-year-olds.

The discussion above shows that factors known to have large influences on traffic fatality risk do not substantially affect **R**. The results, in common with results from any study using real-world data, may still be influenced by an essentially unlimited list of possible biases. However, it seems difficult to posit any plausible bias in the data that could change **R** values by amounts that would materially change the magnitude of the effects in Figure 5.

CONCLUSION

The relationship in Figure 5 is interpreted to apply to blunt trauma in general, including, for example, from falling down stairs or from a roof. Figure 5 shows no systematic influence of gender on risk ratio for ages less than 10 or more than 60. However, from the mid teens to the late 50s, female risk exceeds male risk. For ages 20 to 35, female risk exceeds male risk by (28 ± 3)%.

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