Female vs. Male Relative Risk of Body System Injuries in Fatal and Non-Fatal Crashes

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Abstract Motor vehicle crashes are a leading cause of death both in the United States and around the world. While research has showed younger females are at increased risk of fatality in fatal crashes, the underlying cause of this disparity is unclear. Data from the Fatality Analysis Reporting System (FARS), Mortality Multiple Cause of Death (MCOD), and National Automotive Sampling System Crashworthiness Data System (NASS-CDS) were used with the double-pair comparison method to identify relative risk of head injury and injury to other major body systems in motor vehicle crashes. FARS cases were linked to detailed cause of death records in MCOD. Young female occupants are at increased risk of fatal and severe head and abdominal injuries in motor vehicle crashes. This increased risk is pronounced for young females in both fatal crashes and non-fatal crashes with severe injuries. Along with previous research pointing to an increased overall fatality risk for young females in fatal crashes, these findings suggest a need to more carefully study biomechanical sex differences in car crashes.

Keywords Crash analysis, FARS, relative fatality risk, sex differences, vehicle safety trends

I. INTRODUCTION

Motor vehicle accidents are one of the leading causes of mortality worldwide, as the 8th leading cause of death for people of all ages, and the top cause of death for children and young adults 5-29 years old [1]. In the United States, mortality from motor vehicle accidents is the 2nd leading nationwide cause of unintentional injury death, resulting in 1.4 million years of life lost annually [2]. Motor vehicle fatalities rank in the top 3 causes of death for individuals under the age of 34. Previous research has shown that female drivers and vehicle occupants are more likely than males to suffer severe or fatal injuries when involved in a fatal crash [3-6]. This potential disparity between men and women in automobile crashes is a major public health issue with implications for automobile design, personnel protection, and governmental regulation.

While there is a clear disparity in the likelihood of fatality in a fatal crash for women compared to men, the underlying cause of this difference is not understood. Postmortem human subject (PMHS) testing has lagged behind the increasing evidence for sex differences in injury and fatality outcomes. Only 15% of PMHS tests involving head/torso response to inertial loads and direct head/body impacts utilised female PMHS [7]. Looking to other domains, we find female athletes have an overall higher injury rate than males [8], and women/girls have higher rates of brain injury in contact sports than men/boys [9,10]. To assess whether this increased risk of head injury translates to fatal injuries in motor vehicle crashes, the goal of this study is to examine the relative risk of severe injury or fatality caused by injuries to specific body systems.

II. METHODS

Data Sources

The Fatality Analysis Reporting System (FARS) dataset is a collection of all fatal crashes (with a fatality at most 30 days from the incident) in the United States since 1975. This dataset includes information ranging from the number, make and model of vehicles involved, to the number, age, sex, and seating position of all occupants, to the type of roadway and weather conditions when the crash occurred. While comprehensive of all fatal vehicle crashes in the United States, FARS lacks detailed information about the types of injuries sustained by vehicle occupants. In contrast, the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and Crash Investigation Sampling System (CISS) provide detailed information about specific injuries and their

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severities but contain a sample of both fatal and non-fatal crashes [11]. However, the NASS-CDS/CISS datasets are samples statistically selected for inclusion and are not comprehensive to all crashes nationwide.

It is possible to connect FARS data to a more detailed dataset based on common information [12]. Here, we link FARS to the Centers for Disease Control National Center for Health Statistics (NCHS) Multiple Cause of Death (MCOD) data. MCOD contains a detailed description of all individuals who die in the US each year, including age, sex, underlying cause of death, and a listing of nature of injury fields, or contributing factors.

Data Pre-Processing

Data were downloaded from the NHTSA FARS FTP directory, the NHTSA NASS-CDS FTP directory, and the CDC MCOD website. Data analyses were performed using Python v.3.7.7, with packages installed and managed using Anaconda v4.10.3 on MacOS 12.2.1. FARS files were downloaded and pre-processed as in [13].

MCOD data were scraped from the NCHS website. The MCOD data were filtered to only include fatalities due to motor vehicle crashes. For fatalities prior to 1999, the Underlying Cause of Death field used to select only cases with ICD-9 codes E810–E825 (see Appendix 1 for the specifics of these codes). For fatalities from 1999-2018, ICD-10 *V* codes V20-V59 (external causes of morbidity) were used to extract transportation-related causes of death (see Appendix 1) [12,14,15]. Where possible, occupant seating position was derived from the detailed ICD-9 and ICD-10 codes. For example, ICD-9 code *E810.1: Motor vehicle traffic accident involving collision with train injuring passenger in motor vehicle other than motorcycle* would be coded as *Passenger*, and ICD-10 code *V47.5: Car driver injured in collision with fixed or stationary object in traffic accident* would be coded as *Driver*.

NASS-CDS data from 1988-2015 and CISS data from 2017-2020 were downloaded from the NHTSA FTP directory manually. All female occupants were classified as “Female,” including those marked as pregnant.

Case Matching

FARS cases were matched to the detailed MCOD data through an iterative, multi-level process. FARS cases were first filtered to include only those individuals who died during the crash, and MCOD cases were filtered on primary underlying cause of death as described above. Matches were made using variables similar to those described in [12]. Occupant position was determined from ICD-9 or ICD-10 codes in the MCOD data for each occupant. Matches were extracted iteratively, using all unique combinations of a subset of the variables as detailed in Table I. For data years 1975-2004, all iterations include state, date of death, and sex.

TABLE I

VARIABLES USED FOR FARS-MCOD MATCHING BY YEAR. “BASELINE” INDICATES VARIABLE USED IN ALL COMBINATIONS DURING EACH ITERATION.

Years	Age	Sex	Date of Death	State	County	Occupant Seating Position	Injury at Work	Hispanic	Race
1975-1992	Yes	Baseline	Baseline	Baseline	Yes	Yes	No	No	No
1993-1998	Yes	Baseline	Baseline	Baseline	Yes	Yes	Yes	No	No
1999-2004	Yes	Baseline	Baseline	Baseline	Yes	Yes	Yes	Yes	No
2005-2018	Yes	Baseline	Baseline	No	No	Yes	Yes	Yes	Yes

Due to changes in the data contained in the FARS and MCOD data files, matching data from 2005-2018 was much coarser. MCOD removed state and county information from the public-use data files to prevent identification of a specific individual from the released data. Additionally, date of death was obfuscated to the month and day of the week of the individual’s death. As such, variables used for matching were modified by year as shown in Table I to maximize the likelihood of finding a unique match. The matching procedure was as follows:

1. Match on baseline date (state, date of death, sex)
2. Match on all combinations of baseline with one additional variable (see Table I)
3. Match on all combinations of baseline with two additional variables (see Table I)
4. Match on all combinations of baseline with *n* additional variables (where *n* is at most the number of possible variables in Table I)
5. Repeat steps 1-4 with FARS age + 1 year

6. Repeat steps 1-4 with FARS age – 1 year
7. Repeat steps 1-6 until no new matches found.

MCOD cases were classified by ICD-9 and ICD-10 code to determine the general body region of the most severe injury (see Appendix 2).

Double Pair Comparison Method: MCOD-FARS

A modified version of the double pair comparison method was utilised to determine relative risk ratios. This method is described in detail in [3,16,17]. Given

A = Number of female drivers killed in vehicles with a control occupant (also killed). (1)
B = Number of female drivers killed in vehicles with a control occupant (not killed). (2)
C = Number of control occupants killed in vehicles with a female driver (not killed). (3)
E = Number of male drivers killed in vehicles with a control occupant (also killed). (4)
F = Number of male drivers killed in vehicles with a control occupant (not killed). (5)
G = Number of control occupants killed in vehicles with a male driver (not killed). (6)

the relative risk ratio is given by:

$$R = \frac{{}^{A+B}/_{A+C}}{{}^{E+F}/_{E+G}} \tag{7}$$

As in [17], variance for the log of the relative risk ratio is given with:

$$\Delta R = \frac{\left[\left(A\times(A+B+C)+(B\times C)\right)\times(F+G)\right]+\left[\left(E\times(E+F+G)+(F\times G)\right)\times(B+C)\right]}{(A+B)\times(A+C)\times(E+F)\times(E+G)} \tag{8}$$

Weighted risk ratios ($\bar{R}$) and weighted estimates of variance ($\Delta\bar{R}$) are given by:

$$\bar{R} = \exp\left(\frac{\sum(\ln R \times 1/\Delta R)}{\sum 1/\Delta R}\right) \tag{9}$$

$$\Delta\bar{R} = \frac{1}{\sum 1/\Delta R} \tag{10}$$

Confidence intervals were determined using a bootstrap estimation method, sampling with replacement many times to calculate the relative risk and variance estimates. Ninety-five percent confidence intervals were taken between the 2.5 and 97.5 percentiles of the resulting distribution [17]. For all analyses, cases were selected with at least two occupants and with at least one fatality in the vehicle. Fatalities used for the comparison were those matched to the MCOD data only. Analyses were performed with no airbag deployment and with matched airbag deployment (cases where both the subject and the control occupant experienced the same airbag deployment at their seating position, i.e., deployment or no deployment. Cases with unknown airbag deployment were excluded. Fatality due in part to head injury or abdominal injury were both examined.

As *n* decreases with the granularity of comparison, age ranges were examined in five-year periods for subject occupants, while control occupants were grouped as in previous analyses: ages 16–24, 25–34, 35–54, and 55+ [4]. A control occupant is some passenger present in the vehicle alongside the "subject" – for example, when male or female belted drivers are the subject occupant, a control occupant could be a 16–24-year-old male passenger in the front right seat.

Double Pair Comparison Method: NASS-CDS and CISS

The double pair comparison was used as described above. Relative risk ratios were calculated for Abbreviated Injury Scale (AIS) level 2+, AIS-3+, and AIS-4+ head and abdominal injuries. AIS 2+ indicates a moderate injury, AIS3+ indicates a serious injury, and AIS4+ indicates severe injury [18]. Analyses were performed irrespective of airbag deployment, with and without seat belt use. Crashes reported in NASS-CDS and CISS can be either fatal or non-fatal. Fatality outcomes were not considered for these analyses, instead taking the specified injury as the outcome.

III. RESULTS

FARS-MCOD Matching

Due to differences in available data, the matching success rate for FARS-MCOD differed from 1975-2004 (81.97 ± 12.0%), and 2005-2018 (18.82 ± 1.6%), with an overall matching rate of 61.88 ± 31.1% (Fig. 1). Up to 10 injuries can be listed for each fatality in MCOD. When there are multiple listed, the first injury listed is considered the most severe. Besides *Other* injuries (not matching a specific body region), head injuries account for the largest proportion of fatalities, with 135,031 out of the 1,180,910 total matches (~11%) listing head injury in this initial field. Across all 10 injury fields, 321,104 fatalities were due to head injuries (~27%).

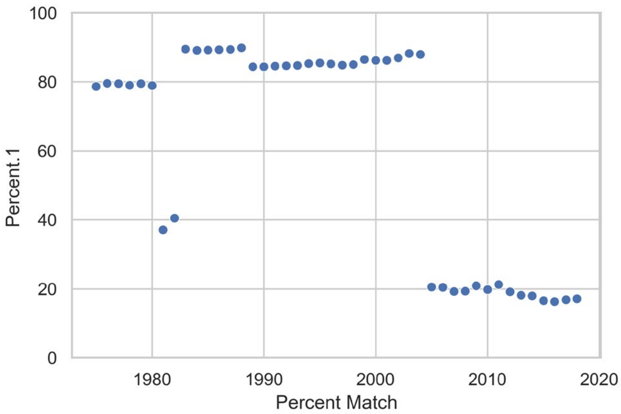

Fig. 1. Percentage of FARS cases successfully matched to MCOD fatality records by year. Matching rate drops in 2005 due to changes in MCOD public data reporting.

In fatal crashes without airbag deployment, females aged 20-40 were more likely to suffer fatal head injuries than males, as in Fig. 2, i.e., 20-25 year-old R=1.29, 95% CI [1.17, 1.42]; 30-35 year-old R=1.18, 95% CI [1.08, 1.34], and females aged 20-30 were more likely to suffer fatal abdominal injuries, as in Fig. 3 and Table II. Accounting for airbag deployment, ~23 year-old females were 30% more likely to suffer fatal head injuries in a crash compared to males (~20-25 year-old females, R=1.33, 95% CI [1.19, 1.53]) as in Fig. 4. Young females are similarly more likely to suffer fatal abdominal injury than young men under matched airbag deployment as in Fig. 5 and Table II.

TABLE II

FARS-MCOD RELATIVE RISK OF FATAL INJURY FOR FEMALE VS MALE OCCUPANTS, 1975-2019

Age	Injury Type	R [95% CI]	
		No Airbags	Matched Airbag
15-20	Head	1.31 [1.25, 1.38]	1.44 [1.34, 1.53]
20-25	Head	1.29 [1.17, 1.42]	1.33 [1.19, 1.53]
25-30	Head	1.19 [0.94, 1.43]	1.30 [1.17, 1.45]
30-35	Head	1.18 [1.08, 1.34]	0.82 [0.65, 1.19]
20-25	Abdomen	1.23 [1.03, 1.56]	1.36 [1.15, 1.69]
25-30	Abdomen	1.61 [1.34, 2.17]	1.39 [1.18, 1.78]

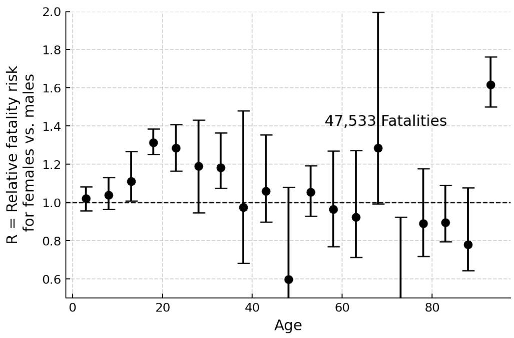

Fig. 2. Relative risk of fatal head injury, MCOD-FARS data, passenger car occupants with no airbag deployment, 1975-2018.

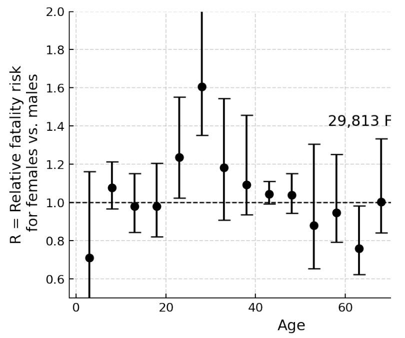

Fig. 3. Relative risk of fatal abdominal injury, MCOD-FARS data, passenger car occupants with no airbag deployment, 1975-2018.

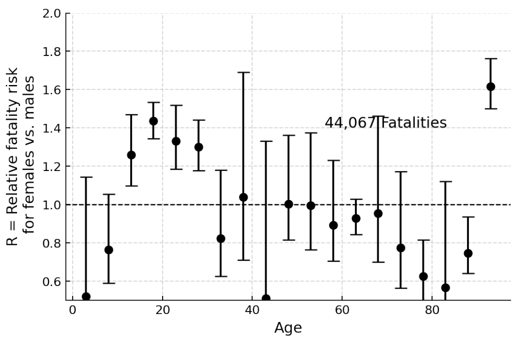

Fig. 4. Relative risk of fatal head injury, MCOD-FARS data, passenger car occupants with matched airbag deployment, 1975-2018.

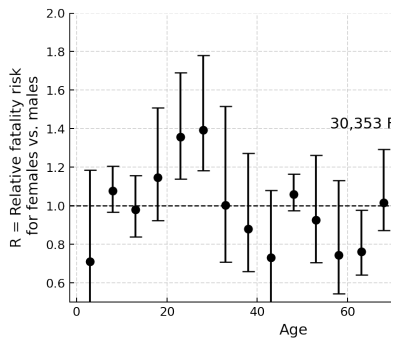

Fig. 5. Relative risk of fatal abdominal injury, MCOD-FARS data, passenger car occupants with matched airbag deployment, 1975-2018.

In the mixed non-fatal and fatal sample from NASS-CDS/CISS, young females (early twenties) are approximately 30% more likely to suffer AIS-2+ or AIS-3+ head injuries compared to males (~20-25 year-old females, AIS-3+ R=1.28, 95% CI [1.22, 1.51]) (Fig. 6 and Fig. 7). Further results for both abdominal and head injuries are reported in Table III.

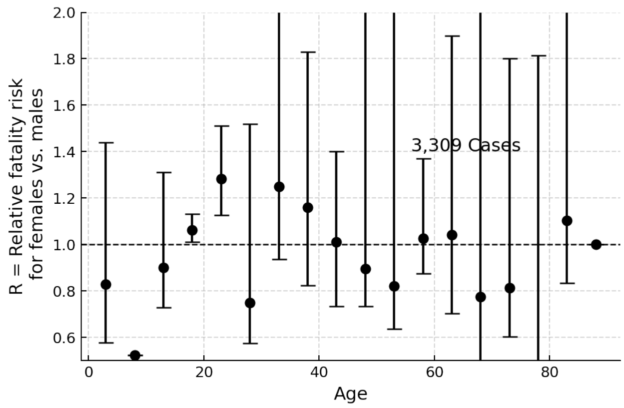

Fig. 6. Relative risk of AIS-3+ head injury, NASS-CDS/CISS, 1988-2015 and 2017-2020.

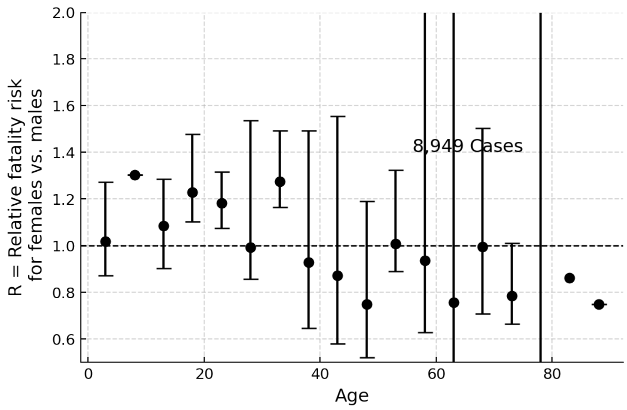

Fig. 7. Relative risk of AIS-2+ head injury, NASS-CDS/CISS, 1988-2015 and 2017-2020.

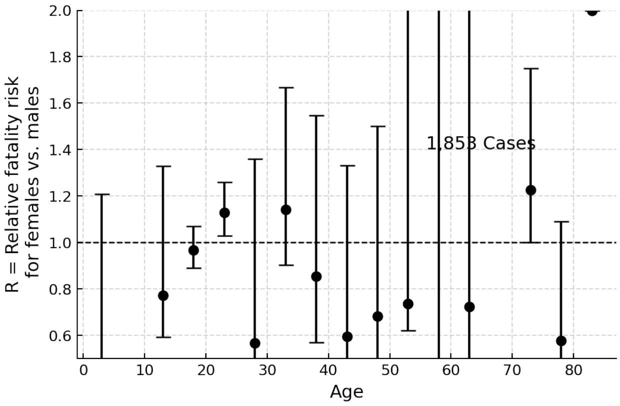

Fig. 8. Relative risk of AIS-4+ head injury, NASS-CDS/CISS 1988-2015 and 2017-2020.

There is likewise an increased risk of abdominal injury for young females. Notably, young females aged 20-25 are 50% more likely to sustain an AIS 3+ abdominal injury compared to males (R = 1.50, 95% CI [1.43, 1.58]). AIS 4+ injuries are not reported as there were insufficient samples to produce any meaningful results for abdominal injuries.

TABLE III

NASS-CDS/CISS RELATIVE RISK OF INJURY FOR FEMALE VS MALE OCCUPANTS, 1988-2015, 2017-2020

Age	**Injury Type**	**R [95% CI]**		
		AIS 2+	**AIS 3+**	**AIS 4+**
15-20	Head	1.23 [1.10, 1.48]	1.06 [1.01, 1.13]	0.97 [0.89, 1.07]
20-25	Head	1.18 [1.08, 1.32]	1.28 [1.12, 1.51]	1.13 [1.03, 1.26]
25-30	Head	0.99 [0.86, 1.54]	0.75 [0.57, 1.52]	0.57 [0.40, 1.36]
30-35	Head	1.27 [1.16, 1.47]	1.25 [0.94, 2.21]	1.14 [0.90, 1.67]
15-20	Abdomen	1.35 [1.21, 1.49]	1.27 [1.00, 1.66]	—
20-25	Abdomen	0.48 [0.27, 1.53]	1.50 [1.43, 1.58]	—
25-30	Abdomen	1.57 [1.36, 1.75]	1.31 [1.01, 1.97]	—
30-35	Abdomen	1.63 [1.24, 2.59]	1.17 [0.83, 2.10]	—

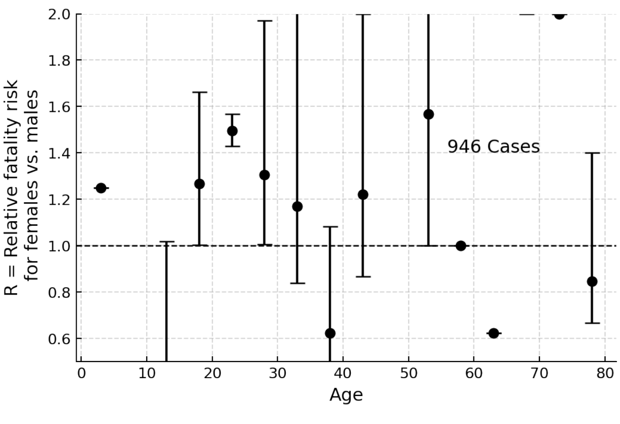

Fig. 9. Relative risk of AIS-3+ abdominal injury, NASS-CDS/CISS, 1988-2015 and 2017-2020.

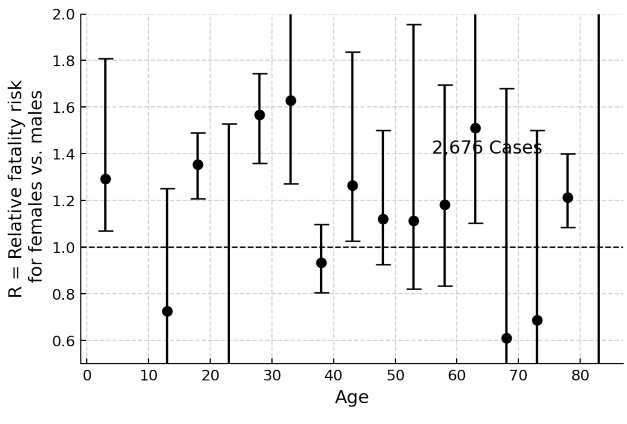

Fig. 10. Relative risk of AIS-2+ abdominal injury, NASS-CDS/CISS, 1988-2015 and 2017-2020.

IV. DISCUSSION

Previously, we and others have shown that in a fatal crash, a younger female occupant is approximately 20% more likely to suffer a fatal injury than a male occupant of the same age, regardless of seating position, airbag deployment, or seat-belt usage [3,4,13]. Also in previous work, we investigated several potential covariates that might explain these findings, including rural vs. urban crashes, vehicle mass differences by sex, drug and alcohol use by drivers, number of passengers, and number of vehicles involved [13]. The nature of the FARS dataset alone makes it difficult to delve deeper into the cause of this increased risk, since FARS lacks any meaningful injury details. This study provides insight into the potential sources of the female/male fatality risk difference by providing specific body system level injuries that contribute to these fatalities by using MCOD data linked with FARS, and separately examining NASS-CDS/CISS.

Brain/intracranial injuries are a leading cause of death in motor vehicle crashes, and motor vehicle crashes account for over 30% of traumatic brain injury-related deaths in the US [19,20]. In this study, we see a 20-30% increased risk of fatal head injury to young female vehicle occupants, overall accounting for 27% of the linked FARS-MCOD cases. For female occupants in their young twenties, we see an increased risk of AIS-2+, 3+, and 4+ head injury of 15-30% in fatal and non-fatal cases. Beyond the results reported here, female athletes have higher rates of brain injury in contact sports than males [9,10]. The consistency of the increased risk to young women compared to men for serious head injury suggests a biomechanical difference that demands further study.

This increased risk of both head and abdominal injuries (the two most common injury categories for motor vehicle crash related MCOD cases) for young females over young males is concerning. This disparity between men and women in automobile crashes is a major public health issue with implications for automobile design, personnel protection, and governmental regulation. Differences in the incidence of injuries to specific body regions suggests potential underlying physiological/anatomical differences. Current vehicle testing standards in the US primarily require the use of the 50th percentile Hybrid III (HIII) adult male ATD, with a few tests adding in the 5th percentile adult female as a passenger. Since the 5th percentile female ATD is primarily a dimensionally scaled version of the HIII male [21], the physiological and anatomical differences between the sexes may not be completely reproduced in testing methods. While the HIII ATD family has known limitations [22,23], and other ATDs exist that outperform HIII in some tests, the lack of an accurate 50th percentile female ATD is concerning. Only a small percentage of PMHS head/torso crash testing involves female specimens [7], potentially prohibiting the development of biofidelic female ATDs in the near future. While increasing the number of required crash tests using a female ATD would be a meaningful step forward in equitably addressing safety technologies, further work must be done to assess the biomechanical differences between males and females in crash scenarios.

V. Limitations

The publicly available data results in some inherent restrictions on the available analyses. Public reporting changes in 2005 significantly reduces the success rate when matching between FARS and MCOD, due to the removal of the state and county of death. This reduces the *n* of our analysis for 2005-2018, noticeably increasing the confidence bounds.

Additionally, the double pair comparison method struggles with cohorts of very small *n*. As the final calculation is a ratio of ratios, any subgrouping with either A+C, E+F or E+G equal to 0 is discarded to prevent a divide by zero error (Eq. 7). Given the relative size of NASS-CDS and CISS compared to FARS, there are more groupings that match this condition when breaking cases down by both body region and AIS. Unfortunately, there are insufficient cases with AIS 4+ and AIS 5+ across age groups for specific body region injuries to adequately calculate relative risk using the double pair method.

VI. Conclusions

Young female occupants are at increased risk of fatal and severe head and abdominal injuries in motor vehicle crashes. This increased risk is pronounced for young females in both fatal crashes and non-fatal crashes where the occupant sustained severe injuries. Along with previous research pointing to an increased overall fatality risk for young females in fatal crashes, these findings suggest a need to more carefully study biomechanical sex differences in car crashes.

VII. References

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VIII. APPENDIX 1: ICD-9 AND ICD-10 CODES INDICATING FATALITY DUE TO MOTOR VEHICLE CRASHES

ICD-9 Codes

E810 Motor vehicle traffic accident involving collision with train
E811 Motor vehicle traffic accident involving re-entrant collision with another motor vehicle
E812 Other motor vehicle traffic accident involving collision with motor vehicle
E813 Motor vehicle traffic accident involving collision with other vehicle
E814 Motor vehicle traffic accident involving collision with pedestrian
E815 Other motor vehicle traffic accident involving collision on the highway
E816 Motor vehicle traffic accident due to loss of control without collision on the highway
E817 Noncollision motor vehicle traffic accident while boarding or alighting
E818 Other noncollision motor vehicle traffic accident
E819 Motor vehicle traffic accident of unspecified nature
E820 Nontraffic accident involving motor-driven snow vehicle
E821 Nontraffic accident involving other off-road motor vehicle
E822 Other motor vehicle nontraffic accident involving collision with moving object
E823 Other motor vehicle nontraffic accident involving collision with stationary object
E824 Other motor vehicle nontraffic accident while boarding and alighting
E825 Other motor vehicle nontraffic accident of other and unspecified nature

ICD-10 Codes

V00-V09 Pedestrian injured in transport accident
V10-V19 Pedal cycle rider injured in transport accident
V20-V29 Motorcycle rider injured in transport accident
V30-V39 Occupant of three-wheeled motor vehicle injured in transport accident
V40-V49 Car occupant injured in transport accident
V50-V59 Occupant of pick-up truck or van injured in transport accident
V60-V69 Occupant of heavy transport vehicle injured in transport accident
V70-V79 Bus occupant injured in transport accident
V80-V89 Other land transport accidents
V90-V94 Water transport accidents
V95-V97 Air and space transport accidents
V98-V99 Other and unspecified transport accidents

IX. APPENDIX 2: FARS-MCOD BODY REGION DETERMINATION

ICD-9 and ICD-10 codes were used to extract the body region for each injury. Through 1998, MCOD utilised ICD-9 coding. From 1999 on, ICD-10 codes were used. Table SI shows the ICD codes and associated body region used for analysis. For ICD-10 codes, detailed codes including the word "superficial" were ignored.

TABLE SI
ICD CODES AND ASSOCIATED BODY REGIONS

ICD Code Range	Code Description	ICD Version	Body Region
800-804	Fracture of Skull	9	Head
850-854	Intracranial Injury, Excluding Those With Skull Fracture	9	Head
860-869	Internal Injury of Chest, Abdomen, and Pelvis	9	Abdomen, lower back, spine, and pelvis
805-809	Fracture of Spine And Trunk	9	Spine and Trunk
810-819	Fracture of Upper Limb	9	Upper Limb
820-829	Fracture of Lower Limb	9	Lower Limb
S00-S09	Injuries to the head	10	Head
S10-S19	Injuries to the neck	10	Neck
S20-S29	Injuries to the thorax	10	Spine and Trunk
S30-S39	Injuries to the abdomen, lower back, lumbar spine, pelvis and external genitals	10	Abdomen, lower back, spine and pelvis
S40-S49	Injuries to the shoulder and upper arm	10	Upper Limb
S50-S59	Injuries to the elbow and forearm	10	Upper Limb
S60-S69	Injuries to the wrist, hand and fingers	10	Upper Limb
S70-S79	Injuries to the hip and thigh	10	Lower Limb
S80-S89	Injuries to the knee and lower leg	10	Lower Limb
S90-S99	Injuries to the ankle and foot	10	Lower Limb

X. APPENDIX 3: DISTRIBUTIONS OF INJURIES

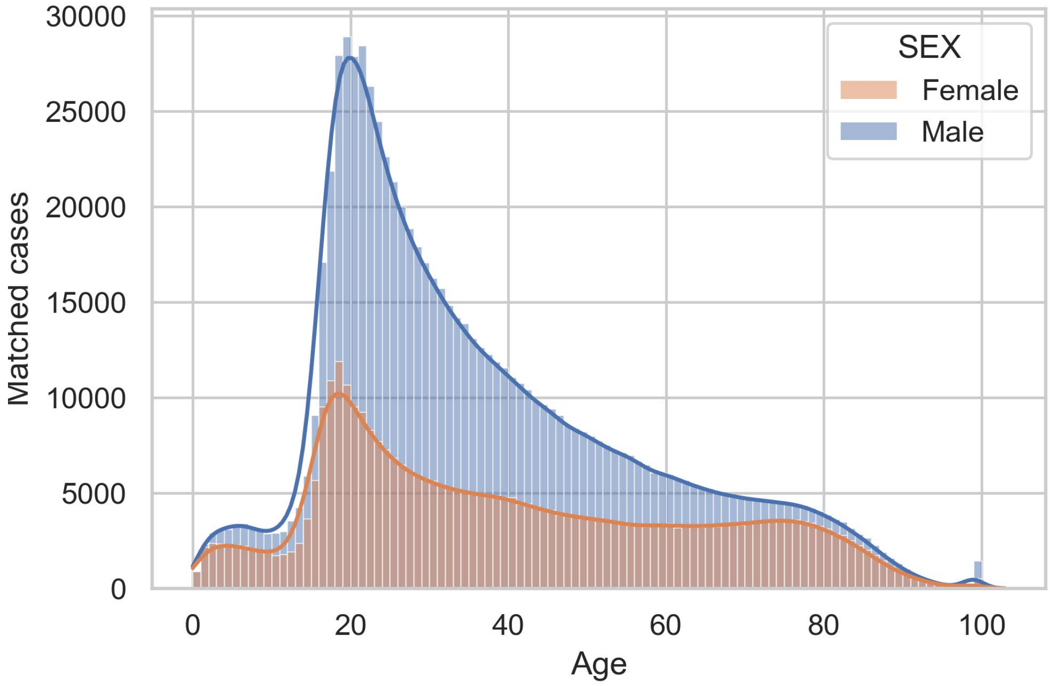

Fig. A1. Distribution of matched FARS-MCOD cases, by age and sex.

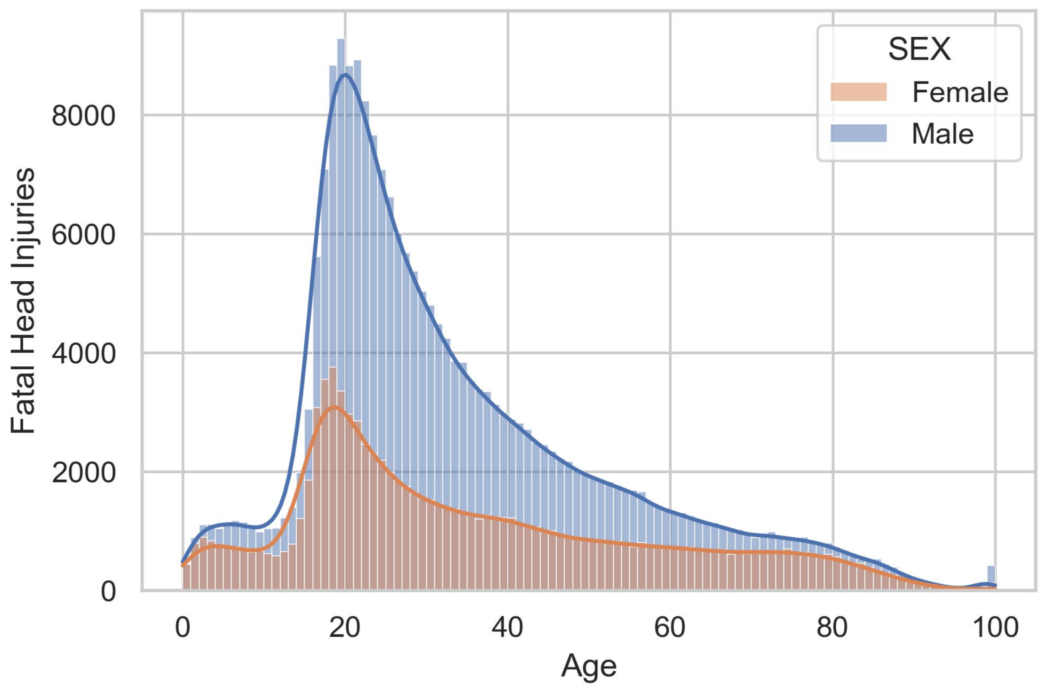

Fig. A2. Distribution of matched FARS-MCOD fatal head injuries, by age and sex.

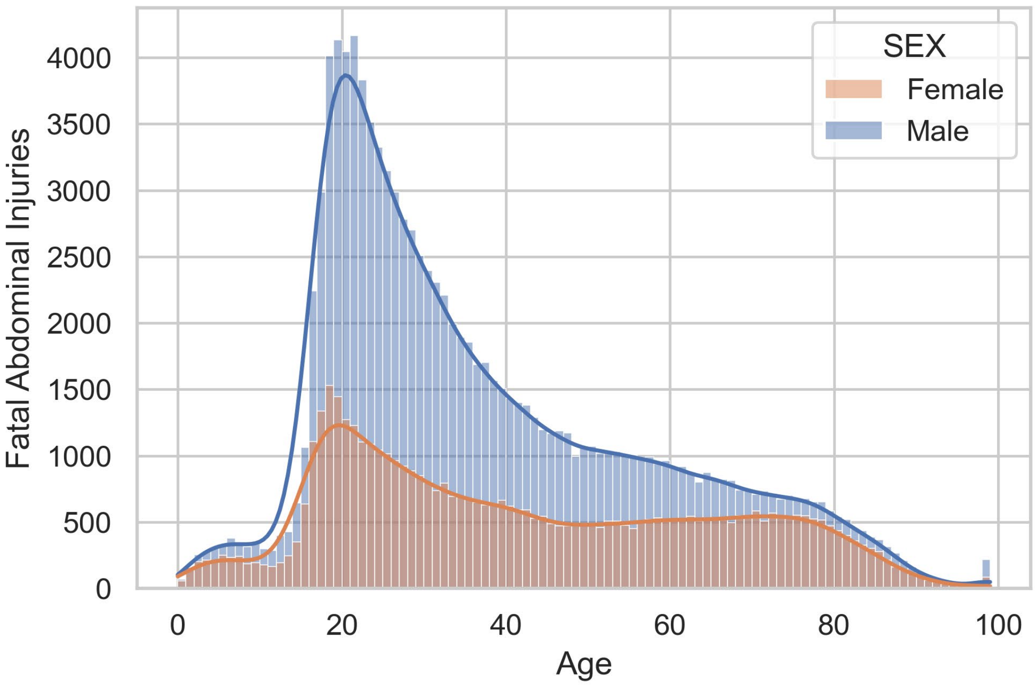

Fig. A3. Distribution of matched FARS-MCOD fatal abdominal injuries, by age and sex.