Sex-Based Differences in Odds of Motor Vehicle Crash Injury Outcomes

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AAAM 67th Annual Scientific Conference - October 3-6, 2023

Background & Study Aims

Background

- Forman et al. (2019), in studying belted front row occupants in frontal crashes from NASS-CDS, found females to be at 2.4-, 1.7-, and 3.8-times higher odds of sustaining AIS 2+, AIS 3+, and ankle injuries, respectively
- Brumbelow and Jermakian (2022), also using NASS-CDS, found females to be at significantly higher odds of MAIS 2+ injury (OR of 2.2) in frontal crashes but found a non-significant difference for MAIS 3+ (OR of 0.98)
  - Also studied side impacts and found no significant difference in odds of injury for females
  - Demonstrated that females experienced similar or greater improvements (i.e., reductions in injury odds/risk) with improved vehicle crashworthiness performance
- Noh et al. (2022) (*NHTSA FARS-based study*) found newer vehicles had significantly reduced relative fatality risk differences for females versus males (e.g., 2.9% higher relative risk for females for MY 2015 to 2020 vs. 18.3% for MY 1960 to 2009)

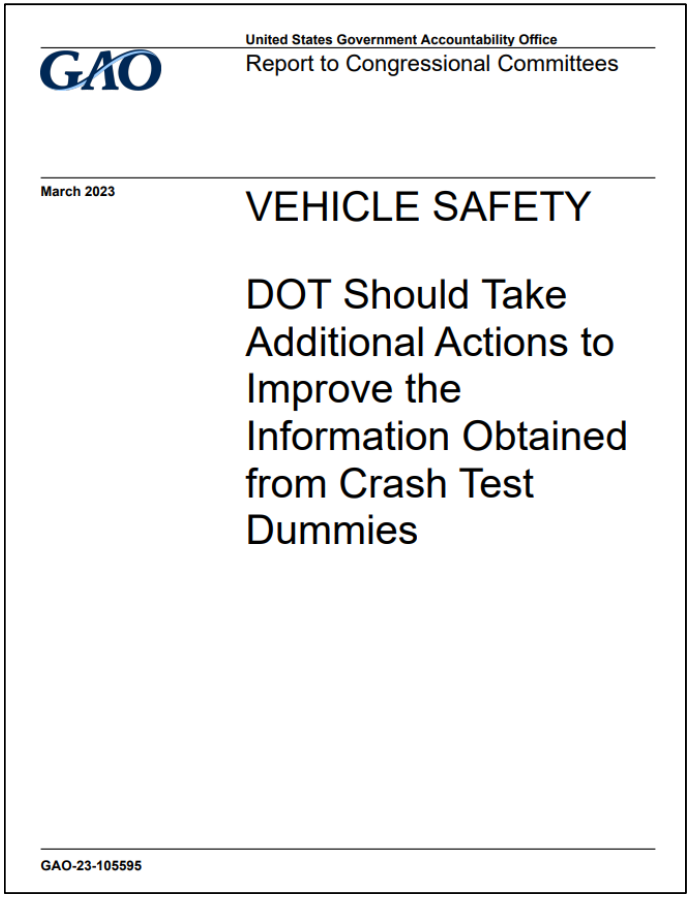
NASS-CDS = National Automotive Sampling System – Crashworthiness Sampling System

GAO Report on Dummies (2023)

Recommendation:

"The Administrator of NHTSA should develop and communicate a plan to address limitations in the information dummies provide related to the greater risks certain demographic groups face in vehicle crashes."

https://www.gao.gov/assets/gao-23-105595.pdf


United States Government Accountability Office

GAO

Report to Congressional Committees

March 2023

VEHICLE SAFETY

DOT Should Take Additional Actions to Improve the Information Obtained from Crash Test Dummies

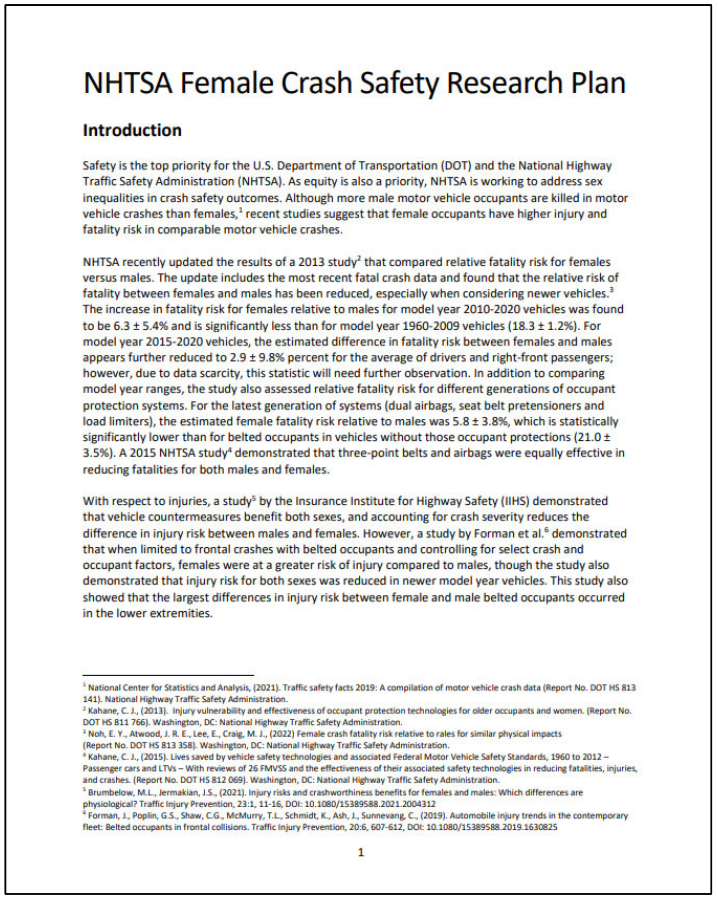
GAO-23-105595

NHTSA Female Crash Safety Research Plan (2022)

Summarizes our efforts in:

1. Field Data Analysis
2. Advanced Dummies & Experimental Biomechanics
3. Virtual Testing
4. Fleet Testing & Countermeasure Studies

https://www.regulations.gov/document/NHTSA-2022-0091-0002



NHTSA Female Crash Safety Research Plan

Introduction

Safety is the top priority for the U.S. Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA). As equity is also a priority, NHTSA is working to address sex inequalities in crash safety outcomes. Although more male motor vehicle occupants are killed in motor vehicle crashes than females,[1] recent studies suggest that female occupants have higher injury and fatality risk in comparable motor vehicle crashes.

NHTSA recently updated the results of a 2013 study[2] that compared relative fatality risk for females versus males. The update includes the most recent fatal crash data and found that the relative risk of fatality between females and males has been reduced, especially when considering newer vehicles.[3] The increase in fatality risk for females relative to males for model year 2010-2020 vehicles was found to be 6.3 ± 5.4% and is significantly less than for model year 1960-2009 vehicles (18.3 ± 1.2%). For model year 2015-2020 vehicles, the estimated difference in fatality risk between females and males appears further reduced to 2.9 ± 9.8% percent for the average of drivers and right-front passengers; however, due to data scarcity, this statistic will need further observation. In addition to comparing model year ranges, the study also assessed relative fatality risk for different generations of occupant protection systems. For the latest generation of systems (dual airbags, seat belt pretensioners and load limiters), the estimated female fatality risk relative to males was 5.8 ± 3.8%, which is statistically significantly lower than for belted occupants in vehicles without those occupant protections (21.0 ± 3.5%). A 2015 NHTSA study[4] demonstrated that three-point belts and airbags were equally effective in reducing fatalities for both males and females.

With respect to injuries, a study[5] by the Insurance Institute for Highway Safety (IIHS) demonstrated that vehicle countermeasures benefit both sexes, and accounting for crash severity reduces the difference in injury risk between males and females. However, a study by Forman et al.[6] demonstrated that when limited to frontal crashes with belted occupants and controlling for select crash and occupant factors, females were at a greater risk of injury compared to males, though the study also demonstrated that injury risk for both sexes was reduced in newer model year vehicles. This study also showed that the largest differences in injury risk between female and male belted occupants occurred in the lower extremities.

[1] National Center for Statistics and Analysis, (2021). Traffic safety facts 2019: A compilation of motor vehicle crash data (Report No. DOT HS 813 141). National Highway Traffic Safety Administration.
[2] Kahane, C. J., (2013). Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women. (Report No. DOT HS 811 766). Washington, DC: National Highway Traffic Safety Administration.
[3] Noh, E. Y., Atwood, J. R. E., Lee, E., Craig, M. J., (2022) Female crash fatality risk relative to rales for similar physical impacts (Report No. DOT HS 813 358). Washington, DC: National Highway Traffic Safety Administration.
[4] Kahane, C. J., (2015). Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger cars and LTVs – With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes. (Report No. DOT HS 812 069). Washington, DC: National Highway Traffic Safety Administration.
[5] Brumbelow, M.L., Jermakian, J.S., (2021). Injury risks and crashworthiness benefits for females and males: Which differences are physiological? Traffic Injury Prevention, 23:1, 11-16, DOI: 10.1080/15389588.2021.2004312
[6] Forman, J., Poplin, G.S., Shaw, C.G., McMurry, T.L., Schmidt, K., Ash, J., Sunnevang, C., (2019). Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions. Traffic injury Prevention, 20:6, 607-612, DOI: 10.1080/15389588.2019.1630825

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Aim of current study

- Prior studies, while exploring similar aims to ours, did not combine data from NASS-CDS and CISS and focused on a more limited sample of crash types, occupants, and restraint conditions, among other confounding factors/crash variables

- Aim of current study was to document the odds of various injury outcomes for females versus males while considering a broad range of passenger vehicle crash scenarios, pre-crash and crash variables, and occupant characteristics

CISS = Crash Investigation Sampling System

Methods

Study Phases

Phase I: Confirmed results from Forman et al. (2019)

- Observed higher injury odds for belted driver and right front passenger females for frontal crashes
- Evaluated different missing data approaches (i.e., imputation)

Phase II: Comprehensive approach that considered all crash types *(focus of AAAM study)*

- Selected and applied a single missing data approach
- Included all age 13+ passenger car/light vehicle occupants (e.g., restraint status, seating position, ejection)
- Expanded use of independent predictor variables (29 total vs. ~5 used in prior studies) for improved model fitting
- Combined NASS-CDS and CISS

FARS Relative Fatality Risk vs. NASS-CDS/CISS Injury Odds

	Prior Fatality Risk Study*	Current Injury Odds Study
Scope	• Fatalities • Front row occupants	• Injuries for various body regions and severities • All occupants
Data Source(s)	FARS 1975 to 2019	NASS-CDS & CISS 2000 to 2021
Analytic Approach	Double pair comparison	Multivariable logistic regression
Risk Metric	Relative risk	Odds ratio

* https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813358.pdf

Methods: *Outcomes & Crash Types*

	No.	Logistic Regression Model Elements
Injury Outcomes	25	MAIS 2+, 3+, 4+ and fatal; body region AIS 2+, 3+
Crash Type Models	6	*See Below*
Predictor Variable Sets	2	*See Following Slides*
Total Models	**300** *(25 x 6 x 2)*	

Modeled Crash Type Groupings:

- ***All Crashes***: Includes all crash types (frontal, side, rear, rollover, other) and belted or unbelted occupants in any seating position; occupants were age 13 and older in this and all other crash type models
- ***Frontal***: Belted drivers and right front passengers where frontal was most severe event; no rollover; limited to front row belted occupants to enable comparison to prior studies (e.g., Forman et al., 2019)
- ***Near-side***: 1st and 2nd row outboard occupants in a GAD1 = L or R crash where they are seated in a struck- or near-side position (same side as crash); no rollover; both belted and unbelted occupants
- ***Far-side***: Same as near-side, but targeting belted center- or belted outboard-seated occupants located opposite struck side of the vehicle
- ***Rear Impact***: Front row occupants involved in GAD1= (B, C, D) crashes; no rollover; both belted and unbelted occupants
- ***Rollover***: All cases that had any rollover; all occupants (belted and unbelted)

Methods: *Model Predictor Variables*

Two sets of variables considered:

1. Pre-crash/environment + crashworthiness
    - 29 total variables (7 pre-crash + 22 crashworthiness related)
2. Crashworthiness *only*
    - 9 occupant focused
    - 13 vehicle/crash focused

Methods: *Predictor Variables*

		Description	Missing %
Pre-crash / Environment	**Alcohol / Drug Use**	Documented presences of alcohol/drugs in system of case occupant	16.3%
	Avoidance Maneuver	Case vehicle pre-impact crash avoidance maneuver	0.0%
	Critical Event	Case vehicle recorded pre-crash event	0.0%
	Pre-impact Movement	Description of case vehicle's pre-impact movement	0.0%
	Weather	Documented weather conditions at time of crash	0.6%
	Lighting	Documented lighting conditions at time of crash	0.1%
	Rural/Urban	Crash location	0.0%
Crash - *Occupant*	**Sex**	Case occupant's documented sex	0.0%
	Seat Belt Use	Case occupant documented seat belt use	17.3%
	Ejection	Case occupant ejection	9.4%
	Entrapment	Case occupant entrapment	11.7%
	Seating Position	Designated seating position for case occupant	4.5%
	BMI	Case occupant's body mass index (BMI)	32.2%
	Belt Anchor	Documented shoulder belt adjustment position	19.2%
	Seat Track Position	Case occupant seat track position	20.8%
	Occupant Age	Case occupant's age in years	2.8%
Crash - *Vehicle*	**Crash Type**	Designated crash type by GAD and PDOF for most severe crash event	0.0%
	Manner of Collision	Generic description of crash scenario	2.3%
	Object Contacted	Partner vehicle/object that case vehicle interacted with as part of most severe event	4.4%
	Airbag Deployment	Airbag deployment at case occupant seating location	1.2%
	Intrusion	Any intrusion at occupant seating location	0.0%
	Multi-impact	Case vehicles experiencing more than one documented crash event	0.0%
	Vehicle Body Type	Case vehicle body type	0.0%
	Vehicle Vintage	Case vehicle MY 2009 and newer vs. 2008 and older.	0.0%
	Weight Ratio	Case vehicle weight divided by other vehicle weight.	10.6%
	Compatible Crash	Compatible: case and other vehicle weight within 1000 lbs	10.6%
	Delta V	Case vehicle change in velocity; most significant event	43.4%
	Vehicle Age	Case vehicle age at time of crash	0.0%
	Curb Weight	Case vehicle curb weight in kilograms	40.0%

Methods: *Imputation & Regression Modeling Steps*

- **Step 1**: Multiply impute missing data (Hot-Deck, Approximate Bayesian Bootstrap)
- **Step 2**: Fit injury outcome regression model using predictor variables, accounting for sampling error

Logistic Regression Models:

$$Logit(p) = \log\left(\frac{p}{1-p}\right) = \log(odds)$$

$$= \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k$$

- k is the number of independent variables; $X_1, \ldots, X_k$ are independent predictor variables; $\beta_0, \ldots, \beta_k$ are coefficient estimates

- **Step 3**: Drop insignificant predictor variables (p-value > 0.1) (*Sex* retained in all models)
- **Step 4**: Create 300 unique ***final*** models (e.g., MAIS 2+) applying only significant predictor variables (p-value ≤ 0.1) and document female vs. male injury odds ratios (ORs)

$$y_i = \begin{cases} 1 & if\ MAIS\ 2+ \\ 0 & otherwise \end{cases}$$

Results

Results: *Summary*

- *276 of 300* models had "good" model fit (c-statistic ≥ 0.7)
- Summary of female vs. male injury odds ratio (OR) results from the 300 multivariable logistic regression models:

Females at significantly* **lower** odds (OR<1.0) of injury: **43 of 300 models**
Females at significantly** **higher** odds (OR>1.0) of injury: **36 of 300 models**
Females at non-significantly** **lower** odds (OR<1.0) of injury: **114 of 300 models**
Females at non-significantly** **higher** odds (OR>1.0) of injury: **103 of 300 models**

Four models found *Sex* OR to be 1.00

**Statistically significant (p-value ≤ 0.05)*
***Not statistically significant (p-value > 0.05)*

Results*

- Each cell value is the result of a unique multivariable logistic regression model
- Value represents female vs. male injury odds ratio (OR) for the given crash type / injury outcome pairing
  - OR > 1.0 = higher odds of injury for females
  - OR < 1.0 = lower odds of injury for females

		All Crashes	Frontal	Near-Side	Far-Side	Rear	Rollover
	Total Cases	*79,209,449*	*29,292,444*	*8,909,067*	*7,732,107*	*4,918,052*	*6,476,503*
Whole Body	MAIS 2+	1.69	2.34	1.08	2.68	1.00	2.38
	MAIS 3+	1.17	1.51	1.30	1.02	0.49	1.66
	MAIS 4+	0.94	0.91	0.90	0.88	0.88	1.37
	Fatal Injury	0.86	0.95	1.09	0.43	0.42	1.02
Body Region AIS 2+	Head	1.10	1.63	0.77	0.75	1.09	1.13
	Neck & C-spine	0.74	0.90	0.69	0.71	0.38	0.36
	Thorax	0.52	0.54	0.53	0.70	0.32	0.75
	Abdomen	0.72	0.45	0.68	0.78	0.26	1.19
	Thoracolumbar	1.10	1.72	0.46	2.00	0.57	1.14
	Knee–Thigh–Hip	0.87	1.16	0.37	2.76	0.26	0.69
	Leg	0.80	1.38	1.73	0.07	9.27	1.19
	Foot & Ankle	2.01	5.00	1.26	6.18	2.40	2.87
	Upper Extremity	1.72	1.89	1.89	1.45	1.08	1.18
Body Region AIS 3+	Head	0.74	0.44	1.11	1.69	0.65	0.99
	Neck & C-spine	0.47	0.41	0.53	2.53	0.06	0.28
	Thorax	0.65	1.38	0.53	0.39	0.10	0.85
	Abdomen	0.73	0.62	0.72	0.34	0.94	1.59
	Thoracolumbar	1.26	1.45	0.37	4.40	0.27	0.58
	Knee–Thigh–Hip	0.86	0.94	0.78	0.19	6.89	0.50
	Leg	1.18	0.97	5.51	1.34	1.00	0.23
	Upper Extremity	1.28	1.36	2.43	10.20	0.01	0.89

Females significantly lower (p-value ≤ 0.05)

Females lower - not significant (p-value > 0.05)

Females higher - not significant (p-value > 0.05)

Females significantly higher (p-value ≤ 0.05)

* Model results shown are for ***Crashworthiness*** models

Results

- How to interpret results?
  - OR of 1.51 for **MAIS 3+** in **Frontal** crashes = “Belted front row seated females have a 51% higher odds of sustaining a MAIS 3+ injury in frontal crashes than males.”
  - OR of 0.44 for **Head AIS 3+** in **Frontal** crashes = “Belted front row seated females have a 56% lower odds of sustaining an AIS 3+ head injury in frontal crashes than males.”

		All Crashes	Frontal	Near-Side	Far-Side	Rear	Rollover
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Whole Body	MAIS 2+	1.69	2.34	1.08	2.68	1.00	2.38
	MAIS 3+	1.17	1.51	1.30	1.02	0.49	1.66
	MAIS 4+	0.94	0.91	0.90	0.88	0.88	1.37
	Fatal Injury	0.86	0.95	1.09	0.43	0.42	1.02
Body Region AIS 2+	Head	1.10	1.63	0.77	0.75	1.09	1.13
	Neck & C-spine	0.74	0.90	0.69	0.71	0.38	0.36
	Thorax	0.52	0.54	0.53	0.70	0.32	0.75
	Abdomen	0.72	0.45	0.68	0.78	0.26	1.19
	Thoracolumbar	1.10	1.72	0.46	2.00	0.57	1.14
	Knee–Thigh–Hip	0.87	1.16	0.37	2.76	0.26	0.69
	Leg	0.80	1.38	1.73	0.07	9.27	1.19
	Foot & Ankle	2.01	5.00	1.26	6.18	2.40	2.87
	Upper Extremity	1.72	1.89	1.89	1.45	1.08	1.18
Body Region AIS 3+	Head	0.74	0.44	1.11	1.69	0.65	0.99
	Neck & C-spine	0.47	0.41	0.53	2.53	0.06	0.28
	Thorax	0.65	1.38	0.53	0.39	0.10	0.85
	Abdomen	0.73	0.62	0.72	0.34	0.94	1.59
	Thoracolumbar	1.26	1.45	0.37	4.40	0.27	0.58
	Knee–Thigh–Hip	0.86	0.94	0.78	0.19	6.89	0.50
	Leg	1.18	0.97	5.51	1.34	1.00	0.23
	Upper Extremity	1.28	1.36	2.43	10.20	0.01	0.89

Results

- AIS 2+ non-extremity injuries, including neck, chest, and abdomen show generally lower odds for females
- Females showed higher odds for AIS 2+ extremity injuries
- Females showed generally lower odds of AIS 3+ injuries

		All Crashes	Frontal	Near-Side	Far-Side	Rear	Rollover
	Total Cases	*79,209,449*	*29,292,444*	*8,909,067*	*7,732,107*	*4,918,052*	*6,476,503*
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	Abdomen	0.72	0.45	0.68	0.78	0.26	1.19
	Thoracolumbar	1.10	1.72	0.46	2.00	0.57	1.14
	Knee–Thigh–Hip	0.87	1.16	0.37	2.76	0.26	0.69
	Leg	0.80	1.38	1.73	0.07	9.27	1.19
	Foot & Ankle	2.01	5.00	1.26	6.18	2.40	2.87
	Upper Extremity	1.72	1.89	1.89	1.45	1.08	1.18
Body Region AIS 3+	Head	0.74	0.44	1.11	1.69	0.65	0.99
	Neck & C-spine	0.47	0.41	0.53	2.53	0.06	0.28
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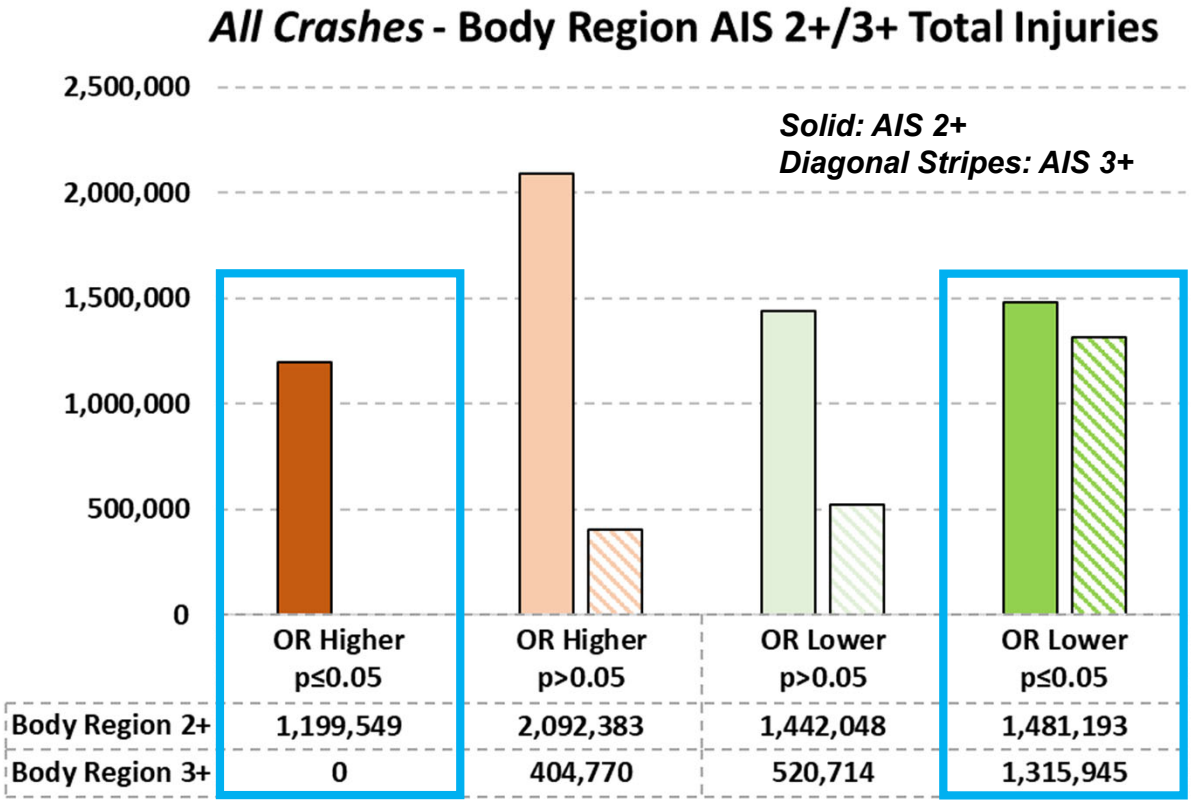
	Abdomen	0.73	0.62	0.72	0.34	0.94	1.59
	Thoracolumbar	1.26	1.45	0.37	4.40	0.27	0.58
	Knee–Thigh–Hip	0.86	0.94	0.78	0.19	6.89	0.50
	Leg	1.18	0.97	5.51	1.34	1.00	0.23
	Upper Extremity	1.28	1.36	2.43	10.20	0.01	0.89

Results

- Cell values represent total weighted injury count for the respective crash type model and injury outcome

		All Crashes	Frontal	Near-Side	Far-Side	Rear	Rollover
	Total Cases	*79,209,449*	*29,292,444*	*8,909,067*	*7,732,107*	*4,918,052*	*6,476,503*
Whole Body	MAIS 2+	5,194,296	1,589,713	603,599	281,661	180,510	872,777
	MAIS 3+	1,919,167	426,878	274,781	75,656	44,036	384,408
	MAIS 4+	737,206	107,635	127,772	30,057	16,644	187,020
	Fatal Injury	352,381	50,355	58,823	13,057	5,465	105,457
Body Region AIS 2+	Head	1,691,209	376,348	243,187	72,737	73,254	383,003
	Neck & C-spine	296,460	58,667	40,100	8,918	7,489	82,591
	Thorax	1,184,733	347,489	198,551	58,243	32,582	227,849
	Abdomen	402,301	87,572	78,712	18,759	9,759	76,757
	Thoracolumbar	401,174	115,198	40,252	21,972	18,138	117,101
	Knee–Thigh–Hip	767,924	209,330	121,669	74,019	11,526	85,206
	Leg	271,823	98,426	32,100	3,684	3,105	34,869
	Foot & Ankle	447,919	244,382	17,304	8,550	5,514	31,427
	Upper Extremity	751,630	340,250	49,357	34,247	10,454	104,681
Body Region AIS 3+	Head	449,104	63,311	79,855	16,422	9,380	109,736
	Neck & C-spine	123,449	20,787	16,667	2,963	3,254	37,546
	Thorax	743,392	153,536	140,918	39,590	14,937	167,572
	Abdomen	172,733	34,949	36,126	8,613	6,381	33,203
	Thoracolumbar	102,298	30,546	4,901	11,842	5,670	30,957
	Knee–Thigh–Hip	347,981	80,808	64,948	8,918	3,522	47,426
	Leg	112,801	45,478	13,098	925	333	11,892
	Upper Extremity	189,671	62,011	18,511	5,662	1,542	38,081

Results



- Total body region AIS 2+ and 3+ injury counts by sex-based OR outcomes
- Significantly higher to significantly lower odds of injury for females shown (left to right)

Female Injury ORs w/ and w/o Imputation

	All Crashes Models – Odds Ratios			
	Full		*Crashworthiness*	
	Imputed Sample	No Imputation	Imputed Sample	No Imputation
MAIS 2+	1.75*	1.80*	1.69*	1.70*
MAIS 3+	1.24*	1.17	1.17	1.11
Head - AIS 2+	1.11	1.20	1.10	1.22
Foot & Ankle - AIS 2+	1.66*	1.69	2.01*	1.68
Upper Extremity - AIS 2+	1.75*	1.79*	1.72*	1.78*
Thorax - AIS 3+	0.67*	0.63*	0.65*	0.55*

* p-value ≤ 0.05

- Studied influence of imputation on female vs. male injury odds ratios
- In general, similar results were found

Other Predictor Variable ORs w/ and w/o Imputation

			All Crashes Models - Odds Ratios	
Injury Model	**Predictor Variable**		**Imputed Sample**	**No Imputation**
MAIS 2+	Vehicle age		1.02*	1.01
Head AIS 2+	Crash Type	*Frontal impact*	0.51*	0.68
		Other	2.1	2.6
		Rollover	0.90	0.86
		Side impact	0.70	0.88
Thorax AIS 3+	Critical Event	*Control loss*	2.50*	3.00*
		Other vehicle in lane	1.32	1.22
		Run off road/turning into path	2.07	2.07
Foot & Ankle AIS 2+	Critical Event	*Control loss*	0.45	0.72
		Other vehicle in lane	0.14*	0.76
		Run off road/turning into path	0.33	1.49
Upper Extremity 2+	Crash Type	*Frontal impact*	5.35*	2.38
		Other	5.48*	3.72
		Rollover	2.98*	1.65
		Side impact	2.51	1.2

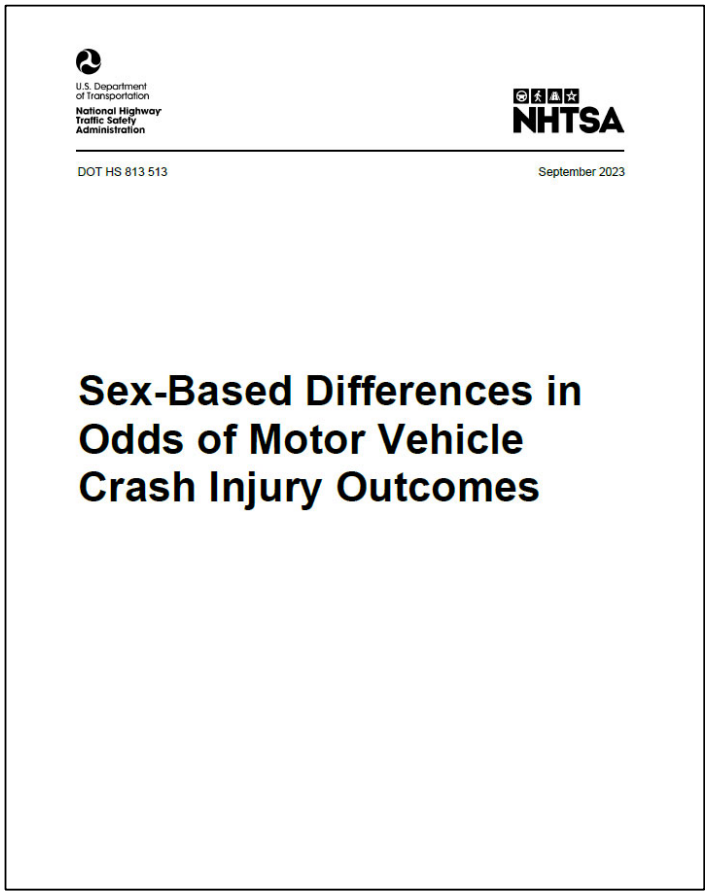
* p-value ≤ 0.05

- Studied influence of imputation on ORs for other predictor variables
- Imputation can change point estimate and increase statistical significance

Injury Odds – NHTSA Full Report

- In addition to AAAM, NHTSA recently published an expanded version of this study
- The main methods and findings are unchanged
- Full report contains additional details on model fit, variable selection, and predictor variable odds ratios as well as results of efforts to further explore the sensitivities of the sex-based injury ORs to changes in model predictor variables

  https://rosap.ntl.bts.gov/view/dot/70069



Limitations

Limitations

- High missing data rates in NASS-CDS and CISS
- Absent imputation, if following a complete case approach, we would drop more than 70% of cases due to missing data (delta V was most frequently missing at 43.4%)
- Smaller sample size for some crash/injury models (e.g., *lower extremities in rear impacts*) may have contributed to fewer significant sex-based injury odds findings than for models with higher case counts (e.g., *MAIS 2+ injuries in Frontal Crashes*)
- The AIS version used across the sample varied, which can result in biased findings when comparing newer and older case data; however, this should affect females and males equally in current study
- Post-crash factors were not considered in this study (e.g., differences in emergency response, decisions on transport, or treatment that may not be evenly distributed between females and males)
- The current study did not evaluate causes or recommend countermeasures for how to address differences in injury odds between females and males

Conclusions

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- This study provides the most comprehensive summary to date of the odds of motor vehicle crash injury outcomes for females versus males
- Results show that it is not accurate to broadly state that one sex has higher motor vehicle crash-related injury risks than the other
- Injury odds for females vs. males depend on injury type and severity, crash characteristics, and various other confounding factors
- Some injury types and associated crash scenarios require further investigation to address higher injury odds for females versus males (e.g., lower extremity injuries in frontal crashes)

Thank you!

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