Equitable Occupant Protection: Underlying Causes of Injury Risk Differences by Sex in Road Crashes

Guorong Li, Peng Wang, Carol Flannagan, Nils Lubbe

Abstract Female occupants are observed to be at higher risk in road crashes. The causes can be either physiological or non-physiological, as occupants of different sexes have distinct physiological characteristics and are exposed to various hazardous situations on the road. This study investigates the underlying causes of injury risk differences by sex, based on the China In-depth Accident Study (CIDAS). The findings indicate that female occupants have a higher injury risk than males, particularly for MAIS1+ injuries in frontal and side impacts. Seating position was identified as the primary confounder, with a higher proportion of females occupying the front passenger seats, which are associated with higher injury risks. According to results of multivariate logistic regression models, sex itself did not significantly affect injury risk at any severity after controlling for seating position and other influencing factors. Compared with drivers, front passengers have around twice the odds of being injured in frontal impacts (MAIS1+ and MAIS2+) and six times the odds in far-side impacts (MAIS1+).

Keywords Confounder identification, crash data analysis, front passenger seat, injury severity, sex difference.

I. INTRODUCTION

Equitable occupant protection has become a critical focus in protective safety, with the aim of providing equal protection to diverse occupants regarding sex, age, stature, and size. Sex is given high priority among these diversity aspects. Existing regulatory frameworks and safety assessment protocols have historically prioritised male occupant profiles due to higher absolute numbers of injuries and fatalities derived from males' greater exposure in road transportation systems. However, female occupants typically exhibit higher injury risk ratios despite lower exposure compared to males [1]. Furthermore, the exposure of female occupants has increased substantially in recent decades, amplifying their vulnerability within current safety standards. This discrepancy highlights the need to re-evaluate occupant protection standards from an equity perspective to address the systemic biases.

To enhance protection of a diverse population, the United Nations Economic Commission for Europe (UNECE) established an ad-hoc working group on equitable occupant protection [2]. New Car Assessment Programmes (NCAPs), such as Euro NCAP and C-NCAP, are exploring the potential of virtual testing to evaluate protection performance for diverse occupants [3]. Analysing injury risk differences by sex is essential to achieve that goal. Finite element (FE) simulations and field data analysis are commonly used for these comparisons. Simulation studies provide detailed insights into the loads of specific body parts during a crash, offering a high-resolution comparison from a biomechanical perspective [4]. In contrast, field data (e.g. in-depth crash data, insurance data) offer insights into factors contributing to equity issues beyond physiological differences, providing a comprehensive picture of the equity issues in real-world crashes [5].

Field data have been used to investigate equity issues in several countries. The Insurance Institute for Highway Safety (IIHS) in the US, using data from the National Automotive Sampling System –

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Crashworthiness Data System (NASS-CDS), found that females may require additional protection against extremity injuries [5]. The high extremity injury risk of female occupants was also identified by a study from the National Highway Traffic Safety Administration (NHTSA) [6]. The German Insurers Accident Research (UDV) investigated their insurers' accident database (UBD) and identified a non-significant higher risk for female occupants in frontal impacts [7]. The Transport Research Laboratory (TRL) in the UK, using data from Road Accident In-Depth Studies (RAIDS), found that age significantly affects overall injury risk in both frontal and side impacts, while sex significantly affects overall injury risk only in side impacts [8]. Females experienced a significantly higher risk of lower extremity injuries than males in both frontal and side impacts.

To clearly understand the causation of equity issues, it is beneficial to start by investigating any substantial confounding factors between sex and injury outcomes [1]. Unfortunately, most studies did not thoroughly review potential confounders before conducting comparative analyses, which poses a high risk of misleading conclusions. To avoid this risk, this study attempts to start with confounder identification by developing univariate models among sex, injury severity, and possible confounders. The overall influence of injury risk by sex and confounders is discussed through multivariate models.

II. METHODS

Data Selection

This study primarily leverages the crash data from the China In-depth Accident Study (CIDAS), which has been conducting on-site investigation of road crashes since 2011, to understand vehicle damage and personal injury mechanisms. To ensure the representativeness of the data, the investigation sites were established in ten cities across different geographic regions, featuring diverse terrain conditions, road environments, and economic levels. Only crashes involving at least one four-wheel motorised vehicle and one injured (any severity level) person are included in the database. There are a total of 10,031 crashes included in the latest released version (September 2024).

The focus of this study was belted occupants in passenger cars that did not collide with vulnerable road users (VRUs). Occupants with unknown sex were excluded. To ensure the cases in the dataset are more comparable, additional exclusions were applied regarding crash complexity, occupant comparability, and information completeness. A total of 1,032 occupants were selected for descriptive statistical analysis, and 917 were kept for modelling, mainly excluding data with unknown vehicle or occupant information. The complete data-selection process is detailed in the appendix (Table AI).

Information regarding crashes, vehicles, and occupants was covered in this study. Impact type and closing velocity were selected from the worst injury event. Impact type was defined by the Principal Direction of Force (PDOF), coded according to the clock directions from 1 to 12, and the damage location of the vehicle. The impact type is frontal if PDOF is 11, 12 or 1; side if PDOF is 2, 3, 4, 8, 9 or 10; and rear if PDOF is 5, 6 or 7. However, the impact type will be classified as 'other' if the PDOF and the damage location were inconsistent (e.g. a frontal PDOF with side damage). We calculated the closing velocity by collision velocities and the collision angle between the vehicle and the opponent. The collision velocity in CIDAS was from reconstruction for reconstructed cases. Otherwise, the CIDAS team estimated the velocities based on surveillance videos, tire marks, vehicle deformation, or directly extracted from the police report. Of 1,032 data records, 56% were reconstructed.

Host and opponent vehicles were classified into sedan, light truck and van (LTV), and heavy vehicle (HV) based on vehicle compatibility [9]. LTV includes pick-up trucks, vans, SUVs, and off-road vehicles, while HV includes buses and heavy goods vehicles. The registration years of vehicles were classified into two subgroups: 2012 (median) and earlier; and newer than 2012. Other available vehicle details included curb weight and damage location, which were extracted from case photos taken during on-site investigations or inspections of towed vehicles. Front damage locations were classified into right, middle, and left of the vehicle front, side damage locations were classified into area between A and C pillar, and the rest of the vehicle side (i.e. areas before A pillar and after C pillar).

Available occupant information included sex, age, height, weight, seating position (i.e. driver seat, front passenger seat, rear passenger seat), and injury severity. Injury severity was measured using the Abbreviated Injury Scale (AIS).

Confounder Identification

To understand the underlying causes of injury risk differences by sex, it is crucial to identify confounders that affect both sex and injury risk. We established univariate logistic regression models for both sex and injury severity (i.e. MAIS1+, MAIS2+, MAIS3+, respectively) with potential confounder, as shown in Fig. 1. Factor X_i showing significant relationships with both sex and injury risk was identified as a confounder. In this study, confounder identification (CI) models were established for frontal impact, near-side impact, and far-side impact. Rear impact models were excluded due to the lack of significance in most factors. Side impacts were divided into near-side and far-side models to avoid potential bias caused by different injury mechanisms. A total of 132 CI models were created for checking 11 potential confounders.

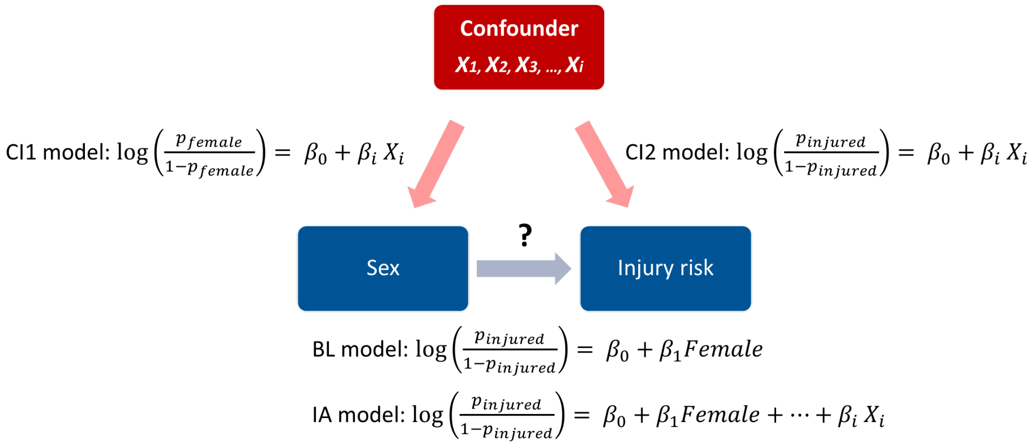


Fig. 1. Relationships among sex, injury risk, confounders, and the models developed.
CI refers to confounder identification; BL refers to baseline; IA refers to impact assessment.

Impact Assessment of Sex and Confounders

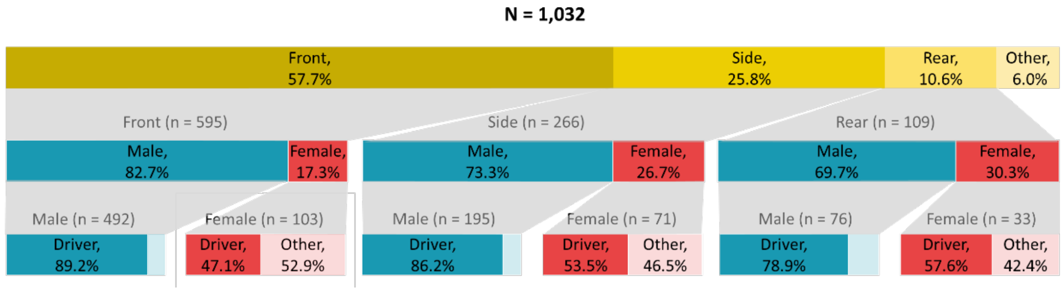
Nine multivariate logistic regression models were developed to estimate the impact of sex on injury risk, considering three types of impact and three levels of injury severity for each type. The identified confounders and other factors influencing injury risk were included in the impact assessment (IA) models. Factors showing a p-value greater than 0.05 across all impact types and injury severities were excluded according to CI model results. To compare the odds ratios of sex with and without controlling for other factors, we also created a baseline (BL) univariate model for each IA model, with injury severity as the dependent variable and sex as the independent variable, as shown in Fig. 1.

All statistical analysis and modelling work were performed using R 4.4.1 [10].

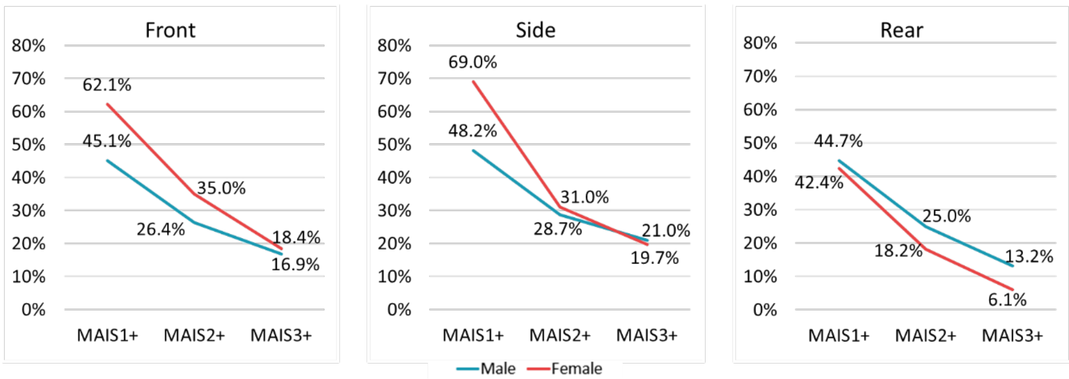
III. RESULTS

Descriptive Statistics of CIDAS Data

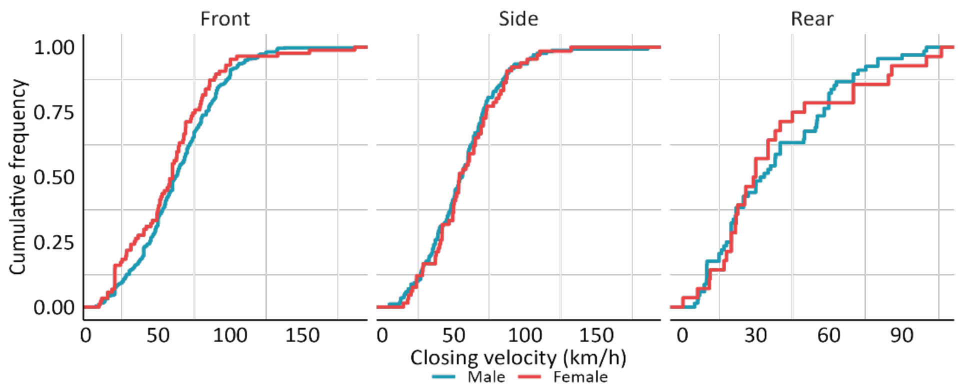
This section provides a preliminary understanding of the selected CIDAS data and sex distributions from various perspectives. Figure 2 illustrates the distributions of male and female occupants by impact types. Among the 1,032 selected occupants, more than half of the occupants were subjected to frontal impacts (57.7%), followed by side impacts (25.8%), and rear impacts (10.6%), as shown in Fig. 2(a). Male occupants accounted for the largest share across all impact types, particularly in frontal impacts (82.7%). Additionally, males were more frequently seated in driver seats compared to females. Fig. 2(b) indicates that higher percentages of female occupants were injured in frontal and side impacts. In frontal crashes, the percentage of injured females is 17% higher than that of males, and 8.6% higher for MAIS2+ injuries. In side impacts, females were injured 20.8% more often than males, and 2.3% higher for MAIS2+ injuries. In contrast, rear impact showed an opposite relationship between male and female occupants compared to frontal and side impacts, with males being 7.1% more seriously injured (i.e. MAIS3+) than females. To understand the causes of observed injury risk differences, we first investigated distributions of closing velocity, which is one of the most relevant crash severity indicators, as shown in Fig. 2(c). The distributions of closing velocity for females are quite similar to those for males, especially in side impact. Female occupants exhibited slightly lower closing velocities close to the 25th and 75th percentiles in frontal impact, as well as lower closing velocities close to the 75th percentile in rear impacts.



(a) Percentages of sex and seating postion.



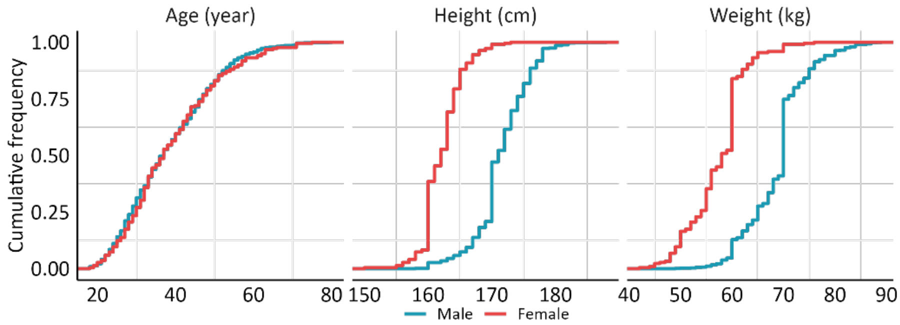
(b) Injured percentages of different severity level.



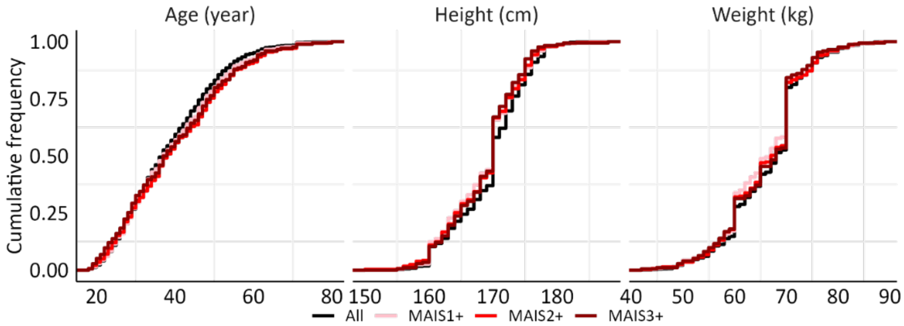
(c) Cumulative distribution of closing velocity.

Fig. 2. Distributions of male and female occupants by impact types.

Considering the potential impact of physiological differences, we compared the age, height, and weight distributions of occupants by sex and injury severity, as shown in Fig. 3. All refers to all occupants exposed to the crashes, including the uninjured occupants. The age distributions look quite similar for males and females. Meanwhile, for age distributions of all exposed occupants and injured occupants, slight deviations are observed starting from approximately 40 years old, indicating that more elder occupants were injured. Although substantial gaps of height and weight are observed between males and females, the distributions by injury severity are close to each other. Compared with all exposed occupants, injured occupants tend to have slightly smaller size. Vehicle characteristics are also critical factors influencing injury risks.

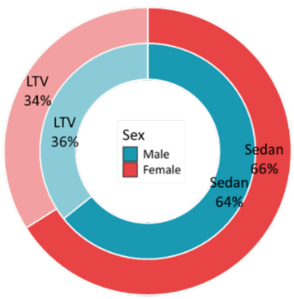


(a) Cumulative frequency by sex.

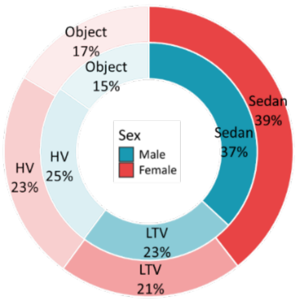


(b) Cumulative frequency by injury severity.

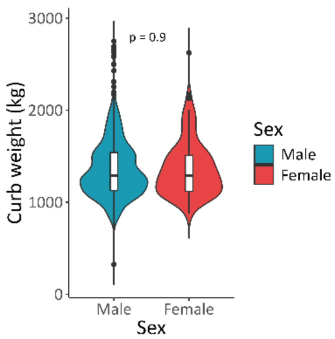
Fig. 3. Cumulative distributions of age and body size of occupants.



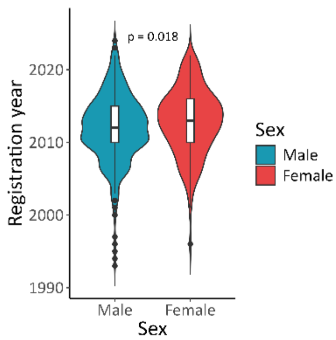
(a) Type of host vehicle.



(b) Type of opponent.



(c) Curb weight of host vehicle.

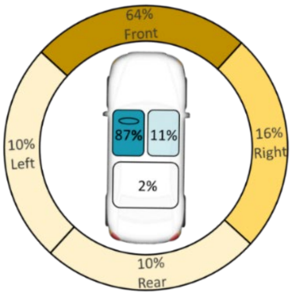


(d) Registration year of host vehicle.

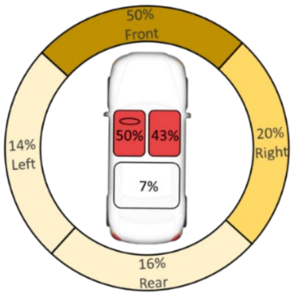
Fig. 4. Vehicle characteristics of male (n=814) and female (n=218) occupants.

In Fig. 4, the distributions of host vehicle type and opponent vehicle type are quite similar for male and female occupants, as well as that of curb weight and registration year of the vehicle. Female occupants were 2% more frequently in the sedan group for both host and opponent vehicle types. According to the T-test, host vehicles occupied by females were insignificantly lighter (5kg; p=0.9), but one year newer (p=0.018).

Since the effects of impact type and seating position interact with respect to injury risk to occupants, visualising distributions of impact directions and seating positions for male and female occupants together could offer more insights. As shown in Fig. 5, frontal impact is the most frequent impact type, followed by right, rear, and left. Male occupants are more frequently involved in frontal impacts (64%) compared to female occupants (50%). A near-side impact (i.e. left-side impact for the driver or right-side impact for the front passenger) is generally considered to have a higher injury risk than a far-side impact [11]. It is observed that females are more frequently exposed to near-side impacts as front passengers. We calculated the product of the percentages of impact direction and seating position to measure the occupant exposure in specific crash scenarios. Specifically, the exposure of female occupants is 4.89 times the exposure of male occupants in near-side impacts while seated in front passenger seats. The exposure of female occupants is even higher in rear impacts as rear passengers, being 5.6 times of male occupants. However, it is noteworthy that males account for only 2% of rear passengers while females account for 7%.



(a) Male, n=814.



(b) Female, n=218.

Fig. 5. Distribution of impact type and seating positions by sex.

Confounder Identification: Univariate Logistic Regression Model

Table I presents the odds ratios and significance levels of the possible confounders for all univariate models. The sample sizes for frontal impact, near-side impact, and far-side impact are 531, 109, and 127, respectively. For all modelled impact types, seating position significantly influences both sex and injury risk ($p \leq 0.01$), particularly for MAIS1+ and MAIS2+ injuries. Compared to driver seats, the odds of a female being in the front passenger seats are over six times higher for all impact types. The odds of sustaining MAIS1+ injury in front passenger seats are 2.869, 4.270, and 6.692 times as high as those in the driver seat for frontal, near-side, and far-side impact, respectively. For MAIS2+ injuries during frontal impacts, the odds of injury in the front passenger seats are 2.467 times ($p \leq 0.001$) as high as those in the driver seats.

Height and weight show significant odds ratios ($p \leq 0.001$) in all sex models, consistent with the trends in Fig. 3. Height, as the only indicator, shows significant relationship with injury risk in frontal ($p \leq 0.01$), near-side ($p \leq 0.05$), and far-side impacts ($p \leq 0.05$). In frontal impacts, the odds of being injured decrease by 4.6% for MAIS1+, by 4.9% for MAIS2+, and by 6.4% for MAIS3+ with each 1 cm increase in occupant height. For near-side impacts and far-side impacts the odds decrease by 6.8% and 7.1%, respectively. No other significant odds ratios were found in the sex models, indicating that the remaining possible confounders did not significantly affect sex distributions.

In this section, seating position and height were identified as confounders of injury risk by sex according to the univariate models. A comprehensive impact assessment using multivariate logistic regression models is presented in the following section.

Impact Assessment: Multivariate Logistic Regression Model

Table II presents the results of sex and confounders (i.e. seating position and height) in the multivariate models across impact types and injury severities. The full results of the multivariate models are available in the Appendix. The multivariate models include all independent variables except for weight and host type, as they did not show significance in any models. To compare with the observed injury risk difference by sex without controlling for other factors, we also list the results of the baseline univariate model (i.e. sex as the only predictor of injury risk) in Table II. Among these baseline models, regardless of significance, most odds ratios for sex are greater than 1 (i.e. more females were injured compared to males), except for the far-side MAIS3+ model. All MAIS1+ models show p-values for sex lower than 0.1. The odds ratios for sex are 1.602 ($p \le 0.05$), 2.175 ($p \le 0.1$), and 2.462 ($p \le 0.05$) for frontal, near-side, and far-side impacts, respectively, indicating that female occupants experience approximately twice as many injuries as males.

In frontal impact multivariate models the odds ratios for sex were 1.129, 0.851, and 0.591 for MAIS1+, MAIS2+ and MAIS3+ injuries, respectively. Compared to the baseline models, the values decreased and were not significant after controlling for other factors. Seating position maintained a significant effect on MAIS1+ and MAIS2+ injuries, with odds ratios of 2.273 ($p \le 0.01$) for the MAIS1+ model and 1.937 ($p \le 0.05$) for the MAIS2+ model. This indicates a strong correlation between front passenger seats and higher injury risks under similar crash configurations. Furthermore, height showed a significant negative correlation (OR = 0.916, $p \le 0.01$) with MAIS3+ injuries, regardless of sex.

In near-side and far-side multivariate models, the odds of female occupants being injured were still 2.080 and 2.754 times the odds of males after controlling for other influencing factors, though these differences were not statistically significant. Similarly, for seating position the odds ratios were above 1.5 in all side impact models but were generally not significant. However, in the far-side MAIS1+ model the odds ratio was significantly high at 5.806 ($p \le 0.05$). Height was not significantly related to injury risk at any level in side impacts.

IV. DISCUSSION

Identified Causes of Injury Risk Differences by Sex

This study found that female occupants sustained more MAIS1+ and MAIS2+ injuries than male occupants. It is difficult to draw concrete conclusions for MAIS3+ injured occupants considering the small sample size we have. Among the potential confounders extracted from in-depth crash data, the injury risk differences are primarily due to non-physiological factors (i.e. seating position) rather than physiological ones (i.e. height, weight, age). Similarly, a study from the US indicated that considerable injury risk discrepancies between sexes could be attributed to differences in vehicles and crashes [5]. Among physiological factors, the age distributions of males and females in our crash data are quite similar, although we acknowledge that higher age could increase injury risk to some extent. On the other side, limited impact of height and weight on injury risk was identified, despite substantial differences in size and stature between males and females.

Among non-physiological factors, vehicle size was found to be a primary influencing factor of higher injury risk for females in the US and Europe, where females were travelling in small, light cars more often than males [1][5][12]. However, we did not observe similar phenomena in China, where the vehicle type distribution is quite similar for males and females. Distributions of the registration year of the vehicles are also quite similar for male and female occupants, indicating that it was not a main cause of the existing injury risk differences. An interesting finding was that female occupants were 4.89 times as likely to be exposed to right-side impact as front passengers (i.e. near-side impact) compared to male occupants. This is because a higher percentage of females sit in front passenger seats and are more often involved in right-side crashes. There are two main reasons for observing fewer female drivers: first, fewer female drivers were registered in China (34% until 2021) [13]; and second, even when females hold a driving license, they tend to drive less than males [14]. On the other hand, front passenger seats were found to have significantly higher injury risks in frontal and side crashes compared with driver seats, consistent with findings from previous studies in Germany and the US [6-7]. This makes seating position a primary confounder that affects both sex and injury risk.

After confounding control through multivariate regressions, the effects of these confounders were isolated from sex. The sex-injury association diminished after adjustment, as did the effect of height. However, seating position remained a significant factor in injury risk. Under similar prerequisites, the probabilities of sustaining MAIS1+ and MAIS2+ injuries in the front passenger seat were approximately twice as high as in the driver seat during frontal impacts. For far-side impacts, the probability of sustaining a MAIS1+ injury in the front passenger seat was nearly six times as high as in the driver seat.

Injury Risk Differences by Seating Position

The injury risk differences by seating position could be attributed to several aspects. Regarding the significantly different injury risks between driver seats and front passenger seats in side impacts, a suspicion is that passenger cars in the fleet may have stronger structural integrity on the driver side compared to the passenger side. Vehicle manufacturers primarily optimise vehicle structures according to regulatory and rating requirements (e.g. NCAP tests), which is called “teaching to the test” and is an open secret in the automotive industry [15]. Back in 2012, when the IIHS introduced the small-overlap test, some auto-makers enhanced vehicle structures and airbags on the driver side of the vehicle, where the test was focused. However, similar improvements were not made to the passenger side until 2017, when the test was introduced also for the passenger side. Similarly, C-NCAP did not test the passenger side of vehicles in side crash tests until 2021 [16], and over 90% of the passenger cars involved in this study were registered before 2021. Considering the delay in the impact of regulations and ratings on vehicles in the fleet, it can be assumed that the majority of vehicles in the datasets did not undergo C-NCAP crash test on their passenger side, which might be a reason causing unequal protection to drivers and front passengers.

However, since the odds of front passengers being injured in far-side impacts are more than five times higher than that of drivers, there must be factors at play beyond possible structural differences. Although similar statistics have been reported in previous studies [14], there has been no further discussion to speculate about the causes. It should be noted that there is always a driver beside the front passenger. But drivers may or may not have a front passenger beside them. To avoid possible confounding effects from mutual impact between drivers and front passengers, we investigated separately the injury distributions for front passengers, drivers with front passenger, and drivers without front passenger. Front passengers exhibit the highest injury rate, followed by drivers without front passengers, and then drivers with front passengers, as shown in Fig. A1. For drivers, the group with front passengers beside them did not show a higher injury rate than the group without front passengers. We can speculate that mutual impact is not a primary cause of high injury risk for front passengers. Further analyses are suggested to understand the mechanism underlying this.

Regarding frontal impacts, the differences in injury risk between drivers and front passengers may be attributed to their different preferences in seat adjustment. Crash tests conducted by DEKRA revealed considerable differences in injury outcomes between large male and small female dummies, especially in the passenger seats [17]. For the 5th percentile female dummy, the optimal seat position should be higher up and much further forward than the middle (default) position, which is better suited to the 50th percentile male dummy. However, the reality tends to be the opposite of the ideal situation. Front passengers are less likely to adjust their seats to the optimal position compared to drivers, who are more likely to adjust their seats for a better driving experience [18]. Our data also indicate that front passengers, who are more often small females, tend to stay in the middle or more rearward positions, while drivers, who are more often taller males, tend to stay in the middle or more forward positions, as shown in Fig. A2. Current vehicles have limited adaptivity to provide equal protection to occupants of various sizes. Developing adaptive safety solutions could help mitigate inequality in this context.

Limitations

The representativeness, completeness, and precision of data are primary challenges in crash data analysis. Although CIDAS investigate crashes with injury at any severity level, like other in-depth crash databases, it exhibits a selection bias towards more severe crashes. Many low severity crashes were ignored because they were more likely not reported to the police. However, this systematic bias has a limited impact on our comparative analysis, as underreporting tends to affect all groups equally, regardless of sex or seating position. Due to the small sample size of severely injured occupants (MAIS3+), it is challenging to determine whether the lack of statistical significance is a result of insufficient data or a true absence of significant correlations.

When comparing injury risks between drivers and passengers, a systematic sampling bias should be noticed. Crashes are typically included in the databases only if at least one occupant is injured. In vehicles with both a driver and a passenger, this allows for the inclusion of uninjured occupants—the uninjured driver may be included due to the injured passengers, and vice versa—making their injury risks comparable internally. However, for driver-only vehicles, crashes are only recorded if the driver is injured, leading to more injured drivers in the data. Since real-world data includes both driver-only and multi-occupant vehicles, this bias inflates the apparent injury risk for drivers relative to passengers. In our study, we found that front passengers had a higher injury risk than drivers in certain scenarios. Accounting for this sampling bias would likely reveal an even greater disparity. Studies aiming for comparing injury risks of driver and passenger should adjust for this bias to ensure more accurate assessments.

Ideally, delta V is recognised as a high-quality indicator of crash severity. This study chose closing velocity instead, considering the available sample size. Including delta V would result in the loss of two-thirds of our selected crash cases, leading to a much higher bias in the model results. According to our model results, higher closing velocity was significantly related to higher injury risk in most models, indicating it is well-represented in terms of crash severity.

The height and weight of occupants in the data were mostly from visual estimation by the investigators, which may introduce bias compared to actual measurements.

When analysing crash data, which mostly uses discrete measures to describe injury severity (e.g. AIS), it is challenging to capture injury severity differences within the same level. High-resolution data, such as body loads from crash simulations or crash tests, can complement this limitation by providing insights into same-level differences [4].

This study is based on Chinese crash data. The primary confounding effect of equity issues might differ in other countries or regions.

V. CONCLUSION

There is an intrinsic need to identify the confounding factors that contribute to higher injury risks to fully understand inequalities in road crashes. This study identified that seating position is the primary confounder, leading to higher MAIS1+ and MAIS2+ injury risk for female occupants because they are more frequent occupants of the front passenger seats. This highlights the need for better protection solutions for front passengers, which could particularly benefit female occupants.

VI. ACKNOWLEDGEMENTS

We would like to extent our gratitude to our Autoliv colleagues Martin Östling, Torbjörn Andersson, Ron Schindler, and the CIDAS team for their valuable ideas and language review.

TABLE I

ODDS RATIOS OF UNIVARIATE LOGISTIC REGRESSION MODELS FOR CONFOUNDER IDENTIFICATION

Possible confounder		Sex (CI1 models)			Injury severity (CI2 models)								
		Front (n=531)	Near-side (n=109)	Far-side (n=127)	Front (n=531)			Near-side (n=109)			Far-side (n=127)		
Variable	Level	Female	Female	Female	MAIS1+	MAIS2+	MAIS3+	MAIS1+	MAIS2+	MAIS3+	MAIS1+	MAIS2+	MAIS3+
SP	FP	9.542***	7.211***	7.037***	2.869***	2.467***	1.700	4.270**	2.206	1.879	6.692**	1.860	1.653
Closing velocity		0.993	1.004	1.001	1.006*	1.012***	1.011*	1.009	1.027**	1.018*	1.022**	1.032***	1.026**
Age		1.012	0.994	0.965	1.013	1.021*	1.007**	1.012	1.032*	1.020	0.996	0.989	0.985
Height		0.612***	0.532***	0.510***	0.954**	0.951**	0.936**	0.932*	0.970	0.992	0.929*	0.976	0.986
Weight		0.730***	0.604***	0.635***	0.978	0.989	0.989	0.958	0.983	0.973	0.962	0.970	0.983
Host type	Sedan	0.976	2.083	0.689	1.113	0.908	1.066	1.307	1.182	1.286	0.916	0.952	0.833
Opponent	Sedan	0.765	1.901	1.867	0.197***	0.241***	0.166***	0.098*	0.216*	0.167*	0.062*	0.151*	0.097*
	LTV	0.832	0.933	0.960	0.317***	0.365***	0.293***	0.200	0.267	0.217	0.156	0.424	0.348
	HV	0.524	1.089	1.680	0.894	1.044	1.019	1.111	0.667	0.571	0.147	0.444	0.308
RY	2012+	1.448	1.224	1.780	1.142	1.328	1.059	0.742	0.510	0.508	0.468*	0.656	0.433
Curb weight		1.000	1.000	1.000	0.999**	1.000	1.000	0.998*	0.997**	0.997**	1.000	1.000	0.998
Front DL	Left	0.984	-	-	0.934	0.621	0.796	-	-	-	-	-	-
	Right	0.617	-	-	0.502*	0.538	0.376*	-	-	-	-	-	-
Side DL	A-C pillar	-	2.357	0.366	-	-	-	15.54***	12.000*	6.545	1.548	2.174	3.600

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001; SP refers to seating position, FP refers to front passenger, RY refers to registration year, and DL refers to damage location; reference group is driver for seating position, LTV for host type, object for opponent, middle for front damage.

TABLE II

RESULTS OF MULTIVARIATE LOGISTIC REGRESSION MODELS FOR SEX AND CONFOUNDERS

Models	Independent variable	MAIS1+		MAIS2+		MAIS3+	
		Coef. (OR)	95% CI	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Front (n=532)							
BL models	Sex: female	0.471 (1.602) *	(1.010,2.557)	0.363 (1.437)	(0.873,2.331)	0.194 (1.214)	(0.659,2.140)
IA models	Sex: female	0.122 (1.129)	(0.554,2.304)	-0.161 (0.851)	(0.392,1.823)	-0.526 (0.591)	(0.235,1.442)
	SP: front passenger	0.821 (2.273) **	(1.288,4.080)	0.661 (1.937) *	(1.085,3.455)	0.289 (1.335)	(0.668,2.604)
	Height	-0.016 (0.984)	(0.939,1.032)	-0.039 (0.962)	(0.913,1.012)	-0.088 (0.916) **	(0.861,0.973)
Near-side (n=109)							
BL models	Sex: female	0.777 (2.175)	(0.940,5.325)	0.248 (1.282)	(0.562,2.897)	0.182 (1.200)	(0.469,2.980)
IA models	Sex: female	0.732 (2.080)	(0.306,14.153)	0.131 (1.140)	(1.089,7.156)	0.995 (2.704)	(0.372,23.285)
	SP: front passenger	0.996 (2.707)	(0.664,12.849)	0.842 (2.322)	(0.612,9.487)	0.577 (1.781)	(0.470,7.209)
	Height	-0.056 (0.945)	(0.831,1.067)	-0.002 (0.998)	(0.874,1.144)	0.087 (1.091)	(0.933,1.295)
Far-side (n=127)							
BL models	Sex: female	0.901 (2.462) *	(1.030,6.052)	0.027 (1.028)	(0.312,2.911)	-0.367 (0.693)	(0.152,2.308)
IA models	Sex: female	1.013 (2.754)	(0.540,15.210)	-0.547 (0.578)	(0.091,3.291)	-0.944 (0.389)	(0.043,2.764)
	SP: front passenger	1.759 (5.806) *	(1.272,32.775)	0.513 (1.670)	(0.311,7.867)	0.643 (1.902)	(0.253,12.146)
	Height	-0.057 (0.945)	(0.835,1.064)	-0.064 (0.938)	(0.813,1.071)	-0.068 (0.934)	(0.796,1.085)

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001; reference group is male for sex, driver for seating position (SP); CI refers to confidence interval; full results of multivariate models can be found in the Appendix.

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VIII. APPENDIX

TABLE AI
DATA SELECTION STEPS AND SAMPLE SIZE

	Database and exclusion criteria	$N_{crashes}$	$N_{vehicles}$	N_{person}
Step 0	CIDAS database (September 2024)	10,031	-	-
Step 1	Crashes that did not involve a passenger car	7,814	8,325	11,085
Step 2	• Car-to-VRU crashes • Crashes with more than two vehicles • Rollover and fall-down vehicles • Running out of road * • Underride crashes	886	1,224	2,294
Step 3 (for descriptive statistics)	• Occupants with unknown sex • Occupants under 18 years old • Pregnant occupants • Unbelted occupants • Fatalities not due to injuries • Ejected occupants	635	837	1,032
Step 4 (for model)	• Data with unknown vehicle information (i.e. year of registration, curb weight, impact speed) • Data with unknown occupant information (i.e. height, weight, age, MAIS) • Rear passengers	587	766	917

*Running out of road means a vehicle completely running out of road before having a major crash.

TABLE AII

RESULTS OF MULTI-VARIATE LOGISTIC REGRESSION MODEL FOR FRONT IMPACT

Independent variable		Front (n=532)					
		MAIS1+		MAIS2+		MAIS3+	
Variable	Level	Coef. (OR)	95% CI	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Intercept	/	3.234 (25.369)	(0.008,8.2e4)	4.526 (92.379)	(0.014,6.3e5)	12.980 (4.3e5) *	(13.903,1.7e10)
Sex	Female	0.122 (1.129)	(0.554,2.304)	-0.161 (0.851)	(0.392,1.823)	-0.526 (0.591)	(0.235,1.442)
Seating position	Front passenger	0.821 (2.273) **	(1.288,4.080)	0.661 (1.937) *	(1.085,3.455)	0.289 (1.335)	(0.668,2.604)
Closing velocity	/	0.010 (1.010) **	(1.003,1.017)	0.016 (1.015) ***	(1.008,1.024)	0.015 (1.015) ***	(1.006,1.024)
Age	/	0.018 (1.018) *	(1.001,1.036)	0.029 (1.029) **	(1.011,1.048)	0.013 (1.013)	(0.992,1.035)
Height	/	-0.016 (0.984)	(0.939,1.032)	-0.039 (0.962)	(0.913,1.012)	-0.088 (0.916) **	(0.861,0.973)
Opponent	Sedan	-1.713 (0.180) ***	(0.101,0.314)	-1.537 (0.215) ***	(0.116,0.392)	-1.842 (0.159) ***	(0.073,0.330)
	LTV	-1.214 (0.297) ***	(0.162,0.535)	-1.109 (0.330) ***	(0.173,0.620)	-1.269 (0.281) **	(0.129,0.590)
	HV	0.009 (1.009)	(0.548,1.847)	0.189 (1.208)	(0.673,2.177)	0.215 (1.240)	(0.661,2.349)
Registration year	2012+	0.099 (1.104)	(0.745,1.638)	0.190 (1.209)	(0.783,1.877)	-0.094 (0.910)	(0.546,1.524)
Curb weight	/	-0.001 (0.999) **	(0.998,1.000)	-0.000 (1.000)	(0.999,1.000)	-0.000 (1.000)	(0.999,1.000)
Damage location	Left	0.270 (1.311)	(0.767,2.242)	-0.299 (0.741)	(0.386,1.372)	0.069 (1.072)	(0.507,2.151)
	Right	-0.534 (0.586)	(0.306,1.092)	-0.330 (0.719)	(0.334,1.454)	-0.639 (0.528)	(0.171,1.340)

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001; reference group is male for sex, driver for seating position, object for opponent, and middle for damage location; CI refers to confidence interval.

TABLE AIII

RESULTS OF MULTI-VARIATE LOGISTIC REGRESSION MODEL FOR NEAR-SIDE IMPACT

Independent variable		Near-side (n=109)					
		MAIS1+		MAIS2+		MAIS3+	
Variable	Level	Coef. (OR)	95% CI	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Intercept	/	9.744 (1.7e4)	(0.000,8.0e13)	-2.265 (0.104)	(0.000,1.0e9)	-14.680 (0.000)	(0.000,2.2e5)
Sex	Female	0.732 (2.080)	(0.306,14.153)	0.131 (1.140)	(1.089,7.156)	0.995 (2.704)	(0.372,23.285)
Seating position	Front passenger	0.996 (2.707)	(0.664,12.849)	0.842 (2.322)	(0.612,9.487)	0.577 (1.781)	(0.470,7.209)
Closing velocity	/	0.008 (1.008)	(0.988,1.030)	0.045 (1.046) ***	(1.022,1.075)	0.031 (1.032) **	(1.009,1.058)
Age	/	0.013 (1.014)	(0.971,1.061)	0.047 (1.048) *	(1.006,1.099)	0.035 (1.036)	(0.993,1.084)
Height	/	-0.056 (0.945)	(0.831,1.067)	-0.002 (0.998)	(0.874,1.144)	0.087 (1.091)	(0.933,1.295)
Opponent	Sedan	-2.322 (0.098)	(0.004,0.778)	-2.204 (0.110) *	(0.014,0.700)	-2.210 (0.110) *	(0.016,0.667)
	LTV	-1.311 (0.269)	(0.012,2.190)	-2.009 (0.134) *	(0.017,0.866)	-1.900 (0.150)	(0.020,0.951)
	HV	0.320 (1.377)	(0.052,21.221)	-0.553 (0.575)	(0.081,3.769)	-0.494 (0.610)	(0.095,3.669)
Registration year	2012+	-0.715 (0.489)	(0.152,1.464)	-1.028 (0.358)	(0.113,1.051)	-0.854 (0.426)	(0.133,1.284)
Curb weight	/	-0.001 (0.999)	(0.997,1.001)	-0.003 (0.997) *	(0.995,1.000)	-0.003 (0.997) *	(0.993,0.999)
Damage location	A-C pillar	2.660 (14.297) **	(3.302,85.451)	2.742 (15.514)	(1.475,576.001)	1.265 (3.543)	(0.442,84.668)

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001; reference group is male for sex, driver for seating position, object for opponent, and other for damage location; CI refers to confidence interval.

Note: * p-value ≤ 0.05, ** p-value ≤ 0.01, *** p-value ≤ 0.001; reference group is male for sex, driver for seating position, object for opponent, and other for damage location; CI refers to confidence interval.

TABLE AIV

RESULTS OF MULTI-VARIATE LOGISTIC REGRESSION MODEL FOR FAR-SIDE IMPACT

Independent variable		Far-side (n=127)					
		MAIS1+		MAIS2+		MAIS3+	
Variable	Level	Coef. (OR)	95% CI	Coef. (OR)	95% CI	Coef. (OR)	95% CI
Intercept	/	9.779 (1.8e4)	(0.000,3.0e13)	8.696 (6.0e3)	(0.000,1.3e14)	10.992 (5.9e4)	(0.000,1.9e16)
Sex	Female	1.013 (2.754)	(0.540,15.210)	-0.547 (0.578)	(0.091,3.291)	-0.944 (0.389)	(0.043,2.764)
Seating position	Front passenger	1.759 (5.806) *	(1.272,32.775)	0.513 (1.670)	(0.311,7.867)	0.643 (1.902)	(0.253,12.146)
Closing velocity	/	0.028 (1.028) **	(1.010,1.049)	0.037 (1.038) ***	(1.018,1.063)	0.030 (1.031) **	(1.011,1.055)
Age	/	0.017 (1.017)	(0.977,1.059)	0.001 (1.001)	(0.954,1.049)	0.005 (1.005)	(0.955,1.057)
Height	/	-0.057 (0.945)	(0.835,1.064)	-0.064 (0.938)	(0.813,1.071)	-0.068 (0.934)	(0.796,1.085)
Opponent	Sedan	-4.110 (0.016) **	(0.001,0.179)	-1.848 (0.157)	(0.016,1.528)	-2.485 (0.083) *	(0.007,0.937)
	LTV	-2.809 (0.060) *	(0.002,0.570)	-0.667 (0.513)	(0.056,4.681)	-1.054 (0.348)	(0.033,3.536)
	HV	-2.949 (0.052) *	(0.002,0.570)	-0.393 (0.675)	(0.075,6.419)	-1.079 (0.340)	(0.032,3.522)
Registration year	2012+	-1.787 (0.167) ***	(0.058,0.437)	-0.744 (0.475)	(0.160,1.345)	-1.234 (0.291) *	(0.078,0.951)
Curb weight	/	0.001 (1.001)	(0.999,1.002)	-0.000 (1.000)	(0.998,1.012)	-0.001 (0.999)	(0.996,1.001)
Damage location	A-C pillar	0.379 (1.461)	(0.392,6.336)	-0.051 (0.950)	(0.187,7.360)	0.739 (2.094)	(0.264,48.936)

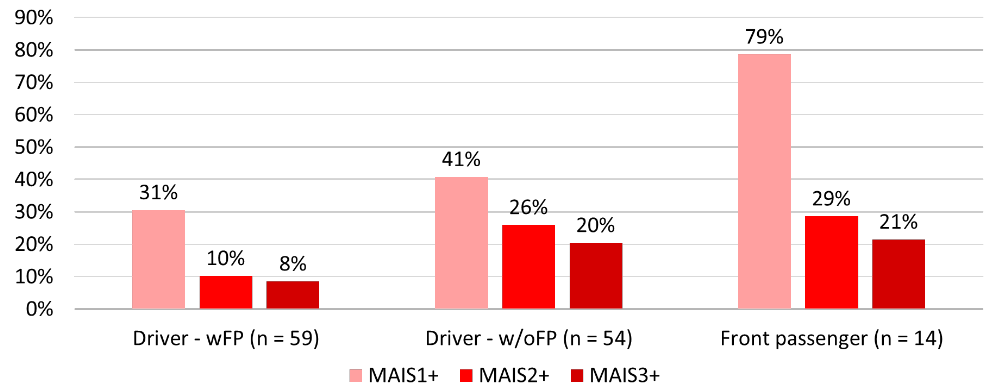

Fig. A1. Injury rate of occupants exposed to far-side impacts; wFP means ‘with front passenger’ and w/o FP means ‘without front passenger’.

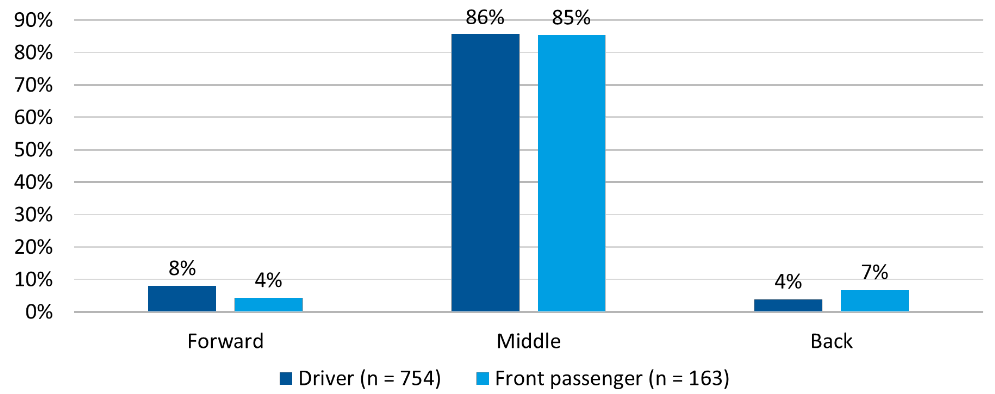

Fig. A2. Seat adjustment for drivers (median height: 170 cm) and front passengers (median height: 165 cm).