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Research article

Which is the role of driver- or passengers-sex on the severity of road crashes?

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ABSTRACT

Aim: The aim of the study is to quantify the main ways in which the sex of the driver/occupant of a passenger car affects the severity of road crashes.
Methods: All 171 230 cars occupied by the driver and one or more passengers included in the Spanish Register of Victims of Road Crashes from 2014 to 2020 were included. We designed two cohort studies: In the first one, we estimated the Incidence Rate Ratios (IRR) between the sex of the drivers and the occurrence of any death and/or severe injuries among their passengers. In the second one we estimated the conditioned IRR between the sex of the occupants of the same car and their risk of death and/or severe injuries. We used fixed Poisson models to obtain IRR estimates, crude and adjusted by individual- environment- and vehicle-related variables.
Results: A consistent inverse relationship between driver's female sex and passenger's severity was found, (IRR 0.72, 95 % CI 0.68–0.77), stronger for single crashes (IRR 0.67, 95 % CI 0.60–0.65). The magnitude decreased after adjusting for vehicle- and environment-related variables (IRR 0.82, 95 % CI 0.73–0.92). In the second study, the risk of death or hospitalization was higher for occupants of female sex (IRR 1.23, 95 % CI 1.17–1.30).
Conclusions: The risk of death or severe injuries among passengers of cars involved in single crashes is lower for female drivers, probably due to safer driving. On the contrary, in similar crashes, the risk of injuries leading to hospitalization is higher for females.

1. Introduction

The roles of Sex or Gender (SG), respectively defined under biological or psychosocial features, have been widely addressed in the epidemiology of road crashes. In fact, studies which do not stratify any crash-related outcome (crash rate, fatality rate, injury severity, etc.) by age and SG categories are unusual. However, from a theoretical viewpoint, it should be desirable to differentiate three outcomes potentially related to SG: the amount and type of exposure (i.e. mobility, usually defined by number of trips, time or distance

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accounted by each type of road user/vehicle driven) [1–5]; the risk of suffering a road crash adjusted by exposure [1,4,6–9], and the severity of the injuries suffered by people involved in road crashes [1,6,7,10,11]. Unfortunately, the associations previously found between SG and the last outcome are heterogeneous and hard to interpret across studies. For example, higher fatality rates (adjusted by an estimate of driving exposure) have been usually reported for male compared to female drivers [6,7,12,13]. Furthermore, several studies have observed higher risks of fatal or severe injuries in male drivers after a crash [10,14–19]. On the contrary, other studies reported higher risks of death or severe injuries for women [1,11,20–25]. Besides, a recent study designed different models to quantify the odds of injury after a crash according to sex, resulting in higher odds for males in certain injuries (head, neck, thorax) and higher in females in others (lower extremity injuries) [26]. The comparability of results across studies is hampered by deep differences in their design, study populations and strategies of analysis [19]. As some authors have acknowledged [1,6,9,27,28], many causal paths may mediate the sense and the magnitude of the association between SG and crash or injury severity. Therefore, the estimation of this association reported in many previous studies is the result of the combination of these different paths. Depending on the study design and analysis, the contribution of each path to the final estimation will be different, thus explaining the heterogeneity found across studies.

At the outset, we should answer two quite different questions: First, are there differences in crash severity depending on the SG of the driver involved or responsible of the crash? Second, there are SG-related differences in the severity of the injuries suffered by people involved in the same crash? Regarding the first question, the study population should comprise drivers involved or responsible of road crashes. The hypothesis to be tested is that driver's gender (i.e., from a psychosocial perspective), influences driving patterns which, in turn, are related to the severity of the injuries suffered by the people involved in a crash (the driver himself/herself or the other involved people). Two theoretically causal paths may further mediate this association. First, as it has been previously stated [29–31], driver gender may be related to the probability of driving in safer vehicles or in safer driving environments, especially at older ages [32]. Second, in similar vehicles and environments, driver gender may be related with risk-driving styles, an association also observed in previous studies [29,33–35]. For example, if women drivers tend to be less frequently involved in fatal crashes compared to men drivers, part of this association may be explained if women tend to drive less frequently in adverse environments, where crashes are more severe (at night, in bad weather, or on highways). However, another part could be explained if, driving on the same environment, women tend to drive more cautiously than men (for example, at lower speed). We have not found any previous study designed to differentiate these two paths.

Regarding the second question, the study population could be any person involved in the crash (drivers, passengers, or pedestrians). The hypothesis to be tested is that sex (now mainly from a biological perspective), affects vulnerability to the energy released and transferred in the crash. For example, if fragility were higher for females compared to males, it could be hypothesized that the same amount of energy would lead to higher risk of death or severe injuries among the former. For example, Bose et al. [36] found that belted female drivers were 47%–71 % more susceptible to injuries compared with belted male drivers when involved in a comparable motor vehicle crash.

Fig. 1 displays a simplified Directed Acyclic Graph (DAG) showing the three aforementioned causal paths between driver's SG and the severity of the crash. We have not found previous studies focused on identify these different paths from the same set of road crashes and vehicle occupants (driver and passengers) involved on them. This has led us to perform the current study, aimed to assess the role of sex on crash severity in Spain, from 2014 to 2020, from a triple approach: 1) the relationship between the sex of the driver and the severity of injuries suffered by the other passengers of his or her vehicle (the sum of paths 1a and 1b); 2) the part of this association that cannot be explained by the vehicle and environment conditions (path 1b), and 3) the relationship between sex and the severity of the injuries suffered from occupants (drivers or passengers) of the same vehicle involved in a crash (path 2).

2. Methods

The source population was the retrospective case series comprised by all occupants of private cars involved in road crashes with victims in Spain, from 2014 to 2020, included in the Spanish National Register of Victims of Road Crashes, maintained by the Spanish

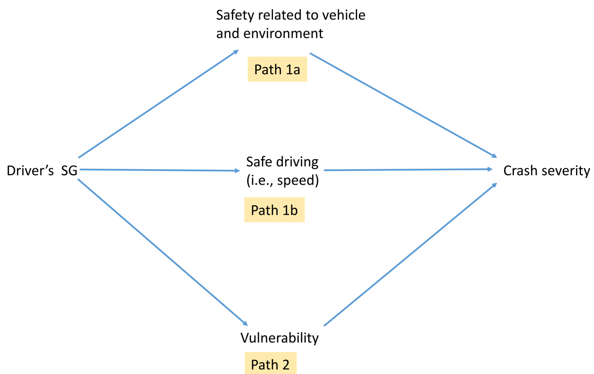

Fig. 1. Possible causal paths between driver's sex or gender (SG) and crash severity.

General Traffic Directorate [37]. This nationwide register includes the information collected by police officers at the scene of each crash with victims regarding the characteristics of the crash, the vehicles and the persons involved on it (Tables 1–3 show the corresponding sets of variables selected from the Register for the study).

From this source, we have designed two different retrospective cohort studies, to answer the following research questions: 1) is there association between the sex of the driver and the severity of injuries suffered by the occupants (drivers or passengers)? 2) Which part of this association cannot be explained by vehicle or environmental conditions? The DAGs displayed in Figs. 2 and 4 showed the theoretical background of each design. Although the design of both DAGs was initially grounded on the review of previous bibliography, we explored their suitability to our dataset using a modified version of Sankey diagrams [38], which depicts flows rates from one set of values to another. In our case, these flow rates graphically display the relative amounts of persons who moves from the values of our exposure variable (sex) to the values of the outcome variables (death or DSI), including the values of one or more possible

Table 1
Distribution of driver-related variables (A) and passenger-related variables (B).

A) Driver-related variables				
Variable	Categories	Not imputed		Imputed
		n	%	%
Death	No	170 335	99.5	
	Yes	895	0.5	
DSI	No	167 041	97.6	
	Yes	4189	2.5	
Sex	Male	118 583	69.3	69.4
	Female	52 215	30.5	30.6
	Unknown	432	0.3	
Age group	<25	27 516	16.1	16.3
	25 to 34	39 037	22.8	23.0
	35 to 44	39 811	23.3	23.5
	45 to 54	28 795	16.8	17.0
	55 to 64	16 979	9.9	10.0
	65 to 74	11 401	6.7	6.7
	>74	5933	3.5	3.5
	Unknown	1758	1.0	
Seat belt use	Yes	136 620	79.8	98.1
	No	2463	1.4	1.9
	Unknown	32 147	18.8	
Speed-related infractions	No	90 381	52.8	87.4
	Yes	12 478	7.3	12.6
	Unknown	68 371	39.9	
Other driving errors/infractions	No	52 875	30.9	51.4
	Yes	48 937	28.6	48.6
	Unknown	69 418	40.5	
B) Passenger-related variables				
Death	No	259 095	99.5	
	Yes	1315	0.5	
DSI	No	253 124	97.2	
	Yes	7286	2.8	
Sex	Male	105 188	40.4	40.8
	Female	152 768	58.7	59.2
	Unknown	2454	0.94	
Age group	<25	102 784	39.5	41.5
	25 to 34	42 624	16.4	17.6
	35 to 44	33 062	12.7	13.8
	45 to 54	25 547	9.8	10.6
	55 to 64	19 220	7.4	7.8
	65 to 74	13 533	5.2	5.4
	>74	8579	3.3	3.4
	Unknown	15 061	5. 8	
Position	Front seat	141 186	54.2	58.2
	Rear left	37 088	14.2	15.3
	Rear right	49 107	18.9	20.3
	Rear center	10 859	4.2	4.5
	Other positions	2413	0.9	1.0
	Additional passenger	1453	0.6	0.6
	Unknown	18 304	7.0	
Seat belt use	Yes	193 497	74.3	95.8
	No	7933	3.1	4.2
	Unknown	58 980	22.7	

DSI, death or severe injury.

Table 2
Distribution of drivers according to the characteristics of their passengers sets.

Variable	Categories	Not imputed		Imputed
		n	%	%
Any death among passengers	No	170 065	99.3	
	Yes	1165	0.68	
Any DSI among passengers	No	165 356	96.6	
	Yes	5874	3.4	
n of passengers	1	112 624	65.8	
	2	35 039	20.5	
	3	17 224	10.1	
	4	5860	3.4	
	5 or more	483	0.30	
Female passengers	0	51 666	30.2	30.3
	1	91 199	53.3	53.6
	2	21 212	12.4	12.5
	3 or more	6025	3.5	3.6
	Unknown	1128	0.66	
Passengers aged <10 years	0	140 771	82.2	85.7
	1	17 473	10.2	11.1
	2	4866	2.8	2.9
	3 or more	544	0.30	0.3
	Unknown	7576	4.4	
Passengers aged ≥ 75 years	0	155 788	91.0	95.3
	1	7213	4.2	4.3
	2	600	0.4	0.4
	3 or more	53	0.03	0.0
	Unknown	7576	4.4	
Unbelted passengers	0	129 076	75.4	94.6
	1	5019	2.9	4.6
	2	997	0.58	0.7
	3 or more	276	0.16	0.2
	Unknown	35 862	20.9	

DSI, death or severe injury.

mediator variables theoretically involved in this flow. We will describe below an example of how we used these diagrams.

The first cohort study (Study 1; Fig. 2) comprised the 171 230 drivers of private cars involved in crashes and occupied by the driver and 1 or more additional passengers. Exposure variable was the sex of the driver.

Red arrows indicate the causal path 2 in Fig. 1 that has been blocked thorough adjusting by passenger's characteristics (boxed). Green and blue arrows display causal paths 1a and 1b in Fig. 1, respectively. To estimate the magnitude of the later, adjustment by vehicle safety and environment should be performed (dashed lines in the boxes for these variables). Black arrows display the possible overadjustment by driver's death or DSI (see text for details), applied as a sensitivity analysis. Finally, the shadowed area includes the path suggested by the Sankey diagram –see Fig. 3-, supporting *the hypothesis that adjusting by speed-related infractions should decrease the magnitude of path 1b. DSI: Death or severe injury*.

Two different dichotomous outcomes were defined: The occurrence of any death (in the 30 days after the crash) and the occurrence of any Death or any Severe Injury (DSI) (the later defined as injuries that lead to hospitalization for more than 24 h) among additional passengers in the car. Fixed Poisson regression models were fitted to estimate the Incidence Rate Ratio (IRR) between female sex of the driver and each outcome. As potential confounders we included in the models the driver's age and, for each passengers set (those occupying the same vehicle), the following aggregated variables: number of passengers, mean age, number of passengers aged less than 10 and more than 74 years old, number of female passengers and number of passengers not using seat belts. We hypothesized that any association between exposure and both outcomes should be explained by the combination of paths 1a and 1b in Fig. 1, but not thorough path 2. To estimate the magnitude of path 1b, we adopted two alternative strategies: In the first one, we added to the model the following vehicle- and environment-related variables (the categories for each one are described in Tables 2 and 3): age of the vehicle, province, year, month, hour, place and type of road, road- and weather-conditions. Then, separate models were fitted for two subsets of crashes: crashes in which only one car was involved (single crashes) and collisions involving two or more cars. In the second strategy, a conditional fixed Poisson model was fitted for each outcome, in order to condition their associations with driver's sex by the involvement in the same crash. Age of the vehicle was retained in these last models. Although this procedure reduces notably the sample size of the study (now restricted to sets of car drivers of different sexes involved in the same multi-vehicle collision in which at least one passenger developed the outcome), it allowed an almost perfect adjustment for all characteristics of the environment conditions in which the crash took place. We tested the existence of an interaction term ($P < 0.01$) between sex and age in all the models.

Unfortunately, the sole vehicle-related variable for which we could extract information from the Register was vehicle age. If driver sex was associated with other characteristics of the vehicle (for example, if female drivers tend to use less safe vehicles than males), the estimation of the magnitude of path 1b would be biased. To deal with this problem, we repeated the analyses including in the models the corresponding driver's outcome (death or DSI), strongly correlated with both passenger severity and vehicle safety systems, as an

Table 3
Distribution of drivers according to the type of crash and environment-related variables.

Variable	Categories	Not imputed		Imputed
		n	%	%
Year	2014	17 374	10.2	
	2015	18 572	10.9	
	2016	30 132	17.6	
	2017	29 762	17.4	
	2018	29 185	17.0	
	2019	28 395	16.6	
	2020	17 810	10.4	
Month	January	14 347	8.4	
	February	13 089	7.6	
	March	13 214	7.7	
	May	12 585	7.4	
	April	13 277	7.8	
	June	14 649	8. 6	
	July	16 578	9.7	
	August	16 002	9.4	
	September	14 264	8.3	
	October	14 306	8.4	
	November	14 052	8.2	
	December	14 867	8.7	
Hour of the day	0 to 5	11 926	7.0	
	6 to 11	34 999	20.4	
	12 to 17	65 669	38.4	
	18 to 23	58 636	34.2	
Place and type of road	Urban – street	69 052	40.3	
	Urban – crossing (conventional road)	2128	1.2	
	Urban – others (no conventional road)	2887	1.7	
	Toll highway (urban or non-urban)	5521	3.2	
	No-toll highway (urban or non-urban)	4728	2.8	
	Freeway (urban or non-urban)	29 442	17.2	
	Non-urban dual carriageway conventional road	12 613	7.4	
	Non-urban single carriageway conventional road	40 600	23.7	
	Other non-urban ways: service road or branch line	1460	0.85	
	Non-urban country road	2052	1.2	
	Other non-urban ways	747	0.44	
Intersection	No	64 497	37.7	37.7
	Yes	106 668	62.3	62.3
	Unknown	65	0.04	
Road surface	Normal	143 570	83.9	85.7
	Altered	24 086	14.1	14.3
	Unknown	3574	2.1	
Weather conditions	Good	131 371	76.7	83.3
	Cloudy	10 886	6.4	6.8
	Adverse	15 644	9.1	10.0
	Unknown	13 329	7. 8	
Type of crash	Frontal collision	8611	5.0	
	Frontal-lateral collision	40 063	23.4	
	Lateral collision	12 838	7.5	
	Rear-end collision	54 699	31.9	
	Multiple collision	16 660	9.7	
	Collision with obstacle or road fixture	11 618	6.8	
	Run over of a person	4352	2.5	
	Run over of an animal	1003	0.59	
	Fall	985	0.58	
	Overturning	6700	3.9	
	Cliff	1112	0.65	
	Off-track only	2369	1.4	
	Other	10 220	6.0	

additional covariate. Although we are aware that this procedure could lead to an overadjustment bias (by including a collider in the model, see Fig. 2), we decided to apply it as a way to perform a sensitivity analysis.

The Spanish Register of Victims of Road Crashes does not contain information about the speed of the vehicles involved in each crash. Police only records if the driver had committed any speed infraction (including driving at an inadequate speed or at a speed higher than that allowed in that road). To test the hypothesis that the association between driver sex and each outcome would move towards the null after considering this variable in single crashes, we compared the IRRs obtained from models with and without it in this subset of crashes. This hypothesis was previously supported by our data, as it can be graphically seen from the Sankey diagram

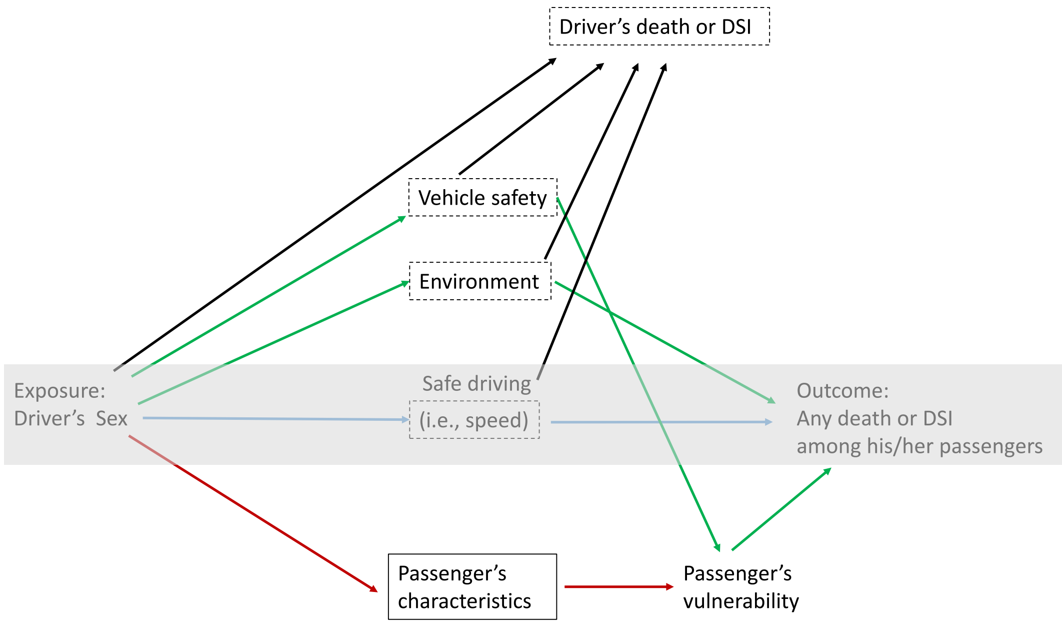

Fig. 2. Directed acyclic graph displaying the causal relationships between variables included in Study 1.

showed in Fig. 3. In the upper left part, starting from an equal number of drivers of both sexes, the flow of drivers who moves to speed infractions is higher from the subgroup of males. Furthermore, ending in an equal number of outcomes (presence or absence of any DSI among passengers) (lower right part of Fig. 3), the mainstream from speed infractors moves to the presence of DSI.

The columns of the diagram show the sex of the driver (on the left), speed infractions (in the middle) and the outcome death or severe injury (on the right).In order to improve visualization, the first diagram (top) shows a scenario in which both driver's sexes — male vs. female — are evenly represented, whereas the second diagram (bottom) shows a scenario in which both severity categories of the aforementioned outcome — any DSI vs. no DSI — are evenly represented. The size (width) of each flow line is proportional to the number of drivers, while the colour indicates the driver's sex (first diagram) and the driver's outcome (second diagram), respectively.

Finally, we repeated all the models described above restricting the study population to drivers that had committed any driver error or infraction just before the crash (i.e., assuming that their probability of being responsible of this crash was high).

In the second study (Study 2, Fig. 4), the source cohort comprised 431 640 occupants of private cars involved in crashes and occupied by the driver and one or more additional passengers: the same 171 230 drivers of Study 1 plus 260 410 passengers. Exposure variable was the sex of the occupant. The outcomes were death in the 30 days after the crash and DSI.

Red arrows indicate causal paths 1a and 1b in Fig. 1 that have been blocked thorough matching by occupying the same vehicle (crash severity) (boxed). Blue arrows display causal path 2 in Fig. 1. Black arrows display causal paths blocked thorough adjustment by seat belt and position (boxed). Green arrows display a possible source of bias (see the discussion for details). DSI: Death or severe injury.

Conditional fixed Poisson regression models were fitted to estimate the IRR between female sex and each outcome, conditioned to occupy the same vehicle. As potential confounders we included in the models age (as a continuous variable) and the position on the vehicle (the categories of this last variable are described in Table 1). Because all crash-, vehicle- and environment related characteristics are the same for each set of occupants of the same vehicle, we hypothesized that any association between sex and both outcomes should be explained only by path 2 in Fig. 1. In a second stage, seat belt use was added to the model, in order to test the hypothesis that all or part of the association between female sex and injury severity could be mediated thorough seat belt use.

Finally, all the aforementioned analyses were repeated only for the subsets of passengers occupying the same vehicle (i.e., excluding the drivers). Although this strategy reduced notably our sample size (now restricted to sets comprised by two or more passengers of different sexes occupying the same vehicle, in which at least one but not all suffered the outcome), our aim was to control the different roles of the occupants (active for the driver, passive for the passengers) which may distort the association between sex and severity mediated only by the vulnerability. We tested the existence of an interaction between sex and age in all the models ($P < 0.01$).

As it can be seen from Tables 1–3, a substantial volume of missing values was found for several relevant variables. Assuming that an important part of these missing values was generated by a Missing-At-Random (MAR) mechanism, a multiple (30 files) imputation procedure was first applied to the database of drivers and passengers, using the chained equation method [39,40]. All analyses were performed using Stata® (version 17) (StataCorp, 2021).

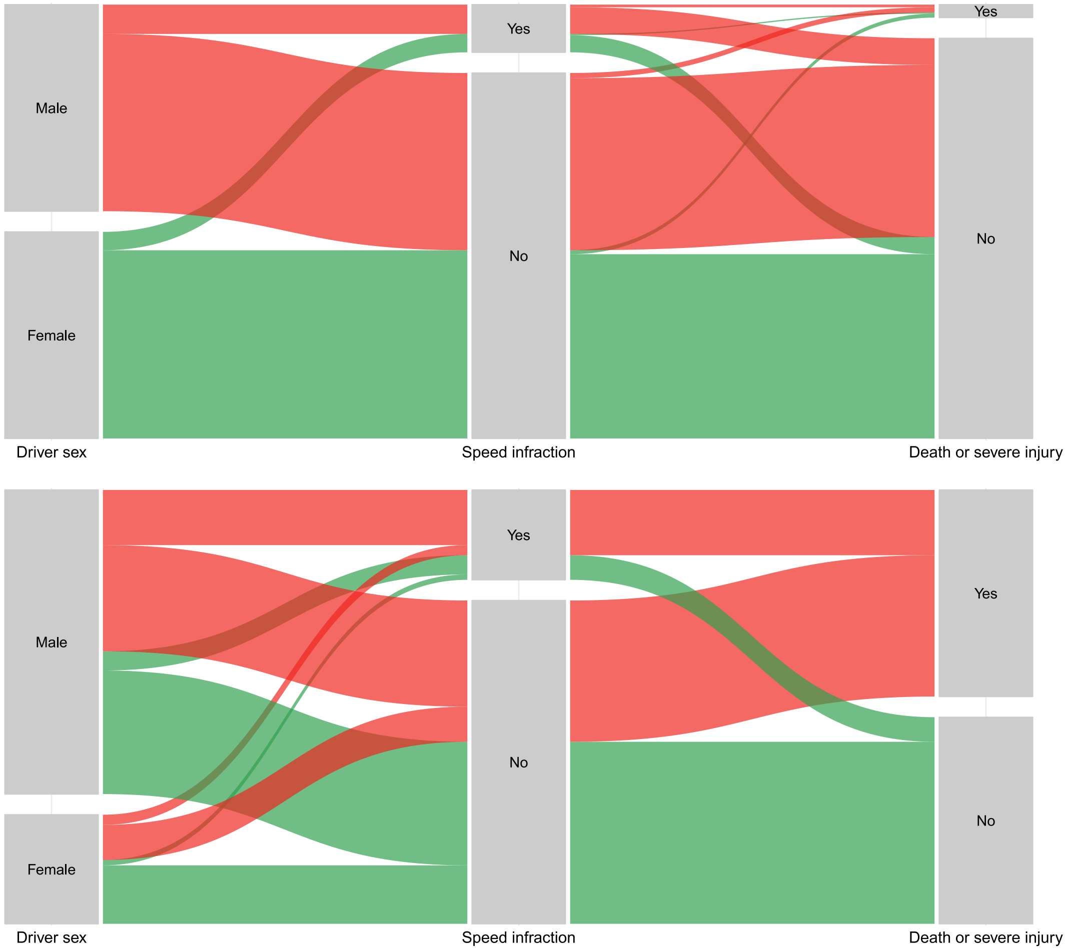

Fig. 3. Sankey flow diagrams of the distribution of speed infractions of the driver and the outcome (any death or severe injury among their passengers), stratified by the driver's sex.

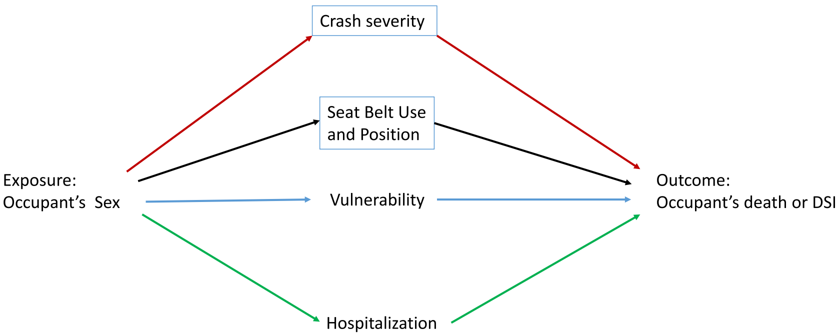

Fig. 4. Directed acyclic graph displaying the causal relationships between variables included in Study 2.

3. Results

Table 1 displays the distribution of driver- and passenger-related variables, respectively. For the subsample of drivers, Table 2 shows the characteristics of each set of passengers occupying him or her car and Table 3 displays the type of crash in which they were involved and the related environmental variables. In all tables, the proportion of each category after multiple imputation is also shown for those variables with missing values. The IRRs between driver's female sex and driver's outcomes (only adjusted for age) were 0.51 (95 % CI: 0.43–0.61) for death and 0.83 (95 % CI: 0.77–0.89) for DSI. As we described in the introduction, these inverse associations should be the result of the combination of at least two different causal paths. The results of studies 1 and 2 shown below try to estimate the magnitude of each one.

Study 1. Table 4 shows the IRRs obtained for the association between the sex of the driver and the aggregated severity of injuries suffered by the passengers occupying the same vehicle (alternatively defined as any death or any DSI among them), adjusted for their aggregated characteristics, considering all type of crashes jointly.

In both the unadjusted model and the model adjusted by vehicle and environment characteristics, an inverse relationship between driver's female sex and the two severity outcomes were found, although it was a bit stronger in the unadjusted versus the adjusted models (0.75 vs 0.80 for death and 0.72 vs 0.76 for DSI, respectively). When the driver's outcome was added to the adjusted models, the IRRs slightly moved towards the null (0.88 for death and 0.81 for DSI). In the models fitted for DSI, we found a significant interaction between driver's sex and age. Therefore, Table 5 shows the IRRs for driver's sex in each age group. In both the unadjusted model and the adjusted model by environment-related variables, the inverse associations between female sex and DSI decreased as age increased up to the 55–64 age group, where they disappeared, although in the unadjusted model it seemed to emerge again in older drivers.

In the subset of single crashes (Table 6), the inverse associations between female sex and each outcome described above were stronger (0.66 and 0.67 for death and DSI, respectively) than those found for all types of crashes considered jointly. The inclusion of driver's outcome and speed infractions moved these IRR towards the null, up to 0.77 (for death) and 0.76 (for DSI) when both variables were included in the same model.

For collisions involving two or more cars (Table 6), the results were different depending on the outcome: when any death among passengers was considered, a positive association with driver's female sex was found. The IRRs were close to the null in the unmatched models: 1.12 and 1.07 with and without adjusting by driver's death, respectively, but they moved away from the null in the matched models (2.42 and 2.73, respectively). However, when any DSI was taken as the outcome, the inverse association with driver's female sex remained in the unmatched models (0.80 and 0.82, respectively), but not in the matched ones (1.12 and 1.21, respectively). It is important to note the small sample sizes used in the matched models: 349 drivers for deaths and 1950 drivers for DSI. When we restricted all the unmatched models to those drivers who had committed any driving error or infraction prior to the crash, the results were quite similar to those observed for the whole sample (data not shown).

Study 2. Table 7 displays the IRRs between occupant's sex (driver or passengers occupying the same car) and their risk of death or DSI.

When death was taken as the outcome, only 4672 occupants were included (drivers driving alone and sets of occupants in which the sex or the outcome was the same for all of them were excluded). This sample size was reduced to 1531 when the analysis was restricted to passengers. When the outcome was DSI, the corresponding sample sizes were higher: 20 628 for all occupants and 7197 for passengers. No relevant relationship between sex and death was found in any model, with IRR ranging from 1.04 to 1.08. When the outcome was DSI, a positive association was found, with IRR ranging from 1.20 to 1.24, independently of the population studied (all occupants or only passengers), or the adjustment or not by seat belt use.

4. Discussion

The following points summarise the main findings of our study.

1. Female drivers tend to be involved in less severe crashes than males. Our results suggest that a safer driving style in women is the main reason for this association, because its magnitude decreases only by a small amount after adjusting by vehicle and environment-related variables, an even by the own driver's outcome. However, this finding indicates that another reason to explain this association is that women drive more frequently than men on environments in which crashes are intrinsically less severe. The magnitude of these associations does not substantially change depending on the outcome considered (death or DSI). In general, most previous studies supports these findings and consider female drivers safer than male drivers [35,41,42]. In a previous study performed by our group, we also found that the intrinsic severity of crashes involving female drivers was lower (RR of 0.85) than those involving male drivers [43]. Recently, Lee et al. (2023), have found that male drivers of all ages were more likely to produce a crash leading to injury or death than female drivers [44]. Regarding the reasons to explain these gender-related differences, several previous studies have reported a higher frequency of aggressive and risk-taking behaviour driving in males [9,33,34,45–47].

Table 4
Incidence relative risks (IRR) for the association between female sex of the driver and any DSI among the remaining passengers occupying the vehicle.

	Any death among passengers		Any DSI among passengers	
Model fitted[a]	IRR	95 % CI	IRR	95 % CI
Unadjusted by vehicle age and environmental variables	0.75	0.65–0.87	0.72*	0.68–0.77
Adjusted by vehicle age and environmental variables[b]	0.80	0.69–0.93	0.76*	0.72–0.82
Adjusted by vehicle age, environmental variables[b] and driver's outcome	0.88	0.76–1.02	0.81	0.76–0.86

(*): Interaction term ($P < 0.01$) between sex and age was found. See Table 5 for details.

[a] *All models included driver's age and the following aggregated variables for passengers: number of passengers, mean age, number of passengers aged less than 10 and more than 74 years old, number of female passengers and number of passengers not using seat belts.*

[b] Province, year, month, hour, place and type of road, road- and weather-conditions.

Table 5
Incidence relative risks (IRR) for the association between female sex of the driver and death or severe injuries among the remaining passengers occupying the vehicle for each driver's age group.

Age groups	Unadjusted by vehicle age and environmental variables[a]		Adjusted by vehicle age and environmental variables[a,b]	
	IRR	95 % CI	IRR	95 % CI
<25	0.60	0.51–0.69	0.66	0.56–0.75
25–34	0.58	0.50–0.66	0.61	0.53–0.69
35–44	0.76	0.65–0.87	0.77	0.67–0.89
45–54	0.86	0.73–0.99	0.88	0.75–1.01
55–64	1.10	0.90–1.31	1.12	0.91–1.33
65–74	0.78	0.59–0.96	0.86	0.66–1.06
>74	0.79	0.50–1.08	1.03	0.65–1.41

[a] *All models included driver's age and the following aggregated variables for passengers: number of passengers, mean age, number of passengers aged less than 10 and more than 74 years old, number of female passengers and number of passengers not using seat belts.*
[b] *Province, year, month, hour, place and type of road, road- and weather-conditions.*

Table 6
Incidence relative risks (IRR) for the association between female sex of the driver and death or severe injuries (DSI) among the remaining passengers occupying the vehicle for single and multivehicle collisions.

Model fitted[a]	Any death among passengers		Any DSI among passengers	
Single crashes (only one car involved)	IRR	95 % CI	IRR	95 % CI
Adjusted by vehicle age and environmental variables[b]	0.66	0.51–0.84	0.67	0.60–0.75
Adjusted by vehicle age, environmental variables[b] and driver's outcome	0.73	0.56–0.93	0.73	0.66–0.82
Adjusted by vehicle age, environmental variables[b] and speed infractions	0.71	0.55–0.91	0.71	0.64–0.80
Adjusted by vehicle age, environmental variables[b], speed infractions and driver's outcome	0.77	0.60–0.99	0.76	0.68–0.85
Collisions involving two or more cars				
Adjusted by vehicle age and environmental variables[b]	1.07	0.82–1.40	0.82	0.73–0.92
Adjusted by vehicle age, environmental variables, and driver's outcome	1.12[c]	0.84–1.51	0.80	0.72–0.89
Matched by collision[d], adjusted by vehicle age	2.73	1.29–5.78	1.21	0.96–1.52
Matched by collision[d], adjusted by vehicle age and driver's outcome	2.42	1.04–5.64	1.12	0.88–1.43

[a] *All models included driver's age and the following aggregated variables for passengers: number of passengers, mean age, number of passengers aged less than 10 and more than 74 years old, number of female passengers and number of passengers not using seat belts.*
[b] Province, year, month, hour, place and type of road, road- and weather-conditions.
[c] *Logistic regression was used for this estimation because convergence was not achieved with Poisson model.*
[d] *n=349 for death and n=1950 for DSI.*

Table 7
Incidence relative risks (IRR) for the association between female sex of the occupants of a car involved in a crash and their risk of death or severe injuries (DSI).

Models for all occupants	Death (n = 4672)		DSI (n = 20 628)	
	IRR	95 % CI	IRR	95 % CI
Unadjusted by seat belt use	1.05	0.93–1.19	1.24	1.17–1.30
Adjusted by seat belt use	1.04	0.92–1.18	1.23	1.17–1.30
	Death (n = 1531)		DSI (n = 7197)	
Models only for passengers	IRR	95 % CI	IRR	95 % CI
Unadjusted by seat belt use	1.08	0.87–1.35	1.20	1.09–1.31
Adjusted by seat belt use	1.08	0.87–1.36	1.20	1.09–1.31

All models also included age and position in the vehicle.

According to Cordellieri et al. (2016), differences in 'concern about risk', is an important determinant of risk-taking behaviour, with men less concerned than women about risk of consequences [48]. Finally, as we stated in the introduction, several studies have shown that females tend to drive more frequently than males in environments in which crashes are intrinsically less severe [29–31, 49].

2. The associations described above are stronger in single crashes and for younger drivers. Regarding the type of crash, several authors [10,16] also found that male drivers were associated with increased probability of fatal or severe injuries in single-vehicle crashes. However, other authors [21,23] found the opposed result (i.e., a higher risk of fatal injuries in females) or no association [26]. In collisions between two or more cars, and after adjusting by vehicle- and environment conditions, crash severity depends on the interaction between the manoeuvres performed by all the drivers involved. Therefore, the role of driver's gender on crash severity can be more easily identified in those crashes involving only one driver. The reduction of the magnitude of the inverse association

between female drivers and crash severity after adjusting by speed infractions in single crashes also gives support to the hypothesis that safer driving styles among women (for example, driving at lower speeds than men), mainly explain the relationship between women and less severe crashes, at least in single crashes. On the other hand, many previous studies have stressed the excess of risk of crash posed by adolescent and young male drivers compared to females of the same age, related with risky driving [8,50–52]. It is therefore not surprising that this riskier behaviour in young men also affects crash severity. Apart from age, some previous studies have addressed significant changes in the magnitude of the association between other several well-known driver- vehicle- and environment-related variables (not addressed in our study) and injury severity depending on driver's sex [53–56].

3. In collisions between two or more cars, the associations observed depended on the method of analysis used and the outcome considered: in accordance with the results described above, these types of crashes seemed less severe for female drivers compared to males in unmatched designs when the outcome was DSI, but the opposed pattern was observed when death was taken as the outcome, especially in matched designs. We cannot offer clear explanations for these somewhat conflicting findings. Indeed, matched design provided an almost perfect control of all environment-related factors which, apart from those related to the driver and the vehicle, may affect crash severity. Hence, the question is why, in a multivehicle collision involving two or more cars, the risk of occurrence of any death among passengers of the car driven by a woman is higher than that of passengers of the car driven a by a man? First, as some authors have shown, it is possible that woman drivers tend to carry vulnerable passengers (i.e., children, old and disabled people) more frequently than man drivers do [57,58]. However, we believe that we have appropriately controlled this source of bias including in the models the aggregated values of most relevant characteristics of passengers that could influence their risk of death. On the other hand, the association found could also be explained if women tend to drive less safe cars than men involved in the same crash, a hypothesis recently supported by the study of Brumbelow and Jermakian (2022), which have found that most of the increased severity of injuries in female drivers are not physiological, but attributed to differences between crash characteristics and vehicle crashworthiness [59]. Although we have adjusted our estimation for vehicle age and by the risk of DSI of the driver, we cannot rule out this hypothesis. However, if all the observed association would depend on vehicle safety systems, we hypothesize that it would have disappeared after adjusting by driver's outcome, but this was not the case. Finally, it could be hypothesized a worse driving performance in women that could lead to more severe collisions. For example, in a simulation study of stopping manoeuvres to avoid a rear-end collision (Ferrante et al., 2020), women showed a worse performance than men (i.e., brake in delay when there was not enough time and space to stop in safety condition with result high value of pressure on brake pedal and lead to slip risk braking) [32]. In a meta-analysis of studies that used the Driving Behaviour Questionnaire, it was observed that female drivers commit fewer violations but more errors than male drivers [60]. Maybe a lower driving experience in women drivers are in the ground of these differences.
4. In crashes of the same severity, we did not find differences between sexes in the risk of death. However, the risk of DSI was clearly higher for females. These results do not change depending on neither the role of the occupant (driver or passenger), nor seat belt use. The excess risk of death or severe injuries for female in comparison to male driver or passengers has also been described in many previous studies [11,20–22,24,27,31,36,50,61–66]. According to our results, in the study of Kullgren et al. (2020) females were found to have higher risk for all types of injury severity studied, except for fatal injury [65]. Assuming that we have adequately take into account the severity of the crash, the increased risk of DSI among female occupants may be explained by two different paths:

First, we have labelled severe injuries as those requiring hospitalization. Therefore, it could be hypothesized that, independently of the severity of the injuries suffered, the probability of being hospitalized were higher for females. This would occur if women were more frequently transported to hospital than men or if the threshold for hospital admission were lower for women, as Cullen et al. (2021) suggested in their DRIVE cohort of young drivers [9]. They found women were 1.47 times more likely to be involved in crashes that resulted in hospitalization compared to men, although there was no difference between genders in the severity of hospitalized injuries. Accordingly, in injured people after a motor vehicle collision included in the UK-trauma registry (TARN), Nutbeam et al. (2022) did not find differences in mortality between males and females, although the frequency of entrapment (a situation presumably related with a higher risk of hospitalization), was higher among females [28].

Second, using the same vehicle safety devices, women may be more vulnerable to injury following crash compared to men, depending on SG-related differences in the prevalence of conditions affecting body resilience (i.e., chronic illness or drugs) or on SG-related differences in anthropometric measures, injury tolerance or biomechanical response [11,36,63]. For example, some studies have specifically observed an increased risk of females specifically for extremity injuries [11,59]. As some authors have stated [9,25], it seems that the level of protection conferred by passive safety systems of vehicles are higher for male compared to female occupants, mainly because these systems have been male-oriented designed (i.e., mainly using male dummies or wrong female dummies), leading to serious gender inequality in the safety performance of vehicles [28]. Some studies suggests that improvements in vehicle crash-worthiness have been larger for females [65,66]. For example, Noh et al. (2022) have recently found that the increased fatality risk of females versus males after similar physical impacts (i.e., in comparable crashes), has been reduced in newer model year vehicles and in vehicles with newer generations of occupant protection systems [66].

The limitations of our study mainly depend on the source of information. Although the Spanish Register of Victims of Roads has the advantage of providing a large, nationwide database containing many relevant information about the crashes, the vehicles and the people involved on each crash, it has many drawbacks that may affect the internal validity of our estimates. First, it only covers crashes resulting in any casualty. This affects the reference category for our outcomes because we cannot include crashes with only property damages. Second, there are many relevant variables with a large number of missing values (in our study affecting mainly seat belt use). Although a MAR mechanism is plausible for most of these missing values (for example, for seat belt use they are much more frequent for crashes occurring in urban areas), and our multiple imputation procedure should have corrected this source of bias, a Missing-Not-At-Random mechanism could not be rejected for an undetermined number of missing values. Third, regarding exposure, police recorded the sex of the driver, and we assume that they do it from a purely biological perspective. However, most of our hypothesis are related with the (not registered) gender of the driver. At this point, we are assuming a high correlation between both variables for most people (i.e., most female persons are women, and vice versa). Indeed, this oversimplification, along with the consideration of gender as a dichotomous variable, should be overcome in future research. Fourth, we have just commented above the drawbacks regarding the way to define severe injuries. Fifth, although the objective of this study was not to identify all the mediators of each one of the three paths theoretically hypothesized between sex and severity, it would have been highly valuable to have as much information as possible about them. Unfortunately, we have not reliable information (or not information at all) regarding some relevant mediators such as weight and height of each person, comorbidities, alcohol or drug consumption, speed of each car involved in the crash and all variables related to the safety systems of the car. Besides, the inclusion of individual drivers' behaviours is a significant challenge, although some recent studies pointed strategies to collect proxies from demographic data [67], not included in our database.

The practical usefulness of our results should be considered in the context of the gender perspective that, for some years now, has been a key element in public health research and, in particular, in road safety research. From this point of view, it doesn't look daring wish (and promote), that men had a driving behaviour similar to that of women. The message for men should be, roughly, the following: *try to drive as women do: More safely in more safely settings*. Indeed, this message, and the strategies devoted to reach this objective, should be emphasized on the younger drivers. On the other hand, our results stress the need to elucidate the reasons to explain the higher risk of DSI among females involved on the same crashes than males (higher vulnerability, gender-gap in car safety systems or higher probability of hospitalization) and, once detected, adopt strategies to reduce these differences (i.e., adapting passive safety systems to sex-related biological differences [25,36], or establish clear rules to provide the same quality of health care –including the criteria for hospitalization-, independently of the SG of the injured person). Besides, knowledge on general road traffic accident prevention should be reinforced for secondary students [68] and young drivers, and ideally adapted according to sex differences.

Future studies should analyse the impact of such strategies on the prevention of road crash severity according to sex.

5. Conclusions

In conclusion, the evidence provided by our results gives support to the hypothesis that, especially for young drivers and single crashes, female drivers are related to less severe injuries among the passengers they carried in their cars. Although the main part of this association seems related to safer driving styles among women, the safer environmental conditions in which they drive also plays a role. On the contrary, in similar crashes, the risk of injuries leading to hospitalization is higher for females compared to males. Further studies are required to replicate these associations and identify their key mediators.

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Data availability

The authors do not have permission to share the data.

Ethics statement

Approval by an ethics committee was not needed for this study as the database was anonymized and provided by the Spanish Traffic Directorate (Government of Spain) with no identification data.

CRediT authorship contribution statement

Pablo Lardelli-Claret: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Nicolás Francisco Fernández-Martínez:** Writing – review & editing, Investigation. **Luis Miguel Martín-delosReyes:** Writing – review & editing, Investigation. **Eladio Jiménez-Mejías:** Writing – review & editing, Investigation. **Mario Rivera-Izquierdo:** Writing – review & editing, Investigation. **Virginia Martínez-Ruiz:** Writing – review & editing, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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