"Population density in aging societies and severity of motor vehicle crash injuries: the case of Spain"

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Abstract

Background: The concentration of population in cities and processes of rural depopulation coupled with the generational shift to older societies represent new challenges in road safety. Here, we examine the severity of injuries suffered by the occupants of motor vehicles involved in a crash based on the population density of the area in which the accident occurs, the driver's age and the density of their place of residence and other risk factors. We conduct the study in Spain, a country with one of the oldest populations in Europe, and with a high concentration of urban population.

Method: Relational methods are used to match Eurostat's urbanization classifications with the accident database of Spain's Directorate General of Traffic so as to correlate each crash with the population density of the place where it occurred. A set of generalized linear models with random effects is fitted to analyze the relationship between population density and the bodily injury severity of the occupants of the vehicle(s) involved in a crash, measuring the effect of drivers' relocation and aging by geographical area.

Results: Independence of injury severity and the degree of urbanization was rejected at the 5% significance level. Of the total population, 53.8% lived in densely populated areas and 13.5% in rural areas, with the latter concentrating most crashes with fatalities: 4.3 times more than in urban areas (43.5 and 10.1%, respectively). Drivers living in rural areas were more likely to be associated with serious or fatal injuries when involved in a crash in urban and intermediate areas. Moreover, drivers aged over 75 were significantly more likely to be associated with serious and fatal injuries, especially when the crash occurred in urban areas.

Conclusions: The concentration of public services in densely populated areas obliges rural (most typically, elderly) individuals to drive longer distances to unfamiliar environments to acquire these services, particularly healthcare, both for themselves and those under their care. Policy decision-makers need to address this issue to reduce the number of victims, and demonstrate an awareness that the serious and fatal injuries suffered in motor vehicle crashes in more densely populated areas are also a rural health concern.

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1. Introduction

Many factors determine the risk of being injured in a road traffic accident; moreover, these factors change over time and their interaction is complex. The generational shift to older societies and the new mobility patterns they usher in are of concern to governments and mobility stakeholders alike (INE, 2022). Furthermore, the unequal spatial distribution of people and their different sociodemographic characteristics condition the effects of these demand patterns and appear likely to exacerbate existing differences (Gogola et al., 2018). People living in cities enjoy easier access to public services, such as hospitals and schools, with authorities opting to locate them in densely populated areas so as to serve the maximum number of people possible and to spread fixed costs (Camarero and Oliva, 2019; López Laborda and Salas, 2002; Porru et al., 2020). This ongoing concentration of population in cities in conjunction with rural depopulation hinders the achievement of economies of scale outside cities (Bock, 2019), which continue to concentrate more facilities over time, while the provision of local services in low-density areas continues to fall (Milbourne and Kitchen, 2014). Camarero and Oliva (2019) reported that Spain's rural inhabitants encounter greater obstacles in accessing primary healthcare (22%) and public transportation (21.7%) than urbanites do (7.4 and 4.3%, respectively). This trend is widespread throughout the EU, with some countries presenting a difference in rural and urban accessibility of more than 40 percentage points (Eurostat, 2012). As such, permanent rural residents, especially the elderly and households with children, have traditionally been forced to be more reliant on their private vehicles and to commute longer distances to urban centers where jobs, education and other services are concentrated (Poltimäe et al., 2022).

Many studies have shown that the relationship between distance driven and involvement in a motor vehicle crash is nonlinear (Boucher et al., 2013; Janke, 1991), with some suggesting that the increase in the number of accidents per driver per unit of time is roughly proportional to the square root of the distance driven (Elvik, 2023). Clark and Cushing (2004) provide evidence that increased distance between people and/or medical facilities – in essence the inverse of population density – is a determinant of mortality from vehicle collisions. Other studies have shown that the severity of traffic accidents is higher on highways than in urban areas (Beck et al., 2017; Raatiniemi et al., 2016; Zwerling, 2005), and that the frequency of accidents is also higher in rural areas, with over 52% of all road traffic fatalities in Spain in 2021 occurring on rural roads (European Commission, 2023). Indeed, the place where an accident takes place is a common factor in modeling, typically differentiating between accidents that occur in populated or in uninhabited areas. However, to the best of our knowledge, few studies have undertaken in-depth analyses of these differences, above all, as far as population density is concerned, by geographical area.

Here, we seek to determine how the severity of the injuries suffered by victims of a motor vehicle crash differs in relation to the population density of the area in which the accident occurs. Our goal is to contextualize traffic accidents in the geographical area in which they take place, based on whether it has a low, medium, or high population density. To do so, an exhaustive exercise has first to be conducted to determine the location of each accident and to assign to that place its corresponding population density. In addition, we analyze the influence of other variables related to the accident, namely, the vehicle, the driver, and the occupants, on the severity of the injuries. Specifically, we seek to determine the relationship between the population density of the place where the accident occurred and the age of the driver and other risk factors, and their impact on the injuries suffered. Ultimately, we wish to examine possible links between higher concentrations of the elderly in rural areas (resulting from decentralization) and the severity of bodily injuries incurred; yet, also, we seek to determine whether drivers from rural areas are more likely to be associated with serious or fatal injuries when involved in crashes in urban and intermediate areas. In our study, we control for the population density of the driver's residence, given that this may differ from the population density of the place in which the crash occurred.

We focus here on the specific case of Spain, one of the countries with the oldest populations in Europe, and with a very high concentration of population in its cities (Gutiérrez, 2020). In so doing, we draw on the accident database of the Directorate General of Traffic (DGT), focusing on accidents that occurred between 2016 and 2019, and combine this with the Eurostat classification of the degree of urbanization of Spanish municipalities, to attribute a population density to each geographical location at which an accident occurred. Although we also dispose of accident data for 2020 accidents, we opted to exclude them because they reflect the consequences of the SARS-CoV-2 epidemic on mobility. In the analysis, we include a wide range of regressors, among which we highlight the age of the drivers segmented as follows: under 65, between 65 and 75, and over 75.[1] From a methodological perspective, therefore, we evaluate the severity of injuries suffered by occupants of a vehicle involved in motor vehicle crashes in Spain according to the degree of urbanization, using univariate and multivariate analyses, and in this sense each vehicle is our unit of analysis. For each vehicle, we classify its global bodily injury (BI) severity level according to the maximum BI severity observed for its occupants and, in this sense, we establish four categories: i) non-BI damages, when none of the occupants suffers BI damages; ii) slight BI damages, when the greatest severity suffered by the occupants is slight; iii) severe BI damages, when the maximum category is serious and, iv) fatal, when at least one occupant is killed. We use generalized linear mixed models (GLMMs), which include random effects to accommodate dependency between observations in the data set and so can include the different vehicles involved in a crash (Santolino et al., 2022).

The analysis of driver longevity is not new. Researchers have highlighted that in numerous high-income countries, older drivers are disproportionately represented among the victims of road accident statistics (CDC, 2022; Lyman et al., 2002; Skyving et al.,

[1] Note that this age segmentation has been statistically validated in a previous study of motor vehicle crashes in Spain (Ayuso, M., Sánchez, R., Santolino, M., 2020).

2009; Yee et al., 2006). Many argue that the increased physical frailty of the elderly explains why they suffer worse crash outcomes (Shen and Neyens, 2015; Staplin et al., 2017), with less energy being required to produce tissue damage, damaging skeletal structures is easier, especially in older adults aged 75 years and above (Ang et al., 2017). Additionally, the consequences of an accident are more likely to be exacerbated by pre-existing health conditions (Gopinath et al., 2015; Welsh et al., 2006), while a reduction in tolerance to the forces triggered by a crash could account for a 60–95% increase in the death rate per distance travelled for people aged 60 or more (Li et al., 2003). It has also been reported that the loss of visual and cognitive capacities among the elderly leads to impaired driving and increases their likelihood of being involved in a crash (Doi et al., 2020), for example, they are more likely to fail to respect the right-of-way and to make inappropriate gap selections at intersections (Rubin et al., 2007; Oxley et al, 2006). However, other studies demonstrate that some older drivers are aware of their limitations (Rivera-Izquierdo et al., 2021) and self-regulate the number of kilometers they drive, either by reducing their exposure to challenging driving conditions, decreasing their overall mileage, changing how they drive or even ceasing to drive at all (Ang et al., 2019; Molnar et al., 2015; Molnar et al., 2018; Rolison et al., 2012; Papa et al., 2014).

Yet, the capacity of older drivers to self-regulate may be limited by their desire to maintain their lifestyle, the unavailability of family and friends to provide transport when required, or an unwillingness to ask them for help with transportation, and the lack of availability of public transport (Baldock et al., 2006; Betz et al., 2016). There is evidence that driving cessation has a detrimental effect on the social and physical health of older adults (Chihuri et al., 2015; Choi and DiNitto, 2016; Qin et al., 2019) but, while to date no country has fixed a maximum driving age, governments have gradually introduced tougher conditions and more frequent evaluations for the renewal of driving licenses (Asbridge et al, 2017; O'Byrne et al., 2015; Shen et al, 2020). Existing inequalities to access basic services, such as hospitals, especially for older adults in rural areas, are likely to be exacerbated, albeit that this runs counter to the Sustainable Development Goals of the 2030 Agenda (UN General Assembly, 2015; WHO, 2020) sponsored by the United Nations and national governments. In this regard, public policies will have to balance the potential risks to others and the elderly themselves from impaired driving, on the one hand, and the benefits the elderly derive from driving, a key instrumental activity of daily living that enhances their quality of life, on the other (Carr et al., 2019).

In this study, we analyze the connection between the population density where a crash occurs, the driver's age and the severity of the BI. The first relevant contribution of our research is to employ the European classification of the degree of urbanization in conjunction with Spain's official traffic accident statistics in an attempt at correlating each crash with the population density where it occurred. Secondly, we model the relationship between population density and the severity of the accident, measuring the effect of relocation and aging by geographical area on the bodily injuries suffered by the victims.

The rest of this paper is structured as follows. Section 2 presents the Eurostat methodology for determining the degree of urbanization of a municipality and its specific application to Spanish geography, as we seek to assign the correct population density to each place where a crash was recorded. In section 3 we detail the criteria used to structure the micro databases provided by Spain's DGT and identify the variables we opt to maintain. Additionally, we present the methodology used to model the severity of bodily injuries suffered. The main results of the analysis are presented in section 4, both at a descriptive statistical level as well as for the binomial logistic regression with random effects modelling. We conclude the paper with a discussion of these findings and present our main conclusions.

2. Contextualization

2.1. Composition of population density in Spain and distribution of motor vehicle crashes by zone

We use Eurostat's urbanization classification procedure (DEGURBA) to classify the degree of urbanization of Spain's municipalities. This methodology classifies each Local Administrative Unit (LAU) according to its population density and contiguity into three categories: "Cities" (densely populated areas), "Towns and suburbs" (intermediate density areas) and "Rural areas" (thinly populated areas). In the rest of this study we refer to the categories as 'Urban', 'Intermediate' and 'Rural', respectively.

The classification follows a two-step procedure. First, the EU territory is divided into 1-km^2 raster cells, which are classified based on population density and contiguity. Urban centers are defined as contiguous cells with a density of at least 1,500 inhabitants/km^2 and a minimum of 50,000 inhabitants. Urban clusters are defined as contiguous cells (including diagonals) with a density of at least 300 inhabitants/km^2 and a minimum of 5,000 inhabitants. Cells that are not labeled as urban centers or urban clusters are assigned to the "rural grid cell" category.

In the second step, each LAU is classified based on the share of its population living in urban clusters and urban centers. LAUs with at least 50% of their population living in urban centers are classified as densely populated areas; those with less than 50% of their population living in urban centers and less than 50% of their population living in rural grid cells are classified as intermediate density areas; and, those with at least 50% of their population living in rural grid cells are classified as thinly populated areas.

We have mapped Spanish municipalities by their respective degree of urbanization, according to Eurostat's 2018 classification (Fig. 1, left), and the natural logarithm of the number of crashes between 2016 and 2019 (Fig.1, right).

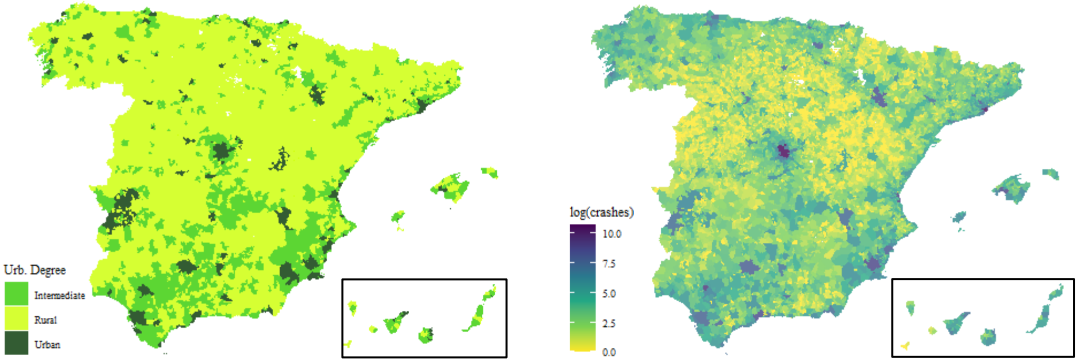

Fig. 1. Map of Spanish municipalities by degree of urbanization in 2018 (right) and natural logarithm of the number of motor vehicle crashes 2016–2019 (left).

Source: Based on LAU 2018 from Eurostat and DGT data sets.

The Spanish population is not evenly distributed, being essentially concentrated in the Mediterranean coast and provincial capitals of the interior. Cities tend to be surrounded by areas of intermediate population in the southern half of the country and by rural areas in nearly all the northern half with the exception of Catalonia. Motor vehicle crashes seem to correlate to the degree of urbanization as the more dense the population is, the higher the number of crashes recorded in the municipality. However, this comparison for rural areas is not as direct given the differences in the number of crashes depending on their geographical location.

2.2. Composition of the driver census by population density in Spain

Table 1 shows the evolution in the percentage of drivers (that is, individuals holding a valid driving license) and their share over the population by degree of urbanization. To obtain these percentages, we have combined data from Eurostat's annual correspondence table, which contains the degree of urbanization of each municipality, with the DGT's driver census by municipality.

We collected Spanish driver census data in December 2016, 2017, 2018, and 2021, the latest years for which the disaggregation by municipality was available. First, the driver census and the degree of urbanization data by municipality were summarized. Each table contained the name of a municipality together with the number of drivers in each year and the corresponding urbanization categorization. Then, for each year, the number of drivers conditional on the degree of urbanization of the municipality (urban, intermediate or rural) was summed. Finally, the number of drivers in each area was divided by the total to obtain their share.

When grouping these data, we faced two obstacles: first, the driver census by municipality was not available for years 2019 and 2020; and, second, the criteria change in the attribution of the degree of urbanization for 2017 was applied in the table corresponding to 2018 thus limiting comparability prior to that year. To address the first issue, the compound annual growth rate by degree of urbanization between 2018 and 2021 was calculated, and the 1-year estimated growth was applied to 2018's figures. In the case of the second issue, given that year-on-year changes tend to be small and non-significant when the criteria do not change, the degree of urbanization for 2018 was attributed to the number of drivers per municipality in 2016 and 2017.

Table 1. Drivers, population and drivers with respect to population by degree of urbanization, Spain 2016–2019 (%).

Year	Drivers			Population			Drivers with respect to population		
	Urban (%)	Intermediate (%)	Rural (%)	Urban (%)	Intermediate (%)	Rural (%)	Urban	Intermediate	Rural
2016	52.5	33.3	14.3	53.7	32.6	13.7	66.3	69.2	70.5
2017	52.4	33.4	14.2	53.7	32.6	13.7	66.4	69.6	70.3
2018	52.4	33.5	14.2	53.7	32.7	13.6	66.4	69.8	70.7
2019	52.2	33.6	14.1	53.8	32.7	13.5	65.9	69.9	70.9

Source: Based on DGT (2023) and Eurostat (2023).

In Table 1, the three columns corresponding to 'Drivers' show the distribution of Spanish drivers by the degree of urbanization in their municipality of residence. The three columns corresponding to 'Population' show the residential distribution of the general Spanish population aged 15 and above. Finally, the last three columns, labeled 'Drivers with respect to population' show the proportion of drivers relative to the total population, categorized by degree of urbanization.

Between 2016 and 2019, there was no noticeable change in the share of drivers by degree of urbanization. When comparing the distribution of drivers and population with respect to the degree of urbanization, the pattern that emerges is largely similar. However, the percentage of drivers in urban areas is smaller than their representation in the general population, while the opposite is the case for drivers in intermediate and rural areas. When evaluating the number of drivers with respect to the population by area, even though most of the population live in urban areas, people with valid driving licenses in these areas constitute the smallest percentage of the three areas considered. Conversely, rural areas concentrate the smallest percentage of the population but present the highest proportion of drivers, exceeding that of urban areas by 5 percentage points, with intermediate areas falling between the two.

3. Research design

3.1 Data

To study the effect of both driver and motor vehicle crash attributes on the severity of an accident by geographical area, four DGT datasets were used. Detailed information of police reports for all motor vehicle accidents between 2016 and 2019 involving at least one injured victim is available. Police officers monitor the health progression made by these victims over a 30-day period and update their reports accordingly. Each data set comprises a set of micro databases centered on a specific aspect of the accident: namely, traffic accident (Accident dataset), vehicles involved (Vehicle dataset), drivers (Driver dataset) and passengers (Passenger dataset). The degree of urbanization was attributed by linking the postal code of the crash location to the Eurostat data set (Urbanization dataset).

All the information from the different datasets is related by means of a relational model, employing a series of chained one-to-many relationships. In the Urbanization dataset, each unique postal code is attributed a population density classification. The postal code links this dataset and the Accident dataset, which includes the location of the accident. The Accident dataset has a unique ID for each traffic accident that links it to the Vehicle dataset, which contains the accident ID for each vehicle. The Vehicle, Driver and Passenger datasets have two identifiers, one for the accident and another for the specific vehicle in the accident, which are concatenated to create a joint accident and vehicle ID. The joint accident and vehicle ID links each vehicle to its driver and each driver to his or her passengers.

The complete database contains information for 398,590 police-reported crashes involving 672,439 vehicles for the period from January 2016 to December 2019. Occupants suffered no injuries in 283,097 (42.1%) of these vehicles, while there was at least one injured occupant in the remaining 389,342. Only those vehicles presenting complete records in line with our research requirements were selected, so we ended up with a database of 177,193 crashes involving 286,438 vehicles. When more than one vehicle was involved in a crash, they were all included as long as complete information for all vehicles involved in the crash was available.

The severity of the injuries in a vehicle was classified according to the worst injury suffered by one or more of the occupants. A vehicle with light injuries (*slight*) is one in which an occupant suffered minor injuries but hospitalization was not required. A vehicle with serious injuries (*serious*) is one in which at least one occupant required hospitalization for more than 24 h and did not die. Finally, a vehicle with fatal injuries (*fatal*) is one in which at least one occupant died within 30 days as a result of the crash. According to these criteria, 41.6% of the vehicles had occupants that presented no injuries, 52.7% had occupants with slight injuries, 4.5% had occupants with serious injuries, and 1.2% had occupants with fatal injuries.

The percentage of crashes by the degree of urbanization of the crash location and the injury severity of the vehicle(s) involved is disaggregated in Tables 2 and 3. Table 2 shows that 72.8% of vehicles involved in a crash in rural areas had at least one occupant who was injured, in contrast to 53% of vehicles in urban areas and 60.6% of vehicles in intermediate areas. The proportion of vehicles which had occupants that did not present any bodily injuries differs markedly between the areas. Thus, rural areas have the smallest share of occupants without injuries (none), 19.8 percentage points below that of urban areas, and concentrate more vehicle occupants in worse injury categories. Thus, the proportion of vehicles associated with serious bodily injuries in rural areas is 3.6 times greater than that in cities, while in the case of fatalities it is 8.5 times higher. Independence in the number of crashes between BI severity and degree of urbanization was rejected at the 5% significance level according to Pearson's chi-square test (p-value <2.2e-16).

Table 2. Distribution of BI severity of occupants of vehicles involved in a motor vehicle crash with victims by degree of urbanization of the crash location (Spain, 2016–2019).

Injury	Urban	Inter.	Rural	Total
None (%)	47.0	39.4	27.2	41.6
Slight (%)	49.9	54.1	59.8	52.7
Serious (%)	2.7	5.0	9.6	4.5
Fatal (%)	0.4	1.5	3.4	1.2
Total (%)	100	100	100	100

When examining the distribution of the degree of urbanization of the places where the crashes occurred differentiated by the BI severity of the vehicles involved, urban areas present the highest share of vehicles with none or slight injuries (Table 3). Vehicles with serious injuries are more evenly split although most are reported in intermediate areas (35%), while rural areas concentrate most vehicles with fatalities (43.5%), that is, 4.3 times more than urban areas (10.1%).

Table 3. Distribution of the degree of urbanization of the location where motor vehicle crashes with victims occurred by BI severity of vehicles involved (Spain, 2016–2019).

Area	None (%)	Slight (%)	Serious (%)	Fatal (%)	Total (%)
Urban	60.2	50.4	32	18.6	53.2
Inter.	29.7	32.1	35	37.9	31.3
Rural	10.1	17.5	33	43.5	15.4
Total	100	100	100	100	100

3.2 Risk factors

We analyze the factors that affect the severity of bodily injuries of the occupants of a vehicle involved in a crash based on the geographical area in which the accident took place. The variables included are shown in Table 4. Thus, for the driver, we consider age, sex, and place of residence; for the vehicle, we consider age, type, and number of occupants. In the case of the crash, we consider the degree of urbanization where the accident occurred as our segmentation variable, and a number of additional variables, including road pavement conditions, light and visibility, traffic flow, number of drivers involved in the crash, damage to the vehicle, and road type.

Driver ages are divided into three categories: 18–64, 65–75, and 76 and older. Initially, we considered just two groups: younger drivers (aged 18–64) and older drivers (65 and older), as we sought to stress the potential differences attributable to aging. Then, we split the older drivers into young-older (65–75) and old-older (76 or older), to account for the different outcomes on bodily injuries reported by Ayuso et al. (2020) when using the DGT's 2016 datasets.

Table 4. Description of variables

Name	Categories	Description	Mean*	Min	Max
Driver and vehicle					
Driver age	18– 64	Driver is aged below 65 years old (Reference category)	91.3%	0	1
	65–75	Driver is aged between 65 and 75 years old	6.0%	0	1
	>75	Driver is older than 75 years old	2.7%	0	1
Driver sex	Man	Driver is a man (Reference category)	71.4%	0	1
	Woman	Driver is a woman	28.6%	0	1
Driver residence	Urban	Densely populated areas (Reference category)	54.1%	0	1
	Intermediate	Intermediate populated areas	33.2%	0	1
	Rural	Thinly populated areas	12.7%	0	1
Vehicle age		Age of the vehicle involved in the crash	10.7	0	74
Vehicle type	Car	Passenger cars (Reference category)	70.4%	0	1
	Heavy vehicles	Trucks, tractors, and other heavy vehicles	5.5%	0	1
	Motorcycles	Motorcycles and quads	16.5%	0	1
	Van	Vans and minibuses	7.6%	0	1
Occupants		Number of occupants in the vehicle (including the driver)	1.4	1	61
Crash					
Road conditions	Optimal	Optimal driving conditions of the road surface (Reference category)	86.0%	0	1
	non-optimal	Non-optimal driving conditions of the road surface (wet, frozen, muddy)	14.0%	0	1
Light conditions	Optimal	Driving with good visibility (Reference category)	71.2%	0	1
	Moderate	Driving with moderate visibility	6.5%	0	1
	not optimal	Driving without appropriate visibility	22.3%	0	1
Traffic conditions	White	Traffic is fluid and normal (Reference category)	68.4%	0	1
	Green	The traffic is so intense that it does not allow the maximum speed allowed on the road to be reached	19.3%	0	1
	Other	Intermittent or interrupted traffic	12.3%	0	1
Vehicle damage	No damage	Vehicle has no damage (Reference category)	7.7%	0	1
	Frontal	Vehicle has the most damage in the frontal area	49.4%	0	1
	Rear	Vehicle has the most damage in the rear area	18.8%	0	1

	Side	Vehicle has the most damage on one of its sides	24.1%	0	1
Road type	Local	City streets and township roads (Reference category)	45.7%	0	1
	Conventional	Minor arterials	31.1%	0	1
	High speed	Highways, freeways, and other principal arterials	19.8%	0	1
	Other	Subsidiary roads, unpaved roads, cycling lanes, and others	3.4%	0	1
Number of drivers		Number of drivers involved in the crash	2.0	1	63
Crash location urbanization	Urban	Densely populated areas (Reference category)	53.2%	0	1
	Intermediate	Intermediate populated areas	31.3%	0	1
	Rural	Thinly populated areas	15.4%	0	1
Vehicle injury severity					
Slight injuries		Vehicle in which a slight injury is the most severe injury	52.7%	0	1
Serious injuries		Vehicle in which a serious injury is the most severe injury	4.5%	0	1
Fatal injuries		Vehicle in which a fatal injury is the most severe injury	1.2%	0	1

* Relative frequency in % for categorical variables.

3.3 Generalized linear model with random effects

Our analysis focuses on the relationship between a set of risk factors and the injury severity of the occupants of a vehicle involved in a crash, where the unit of observation is the vehicle involved in a crash. We include three dependent binary variables: a vehicle with light injures (*l)*, a vehicle with serious injuries (*s*) and a vehicle with fatalities (*f*). Generalized linear models (GLMs) for binary variables assume that observations are independent. However, when multiple vehicles are involved in a crash, the injury severity of occupants of different vehicles could presumably be correlated. When data present correlated clusters, generalized linear mixed models (GLMMs) are a more appropriate specification (Lulu et al., 2017; Washington et al., 2020). GLMMs are an extension of GLMs that incorporate random effects for the analysis of multilevel data.

The GLM relates the conditional mean of the distribution μ^j for the vehicle injury severity j, $j\epsilon\{l, s, f\}$, and the linear regression through the link function g as follows: $g(\mu_i^j) = \eta_i = x_i^{\mathrm{T}}\beta^j$ for the i-th vehicle, i=1,…, I, where η_i is the linear predictor, β^j is the vector of the regression coefficients and x_i is the vector of regressors. We focus on a binomial distribution with a canonical function, $g(\mu_i^j) = \frac{\pi_i^j}{1-\pi_i^j}$, where π_i^j is the probability that vehicle i presents an injury severity j. In this case, the binomial specification is equivalent to the logit regression model (McCullagh and Nelder, 1989).

The GLM for discrete variables assumes that observations are independent. Now we introduce a Q-dimension vector of cluster-specific parameters $\Theta_n^j = (\Theta_{n1}^j, \ldots, \Theta_{nQ}^j)$ and a vector z_{ni} of predictors corresponding to the random effects, for n=1,…,N. In our case n indicates the crash and only one cluster-specific parameter is considered, so Θ_n^j and z_{ni} are scalars. In the GLMM with a cluster-specific variable, the conditional mean π_{ni}^j is regressed on the predictors as follows: $\pi_{ni}^j/(1-\pi_{ni}^j) = x_{ni}^{\mathrm{T}}\beta^j + z_{ni}\Theta_n^j$. The constant term of the linear predictor is no longer the same for all observations but now varies for each group of vehicles involved in the same crash. Thus, unobserved individual-specific heterogeneity associated with the crash in which the vehicle was involved is introduced into the regression modeling.

4. Results

4.1 Descriptive statistics

The characteristics of the parties involved in a crash differ with the degree of urbanization, as illustrated by the variables presented in Table 5. The differences in proportions tend to be greater when comparing the injury severity levels by different degrees of urbanization, i.e., comparing serious injuries in the three areas, rather than when making a comparison of the proportion of different BI categories within the same area, i.e., comparing the proportions of the three injury severities in urban, intermediate and rural areas. Pearson's chi-square tests for each of these categorical variables reject the fact that the distribution by the degree of urbanization of the crash location are the same for all variables and BI categories.

Table 5. Descriptive statistics of risk factors by degree of urbanization of crash location and bodily injury severity of vehicle(s) involved [(*)]

	Slight				Serious				Fatal			
Crash location urbanization	Urban	Inter.	Rural		Urban	Inter.	Rural		Urban	Inter.	Rural	
Sample size for vehicles with injured occupants	76,001	48,487	26,446		4,131	4,525	4,260		639	1,302	1,493	
Categorical variables (relative frequency in %)												
Driver age												
Under 65 years old	95.1	91.4	87.8		93.6	89.9	85.5		88.0	83.3	81.9	
65–75 years old	3.7	5.9	7.7		4.7	6.7	9.6		7.8	9.4	10.8	
Over 75 years old	1.2	2.8	4.4	a	1.7	3.4	4.9	a	4.2	7.4	7.4	a
Driver sex												
Man	67.5	67.1	72.0		85.8	83.2	84.3		89.7	87.3	89.2	
Woman	32.5	32.9	27.9	a	14.2	16.8	15.7	a	10.3	12.8	10.8	
Driver residence												
Urban	81.0	23.1	30.1		81.6	22.0	30.2		72.9	22.2	28.9	
Intermediate	14.9	67.0	24.7		14.1	66.9	24.4		18.8	63.9	24.7	
Rural	4.1	9.9	45.1	a	4.3	11.1	45.4	a	8.3	13.9	46.4	a
Vehicle type												
Car	59.1	71.9	72.9		26.8	48.8	56.5		42.7	55.0	61.1	
Heavy vehicles	2.5	3.2	5.1		2.7	4.2	5.9		5.0	6.7	9.9	
Motorcycles	34.4	17.9	13.8		67.9	41.2	31.9		48.2	30.6	21.8	
Van	4.0	7.0	8.1	a	2.6	5.8	5.7	a	4.1	7.8	7.2	a
Road conditions												
Optimal	85.7	84.7	77.6		88.3	87.5	82.2		90.1	87.7	82.3	
non-optimal	14.3	15.3	22.3	a	11.7	12.5	17.8	a	9.9	12.3	17.8	a
Light conditions												

Optimal	69.5	70.7	71.6		62.5	63.9	72.4		56.7	61.3	65.9	
Moderate	6.6	6.5	5.4		6.4	6.5	4.7		6.4	6.2	5.3	
non optimal	23.8	22.8	22.9	a	31.1	29.6	22.9	a	36.9	32.5	28.8	a
Traffic conditions												
White	63.2	73.0	87.5		68.1	80.3	91.1		82.5	88.3	90.7	
Green	21.5	17.6	9.3		22.1	15.7	7.7		13.6	9.5	7.7	
Other	15.4	9.4	3.1	a	9.8	4.0	1.3	a	3.9	2.2	1.6	a
Vehicle damage												
No damage	2.4	1.0	0.7		1.6	0.8	0.7		0.8	0.4	0.5	
Frontal	41.7	53.5	61.9		53.0	63.4	61.9		58.4	62.4	62.6	
Rear	25.7	21.1	11.2		5.7	5.1	4.3		7.7	5.7	4.6	
Side	30.2	24.5	26.1	a	39.7	30.7	33.1	a	33.2	31.6	32.2	
Road type												
Local	63.4	24.8	4.4		58.6	16.5	3.5		31.3	6.6	2.5	
Conventional	11.9	49.5	73.0		19.4	62.1	76.8		33.5	67.4	76.8	
High-speed	22.2	21.0	18.2		18.2	15.5	14.2		30.7	19.7	14.1	
Other	2.6	4.7	4.3	a	3.8	5.9	5.5	a	4.5	6.2	6.6	a
Numerical variables (mean and standard deviation -in parentheses)												
Vehicle age	9.9	11.4	12.1	a	10.3	11.6	12.3	a	11.1	12.7	13.1	a
	(6.4)	(6.6)	(6.7)		(6.8)	(6.8)	(7.2)		(7.1)	(7.0)	(7.5)	
Occupants	1.5	1.6	1.6	a	1.3	1.5	1.6	a	1.5	1.6	1.6	a
	(0.9)	(1.0)	(1.1)		(0.7)	(1.1)	(1.6)		(1.3)	(2.3)	(1.4)	
Number of drivers	2.1	1.9	1.6	c	1.8	1.7	1.5	a	1.7	1.7	1.6	b
	(0.8)	(0.9)	(1.0)		(0.8)	(0.8)	(0.8)		(1.0)	(1.0)	(0.7)	

(*) Statistical independence between the risk factors and the degree of urbanization of the crash location was evaluated. Pearson's chi-square test for independence in categorical variables and the one-way ANOVA for differences in the means in numerical variables were computed. a. P-value < 0.01, b. P-value < 0.05, c. P-value < 0.1

It is worth highlighting that less densely populated areas (primarily rural) are associated with a higher share of older drivers involved in motor vehicle crashes with injuries, and with a higher proportion of vehicles involved in crashes that occur when traffic conditions are fluid. Male drivers are involved in a markedly higher proportion of motor vehicle crashes with injured occupants than women drivers; moreover, in less densely populated areas, a greater share of men are recorded as drivers of vehicles associated with slight injuries. As regards driver residence, drivers in each of the three categories (i.e., urban, intermediate and rural) suffer the most crashes in their own area of residence, regardless of the BI classification. For all BI levels, the proportion of motorcycles involved in an accident is significantly higher in urban areas compared to the rest; in contrast, the proportion of passenger cars and heavy vehicles is higher in less densely populated areas.

Vehicles with injured occupants in rural and intermediate areas were involved in more crashes while driving in non-optimal road conditions. Frontal damage to vehicles tends to be more prevalent in intermediate and rural areas, while urban areas presented a greater prevalence of rear and side damage. Finally, road types present the greatest proportional differences. Thus, local roads in urban areas present the highest proportion of crashes for all BI injuries, significantly more than on these roads in intermediate and, especially, rural areas. The opposite is the case for conventional roads, with rural areas presenting the highest proportions, with intermediate areas at some distance albeit this gap closes as the severity of the BI injury increases. As for high-speed roads, the difference is most noticeable in the case of fatal injuries, where the proportion of vehicles recording fatalities in urban areas doubles that in the other two areas.

4.2 Model selection

The logit regression model with random effects described in section 3.3 is fitted to explain the injury severity based on the risk factors included in Table 4. Nine regression models combining the three degrees of urbanization and the three injury levels are considered. To dispose of a benchmark, the same number of regression models without random effects were fitted. We present the Akaike information criteria (AIC) and the Bayesian information criteria (BIC) for the regressions in Table 6. The inclusion of random effects led to the lowest AIC and BIC in six of the models, i.e., all the models except those for which we evaluated vehicles associated with slight injuries. Although the differences are not large, the consistent improvement in the information criteria across most of the regressions is a sign of the presence of heterogeneity in the data and the way in which GLMMs can help to partially capture it.

Table 6. Comparison of logit regressions with and without random effects

Injury	Degree Urb.		Without Random Effects	With Random Effects
Slight	Urban	AIC	165,383	-
		BIC	165,611	-
Slight	Intermediate	AIC	108,003	108,005
		BIC	108,219	108,230
Slight	Rural	AIC	53,641	53,643
		BIC	53,841	53,851
Serious	Urban	AIC	31,552	31,510
		BIC	31,780	31,748
Serious	Intermediate	AIC	31,336	31,242
		BIC	31,552	31,468
Serious	Rural	AIC	25,948	25,905
		BIC	26,148	26,113
Fatalities	Urban	AIC	6,997	6,984
		BIC	7,225	7,223
Fatalities	Intermediate	AIC	12,119	12,103
		BIC	12,335	12,329
Fatalities	Rural	AIC	12,475	12,464
		BIC	12,675	12,673

4.3 Model estimation results

Table 7 shows the estimated coefficients for the selected logistic regression models by injury type and the degree of urbanization of the crash location. Logit regression models were preferred without random effects for vehicles in crashes classified as slight injury severity and with random effects for those classified as serious or fatal. A negative (positive) coefficient indicates a decrease (increase) in the expected probability of the maximum injury severity in the vehicle being slight, serious and fatal, respectively.

Table 7. Coefficient estimates of the logistic regression with random effects according to the degree of urbanization of the crash location and the maximum injury severity by vehicle.

		Slight			Serious			Fatal		
		Urban	Inter.	Rural	Urban	Inter.	Rural	Urban	Inter.	Rural
	Intercept	-3.30a	-2.78a	-1.86a	-6.07a	-5.47a	-4.49a	-8.17a	-8.04a	-6.08a
Driver age	Under 65 years old (Ref.)	-	-	-	-	-	-	-	-	-
	Between 65–75 years old	-0.30a	-0.20a	-0.15a	0.27a	0.10	0.27a	0.67a	0.47a	0.36a
	Above 75 years old	-0.27a	-0.12a	-0.09c	0.39a	0.12	0.12	1.10a	0.87a	0.47a
Driver sex	Man (Ref.)	-	-	-	-	-	-	-	-	-
	Woman	0.58a	0.54a	0.59a	-0.37a	-0.30a	-0.30a	-0.82a	-0.62a	-0.76a
Driver residence	Urban (Ref)	-	-	-	-	-	-	-	-	-
	Intermediate	-0.10a	0.04b	0.03	0.06	0.06	0.00	0.10	0.11	0.01
	Rural	-0.15a	0.02	-0.08a	0.25a	0.22a	0.05	0.60a	0.36a	0.00
Occupants		0.80a	0.38a	0.15a	0.14a	0.09a	0.10a	0.15a	0.08a	0.04b
Drivers		-0.21a	-0.37a	-0.55a	-0.32a	-0.33a	-0.28a	-0.52a	-0.30a	-0.22a
Vehicle age		0.02a	0.01a	0.01a	0.03a	0.02a	0.02a	0.02a	0.03a	0.02a
Road conditions	Optimal (Ref.)	-	-	-	-	-	-	-	-	-
	Non-optimal	0.31a	0.34a	0.31a	-0.28a	-0.17a	-0.13a	-0.59a	-0.25a	-0.20a
Light conditions	Optimal (Ref.)	-	-	-	-	-	-	-	-	-
	Moderate	-0.04c	-0.06b	0.05	0.10	0.16b	0.03	0.23	0.22c	0.19
	Non-optimal	-0.01	0.00	0.04c	0.40a	0.40a	0.17a	0.57a	0.47a	0.46a
Traffic conditions	White (Ref.)	-	-	-	-	-	-	-	-	-
	Green	-0.13a	-0.10a	0.02	0.07	-0.02	-0.12c	-0.45a	-0.52a	-0.07
	Other	-0.20a	-0.18a	0.01	-0.19a	-0.54a	-0.59a	-1.54a	-1.22a	-0.28
Vehicle damage	No damage (Ref.)	-	-	-	-	-	-	-	-	-
	Frontal	1.81a	2.46a	2.41a	1.62a	1.90a	1.73a	2.25a	2.31a	1.88a
	Rear	2.58a	3.02a	2.52a	0.62a	0.81a	0.88a	1.45a	1.36a	1.09a
	Side	1.85a	2.47a	2.32a	1.26a	1.61a	1.66a	1.85a	2.23a	1.92a
Vehicle type	Car (Ref.)	-	-	-	-	-	-	-	-	-
	Heavy vehicles	-0.23a	-0.85a	-0.98a	0.34a	-0.06	-0.16b	0.27	0.21c	0.24b
	Motorcycle	2.61a	1.39a	0.27a	2.31a	1.74a	1.33a	1.52a	1.17a	0.62a
	Van	-0.28a	-0.23a	-0.15a	0.02	-0.02	-0.23a	-0.04	0.12	-0.09
Road type	Local (Ref.)	-	-	-	-	-	-	-	-	-

Conventional	0.34a	0.36a	0.49a	1.00a	0.93a	0.55a	1.88a	1.71a	0.85a
High-speed	0.48a	0.61a	0.69a	0.75a	0.84a	0.62a	1.79a	1.80a	0.75a
Other	0.19a	0.22a	0.36a	0.67a	0.76a	0.56a	1.33a	1.53a	1.09a
SD(Random effect)	-	-	-	0.73	0.80	0.65	1.01	0.82	0.69

a. P-value < 0.01. b. P-value < 0.05. c. P-value < 0.1

The significance of the effect of driver age differs according to the degree of urbanization. For slight and fatal injuries, the direction of the effects of age are consistent by injury type across urbanization areas for drivers aged 65–75 and those aged over 75, as the likelihood of crashes with slight injuries falls with older drivers while that of fatal accidents increases. However, in the case of serious injuries, we find that drivers aged over 75 are significantly more likely to cause injuries in an accident that occurs in urban areas than they are in intermediate and rural areas where there is no significant difference in this likelihood with drivers below the age of 65. The effects of age seem to be less relevant as the density of the population falls.

When evaluating the sex of the driver, women are more likely in all three areas to cause slight injuries to their vehicles' occupants and less likely to cause them serious or fatal injuries. Drivers resident in rural areas are significantly less likely to be involved in accidents resulting in slight injuries when driving in urban areas, but more likely to be involved in accidents with serious or fatal injuries in crashes in urban and intermediate areas. This effect is greater in urban areas, especially in crashes involving fatal injuries. These same drivers (rural residents) are as likely to suffer serious and fatal injuries in rural areas as urban drivers. All three levels of BI are positively associated with the number of vehicle occupants. The more occupants there are in a car, the greater is the likelihood of one of them suffering an injury. The size of this effect is greater in urban areas. In contrast, the greater the number of drivers (i.e., vehicles) involved in a crash reduces the likelihood of occupants suffering injuries of any kind. The significance of road conditions is similar for all areas; thus, non-optimal conditions increase the likelihood of slight injuries, while they reduce it for serious and fatal injuries.

Moderate light conditions do not affect the likelihood of injury in rural areas, while they reduce the likelihood of slight injuries in urban and intermediate areas and increase it for serious and fatal injuries in intermediate areas. Non-optimal light conditions increase the likelihood of all injuries except for slight injuries in urban and intermediate areas. An evaluation of traffic conditions shows that less fluid traffic flows seem to be associated with a reduction in slight and fatal injuries when the crash takes place in urban and intermediate areas, as well as in serious injuries in rural areas.

As for the actual vehicles involved in the crash, heavy vehicles are associated with a greater reduction in the likelihood of occupants' suffering slight injuries in less densely populated areas, while in the case of serious injuries, heavy vehicles increase this likelihood of BI in urban areas but reduce it in rural areas. Accidents involving motorcycles increase the likelihood of all injuries in all areas; however, the less densely populated an area is, the smaller the increase in the likelihood of injury is. Finally, all other road types are significantly more dangerous than local roads for all three degrees of urbanization, the effects being greatest in the case of slight injuries and lowest in those of serious and fatal injuries in rural areas.

5. Discussion

It has been well documented in the literature that most drivers crash at locations close to their homes (Burdett et al., 2018; Chen et al., 2005; Steinbach et al., 2013), it being argued that familiarity increases proneness to crashes as a result of driving processes becoming more automated. This, in turn, leads to more distractions and non-driving-related thoughts, which could slow drivers' reactions down to external stimuli (Intini et al., 2018). Studies further contend that the more familiar drivers are with their road environment, the more they seek to minimize their travel time, typically at the expense of an increased risk of accident due to speeding and dangerous driving (Intini et al., 2016; Noland, 2013). Thus, it might be assumed that drivers unfamiliar with their environment are safer, because they pay more attention to the traffic and are more aware of their surroundings (Mason et al., 2007), so even if they have to make a greater cognitive effort which might increase the risk of an accident, their increased attention factor outweighs this danger. The univariate analysis reported here validates these findings: more crashes occur in more densely populated areas with most of them involving drivers from that area; however, the proportion of injuries actually rises as the population density of the area falls, a finding that is also well documented in the literature (Blatt and Furman, 1998; Zwerling et al., 2005). Here, it should be stressed that we have not opted to use count data models for crashes and we have not evaluated the likelihood of the occurrence of motor vehicle accidents, rather our focus has been on the level of injuries presented by the occupants of each vehicle. When the argument regarding a driver's 'familiarity' with his or her road environment is made in the literature, it is employed primarily to frame differences in the crash rate rather than in the injury rate by either crash location or driver residence, although some studies, most notably Burdett et al. (2018), also provide validation that the familiarity effect also applies to all levels of injury.

However, when we controlled for key driver and crash characteristics, we obtained results contrary to what we might expect from the 'familiarity' argument insofar as driving in a familiar environment does not increase the risk of injury. Indeed, only drivers from rural areas present a significantly higher likelihood of suffering worse injuries when driving outside areas similar to those of their place of residence. In this respect, our findings run contrary to those obtained by other researchers, including Donaldson et al. (2006), who reported that it was drivers from urban counties that presented the highest risk of fatalities when involved in rural as opposed to urban crashes; Chen et al. (2009), who observed no difference in the risk of injurious crashes by place of residence among young drivers; and, in part, Shrira and Noguchi (2016), who found that urban residents presented a substantially higher fatality risk than rural residents when driving in rural areas. However, in line with our results, the latter authors also found that rural residents presented higher fatality rates than urban residents on urban roads, as did Keeves et al. (2019) in their literature review focused on geographical location and injury outcomes, where they concluded that 93% of the studies presenting mortality statistics had significantly higher fatality outcomes for those injured in rural areas or for rural residents. This increased risk of injury among rural drivers in more densely populated areas might be linked to a lack of familiarity with their road environment, denser traffic, a more hazardous environment or even greater fatigue due to the longer distance driven or, potentially, Spanish urban and suburban drivers may have safer driving habits, as seems to be the case in America (Rakauskas et al., 2009). Another potential explanation might have a methodological basis. Although previous studies have used ZIP codes to study the relationship between crash characteristics and those injured (Clark, 2003; Lee et al., 2014; Lerner et al., 2001), the consideration of crash location and driver residence by area is not a common practice in the literature, seemingly because researchers lack one of the variables, the definitions of the areas might differ categorically or they may instead opt for a numerical variable (distance in km or miles). A more detailed analysis of rural drivers on urban roads may well be needed to shed greater light on this gap in injury severity.

According to our findings, conditions characterized by higher traffic volumes seem to increase levels of safety, with injuries of all types being reduced in urban and intermediate areas. Similar outcomes have been reported by Hadayeghi et al. (2003) and Noland and Oh (2004), who find a negative relationship between the level of traffic congestion and fatal crashes, while Li et al. (2013), accounting for geographical location, detected a negative relationship between urban traffic and fatal crashes, and noted that traffic accidents in rural areas have a higher likelihood of fatalities, in line with the outputs of our models herein. It is reasonable to assume that in conditions of more intense traffic, driving speeds are reduced and, in the case of a crash, the severity of injuries would not be so great. Nevertheless, we do not detect the absence of this safety effect for slight and fatal injuries in rural areas.

In urban areas, our models indicate that drivers over the age of 75 years are more likely to have a passenger that suffers serious injuries than are drivers under the age of 65, while the likelihood of a driver over the age of 64 having a passenger that suffers a fatal injury following a crash increases as the density of the population of the area increases. Some of the obvious challenges the elderly face when driving in urban environments have been identified by Payyanadan et al. (2018): namely, driving in heavy traffic, problems taking alternative routes when a primary route cannot be taken, poor understanding of certain driving rules, and problems associated with an awareness of differing speed limits on certain roads. To these factors we should add the compounding effects of the gradual loss of visual and cognitive capabilities that the elderly experience. However, having said that, our outcomes contradict those reported for Australia by Thompson et al. (2010) and Thompson et al. (2013), who find that older urban drivers are associated with a safer environment being characterized by less serious injuries, while older rural drivers were the most likely to present serious or fatal injuries following a crash.

The inclusion of random parameters in the data modelling process appears to be an improvement on the use of conventional logistic regression, showing itself to be, in line with other studies (Anastasopoulos and Mannering, 2011; Gkritza and Mannering, 2008), a better fit. In the case of both serious and fatal injuries, we corroborate the existence of dependence between the injuries of the occupants of vehicles involved in the same crash.

This study is not without its limitations, First, we have assumed that the factors impacting injury severity are stable overtime; however, Mannering (2018) and Islam and Mannering (2020) demonstrate that some caution is required in this respect. Additionally, in terms of other potential regressors we might have included in our study, we should recognize the fact that we are unable to validate who the at-fault driver is in our data set of police reports. While police officers issue an opinion, ultimate responsibility may be contested and modified by the judge at trial depending on the legal implications of the accident. Here, responsibility for the crash would have been a good proxy for at-fault driving and, together with its potential interactions, would certainly have enhanced our understanding of the reasons for the greater likelihood of injury of rural drivers in urban settings. Finally, efforts to compare our results with those in the extant literature have been hampered by the absence of a standardized approach to the categorization of rural, intermediate and urban areas. However, arguably the main contribution of this paper has been to demonstrate the practical utility of Eurostat's degree of urbanization framework when categorizing such areas. This framework is characterized above all by its simplicity and methodological transparency, given that the categorizations are publicly available. Significantly, employing this categorization enables more robust comparisons to be made, not only with other EU member states, but also with other geographical regions where the methodology is applied.

Finally, this study has highlighted how the effects of crash characteristics can differ depending on the location of the accident. Interestingly, as we delve deeper into this research field, more questions related to motor vehicle crashes are raised in our effort to obtain a more comprehensive understanding of them. Indeed, future studies could usefully examine crashes that occur outside a driver's home municipality but in a location with the same degree of urbanization. Additionally, a further line of fruitful investigation would be the study of injury outcomes within a vehicle, with a specific focus on how individual occupant characteristics such as age, sex, and other variables contribute to differences in these outcomes.

6. Conclusions

The study reported here has sought to offer a comprehensive understanding of how the degree of urbanization impacts occupant injuries in motor vehicle crashes, assessing the influence of both the location of the crash and the driver's origin on injury outcomes. In an effort at providing a broader perspective of the effects of a crash's characteristics by level of injury and location, rather than focusing on a single urbanization category (i.e., urban, suburban, or rural) and assessing only one type of injury (i.e., serious or fatal), all possible combinations have been considered in our analysis.

Drivers hailing from rural areas are more likely to sustain serious or fatal injuries when involved in crashes within urban or intermediate areas. Although the influence of a driver's age seems consistent across all areas, the accelerated aging of rural areas and the growing population of elderly drivers seems likely to result, on average, in more older victims and more severe crash outcomes. The current increase in urban population and the ongoing concentration of public services in densely populated areas continue to oblige the rural elderly to drive longer distances to unfamiliar environments to acquire these services, particularly healthcare, both for themselves and those under their care. Addressing this issue effectively requires a joint institutional response from different government bodies, not just the traffic authorities but also those responsible for services provision. It is apparent that to reduce the number of victims from rural areas, analyses must extend beyond the obvious rural factors and focus their attention also on the journeys that rural residents make to cities, in an awareness that both serious and fatal injuries from motor vehicle crashes in more densely populated areas are also a rural health concern.

References

Anastasopoulos, P., Mannering, F.L., 2011. An empirical assessment of fixed and random parameter logit models using crash- and non-crash-specific injury data. Accid. Anal. Prev., 43(3), 1140–1147. https://doi.org/10.1016/j.aap.2010.12.024

Ang, B.H., Chen, W.S., Lee, S.W.H., 2017. Global burden of road traffic accidents in older adults: A systematic review and meta-regression analysis. Arch. Gerontol. Geriatr., 72, 32–38. https://doi.org/10.1016/j.archger.2017.05.004

Ang, B.H., Oaxley, J., Chen, W.S., Lee, S.W.H., 2019. Factors and challenges of driving reduction and cessation: A systematic review and meta-synthesis of qualitative studies on self-regulation. J. Saf. Res., 69, 101–108. https://doi.org/10.1016/j.jsr.2019.03.007

Asbridge, M., Desapriya, E., Ogilvie, R., Cartwright, J., Mehrnoush, V., Ishikawa, T., Nuwan Weerasinghe, D., 2017. The impact of restricted driver's licenses on crash risk for older drivers: A systematic review. Transport. Res. A: Policy Pract., 97, 137–145. https://doi.org/10.1016/j.tra.2017.01.006

Ayuso, M., Sánchez, R., Santolino, M., 2020. Does longevity impact the severity of traffic crashes? A comparative study of young-older and old-older drivers. J. Saf. Res., 73, 37-46.

Baldock, M.R.J., Mathias, J.L., McLean, A.J., Berndt, A., 2006. Self-regulation of driving and its relationship to driving ability among older adults. Accid. Anal. Prev., 38(5), 1038–1045. https://doi.org/10.1016/j.aap.2006.04.016

Beck, L.F., Downs, J., Stevens, M.R., Sauber-Schatz, E.K., 2017. Rural and Urban Differences in Passenger-Vehicle–Occupant Deaths and Seat Belt Use Among Adults — United States, 2014. MMWR. Surveillance Summaries, 66(17), 1–13. https://doi.org/10.15585/mmwr.ss6617a1

Betz, M.E., Jones, J., Genco, E., Carr, D.B., DiGuiseppi, C., Haukoos, J.S., Lowenstein, S.R., Schwartz, R., 2016. Perspectives on Tiered Older Driver Assessment in Primary Care Settings. The Gerontol., 56(2), 272–281. https://doi.org/10.1093/geront/gnu038

Blatt, J., Furman, S.M., 1998. Residence location of drivers involved in fatal crashes. Accid. Anal. Prev., 30(6), 705–711. https://doi.org/10.1016/S0001-4575(98)00014-1

Bock, B.B., 2019. Rurality and multi-level governance: Marginal rural areas inciting community governance. In The Routledge Companion to Rural Planning (1st ed., pp. 103–113). Routledge. https://doi.org/10.4324/9781315102375-11.

Burdett, B.R.D, Starkey, N.J., Charlton, S.G., 2018. Characteristics of the close to home crash. Saf. Sci., 105, 222–227. https://doi.org/10.1016/j.ssci.2018.02.020

Camarero, L., Oliva, J., 2019. Thinking in rural gap: mobility and social inequalities. Palgrave Communications, 5(1). https://doi.org/10.1057/s41599-019-0306-x

Carr, D.B., Stowe, J.D., Morris, J.C., 2019. Driving in the elderly in health and disease. Handbook of Clinical Neurology, 167, 563–573. https://doi.org/10.1016/B978-0-12-804766-8.00031-5

Center for Disease Control and Prevention, 2022. Older Adult Drivers. Available from: https://www.cdc.gov/transportationsafety/older_adult_drivers/index.html. Accessed 13 July 2023.

Chen, I.G., Durbin, D.R., Elliott, M.R., Kallan, M.J., Winston, F.K., 2005. Trip characteristics of vehicle crashes involving child passengers. Inj. Pre., 11(4), 219–224. https://doi.org/10.1136/ip.2004.006767

Chen, H.Y., Ivers, R.Q., Martiniuk, A.L.C., Boufous, S., Senserrick, T., Woodward, M., Stevenson, M., Williamson, A., Norton, R., 2009. Risk and type of crash among young drivers by rurality of residence: Findings from the DRIVE Study. Accid. Anal. Prev., 41(4), 676–682. https://doi.org/10.1016/j.aap.2009.03.005

Chihuri, S., Mielenz, T.J., DiMaggio, C.J., Betz, M.E., DiGuiseppi, C., Jones, V. C., Li, G., 2016. Driving Cessation and Health Outcomes in Older Adults. J. Am. Geriatr. Soc., 64(2), 332–341. https://doi.org/10.1111/jgs.13931

Choi, N.G., DiNitto, D.M., 2016. Depressive Symptoms Among Older Adults Who Do Not Drive: Association With Mobility Resources and Perceived Transportation Barriers. The Gerontol., 56(3), 432–443. https://doi.org/10.1093/geront/gnu116

Clark, D.E., Cushing, B.M., 2004. Rural and urban traffic fatalities, vehicle miles, and population density. Accid. Anal. Prev., 36(6), 967–972. https://doi.org/10.1016/j.aap.2003.10.006

Clark, D.E., 2003. Effect of population density on mortality after motor vehicle collisions. Accid. Anal. Prev., 35(6), 965-971.

Doi, T., Ishii, H., Tsutsumimoto, K., Nakakubo, S., Kurita, S., Shimada, H., 2020. Car Accidents Associated with Physical Frailty and Cognitive Impairment. Gerontol., 66(6), 624–630. https://doi.org/10.1159/000508823

Donaldson, A.E., Cook, L.J., Hutchings, C.B., Dean, J.M., 2006. Crossing county lines: The impact of crash location and driver's residence on motor vehicle crash fatality. Accid. Anal. Prev., 38(4), 723–727. https://doi.org/10.1016/j.aap.2006.01.002

Elvik, R., 2023. Driver mileage and accident involvement: A synthesis of evidence. Accid. Anal. Prev., 179, 106899–106899. https://doi.org/10.1016/j.aap.2022.106899

European Commission, 2023. Road safety in the EU: fatalities below pre-pandemic levels but progress remains too slow. Available from: https://transport.ec.europa.eu/news-events/news/road-safety-eu-fatalities-below-pre-pandemic-levels-progress-remains-too-slow-2023-02-21_en. Accessed 13 July 2023.

Eurostat, 2012. Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation.

Gkritza, K., Mannering, F.L., 2008. Mixed logit analysis of safety-belt use in single- and multi-occupant vehicles. Accid. Anal. Prev., 40(2), 443–451. https://doi.org/10.1016/j.aap.2007.07.013

Gopinath, B., Harris, I.A., Nicholas, M., Casey, P., Blyth, F., Maher, C.G., Cameron, I.D., 2015. A comparison of health outcomes in older versus younger adults following a road traffic crash injury: a cohort study. PloS One, 10(4), e0122732–e0122732. https://doi.org/10.1371/journal.pone.0122732

Gutiérrez, E., Moral-Benito, E., Oto-Peralías, D., Ramos, R., 2020. The spatial distribution of population in Spain: an anomaly in European perspective, Documentos de Trabajo, n.º 2028, Banco de España.

Hadayeghi, A., Shalaby, A.S., Persaud, B., 2003. Macrolevel accident prediction models for evaluating safety of urban transportation systems. Transp. Res. Rec., 1840(1), 87-95.

AAA Foundation for Traffic Safety, 2007. Improving traffic safety culture in the United States: The journey forward. pp. 241-256.

INE, 2022. Territorio y medio ambiente. España en cifras 2022. ISSN: 1136-1611. http://www.ine.es/prodyser/espa_cifras

Intini, P., Berloco, N., Colonna, P., Ranieri, V., Ryeng, E., 2018. Exploring the relationships between drivers' familiarity and two-lane rural road accidents. A multi-level study. Accid. Anal. Prev., 111, 280–296. https://doi.org/10.1016/j.aap.2017.11.013

Intini, P., Colonna, P., Berloco, N., Ranieri, V., 2017. Measuring trade-offs between risk and travel time based on experimental speed data. In Advances in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation, July 27-31, 2016, Walt Disney World®, Florida, USA (pp. 1103-1116). Springer International Publishing.

Islam, M., Mannering, F.L, 2020. A temporal analysis of driver-injury severities in crashes involving aggressive and non-aggressive driving. Anal. Methods Accid. Res., 27, 100128–. https://doi.org/10.1016/j.amar.2020.100128

Janke, M.K., 1991. Accidents, mileage, and the exaggeration of risk. Accid. Anal. Prev., 23(2), 183–188. https://doi.org/10.1016/0001-4575(91)90048-A

Boucher, J.P., Pérez-Marín, A.M., Santolino, M., 2013. "Pay-as-you-drive insurance: the effect of the kilometers on the risk of accident, An. Inst. Actuar. Esp. 19 (3), 135-154

Keeves, J., Ekegren, C.L., Beck, B., Gabbe, B.J., 2019. The relationship between geographic location and outcomes following injury: A scoping review. Inj., 50(11), 1826–1838. https://doi.org/10.1016/j.injury.2019.07.013

Lee, J., Abdel-Aty, M., Choi, K., 2014. Analysis of residence characteristics of at-fault drivers in traffic crashes. Saf. Sci., 68, 6-13.

Lerner, E.B., Jehle, D.V.K., Billittier, A.J., Moscati, R.M., Connery, C.M., Stiller, G., 2001. The influence of demographic factors on seatbelt use by adults injured in motor vehicle crashes. Accid. Anal. Prev., 33(5), 659-662.

Li, G., Braver, E.R., Chen, L.H., 2003. Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. Accid. Anal. Prev., 35(2), 227–235. https://doi.org/10.1016/S0001- 4575(01)00107-5

Li, Z., Wang, W., Liu, P., Bigham, J.M., Ragland, D.R., 2013. Using Geographically Weighted Poisson Regression for county-level crash modeling in California. Saf. Sci., 58, 89–97. https://doi.org/10.1016/j.ssci.2013.04.005

López Laborda, J., Salas, V., 2002. Financiación de servicios públicos en territorios con desigual densidad de demanda. Revista de economía aplicada, Revista de Economía Aplicada (España) Num.28 Vol.X(28).

Lulu G., Hutcherson, T., Qi Tang, Quanquan G., 2017. Mixed linear modeling techniques for predicting fatalities in vehicle crashes. 2017 Systems and Information Engineering Design Symposium (SIEDS), 353–358. https://doi.org/10.1109/SIEDS.2017.7937745

Lyman, S., Ferguson, S.A., Braver, E.R., Williams, A.F., 2002. Older driver involvements in police reported crashes and fatal crashes: trends and projections. Inj. Pre., 8(2), 116–120. https://doi.org/10.1136/ip.8.2.116

Gogola, M., Sitanyiová, D., Černický, L., Veterník, M., 2019. New Demand Patterns for Public Transport due to demographic Change. RUMOBIL Working Paper. Interreg Central Europe, Lille.

Mannering, F.L., 2018. Temporal instability and the analysis of highway accident data. Anal. Methods Accid. Res., 17, 1–13. https://doi.org/10.1016/j.amar.2017.10.002

Mason, M.F., Norton, M.I., Van Horn, J.D., Wegner, D.M., Grafton, S.T., Macrae, C.N., 2007. Wandering Minds: The Default Network and Stimulus-Independent Thought. Sci., 315(5810), 393–395. https://doi.org/10.1126/science.1131295

McCullagh, P., Nelder, J.A., 1989. Generalized linear models. 2nd Edition. Monographs on Statistics and Applied Probability 37, Chapman & Hall/CRC.

Milbourne, P., Kitchen, L., 2014. Rural mobilities: Connecting movement and fixity in rural places. J. Rural Stud., 34, 326–336. https://doi.org/10.1016/j.jrurstud.2014.01.004

Molnar, L.J., Eby, D.W., Zhang, L., Zanier, N., St. Louis, R.M., Kostyniuk, L.P., 2015. Self-regulation of driving by older adults: A synthesis of the literature and framework for future research. AAA Foundation for Traffic Safety. Available at https://aaafoundation.org/wp-content/uploads/2017/12/SelfRegulationOfDrivingByOlderAdultsReport.pdf

Molnar, L.J., Eby, D.W., Zakrajsek, J.S., Kostyniuk, L.P., Bogard, S.E., St. Louis, R.M., Zanier, N., Ryan, L.H., LeBlanc, D.J., Yung, R., Nyquist, L., Betz, M.E., DiGuiseppi, C., Li, G. & the LongROAD Research Team. (2019). The Role of Driving Comfort in Self-Regulation among a Large Cohort of Older Drivers: AAA LongROAD Study (Research Brief). Washington, D.C.: AAA Foundation for Traffic Safety.

Noland, R.B., Oh, L., 2004. The effect of infrastructure and demographic change on traffic-related fatalities and crashes: a case study of Illinois county-level data. Accid. Anal. Prev., 36(4), 525-532.

Noland, R.B., 2013. From theory to practice in road safety policy: Understanding risk versus mobility. Res. Transp. Econ., 43(1), 71–84. https://doi.org/10.1016/j.retrec.2012.12.007

O'Byrne, C., Naughton, A., O'Neill, D., 2015. Is driver licensing restriction for age-related medical conditions an effective mechanism to improve driver safety without unduly impairing mobility? Eur. Geriatr. Med., 6(6), 541–544. https://doi.org/10.1016/j.eurger.2015.08.008

Oxley, J., Fildes, B., Corben, B., Langford, J., 2006. Intersection design for older drivers. Transport. Res. F: Traffic Psychol. Behav, 9(5), 335–346. https://doi.org/10.1016/j.trf.2006.06.005

Papa, M., Boccardi, V., Prestano, R., Angellotti, E., Desiderio, M., Marano, L., Rizzo, M.R., Paolisso, G., 2014. Comorbidities and crash involvement among younger and older drivers. PloS One, 9(4), e94564–e94564. https://doi.org/10.1371/journal.pone.0094564

Payyanadan, R.P., Lee, J.D., Grepo, L.C., 2018. Challenges for Older Drivers in Urban, Suburban, and Rural Settings. Geriatr., 3(2), 14–. https://doi.org/10.3390/geriatrics3020014

Poltimäe, H., Rehema, M., Raun, J., Poom, A., 2022. In search of sustainable and inclusive mobility solutions for rural areas. Eur. Transp. Res. Rev., 14(1), 1–17. https://doi.org/10.1186/s12544-022-00536-3

Porru, S., Misso, F.E., Pani, F.E., Repetto, C., 2020. Smart mobility and public transport: Opportunities and challenges in rural and urban areas. J. Traffic Transp. Eng. (English Edition), 7(1), 88–97. https://doi.org/10.1016/j.jtte.2019.10.002

Qin, W., Xiang, X., Taylor, H.O., 2019. DRIVING CESSATION AND SOCIAL ISOLATION IN OLDER ADULTS. Innovation in Aging, 3(Supplement_1), S827–S827. https://doi.org/10.1093/geroni/igz038.3048

Raatiniemi, L., Steinvik, T., Liisanantti, J., Ohtonen, P., Martikainen, M., Alahuhta, S., Dehli, T., Wisborg, T., Bakke, H.K., 2016. Fatal injuries in rural and urban areas in northern Finland: a 5-year retrospective study. Acta Anaesthesiologica Scandinavica, 60(5), 668–676. https://doi.org/10.1111/aas.12682

Rakauskas, M.E., Ward, N.J., Gerberich, S.G., 2009. Identification of differences between rural and urban safety cultures. Accid. Anal. Prev., 41(5), 931–937. https://doi.org/10.1016/j.aap.2009.05.008

Rivera-Izquierdo, M., Valverde-Cano, L.M., Martínez-Ruiz, V., Sánchez-Pérez, M.R., Atienza-Martín, F.J., Martín-delosReyes, L.M., Jiménez-Mejías, E., 2021. Prevention of road crashes in older adults: perspectives on facilitators, barriers and the role of the family doctor. BMC Geriatr., 21(1), 1–635. https://doi.org/10.1186/s12877-021-02569-0

Rolison, J.J., Hewson, P.J., Hellier, E., Husband, P., 2012. Risk of Fatal Injury in Older Adult Drivers, Passengers, and Pedestrians. J. Am. Geriatr. Soc., 60(8), 1504–1508. https://doi.org/10.1111/j.1532-5415.2012.04059.x

Rubin, G.S., Ng, E.S.W., Bandeen-Roche, K., Keyl, P.M., Freeman, E.E., West, S.K., SEE Project Team, 2007. A Prospective, Population-Based Study of the Role of Visual Impairment in Motor Vehicle Crashes among Older Drivers: The SEE Study. Investig. Ophthalmol. Vis. Sci., 48(4), 1483–1491. https://doi.org/10.1167/iovs.06-0474

Santolino, M., Cespedes. L., Ayuso, M., 2022. The Impact of Aging Drivers and Vehicles on the Injury Severity of Crash Victims. Int J Environ Res Public Health. Dec 19;19(24):17097. doi: 10.3390/ijerph192417097

Shen, S., Neyens, D.M., 2015. The effects of age, gender, and crash types on drivers' injury-related health care costs. Accid. Anal. Prev., 77, 82–90. https://doi.org/10.1016/j.aap.2015.01.014

Shen, S., Ratnapradipa, K.L., Pervall, G.C., Sweeney, M., Zhu, M., 2020. Driver License Renewal Laws and Older Adults' Daily Driving, United States, 2003–2017. J. Gerontol. B: Psychol. Sci. Soc. Sci., 75(10), 2268–2277. https://doi.org/10.1093/geronb/gbaa070

Shrira, I., Noguchi, K., 2016. Traffic fatalities of drivers who visit urban and rural areas: An exploratory study. Transport. Res. F: Traffic Psychol. Behav, 41, 74–79. https://doi.org/10.1016/j.trf.2016.05.003

Skyving, M., Berg, H.Y., Laflamme, L., 2009. A pattern analysis of traffic crashes fatal to older drivers. Accid. Anal. Prev., 41(2), 253–258. https://doi.org/10.1016/j.aap.2008.11.008

Staplin, L., Mastromatto, T., Sifrit, K.J., Trazzera, K.M., 2017. Can Your Older Patients Drive Safely? Am. J. Nurs., 117(9), 34–43. https://doi.org/10.1097/01.NAJ.0000524519.45105.8d

Steinbach, R., Edwards, P., Grundy, C., 2013. The road most travelled: the geographic distribution of road traffic injuries in England. Int. J. Health Geogr., 12(1), 30–30. https://doi.org/10.1186/1476-072X-12-30

Thompson, J.P., Baldock, M.R.J., Mathias, J.L., Wundersitz, L.N., 2013. An examination of the environmental, driver and vehicle factors associated with the serious and fatal crashes of older rural drivers. Accid. Anal. Prev., 50, 768–775. https://doi.org/10.1016/j.aap.2012.06.028

Thompson, J.P., Baldock, M.R.J., Mathias, J.L., Wundersitz, L.N., 2010. Older drivers in rural and urban areas: Comparisons of crash, serious injury, and fatality rates. Proceedings of the Australasian Road Safety Research, Policing and Education Conference, Canberra, Australian Capital Territory, pp. 1-10

UN General Assembly,2015. Resolution Adopted by the General Assembly on 25 September 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. Available at http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

Washington, S., Karlaftas, M., Mannering, F.L., Anastasopoulos, P, 2020. Statistical and econometric methods for transportation data analysis. Chapman & Hall/CRC, 3rd edition.

Welsh, R., Morris, A., Hassan, A., Charlton, J., 2006. Crash characteristics and injury outcomes for older passenger car occupants. Transport. Res. F: Traffic Psychol. Behav, 9(5), 322–334. https://doi.org/10.1016/j.trf.2006.03.007

World Health Organization, 2020. Decade of healthy ageing: baseline report. ISBN 978- 92-4-001791-7. License: CC BY-NC-SA 3.

Yee, W.Y., Cameron, P. A., Bailey, M.J., 2006. Road traffic injuries in the elderly. Emerg. Med. J., 23(1), 42–46. https://doi.org/10.1136/emj.2005.023754

Zwerling, C., Peek-Asa, C., Whitten, P. S., Choi, S.W., Sprince, N.L., Jones, M.P., 2005. Fatal motor vehicle crashes in rural and urban areas: decomposing rates into contributing factors. Inj. Pre., 11(1), 24–28. https://doi.org/10.1136/ip.2004.005959

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