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Factors related to the risk of pedestrian fatality after a crash in Spain, 1993–2013

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A R T I C L E I N F O

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A B S T R A C T

Introduction: The aim of this study was to quantify the magnitude of association between pedestrian fatalities during the first 24 h after a crash and pedestrian-, driver-, vehicle- and environment-related characteristics in Spain from 1993 to 2013.

Methods: Data were analyzed for all 203,622 traffic crashes involving a pedestrian and a motor vehicle recorded in the Spanish Registry of Road Crashes with Victims. After multiple imputation for missing values, crude (CMRR) and adjusted mortality rate ratios (AMRR) were obtained for each variable with Poisson regression models.

Results: Pedestrian risk of death after a crash increased nearly exponentially with pedestrian age. Male sex, committing an infraction and having a physical defect were also associated with a higher risk of death (AMRR 1.27, 95%CI 1.17–1.37 for physical defect). Regarding driver-related factors associated with pedestrian fatalities, visual defects (AMRR 1.21, 95%CI 1.08–1.37) and the commission of a speed infraction (AMRR 2.59, 95%CI 2.43–2.76) increased the risk. Heavy vehicles (trucks, vans, buses) and the presence of passengers were also associated with a higher risk of pedestrian death. The risk of pedestrian death was lower for crashes that occurred between 12:00 and 14:00, in good light conditions, at intersections, and when the pedestrian was on a sidewalk. Risk was higher in crashes in rural areas with fewer than 5000 inhabitants.

Conclusions: We identified several factors strongly associated with the risk of pedestrian fatality; some of these factors are analyzed here for the first time. This knowledge is potentially useful in the design and prioritization of measures intended to increase pedestrian safety.

1. Introduction

Mortality in pedestrians due to road crashes is an important public health issue worldwide, even in the most developed countries. Among all traffic deaths, pedestrian fatalities account for 27% in Europe (World Health Organization, 2018) and 21% in Spain

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(Dirección General de Tráfico, 2017). This problem is expected to worsen due to the increase in the number of older people (who are the most likely to die as a consequence of a crash) and to the tendency toward increased walking in urban settings (Niebuhr et al., 2016; Rolison et al., 2012; Shinar, 2012). Consequently, it seems advisable to identify factors that influence the risk of pedestrian death after a vehicle impact, which can be subdivided into four groups: pedestrian-, driver-, vehicle- and environment- (geographic and temporal) related factors.

Many previous studies have assessed the impact of some factors in the aforementioned groups on the severity of crashes involving pedestrians. For example, older pedestrian age is recognized as a marker of higher fatality in most studies (Haleem et al., 2015; Islam and Hossain, 2015; Ma et al., 2017; Mohamed et al., 2013; Niebuhr et al., 2016; Pour-Rouholamin and Zhou, 2016; Vanlaar et al., 2016). Regarding vehicle-related factors, speed is undoubtedly the most relevant predictor of crash severity (Kröyer et al., 2014; Li et al., 2017; Matsui et al., 2016; Oikawa et al., 2016; Olszewski et al., 2015; Verzosa and Miles, 2016; Xu et al., 2016; Zhang et al., 2014). There is also agreement regarding the greater severity related with crashes involving heavier vehicles such as trucks or buses (Aziz et al., 2013; DiMaggio et al., 2006; Jang et al., 2013; Ma et al., 2017; Matsui et al., 2016; Mohamed et al., 2013; Oikawa et al., 2016; Tay et al., 2011; Zajac and Ivan, 2003). Finally, some environment-related characteristics have also consistently been related with severity in most previous studies, such as crashes occurring at night and/or with poor light conditions (Aziz et al., 2013; Coate and Markowitz, 2004; Islam and Hossain, 2015; Jang et al., 2013; Li et al., 2017; Mohamed et al., 2013; Moudon et al., 2011; Olszewski et al., 2015; Pour-Rouholamin and Zhou, 2016, p.; Tay et al., 2011; Verzosa and Miles, 2016; Zhang et al., 2014) and in rural areas compared to urban settings (Islam and Hossain, 2015; Islam and Jones, 2014; Pour-Rouholamin and Zhou, 2016; Tay et al., 2011).

However, few studies have attempted to jointly consider the following aspects of risk in connection with pedestrian fatalities:

– Treating death as the specific outcome. Fortunately, pedestrian death is a rare event after a road crash. Therefore the number of crashes required to obtain precise estimates of the association between this outcome and different risk factors is usually unattainable in datasets available at present.
– Including all types of crashes involving pedestrians, rather than specific subsets of them (based, for example, on characteristics of the pedestrian, the environment or the type of vehicle involved). This limits the external validity of the results.
– Using datasets from a nationwide register of road crashes to cover long sampling periods. Apart of solving the problems of achieving a large sample size and improving external validity, this would also make it possible to estimate the effect of temporal trends on the risk of death. Most published research is restricted to a single city, region or county, and usually comprises a period of only a few years.
– Considering, in the same design, the complete set of factors involved in the risk of pedestrian death – an important issue given that many factors are strongly interrelated. This is especially relevant for factors related with the characteristics of the driver of the vehicle involved in the crash, which are not well addressed in most studies.

All the above limitations are notable even within Spain, where there are no studies of the association between different types of traffic-related factors and the risk of pedestrian fatality after a crash.

In an attempt to overcome these limitations, we designed the present study to determine the adjusted association between pedestrian-, driver-, vehicle-, and environment-related factors and the risk of pedestrian death in the 24 hours after a crash in Spain for the period from 1993 to 2013.

2. Material and methods

From the Spanish Registry of Road Crashes with Victims (a police-based registry maintained by the Spanish General Traffic Directorate [DGT]), we collected information on all 203,622 traffic crashes in Spain from 1993 to 2013 which involved a pedestrian and a motor vehicle. The registry contains information collected by the Spanish Traffic Police at the scene of all collisions with victims. This information is classified in three categories: crash-related information, vehicle-related information, and information about the drivers, passengers and pedestrians involved in the crash. From this source we selected the following study variables:

– Dependent variable: pedestrian death within the first 24 hours post-crash.
– Pedestrian-related variables: age (categories are shown in Table 1), sex, psychophysical circumstances (yes, no; yes included alcohol, drugs, distractions, sleepiness, fatigue, unexpected illness, etc.), previous physical defects (yes, no; yes included sight, hearing, upper limb or lower limb defects), commission of an infraction (yes, no), and use of reflectors or reflective clothing (yes, no).
– Driver-related variables: age (categories are shown in Table 2), sex, nationality (Spanish or foreign), years in possession of a driving license, use of seat belts or helmets (yes, no), visual defects (yes, no), psychophysical circumstances (yes, no), commission of a speed infraction (yes, no), commission of other infractions (yes, no), type of driver (professional, nonprofessional), reason for driving (leisure/holiday, work).
– Vehicle-related variables: type of vehicle (passenger car, moped, motorcycle, truck less than 3500 kg, van, truck more than 3500 kg, bus), vehicle age, number of occupants (one, two, more than two) and vehicle defects (yes, no; yes included defects in lights, brakes, etc.)
– Environment-related variables: year, month, day of the week, type of day (working day, before holiday, holiday, after holiday), time of day, province, zone (open road, major roadway through an urban area, urban area of unknown population, urban area

Table 1
Crude (CMRR) and adjusted mortality rate ratio (AMRR) for the association between pedestrian-related characteristics and the risk of pedestrian death after a crash.

Variable	Categories	N	%	CMRR	95% CI		AMRR	95% CI	
Age (years)	< 15	29,859	14.7	0.57	0.50	0.66	0.97	0.84	1.11
	15–24	22,359	11.0	1	–	–	1	–	–
	25–34	20,540	10.1	1.56	1.39	1.74	1.30	1.16	1.46
	35–44	18,476	9.1	1.91	1.72	2.13	1.60	1.44	1.79
	45–54	19,077	9.4	2.01	1.81	2.24	2.02	1.81	2.25
	55–64	20,989	10.3	2.21	1.99	2.46	2.54	2.28	2.83
	65–74	25,231	12.4	2.85	2.58	3.15	3.44	3.10	3.81
	75–84	23,266	11.4	3.57	3.24	3.94	4.70	4.25	5.21
	> 84	6883	3.4	4.17	3.71	4.68	6.32	5.59	7.14
	Unknown	16,942	8.3						
Sex	Female	93,654	46.0	1	–	–	1	–	–
	Male	100,652	49.4	1.85	1.77	1.94	1.15	1.09	1.20
	Unknown	9316	4.6						
Physical defects	No	111,872	54.9	1	–	–	1	–	–
	Yes	10,306	5.1	1.84	1.72	1.98	1.27	1.17	1.37
	Unknown	81,444	40.00						
Psychophysical circumstances	No	130,490	64.1	1	–	–	1	–	–
	Yes	4430	2.2	2.44	2.19	2.72	0.85	0.77	0.95
	Unknown	68,702	33.7						
Commission of infraction	No	85,969	42.2	1	–	–	1	–	–
	Yes	107,839	53.0	2.83	2.70	2.98	1.72	1.62	1.83
	Unknown	9814	4.8						
Use of reflectors or reflective clothing	No	122,061	59.9	1	–	–	1	–	–
	Yes	1562	0.8	0.89	0.73	1.10	0.65	0.53	0.80
	Unknown	79,999	39.3						

with more than 100,000 inhabitants, urban area with 50,000–100,000 inhabitants, urban area with 5000–50,000 inhabitants, urban area with fewer than 5000 inhabitants), type of road (multilane highway used by automobiles only or by all types of vehicles, conventional road with limited access, conventional road with slow lane, conventional road, local or rural road, service road, entrance or exit ramp, other), roadway trajectory (straightaway, gentle curve, unsignalized sharp curve, signalized sharp curve without posted speed limit, signalized sharp curve with posted speed limit, T or Y intersection, X or + intersection, entrance ramp, exit ramp, traffic circle, other), road surface condition (normal, altered), light (broad daylight, twilight, sufficient light at night, insufficient light at night, no light at night), visibility factors (good, adverse), road surface width (< 5.99 m, 6–6.99 m, > 6.99 m), lane width (> 3.75 m, 3.25–3.75 m, < 3.25 m), shoulder (none, < 1.5 m, 1.5–2.49 m, > 2.49 m), regulated right-of-way (yes, no) and presence of sidewalks (yes, no).

2.1. Analysis

The frequency of missing values varied widely across variables in the present study, and ranged from less than 5% to more than 30% (see tables for details). This characteristic of our dataset should be kept in mind, because if we had excluded from our analysis those registers with missing data for any item, this would have substantially reduced our sample size, and might have given rise to selection bias if the records with missing values were different from complete records. However, we assumed that for some of these missing values, the reasons why they were not recorded by the police were related to other variables that were recorded in the register (this is confusingly termed the missing-at-random or MAR assumption) (Donders et al., 2006). Therefore we used a multiple imputation procedure for our dataset: each missing value for each variable was replaced with a set of possible values obtained from the multivariate combination of non-missing values for variables that were recorded in the dataset and potentially related with the likelihood of a missing value. This was done with the chained equation method proposed by van Buuren et al. (1999) and implemented with the *ice* command in Stata (Royston, 2007), and yielded 50 completed datasets. We used the same strategy to analyze each dataset (see below). Next, we combined the estimates obtained for each completed file with the Rubin method (Li et al., 1991) implemented with the *mim* command in Stata (Royston et al., 2009). For all estimates, we calculated 95% confidence intervals. The analysis used for each file was based on a Poisson regression model. This is the preferred model for rare dichotomous outcomes from a large cohort of people at risk (Szklo and Nieto, 2014), as in our study: death within the first 24 h after a crash (our dependent variable) is a dichotomous and (fortunately) rare outcome in the cohort defined by pedestrians involved in a road crash. In addition, this model makes it possible to estimate mortality rate ratios for each category of the independent variables included in the model, compared to the reference category. First, a bivariate model was fitted for each independent variable to obtain crude mortality rate ratios (CMRR) for each category. In a second step, a multivariate model was built including all variables noted above as independent variables, to obtain the corresponding adjusted mortality rate ratios (AMRR).

All analyses were done with Stata software (v. 14.0) (StataCorp., 2015).

Table 2
Crude (CMRR) and adjusted mortality rate ratio (AMRR) for the association between driver-related characteristics and the risk of pedestrian death after a crash.

Variable	Categories	N	%	CMRR	95% CI		AMRR	95% CI	
Age (years)	< 18	5950	2.92	0.39	0.32	0.47	0.94	0.75	1.19
	18–24	39,128	19.22	1	–	–	1	–	–
	25–34	54,231	26.63	1.16	1.09	1.23	0.94	0.88	1.00
	35–44	38,076	18.70	1.09	1.02	1.16	0.86	0.79	0.93
	45–54	25,303	12.43	1.10	1.02	1.18	0.86	0.78	0.95
	55–64	15,371	7.55	1.05	0.96	1.15	0.86	0.76	0.96
	65–74	6930	3.40	0.82	0.72	0.94	0.76	0.65	0.90
	75–84	2681	1.32	0.65	0.51	0.81	0.70	0.54	0.90
	> 84	321	0.16	0.49	0.23	1.03	0.60	0.28	1.28
	Unknown	15,631	7.68						
Sex	Female	35,269	17.32	1	–	–	1	–	–
	Male	157,675	77.44	1.77	1.66	1.89	1.20	1.12	1.29
	Unknown	10,678	5.24						
Visual defects	No	147,023	72.20	1	–	–	1	–	–
	Yes	2943	1.45	2.17	1.94	2.42	1.21	1.08	1.37
	Unknown	53,656	26.35						
Psycho-physical circumstances	No	166,175	81.61	1	–	–	1	–	–
	Yes	5466	2.68	2.23	2.05	2.43	1.59	1.44	1.74
	Unknown	31,981	15.71						
Commission of speed infraction	No	116,150	57.04	1	–	–	1	–	–
	Yes	13,478	6.62	2.77	2.63	2.92	2.59	2.43	2.76
	Unknown	73,994	36.34						
Commission of any other infraction	No	91,074	44.73	1	–	–	1	–	–
	Yes	102,739	50.46	0.69	0.67	0.72	0.98	0.93	1.04
	Unknown	9809	4.82						
Type of driver	Professional	22,948	11.27	1	–	–	1	–	–
	Nonprof.	132,963	65.30	0.54	0.51	0.57	1.05	0.96	1.14
	Unknown	47,711	23.43						
Reason for driving	Leisure/Holiday	113,038	55.51	1	–	–	1	–	–
	Work	64,603	31.73	1.25	1.19	1.30	1.10	1.04	1.16
	Unknown	25,981	12.76						
Use of safety devices	No	22,258	10.93	1	–	–	1	–	–
	Yes	111,634	54.82	0.83	0.79	0.88	0.96	0.88	1.04
	Unknown	69,730	34.24						
Nationality	Spanish	187,802	92.23	1	–	–	1	–	–
	Other	6189	3.04	1.25	1.13	1.39	0.96	0.86	1.07
	Unknown	9631	4.73						
Years in possession of a license	One-year increase	Mean (SE): 12.5 (11.4)		1.0025	1.0007	1.0043	1.00	0.9993	1.0057
	Unknown	39,435	19.4						

Table 3
Crude (CMRR) and adjusted mortality rate ratio (AMRR) for the association between vehicle-related characteristics and the risk of pedestrian death after a crash.

Variable	Categories	N	%	CMRR	95% CI		AMRR	95% CI	
Type of vehicle	Passenger car	144,850	71.1	1	–	–	1	–	–
	Moped	20,521	10.1	0.23	0.20	0.26	0.27	0.23	0.31
	Motorcycle	13,591	6.7	0.58	0.52	0.64	0.82	0.73	0.92
	Truck less than 3500 kg	3141	1.5	2.59	2.33	2.89	2.65	2.33	3.02
	Van	13,662	6.7	1.27	1.18	1.37	1.21	1.11	1.31
	Truck more than 3500 kg	2612	1.3	7.18	6.68	7.73	2.78	2.47	3.14
	Bus	5245	2.6	1.49	1.33	1.66	2.16	1.86	2.50
Number of occupants	One	170,108	83.5	1	–	–	1	–	–
	Two	15,957	7.8	1.38	1.29	1.47	1.25	1.17	1.34
	More than two	6278	3.1	1.83	1.68	2.01	1.29	1.17	1.42
	Unknown	11,279	5.5						
Vehicle defects	No	189,255	92.9	1	–	–	1	–	–
	Yes	1355	0.7	1.98	1.65	2.36	1.56	1.30	1.87
	Unknown	13,012	6.4						
Vehicle age (years)	One-year increase	Mean (SE): 6.4 (5.0)		1.0019	0.9977	1.0061	0.99	0.9885	0.9975
	Unknown	51,416	25.3						

Table 4
Crude (CMRR) and adjusted mortality rate ratio (AMRR) for the association between time-related variables and the risk of pedestrian death after a crash.

Variable[a]	Categories	N	%	CMRR	95% CI		AMRR	95% CI	
Years	1993	11,199	5.5	1	–	–	1	–	–
	1994	11,198	5.5	0.92	0.82	1.03	0.93	0.83	1.04
	1995	11,195	5.5	0.94	0.84	1.05	0.95	0.85	1.07
	1996	11,215	5.5	0.90	0.81	1.01	0.99	0.88	1.11
	1997	10,997	5.4	0.89	0.79	0.99	0.95	0.84	1.06
	1998	11,083	5.4	0.86	0.77	0.96	0.98	0.87	1.10
	1999	10,332	5.1	0.87	0.78	0.98	0.94	0.84	1.06
	2000	9861	4.8	0.89	0.79	1.00	0.97	0.86	1.10
	2001	10,253	5.0	0.88	0.78	0.98	0.98	0.87	1.11
	2002	10,176	5.0	0.82	0.73	0.93	0.99	0.88	1.12
	2003	9906	4.9	0.87	0.78	0.98	1.09	0.97	1.23
	2004	9422	4.6	0.76	0.67	0.86	0.94	0.83	1.06
	2005	9121	4.5	0.75	0.66	0.85	0.99	0.87	1.12
	2006	9087	4.5	0.63	0.55	0.72	0.87	0.76	1.00
	2007	8514	4.2	0.69	0.60	0.79	0.99	0.86	1.13
	2008	8316	4.1	0.63	0.55	0.72	0.93	0.81	1.07
	2009	8414	4.1	0.57	0.50	0.66	0.91	0.79	1.06
	2010	8549	4.2	0.56	0.49	0.65	0.91	0.78	1.05
	2011	8467	4.2	0.47	0.41	0.55	0.83	0.71	0.97
	2012	8225	4.0	0.48	0.42	0.56	0.92	0.78	1.07
	2013	8092	4.0	0.43	0.37	0.50	0.82	0.70	0.97
Month	January	17,673	8.7	1	–	–	1	–	–
	February	16,976	8.3	0.88	0.80	0.97	0.95	0.86	1.05
	March	18,148	8.9	0.85	0.77	0.93	0.96	0.87	1.06
	April	16,708	8.2	0.73	0.65	0.80	0.87	0.78	0.97
	May	17,819	8.8	0.66	0.59	0.73	0.85	0.76	0.94
	Jun	17,721	8.7	0.73	0.66	0.80	0.97	0.87	1.07
	July	16,415	8.1	0.82	0.74	0.91	0.89	0.80	0.99
	August	12,656	6.2	1.12	1.01	1.23	0.95	0.86	1.05
	September	16,339	8.0	0.92	0.83	1.01	0.95	0.86	1.05
	October	18,261	9.0	0.94	0.86	1.04	0.95	0.86	1.04
	November	17,851	8.8	0.96	0.87	1.05	0.97	0.88	1.07
	December	17,055	8.4	1.04	0.95	1.14	0.96	0.88	1.06
Week day	Monday	31,697	15.6	1	–	–	1	–	–
	Tuesday	31,583	15.5	0.90	0.83	0.98	0.96	0.87	1.06
	Wednesday	31,961	15.7	0.92	0.85	0.99	0.95	0.86	1.05
	Thursday	32,135	15.8	0.98	0.91	1.06	0.99	0.90	1.10
	Friday	34,929	17.2	1.02	0.94	1.09	1.00	0.91	1.10
	Saturday	23,705	11.6	1.32	1.22	1.42	1.05	0.93	1.19
	Sunday	17,612	8.7	1.65	1.53	1.79	1.02	0.88	1.17
Type of day	Working day	130,805	64.2	1	–	–	1	–	–
	Before hol./vacation	25,235	12.4	1.31	1.23	1.39	0.99	0.89	1.09
	Holiday/vacation	24,055	11.8	1.04	0.97	1.11	1.00	0.91	1.11
	After hol./vacation	23,527	11.6	1.73	1.64	1.83	1.05	0.94	1.18

[a] Estimates for the time of the day are shown in Fig. 2.

3. Results

Of the 203,622 pedestrians included in the study, 9119 (4.5%) died within 24 hours after the crash. For each group of independent variables, the CMRR and AMRR are shown in Tables 1–5, along with the distribution of their categories in the study population. Table 1 summarizes the estimates for pedestrian-related factors. Higher risk of fatality was associated exponentially with increasing age. This relationship is graphically depicted in Fig. 1 (solid line), in which an almost perfect linear trend is evident in the log AMRR values for increasing age groups of pedestrians. Other factors related with a significant risk of pedestrian death were male sex (AMRR = 1.15), physical defects (AMRR = 1.27) and infraction by the pedestrian (AMRR = 1.72). Abnormal psychophysical circumstances were linked to an increase in pedestrian fatality in the crude analysis (CMRR = 2.19), but this association was reversed in the adjusted model (AMRR = 0.85). A final association was that between the use of reflectors or reflective clothing and a lower risk of fatality (AMRR = 0.65).

Regarding driver-related characteristics (Table 2), driver age was related inversely with the risk of pedestrian death, with the highest AMRR values in the youngest groups of drivers, and the lowest values in the oldest drivers. This inverse relationship is plotted in Fig. 1 (dashed line).

In contrast, driver male sex, visual defects, abnormal psychophysical circumstances, and especially commission of a speed infraction (AMRR = 2.59) were associated with a higher risk of pedestrian death after a crash. The AMRR values for all these factors were lower than their corresponding crude values. Work-related driving (including commuting) was also associated with a slight

Table 5
Crude (CMRR) and adjusted mortality rate ratio (AMRR) for the association between environment-related variables and the risk of pedestrian death after a crash.

Variable	N	%	CMRR	95% CI		AMRR	95% CI	
Zone								
Open road	24,496	12.0	1	–	–	1	–	–
Major roadway through an urban area	7785	3.8	0.47	0.44	0.51	0.84	0.77	0.92
Urban area, unknown inhabitants	1829	0.9	0.07	0.05	0.11	0.31	0.20	0.46
Urban area, > 100,000 inhabs.	122,333	60.1	0.09	0.09	0.10	0.43	0.38	0.49
Urban area, 50-100,000 inhabs.	22,476	11.0	0.09	0.08	0.10	0.40	0.35	0.47
Urban area, 5-50,000 inhabs.	21,592	10.6	0.13	0.12	0.15	0.57	0.50	0.66
Urban area, < 5000 inhabs.	3111	1.5	0.33	0.29	0.38	1.07	0.90	1.28
Type of road								
Multilane highway (automobiles only)	863	0.4	1	–	–	1	–	–
Multilane highway	2515	1.2	1.23	1.08	1.41	0.84	0.73	0.97
Conventional road (limited access)	525	0.3	0.58	0.46	0.74	0.64	0.50	0.82
Conventional road with slow lane	845	0.4	0.74	0.61	0.89	0.58	0.47	0.70
Conventional road	31,931	15.7	0.41	0.36	0.46	0.49	0.43	0.56
Local/Rural road	1043	0.5	0.36	0.29	0.44	0.55	0.43	0.69
Service road	444	0.2	0.29	0.21	0.40	0.46	0.32	0.64
Entrance or exit ramp	506	0.3	0.16	0.11	0.24	0.34	0.23	0.52
Other	164,950	81.0	0.07	0.06	0.07	0.42	0.36	0.50
Roadway trajectory								
Straightaway	130,193	63.9	1	–	–	1	–	–
Gentle curve	8839	4.3	2.38	2.23	2.55	1.05	0.98	1.13
Unmarked sharp curve	929	0.5	1.79	1.43	2.23	0.81	0.64	1.01
Marked sharp curve without posted speed limit	410	0.2	3.32	2.60	4.24	0.83	0.64	1.07
Marked sharp curve with posted speed limit	575	0.3	3.63	2.97	4.42	0.89	0.72	1.09
T or Y intersection	21,952	10.8	0.58	0.53	0.63	0.83	0.76	0.90
X or + intersection	34,097	16.8	0.47	0.44	0.51	0.84	0.78	0.91
Entrance ramp	560	0.3	2.47	1.93	3.14	1.03	0.81	1.33
Exit ramp	397	0.2	3.06	2.36	3.96	0.83	0.64	1.09
Traffic circle	3301	1.6	0.46	0.36	0.58	0.64	0.50	0.81
Other	2369	1.2	0.77	0.62	0.95	0.91	0.73	1.14
Road surface condition								
Normal	181,870	89.3	1	–	–	1	–	–
Altered	21,752	10.7	1.20	1.13	1.27	0.97	0.87	1.07
Light								
Broad daylight	141,823	69.7	1	–	–	1	–	–
Twilight	8607	4.2	1.72	1.56	1.90	1.25	1.11	1.40
Sufficient light (night)	40,918	20.1	1.21	1.14	1.28	1.20	1.09	1.32
Insufficient light (night)	6213	3.1	5.24	4.88	5.62	1.61	1.45	1.78
No light (night)	6061	3.0	11.96	11.35	12.60	2.01	1.82	2.22
Atmospheric factors								
Good	181,215	89.0	1	–	–	1	–	–
Adverse	22,407	11.0	1.13	1.06	1.21	0.92	0.83	1.02
Road surface width								
< 5.99 m	27,143	13.3	1	–	–	1	–	–
6–6.99 m	40,454	19.9	1.61	1.48	1.75	1.24	1.13	1.35
≥ 7 m	107,469	52.8	2.31	2.14	2.49	1.54	1.42	1.68
Unknown	28,556	14.0						
Lane width								
> 3.75 m	31,591	15.5	1	–	–	1	–	–
3.25–3.75 m	88,139	43.3	2.07	1.94	2.22	1.05	0.97	1.12
< 3.25 m	55,273	27.1	1.05	0.97	1.13	1.15	1.06	1.25
Unknown	28,619	14.1						
Shoulder								
None	165,195	81.1	1	–	–	1	–	–
< 1.5 m	13,860	6.8	6.20	5.89	6.52	1.39	1.30	1.49
1.5–2.49 m	9796	4.8	8.20	7.78	8.64	1.53	1.42	1.64
≥ 3 m	2520	1.2	4.96	4.43	5.56	1.54	1.36	1.75
Unknown	12,251	6.0						
Right of way								
Nonregulated	93,039	45.7	1	–	–	1	–	–
Regulated	88,303	43.4	0.53	0.51	0.56	0.98	0.93	1.03
Unknown	22,280	10.9						
Sidewalks								
No	57,143	28.1	1	–	–	1	–	–
Yes	135,170	66.4	0.29	0.28	0.31	0.73	0.68	0.77
Unknown	11,309	5.6						

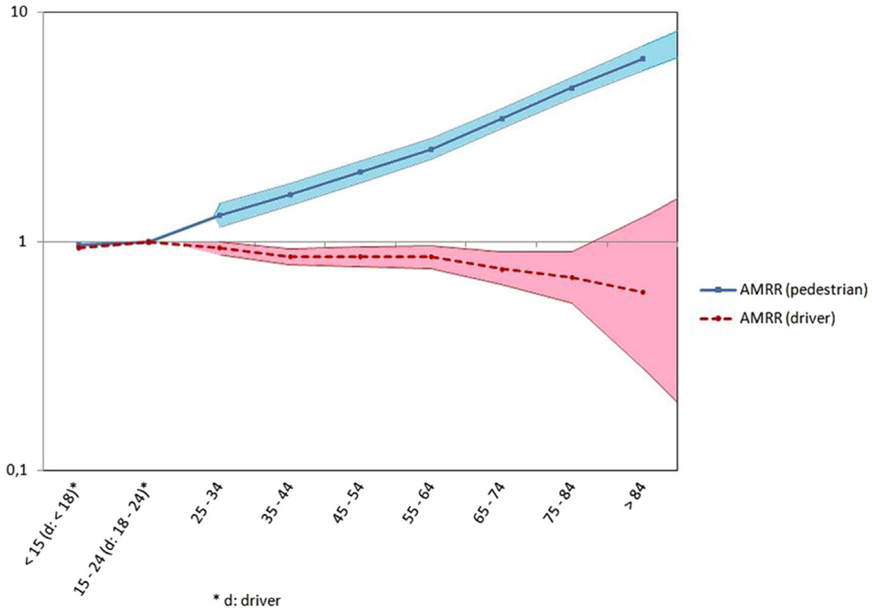

Fig. 1. Adjusted mortality rate ratio (AMRR) for the association between pedestrian and driver age and the risk of pedestrian death after a crash.

increase in the risk of pedestrian death (AMRR = 1.10). The remaining driver-related variables did not show any association with the risk of death in the adjusted analysis.

Table 3 summarizes the estimates for the associations of vehicle-related characteristics with pedestrian fatalities. Compared to private cars, two-wheeled vehicles (especially mopeds) were associated with a lower risk of pedestrian death, but all other types of vehicle including vans were associated with a higher risk – an increase that was especially notable for heavier trucks (AMRR = 2.78). The presence of passengers in the vehicle, and especially the presence of vehicle defects (AMRR = 1.56) were also associated with a significantly higher risk of fatality. However, vehicle age was inversely associated with pedestrian fatality in the adjusted analysis.

Fig. 2 shows the association between time of day and pedestrian fatalities. The crude estimates (solid line) revealed striking differences in pedestrian risk of death between the highest values (from 00:00 to 8:00) and the lowest ones (from 8:00 to 21:00). These differences were strongly attenuated in the adjusted analysis (dashed line), although the pattern of associations according to the time of the crash remained almost unchanged: the risk was lowest between 12:00 and 14:00, and highest between 3:00 and 5:00.

The remaining time-related variables are shown in Table 4. None of them were related with pedestrian risk of death in the

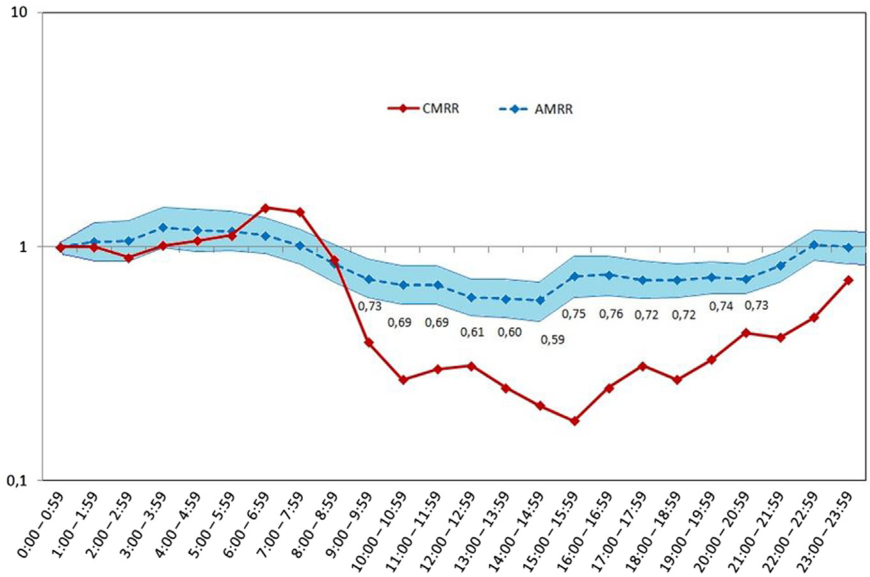

Fig. 2. Crude (CMRR) and mortality rate ratio (AMRR) for the association between time of day and the risk of pedestrian death after a crash. Note: Confidence intervals for CMRR are not shown in the figure for the sake of clarity.

adjusted analysis. However, the crude analysis showed a clear decrease in the risk of death in more recent years. Furthermore, CMRR were higher during weekends and on the days after or before holidays or vacation periods.

Estimates for environment-related variables are shown in Table 5. The highest risk of pedestrian death was observed on open roads, on major roads through an urban area, and in rural areas (fewer than 5,000 inhabitants), whereas the risk was significantly lower for crashes in urban areas with more than 50,000 inhabitants. Regarding the type of road, the risk of pedestrian fatality increased with the maximum speed limit on each type of road. Accordingly, it was higher for wider roads and roads with shoulders, and lower for intersections and traffic circles, and for roads or streets with sidewalks. A final association of note was that between the higher risk of death and worse light conditions, with the highest AMRR (2.01) at night with no lighting.

4. Discussion

Our results are generally consistent with the findings of earlier studies that investigated some of the same variables. For example, the higher risk of fatality in older pedestrians was described in almost all previous studies (Haleem et al., 2015; Islam and Hossain, 2015; Li et al., 2017; Ma et al., 2017; Mohamed et al., 2013; Moudon et al., 2011; Niebuhr et al., 2016; Oikawa et al., 2016; Olszewski et al., 2015, 2016; Pour-Rouholamin and Zhou, 2016, p.; Rolison et al., 2012; Santamariña-Rubio et al., 2014; Tay et al., 2011; Vanlaar et al., 2016; Verzosa and Miles, 2016; Xu et al., 2016; Zajac and Ivan, 2003; Zhang et al., 2014). In addition, our results reveal a nearly perfect direct exponential correlation between age and risk of fatality, and unlike Jang et al. (2013), we did not detect a higher risk of fatality in children and teenagers compared to adults. Regarding sex, the higher fatality among males was also described previously (Islam and Hossain, 2015; Ma et al., 2017; Mohamed et al., 2013; Olszewski et al., 2015; Santamariña-Rubio et al., 2014; Verzosa and Miles, 2016; Zhang et al., 2014). However, Tay et al. (2011) and Oikawa et al. (2016) reported a higher risk of severe injuries or death among women, whereas other studies found this association only for crashes in urban areas (Moudon et al., 2011; Oikawa et al., 2016) or in specific age groups (Santamariña-Rubio et al., 2014). The higher risk of fatality among infractor pedestrians (traffic infractions potentially associated with high-speed crashes) is consistent with the higher risk of death observed in pedestrians who were considered at fault for the crash (Haleem et al., 2015; Mohamed et al., 2013; Olszewski et al., 2016; Zhang et al., 2014). We found no previous studies that investigated the effect of pedestrians' physical defects on fatality, but the positive association in our results appears to be plausible, and may be explained by the greater vulnerability of these people to the effects of the energy transferred during a crash. The negative association in our adjusted analysis between fatality and abnormal psychophysical circumstances (drugs, distraction, etc.) is surprising. However, the crude estimates showed a positive association, which is in agreement with previous studies (Jang et al., 2013; Moudon et al., 2011; Vanlaar et al., 2016; Zajac and Ivan, 2003). The association in our crude analysis may have been confounded by the effect of other variables included in our multivariate model. In any case, it is difficult to determine the effect of this relationship because the variables used in our study included a heterogeneous group of factors such as alcohol or drug consumption, fatigue or distraction. The lower risk of fatality associated with the use of reflectors or reflective clothing by pedestrians may be attributable to their increased conspicuity, which would result in a better driver's response distance, as reported in previous studies (also regarding other vulnerable road users) (Balk et al., 2008; Wood et al., 2012).

An intermediate factor for the association between pedestrian fatality and most independent variables is vehicle speed, perhaps the factor most strongly related to crash severity (Kröyer et al., 2014; Li et al., 2017; Matsui et al., 2016; Oikawa et al., 2016; Olszewski et al., 2015; Verzosa and Miles, 2016; Xu et al., 2016; Zhang et al., 2014). We did not have information about vehicle speed, and used instead the commission of a speed infraction by the driver as a surrogate. As expected, this variable showed a strong association with pedestrian risk of death. Regarding the other driver-related variables we analyzed, the associations are consistent with results reported in previous studies. Our results showed an inverse association between driver age and pedestrian fatality (Pour-Rouholamin and Zhou, 2016; Tay et al., 2011), probably because older drivers tend to drive more slowly. This behavior may also explain the lower risk related with driver female sex (Mohamed et al., 2013; Tay et al., 2011; Zajac and Ivan, 2003), although Wang et al. (2017) reported the opposite association. Our results are also consistent with the higher risk of pedestrian death when the driver was influenced by abnormal psychophysical circumstances, particularly alcohol consumption, as found in previous studies (Mohamed et al., 2013; Moudon et al., 2011; Pour-Rouholamin and Zhou, 2016; Tay et al., 2011; Zajac and Ivan, 2003; Zhang et al., 2014). We found no studies designed to compare the positive association between driver's visual defects and greater crash severity. However, this association is unsurprising, and can also be explained by the higher speeds of vehicles driven by people who, because of their visual defect, have longer reaction times in response to the presence of a pedestrian whom they did not see, or saw too late to avoid a collision.

Regarding vehicle-related characteristics, and also in agreement with previous studies (Aziz et al., 2013; DiMaggio et al., 2006; Haleem et al., 2015; Jang et al., 2013; Ma et al., 2017; Matsui et al., 2016; Mohamed et al., 2013; Oikawa et al., 2016; Pour-Rouholamin and Zhou, 2016, p.; Tay et al., 2011; Verzosa and Miles, 2016; Zajac and Ivan, 2003; Zhang et al., 2014), our results show that compared to private car, vans, trucks and buses were associated with a higher risk of pedestrian fatality, attributable to the greater mass and the design of the front of the vehicle. In contrast, crashes involving mopeds or motorcycles resulted in lower rates of pedestrian fatality, as reported previously (Tay et al., 2011; Zhang et al., 2014). Vehicle age and the presence of structural defects in the vehicle are directly related variables. This relationship may explain their inverse adjusted association with pedestrian risk of death, which was not observed in the crude estimates. Finally, the presence of passengers was also related with a higher risk of fatality, perhaps because distractions caused by passengers may affect driving speed at the moment of impact.

As in the present analysis, many previous studies also found that crashes involving pedestrians tended to be more severe if they occurred at night and/or in poor light conditions (Aziz et al., 2013; Coate and Markowitz, 2004; Haleem et al., 2015; Islam and Hossain, 2015; Jang et al., 2013; Li et al., 2017; Mohamed et al., 2013; Olszewski et al., 2015; Pour-Rouholamin and Zhou, 2016; Tay et al., 2011; Verzosa and Miles, 2016; Zhang et al., 2014). Interestingly, since both variables were included simultaneously in our multivariate model, the excess risk observed during nighttime may be explained by a combination of other confluent factors during nighttime, in addition to poor visibility (i.e., riskier pedestrian attitudes, higher driving speeds or longer delays in receiving health care after the crash). Regarding other temporal variables, the decrease in the CMRR in more recent years may be explained by factors such as improved vehicle design, better health care for the victims, or lower mean vehicle speeds, given that all these circumstances hold for Spain during the study period. However, the adjusted estimates did not show this downward trend, suggesting that the decrease we observed in the crude risk of death may be explained by other factors also included in our model.

With regard to environment-related circumstances, the associations found for many of them may be partially explained by vehicle speed at the time of the crash. For example, greater speeds are a likely explanation for the excess fatalities seen on open roads, as also observed in previous studies (Mohamed et al., 2013; Moudon et al., 2011; Olszewski et al., 2015; Pour-Rouholamin and Zhou, 2016; Tay et al., 2011). Another notable finding is the higher fatality associated with crashes in rural areas (fewer than 5000 inhabitants). Different factors may contribute to this association, as was also observed in other studies (Islam and Hossain, 2015; Islam and Jones, 2014; Pour-Rouholamin and Zhou, 2016; Tay et al., 2011), including the lower access to medical care. Otherwise, these results are consistent with the higher fatality rates from crashes related to the greater dispersion of small urban areas, as shown in previous studies (Ewing et al., 2003; Zajac and Ivan, 2003) and attributed to higher traffic speeds in these areas. The lower risk of fatality associated with crashes at intersections has been also reported previously (Aziz et al., 2013; Ma et al., 2017; Mohamed et al., 2013; Olszewski et al., 2015; Xu et al., 2016), although some studies found different patterns depending on the location of the intersection in open roads or urban areas (Moudon et al., 2011; Oikawa et al., 2016), or depending on the type of signalization at the intersection, e.g. exclusive or concurrent signal phasing for pedestrian crossing (Zhang et al., 2015).

Greater road width was positively associated with a higher risk of pedestrian death. This result, in agreement with research published by Tay et al. (2011), is consistent with the higher risk of pedestrian mortality on roads with more than two lanes, which probably reflects the higher driving speeds on this type of road (Aziz et al., 2013; Mohamed et al., 2013; Olszewski et al., 2015; Pour-Rouholamin and Zhou, 2016, p.). A similar explanation may account for the higher fatality associated with the presence of a shoulder and with wider shoulders, and to the absence of sidewalks. Finally, although the association was not statistically significant, bad weather conditions were related with a lower risk of fatality in our multivariate model, which is in agreement with previous research (Ma et al., 2017; Mohamed et al., 2013; Pour-Rouholamin and Zhou, 2016; Verzosa and Miles, 2016). This association may be explained by lower traffic speeds under adverse meteorological conditions.

Our study has several limitations which should be taken into account when interpreting our results. First, police-based crash registries tend to underreport less severe crashes (Sciortino et al., 2005; Teanby, 1992) and those occurring in urban areas, where most crashes involving pedestrians take place. This means that all the denominators in the fatality rates being compared across categories of independent variables were underestimated, and consequently, all fatality rates were overestimated to a certain degree. This overestimation was presumably greater in categories related to less severe crashes (i.e., higher for younger pedestrians than older ones, and higher for crashes occurring during daylight hours than at night). This, in turn, would lead to bias towards the null in the strength of the association between high-risk categories and the risk of pedestrian death.

In addition, the accuracy of the information collected by the police may be questionable, especially for variables such as physical defects and psychophysical circumstances in the people involved. Hypothetically, this information bias may differ depending on the severity of the crash. For example, if police tend to look for (and thus find and record) information about these circumstances more frequently in more severe crashes, this might lead to an away-from-the-null bias (i.e., overestimating the magnitude of associations between these factors and the risk of pedestrian death).

Furthermore, although we tried to minimize the impact of missing values through a multiple imputation process, we cannot ensure the MAR hypothesis for missing values, required to completely control for the selection bias that may arise from missing values. Therefore, we must assume that some of these missing values were dependent on factors not recorded by the police yet potentially related to the risk of pedestrian death. Unfortunately, we cannot predict the direction or magnitude of this source of bias.

Finally, we are aware of the lack of information on vehicle speed at the time of the crash, a mediator in the causal pathway between the risk of pedestrian death and many of the factors considered in our study. Undoubtedly, inclusion of this variable in multivariate models would have reduced the magnitude of the associations found for many independent variables.

5. Conclusions

Our study confirms that the patterns of association in Spain between the risk of pedestrian death and some individual-, vehicle- and environment-related factors (i.e., ageing, heavy vehicles and crashes occurring at night) are similar, in many respects, to the patterns reported in previous research from other countries. More importantly, we detected other associations not found in previous studies, such as those for vehicle-related (previous defects, presence of passengers) and driver-related (visual defects) variables. Because our study was designed to assess the magnitude of the associations between risk factors and the risk of pedestrian death (and not the associations between specific preventive strategies and this risk), our results do not constitute direct evidence to support any specific strategy aimed at reducing the risk of death of a pedestrian after a crash. However, the pattern of associations we found strongly, albeit indirectly, suggests that some of the following measures could be useful to reduce this risk and should be encouraged:

– Reduce the speed limit for vehicles in urban areas with high pedestrian densities, enforce speed limits for vehicles on urban roads, and increase sanctions for speed-related infractions.
– Prevent pedestrian crossing (with physical barriers) in areas where the risk of more severe injuries after a crash is highest (for

example, near bus stops or on roads with higher speed limits).
– Prevent the circulation of heavy vehicles on urban roads frequently crossed by pedestrians.
– Improve lighting conditions in urban areas.
– Perform an in-depth analysis of pedestrian deaths in rural areas, in order to detect possible deficiencies in medical care provided to the victims.
– Construct and improve sidewalks.
– Reinforce the assessment of drivers' visual acuity.
– Increase the detection of and sanctions for driving under the influence of alcohol or other drugs in urban areas.
– Increase the detection of and sanctions for pedestrians who commit traffic infractions. (Currently no such legal sanctions exist in Spain.)
– Design and implement traffic safety education programs focused on both vulnerable pedestrians (older people and those with physical defects) and high-risk drivers (i.e. younger drivers, males, and those likely to drive under the influence of alcohol or other drugs).

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Conflict of interest

The authors declare that they have no conflicts of interest.

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