Comparing Female and Male Pedestrians' Relative Vulnerability Based on Crash Locations

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Key Findings

- Female pedestrians are more likely to suffer fatal injuries than male pedestrians.
- Factors that increase the risk of fatal injuries for female pedestrians include:
  - being under 15 years old or 41-64 years old;
  - lacking formal education;
  - being single;
  - not receiving trauma care in time due to resting at home or long transfer time to a hospital;
  - not wearing contrasting clothes in urban areas; and
  - being involved in a crash on rural roads or at dusk/dawn on intercity roads.

Abstract

While pedestrian fatalities represent 23% of all road crash fatalities in Iran, fatalities seem more common amongst female pedestrians than male pedestrians. This study investigated female pedestrian fatalities and contributing factors such as age, education, and visibility. Using Iran's 2014 death registry data, a relative vulnerability ratio was estimated for different groups stratified by crash locations. Factors that increase the risk of fatal injuries for female pedestrians included: being under 15 years old or 41-64 years old; lacking formal education; being single; not receiving trauma care in time due to resting at home or long transfer time to a hospital; not wearing contrasting clothing in urban areas; and being involved in a crash on rural roads or at dusk/dawn on intercity roads.

Keywords

pedestrian fatalities, female pedestrians, Iran road safety

Introduction

About 23% of all road crash deaths in the world are suffered by pedestrians and males are typically over-represented in pedestrian deaths (WHO, 2018). For example, a study conducted in the United States of America (USA) revealed that males accounted for 70% of pedestrian deaths, with a fatality rate of 2.19 deaths per 100,000 populations, compared to 0.91 for females (WHO, 2013). According to official statistics published by the Iranian Legal Medicine Organisation (LMO, 2014), pedestrian fatalities annually accounted for 23% of all road-user fatalities in the Islamic Republic of Iran. Similarly, men who represented 51% of the Iranian population accounted for 73% of pedestrian deaths in traffic crashes in 2014. The annual rate of pedestrian deaths per 100,000 population by gender (Figure 1) has shown a descending trend for both males and females since 2009. However, the male fatality rate on average is 2.6 times that of females (LMO, 2014). After reviewing 35 studies, Kim et al. (2014) found that the factors associated with pedestrian-vehicle crashes are related to drivers, pedestrians, vehicles, neighbourhood-level environment, street-level environment, other environmental factors,

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law, regulation or educational factors. Through field observations, Balk et al. (2008) found conspicuity, pedestrian motion, and driver perception/reaction behaviour are related to pedestrian crashes.

Women are often traditionally dressed in dark clothing in Middle East countries. Hence, examination of pedestrian crashes in these countries comparing the vulnerabilities between female and male pedestrians is needed. This is even more important considering that some of these countries are moving toward more equitable gender occupation rates compared to previous years (Findlow, 2013). Although male pedestrian fatality rates are higher than female pedestrian fatality rates, existing literature shows conflicting results in terms of gender and injury severity to pedestrians. According to Rouholamin and Zhou (2016), pedestrian gender was not significantly related to crash injury severity whereas the study conducted by Kim et al. (2008) showed that male pedestrians are 1.2 times more likely to be severely injured compared to their female counterparts. Zhu et al. (2013) also demonstrated that the pedestrian death rate per person-year of men was 2.3 times greater than that of women. Eluru, Bhat, and Hensher (2008) argued that male pedestrians were more susceptible to severe or fatal injuries compared to females, attributing the gender disparity to risk perception and risk-taking behaviour while walking or crossing the road. Contrary to the previous findings, Islam and Jones (2014) indicated that female pedestrians are 3.3% more likely to endure severe injuries compared to male pedestrians. Lee and Abdel-Aty (2005) as well as Sze and Wong (2007) concluded that female pedestrians are more likely to sustain severe or fatal injuries, due to men's relative physiological strength compared to women. Vestrup and Reid (1989) found females were involved in pedestrian injuries in 60% of cases, particularly elderly females who were more likely to require hospital admission.

In terms of pedestrian exposure to traffic, while it is usually hypothesised that males may walk more than females, National Highway Traffic Safety Administration (NHTSA) data from 2001 showed that the number of walking trips was mostly similar between males and females. However, Ghani et al. (2016) showed there is evidence that in general males may walk further than females per trip on average, which would increase their exposure to traffic and partly account for any differences in terms of survivability trends. Although there has been speculation that males may tend to walk in more dangerous locations or exhibit riskier behaviours than females, little information is available to confirm or refute these assumptions (NHTSA, 2008). Zhu et al. (2013) examined the factors that contribute to this male-female discrepancy by analysing three - comparative ratios of walking exposure, vehicle-pedestrian collision risk, and vehicle-pedestrian collision fatality rate. This study identified that walking exposure did not contribute to the difference in pedestrian death rate between genders. It appeared that crash location, road type and environment, and pedestrian behaviour could affect pedestrian vulnerabilities in road traffic crashes.

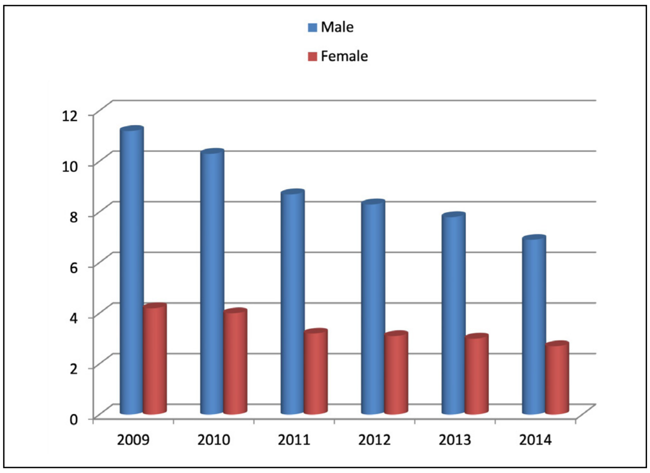

Figure 1. Rate of pedestrian fatalities in Iran per 100,000 population stratified by gender (Source: LMO, 2014).

Many studies have concluded crash location has a significant association with pedestrian risk and vulnerability. According to NHTSA (2008), the higher frequency of pedestrian trips in urbanised areas led to a more significant probability of pedestrian fatalities.

Mueller (1988) indicated that although fewer pedestrian fatalities occur in rural areas, pedestrians are 2.3 times more likely to die from a pedestrian crash in rural areas compared to urban areas. On the other hand, Zajac and Ivan (2003) showed there is a significant difference between the injury severities in condensed residential areas compared to low-density areas. Additionally, Zegeer and Hunter (2010) also demonstrated that urban roads had the highest incidence of fatal crashes compared to rural and local roads. The data for female pedestrian fatalities during 2009-2014 in Iran indicate that an average of 59% are in urban areas, 34% on intercity roads, and 7% on rural

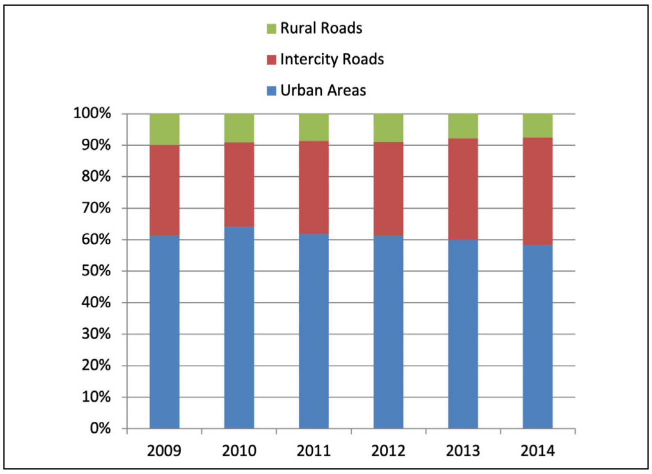

Figure 2. Female pedestrian fatalities in Iran stratified by crash location (Source: LMO, 2014).

roads as shown in Figure 2. The trends reveal a decreasing proportion of female pedestrian fatalities in urban and rural areas but increasingly more severe fatal injuries on intercity roads.

To estimate risk functions, Marcianòet al. (2010) defined the pedestrian vulnerability as an impact resistance measure represented in the interval [0-1] multiplied by the probability of pedestrian crash involvement and exposure. Al-Madani (2007) assumed vulnerability as an over-representation of pedestrian victims indicated by a positive weighted residual. Grembek (2012) defined a relative vulnerability index as the number of injuries by a specific mode compared to another and demonstrated the index for different modes in different locations. Therefore, a vulnerability index could be used to explain any differential in fatal crash risk between male and female pedestrians.

Considering the above-mentioned research and the proposed definition of a vulnerability index, if it is assumed that the likelihood of being involved in a car crash is the same regardless of gender, and that females generally have lower exposure in traffic, it is hypothesised in this present study that female pedestrian vulnerability is equal to or lower than male pedestrian vulnerability, i.e. null hypothesis. Thus, analysing the Iranian crash data using statistical methods in this study attempts to reject this null hypothesis $\mu_f \leq \mu_m$ by examining whether female pedestrian could have more significant vulnerability based on their crash locations. The data are analysed by taking into consideration female pedestrians' age, education, marital status, crash time, location of death, and conspicuity. The alternative hypothesis that $\mu_f > \mu_m$ will equally be considered.

Methodology

Traffic fatality death registry data collected by the Iranian Legal Medicine Organization (LMO) was used to conduct this study. Comparison and cross reference tables of the collected data enabled the assessment of the locations where pedestrian-motor vehicle crashes resulted in a pedestrian fatality. Although the death registry data used in the study do not capture all the essential aspects of walking and crossing behaviours of pedestrians at the time of the crash, the data are not subject to underreporting of deaths due to the nature of how the data were collected by the LMO. In this study, the contributing factors are limited to those data available in the dataset: gender, personal specifications such as age, marital status, clothing worn, death location, and crash location.

A similar pattern is observed in the proportion of road fatalities from 2009 to 2014 as shown in Figure 1. Therefore, a total number of 3,755 pedestrian deaths reported in 2014 accounting for 22.3% of total motor vehicle crash fatalities, was selected for the analysis (LMO, 2014). Variables related to pedestrian crashes were stratified according to gender within three road types namely, urban areas, intercity and rural roads. Data for the variables of age, education level, marital status, death location, crash time, clothing colour, and time of day were extracted. Table 1 shows the variables analysed in this study cross-tabulated with the three crash location road types. The number of pedestrian fatalities is separated by a slash ("/") where the left value is the number of males versus the right value as the number of females.

Relative Vulnerability (RV), introduced by Grembek, (2012), was used as the parameter to compare vulnerability. RV was defined as the number of female pedestrian fatalities for each variable divided by the total female pedestrian fatalities, in a particular crash location type, compared to the same ratio for males. As an illustrative example, the RV is calculated using the values from Table 1 of female and male fatalities for the variable "Age" in the group (0-15) as $\frac{106/600}{180/1601} = 1.57$ (shown in respective cell in Table 2).

RV represents the vulnerability of female pedestrians in fatal crashes compared to male pedestrians for the same road conditions. The above ratio should be significantly greater than 1 when greater vulnerability for a particular gender and associated factor is hypothesised. The comparison of pedestrian vulnerability for females and males can be expressed as a ratio formulated by equation (1) where V_{ij}^{fm} is the relative vulnerability of a female pedestrian compared to a male for each group *i* at location *j*. N_{ij}^{f} and N_{ij}^{m} are respectively the numbers of female and male pedestrian fatalities for group *i* at location *j*. $\sum_i N_{ij}^{m}$ and $\sum_i N_{ij}^{f}$ and represent the number of male and female pedestrian fatalities in all groups *i*, calculated as the sum for each location *j*. Finally, V_{ij}^{mf} known as the relative vulnerability of male to female is now calculated by inverting the V_{ij}^{fm} ratio.

$$V_{ij}^{fm} = \frac{N_{ij}^{f}/\sum_i N_{ij}^{f}}{N_{ij}^{m}/\sum_i N_{ij}^{m}} = \frac{N_{ij}^{f}}{N_{ij}^{m}} \times \frac{\sum_i N_{ij}^{m}}{\sum_i N_{ij}^{f}} \quad and$$
$$V_{ij}^{mf} = \frac{1}{V_{ij}^{fm}} \ \forall\, i, j \qquad (1)$$

Table 2 summarises the relative vulnerabilities of female pedestrians in the third to fifth columns for all variables at their corresponding crash locations. To check whether female vulnerability is significantly greater than the relative vulnerability of men, the value should be compared to the constant-coefficient of 1 using the single-sample T-test. Where the size of data set is small, the calculated T-test value and standard deviation can be compared to the significance values in the tables for hypothesis testing (Chafjiri & Mahmoudabadi, 2018).

Statistical values of standard deviation (SD), degree of freedom (DF), and the critical value of T-test (TC)

Table 1. Pedestrian fatalities stratified according to gender for the different collision variables (male/female).

Variable	Group	Total	Urban Areas	Intercity Roads	Rural Roads
Age	0-15	341/222	180/106	113/80	47/36
	16-24	186/34	95/14	84/19	7/1
	25-40	427/110	219/64	179/41	21/4
	41-64	772/352	449/198	291/132	28/20
	65+	958/312	631/215	287/77	35/16
Education	No Education	1016/583	608/325	378/192	70/62
	Primary School	702/248	407/139	254/95	36/12
	Secondary School	332/52	181/28	130/23	18/1
	High School	392/79	246/57	136/22	9/0
	University	151/48	109/35	38/11	3/1
Marital Status	Single	742/351	400/192	272/118	64/39
	Married	1949/667	1187/399	680/226	72/37
Death Location	Crash Site	1014/398	426/187	534/187	48/23
	Transferring	205/88	103/42	83/32	18/13
	Hospital	1451/527	1040/356	331/126	70/40
	Home	22/17	18/12	3/4	1/1
Crash Time	Day Light	1476/628	907/389	475/178	82/56
	Night	864/278	468/143	355/116	38/18
	Dusk/Dawn	321/113	190/157	115/51	15/4
Clothing Colour	Bright	1059/253	697/145	301/76	53/32
	Dark	818/538	409/302	356/203	50/28
Time of day	Day Light	418/311	222/201	168/89	27/18
	Night	285/146	127/67	142/70	14/8
	Dusk/Dawn	104/76	55/29	41/44	8/2
Total		2718/1037	1601/600	961/352	138/78*

*Note: May not add up to 100 percent as blank responses were not available for location strata.

at significance level of α=0.05 have been respectively tabulated in brackets for each variable under each group in Table 2. For example, the standard deviation for variable "Age" where 15 RVs are calculated, is equal to 0.57 and the degree of freedom is 15-1=14. Thus, the value for the T-test extracted from the table of values (0.05, 14) is 2.14 (Walpole & Myers, 2012). These values have been calculated for all variables and RVs using equation (2) are tabulated in Table 2.

$$t_{ij} = \frac{RV_{ij} - 1}{\frac{\sigma}{\sqrt{n-1}}} \qquad (2)$$

The T-test for comparing the individually obtained values of RVs is also calculated using equation (2), where RV_{ij} is the relative female pedestrian vulnerability compared to male vulnerability and t_{ij} is T-test for the group i at location j. In this case, σ represents the standard deviation

Table 2. Relative Vulnerability (RV) for different crash locations

Variable	Group	RV			T-test		
		Urban Areas	Intercity Roads	Rural Roads	Urban Areas	Intercity Roads	Rural Roads
Age	0-15	1.57	1.89	2.04	**3.75**	**5.85**	**6.83**
	16-24	0.39	0.60	0.38	-4.01	-2.63	-4.07
	25-40	0.78	0.61	0.51	-1.45	-2.56	-3.22
	41-64	1.18	1.21	1.91	1.18	1.38	**5.98**
	65+	0.91	0.72	1.22	-0.59	-1.84	1.45
Stats:	[SD; DF; TC]	[0.57; 14; **2.14**]					
Education	No Education	1.43	1.36	2.36	**2.78**	**2.33**	**8.79**
	Primary School	0.91	1.00	0.89	-0.58	0.00	-0.71
	Secondary School	0.41	0.47	0.15	-3.81	-3.43	-5.50
	High School	0.62	0.43	0.00	-2.46	-3.69	-6.46
	University	0.86	0.77	0.89	-0.91	-1.49	-0.71
Stats:	[SD; DF; TC]	[0.58; 14; **2.14**]					
Marital Status	Single	1.28	1.16	1.63	2.19	1.25	**4.93**
	Married	0.90	0.89	1.37	-0.78	-0.86	**2.90**
Stats:	[SD; DF; TC]	[0.29; 5; **2.57**]					
Location of Death	Crash Site	1.17	0.93	1.28	0.69	-0.29	1.14
	Transferring	1.09	1.03	1.93	0.37	0.12	**3.80**
	Hospital	0.91	1.02	1.52	-0.37	0.08	2.12
	Home	1.78	3.56	2.67	**3.18**	**10.45**	**6.82**
Stats:	[SD; DF; TC]	[0.81; 11; **2.20**]					
Crash Time	Day Light	1.14	1.00	1.82	1.16	0.00	**6.82**
	Night	0.82	0.87	1.26	-1.50	-1.08	2.16
	Dusk/Dawn	0.80	1.18	0.71	-1.66	1.50	-2.41
Stats:	[SD; DF; TC]	[0.34; 8; **2.31**]					
Clothing Color	Bright	0.56	0.67	1.61	-1.75	-1.32	2.43
	Dark	1.97	1.52	1.49	**3.87**	2.07	1.95
Stats:	[SD; DF; TC]	[0.56; 5; **2.57**]					
Time vs.	Day Light	2.42	1.41	1.78	**6.22**	1.80	**3.42**
Dark Cover	Night	1.41	1.32	1.52	1.80	1.40	2.28
	Dusk/Dawn	1.41	2.86	0.67	1.80	**8.15**	-1.45
Stats:	[SD; DF; TC]	[0.65; 8; **2.31**]					

SD = Standard Deviation; DF = Degree of Freedom; TC = Critical value for T
Bold and grey highlighted values identify significant differences between females and males.

for all RVs related to a specific variable, and *n* is the number of stratified groups for the particular group and location area. For instance, the T-test for the specific age group (0-15), in urban areas is calculated as $t_{11} = \frac{1.57-1}{0.57/\sqrt{15-1}} = 3.75$. The calculated T-test value can thus be compared to the critical value of t(α=0.05,14) = 2.14. That is, the relative pedestrian vulnerability for female pedestrians in the age group 0-15 in urban areas is significantly more than for males. The calculation procedure has been performed for all stratified groups and locations and presented in Table 2 in columns six to eight. The obtained T-test values where there is a significant difference between females and males are shown in bold and grey highlight.

The variable "Time vs. Dark Cover" is an interaction of crash time and clothing colour to check whether it has significant effect on female vulnerability. The results show that Dark Cover has a significant effect at night and Dark Cover times.

Discussion

Table 2 shows that female pedestrians under 15 years of age experience a greater vulnerability than any of the other age groups regardless of their crash locations. Comparing the individual T-test values to TC (the critical value for T calculated at the bottom of each variable box) for the variable "Age" t(0.05, 14) = 2.14, revealed that female pedestrians under 15 years old and involved in crashes both on intercity (5.83) and rural (6.83) roads, are more vulnerable than those in urban areas. They are estimated to be around 2 times more vulnerable than male pedestrians for the same age group [RV=1.89, 2.04]. The results also show females have greater vulnerability compared to their male counterparts in the 41-64 age group.

Low-level education seems to be another factor associated with women involved in fatal traffic crashes compared to men at all crash locations in rural areas. The same conclusion was reached by Al-Madani and Al-Janahi (2005) who showed that young and old male and female pedestrians with low educational qualifications were associated with higher fatality risk.

This study further revealed that female pedestrians in rural areas either single or married are more likely to have a higher risk of fatal injuries. This may suggest a need to address the limited coverage of emergency medical services in rural areas. The most concerning result, however, is the death ratio at home at all locations for female pedestrians. An old common misconception (customary belief) among Iranian people, particularly among women, is that it is better to recover from an injury at home instead of attending a hospital.

In the case of crashes that occur at night, female pedestrians are less vulnerable to death in urban areas and intercity roads compared to rural areas. The increased female pedestrian vulnerability in the daytime for rural roads may be a proxy for impact speed. This result is somewhat at odds with previous findings by Kim et al., (2008) who found darkness contributing 2–4 times more to pedestrian fatality than daylight.

It is commonly believed that wearing bright or contrasting clothes increases pedestrian conspicuity whereas clothes that do not provide any contrast, reduce driver detection of the pedestrian (Noy & Karwowski, 2004). The present findings support the conclusion that dark clothing may be a contributing factor in female pedestrian vulnerability in Middle Eastern countries.

Since variables such as clothing colour and crash time may have a confounding effect on pedestrians' casualties, a combination of these two variables were examined to assess if there were any possible significant differences. For nearly all crash locations, female pedestrians have a higher vulnerability during day light than night time. That is, these results do not support the premise that women who wear dark clothes at night time are more vulnerable than men. However, the female vulnerability index for intercity roads approaches a value of 3 [RV=2.86, T-Test=8.15]. This possibly indicates that drivers may have difficulties perceiving and reacting to females walking near the intercity roads at dusk/dawn times because of gradual change in lighting conditions.

The results in Table 2 generally indicate that women in rural areas have a more significant vulnerability compared to men. This research provides some insight for transport authorities and decision-makers who are dealing with improving pedestrian safety.

Conclusions

This study analysed female pedestrian vulnerability using Iran's LMO pedestrian fatality data collected in 2014. The null hypothesis, in which female pedestrian vulnerability is equal to or lower than male, is rejected based on the vulnerability comparative analysis and T-test results presented in Table 2. Analysing different crash locations for the various possible relevant variables, shows different vulnerability ratios between female and male pedestrians. The results suggest that female pedestrians receive elevated levels of vulnerability compared to males in a number of instances. The results further support the hypothesis that females are also more likely to suffer from fatal injuries on rural roads; notably, when young children and older women (0-15 and 41-64 years old) are involved in a pedestrian crash.

More insights can be gained from comparing the design features and female pedestrian behaviours across locations that have various elevated levels of gender relative vulnerability. Changes over time in road design manuals, instructions, traffic operations and regulations, levels of education, clothes wearing customs, attitudes and perceptions towards walking could be tracked. By applying a more focused approach investigating gender differences at road sites (intersections, undivided roads, the existence of a median, crossing facilities), and for different user behaviours (drivers, pedestrians, motorcyclists) and other variables, the relative vulnerability of female pedestrians compared to male pedestrians in various road sites and road user cultures may be explored.

There were several limitations when conducting the study. The female vulnerability factors presented in Table 2 have not been investigated in previous literature. Future research efforts should additionally include walking exposure surveys to gain a better understanding of how the crash location and walking areas differ between genders.

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Author Contributions

H. Abdous contributed to the study conception and design and data collection. H. Abdous and A. Mahmoudabadi contributed to data analysis, interpretation of results, and manuscript preparation. All authors have read and agreed to the published version of the manuscript.

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Ethics

Authors stated that there was no human or animal treatment or examination regarding this research work.

Data Availability Statement

Data supporting reported results can be found in general form at www.lmo.ir and detailed information can be provided on request to the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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