INVESTIGATING OLDER PEDESTRIAN FATAL CRASH CHARACTERISTICS IN THE UNITED STATES

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ABSTRACT

Age is a dominant factor in pedestrian-vehicle crashes and different crash contributing factors often interact uniquely to make certain age groups more susceptible to crashes. According to the Fatality Analysis & Reporting System (FARS) database, a total of 7,388 pedestrians died on U.S. roads due to motor vehicle crashes in 2021, and around 18.6% (count = 1,375) of them were 65 years or older. To get a comprehensive understanding of the older pedestrian crash problem in the US, this study collected US national-level pedestrian fatal crash data (2017-2021) from the Fatality Analysis and Reporting Systems (FARS). The study considered a comprehensive set of crash variables, including crash location, intersection type, temporal factors, settings, roadway type, and striking vehicle and driver characteristics. The collected fatality frequency data was divided into older (65 years or higher) and non-older (less than 65 years) groups and the risk ratio was calculated based on the comparison of frequencies between the two age groups. Several statistical tests were also conducted to compare the risk ratios including Welch two-sample t-test, Analysis of Variance (ANOVA), and Tukey's Honestly Significant Difference (HSD). The analysis provides critical insights into older pedestrian crash characteristics and discovered higher risk ratio (>1) in crashes resulting in fatalities at intersections, on weekdays, during daytime, urban settings, lower functional classification roadways (e.g., local, collector, and minor arterial), left-turn and right-turn vehicle movement, striking vehicle driver gender as female, and light truck-Van. The findings of this research can help to understand the unique patterns of older pedestrians' fatal crash involvement and the possible scope of safety improvement for this vulnerable age group.

Keywords: *FARS, risk ratio, older pedestrians, intersection, left-turn*

1. INTRODUCTION

The term 'Baby Boomers' is used to represent the generation of people who were born in the United States between the years 1946 and 1964. This 19-year period saw a significant increase in birth rates compared to previous years, with a total of 76 million births during this timeline. The age distribution of the American population is drastically changing because of the baby boomers' aging (details in Figure 1a). According to the US Census Bureau database, the number of older populations (65 years or higher) in the United States was 55.7 million in 2020 which represents 17% of the total population (one in every seven Americans). With the growing older population, traffic deaths associated with this specific age group are also on the rise. In 2020, a staggering 17% (count = 6,549) of all traffic fatalities involved people aged 65 and older (source: Fatality Analysis Reporting System). Following a similar trend, older pedestrians are depicted as a vulnerable age group in the U.S. representing around 19% of total pedestrian fatalities (corresponds to one in every five pedestrian fatalities) in 2021. The frequency of older pedestrian fatalities in 2021 was a 44% increase compared to a decade ago in 2012 (details in Figure 1).

Recognizing and addressing the safety of elderly pedestrians is crucial to identify the factors contributing to crashes involving this demographic. This study focused on analysing older pedestrian (65 years or higher) fatal crash characteristics using US national-level data (2017-2021) collected from the Fatality Analysis Reporting System (FARS) considering a wide range of factors including human, vehicle, roadway, environment, and temporal factors. The findings of this research are expected to provide a critical understanding of the general trend of older pedestrian-involved fatal crashes in the US. The findings of this study have important implications for improvements in roadway environment and infrastructure and thus making roads safer for older pedestrians.

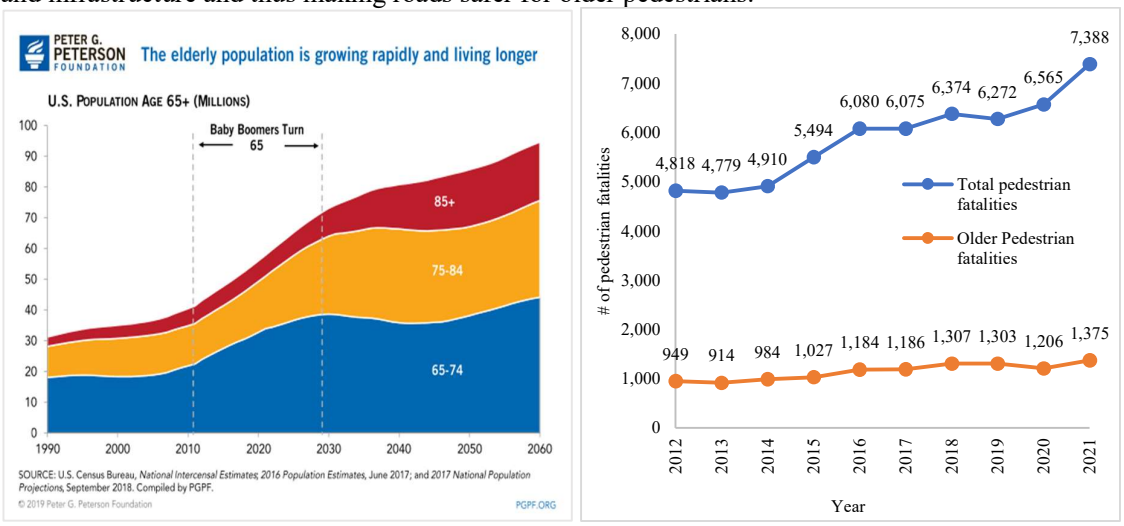

Figure 1: a) Older population growth in the US (Source: US Census Bureau); b) Pedestrian fatalities in the US (Source: FARS)

2. LITERATURE REVIEW

Demographic changes, such as an aging population, have significant implications for transportation planning, infrastructure, and safety measures. Due to the current demographic changes in the US, the unique safety challenges of older pedestrians remain a key transportation issue. A substantial amount of research has been conducted focusing on older pedestrians (Das et al., 2019; Guo et al., 2021a; S. Kim & Ulfarsson, 2019; Koepsell et al., 2002; Lalika et al., 2022; Naumann et al., 2011; Nicaj et al., 2006; Noh et al., 2018; Prange et al., 2010; Rod et al., 2021). The majority of these investigations identified the age of pedestrians as a significant risk factor for injuries, with older pedestrians having a greater likelihood of suffering serious injuries in collisions due to physical vulnerabilities. The explanation underlying this is that elderly pedestrians have diminished sensory, perceptual, cognitive, and physical capacities, which leads to challenges in managing complex traffic situations. An overview of these investigations is summarized in the following **Table 1.**

Table 1: Key findings from selected studies

Study	Methods; Location	Factors contributing to older pedestrian crashes
(D. Kim, 2019)	Multinomial logistic regression (MLR) model; County of Los Angeles, California, US;	• The model's outputs indicate that features like three-way intersections, raised medians, street trees, and recreational land use enhance the safety of older pedestrians. • Bus stops may lead to an increase in crashes involving older pedestrians, whereas intersections with crosswalks do not enhance the safety of older pedestrians but relatively contribute more to the safety of younger pedestrians.
(S. Kim & Ulfarsson, 2018)	A random-effects logistic regression model, General Estimate Systems (GES) database; US	• Older drivers are more likely to hit older pedestrians. • Older pedestrian crashes are more likely to occur in driveways and parking lots when compared to younger pedestrians. • Sport utility vehicles (SUVs) and minivans pose a greater risk to the safety of elderly pedestrians.
(Chong et al., 2018)	Multivariable logistic regression; NHTSA's FARS database and NASSGES, US	• Factors contributing to a higher risk of pedestrian fatality includes drivers aged 65 years or older, male gender, alcohol use by either the driver or the pedestrian, collisions occurring during night hours at non-intersections, and involvement of heavy vehicles. • The risk of fatalities was higher at non-intersection locations compared to intersections.
(Safety, 2020)	FARS Database; North Carolina, US	• Once involved in a collision, older pedestrians face a significantly higher probability of fatality compared to younger pedestrians. • Crashes involving older pedestrians are more frequent during weekdays, on daylight hours, and in winter. • Older pedestrians are more prone to be involved in crashes at intersections, especially those with wide street crossings and turning vehicles. • Alcohol involvement was less probable for older pedestrians compared to the younger age groups.
(Anderson et al., 2022)	Random Forest; Oregon	• 20% of the crashes occurred in the dark without street lighting, with an additional 8% and 5% occurring during dawn and dusk. • 19% of the fatal and serious injury crashes involving older pedestrians were attributed to vehicles turning left.
(Taylor et al., 2011)	NEISS-AIP database; US	• On average, older adults take longer to react during crossing the streets. • The primary mechanisms of injury of elderly pedestrians were being struck by a motor vehicle and failing to yield. • Kerbs were a significant contributing factor to crash-related injuries for older pedestrians.
(Guo et al., 2021b)	Machine learning method Extreme Gradient Boosting (XGBoost); Colorado, US	• The driving speed is one of the most important factors related to older pedestrians crashes. • Light condition plays a vital role as older pedestrians are more prone to be involved in fatal crashes from 5 AM to 7 AM.

(Wilmut & Purcell, 2020)	Observational and simulation studies; UK	• Cognitive skills such as selective attention and processing speed play a key role in older pedestrian road crossing. • Perceptual skills such as the ability to judge the vehicle arrival time affect the decision-making of the pedestrian. • The variation of this skill among older pedestrians can be an issue along with other individual constraints like motor skills.
(Budzynski & Tubis, 2019)	Statistical Analysis, Poland	• Identifies the causes of road crashes involving older pedestrians both as drivers and pedestrians. • Carelessly stepping onto the road in front of an oncoming vehicle is the most common reason followed by crossing the road where it is illegal to cross the road and stepping onto a road when it signals a red light.
(Lombardi et al., 2017)	Statistical analysis; Victoria, Australia	• 21% of pedestrian collisions were related to older pedestrian. • Fatality rate was higher for the older pedestrian aged 75 years or older. • Collisions related to older pedestrians mostly occurred during crossing the road, followed by parking lots and intersections.

Based on the review of relevant literature, the research team identified that, analysing older pedestrian fatal crash statistics and its time-dependent variation in the context of US is relatively less explored and there is scope for further investigation. Therefore, the objective of this research is to explore older pedestrian fatal crash statistics in the US and identify the change in fatal crash risk (in terms of risk ratio) considering a five-year period (2017-2021). The findings of this study can inform the unique safety challenges of older pedestrians and help policymakers to develop targeted countermeasures.

2. METHODOLOGY

Using frequency data, Relative Accident Involvement Ratio (RAIR) is a well-known quasi-induced exposure analysis metric that compares 'at-fault' and 'not-at-fault' drivers involved in crashes (Aldridge et al., 1999; Romano et al., 2008; Stamatiadis, 1996; Stamatiadis & Deacon, 1995; Straus & Gu, 2009). In the context of pedestrian-vehicle crashes, the idea of 'at-fault' or 'not-at-fault' is not well established and not available in the FARS database. Another study introduces a measure Crash Incidence Ratio (CIR) in the context of alcohol involved motor vehicle crashes (Voas et al., 2007). The study defined CIR as the ratio of the percentage of alcohol impaired drivers among all drivers in a specific subgroup compared to the percentage who did not drink and drive in the same subgroup. Another study conducted in 1996, used a term called risk ratio to estimate the risk of an approach and landing accident with a particular factor present (Enders et al., 1996). It is calculated as:

$$Risk\ Ratio = \frac{\frac{a}{A}}{\frac{f}{N}} \quad (1)$$

Here, 'a' is number of occurrences of a factor in accidents, and 'A' is number of accidents; 'F' is number of occurrences of the factor in normal flights and 'N' is number of normal flights. Following a similar idea in this research, we considered two age group of pedestrians: older (65 years or higher) and non-older (less than 65 years) pedestrians and calculated risk ratio considering the presence specific variables or settings. For example,

$$Risk\ Ratio = \frac{\frac{Older\ pedestrian\ fatalities\ at\ intersection}{Total\ older\ pedestrian\ fatalities}}{\frac{Non-older\ pedestrian\ fatalities\ at\ intersection}{Total\ non-older\ pedestrian\ fatalities}} = \frac{\frac{488}{1375}}{\frac{1174}{5904}} = 1.78$$

Risk ratio values greater than 1.0 indicate that the older pedestrians are more likely to be involved in crashes (resulting in fatalities) for the presence of specific factors and vice versa. We also considered five-year data (2017-2021) data to explore the time trend of risk ratios. Several statistical tests were also conducted to check if the difference between risk ratios is statistically significant including Welch two sample t-test, and Analysis of Variance (ANOVA).

3. DATA SOURCE

Pedestrian fatality frequency data were obtained from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (www-fars.nhtsa.dot.gov/Main/index.aspx). FARS is a record system for fatal crashes which is defined as a crash on a public roadway in the US causing a death within 30 days of the crash event. Frequencies of fatalities for older (65 years or higher) and non-older (less than 65 years) pedestrians were documented and associated characteristics were calculated in terms of risk ratio. The selected variables include crash location, temporal and spatial factors, and striking vehicle and driver characteristics.

4. RESULTS AND DISCUSSION

The preliminary analysis focused on the spatial patterns of older pedestrian fatalities in the US by identifying the rank of US states with the highest number of older pedestrian fatalities in 2020. The top five states with the highest number of older pedestrian fatalities in 2020 were California (194 deaths), Florida (140 deaths), Texas (98 deaths), New York (70 deaths) and New Jersey (45 deaths). In the next step, the frequency of older pedestrian fatalities was normalized according to the older population of each US states and the following figure illustrates the finding of this investigation.

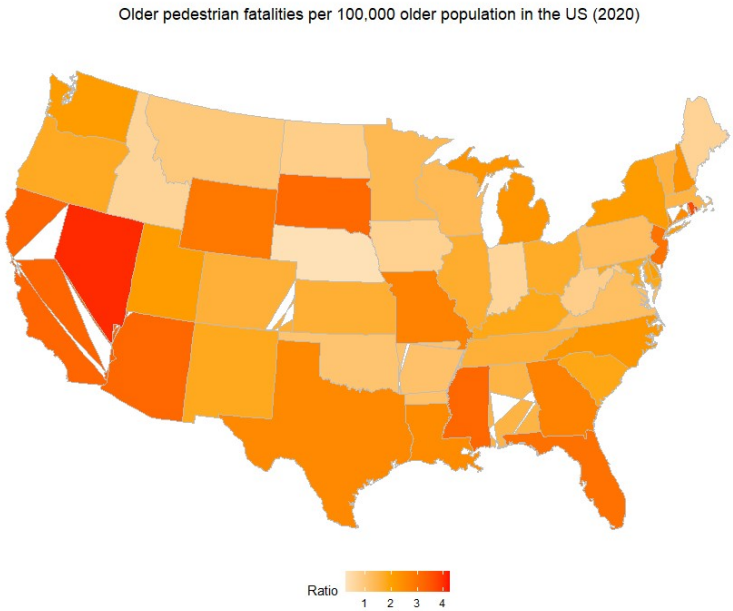

Figure 2: Older pedestrian fatalities per 100,000 older population in the US (2020)

According to Figure 3, the top five states having the highest older pedestrian fatalities per 100,000 older population were Nevada (ratio = 4.05), Rhode Island (ratio = 3.65), California (ratio = 3.25), Arizona (ratio = 3.20) and Mississippi (ratio = 3.20). In the next step, the analysis focused on risk ratios, and the obtained results are summarized under the following subsections.

4.1 Crash locations

The variable 'Intersection' provided in the FARS database classifies if the crash occurs 'at intersection' and 'not at intersection'. Based on the obtained results, the risk ratio for older pedestrian fatalities (compared to non-older pedestrian age groups) according to intersection and 'not at intersection' is provided below.

Table 2: Risk ratio for older pedestrian fatalities 'at intersection' locations

Year	Total non-older (<65y) pedestrian fatalities	Total non-older (<65y) pedestrian fatalities at intersection	Total older (≥65y) pedestrian fatalities	Total older (≥65y) pedestrian fatalities at intersection	Risk Ratio
2021	5,904	1,174	1,375	488	1.78
2020	5,280	1,111	1,206	434	1.71
2019	4,939	1,171	1,303	486	1.57
2018	5,024	1,092	1,307	538	1.89
2017	4,820	1,150	1,186	463	1.64

According to the observations, the obtained risk ratio for older pedestrian fatalities at intersections is consistently greater than 1 for the 5-year period, potentially suggesting the increased likelihood of older pedestrian fatalities at intersections compared to non-older pedestrians. This is consistent with previous research which reported that elderly pedestrians were more likely to be involved in crashes while crossing at intersection locations and the vehicle was turning and failing to yield (Das et al., 2019). Focusing on crash locations away from the intersection, the risk ratio for older pedestrian fatalities for 'not-at-intersection' is provided below.

Table 3: Risk ratio for older pedestrian fatalities for 'not-at-intersection' location

Year	Total non-older (<65y) pedestrian fatalities	Total non-older (<65y) pedestrian fatalities 'Not at intersection'	Total older (≥65y) pedestrian fatalities	Total older (≥65y) pedestrian fatalities 'Not at intersection'	Risk Ratio
2021	5,904	4,707	1,375	883	0.81
2020	5,280	4,149	1,206	763	0.81
2019	4,939	3,748	1,303	814	0.82
2018	5,024	3,908	1,307	765	0.75
2017	4,820	3,658	1,186	723	0.80

In this case, the risk ratio for older pedestrian fatalities at non-intersection locations was found to be consistently lower than 1 for the five-year period under study. This intuitively suggests the typical crossing behaviour of older pedestrians and their reduced likelihood of involvement in crashes resulting in fatalities at non-intersection locations. According to previous research, pedestrian crossing behaviour (e.g., when, how, and where to cross the street) generally depends on several factors including age, and gender (Hussain et al., 2019). Older pedestrians show reduced risk-taking behaviors (e.g., crossing at non-intersection locations) and are thus less represented in crashes at such locations (Bandyopadhyaya & Mitra, 2015).

Welch's two-sample t-test (Keselman et al., 2004) was conducted to compare the risk ratios obtained for 'intersection' and 'not-at-intersection'. The obtained p-value was found as 4.336e-05, potentially suggesting that the difference between the groups is statistically significant (i.e., likelihood of observing such a difference due to random chance is low). In other words, the consistently higher risk of older pedestrian fatalities at intersection compared to non-intersection locations is statistically significant at 5% significance level.

With the identified increased likelihood of older pedestrian fatalities at intersections, the next important question is the type of intersection at which older pedestrians were more likely to be involved in crashes.

According to the FARS database, the variable 'Type of Intersection' is classified as: not an intersection, four-way intersection, T-intersection, Y-intersection, traffic circle, roundabout, five-way intersection, L-intersection, other intersection type, not reported and unknown. For simple interpretation, the most common type of intersection (four-way, T-intersection, and Y-intersection) is primarily selected and analyzed by estimating the risk ratio. Note that, Y-intersection data was finally not considered because of the lower sample size. The obtained results are summarized in the figure below.

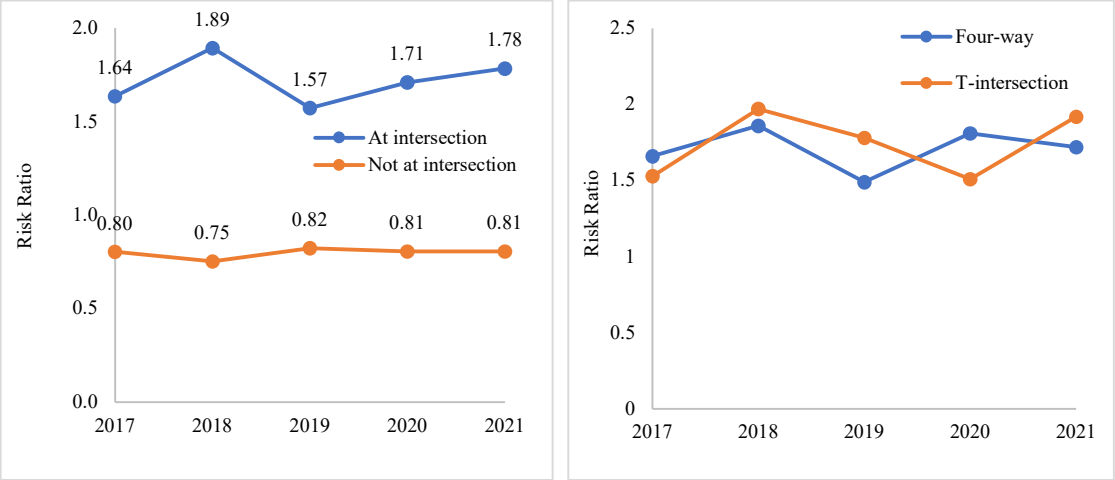

Figure 3: Risk ratio of older pedestrian fatalities: a) crash location, b) type of intersection

Overall, the risk ratio for older pedestrian fatalities at four-way or T-intersection was found to be consistently higher than 1 for the study period. Between the four-way and T-intersection types, the values of the risk ratio do not consistently follow a pattern, making it difficult to determine which type of intersection poses a greater risk to the safety of older pedestrians. The Welch two-sample t-test result also yields a statistically insignificant outcome (p-value > 0.05). In general, four-way intersections are controlled by traffic signals and a pedestrian push-button facility is usually available for crossing the intersection. Older pedestrians may have slower reaction times and reduced mobility, making it challenging for them to navigate intersections quickly. This can increase the likelihood of crashes, especially if they cannot cross the road within the allotted time. This is also consistent with a previous study that reported a strong correlation between four-way intersections and elderly pedestrian crashes (Lee et al., 2020).

4.2. Temporal factors

This study focused on the exploration of several temporal factors including day of week (weekday, weekend), and time of the day (daytime, night-time) and their relationship to older pedestrian fatalities (Figure 4). Consistent with our common intuition, the risk ratio of pedestrian fatalities was found to be steadily higher than 1 for weekdays and lower than 1 for weekends for the study period. Welch two sample t-test also confirms the statistically significant (p-value = 2.967e-12) difference between the groups. The results corroborate previous research that discovered an increased likelihood of elderly pedestrian fatalities on weekdays (O'Hern et al., 2015; Toran Pour et al., 2018). It was interesting to notice that the daytime risk ratio of older pedestrian fatalities was found to be around twice compared to non-older pedestrians potentially suggesting their increased exposure at daytime (i.e., more likely to be walking during daytime hours). This also intuitively suggests that visibility may not be a primary factor contributing to the fatality of older pedestrians (Nicaj et al., 2006). Comparing risk ratios of daytime with nighttime, the Welch two-sample test confirmed statistically significant (p-value = 4.725e-06) differences between them.

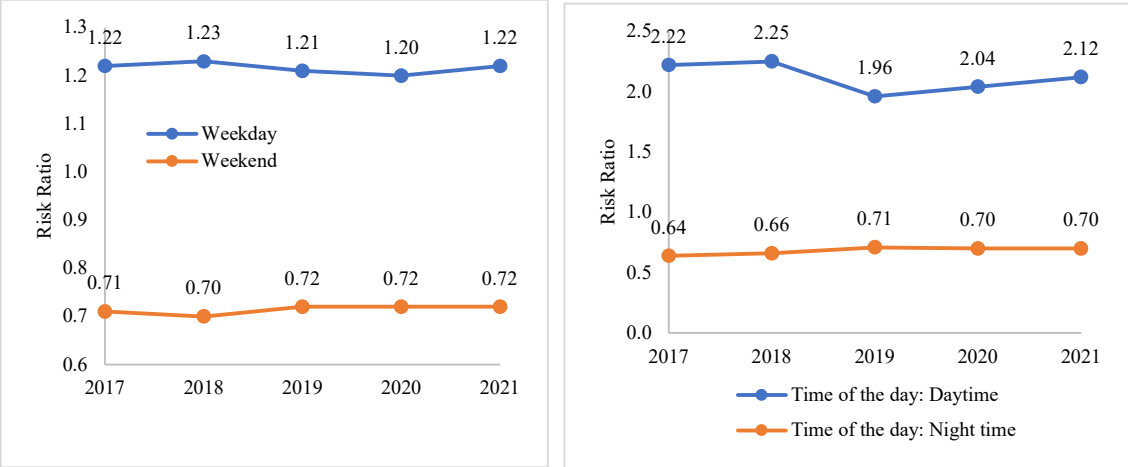

Figure 4: Risk ratio of older pedestrian fatalities considering temporal factors

4.3. Settings (Area and Roadway Type)

The dynamics of traffic, infrastructure, and community characteristics differ between urban and rural areas, impacting the safety of older pedestrians in distinct ways. According to the findings, the risk ratio was found to be consistently slightly greater than 1 (except in 2021) for urban areas, and less than 1 for rural areas. The Welch two-sample t-test confirms the statistically significant (p-value = 0.001) difference in risk ratios between urban and rural areas. Despite the fact that, urban settings usually have more developed pedestrian infrastructure, such as crosswalks, pedestrian signals, and sidewalks which may contribute to the safety of pedestrians, factors such as high traffic volume, complex intersections, aggressive driving behaviors, population density, and non-compliance to the traffic rules is expected to increase the likelihood of older pedestrian fatalities. It was interesting to notice that the risk ratios had two opposite trends (downward for urban areas, and upward for rural areas) potentially suggesting a temporal shift in risk ratios for older pedestrians.

Considering roadway type, older pedestrians were likely to be involved in fatal crashes on lower functional classification roadways (e.g., local, collector, minor arterial). Local roads, often found in residential neighbourhoods, may lack advanced safety features and pedestrian infrastructure most likely to contribute to older pedestrian crashes. Intersections on collector roads can pose challenges for older pedestrians, as they may need to navigate multiple lanes and turn vehicles. Older pedestrians may face difficulties in crossing minor arterials due to higher speeds and more complex traffic patterns.

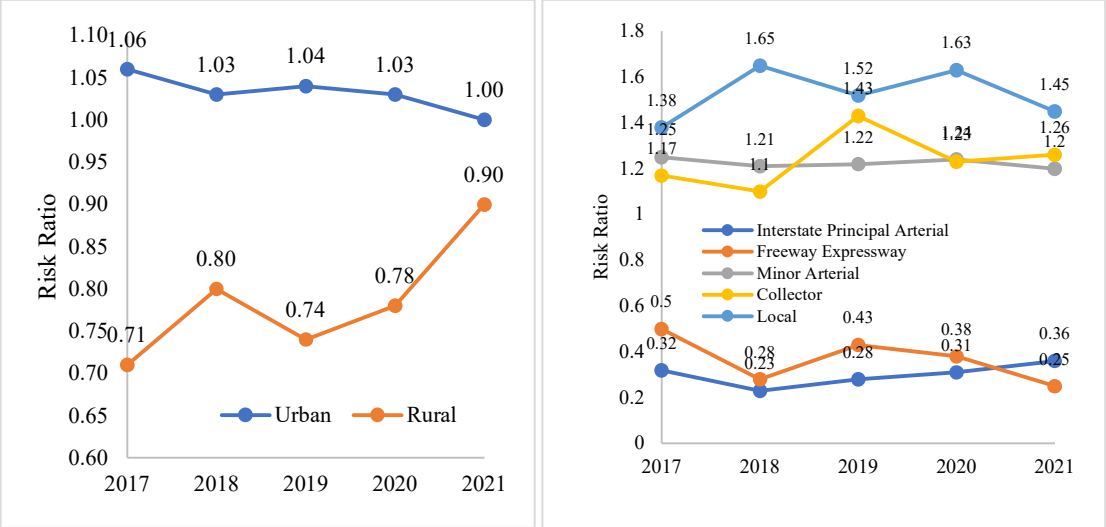

Figure 5: Risk ratio of older pedestrian fatalities: a) area type, b) roadway type

Since, the roadway type consists of 5 groups, ANOVA (Analysis of Variance) was conducted, and the obtained F-statistics were found to be 185.2, with a p-value of 1.69e-15. This suggests significant differences between the means of the groups containing different roadway types. In the next step, Tukey's Honestly Significant Difference (HSD) (Abdi & Williams, 2010) was conducted to identify which specific groups are different from each other. The test results confirm statistically significant differences in risk ratios for local, collector, and minor arterial individually with the interstate principal arterial, or freeway/expressway.

4.4. Striking vehicle and driver characteristics

Considering vehicle maneuvers, the risk ratio was found to be consistently higher for left-turn crashes followed by right-turn and straight-through movement. In general, drivers focus their whole attention on the roadway while going straight. Consequently, compared to collisions involving right and left turns, there was a greater likelihood of spotting a pedestrian (while going straight) and making an effort to prevent the collision (Roudsari et al., 2006). In this case, an ANOVA test was also conducted, and the obtained p-value (1.31e-09) confirmed the statistically significant differences between the groups. Considering driver gender, it was discovered that, except for the 2021 observation, female drivers had a higher risk ratio than male drivers in crashes that resulted in older pedestrian fatalities. The Welch two-sample t-test also confirms statistically significant differences in risk ratios involving male and female drivers.

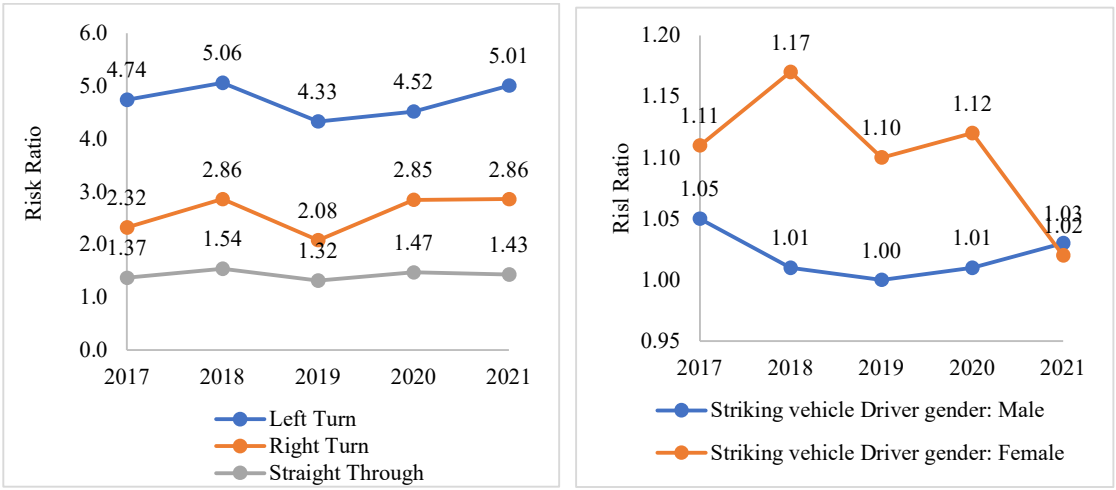

Figure 6: Risk ratio of older pedestrian fatalities: a) vehicle maneuvers, b) driver gender

The observation of the risk ratio considering vehicle type and speeding is provided below.

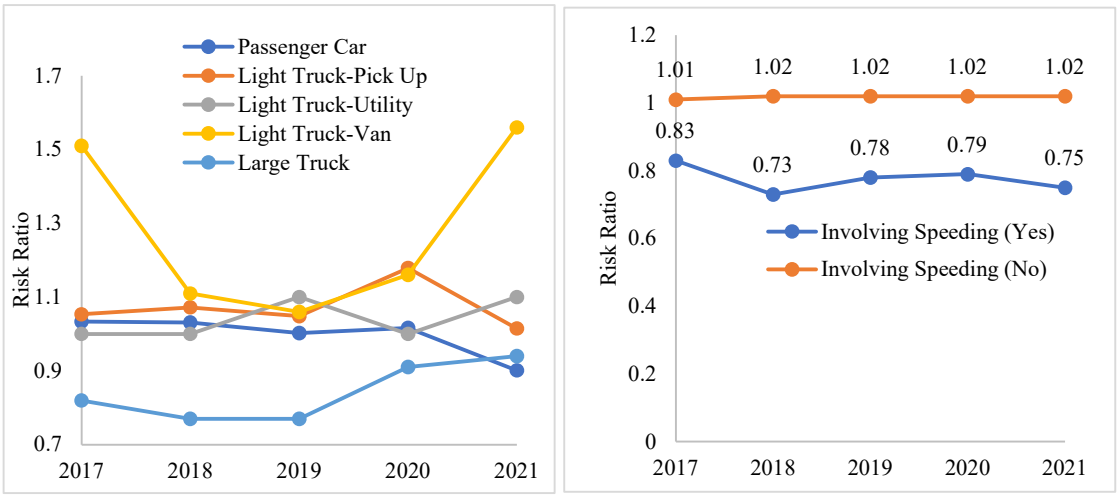

Figure 7: Risk ratio of older pedestrian fatalities: a) vehicle type, b) driver speeding behaviour

Considering vehicle type, the risk ratio for 'light truck – van' was found to be consistently higher than 1 for the study period, potentially suggesting an increased likelihood of older pedestrian fatalities with this specific type of vehicle. The ANOVA test confirms the statistically significant (F value = 8.902, p-value = 0.000268) differences in mean among the groups. Considering the speeding behaviour of drivers, the risk ratio was found consistently less than 1 for speeding behaviors, and slightly higher than 1 for no speeding behaviors (p-value = 0.0001285). This implies an unexpected pattern that is contrary to our conventional expectations of pedestrian-vehicle crashes. Further research is required to be conducted in this specific context.

5. CONCLUSIONS

Pedestrians are vulnerable road users and crashes involving pedestrians can result in severe injuries or fatalities. With the increase in the aging population in the United States, the unique safety challenges of older pedestrians warrant in-depth investigation. This research focused on analyzing older pedestrian fatal crash statistics using five-year data (2017-2021) collected from the Fatality Analysis and Reporting System. The collected fatality frequency data was divided into older (65 years or higher) and non-older

(less than 65 years) groups and the risk ratio was calculated based on the comparison between the two groups. The study considered a comprehensive set of crash variables, including crash location (intersection, non-intersection), intersection type (four-way, T-intersection), temporal factors (day of the week, time of the day), settings (urban, rural), roadway type, and striking vehicle and driver characteristics to gain critical insights into older pedestrian crash characteristics. The findings of this investigation lead to several key conclusions:

- The obtained risk ratio for older pedestrian fatalities is consistently greater than 1 for intersections and less than 1 for non-intersection locations.
- The risk ratio of pedestrian fatalities was found to be steadily higher than 1 for weekdays and lower than 1 for weekends.
- The daytime risk ratio of older pedestrian fatalities was found to be around twice compared to non-older pedestrians potentially suggesting their increased exposure at daytime. his also intuitively suggests that visibility may not be a primary factor contributing to the fatality of older pedestrians.
- According to the findings, the risk ratio was found to be consistently slightly greater than 1 (except in 2021) for urban areas, and less than 1 for rural areas.
- Considering roadway type, older pedestrians were likely to be involved in fatal crashes on lower functional classification roadways (e.g., local, collector, minor arterial).
- Considering vehicle maneuvers, the risk ratio was found to be consistently higher for left-turn crashes followed by right-turn and straight-through movement.
- With the exception of the 2021 observation, female drivers had a higher risk ratio than male drivers in crashes that resulted in older pedestrian fatalities.
- Considering vehicle type, the risk ratio for 'light truck – van' was found to be consistently higher than 1 for the study period, potentially suggesting an increased likelihood of older pedestrian fatalities with this specific type of vehicle.

Based on the analysis, several problem-specific targeted countermeasures can be recommended. For example, older pedestrians were more likely to be involved in fatal crashes at intersections. Intersection design and modifications can be helpful such as adjusting signal timing to provide older pedestrians sufficient time to cross intersections safely. Another suggested measure is the improvement of crosswalk visibility with high-visibility markings and signage. The left turn movement was found to be a critical factor contributing to older pedestrian fatalities. One of the recommended measures can be the optimization traffic signal timings to provide longer pedestrian crossing times during left turn phases. Adjustments to signal phasing can improve the visibility and safety of older pedestrians when crossing during left turns. Developing and implementing educational campaigns targeted at both drivers and pedestrians to raise awareness of the risks associated with older pedestrian crashes. Educational campaigns can be tailored to focus on specific groups including female drivers and light truck -Van drivers.

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