Collaborative Sciences Center for ROAD SAFETY

FINAL REPORT

# Using Integrated Data to Examine Characteristics Related to Pedestrian Injuries

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**16. Abstract**

This study seeks to provide a comprehensive examination of pedestrian motor vehicle crash injuries in North Carolina (NC) using linked crash and emergency department visit data for the period October 1, 2010 – September 30, 2015. Unlike the individual data sources, linked crash-ED visit data provide detailed information on the crash circumstances *and* the pedestrian health outcomes. Approximately, 50% of the crash data were linked to ED visit data using hierarchical deterministic methods for a study population of 6,923 injured pedestrians. This study used categorical analytic techniques (bivariate and multivariate logistic regression analysis) to examine person, crash, environment, roadway, and vehicle characteristics associated with pedestrian injury severity. This study found that pedestrian age, pedestrian gender, pedestrian race/Hispanic ethnicity, pedestrian comorbidities, striking driver age, striking driver gender, crash hour-of-day, pedestrian/driver suspected alcohol use, ambient light levels, pedestrian crash type, intersection-relatedness, and vehicle type were related to pedestrian injury severity, among other factors. In addition, linking crash and ED data facilitated a greater understanding of the types of injuries (e.g., traumatic brain injuries) associated with being struck by a motor vehicle.

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# Contents

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# List of Abbreviations

| | |
|---|---|
| AI | American Indian |
| AIC | Akaike Information Criterion |
| CCI | Charlson Comorbidity Index |
| CDC | Centers for Disease Control and Prevention |
| CI | Confidence interval |
| COPD | Chronic obstructive pulmonary disease |
| CSCRS | Collaborative Sciences Center for Road Safety |
| E-code | External cause of injury code |
| ED | Emergency department |
| EDR | Electronic data recorder |
| EU | European Union |
| HSRC | Highway Safety Research Center |
| ICD | International Classification of Diseases |
| ICD-9-CM | International Classification of Diseases, 9$^{th}$, Clinical Modification |
| ICD-10-CM | International Classification of Diseases, 10$^{th}$, Clinical Modification |
| MPH | Miles per hour |
| MV | Motor vehicle |
| MVC | Motor vehicle crash |
| NA | Native American |
| NC | North Carolina |
| NC DETECT | North Carolina Disease Event Tracking and Epidemiologic Collection Tool |
| NC DOT | North Carolina Department of Transportation |
| NC DPH | NC Division of Public Health |
| NHTSA | National Highway Traffic Safety Administration |
| NTSB | National Transportation Safety Board |
| OR | Odds ratio |
| PBCAT | Pedestrian and Bicycle Crash Analysis Tool |
| PBIC | Pedestrian and Bicycle Information Center |
| PU | Pickup truck |
| SC | Spinal column |
| SES | Socioeconomic status |
| SUV | Sport utility vehicles |
| TBI | Traumatic brain injury |
| UNC | University of North Carolina |
| US | United States |
| US DOT | United States Department of Transportation |
| VC | Vertebral column |
| VIPA | Vulnerable Road User Injury Prevention Alliance |
| WC | Workers' compensation |

# Background

For the majority of people, walking is the first and most fundamental mode of transportation. Individuals walk for health; to engage with friends, family, and the environment; to access employment, shopping, and other services; and to fulfill the human need for movement. Over the last several decades, the prevalence of obesity has increased dramatically, with 42% of Americans currently being categorized as obese or severely obese in 2018 (Hales et al., 2020). The medical and public health communities have recommended, and even prescribed, walking to obtain the weekly recommended level of 150-300 minutes of activity required for maintaining a healthy weight and for maximal physical and mental wellbeing (Office of the Surgeon General, 2015; US Department of Health and Human Services, 2018). For many Americans, walking is not just a form of exercise or recreation, but the primary mode of transportation. In 2017, an estimated 9% of American households did not own a personal vehicle. Many of these households rely on walking for accessing transit and commuting to work, school, healthcare, and other destinations (McGuckin & Fucci, 2018). Unfortunately, despite renewed emphasis on walking as a healthy, environmental-friendly, and necessary mode of transportation, walking is often disregarded for other modes, especially transportation by personal motor vehicle. This has contributed to an increasing pedestrian death toll on United States (US) roadways.

In 2018, 6,283 pedestrians died on US roadways, or approximately one pedestrian every 1.5 hours. Unfortunately, this represents the apex of a disturbing trend, with the number of pedestrian fatalities increasing by 53% since 2009, reversing a decades long decline (National Center for Statistics and Analysis, 2020). This is especially surprising given that mortality has decreased during this same period for most other types of road users (National Center for Statistics and Analysis, 2019). Previous work by the Pedestrian and Bicycle Information Center (PBIC), an international leader in pedestrian and bicycle safety, has identified the following factors (among others) as potentially contributing to increasing numbers of pedestrian fatalities:

- Changing levels of pedestrian exposure,
- Aging populations of pedestrians and drivers,
- An increasing prevalence of chronic and mental health conditions among pedestrians,

- Increasing levels of pedestrian and driver alcohol and drug impairment,
- Increasing mass and changing profiles of motor vehicles,
- Increasing speed limits and increasing vehicle traveling speeds,
- And increasing disparities in the development of pedestrian-friendly infrastructure among lower-income communities and communities of color.

A more comprehensive description of these factors and the broader issue of pedestrian safety is described in the PBIC publication *Toward a Shared Understanding of Pedestrian Safety* (L. Sandt et al., 2020).

One of the gaps highlighted in the PBIC report was the lack of nonfatal pedestrian injury data, especially nonfatal pedestrian injury data integrated with police reported motor vehicle crash data and other data sources. Although there is considerable heterogeneity by source, nonfatal pedestrian injury data sources contain a wealth of information about patient characteristics and outcomes; however, these sources contain minimal information about the circumstances of the crash. In contrast, crash data includes detailed information about the circumstances, but little information about the fate of the pedestrian. In crash data, the only variable that contains information about the severity of the pedestrian injury is the five-point KABCO scale ("K" =killed", "A" =suspected serious injury, "B" = suspected minor injury, "C" = possible injury, and "O" = no injury). For all reportable crashes, the investigating police officer assigns a KABCO score to everyone involved in the crash based on an external examination. As one might expect due to the lack of clinical training and diagnostic tools available to police officers, the KABCO score is not particularly accurate in describing injury severity (Burdett et al., 2015). Therefore, to complete the picture of pedestrian injury, it is important to integrate health outcome and crash data sources. For a more comprehensive overview of data integration, please the CSCRS publication *Completing the Picture of Traffic Injuries: Understanding Data Needs and Opportunities for Road Safety* (Cherry et al., 2018).

The National Transportation Safety Board (NTSB), the Centers for Disease Control and Prevention (CDC), and the National Highway Safety Traffic Safety Administration (NHTSA) have all endorsed crash data linkage and integration, with NHTSA funding 17 states to perform data linkage for one or more years as part of the Crash Outcome Data Evaluation System (CODES) during the period 1992-2013 (Kindelberger & Milani, 2015;

National Center for Injury Prevention and Control, 2019; National Transportation Safety Board, 2018). Unfortunately, many participating CODES states discontinued linkage once the funding was terminated, precluding an analysis of pedestrian injuries using more recent years of data. Certain cities, such as San Francisco, California have integrated crash and health outcome data to describe pedestrian injury, including the development of a high injury network, but there are few pedestrian injury surveillance programs beyond the municipal level (Schwarcz & Wier, 2017).

Currently, the most comprehensive assessment of nonfatal pedestrian injury is being performed by the Vulnerable Road User Injury Prevention Alliance (VIPA), based out of the International Center for Automotive Medicine at the University of Michigan. VIPA conducts in-depth case investigations and crash reconstructions to systematically describe pedestrian (and bicyclist) injuries and kinematics following collisions with motor vehicles. While this study has yielded a rich, high-quality, and comprehensive dataset that could not have been obtained through other means, it contains a relatively small number of observations (<500), due to the number of resources required to collect and analyze the data. In addition, the VIPA dataset only contains cases from select locations within the State of Michigan, raising questions of generalizability. In recent years, VIPA has worked to overcome these limitations by creating a larger, more inclusive, limited dataset using police reported crash and health surveillance data collected from a wider swath of Michigan, however, it still represents outcomes within a single geography (Wang et al., 2019). Consequently, there is a need to tackle the problem of rising pedestrian morbidity and mortality through the study of integrated crash and health outcome data at the population level. Therefore, this study analysed five years of population-based, integrated, police reported crash and emergency department visit data to examine vehicle, crash, roadway, and person-level factors and their association with serious pedestrian injuries, *ascertained using clinical metrics*, rather than police reported injury severity indices. In addition, the results of the descriptive analysis were used to inform a multivariate predictive regression analysis, in which significant predictors of serious pedestrian injury were identified. Finally, the integrated crash-emergency department visit data were used to describe both the nature (laceration, fracture, etc.) and location (head, upper extremity, etc.) of injury to have a better understanding of pedestrian health outcomes following a motor vehicle crash.

# Methods

## Literature Review

Since the Federal Highway Administration, CSCRS, PBIC, and others have already preformed scoping reviews related to pedestrian safety, this project performed a brief, focused review of the epidemiologic literature regarding pedestrian/bicycle traffic crash morbidity and mortality (Brookshire et al., n.d.; Collaborative Sciences Center for Road Safety, 2018; Zeeger et al., 2010). The primary purpose of this review was to identify and define variables, identify methodological considerations, and to discuss the results in context with previously published studies.

Because this was not a systematic literature review, there were no bounds placed on the review, although the search was completed by December 31, 2019 and few additional sources were reviewed after that date. Manuscripts, theses, governmental reports, and other grey literature were reviewed if the source pertained to one of the study's key themes: pedestrian injury outcomes, time, person-related factors, collision-related factors, roadway-related factors, and vehicle-related factors. Each theme was then subdivided into topics for exploration. For example, for pedestrian injury outcomes, we subdivided the theme into hospital admission, death, specific injury diagnoses, and total number of injury diagnoses. In addition to pedestrian injury-specific sources, we reviewed documents describing bicycle crash-related injuries to provide context, address gaps in the pedestrian epidemiologic literature, and to lay the groundwork for future examination of bicycle crash-related injuries. In total, 75 sources were reviewed. Based on the literature review and author subject matter expertise, each topic was given a priority level (high, medium, and low/time-permitting) based on the availability of relevant variables in the linked crash-emergency department visit dataset, the quality of the data in the linked North Carolina crash-emergency department visit dataset, the significance of the topic (i.e., the perceived strength of the relationship between the factor and the health outcomes of interest), and the reasoning behind the priority level classification.

In summary, the following pedestrian health outcomes were assigned a high priority level for analysis: death, hospital admission, and injury diagnosis(es). Death because it is the ultimate adverse outcome of a pedestrian collision, although a limitation of the linked dataset is that emergency department visit data do not capture pedestrian deaths that occur prior to arrival at the healthcare facility. Hospital admission was included because serious injuries requiring hospitalization may result in long-term disability, necessitate long-term treatment, incur substantial medical costs, and lead to decreases in the patient's productivity and quality of life (Miller et al., 2004).

Regarding topics for exploration, pedestrian and driver demographics, pedestrian crash type, speed, light condition, land use, and vehicle type were all classified as being a high priority for analysis. There is a strong body of literature indicating that men, older adults, and individuals from lower-income and black/brown communities have higher rates of pedestrian injuries and fatalities (Campos-Outcalt et al., 2002; Chakravarthy et al., 2010, 2012; National Center for Statistics and Analysis, 2018a; C V Zegeer et al., 1996). While neither crash nor emergency department visit data contain socioeconomic status (although expected source of payment, available in the emergency department visit data, may be used as a proxy), both datasets contain age and gender, and crash data contain race/Hispanic ethnicity (race/Hispanic ethnicity were not incorporated in NC emergency department visit data until after 2015).

Pedestrian crash type was also given a high priority. Although most US crash datasets have limited information about the circumstances of the motor vehicle-pedestrian collision, all NC pedestrian and bicycle crash data are classified according to location, position of pedestrian, and pedestrian crash type, with more than 50 individual crash types available. Certain crash types, such as "crossing roadway – vehicle not turning" tend to have higher levels of severity, with more than 60% of pedestrians involved in this crash type having fatal or disabling injuries according to law enforcement assessment (Thomas, Vann, et al., 2018). In addition, pedestrian crash typing is considered to be the gold standard of pedestrian crash categorization and has been demonstrated to be a critical component of a systemic pedestrian safety analysis (Thomas, Sandt, et al., 2018).

Speed was another factor that was identified as being a high priority for examination. The speed with which a motor vehicle collides with a pedestrian is the single greatest predictor of serious injury and death. Although there is variation across pedestrian fatality prediction curves by publication, all agree that pedestrian fatality risk increases nonlinearly with impact speed. In summary, a pedestrian hit by a motor vehicle at a speed of 30 miles per hour (MPH) has a risk of death of less than 10%; at 40 MPH, the risk approaches 50% (DC Richards & Transport Research Laboratory, 2010). It is important to note that other factors (e.g., pedestrian age; vehicle size, shape, and weight) impact pedestrian fatality risk curves (DC Richards & Transport Research Laboratory, 2010; L. Sandt et al., 2020). While impact speed is the most relevant variable in the crash data for describing the relationship between speed and serious injury, it is an estimate determined by the investigating police officer and may not always be accurate, especially for lower severity pedestrian collisions. Therefore, in addition to impact speed, we also examined posted speed limit, which is likely to be a more objective measure (Imprialou & Quddus, 2019).

Light condition is another factor that has been repeatedly shown to be associated with serious pedestrian injury and death. Dark, and particularly dark unlighted conditions are associated with much higher risks of serious pedestrian injury and death, even after adjusting for speed, rurality, and time of day; however, the magnitude of this relationship still needs exploration, especially using a dataset containing health outcomes (Kemnitzer et al., 2019; Plainis et al., 2006; Uddin & Ahmed, 2018; Uttley & Fotios, 2017).

Another topic of high priority is land use. Although both counts and population-based rates of pedestrian injuries and fatalities are higher in urban areas, there is concern that the *risk* of serious injury and death may be greater in suburban and rural areas, because of higher speeds, poorer lighting, less pedestrian-friendly infrastructure, and greater distances to definitive emergency care (Carter & Council, 2007; Gonzalez et al., 2009; Charles V Zegeer & Bushell, 2012; Zhu et al., 2008). Although location of crash is not always accurate in the crash data (and it is nonexistent in the emergency department visit data), NC pedestrian and bicyclist crashes are manually geocoded.

The last topic of high priority was vehicle type. In recent years, sales of sport utility vehicles (SUVs) and pickup trucks have increased, while sales of passenger vehicles have decreased (United States Environmental Protection Agency, 2021). The size, shape, weight, and power of large vehicles, such as SUVs and pickup trucks, may increase the risk of serious injury or death, especially at lower speed collisions (Henary et al., 2003). One major limitation of our study, however, is that the study period predates the rapid growth of SUV and pickup truck sales and the population shift towards larger personal vehicles; therefore, the relationship between vehicle type and pedestrian injury severity may not be as apparent as it would have been had we used more recent years of data.

The following factors were categorized as medium or low priority: annual trends (medium), seasonal trends (medium), daily trends (medium), hourly trends (medium), pedestrian homelessness (medium), pedestrian comorbidities (medium), pedestrian alcohol impairment (low), pedestrian drug impairment (low), driver alcohol impairment (low), weather condition (medium), roadway classification (medium), number of lanes (medium), and road feature (medium). Some factors categorized as medium priorities, such as homelessness, were excluded from the analysis after limitations in the data were discovered during data cleaning and exploration. Other factors categorized as low priorities, such as pedestrian alcohol impairment, were included in analyses, because of better than anticipated data quality. The full results of the literature review are displayed in Appendix I: Literature Review.

# Data Sources

## North Carolina Pedestrian Crash Data

The PBIC within the UNC Highway Safety Research Center (HSRC) provided pedestrian crash data for the period of October 1, 2010 – September 30, 2015. PBIC maintains an electronic database of all NC police reported collisions between pedestrians and motor vehicles for use by the NC Department of Transportation (NC DOT), other transportation safety professionals, and researchers. This database includes elements documented in the police crash report form and information abstracted from the crash diagram and narrative. All pedestrians are crash-typed according to the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) (Pedestrian and Bicycle Information Center, n.d.). Pedestrian crash records were excluded if they were missing pedestrian date-of-birth and age or pedestrian 5-digit ZIP code-of-residence and city-of-residence. A total of 127 (1%) pedestrian crash records were excluded from the pedestrian crash dataset (N=14,264) for a study population of 14,137 pedestrians. Non-roadway collisions were not excluded, except for select analyses.

## North Carolina Emergency Department Visit Data

The NC Division of Public Health (NC DPH) provided ED visit data for the period October 1, 2010 – September 30, 2015. NC DPH, in collaboration with the Carolina Center for Health Informatics within the Department of Emergency Medicine of the UNC-Chapel Hill, captures information on all patients treated at 24/7 acute-care hospital-affiliated civilian NC EDs, as part of the NC Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT), NC's legislatively mandated statewide syndromic surveillance system (CCHI 2019).

We selected the time frame October 1, 2010 – September 30, 2015 to have five years of contiguous data that did not span the transition from the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) to the 10th Revision (ICD-10-CM). The ICD-9-CM and ICD-10-CM coding systems are based on the World Health Organization's 9th and 10th Revisions of the International Classification of Diseases (ICD), the system for classifying mortality data globally. In the US, the National Center for Health Statistics, in collaboration with the Centers for Medicare and Medicaid Services, modify the ICD system for use with morbidity data. These "clinical modifications" are used by all US healthcare facilities to report diagnoses, classify data for administration and billing, and to collect data for the reporting of health statistics. ICD-9-CM was implemented in 1979 and was used for classifying morbidity data until October 1, 2015, at which time ICD-10-CM was introduced. This was a major transition with the number of codes expanding from ~13,000 in ICD-9-CM to ~68,000 in ICD-10-CM (Cartwright, 2013). Transportation injury codes were greatly impacted, with a considerable expansion in both the number and specificity of the codes from ICD-9- to ICD-10-CM.

For inclusion in the study, the ED visit record had to contain an ICD-9-CM injury diagnosis code (800-999) or external cause of injury code (E-code). NC ED visits were identified as being related to a pedestrian crash if they had an E-code indicating a pedestrian injury and/or a keyword indicating a pedestrian injury in the chief complaint field (Table 1). Since the reporting of E-codes are not mandated by state law, and reporting is variable by facility, analyses were not restricted to ED visits with pedestrian E-codes or keywords, although this information was incorporated into our linkage methodology (see Linkage). To avoid one-to-many linkages, patient transfers to other healthcare institutions were excluded. In addition, ED visit records missing patient date-of-birth and age or patient 5-digit ZIP code-of-residence and city-of-residence were excluded. A total of 107,879 (3%) ED visit records were excluded from the NC DETECT ED visit dataset (N= 4,289,105) for a study population of 4,181,226 ED visit records.

**Table 1: ICD-9-CM and free text pedestrian injury case definition for use with NC DETECT ED visit data**

| ICD-9-CM E-code | Keyword |
| --- | --- |
| E800-E807 (.2)<br>E810-E819 (.7)<br>E820-EE25 (.7)<br>E826-E829 (.0) | "PEDESTRIAN", "PEDESTRAIN", "PED STRUCK", "PEDS STRUCK", "PED VS MVC", "PEDS VS MVC", "PED VS CAR", "PEDS VS CAR", "PDVSCAR", "PED VS TRUCK", "PEDS VS TRUCK", "PED VS MOTORIZED VEHICLE", "PEDS VS MOTORIZED VEHICLE", "HIT BY CAR", "STRUCK BY VEHICLE", STRUCK BY CAR", "RAN OVER BY CAR"<br><br>**AND NOT**<br><br>"MOPED", "BIKE", "PEDAL", "BICYCLE", "BICYCLIST", "MOTORCYCLIST", “MOTOR CYCLIST” |

## Linkage

For the data linkage, we used a hierarchical deterministic method. Hierarchical deterministic linkage matches data according to a list of predefined variables in a stepwise fashion. For a match to occur, the two data sources must match across the linkage variables. However, if a match does not occur during the first linkage step, certain linkage criteria are relaxed (while other linkage criteria are tightened) and a second round of matching is initiated. This process continues until all suitable records have been matched and all linkage variables have been exhausted. For this study, four rounds of matching were performed using combinations of the variables pedestrian age, pedestrian gender, pedestrian date-of-birth, pedestrian ZIP-code of residence, and pedestrian city-of-residence. In addition, matches were restricted to links in which the ED visit occurred *after* the crash and *within* seven days of the crash. For one-to-many matches (i.e., when one crash record matched multiple ED visit records or vice-versa), the higher quality match was selected based on the following criteria: presence of pedestrian E-code or keyword, time since crash, and quality of clinical information, as indicated by number of diagnosis codes. After linkage was completed, a total of 6,923 (49%) pedestrian crash records were linked to ED visit records. For a comparison of linked to unlinked pedestrian crash and ED visit records, see Appendix II: Comparison of Linked and Unlinked Data Sources.

# Definitions of Outcomes

## Serious Injury

We created a binary variable to indicate a serious injury based on the clinical information present in the pedestrian's ED visit record. The definition for a "serious injury" was based on a definition created by the NTSB (2013). An injury was defined as serious if it resulted in one or more of the following outcomes:

- Death;
- Admission to the hospital;
- Injury to the internal organs;
- Injury to the nerves;
- Injury to the blood vessels;
- Fracture (excluding fractures to the digits or nose);
- Open wound (excluding wounds to the digits);
- Crushing injury (excluding injuries to the digits);
- Dislocation (excluding dislocations of the digits);
- And second- and third-degree burns.

Table 2 compares the police-assessed measure of injury severity (KABCO) recorded in the crash data to the serious injury definition created from the ED visit data. While police officers accurately classified fatal ("K") and disabling ("A") injuries, nearly one-half of pedestrians assessed as having "evident" ("B") (i.e., lower severity) injuries were later diagnosed with serious injuries according to the NTSB definition. Among pedestrians with "possible" ("C") and no injuries ("O"), 16% and 12% of pedestrians were later diagnosed with serious injuries. A manual review of these ED visits found a preponderance of internal injuries – injuries that may not have been visible to the investigating police officers.

**Table 2: Comparison of police-assigned injury severity (KABCO) to injury severity based on clinical metrics for pedestrians treated in the emergency department**

| Police assigned injury severity (KABCO) | Serious or fatal injury (based on clinical assessment) N (%) | Non-serious injury (based on clinical assessment) N (%) | Total pedestrians with linked crash-ED visit data N |
|---|---|---|---|
| K: Killed | 206 (100.0%) | 0 (0.0%) | 206 |
| A: Disabling injury | 437 (89.2%) | 53 (10.8%) | 490 |
| B: Evident injury | 1,431 (49.8%) | 1,440 (50.2%) | 2,871 |
| C: Possible injury | 488 (16.2%) | 2,523 (83.8%) | 3,011 |
| O: No injury | 20 (12.4%) | 141 (87.6%) | 161 |
| **Total** | **2,582 (38.3%)** | **4,157 (61.7%)** | **6,739** |

Missing: KABCO (N=184).

## Barell Injury Diagnosis Matrix

For most of our analyses, we selected the binary variable "serious injury" as our health outcome of interest. While useful, it does not provide much detail about the types of injuries that result from the collision of a motor vehicle with a human body. Therefore, we classified pedestrian injuries according to location (head, upper extremity, lower extremity, etc.) and nature of injury (fracture, strain/sprain, internal injury, etc.) according to the Barell Injury Diagnosis Matrix, a widely used tool for classifying injury morbidity data (Barell et al., 2002; National Center for Health Statistics, 2015).

# Analyses

The results of this study are presented in three sections, "Descriptive Epidemiologic Analysis", "Multivariate Modelling of Factors Associated with Severe/Fatal Injuries Among Pedestrians", and an "Examination of Pedestrian Injury Characteristics". Sections one and two examined pedestrian injury severity and its relationship with selected person, collision, roadway, and vehicle factors. Section three examined the location and nature of pedestrian injury using the Barell Injury Diagnosis Matrix described previously.

For sections one (descriptive study) and three (injury characteristics study), frequency tables were produced displaying counts and percentages. In addition, Pearson chi-square tests were used for statistical comparisons between the outcome variables (serious injury, nature/location of injury) and the selected explanatory factors.

Section two (the multivariate modelling study) used logistic regression to produce unadjusted and adjusted odds ratios (ORs) and 95% confidence intervals (CIs) to identify potential predictors of serious injury. More details about the model building process and predictor selection are included in the relevant section.

For all studies, results were considered significant at $p$ value <.05. All statistical analyses for this study were performed using SAS® version 9.4 (SAS Institute, Cary, NC).

# Descriptive Epidemiologic Analysis

## Comparison of Crash and Emergency Department Visit Data

Prior to linking the pedestrian crash and ED visit datasets, the distributions of both datasets were compared to one another. Non-injury ("O") events were not excluded from the crash data; therefore, the term "incidents" rather than "injuries" will be used for the following four figures.

Figure 1 displays the number of pedestrian incidents by month reported in the crash and ED visit data for the period October 1, 2010 – September 30, 2015. The trends for the crash and ED visit data were similar; however, the number of pedestrian injury-related ED visits exceeded the number of pedestrians involved in motor vehicle crashes for the entire study period. It should be noted that there are definitional differences between the two data sources, namely that the ED visit data includes both traffic and nontraffic-related pedestrian injuries. Similar trends have been reported previously (L. S. Sandt et al., 2020)

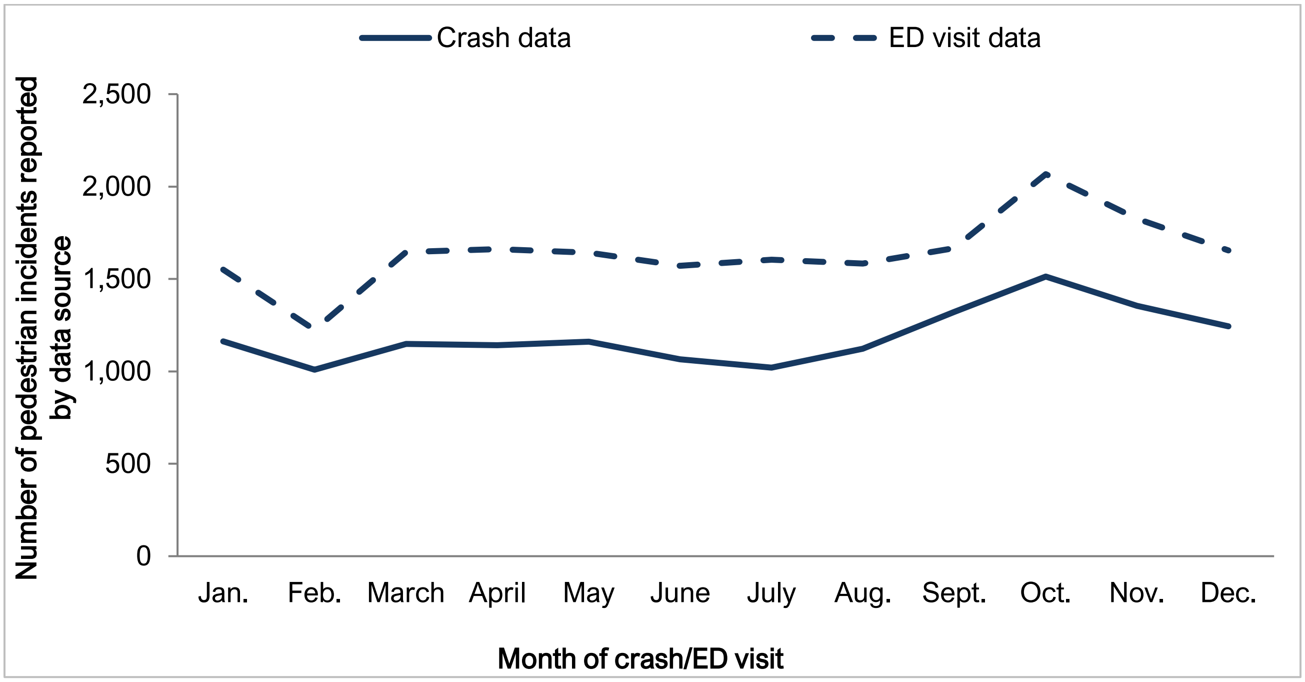


*Figure 1: Number of pedestrians involved in police-related crash data (N=14,264) and pedestrian injuries treated in emergency department visit data (N=19,699), by month*

Figures 2-4 compare the distributions of pedestrian incidents by gender, age group, and time of crash/ED visit for each data source. The number of pedestrian incidents reported in the ED visit data was higher than crash data for all levels of all variables except for the period 4:00-7:59. The discrepancies between the two data sources were especially pronounced for nighttime incidents, incidents involving young adults 20-29 years-of-age, and males. Similar discrepancies have been documented in other studies (Doggett et al., 2018). For example, Sciortino et al. (2005) documented discordance between crash and health data sources for pedestrian injuries, especially among men, teens, and young adults. They also documented differences by race, with persons of color being underrepresented in the crash data (Sciortino et al., 2005). Unfortunately, we could not examine discrepancies by race/ethnicity in our study, as NC DETECT ED visit data did not contain race/ethnicity information for the period 2010-2015.

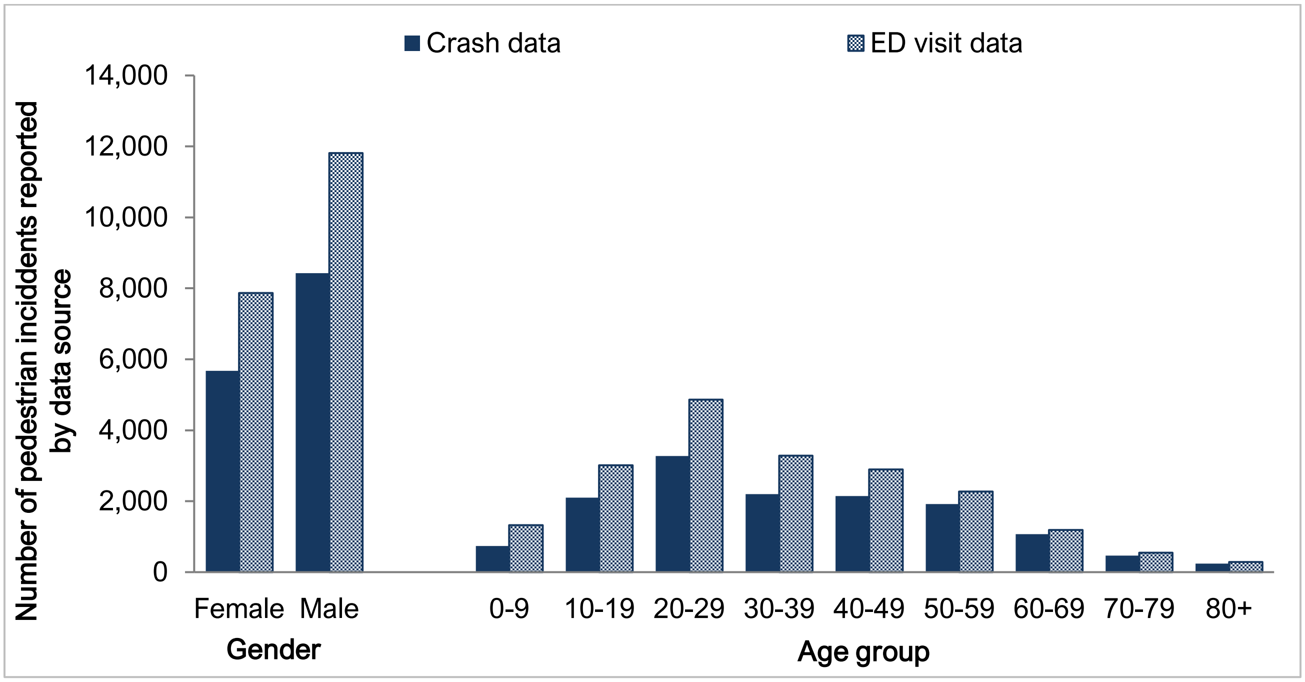


*Figure 2: Comparison of number of pedestrians reported injured in police reported crash data (N=14,264) and emergency department visit data (N=19,699), by selected demographic characteristics*

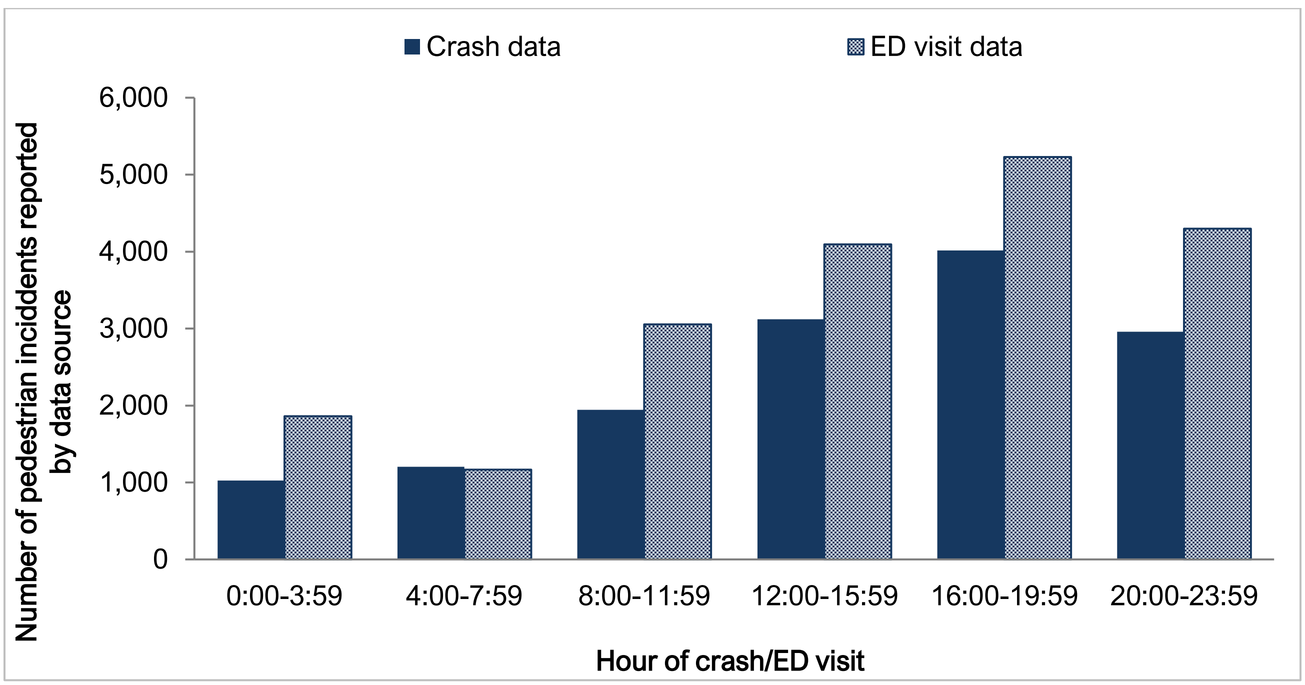


*Figure 3: Comparison of number of police reported pedestrian crashes (N=14,264) and number of pedestrian-related emergency department visits (N=19,699), by hour of crash/emergency department visit*

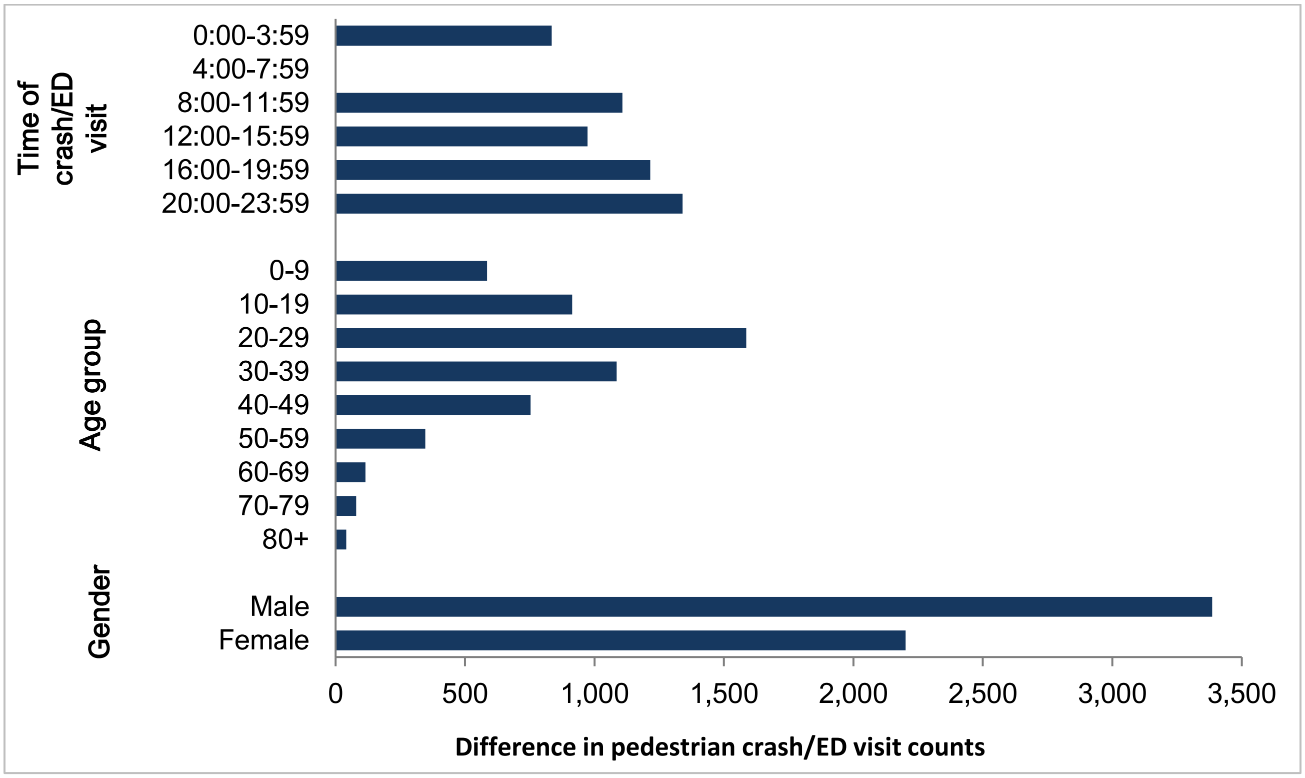


*Figure 4: Difference in number of injured pedestrians reported in police reported crash data (N=14,264) and emergency department visit data (N=19,699), by selected characteristic*

## Temporal characteristics

We linked data from 6,923 pedestrians injured in North Carolina police reported motor vehicle crashes (MVCs) to NC DETECT emergency department visit data from October 1, 2010 through September 30, 2015. There were no significant differences in the number or severity of pedestrian injuries reported by year, with approximately 1,300-1,400 pedestrians treated in NC EDs per year after involvement in MVCs. Depending on the year, 35% - 40% of these pedestrian injuries were classified as serious (Figure 5).

There was not much variation in the number of pedestrian injury-related NC ED visits by month of visit, although there was a slight uptick in the number of visits during the months of autumn. Injury severity did not differ significantly by month of visit (Figure 6).

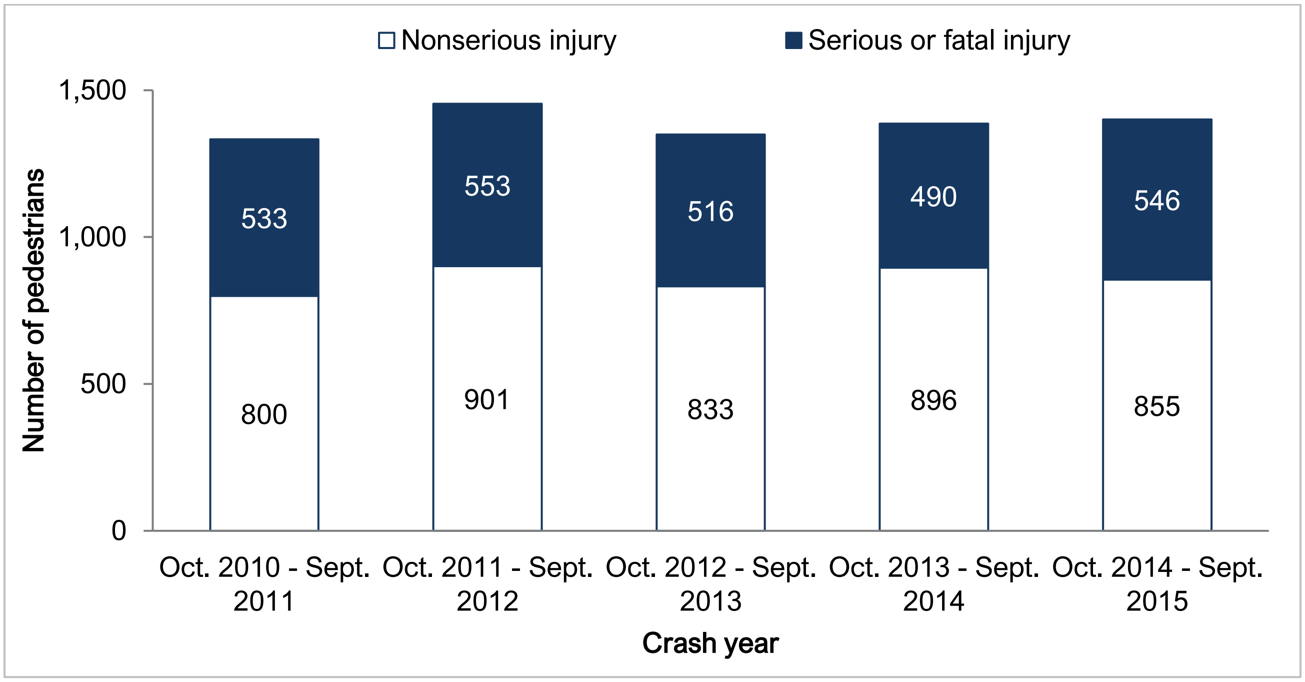


*Figure 5: Annual number of pedestrians treated at NC emergency departments, by pedestrian injury severity (N=6,923)[1]*

[1]Nonsignificant at $p$ =.141

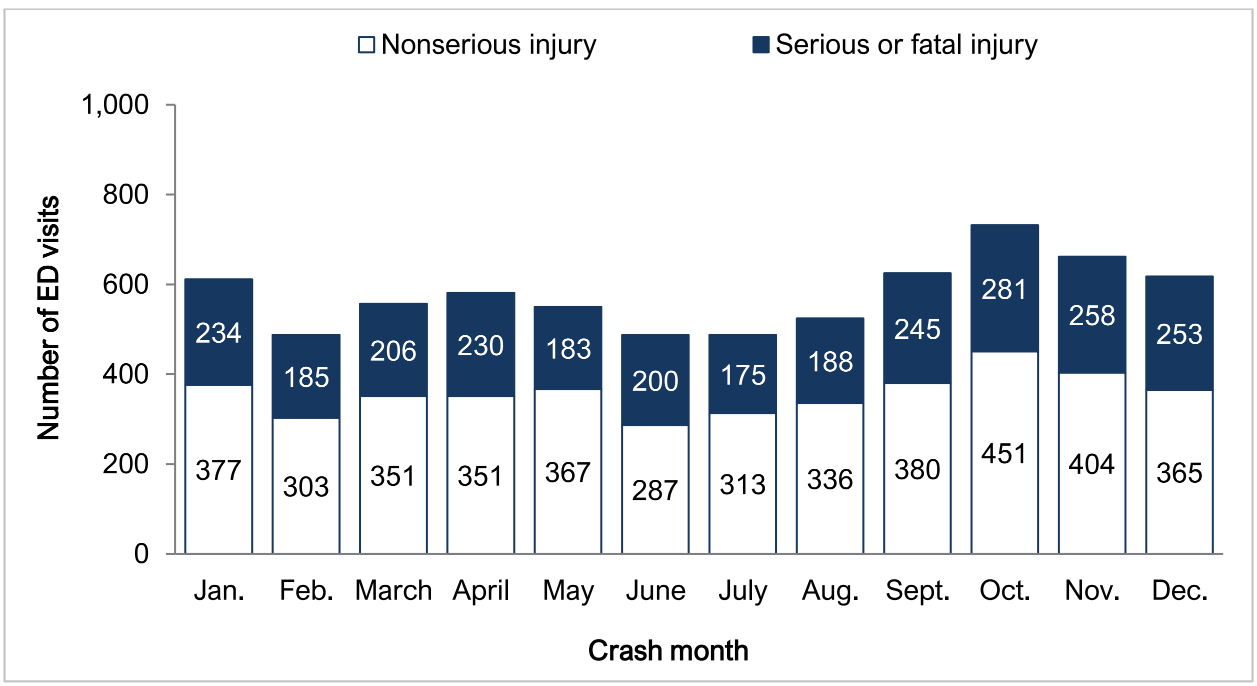


*Figure 6: Number of pedestrians treated at NC emergency departments, by crash month and pedestrian injury severity (N=6,923)[1]*

[1]Nonsignificant at $p$ =.299

Figures 7 and 8 display the number of injured pedestrians treated in NC EDS by crash hour of day. Figure 7 displays counts for Monday – Thursday (weekdays) and Figure 8 displays counts for Friday – Sunday (weekends). Regarding the number of pedestrian injury-related ED visits, the greatest number of visits were observed during the evening hours after 17:00; however, for weekday visits, the number peaked at 17:00 and then declined; while for weekend visits, the number of visits remained elevated at 17:00 and did not start to decline until 22:00. In addition, weekday visits displayed a smaller peak at 7:00; a comparable peak was not observed for weekend visits.

For both weekdays and weekends, crash hour of day was significantly associated with pedestrian injury ($p$ value <.001). The percentage of weekend crashes classified as serious pedestrian injuries was slightly higher during the weekend (40%) than during the weekday (37%). During the period 0:00 – 5:59, the percent of injuries characterized as serious reached 53%, while the percent of injuries characterized as serious for the remainder of the day was only 37%. The difference was not as dramatic for weekday pedestrian injuries, however, with 41% and 37% characterized as serious for the two time periods, respectively.

Figure 9 displays the frequency of pedestrian injury-related ED visits by crash day of week and crash hour of day (in four-hour time blocks). Periods for which more than 50% of pedestrian injuries were classified as severe are highlighted. More than 50% of pedestrians were seriously injured during the early morning hours (0:00-3:59) of Friday, Saturday, Sunday, and Monday, echoing the trends observed for Figures 7 and 8. Other studies have found a relationship between pedestrian injury severity and MVC time of day and day of week (Jang et al., 2013; Mokhtarimousavi, 2019; Pour-Rouholamin & Zhou, 2016; Uddin & Ahmed, 2018).

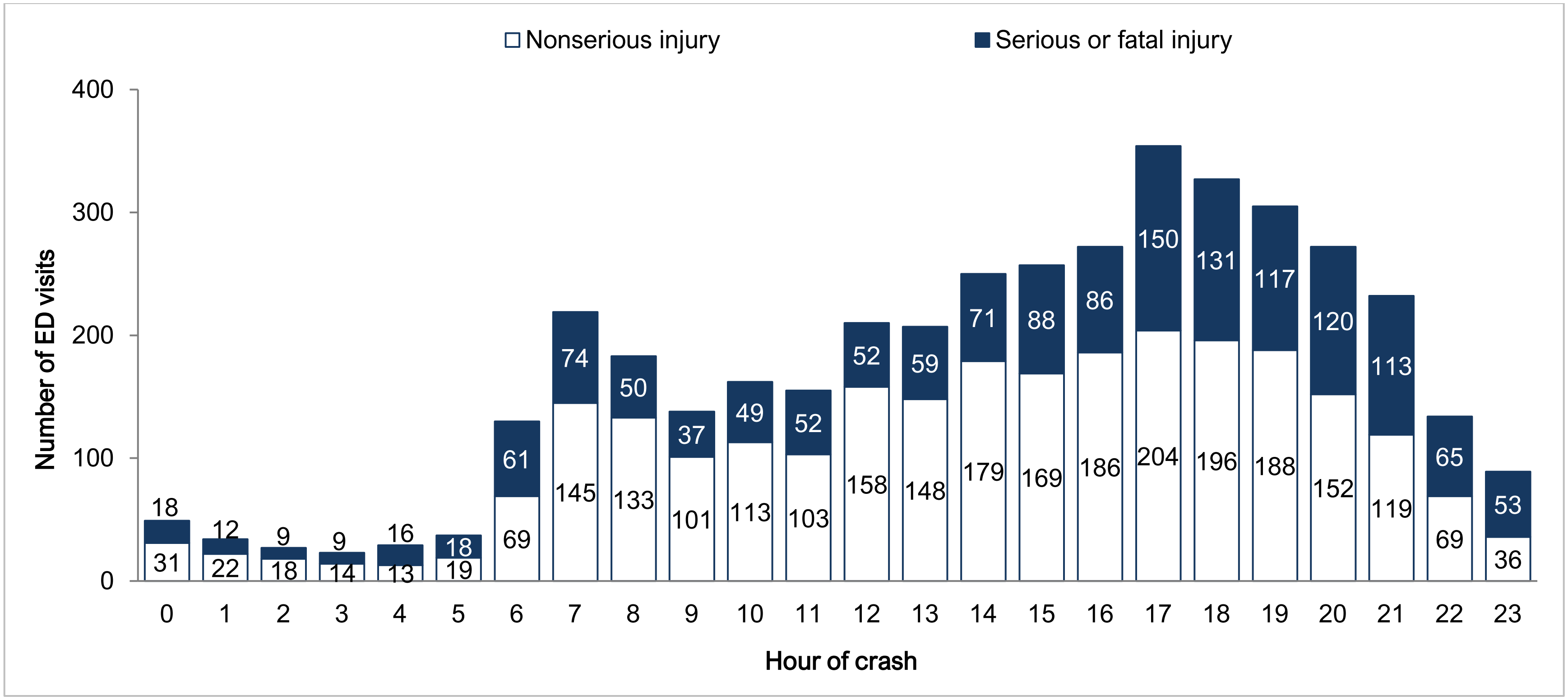


*Figure 7: Number of pedestrians treated at NC emergency departments, by crash hour of day and pedestrian injury severity, for weekday (Monday-Thursday) crashes (N=4,095)*[1]

[1]Significant at $p < .001$.

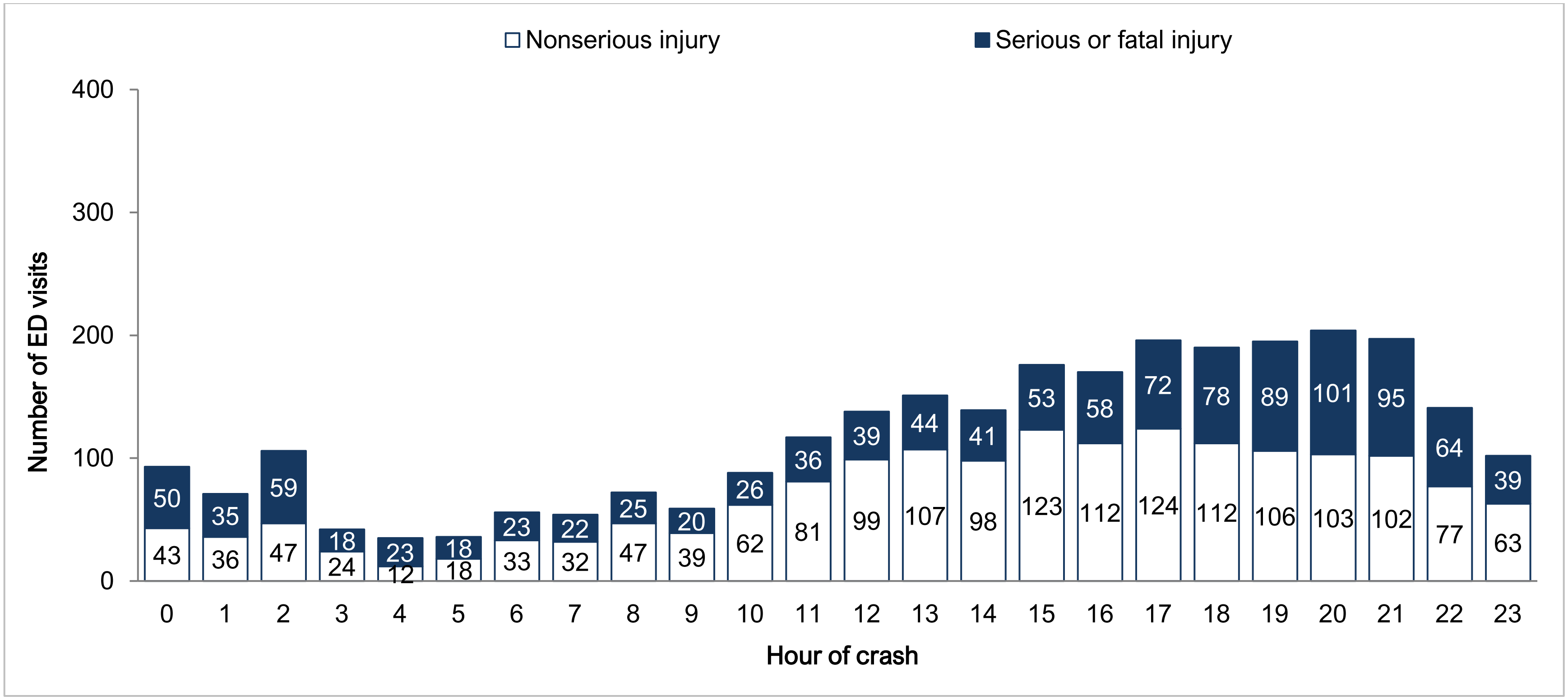


*Figure 8: Number of pedestrians treated at NC emergency departments, by crash hour of day and pedestrian injury severity, for weekend (Friday, Saturday, Sunday) crashes (N=2,828)[1]*

[1]Significant at $p<.001$.

| Hour of crash | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Sun. |
|---|---|---|---|---|---|---|---|
| 0:00-3:59 | 62% | 38% | 28% | 30% | 53% | 51% | 52% |
| 4:00-7:59 | 41% | 37% | 32% | 54% | 48% | 42% | 55% |
| 8:00-11:59 | 26% | 33% | 29% | 30% | 30% | 29% | 43% |
| 12:00-3:59 | 34% | 26% | 29% | 28% | 31% | 28% | 29% |
| 16:00-19:59 | 35% | 41% | 39% | 39% | 42% | 34% | 42% |
| 20:00-23:59 | 50% | 47% | 48% | 48% | 52% | 44% | 40% |

*Figure 9: Frequency of pedestrian injuries categorized as serious or fatal by day of week and hour of crash; date/times for which greater than or equal to 50% of injuries were serious or fatal are highlighted (N=6,923)*

## Demographic and Socioeconomic Characteristics

Table 3 displays the frequency of pedestrians diagnosed with serious or fatal injuries treated in NC emergency departments by selected pedestrian characteristics for the 6,923 pedestrians injured in police reported crashes during the period October 1, 2010 – September 30, 2015. Table 4 displays the percentage of pedestrians diagnosed with serious or fatal injuries. Regarding injured pedestrian demographics, most were male, and a plurality were identified as white, not Hispanic/Latinx. Black, non-Hispanic/Latinx pedestrians were overrepresented in the patient population, making up 45% of pedestrians treated in NC EDs, but only 23% of the NC population in 2015 (National Center for Health Statistics, Centers for Disease Control and Prevention, 2020). Race/ethnicity was significantly associated with pedestrian injury severity (*p* value <.001), with Black, non-Hispanic/Latinx pedestrians having a lower proportion of serious injuries, as compared two white, non-Hispanic/Latinx and Hispanic/Latinx pedestrians. This somewhat unexpected finding may be related to inequities in access to primary and urgent care for the treatment of lower severity injuries and/or possibly related to an inaccurate assessment of injury severity at the point of care (Blanchard, 2003). In a study of acute cardiovascular events, black and brown patients were four times more likely to be mistakenly discharged from the hospital with myocardial infarctions, as compared to white patients (Pope et al., 2000).

The most reported expected source of payment was “self-pay”, with 28% of injured pedestrians reporting this form of payment (Table 3). According to the Agency for Healthcare Research and Quality, patients with this form of payment are generally un- or under-insured (Healthcare Cost and Utilization Project, 2019). This is concerning, as the average total lifetime cost of a pedestrian injury exceeds $135,000 (Miller et al., 2004). Patients with an expected source of payment of “Medicare” were most likely to have a serious or fatal injury (44%), likely reflecting the older age distribution of this population (Table 4).

Nearly one-third of pedestrians treated in NC EDs for MVC-related injuries had one or more recorded comorbidities (i.e., chronic medical conditions) associated with premature mortality according to the Charlson Comorbidity Index (CCI) (Charlson et al., 1987) (Table 3). Perhaps not surprisingly, patients with one or more comorbidities were more likely to have a serious pedestrian injury, as compared to patients with no comorbidities documented in the ED visit record (Table 4).

Figures 10 and 11 display the frequency of serious and fatal pedestrian injuries by age group. Pedestrian age was strongly associated with pedestrian injury severity (*p* value <.001). Figure 10 displays counts of serious pedestrian injuries identified in the linked crash-ED visit data; counts of unlinked pedestrian fatalities (primarily pedestrians who died at the crash scene) are also displayed for comparative purposes. In terms of counts, adult pedestrians aged 25-34 (N=1,221) and 45-54 years (N=1,040) had the highest number of pedestrian injury-related ED visits, as well as the highest number of fatalities on the scene or dead-on-arrival, with 123 and 140 fatalities, respectively. However, the age groups with the highest *proportions* of serious and fatal pedestrian injuries were children 0-4 years of age (46%) and older adults 65-74 (48%) and ≥75 (54%) years of age. The relationship between pedestrian age and injury severity is well-supported and is likely related to both the inherent vulnerability of these groups to serious injuries, such as fractures, as well as the different height and weight profiles of children as compared to adults (Kemnitzer et al., 2019; J.-K. Kim et al., 2008; Niebuhr et al., 2016; Tefft, 2011).

### Table 3: Selected characteristics of pedestrians treated at NC emergency departments (N=6,923)[1]

| Selected pedestrian characteristics | Total ED visits N (%) |
|---|---|
| **Gender** | |
| Male | 3,979 (57.5%) |
| Female | 2,939 (42.5%) |
| Total | 6,918 (100.0%) |
| **Race/Hispanic ethnicity** | |
| White, not Hispanic/Latinx | 3,145 (46.1%) |
| Black, not Hispanic/Latinx | 3,081 (45.1%) |
| Hispanic/Latinx | 374 (5.5%) |
| NA/AI | 80 (1.2%) |
| Other race[2] | 147 (2.2%) |
| Total | 6,827 (100.0%) |
| **Expected source of payment** | |
| Self-pay | 1,855 (28.1%) |
| Insurance company | 1,753 (26.6%) |
| Medicaid | 1,236 (18.7%) |
| Medicare | 505 (7.7%) |
| WC | 237 (3.6%) |
| Other source of payment[3] | 1,012 (15.3%) |
| Total | 6,598 (100.0%) |
| **Patient comorbidities** | |
| Patient had no documented comorbidities | 4,673 (67.5%) |
| Patient had one or more documented comorbidities | 2,250 (32.5%) |
| Total | 6,923 (100.0%) |
| **Mode of transport to hospital** | |
| Ambulance | 3,916 (68.2%) |
| Other mode of transport[4] | 1,828 (31.8%) |
| Total | 5,744 (100.0%) |
| **Total** | **6,923 (100.0%)** |

Abbreviations: SES, socioeconomic; NA, Native American; AI, American Indian; WC, workers' compensation.
Missing: Gender (N=5), race/Hispanic ethnicity (N=96), source of payment (N=325), transport mode (N=1,179).
[1]Column total sums to 100%.
[2]Other race contains "Asian" and "Other race".
[3]Other source of payment contains "no charge", "other type of government payment", and "other payment type".
[4]Other mode of transport contains "walk-ins" and "other mode of transport".

## Table 4: Frequency of pedestrians diagnosed with serious or fatal injuries, by selected pedestrian characteristics (N=6,923)[1]

| Selected pedestrian characteristics | Non-serious pedestrian injury, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Gender** | | | **<.001** |
| Male | 2,278 (53.3%) | 1,701 (42.7%) | |
| Female | 2,007 (68.3%) | 932 (31.7%) | |
| **Race/Hispanic ethnicity** | | | **<.001** |
| White, not Hispanic/Latinx | 1,786 (56.8%) | 1,359 (43.2%) | |
| Black, not Hispanic/Latinx | 2,080 (67.5%) | 1,001 (32.5%) | |
| Hispanic/Latinx | 220 (58.8%) | 154 (41.2%) | |
| NA/AI | 46 (57.5%) | 34 (42.5%) | |
| Other race[2] | 87 (59.2%) | 60 (40.8%) | |
| **Expected source of payment** | | | **.001** |
| Self-pay | 1,195 (64.4%) | 660 (35.6%) | |
| Insurance company | 1,071 (61.1%) | 682 (38.9%) | |
| Medicaid | 734 (59.4%) | 502 (40.6%) | |
| Medicare | 285 (56.4%) | 220 (43.6%) | |
| WC | 154 (65.0%) | 83 (35.0%) | |
| Other source of payment[3] | 656 (64.8%) | 356 (35.2%) | |
| **Patient comorbidities** | | | **<.001** |
| Patient had no documented comorbidities | 3,002 (64.2%) | 1,671 (35.8%) | |
| Patient had one or more documented comorbidities | 1,283 (57.0%) | 967 (43.0%) | |
| **Mode of transport to hospital** | | | **<.001** |
| Ambulance | 2,181 (55.7%) | 1,735 (44.3%) | |
| Other mode of transport[4] | 1,440 (78.8%) | 388 (21.2%) | |
| **Total** | **4,285 (61.9%)** | **2,638 (38.1%)** | |

Abbreviations: SES, socioeconomic; NA, Native American; AI, American Indian; WC, workers' compensation.
Missing: Gender (N=5), race/Hispanic ethnicity (N=96), source of payment (N=325), transport mode (N=1,179).
[1]Row totals sum to 100%.
[2]Other race contains "Asian" and "Other race".
[3]Other source of payment contains "no charge", "other type of government payment", and "other payment type".
[4]Other mode of transport contains "walk-ins" and "other mode of transport".

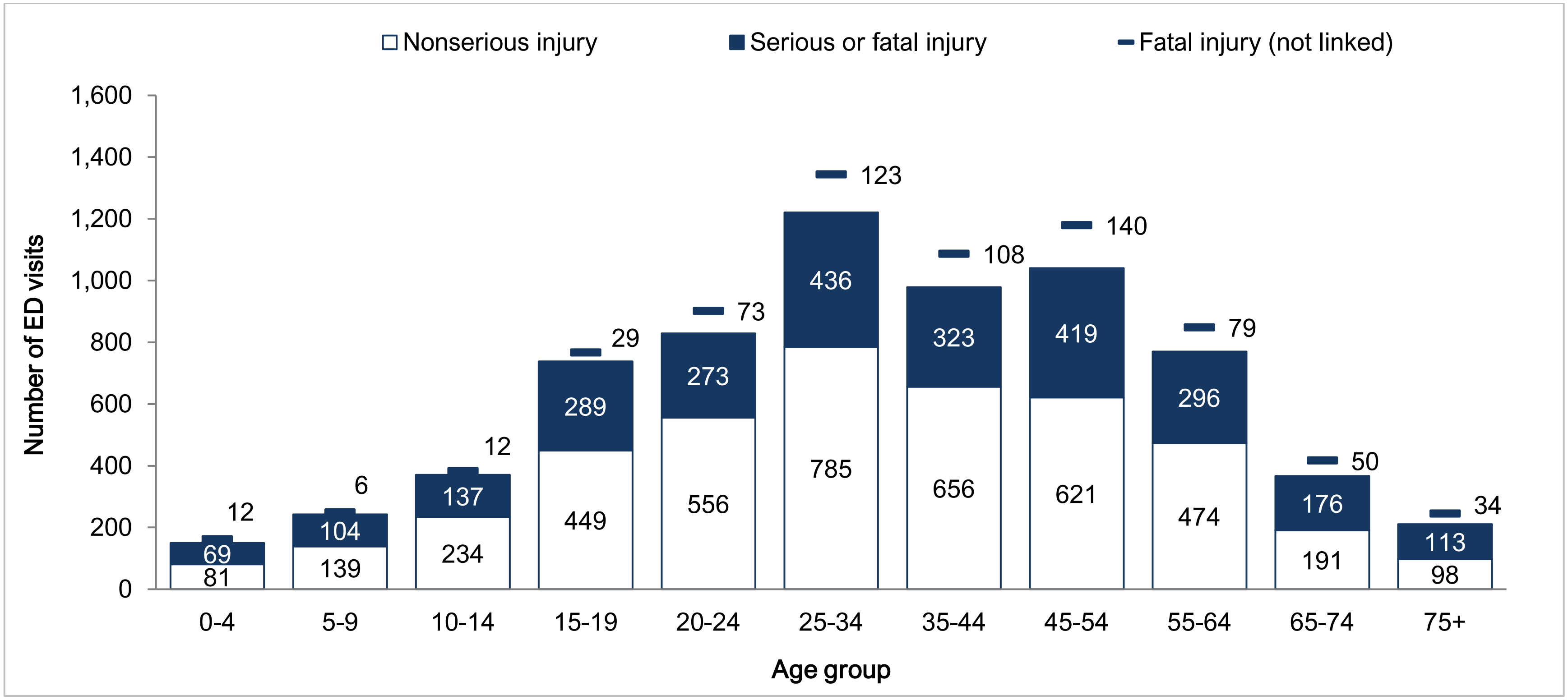


*Figure 10: Number of pedestrians treated at NC emergency departments, by age group and pedestrian injury severity (N=6,919)[1]; number of DOA pedestrian fatalities (unlinked) shown for comparison (N=666)*

Abbreviations: DOA, dead on arrival.
Missing: Age (N<5).
[1]Significant at $p<.001$.

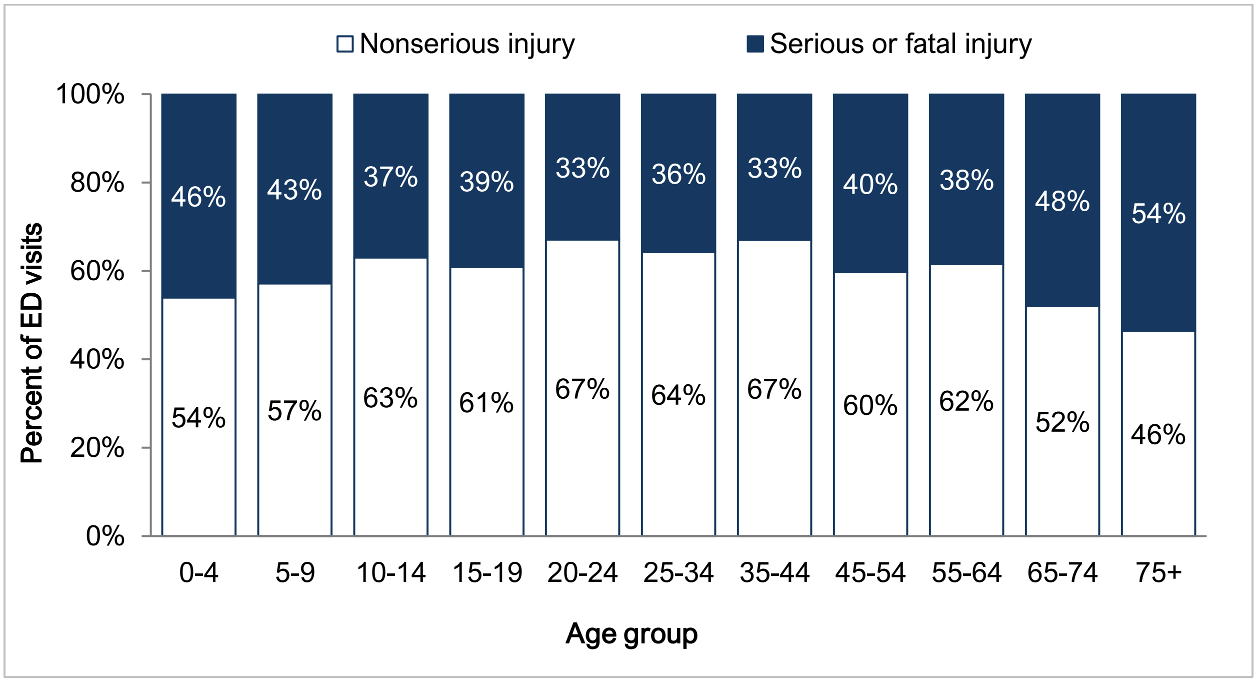


**Figure 11: Frequency of pedestrians treated at NC emergency departments, by age group and pedestrian injury severity (N=6,919)[1]**

Missing: Age (N<5).
[1]Significant at $p$ <.001.

## Driver Demographics

We hypothesized that certain driver characteristics would be associated with pedestrian injury severity. Unfortunately, approximately 15% percent of crash reports were missing information on the striking driver. Many of the drivers who were missing information were involved in the 17% of pedestrian MVCs that were classified as hit and runs, indicating that the missingness was not at random and therefore possibly biasing the results. Among striking drivers with demographic information, Table 5 displays driver gender and race/Hispanic ethnicity and Table 6 displays striking driver demographics by pedestrian injury severity. The relationship between driver gender and pedestrian injury severity was statistically significant ($p$ value <.001), while driver race/Hispanic ethnicity was not ($p$ value <.949).

Figures 12 and 13 display the relationship between striking driver age group and pedestrian injury severity. The age of the striking driver was significantly associated with pedestrian injury severity ($p$ = .002), with young adult drivers 20-24 (43%) and 25-34 years-of-age (42%) being the most likely to be involved in MVCs resulting in serious pedestrian injuries, while older adult drivers 65-74 (34%) and $\geq$75 years (33%) were the least likely to be involved in MVCs resulting in serious pedestrian injuries (Figure 13). Young adult drivers were also overrepresented in terms of the number of pedestrian injuries per licensed driver (Figure 12). Other studies have shown a negative association between increasing driver age and pedestrian injury severity (J.-K. Kim et al., 2008). Although older drivers may be less likely to be involved in MVCs that result in serious and fatal pedestrian injuries, perhaps due to their lower likelihood of traveling on high-speed roads and traveling at night, previous research has suggested that they are more likely to be involved in lower severity MVCs per vehicle mile traveled, as compared to working-age adults (Betz & Lowenstein, 2010; Braver & Trempel, 2004). Since the older adult population is growing in NC and nationwide, this is cause for concern. More research is needed examining the relationship between driver age and pedestrian injury severity.

**Table 5: Demographic characteristics of drivers involved in motor vehicle collisions involving pedestrians treated at NC emergency departments (N=6,923)[1,2]**

| Selected demographic characteristic | Total ED visits N (%) |
|---|---|
| **Gender** | |
| Male | 3,274 (55.5%) |
| Female | 2,629 (44.5%) |
| Total | 5,903 (100.0) |
| **Race/Hispanic ethnicity** | |
| White, not Hispanic/Latinx | 3,307 (56.2%) |
| Black, not Hispanic/Latinx | 2,083 (35.4%) |
| Hispanic/Latinx | 261 (4.4%) |
| NA/AI | 62 (1.1%) |
| Other race[3] | 176 (3.0%) |
| Total | 5,889 (100.0%) |
| **Total** | **6,923 (100.0%)** |

Abbreviations: NA, Native American; AI, American Indian.
Missing: Driver gender (N=1,020), driver race/Hispanic ethnicity (N=1,034).
[1]For collisions involving more than one driver, demographics are provided for only one driver.
[2]Column total sums to 100%.
[3]Other race contains “Asian” and “other race”.

**Table 6: Demographic characteristics of drivers involved in motor vehicle collisions involving pedestrians treated at NC emergency departments, by pedestrian injury severity (N=6,923)[1]**

| Selected demographic characteristic[1,2] | Non-serious pedestrian injury, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Gender** | | | **<.001** |
| Male | 1,907 (58.2%) | 1,367 (41.8%) | |
| Female | 1,671 (63.6%) | 958 (36.4%) | |
| **Race/Hispanic ethnicity** | | | **.949** |
| White, not Hispanic/Latinx | 2,013 (60.9%) | 1,294 (39.1%) | |
| Black, not Hispanic/Latinx | 1,252 (60.1%) | 831 (39.9%) | |
| Hispanic/Latinx | 162 (62.1%) | 99 (37.9%) | |
| NA/AI | 36 (58.1%) | 26 (41.9%) | |
| Other race[3] | 107 (60.8%) | 69 (39.2%) | |
| **Total** | **4,285 (61.9%)** | **2,638 (38.1%)** | |

Abbreviations: NA, Native American; AI, American Indian.
Missing: Driver gender (N=1,020), driver race/Hispanic ethnicity (N=1,034).
[1]For collisions involving more than one driver, demographics are provided for only one driver.
[2]Row totals sum to 100%.

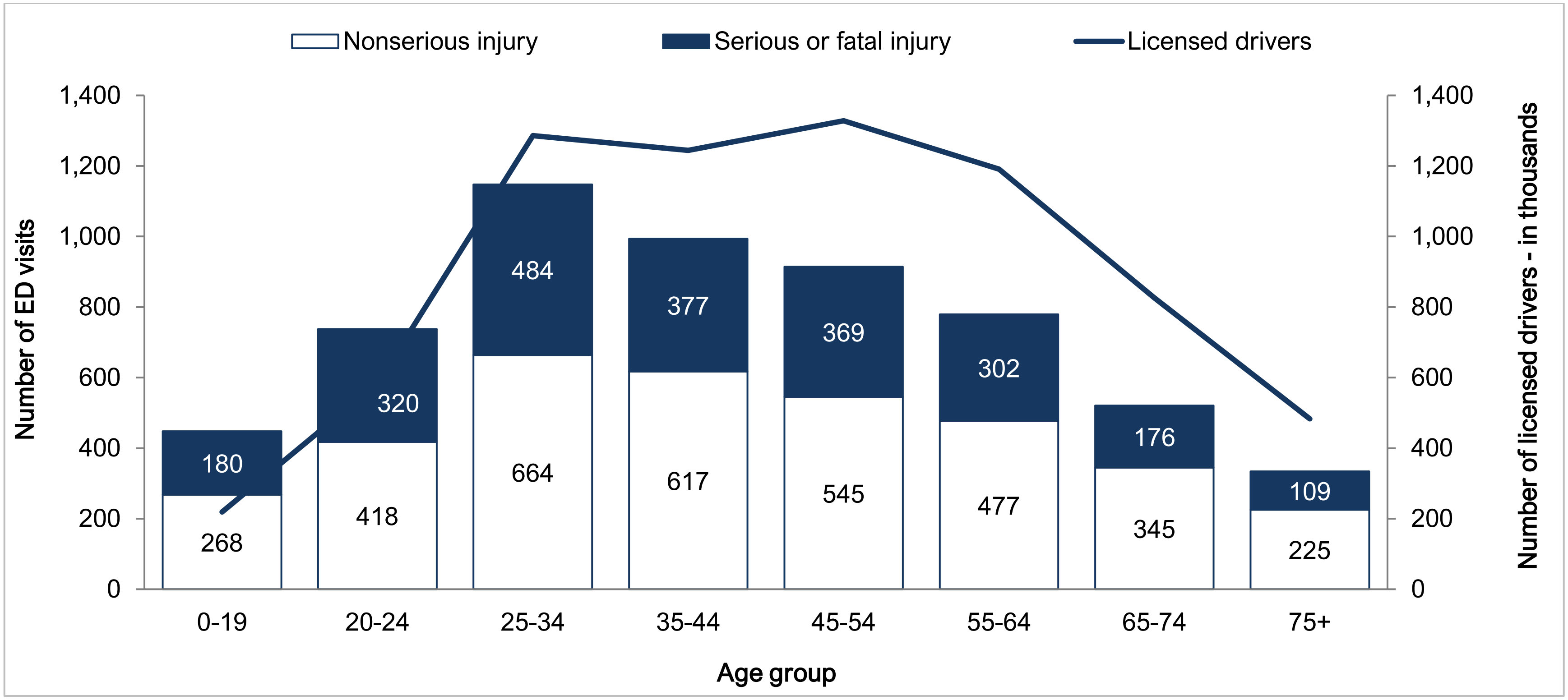


*Figure 12: Number of pedestrians treated at NC emergency departments, by striking driver age group and pedestrian injury severity (N=5,876)[1]; number of 2015 NC licensed drivers shown for comparison (N=7,160,621)(Federal Highway Administration, 2018)*

Missing: Driver age (N=1,047).
[1]Significant at $p$ = .002.

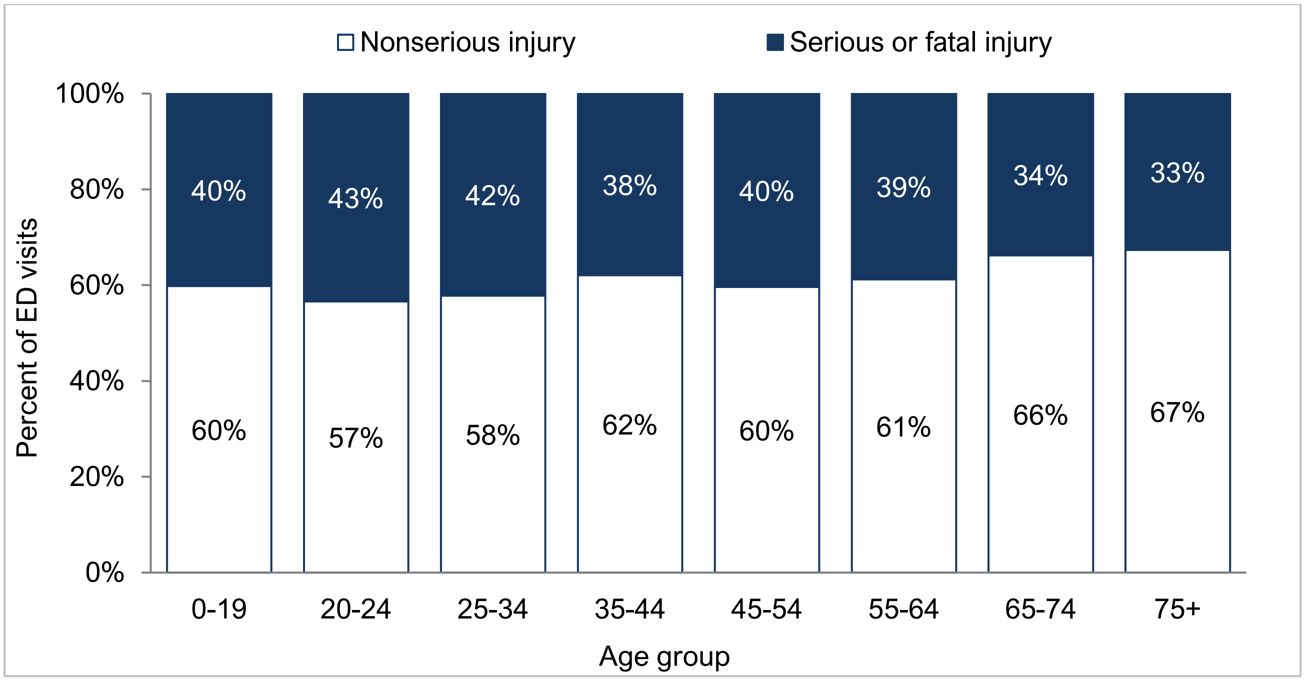


*Figure 13: Frequency of pedestrians treated at NC emergency departments, by striking driver age group and pedestrian injury severity (N=5,876)[1]*

Missing: Driver age (N=1,047).

## Suspected/Detected Alcohol Use

Pedestrian and driver alcohol impairment has long been associated with an increased risk of severe injury and death (Dultz & Frangos, 2013). The quality of pedestrian and striking driver alcohol impairment information in the NC crash data is low, with relatively high levels of missingness for suspected alcohol use, especially among striking drivers (18%). However, we decided to perform analyses using these variables due to the strong relationship between alcohol impairment and MVC injury risk. Table 7 displays the frequency of suspected or detected alcohol use among injured pedestrians and striking drivers, with 5% of pedestrians and 4% of drivers being suspected of being under the influence of alcohol at the time of the crash. Since information on alcohol impairment is often not collected or recorded, these percentages likely underestimate the true prevalence of alcohol use among injured pedestrians and striking drivers. Suspected/detected alcohol use was significantly associated with serious pedestrian injury for both pedestrians ($p<.001$) and striking drivers ($p=.003$), with sixty-seven percent of pedestrians suspected of being under the influence of alcohol having serious injuries (Table 8).

Figures 14 and 15 display the percentage of pedestrians and striking drivers suspected of being under the influence of alcohol by day of week and time of day. Four-hour-blocks in which ≥10% of pedestrians (Figure 14) and striking drivers (Figure 15) were suspected of using alcohol are shaded. The figures for both groups of individuals are remarkably similar, with late night/early morning hours having especially high levels of suspected/detected pedestrian/driver alcohol use, especially on weekends.

Since nearly one-fifth of all striking drivers were missing information regarding suspected alcohol use in our study, we also examined the percentage of pedestrians struck in "hit-and-run" collisions, in which the driver left the crash scene prior to the arrival of police. Prior studies have suggested that among drivers identified by police following a hit-and-run, a considerable proportion are alcohol impaired or have a history of driving while alcohol impaired, although other circumstances, such as low light conditions, may also contribute to a driver leaving the scene of a crash (MacLeod et al., 2012; Solnick & Hemenway, 1995). Therefore, hit-and-runs can serve as an imperfect indicator for driver alcohol involvement. During the study period, 1,175 (17%) of pedestrians with linked crash-ED visit data were injured in hit-and-runs. Figure 16 displays the percentage of pedestrians injured in hit-and-runs by day of week and time of day. Four-hour-time-blocks in which ≥25% of pedestrians were struck in hit-and-run events are shaded. Not surprisingly, the patterns are like those observed in Figure 15, with a higher percentage of pedestrians being struck in hit-and-run collisions during the late night/early morning hours.

### Table 7: Suspected/Detected alcohol use[1] among pedestrians/striking drivers (N=6,923)[2]

| Person type | Total ED visits, N (%) |
|---|---|
| **Pedestrian alcohol use suspected/detected** | |
| Yes | 361 (5.2%) |
| No | 6,562 (94.8%) |
| **Driver alcohol use suspected/detected** | |
| Yes | 228 (4.0%) |
| No | 5,456 (96.0%) |
| **Total** | **6,923 (100.0%)** |

Missing: Driver alcohol status (N=1,239).
[1]The investigating officer detected/suspected the use of alcohol by the pedestrian/driver. This does not mean that the pedestrian/driver was impaired at the time of crash.
[2]Column total sums to 100%.

### Table 8: Suspected/Detected alcohol use[1] among pedestrians/striking drivers, by pedestrian injury severity (N=6,923)[2]

| Person type | Non-serious pedestrian injury, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Pedestrian alcohol use suspected/detected** | | | <.001 |
| Yes | 120 (33.2%) | 241 (66.8%) | |
| No | 4,165 (63.5%) | 2,397 (36.5%) | |
| **Driver alcohol use suspected/detected** | | | .003 |
| Yes | 116 (50.9%) | 112 (49.1%) | |
| No | 3,309 (60.6%) | 2,147 (39.4%) | |
| **Total** | **6,923 (100.0%)** | **2,638 (38.1%)** | |

Missing: Driver alcohol status (N=1,239).
[1]The investigating officer detected/suspected the use of alcohol by the pedestrian/driver. This does not mean that the pedestrian/driver was impaired at the time of crash.
[2]Row totals sum to 100%.

| Hour of crash | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Sun. |
|---|---|---|---|---|---|---|---|
| 0:00-3:59 | 24% | 19% | 15% | 5% | 14% | 21% | 15% |
| 4:00-7:59 | 1% | 0% | 3% | 2% | 2% | 15% | 10% |
| 8:00-11:59 | 0% | 0% | 1% | 2% | 0% | 1% | 2% |
| 12:00-3:59 | 2% | 2% | 2% | 3% | 1% | 3% | 3% |
| 16:00-19:59 | 3% | 3% | 6% | 3% | 4% | 7% | 3% |
| 20:00-23:59 | 10% | 10% | 6% | 8% | 14% | 12% | 14% |

*Figure 14: Heat map displaying the frequency of injured pedestrians with suspected/detected alcohol use[1], by day of week and hour of crash; date/times for which greater than or equal to 10% of patients had suspected alcohol use are highlighted (N=6,923)*

[1]The investigating officer detected/suspected the use of alcohol by the pedestrian. This does not mean that the pedestrian was impaired at the time of crash.

| Hour of crash \ Day of week | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Sun. |
|---|---|---|---|---|---|---|---|
| 0:00-3:59 | 25% | 5% | 13% | 32% | 27% | 30% | 19% |
| 4:00-7:59 | 0% | 2% | 1% | 0% | 3% | 17% | 4% |
| 8:00-11:59 | 1% | 1% | 1% | 1% | 1% | 2% | 0% |
| 12:00-3:59 | 1% | 1% | 1% | 2% | 0% | 4% | 2% |
| 16:00-19:59 | 1% | 4% | 1% | 2% | 3% | 5% | 6% |
| 20:00-23:59 | 4% | 4% | 5% | 8% | 6% | 11% | 11% |

*Figure 15: Heat map displaying the frequency of pedestrians injured by striking drivers with suspected/detected alcohol use[1] by day of week and hour of crash; date/times for which greater than or equal to 10% of drivers had suspected alcohol use are highlighted (N=5,684)*

Missing: Driver alcohol status (N=1,239).

[1]Investigating officer detected/suspected the use of alcohol by the striking driver. This does not mean that the driver was impaired at the time of crash.

| Hour of crash \ Day of week | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Sun. |
|---|---|---|---|---|---|---|---|
| 0:00-3:59 | 43% | 38% | 43% | 38% | 46% | 41% | 37% |
| 4:00-7:59 | 8% | 16% | 19% | 8% | 16% | 31% | 40% |
| 8:00-11:59 | 11% | 11% | 17% | 12% | 13% | 8% | 10% |
| 12:00-3:59 | 13% | 9% | 6% | 14% | 12% | 12% | 13% |
| 16:00-19:59 | 14% | 12% | 13% | 13% | 13% | 19% | 17% |
| 20:00-23:59 | 22% | 21% | 25% | 25% | 20% | 27% | 23% |

*Figure 16: Heat map displaying the frequency of pedestrians injured in hit and runs by day of week and hour of crash; date/times for which greater than or equal to 20% of MVCs were identified as hit and runs are highlighted (N=6,923)*

# Motor Vehicle Collision Characteristics

We examined selected MVC characteristics, because these also have been found to play an important role in both the frequency and the severity of pedestrian injuries. The analysis of motor vehicle crash factors has long served as the bedrock of traditional transportation safety analyses, although more modern approaches tend to take a more expansive approach examining all aspects of the "system" that contributed to the crash (Dumbaugh et al., 2019).

During the period October 1, 2010- September 30, 2015, 79% of pedestrians with linked MVC and ED visit data were injured on public roadways and 21% were injured on non-roadway locations (e.g., parking lots, private driveways, etc.). Among pedestrians injured on the roadway, 1,353 (27%) pedestrians were injured at intersections; 657 (13%) were involved in crashes that were intersection-related, but not directly at intersections; and 2,950 (59%) were injured at locations that were not intersections or were not intersection-related (Figure 17). Crash location was associated with pedestrian injury severity ($p < .001$), with non-intersection crashes (46%) being more likely to result in serious pedestrian injuries, as compared to intersection-related (41%), intersection (37%), and non-roadway crashes (27%). Non-roadway, intersection-related, and intersection crashes are likely less serious than non-intersection crashes due to lower speeds at impact.

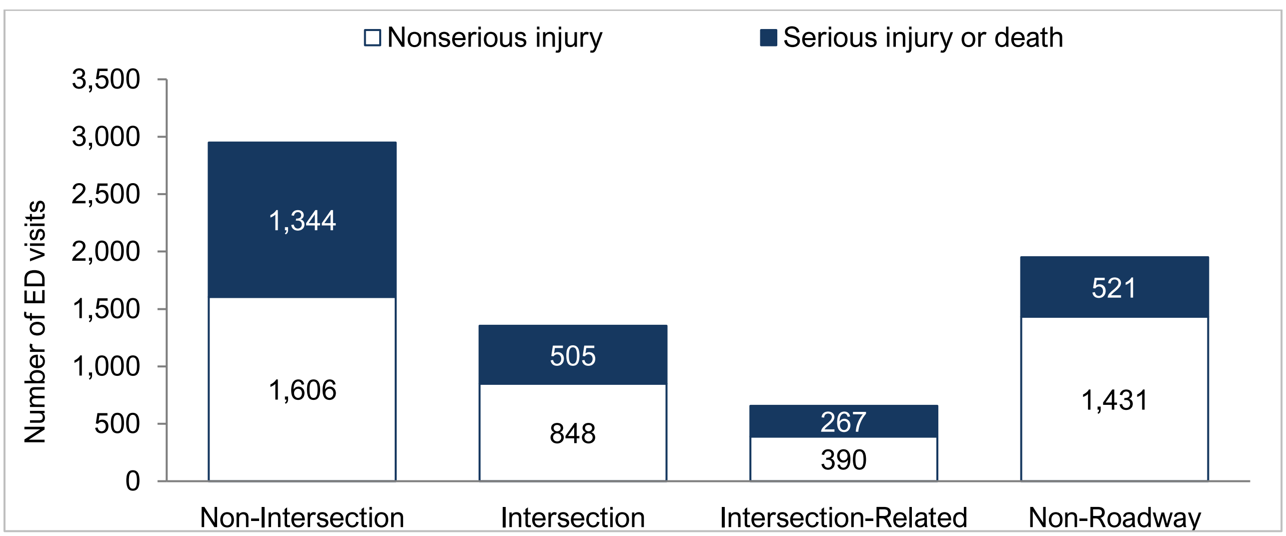


*Figure 17: Number of pedestrians treated at NC emergency departments, by crash location and pedestrian injury severity (n=6,912)[1]*

Missing: Crash location (N=11).
[1]Significant at $p < .001$.

Table 9 displays the frequency of pedestrian crash injuries treated in NC EDs by crash locality, with the locality being defined as "urban", "suburban/mixed development", and "rural" based on the investigating police officer's assessment of the crash location being >70% developed, 30-70% developed, and <30% developed, respectively. The results presented in Table 9 are stratified by roadway location. For 71% of roadway and 80% of non-roadway pedestrian crash injuries, the locality was classified as urban. Crash locality was significantly associated with pedestrian injury severity for both roadway ($p$ = 01) and non-roadway crashes ($p$ = .001), with rural crashes having the highest frequency of serious and fatal pedestrian injuries (Table 10).

**Table 9: Pedestrians treated at NC emergency departments, by crash locality (N=6,912)[1,2]**

| Locality | Total ED visits, N (%) |
|---|---|
| **Roadway** | |
| Urban<br>Suburban/Mixed development<br>Rural | 3,510 (70.8%)<br>697 (14.1%)<br>753 (15.2%) |
| Total | 4,960 (100.0%) |
| **Non-roadway** | |
| Urban<br>Suburban/Mixed development<br>Rural | 1,565 (80.2%)<br>254 (13.0%)<br>133 (6.8%) |
| Total | 1,952 (100.0%) |
| **Total** | **6,912 (100.0%)** |

Missing: Crash location (N=11).
[1]Locality defined according to the following criteria: urban, >70% developed; suburban/mixed development, 30-70% developed; rural, <30% developed.
[2]Column total sums to 100%.

**Table 10: Pedestrians treated at NC emergency departments, by crash locality and pedestrian injury severity (N=6,912)[1,2]**

| Locality | Total ED visits, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Roadway** | | | **.01** |
| Urban | 2,056 (58.6%) | 1,454 (41.4%) | |
| Suburban/Mixed development | 389 (55.8%) | 308 (44.2%) | |
| Rural | 399 (53.0%) | 354 (47.0%) | |
| Total | 2,844 (57.3%) | 2,116 (42.7%) | |
| **Non-roadway** | | | **.001** |
| Urban | 1,169 (74.7%) | 396 (25.3%) | |
| Suburban/Mixed development | 177 (69.7%) | 77 (30.3%) | |
| Rural | 85 (63.9%) | 48 (36.1%) | |
| Total | 1,431 (73.3%) | 521 (26.7%) | |
| **Total** | **4,275 (61.8%)** | **2,637 (38.2%)** | |

Missing: Crash location (N=11).
[1]Locality defined according to the following criteria: urban, >70% developed; suburban/mixed development, 30-70% developed; rural, <30% developed.
[2]Row totals sum to 100%.

In addition to crash location, we were interested in the specific pedestrian crash types and their relationship with pedestrian injury severity. One of the strengths of NC pedestrian crash data is that all pedestrian crashes are categorized ("typed") according to PBCAT (Pedestrian and Bicycle Crash Information Center, n.d.). Since the version of PBCAT applied to the 2010-2015 data contained >30 types, we collapsed across categories. We also stratified by roadway/non-roadway location, due to considerable differences in the frequency of key pedestrian crash types. Tables 11 and 12 display the results of the analysis of pedestrian crash types.

Among NC roadway crashes, pedestrians were most frequently injured in crashes in which the pedestrian was struck while crossing the roadway, with the vehicle traveling straight (37%). Among non-roadway MVCs, pedestrians were mostly commonly injured in backing crashes (Table 11). Pedestrian crash type was statistically significantly associated with injury severity, with pedestrian crossing roadway, traveling straight (55%) and MV loss of control (34%) having the highest frequency of serious pedestrian injuries for roadway and non-roadway collisions, respectively (Table 12).

### Table 11: Pedestrians treated at NC emergency departments, by pedestrian crash type (N=6,912)[1]

| Pedestrian crash type | Total ED visits, N (%) |
|---|---|
| **Roadway** | |
| Backing | 114 (2.3%) |
| Pedestrian crossing roadway – vehicle traveling straight | 1,840 (37.0%) |
| Motorist turning-related crashes – right/unknown | 431 (8.7%) |
| Motorist turning-related crashes – left | 465 (9.4%) |
| Walking along roadway with traffic/unknown | 583 (11.7%) |
| Walking along roadway against traffic | 177 (3.6%) |
| Standing/walking/lying in roadway | 455 (9.2%) |
| Other crash type[2] | 906 (18.2%) |
| Total | 4,971 (100.0%) |
| **Non-roadway** | |
| Backing | 712 (36.5%) |
| Parking lot – not backing | 759 (38.9%) |
| Motor vehicle loss of control | 115 (5.9%) |
| Other crash type[2] | 366 (18.8%) |
| Total | 1,952 (100.0%) |
| **Total** | **6,912 (100.0%)** |

[1]Column total sums to 100%.
[2]Other crash type contains all other crash types, please see the Pedestrian and Bicycle Crash Analysis Tool Manual for a full description.

**Table 12: Pedestrians treated at NC emergency departments, by pedestrian crash type and pedestrian injury severity (N=6,912)[1]**

| Pedestrian crash type | Non-serious pedestrian injury, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Roadway** | | | **<.001** |
| Backing | 84 (73.7%) | 30 (26.3%) | |
| Pedestrian crossing roadway – vehicle traveling straight | 838 (45.5%) | 1,002 (54.5%) | |
| Motorist turning-related crashes – right/unknown | 352 (81.7%) | 79 (18.3%) | |
| Motorist turning-related crashes – left | 309 (66.5%) | 156 (33.5%) | |
| Walking along roadway with traffic/unknown | 374 (64.2%) | 209 (35.8%) | |
| Walking along roadway against traffic | 115 (65.0%) | 62 (35.0%) | |
| Standing/walking/lying in roadway | 239 (52.5%) | 216 (47.5%) | |
| Other crash type[2] | 543 (59.9%) | 363 (40.1%) | |
| Total | 2,854 (57.4%) | 2,117 (42.6%) | |
| **Non-roadway** | | | **.006** |
| Backing | 534 (75.0%) | 178 (25.0%) | |
| Parking lot – not backing | 574 (75.6%) | 185 (24.4%) | |
| Motor vehicle loss of control | 76 (66.1%) | 39 (33.9%) | |
| Other crash type[2] | 247 (67.5%) | 119 (32.5%) | |
| Total | 1,431 (73.3%) | 521 (26.7%) | |
| **Total** | **4,275 (61.8%)** | **2,637 (38.2%)** | |

[1]Row totals sum to 100%.
[2]Other crash type contains all other crash types, please see the Pedestrian and Bicycle Crash Analysis Tool Manual for a full description.

The speed at impact is the single most important factor in predicting pedestrian injury severity, with a recent meta-analysis estimating that for a 1 km/h (0.6 MPH) increase in impact speed, the odds of death increases by approximately 11% (Hussain et al., 2019). Unfortunately, impact speed is not always accurately reported in the crash data, with one study concluding that, using current methods, up to 30% of impact speeds are overestimates (Field, n.d.). Pedestrian crash reconstruction is a complex process requiring considerable expertise, which may not be available in all police jurisdictions. In addition, unlike many crashes involving only motor vehicles, there may be little physical evidence (e.g., vehicular damage) to that can be used to base estimations upon. It remains to be seen if innovations in vehicle data collection (cameras, event data recorders, etc.) will result in better speed data in the future (Böhm et al., 2020).

Despite the limitations of police reported speed data described in the preceding paragraph, it would be remiss to exclude estimated speed at impact in a comprehensive analysis of pedestrian injury severity. Figure 18 displays the frequency of pedestrian injuries treated in NC EDs, with the number of serious pedestrian injuries shaded in blue. The number of pedestrian fatalities that occurred at the scene of the crash that did not link to the NC ED visit data are shown for comparative purposes. Nearly one-third (N=1,976) of all pedestrian crash injuries captured in the linked NC crash-ED visit data during the period October 1, 2010 – September 30, 2015, involved a collision in which the striking vehicle was traveling ≤5 MPH. Among pedestrians struck at impact speeds of ≤5 MPH, 483 pedestrians had serious or fatal injuries, of which 26 persons died on the scene. About one-fifth (N=1,313) of pedestrians with linked NC crash-ED visit data were struck by vehicles traveling at >35 MPH. Among pedestrians struck at impact speeds of >35 MPH, 1,237 pedestrians experienced serious or fatal injuries, of which 487 (39%) did not even survive long enough to obtain medical treatment.

Figure 19 displays the percentage of injured pedestrians treated in NC EDs diagnosed with serious injuries, by estimated vehicle impact speed. Not surprisingly, injury severity was significantly associated with estimated impact speed ($p < .001$). At estimated impact speeds of ≤5 MPH, 23% of pedestrian injuries were diagnosed with serious injuries in the ED; at >35 MPH, 57% were classified as serious.

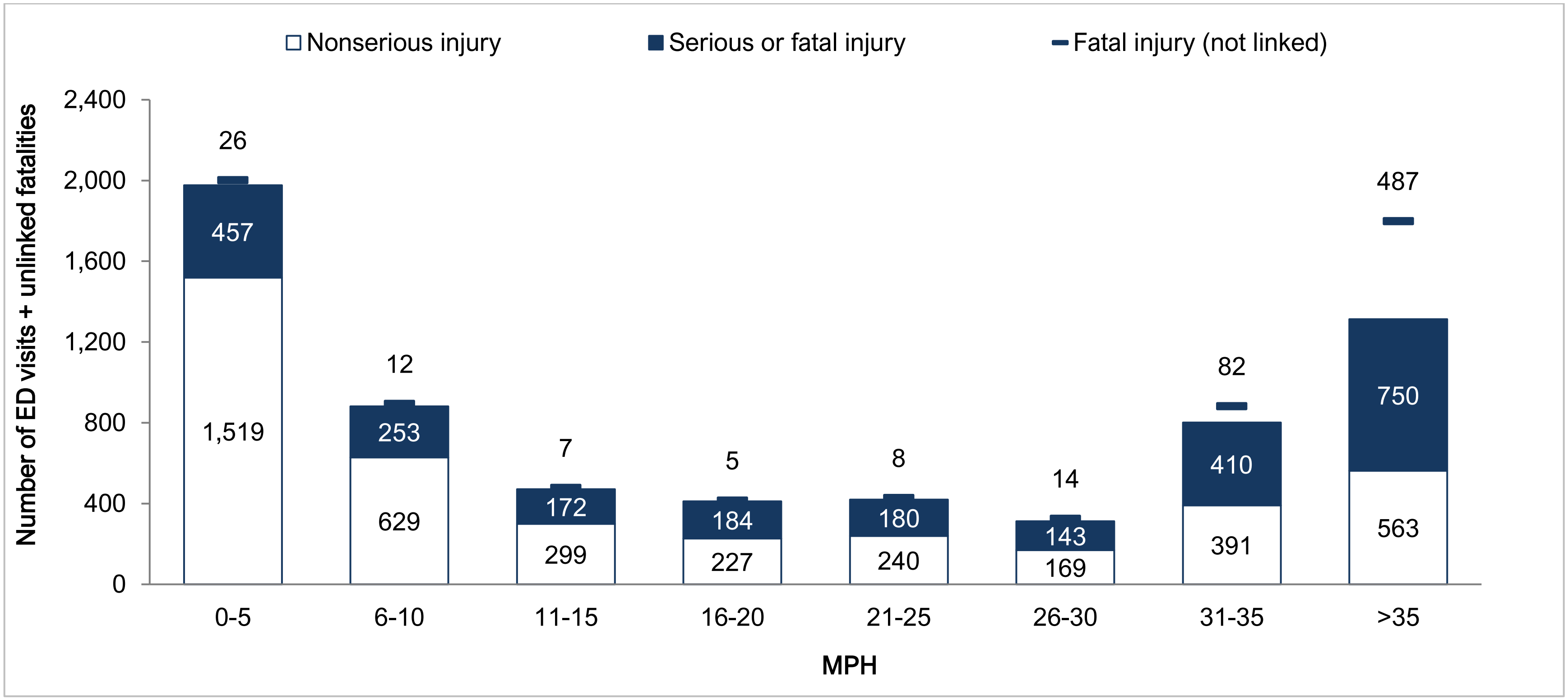


*Figure 18: Number of pedestrians treated at NC emergency departments, by estimated driver speed at impact and pedestrian injury severity (N=6,586)[1,2]; number of DOA pedestrian fatalities (unlinked) shown for comparison (N=641)*

Abbreviations: DOA, dead on arrival; MPH, miles per hour.
Missing: Impact speed (N=337).
[1]Speed at impact estimated by investigating police officer.
[2]Significant at $p$ <.001.

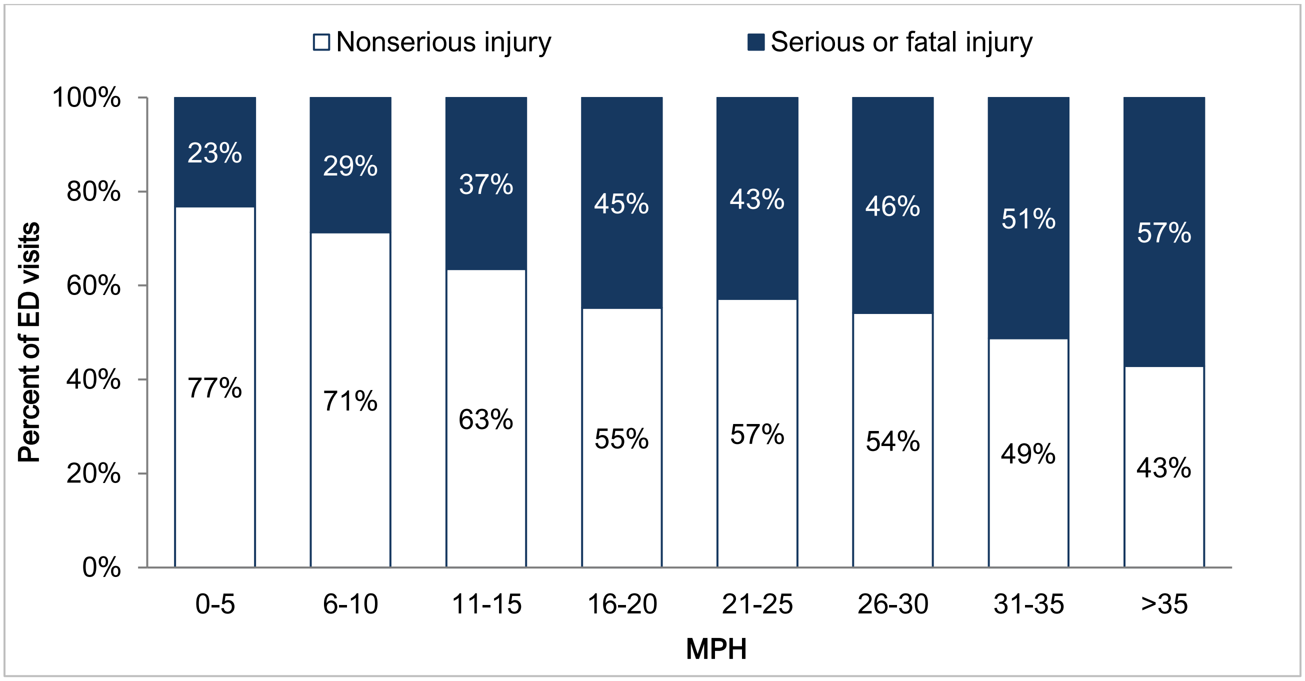


*Figure 19: Frequency of pedestrians treated at NC emergency departments, by estimated driver speed at impact and pedestrian injury severity (N=6,586)*[1,2]

Abbreviations: MPH, miles per hour.
Missing: Impact speed (N=337).
[1]Speed at impact estimated by investigating police officer.
[2]Significant at $p < .001$.

Table 13 displays the frequency of pedestrians treated in NC emergency departments following police reported MVCs by ambient light level and weather condition. Most pedestrians were struck under daylight conditions (57%), with an additional 5% being struck during dawn or dusk and 38% being struck under dark conditions. A low ambient light level has long been recognized as a risk factor for serious and fatal pedestrian injuries (Sullivan & Flannagan, 2002, 2001). Under dark or poorly light conditions, drivers may be less likely to see pedestrians and reduce speed. This study of pedestrians treated in NC EDs supports this conclusion, with light condition having a strong association with pedestrian injury severity ($p$ value <.001) (Table 14). Over half of pedestrians struck under dark and unlighted/unknown conditions were diagnosed with serious or fatal injuries, as compared to 32% of pedestrians struck under daylight conditions. Pedestrians struck under dark and lighted conditions (46%) were slightly less likely to have a serious injury than pedestrians struck under dark and unlighted conditions (50%), although they were still much more likely to have a serious injury than pedestrians struck during daylight hours (Table14). Countermeasures, such as improving roadway lighting, lowering speeds, and separating pedestrians from motor vehicle traffic, can improve pedestrian safety under low ambient light levels (R. A. Retting et al., 2003). Partial or full street closures on streets with high levels of pedestrian activity during nighttime hours (such as streets with high densities of dining, drinking, and entertainment establishments), may be especially effective.

In addition to ambient light condition, Table 13 displays the frequency of pedestrians injured by weather condition. Nearly three-quarters of pedestrians were injured on clear conditions. Weather condition was not associated with pedestrian injury severity ($p = .49$) (Table 14). Zhai et al. (2019) found a relationship between select weather conditions and pedestrian injury severity, although they examined conditions (e.g. high temperatures) not included in our analyses.

**Table 13: Pedestrians treated at NC emergency departments, by light and weather condition (N=6,923)[1]**

| Environmental condition | Total ED visits, N (%) |
|---|---|
| **Light condition** | |
| Daylight | 3,927 (56.9%) |
| Dawn/Dusk | 333 (4.8%) |
| Dark - lighted | 1,465 (21.2%) |
| Dark – unlighted/unknown | 1,175 (17.0%) |
| **Weather condition** | |
| Clear | 5,293 (76.5%) |
| Overcast | 995 (14.4%) |
| Rain | 549 (7.9%) |
| Freezing precipitation | 42 (0.6%) |
| Other[2] | 44 (0.6%) |
| **Total** | **6,923 (100.0%)** |

Missing: Light condition (N=23).
[1]Column total sums to 100%.
[2]Other includes fog, smog, and smoke, and other weather condition.

**Table 14: Pedestrians treated at NC emergency departments, by light and weather condition and pedestrian injury severity (N=6,923)[1]**

| Environmental condition | Non-serious pedestrian injury, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Light condition** | | | **<.001** |
| Daylight | 2,682 (68.3%) | 1,245 (31.7%) | |
| Dawn/Dusk | 215 (64.6%) | 118 (35.4%) | |
| Dark - lighted | 794 (54.2%) | 671 (45.8%) | |
| Dark – unlighted/unknown | 583 (49.6%) | 592 (50.4%) | |
| **Weather condition** | | | **.49** |
| Clear | 3,301 (62.4%) | 1,992 (37.6%) | |
| Overcast | 611 (61.4%) | 384 (38.6%) | |
| Rain | 321 (58.5%) | 228 (41.5%) | |
| Freezing precipitation | 25 (59.5%) | 17 (40.5%) | |
| Other[2] | 27 (61.4%) | 17 (38.6%) | |
| **Total** | **4,285 (61.9%)** | **2,638 (38.1%)** | |

Missing: Light condition (N=23).
[1]Row totals sum to 100%.
[2]Other includes fog, smog, and smoke, and other weather condition.

## Roadway Characteristics

In addition to collision characteristics, we examined characteristics of the roadway, such as road classification, configuration, and posted speed limit. For this section we limited our analyses to roadway crashes, only (N=4,971).

Table 15 displays frequencies of pedestrian crash injuries by road classification, road configuration, intersection-relatedness, and the number of lanes. Among pedestrians treated in NC EDs following police reported MVCs, most pedestrians were injured on local roads (67%), two-way, undivided roads (73%), non-intersections (60%), and roads with two lanes (57%). Table 16 displays selected road characteristics by pedestrian injury severity. All road characteristics were statistically significant. As compared to other road classifications and configurations, proportions of serious and fatal pedestrian injuries were highest on NC routes (52%) and roads with two-way, divided, unprotected medians (49%). Although many pedestrian injuries may be occurring on roads under local jurisdiction, many of the more serious injuries are occurring on state-maintained roads. Regarding intersection-relatedness, most pedestrians were injured at non-intersection locations (Table 15). In addition, non-intersection collisions were the most severe, with 46% of pedestrians involved in non-intersection-related crashes sustaining serious injuries (Table 16). The increased severity of mid-block collisions is likely related to higher vehicle traveling speeds, as well as other factors. Our observation regarding intersections has been observed in other studies (Rothman et al., 2012; Siddiqui et al., 2006). Serious pedestrian injuries due to midblock crossings can be prevented through lowering speed limits, reducing the number of lanes, and incorporating high-visibility crosswalks at uncontrolled crossing locations, among other treatments (Blackburn et al., 2018).

Figures 20 and 21 display pedestrian injury statistics relating to posted speed limit. Since estimates by police officers may be inaccurate regarding estimated speed at impact, posted speed limit may be a better proxy of actual impact speed than that reported in the crash data. Figure 20 displays the frequency of pedestrians treated in NC EDs by posted speed limit. For comparative purposes, the number of unlinked pedestrian fatalities are also displayed. Most pedestrians who received treatment in the ED were injured on roadways with speeds $\leq$ 35 MPH; however, most serious and fatal injuries, including unlinked fatalities, occurred on roadways with higher posted speed limits. The relationship between posted speed limit and pedestrian injury severity was highly significant ($p$ <.001), with only 25% of pedestrians struck on roads with posted speed limits of 5-15 MPH having serious or fatal injuries, as compared to 50% and 54% of pedestrians struck on roadways with posted speed limits of 40-45 MPH and $\geq$50 MPH, respectively (Figure 21). However, it should be noted that 40% of pedestrians struck on roads with posted speed limits of 30-35 MPH had serious injuries, indicating that 35 MPH may not be a “safe speed” for locations with high numbers of pedestrians. Therefore, in locations in which pedestrians cannot be separated from motor vehicles, adopting lower speed limits could reduce pedestrian morbidity and mortality. This reasoning is consistent with Vision Zero principles, which recommend posted speed limits of $\leq$30 km/h (18.6 MPH) for roadways with high pedestrian and bicycle traffic (E. Kim et al., 2017).

## Table 15: Pedestrians treated at NC emergency departments, by selected roadway characteristic (N=4,971)[1,2]

| Road characteristic | Total ED visits, N (%) |
|---|---|
| **Road classification** | |
| Local street | 3,334 (67.1%) |
| State secondary route | 714 (14.4%) |
| NC route | 348 (7.0%) |
| US route | 347 (7.0%) |
| Other road classification[3] | 228 (4.6%) |
| **Road configuration** | |
| One-way, not divided | 241 (4.9%) |
| Two-way, not divided | 3,589 (72.6%) |
| Two-way, divided unprotected median | 807 (16.3%) |
| Two-way, positive median barrier | 308 (6.2%) |
| **Intersection-related** | |
| Yes | 2,010 (40.5%) |
| No | 2,950 (59.5%) |
| **Number of lanes** | |
| 1 lane | 53 (1.1%) |
| 2 lanes | 2,750 (56.8%) |
| 3 lanes | 374 (7.7%) |
| 4 lanes | 824 (17.0%) |
| 5 lanes | 481 (9.9%) |
| ≥6 lanes | 359 (7.4%) |
| **Total** | **4,971 (100.0%)** |

Abbreviations: US, United States; NC, North Carolina.
Missing: Road configuration (N=26); intersection-related (N=11); number of lanes (N=130).
[1]On roadway injuries, only.
[2]Column total sums to 100%.
[3]Other includes road classifications of interstates, public vehicular areas, and private roads/driveways.

### Table 16: Pedestrians treated at NC emergency departments, by selected roadway characteristic and pedestrian injury severity (N=4,971)[1,2]

| Road characteristic | Non-serious pedestrian injury, N (%) | Serious/Fatal pedestrian injury, N (%) | *p* value |
|---|---|---|---|
| **Road classification** | | | <.001 |
| Local street | 1,959 (58.8%) | 1,375 (41.2%) | |
| State secondary route | 395 (55.3%) | 319 (44.7%) | |
| NC route | 167 (48.0%) | 181 (52.0%) | |
| US route | 181 (52.2%) | 166 (47.8%) | |
| Other road classification[3] | 152 (66.7%) | 76 (33.3%) | |
| **Road configuration** | | | <.001 |
| One-way, not divided | 166 (68.9%) | 75 (31.1%) | |
| Two-way, not divided | 2,098 (58.5%) | 1,491 (41.5%) | |
| Two-way, divided unprotected median | 416 (51.5%) | 391 (48.5%) | |
| Two-way, positive median barrier | 159 (51.6%0 | 149 (48.4%) | |
| **Intersection-related** | | | <.001 |
| Yes | 1,238 (61.6%) | 772 (38.4%) | |
| No | 1,606 (54.4%) | 1,344 (45.6%) | |
| **Number of lanes** | | | <.001 |
| 1 lane | 34 (64.2%) | 19 (35.8%) | |
| 2 lanes | 1,639 (59.6%) | 1,111 (40.4%) | |
| 3 lanes | 219 (58.6%) | 155 (41.4%) | |
| 4 lanes | 442 (53.6%) | 382 (46.4%) | |
| 5 lanes | 243 (50.5%) | 238 (49.5%) | |
| ≥6 lanes | 171 (47.6%) | 188 (52.4%) | |
| **Total** | **2,854 (57.4%)** | **2,117 (42.6%)** | |

Abbreviations: US, United States; NC, North Carolina.
Missing: Road configuration (N=26); intersection-related (N=11); number of lanes (N=130).
[1]On roadway injuries, only.
[2]Row totals sum to 100%.
[3]Other includes road classifications of interstates, public vehicular areas, and private roads/driveways.

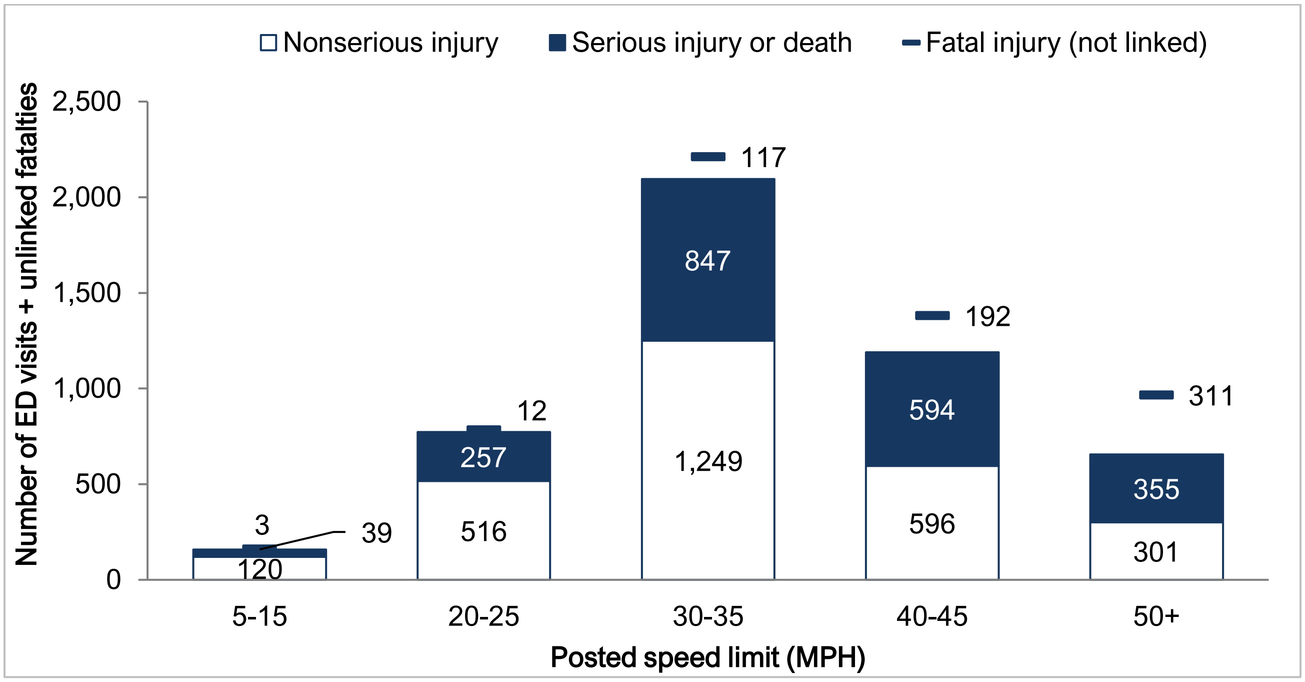


*Figure 20: Number of pedestrians treated at NC emergency departments, by posted speed limit and pedestrian injury severity (N=4,747)[1,2]; number of DOA roadway pedestrian fatalities (unlinked) shown for comparison (N=635)*

Abbreviations: MPH, miles per hour.
Missing: Posted speed limit (N=97).
[1]On roadway injuries, only.
[2]Significant at $p$ <.001.

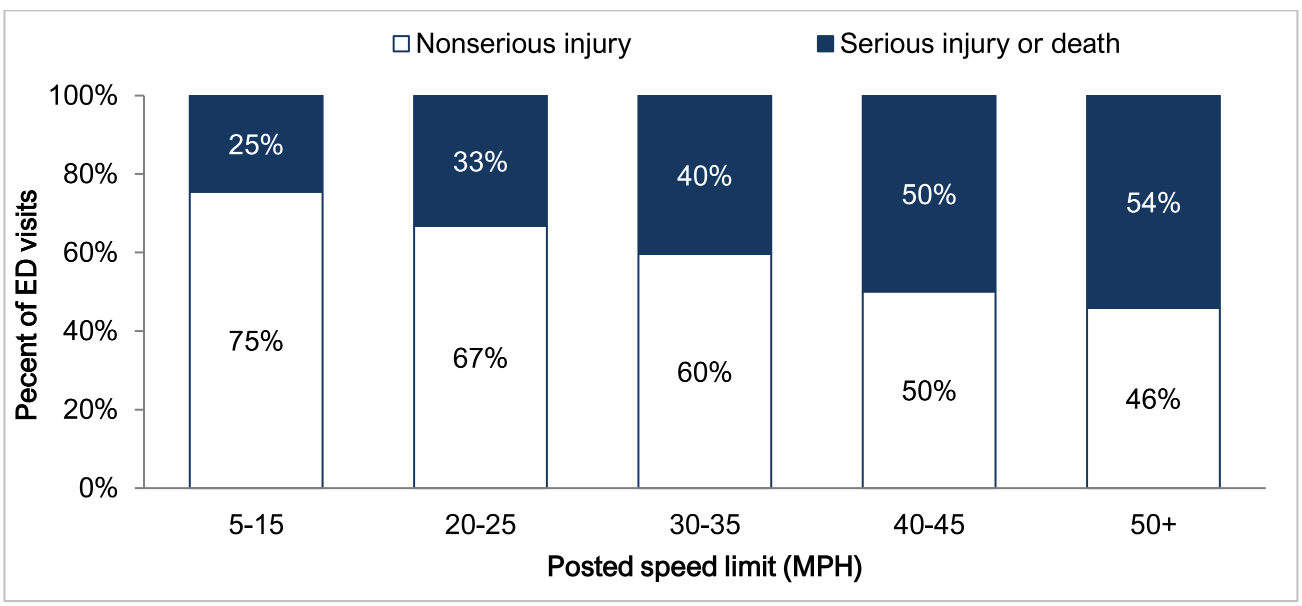


*Figure 21: Frequency of pedestrians treated at NC emergency departments, by posted speed limit and pedestrian injury severity (N=4,747)[1,2]*

Missing: Posted speed limit (N=97).
[1]On roadway injuries, only.
[2]Significant at $p$ <.001.

## Vehicle Characteristics

Both the popular media and the research community have suggested that increasing demand for SUVs, "crossover" SUVs, and pickup trucks, in concert with the increase in these vehicles' size, may be contributing to increasing pedestrian fatality rates in the U.S. (Montfort & Mueller, 2020; Walker, 2018). Therefore, we examined pedestrian injury severity by vehicle type. Figure 22 displays the frequency of pedestrians injured, by vehicle type. During the study period of October 1, 2010 – September 30, 2015, far more pedestrians were struck by passenger cars (N=3,626) than by SUVs (N=1,170) and pickup trucks (N=821) in NC. However, despite passenger vehicles being the most common striking vehicle type, SUVs and pickup trucks were more deadly, with 41% and 43% of these striking vehicle types resulting in serious pedestrian injuries, respectively, as compared to 37% for passenger cars (Figure 23). The relationship between pedestrian injury severity and vehicle type was significant at $p = .025$.

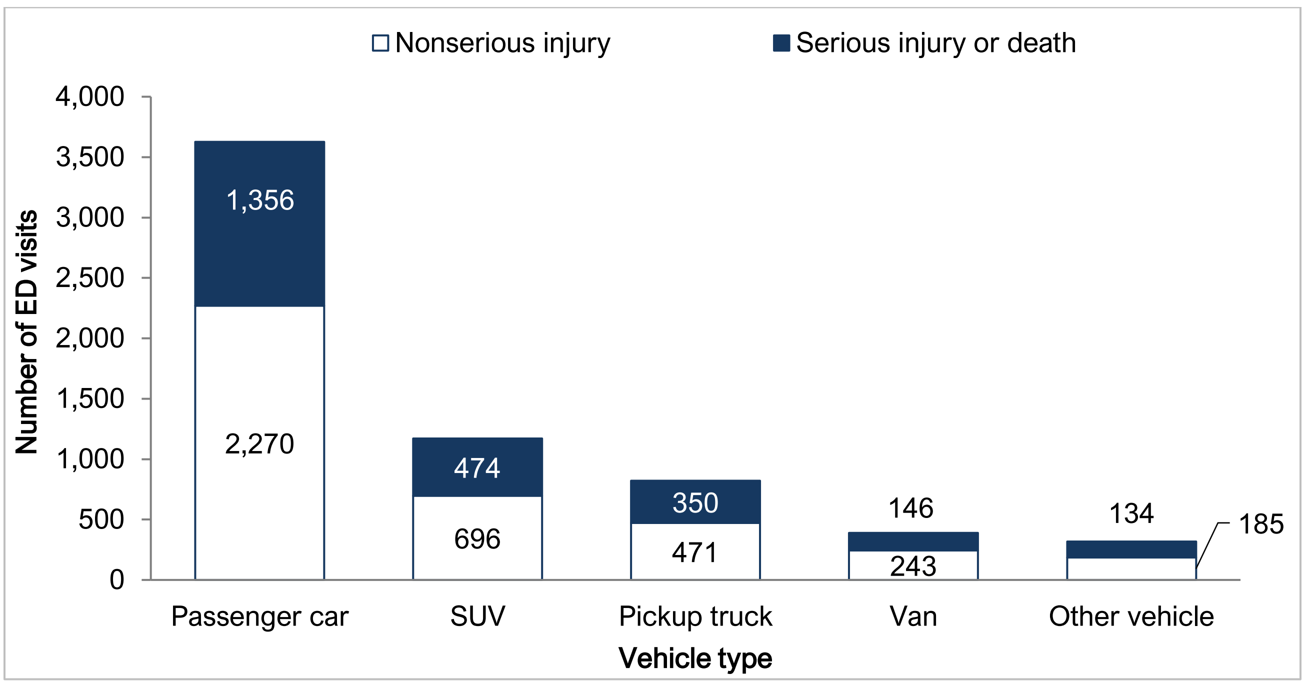


*Figure 22: Number of pedestrians treated at NC emergency departments, by striking vehicle type and pedestrian injury severity (N=6,325)*[1,2]

Abbreviations: SUV, sport utility vehicle.
Missing: Vehicle type (N=598).
[1]Other vehicle contains light trucks, heavy trucks, buses, emergency response vehicles, motorcycles, mopeds, recreational vehicles, and taxicabs.
[2]Significant at $p = .025$.

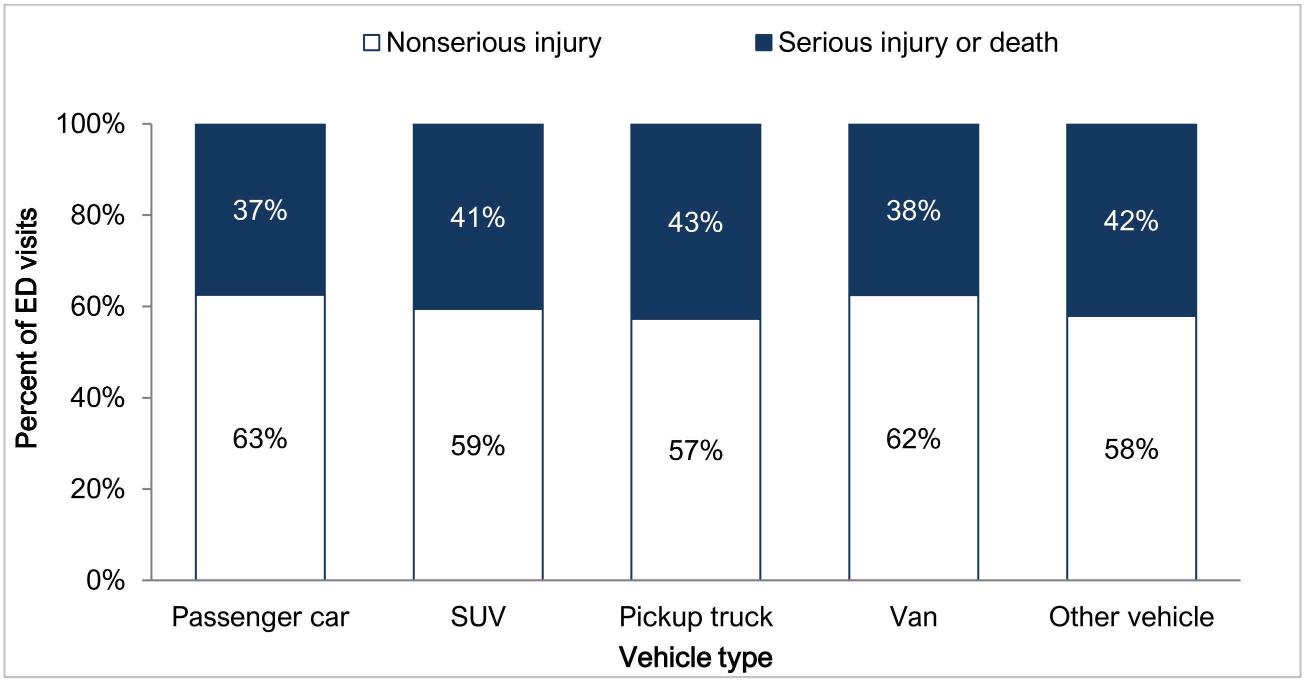


*Figure 23: Frequency of pedestrians treated at NC emergency departments, by striking vehicle type and pedestrian injury severity (N=6,325)*[1,2]

Abbreviations: SUV, sport utility vehicle.
Missing: Vehicle type (N=598).
[1]Other vehicle includes light trucks, heavy trucks, buses, emergency response vehicles, motorcycles, mopeds, recreational vehicles, and taxicabs.
[2]Significant at *p* value = .025.

# Multivariate Modelling of Factors Associated with Severe/Fatal Injuries Among Pedestrians

The following section describes predictors of pedestrian injury severity. Since we hypothesized that roadway and non-roadway pedestrian MVCs would have different predictors, we built separate models for the two groups.

First, we identified variables that we anticipated would be a) significant predictors of pedestrian injury severity and/or b) would contribute to model fit, based on the descriptive analyses performed in the preceding section. Therefore, descriptors identified as being highly insignificant, such as weather conditions at time of crash, were omitted.

Second, we performed a bivariate analysis with pedestrian injury severity as the outcome of interest using logistic regression to calculate unadjusted odds ratios (ORs) and 95% confidence intervals (CIs). If necessary, we recategorized variables to a) improve model fit and/or b) to ensure that all cells contained robust cell counts. Reference values were selected based on standard-of-practice, the project team's expertise, and cell size (in that order). The results of the bivariate analyses are displayed in Tables 17 (pedestrian MVCs on roadways) and 19 (pedestrian MVCs on non-roadways).

Third, we built a parsimonious, predictive model based on the results of the bivariate analyses. For model building, we used a backwards elimination technique. For inclusion in the initial, fully saturated model, the potential predictor had to have a Wald $p$ value of $\leq .25$. All potential predictors were assessed for multicollinearity; there was no multicollinearity detected. Variables were then removed one-by-one from the model starting with the least significant variable. A variable was deleted from the model if it had a $p$ value of $\leq .1$ and if removal resulted in an improved model fit, as indicated by a reduced Akaike Information Criterion (AIC). For the final predictive model, logistic regression was used to produce adjusted ORs and 95% CIs. The results of the multivariate analyses are displayed in Tables 18 (pedestrian MVCs on roadways) and 20 (pedestrian MVCs on non-roadways). The probability (P) of a serious or fatal pedestrian injury (Y) is given by:

$$Y = logit(P) = \propto + \beta_1 + \beta_2 + \beta_3 \ldots$$

## Multivariate Analysis - Roadway Collisions

Table 18 displays the results of the bivariate analysis for the relationship between selected characteristics and pedestrian injury severity, among pedestrian roadway crashes. During the model building phase, the variables year, season, weekend/weekday, locality, and vehicle type were removed from the final model. The variables driver impairment and road configuration had Wald *p* values of > .1, but their removal decreased model fit; therefore, these variables were retained in the final model.

**Table 17: Unadjusted ORs and 95% CIs of potential predictors of serious injury among pedestrians treated in NC emergency departments pedestrians injured on roadways, only (N=4,971)**

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| **Year (reference = Oct. 2010 - Sept. 2011)** | | | |
| Oct. 2011 - Sept. 2012 | 0.96 | 0.81-1.15 | .69 |
| Oct. 2012 - Sept. 2013 | 0.95 | 0.79-1.13 | .56 |
| Oct. 2013 - Sept. 2014 | 0.80 | 0.67-0.96 | .02 |
| Oct. 2014 - Sept. 2015 | 1.02 | 0.86-1.22 | .80 |
| **Season (reference = Jan. - Mar.)** | | | |
| Apr. - Jun. | 0.90 | 0.77-1.07 | .23 |
| Jul. - Sept. | 0.93 | 0.79-1.10 | .39 |
| Oct. - Dec. | 1.03 | 0.89-1.20 | .68 |
| **Day of week (reference = weekday)** | **1.26** | **1.12-1.42** | **<.001** |
| **Hour of day (reference = 16:00-19:59)** | | | |
| 0:00-3:59 | 1.34 | 1.06-1.70 | .02 |
| 4:00-7:59 | 1.05 | 0.85-1.29 | .67 |
| 8:00-11:59 | 0.60 | 0.49-0.73 | <.001 |
| 12:00-15:59 | 0.66 | 0.56-0.79 | <.001 |
| 20:00-23:59 | 1.35 | 1.15-1.57 | <.001 |
| **Gender of pedestrian (reference = female)** | **1.49** | **1.33-1.68** | **<.001** |
| **Age of pedestrian (reference = 25-34)** | | | |
| 0-4 | 1.17 | 0.73-1.86 | .52 |
| 5-9 | 1.06 | 0.77-1.46 | .73 |
| 10-14 | 0.95 | 0.74-1.23 | .72 |
| 15-19 | 1.06 | 0.86-1.31 | .56 |
| 20-24 | 0.79 | 0.64-0.98 | .03 |
| 35-44 | 0.85 | 0.70-1.05 | .13 |
| 45-54 | 1.31 | 1.07-1.59 | .008 |
| 55-64 | 1.19 | 0.96-1.49 | .11 |
| 65-74 | 1.92 | 1.41-2.60 | <.001 |
| 75+ | 2.46 | 1.56-3.89 | <.001 |
| **Race/Hispanic ethnicity of pedestrian (reference = white, not Hispanic/Latinx)** | | | |
| Black, not Hispanic/Latinx | 0.65 | 0.57-0.73 | <.001 |

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| Hispanic/Latinx | 0.85 | 0.66-1.10 | .22 |
| Other race[1] | 0.90 | 0.66-1.24 | .53 |
| **Expected source of payment (reference = insurance company)** | | | |
| Self-pay | 0.86 | 0.73-1.00 | .06 |
| Medicaid | 0.97 | 0.82-1.15 | .76 |
| Medicare | 1.27 | 0.99-1.63 | .06 |
| Workers' compensation | 0.67 | 0.47-0.97 | .04 |
| Other source of payment[2] | 0.83 | 0.68-1.01 | .06 |
| **Pedestrian comorbidities (reference = none)** | **1.50** | **1.33-1.70** | **<.001** |
| **Suspected pedestrian alcohol use (reference = no)** | **3.18** | **2.49-4.06** | **<.001** |
| **Gender of striking driver (reference = female)** | **1.24** | **1.10-1.41** | **.001** |
| **Age of striking driver (reference = 25-44)** | | | |
| 15-24 | 1.07 | 0.91-1.27 | .41 |
| 45-64 | 0.99 | 0.85-1.15 | .87 |
| 65+ | 0.73 | 0.60-0.89 | .002 |
| **Suspected striking driver alcohol use (reference = no)** | **1.51** | **1.10-2.06** | **.01** |
| **Crash locality (reference = urban)** | | | |
| Suburban/Mixed development | 1.12 | 0.95-1.31 | .19 |
| Rural | 1.25 | 1.07-1.47 | .005 |
| **Light condition (reference = daylight)** | | | |
| Dawn/Dusk | 1.18 | 0.91-1.54 | .22 |
| Dark - lighted or unlighted | 1.94 | 1.73-2.19 | <.001 |
| **Crash occurred at/near intersection (reference = no)** | **0.75** | **0.66-0.84** | **<.001** |
| **Road configuration (reference = two-way, not divided)** | | | |
| One-way, not divided | 0.64 | 0.48-0.84 | .002 |
| Two-way, divided, positive median barrier | 1.32 | 1.04-1.66 | .02 |
| Two-way, divided, unprotected median | 1.32 | 1.13-1.54 | <.001 |
| **Road classification (reference = local street)** | | | |
| State secondary route | 1.15 | 0.98-1.35 | .09 |
| NC route | 1.54 | 1.24-1.93 | <.001 |
| US route | 1.31 | 1.05-1.63 | .02 |
| Other road classification[3] | 0.71 | 0.54-0.95 | .02 |
| **Number of lanes (reference = 2 lanes)** | | | |
| 1 lane | 0.85 | 0.48-1.50 | .57 |
| 3-4 lanes | 1.23 | 1.08-1.41 | .003 |
| >4 lanes | 1.56 | 1.34-1.82 | <.001 |
| **Posted speed limit (reference = 5-25 MPH)** | | | |
| 30-45 MPH | 1.68 | 1.44-1.96 | <.001 |
| ≥50 MPH | 2.53 | 2.06-3.11 | <.001 |
| **Estimated driver speed at impact (reference = ≤35 MPH)** | **2.18** | **1.92-2.49** | **<.001** |
| **Striking vehicle type (reference = passenger car)** | | | |
| SUV | 1.12 | 0.95-1.31 | .18 |
| Pickup truck | 1.07 | 0.89-1.28 | .48 |
| Van | 0.98 | 0.76-1.27 | .90 |
| Other vehicle[4] | 1.02 | 0.78-1.34 | .87 |

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| **Pedestrian crash type (reference = crossing roadway - motorist traveling straight)** | | | |
| Backing | 0.30 | 0.19-0.46 | <.001 |
| Motorist turning left-related crashes | 0.42 | 0.34-0.52 | <.001 |
| Motorist turning right/unknown-related crashes | 0.19 | 0.14-0.24 | <.001 |
| Walking along roadway with traffic (or unknown) | 0.47 | 0.39-0.57 | <.001 |
| Walking along roadway against traffic | 0.45 | 0.33-0.62 | <.001 |
| Standing/walking/lying in roadway | 0.76 | 0.62-0.93 | <.001 |
| Other crash type[5] | 0.56 | 0.48-0.66 | <.001 |

[1]Other race contains “American Indian/Native American”, “Asian” and “other race”.
[2]Other source of payment contains "no charge", "other type of government payment", and "other payment type".
[3]Other vehicle contains light trucks, heavy trucks, buses, emergency response vehicles, motorcycles, mopeds, recreational vehicles, and taxicabs.
[4]Other road classification contains interstates, public vehicular areas, and private roads/driveways.
[5]Other crash type contains all other crash types, please see the Pedestrian and Bicycle Crash Analysis Tool Manual for a full description.

The final, parsimonious predictive model contained crash hour-of-day ($p$ = .03), pedestrian gender ($p$ = .001), pedestrian age group ($p$ = .001), race/Hispanic ethnicity of the pedestrian ($p$ < .001), expected source of payment ($p$ = .06), pedestrian comorbidity ($p$ = .03), suspected pedestrian alcohol use ($p$ <.001), driver gender ($p$ = .06), driver age group ($p$ = .05), suspected driver alcohol use ($p$ = .31), light condition ($p$ = .001), intersection-relatedness ($p$ = .04), road configuration ($p$ = .11) road classification ($p$ = .009), number of lanes ($p$ = .06), posted speed limit ($p$ = .03), estimated driver speed at impact ($p$ < .001), and pedestrian crash type ($p$ < .001). The beta coefficients and standard errors are displayed below in Table 18.

### Table 18: Beta coefficients and standard errors for predictive model (roadway crashes, N=4,971)

| Predictor | Beta coefficient | Standard Error |
|---|---|---|
| Intercept | -0.182 | 0.194 |
| Crash hour: 0:00-3:59 | 0.023 | 0.193 |
| Crash hour: 4:00-7:59 | 0.281 | 0.137 |
| Crash hour: 8:00-11:59 | -0.250 | 0.137 |
| Crash hour: 12:00-3:49 | -0.234 | 0.121 |
| Crash hour: 20:00-23:59 | -0.013 | 0.118 |
| Gender: Male | 0.270 | 0.079 |
| Age group: 0-4 | 0.197 | 0.300 |
| Age group: 5-9 | -0.120 | 0.208 |
| Age group: 10-14 | -0.059 | 0.175 |
| Age group: 15-19 | 0.082 | 0.144 |
| Age group: 20-24 | -0.230 | 0.142 |

| Predictor | Beta coefficient | Standard Error |
|---|---|---|
| Age group: 35-44 | -0.307 | 0.139 |
| Age group: 45-54 | 0.015 | 0.148 |
| Age group: 55-64 | -0.097 | 0.191 |
| Age group: 65-74 | 0.595 | 0.245 |
| Age group: 75+ | 0.963 | 0.325 |
| Race: Black | -0.475 | 0.083 |
| Race: Hispanic/Latinx | -0.338 | 0.169 |
| Race: Other | -0.163 | 0.205 |
| Pedestrian alcohol: Yes | 0.852 | 0.173 |
| Comorbidity: Yes | 0.292 | 0.131 |
| Payment: Self-pay | -0.178 | 0.103 |
| Payment: Medicaid | 0.068 | 0.115 |
| Payment: Medicare | -0.111 | 0.172 |
| Payment: WC | -0.386 | 0.228 |
| Payment: Other | -0.258 | 0.123 |
| Driver Gender: Male | 0.144 | 0.075 |
| Driver age: 15-24 | 0.052 | 0.104 |
| Driver age: 45-64 | 0.075 | 0.091 |
| Driver age: 65+ | -0.265 | 0.124 |
| Driver alcohol: Yes | 0.187 | 0.186 |
| Intersection: Yes | -0.178 | 0.088 |
| Light: Dawn/Dusk | 0.023 | 0.179 |
| Light: Dark | 0.400 | 0.116 |
| Lanes: 1 | 0.493 | 0.459 |
| Lanes: 3-4 | 0.181 | 0.105 |
| Lanes: >4 | 0.305 | 0.120 |
| Configuration: One-way | -0.341 | 0.211 |
| Configuration: Two-way, divided, positive median barrier | -0.211 | 0.171 |
| Configuration: Two-way, divided, unprotected median | 0.108 | 0.111 |
| Road: Secondary route | -0.288 | 0.131 |
| Road: NC route | -0.079 | 0.161 |
| Road: US route | -0.489 | 0.154 |
| Road: Other | -0.396 | 0.247 |
| Speed limit: 30-45 MPH | 0.190 | 0.108 |
| Speed limit: 50+ MPH | 0.450 | 0.167 |
| Speed: >35 MPH | 0.580 | 0.106 |
| Crash type: Backing | -0.937 | 0.286 |
| Crash type: Motorist turning left | -0.691 | 0.141 |
| Crash type: Motorist turning right/unk | -1.359 | 0.179 |
| Crash type: Walking along roadway w/ traffic/unk | -0.534 | 0.112 |
| Crash type: Walking along roadway against traffic | -0.525 | 0.141 |
| Crash type: In roadway | -1.004 | 0.242 |
| Crash type: Other | -0.998 | 0.147 |

Abbreviations: WC, workers' compensation; unk, unknown

Table 19 displays the results of the multivariate analysis. After adjustment, crash hour-of-day was statistically significant ($p$ = .03). As compared to the reference period of 16:00-19:59 (the period with the greatest number of injured pedestrians), pedestrians injured during the morning hours of 4:00-7:59 were 1.3 times as likely to be diagnosed with serious injuries. Although not statistically significant, pedestrians injured during the mid-morning (8:00-11:59) and early afternoon hours (12:00-15:59) were less likely to have serious injuries.

The demographic characteristics of gender ($p$ = .001), age ($p$ = .001), and race/ethnicity ($p$ < .001) were all significant predictors of pedestrian injury severity, with men and older adults having a greater likelihood of sustaining serious injuries than women and younger adults, respectively. Older adults 65-74 years and $\geq$75 years were 1.8 and 2.6 times as likely to suffer serious injuries, as compared to adults 25-34 years-of-age, even after adjusting for covariates, such as the presence of comorbidities. Adults 35-44 years-of-age were 26% less likely to sustain serious injuries than the reference group. Race/ethnicity were also significantly associated with pedestrian severity ($p$ < .001), with Black and Hispanic/Latinx pedestrians being less likely to have serious injuries than white pedestrians. The explanation for this finding is unclear, but may be related to differential healthcare utilization patterns, with Black patients being more like to use the ED for routine care what whites (L. E. Brown et al., 2012). In addition, it is also possible that injury severity may not be accurately assessed and documented for Black/Brown pedestrians. The literature suggests that systemic racism is deeply entrenched in the medical establishment (Gao et al., 2018). For example, studies have shown that physicians routinely underdiagnosis and undertreat pain of Black patients (Hoffman et al., 2016).

In the multivariate model, pedestrians with documented comorbidities, such as chronic diseases and mental health conditions, were 1.3 times as likely to be treated in the ED for a serious or fatal injury. Pedestrians suspected of being under the influence of alcohol were also much more likely to be seriously injured. Among roadway collisions, suspected pedestrian alcohol use was one of the strongest predictors of injury severity (p < .001). However, it should be noted that the variables pedestrian comorbidity and suspected pedestrian alcohol use may have data quality issues. Pedestrian comorbidities are not always well-documented in the ED patient record, especially if the patient is unwilling or unable to provide information about their health history. Police reported suspected alcohol use is also often underreported for pedestrians. However, despite these limitations, the strong relationship between suspected alcohol use and injury severity highlights the need for improved safety measures in strategic locations with high alcohol outlet densities and in locations with large populations of pedestrians with comorbidities as well as older adult pedestrians (hospitals, healthcare pavilions, and assisted living communities). Interventions such as lower posted speed limits and/or the partial or full separation of pedestrians from motor vehicles, through such initiatives as "Shared Streets" in these locations may help to curtail serious injuries in these two populations.

Regarding striking driver characteristics, driver gender and suspected driver impairment were not statistically significant after adjusting for the other variables in the model (although both variables were retained in the model to improve predictive ability). Driver age group was significant ($p$ = .05), with older drivers being 23% less likely to be involved in a MVC resulting in a serious pedestrian injury, as compared to drivers 25-44 years-of-age.

Certain environmental, crash, and roadway characteristics were also identified as being statistically significant predictors of pedestrian crash injury severity among pedestrians treated in NC EDs. After adjustment, light condition was a significant predictor of pedestrian crash injury severity ($p$ =.001), with pedestrians being nearly 50% more likely to suffer a serious or fatal injury under dark conditions, as compared to daylight conditions. Estimated speed at impact and posted speed limit were also both statistically significant predictors of pedestrian injury severity, with higher impact speeds and speed limits being associated with greater injury severities, after adjustment. Estimated impact speed demonstrated the stronger association with pedestrian injury severity, out of the two metrics, with pedestrians being struck at $\geq$35 MPH being 79% more likely to be diagnosed with a serious injury. Intersection-relatedness was also significant ($p$ = .04), with pedestrians injured at intersections being less likely to be seriously injured. While number of lanes was not statistically significant ($p$ = .06), pedestrians injured on roadways with four or more lanes were more likely to be seriously injured than pedestrians involved in MVCs on roadways with two lanes.

Another statistically significant predictor was road classification ($p = .009$). As compared to local roads, state secondary routes and U.S. routes were less likely to be associated with serious pedestrian injuries than local roads. The explanation for this relationship is unclear. Since local roads tend to have lower posted speed limits than other types of roadways, we expected to find that all other roadway classifications would have similar or stronger associations with pedestrian injury severity. It could be that "survivor bias" (only pedestrians who survive long enough to receive treatment are captured in the linked crash-ED visit data) may be contributing to the observed relationship between road classification and pedestrian injury severity. Another explanation for the seemingly contradictory results could be that the road classifications captured in the crash data are not meaningful. It may be useful to incorporate better roadway information, such as the data collected by the Highway Safety Information System, in future research.

Finally, we found that pedestrian crash type was a strong predictor of pedestrian crash injury severity after adjusting for all other identified predictors ($p < .001$). To ensure adequate cell counts, we combined multiple pedestrian crash types. We made pedestrian crossing the roadway struck by a driver traveling straight the reference category, because it contained the largest number of observations. As compared to the reference category, all pedestrian crash types were associated with lower frequencies of serious pedestrian injuries. For example, pedestrians struck while walking along the roadway with traffic were 63% less likely to have a serious injury than pedestrians crossing the roadway with the driver traveling straight.

**Table 19: Adjusted ORs and 95% CIs of potential predictors of serious injury among pedestrians treated in NC emergency departments, pedestrians injured on roadways, only (N=4,971)**

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| **Hour of day (reference = 16:00-19:59)** | | | |
| 0:00-3:59 | 1.02 | 0.70-1.49 | .90 |
| 4:00-7:59 | 1.32 | 1.01-1.73 | .04 |
| 8:00-11:59 | 0.78 | 0.60-1.02 | .07 |
| 12:00-15:59 | 0.79 | 0.62-1.00 | .05 |
| 20:00-23:59 | 0.99 | 0.78-1.25 | .91 |
| **Gender of patient (reference = female)** | **1.31** | **1.12-1.53** | **.001** |
| **Age of patient (reference = 25-34)** | | | |
| 0-4 | 1.22 | 0.68-2.19 | .51 |
| 5-9 | 0.89 | 0.59-1.33 | .56 |
| 10-14 | 0.94 | 0.67-1.33 | .73 |
| 15-19 | 1.09 | 0.82-1.44 | .57 |
| 20-24 | 0.80 | 0.60-1.05 | .11 |
| 35-44 | 0.74 | 0.56-0.97 | .03 |
| 45-54 | 1.02 | 0.76-1.36 | .92 |
| 55-64 | 0.91 | 0.62-1.32 | .61 |
| 65-74 | 1.81 | 1.12-2.93 | .02 |
| 75+ | 2.62 | 1.38-4.96 | .003 |
| **Race/Hispanic ethnicity of patient (reference = white, not Hispanic/Latinx)** | | | |
| Black, not Hispanic/Latinx | 0.62 | 0.53-0.73 | <.001 |
| Hispanic/Latinx | 0.71 | 0.51-0.99 | .05 |
| Other race[1] | 0.85 | 0.57-1.27 | .43 |
| **Expected source of payment (reference = insurance company)** | | | |
| Self-pay | 0.84 | 0.68-1.03 | .08 |
| Medicaid | 1.07 | 0.86-1.34 | .55 |
| Medicare | 0.90 | 0.64-1.25 | .52 |
| Workers' Compensation | 0.68 | 0.43-1.06 | .09 |
| Other source of payment[2] | 0.77 | 0.61-0.98 | .04 |
| **Pedestrian comorbidities (reference = none)** | **1.34** | **1.04-1.73** | **.03** |
| **Suspected pedestrian alcohol use (reference = no)** | **2.34** | **1.67-3.29** | **<.001** |
| **Gender of striking driver (reference = female)** | **1.16** | **1.00-1.34** | **.06** |
| **Age of striking driver (reference = 25-44)** | | | |
| 15-24 | 1.05 | 0.86-1.29 | .62 |
| 45-64 | 1.08 | 0.90-1.29 | .41 |
| 65+ | 0.77 | 0.60-0.98 | .03 |
| **Suspected striking driver alcohol use (reference = no)** | **1.21** | **0.84-1.74** | **.31** |
| **Light condition (reference = daylight)** | | | |
| Dawn/Dusk | 1.02 | 0.72-1.45 | .90 |
| Dark - lighted or unlighted | 1.49 | 1.19-1.87 | .001 |
| **Crash occurred at/near intersection (reference = no)** | **0.84** | **0.70-0.99** | **.04** |

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| **Road configuration (reference = two-way, not divided)** | | | |
| One-way, not divided | 0.71 | 0.47-1.08 | .11 |
| Two-way, divided, positive median barrier | 0.81 | 0.58-1.13 | .22 |
| Two-way, divided, unprotected median | 1.12 | 0.90-1.39 | .33 |
| **Road classification (reference = local street)** | | | |
| State secondary route | 0.75 | 0.58-0.97 | .03 |
| NC route | 0.92 | 0.68-1.27 | .62 |
| US route | 0.61 | 0.45-0.83 | .002 |
| Other road classification[3] | 0.67 | 0.42-1.09 | .11 |
| **Number of lanes (reference = 2 lanes)** | | | |
| 1 lane | 1.64 | 0.67-4.02 | .28 |
| 3-4 lanes | 1.20 | 0.98-1.47 | .08 |
| >4 lanes | 1.36 | 1.07-1.72 | .01 |
| **Posted speed limit (reference = 5-25 MPH)** | | | |
| 30-45 MPH | 1.21 | 0.98-1.50 | .08 |
| ≥50 MPH | 1.57 | 1.13-2.18 | .01 |
| **Estimated driver speed at impact (reference = ≤35 MPH)** | **1.79** | **1.45-2.20** | **<.001** |
| **Pedestrian crash type (reference = crossing roadway - motorist traveling straight)** | | | |
| Backing | 0.39 | 0.22-0.69 | .001 |
| Motorist turning left-related crashes | 0.50 | 0.38-0.66 | <.001 |
| Motorist turning right/unknown-related crashes | 0.26 | 0.18-0.37 | <.001 |
| Walking along roadway with traffic (or unknown) | 0.37 | 0.28-0.49 | <.001 |
| Walking along roadway against traffic | 0.37 | 0.23-0.59 | <.001 |
| Standing/walking/lying in roadway | 0.59 | 0.45-0.78 | <.001 |
| Other crash type[4] | 0.59 | 0.47-0.73 | <.001 |

AIC: full model = 4,358.6; reduced model = 4,348.6.
[1]Other race contains “American Indian/Native American”, “Asian” and “other race”.
[2]Other source of payment contains "no charge", "other type of government payment", and "other payment type".
[3]Other road classification contains interstates, public vehicular areas, and private roads/driveways.
[4]Other crash type contains all other crash types, please see the Pedestrian and Bicycle Crash Analysis Tool Manual for a full description.

## Multivariate Analysis – Non-roadway Collisions

Table 20 displays the results of the bivariate analysis examining the relationship between selected characteristics and pedestrian injury severity, among pedestrians injured in non-roadway crashes. We examined fewer variables than for pedestrian roadway crashes, because not all variables were relevant to a non-roadway environment (e.g., road configuration). During the model building phase, the variables year, season, weekend/weekday, locality, pedestrian comorbidity, driver gender, and pedestrian crash type were removed from the final model. The variables driver impairment and light condition had Wald *p* values of >.1, but their removal decreased model fit; therefore, these variables were retained in the final model.

**Table 20: Unadjusted odds ratios (ORs) and 95% confidence intervals (CIs) of potential predictors of serious injury among pedestrians treated in NC emergency departments, pedestrians injured on non-roadways, only (N=1,952)**

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| Year (reference = Oct. 2010 - Sept. 2011) | | | |
| Oct. 2011 - Sept. 2012 | 0.85 | 0.62-1.16 | .29 |
| Oct. 2012 - Sept. 2013 | 0.90 | 0.65-1.23 | .50 |
| Oct. 2013 - Sept. 2014 | 0.87 | 0.63-1.20 | .39 |
| Oct. 2014 - Sept. 2015 | 0.80 | 0.58-1.10 | .17 |
| Season (reference = Jan. - Mar.) | | | |
| Apr. - Jun. | 1.53 | 1.15-2.05 | .004 |
| Jul. - Sept. | 1.17 | 0.87-1.59 | .30 |
| Oct. - Dec. | 1.18 | 0.88-1.59 | .26 |
| Day of week (reference = weekday) | 1.07 | 0.87-1.33 | .52 |
| Hour of day (reference = 16:00-19:59) | | | |
| 0:00-3:59 | 1.65 | 1.07-2.55 | .02 |
| 4:00-7:59 | 1.58 | 1.03-2.42 | .04 |
| 8:00-11:59 | 1.11 | 0.82-1.52 | .49 |
| 12:00-15:59 | 0.86 | 0.66-1.13 | .29 |
| 20:00-23:59 | 1.26 | 0.89-1.77 | .19 |
| Gender of patient (reference = female) | 1.43 | 1.17-1.74 | .001 |
| Age of patient (reference = 25-34) | | | |
| 0-4 | 3.22 | 1.89-5.46 | <.001 |
| 5-9 | 2.81 | 1.57-5.03 | .001 |
| 10-14 | 0.58 | 0.24-1.43 | .24 |
| 15-19 | 1.01 | 0.61-1.66 | .97 |
| 20-24 | 1.08 | 0.70-1.67 | .72 |
| 35-44 | 1.07 | 0.74-1.56 | .72 |
| 45-54 | 1.05 | 0.72-1.52 | .81 |
| 55-64 | 1.15 | 0.79-1.70 | .46 |
| 65-74 | 2.01 | 1.33-3.04 | .001 |
| 75+ | 3.16 | 2.04-4.89 | <.001 |
| Race/Hispanic ethnicity of patient (reference = white, not Hispanic/Latinx) | | | |
| Black, not Hispanic/Latinx | 0.46 | 0.37-0.58 | <.001 |
| Hispanic/Latinx | 1.03 | 0.67-1.60 | .89 |
| Other race[1] | 0.94 | 0.54-1.62 | .82 |
| Expected source of payment (reference = insurance company) | | | |
| Self-pay | 0.70 | 0.53-0.93 | .01 |
| Medicaid | 1.09 | 0.79-1.50 | .61 |
| Medicare | 1.21 | 0.85-1.72 | .29 |
| Workers' compensation | 1.37 | 0.87-2.15 | .17 |

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| Other source of payment[2] | 0.62 | 0.43-0.89 | .01 |
| **Pedestrian comorbidities (reference = none)** | **1.38** | **1.13-1.69** | **.002** |
| **Suspected pedestrian alcohol use (reference = no)** | **3.24** | **1.79-5.88** | **<.001** |
| **Gender of striking driver (reference = female)** | **1.13** | **0.91-1.40** | **.26** |
| **Age of striking driver (reference = 25-44)** | | | |
| 15-24 | 1.17 | 0.87-1.58 | .29 |
| 45-64 | 0.88 | 0.66-1.17 | .38 |
| 65+ | 0.97 | 0.71-1.32 | .84 |
| **Suspected striking driver alcohol use (reference = no)** | **1.47** | **0.86-2.49** | **.16** |
| **Crash locality (reference = urban)** | | | |
| Suburban/Mixed development | 1.28 | 0.96-1.72 | .09 |
| Rural | 1.67 | 1.15-2.42 | .007 |
| **Light condition (reference = daylight)** | | | |
| Dawn/Dusk | 0.89 | 0.52-1.54 | .69 |
| Dark - lighted or unlighted | 1.31 | 1.04-1.66 | .02 |
| **Estimated driver speed at impact (reference = ≤35 MPH)** | **2.18** | **0.99-4.85** | **.05** |
| **Striking vehicle type (reference = passenger car)** | | | |
| SUV | 1.44 | 1.10-1.87 | .007 |
| Pickup truck | 2.08 | 1.55-2.80 | <.001 |
| Van | 1.20 | 0.77-1.85 | 0.42 |
| Other vehicle[3] | 2.02 | 1.26-3.25 | .004 |
| **Pedestrian crash type (reference = backing)** | | | |
| Parking lot-related crash (not backing) | 0.97 | 0.76-1.23 | .78 |
| Motor vehicle loss of control | 1.54 | 1.01-2.35 | <.001 |
| Other crash type[4] | 1.45 | 1.10-1.91 | .009 |

[1]Other race contains “American Indian/Native American”, “Asian” and “other race”.
[2]Other source of payment contains "no charge", "other type of government payment", and "other payment type".
[3]Other vehicle contains light trucks, heavy trucks, buses, emergency response vehicles, motorcycles, mopeds, recreational vehicles, and taxicabs.
[4]Other crash type contains all other crash types, please see the Pedestrian and Bicycle Crash Analysis Tool Manual for a full description.

The final predictive model contained crash hour-of-day ($p = .04$), pedestrian gender ($p = .004$), pedestrian age group ($p < .001$), race/Hispanic ethnicity of the pedestrian ($p <.001$), expected source of payment ($p =.08$), suspected pedestrian alcohol use ($p = .01$), driver age group ($p = .08$), suspected driver impairment ($p = .79$), light condition ($p = .32$), estimated driver speed at impact ($p = .07$), and vehicle type ( $p = .006$). The beta coefficients and standard errors are displayed below in Table 21.

**Table 21: Beta coefficients and standard errors for predictive model (non-roadway crashes, N=1,952)**

| Predictor | Estimate | Standard Error |
|---|---|---|
| Intercept | -1.628 | 0.291 |
| Crash hour: 0:00-3:59 | 0.448 | 0.375 |
| Crash hour: 4:00-7:59 | 0.593 | 0.284 |
| Crash hour: 8:00-11:59 | 0.144 | 0.209 |
| Crash hour: 12:00-3:49 | -0.272 | 0.184 |
| Crash hour: 20:00-23:59 | 0.228 | 0.269 |
| Gender: Male | 0.384 | 0.133 |
| Age group: 0-4 | 1.485 | 0.350 |
| Age group: 5-9 | 1.351 | 0.363 |
| Age group: 10-14 | -0.310 | 0.535 |
| Age group: 15-19 | -0.018 | 0.341 |
| Age group: 20-24 | 0.615 | 0.295 |
| Age group: 35-44 | 0.284 | 0.252 |
| Age group: 45-54 | -0.015 | 0.256 |
| Age group: 55-64 | 0.398 | 0.256 |
| Age group: 65-74 | 1.025 | 0.288 |
| Age group: 75+ | 1.336 | 0.309 |
| Race: Black | -0.747 | 0.150 |
| Race: Hispanic/Latinx | 0.089 | 0.287 |
| Race: Other | -0.442 | 0.372 |
| Pedestrian alcohol: Yes | 1.139 | 0.443 |
| Payment: Self-pay | -0.253 | 0.184 |
| Payment: Medicaid | 0.059 | 0.229 |
| Payment: Medicare | 0.010 | 0.238 |
| Payment: WC | 0.275 | 0.281 |
| Payment: Other | -0.516 | 0.230 |
| Driver age: 15-24 | 0.401 | 0.188 |
| Driver age: 45-64 | -0.092 | 0.173 |
| Driver age: 65+ | -0.018 | 0.196 |
| Driver alcohol: Yes | -0.092 | 0.351 |
| Light: Dawn/Dusk | -0.357 | 0.359 |
| Light: Dark | 0.187 | 0.236 |
| Speed: >35 MPH | 0.867 | 0.474 |
| Vehicle: SUV | 0.346 | 0.167 |
| Vehicle: Pickup truck | 0.677 | 0.190 |
| Vehicle: Van | 0.310 | 0.272 |
| Vehicle: Other | 0.424 | 0.316 |

Abbreviations: WC, workers' compensation; SUV, sport utility vehicle

Table 22 displays the results of the multivariate analysis. Like pedestrian roadway crashes, crash hour-of-day was a significant predictor of pedestrian injury severity among pedestrians treated in NC EDs ($p$ = .04), with pedestrians injured during the morning hours of 4:00-7:59 being more likely to have serious pedestrian injuries.

Also, like pedestrian roadway crashes, pedestrian sex ($p$ = .004), age ($p$ < .001), and race/ethnicity ($p$ < .001) were statistically significant predictors of pedestrian injury severity. There were some notable differences from roadway crashes, however. For example, child pedestrians were not identified as having a greater likelihood of serious injury among roadway collisions; however, among non-roadway collisions, children 0-4 and 5-9 years-of-age were 4.4 and 3.9 times as likely to sustain serious pedestrian injuries, respectively, as compared to the reference group. Older adults were also more likely to sustain serious injuries, with adults 65-74 and ≥75 years-of-age being 2.8 and 3.8 times as likely as 25-34-year-olds, to be diagnosed with serious injuries in an ED setting.

Unlike roadway collisions, the presence of documented comorbidities was not a statistically significant predictor of pedestrian injury severity after adjusting for other predictors. Suspected pedestrian alcohol use was significant, however ($p$ =.01). Pedestrians suspected of being under the influence of alcohol at the time of crash were 3.1 times as likely to sustain a serious injury, as compared to pedestrians not suspected of alcohol use. As mentioned previously, pedestrian alcohol use is of dubious quality in the NC crash data and does not necessarily indicate that the pedestrian was impaired.

Regarding striking driver characteristics, driver gender and suspected driver impairment were not statistically significant after adjusting for the other variables in the model (driver impairment was retained in the model to improve model fit, however). Driver age group was not significant ($p$ = .08), young drivers, 15-24 years-of-age, were 49% more likely to cause serious harm after striking a pedestrian than drivers 25-44 years-of-age. Unlike roadway collisions, there was no difference between older drivers and the reference group regarding pedestrian injury severity.

Unlike for roadway collisions, light condition and impact speed were not significant predictors of pedestrian injury severity among non-roadway pedestrian injury MVCs, although both variables were retained in the model to improve fit. Despite its lack of statistical significance, the point estimate for impact speed suggests greater harm at higher speeds. However, the confidence interval for impact speed was quite large, indicating a lack of precision for this estimate. Therefore, a larger sample size and an improvement in data quality may yield different results.

Perhaps the most interesting result from the non-roadway predictive analysis was the role of vehicle type as a predictor (*p* = .006). Among roadway pedestrian collisions, we were surprised to find that vehicle type was not a statistically significant predictor of pedestrian injury severity after adjustment. However, it was a strong predictor among non-roadway collisions. The odds of serious pedestrian injury were 41% and 97% greater among pedestrians struck by SUVs and pickup trucks, respectively, than pedestrians struck by passenger cars. Perhaps vehicle type has a stronger relationship with pedestrian injury severity among lower speed crash scenarios more common to a non-roadway environment.

**Table 22: Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) of potential predictors of serious injury among pedestrians treated in NC emergency departments, pedestrians injured on non-roadways, only (N=1,952)**

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| **Hour of day (reference = 16:00-19:59)** | | | |
| 0:00-3:59 | 1.57 | 0.75-3.26 | .23 |
| 4:00-7:59 | 1.81 | 1.04-3.16 | .04 |
| 8:00-11:59 | 1.16 | 0.77-1.74 | .49 |
| 12:00-15:59 | 0.76 | 0.53-1.09 | .14 |
| 20:00-23:59 | 1.26 | 0.74-2.13 | .40 |
| **Gender of patient (reference = female)** | **1.47** | **1.13-1.91** | **.004** |
| **Age of patient (reference = 25-34)** | | | |
| 0-4 | 4.41 | 2.22-8.77 | <.001 |
| 5-9 | 3.86 | 1.90-7.86 | <.001 |
| 10-14 | 0.73 | 0.26-2.09 | .56 |
| 15-19 | 0.98 | 0.50-1.92 | .96 |
| 20-24 | 1.85 | 1.04-3.30 | .04 |
| 35-44 | 1.33 | 0.81-2.18 | .26 |
| 45-54 | 0.99 | 0.60-1.63 | .95 |
| 55-64 | 1.49 | 0.90-2.46 | .12 |
| 65-74 | 2.79 | 1.58-4.91 | <.001 |
| 75+ | 3.80 | 2.07-6.97 | <.001 |
| **Race/Hispanic ethnicity of patient (reference = white, not Hispanic/Latinx)** | | | |
| Black, not Hispanic/Latinx | 0.47 | 0.35-0.64 | <.001 |
| Hispanic/Latinx | 1.09 | 0.62-1.92 | .76 |
| Other race[1] | 0.64 | 0.31-1.33 | .23 |
| **Expected source of payment (reference = insurance company)** | | | |
| Self-pay | 0.78 | 0.54-1.11 | .17 |

| Potential predictor | OR | 95% CI | *p* value |
|---|---|---|---|
| Medicaid | 1.06 | 0.68-1.66 | .80 |
| Medicare | 1.01 | 0.63-1.61 | .97 |
| Workers' compensation | 1.32 | 0.76-2.28 | .33 |
| Other source of payment[2] | 0.60 | 0.38-0.94 | .02 |
| **Suspected pedestrian alcohol use (reference = no)** | **3.12** | **1.31-7.45** | **.01** |
| **Age of striking driver (reference = 25-44)** | | | |
| 15-24 | 1.49 | 1.03-2.16 | .03 |
| 45-64 | 0.91 | 0.65-1.28 | .59 |
| 65+ | 0.98 | 0.67-1.44 | .93 |
| **Suspected striking driver alcohol use reference = no)** | **0.91** | **0.46-1.82** | **.79** |
| **Light condition (reference = daylight)** | | | |
| Dawn/Dusk | 0.70 | 0.35-1.41 | .32 |
| Dark - lighted or unlighted | 1.21 | 0.76-1.92 | .43 |
| **Estimated driver speed at impact (reference = ≤35 MPH)** | **2.38** | **0.94-6.03** | **.07** |
| **Striking vehicle type (reference = passenger car)** | | | |
| SUV | 1.41 | 1.02-1.96 | .04 |
| Pickup truck | 1.97 | 1.36-2.85 | <.001 |
| Van | 1.36 | 0.80-2.32 | .26 |
| Other vehicle[3] | 1.53 | 0.82-2.84 | .18 |

AIC: full model = 1,555.4; reduced model = 1,538.0
[1]Other race contains “American Indian/Native American”, “Asian” and “other race”.
[2]Other source of payment contains "no charge", "other type of government payment", and "other payment type".
[3]Other vehicle contains light trucks, heavy trucks, buses, emergency response vehicles, motorcycles, mopeds, recreational vehicles, and taxicabs.

# Examination of Pedestrian Injury Characteristics

The third and final study was an examination of the types of injuries associated with pedestrian MVCs in NC during the period October 1, 2010 – September 30, 2015. We classified all pedestrian injuries according to injury location (e.g., upper extremity) and nature of injury (e.g., fracture) using the Barell Injury Diagnosis Matrix. For the full results, see Appendix III. The tables and figures provided in this section display the most common location and type of injury, as well as these injuries’ relationships with other pedestrian characteristics (e.g., pedestrian age).

Figure 24 displays the most common locations of injury. Nearly one-half of all pedestrians had one or more injuries to the lower extremities. Injuries to the upper extremities (29%) and head (28%) were also common. Although not as common, 20% and 11% of pedestrians had injuries to the torso and spinal column (SC)/vertebral column (VC), respectively. These injuries are particularly concerning, as they tend to be severe, with injuries to the torso including most injuries to the internal organs (other than to the brain and surrounding tissues) and injuries to the SC/VIC possibly leading to permanent losses of strength, sensation, and function below the location of injury.

Table 23 displays the relationship between injury location and selected demographic characteristics. There were striking differences by gender, with males being more likely to sustain injuries to the head (31%) and torso (21%) than females. On the other hand, females were more likely to sustain injuries to the SC/VC (12%) and the lower extremities (48%). Both genders were equally likely to sustain injuries to the upper extremities. There were also differences by age group, with age being significantly associated with head ($p < .001$), SC/VC ($p < .001$), and upper extremity injuries ($p = .004$). For head injuries, pedestrians displayed a U-shaped pattern by age group, with children 0-14 years-of-age (40%) and older adults (33%) being the most likely to be diagnosed with a head injury. The frequency of SC/VC injuries were higher among middle-aged adults 45-64 years-of-age (15%) and older adults (13%), with children being far less likely to be diagnosed with an SC/VC injury (4%). Upper extremity injuries were most common among older adults (33%), with younger pedestrians being less likely to be diagnosed with injuries to this location.

Table 24 displays the relationship between injury location and selected crash characteristic. Speed at impact was significantly associated with all pedestrian crash injury locations. For example, among pedestrians struck by vehicles traveling >35 MPH, 40% of pedestrians suffered head injuries, as compared to 25% of pedestrians struck at speeds $\leq$35 MPH, a percent difference of 45% ($p < .001$). There were also differences by vehicle type. As compared to SUVs (43%) and pickup trucks (41%), pedestrians struck by passenger cars were more likely to have an injury to the lower extremity (50%) ($p < .001$). Pedestrians struck by SUVs (22%) and pickup trucks (25%) were more likely to have an injury to the torso, as compared to passenger cars (19%) ($p = .002$).

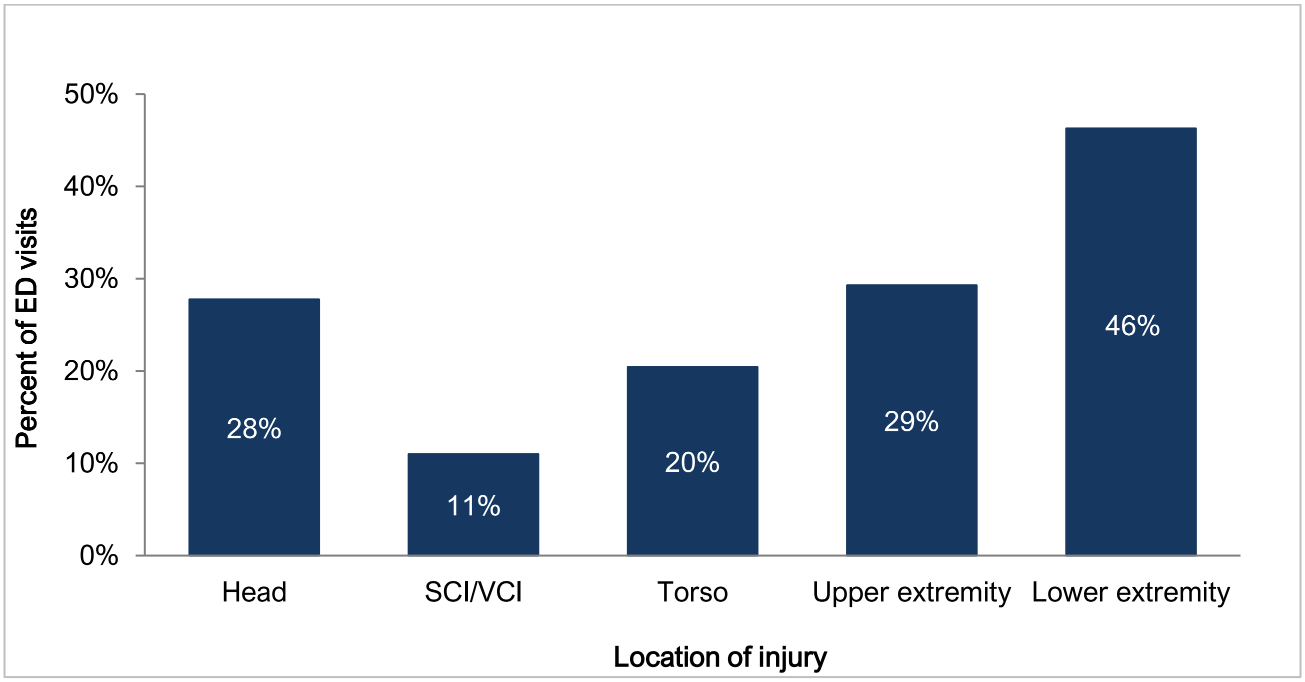


*Figure 24: Frequency of pedestrians treated at NC emergency departments, by location of injury (N=6,923)*[1]

Abbreviations: SCI, spinal column injury; VCI, vertebral column injury.
[1]Injured pedestrians may have more than one injury location; therefore, frequencies do not sum to 100%.

## Table 23: Frequency of pedestrians treated at NC emergency departments, by selected demographic characteristic and location of injury (N=6,923)[1]

| Location of injury | Gender N (%) | | *p* value | Age group N (%) | | | | | *p* value |
|---|---|---|---|---|---|---|---|---|---|
| | Female | Male | | 0-14 | 15-24 | 25-44 | 45-64 | 65+ | |
| Head | 697 (23.7%) | 1,222 (30.7%) | <.001 | 302 (39.5%) | 428 (27.3%) | 518 (23.5%) | 478 (26.4%) | 193 (33.4%) | <.001 |
| SCI/VCI | 353 (12.0%) | 409 (10.3%) | .02 | 29 (3.8%) | 163 (10.4%) | 232 (10.5%) | 265 (14.6%) | 73 (12.6%) | <.001 |
| Torso | 560 (19.1%) | 853 (21.4%) | .02 | 147 (19.2%) | 303 (19.3%) | 436 (19.8%) | 404 (22.3%) | 124 (21.5%) | .15 |
| Upper extremity | 839 (28.5%) | 1,189 (29.9%) | .23 | 187 (24.5%) | 480 (30.6%) | 627 (28.5%) | 541 (29.9%) | 192 (33.2%) | .004 |
| Lower extremity | 1,412 (48.0%) | 1,791 (45.0%) | .01 | 351 (45.9%) | 764 (48.8%) | 1,000 (45.5%) | 836 (46.2%) | 253 (43.8%) | .20 |
| **Total** | **2,939 (100.0%)** | **3,979 (100.0%)** | | **764 (100.0%)** | **1,567 (100.0%)** | **2,200 (100.0%)** | **1,810 (100.0%)** | **578 (100.0%)** | |

Missing: Gender (N=5), age group (N<5).
Abbreviation: SCI, spinal column injury; VCI, vertebral column injury.
[1]Injured pedestrians may have more than one injury location; therefore, frequencies do not sum to 100%.

## Table 24: Frequency of pedestrians treated at NC emergency departments, by selected crash characteristic and location of injury (N=6,923)[1,2]

| Location of injury | Speed at impact N (%) | | *p* value | Vehicle type N (%) | | | | *p* value |
|---|---|---|---|---|---|---|---|---|
| | ≤35 | >35 | | Car | SUV | Pickup truck | Van | |
| Head | 1,333 (25.3%) | 524 (39.9%) | <.001 | 1,005 (27.7%) | 339 (29.0%) | 254 (30.9%) | 110 (28.3%) | .31 |
| SCI/VCI | 550 (10.4%) | 175 (13.3%) | .003 | 390 (10.8%) | 133 (11.4%) | 103 (12.5%) | 42 (10.8%) | .52 |
| Torso | 987 (18.7%) | 369 (28.1%) | <.001 | 693 (19.1%) | 260 (22.2%) | 203 (24.7%) | 78 (20.1%) | .002 |
| Upper extremity | 1,432 (27.2%) | 511 (38.9%) | <.001 | 1,007 (27.8%) | 345 (29.5%) | 273 (33.3%) | 126 (32.4%) | .007 |
| Lower extremity | 2,503 (47.5%) | 543 (41.4%) | <.001 | 1,812 (50.0%) | 497 (42.5%) | 340 (41.4%) | 171 (44.0%) | <.001 |
| **Total** | **5,273 (100.0%)** | **1,313 (100.0%)** | | **3,626 (100.0%)** | **1,170 (100.0%)** | **821 (100.0%)** | **389 (100.0%)** | |

Missing: Speed at impact (N=337), age group (N=598).
Abbreviation: SCI, spinal column injury; VCI, vertebral column injury.
[1]Injured pedestrians may have more than one injury location; therefore, frequencies do not sum to 100%.
[2]Due to small numbers, "other vehicle type" not included in analyses.

Figure 25 and Tables 25 and 26 display the nature of injury. The most common type of injury observed was superficial wounds and contusions, with nearly 60% of pedestrians being diagnosed with this nature of injury (Figure 25). Fractures were also common, with one-fourth of all pedestrians being diagnosed with a fracture. Injuries to the internal organs (12%) and TBIs (9%) were less common, but the frequency is still concerning due to the inherent severity of these types of injuries.

For all injury types examined, gender was statistically significant (Table 25). Males were more likely than females to be diagnosed with TBIs (10%), internal injuries (13%), open wounds and amputations (15%), and fractures (28%). Females were more likely to be diagnosed with sprains/strains/dislocations (18%) and superficial wounds and contusions (59%). The differential was especially noteworthy for open wounds and contusions, in which the percent difference between men (15%) and women (9%) was 48%. There were also differences in the frequency of pedestrian nature of injury across the lifespan (Table 25). Not surprising considering the results observed for head injuries, TBI demonstrated a U-shaped pattern with children 0-14 years-of-age (11%), youth 15-24 years-of-age (10%), and older adults (10%) being more likely to be diagnosed with a TBI than working-age (8%) and middled-aged adults (8%) ($p = .02$). In addition, the frequency of internal injuries also demonstrated a U-shaped pattern ($p = .001$) and, although not statistically significant, internal injuries also displayed a U-shaped pattern across pedestrian age groups ($p = .10$). A different pattern was observed for fractures, with fractures increasing across the lifespan ($p < .001$), with children 0-14 years-of-age have the lowest frequency of fracture (22%) and older adults having the highest frequency of fracture (34%). The frequency of superficial wounds and contusions decreased across the lifespan ($p < .001$), with children 0-14 years-of-age having the highest frequency of superficial wounds and contusions (63%) and older adults having the lowest frequency (54%).

Table 26 displays the relationship between the nature of injury and impact speed. Impact speed was significant for all injury types we examined. Injuries associated with higher severity, such as open wounds and amputations, tended to be more common at higher impact speeds. For example, pedestrians struck at speeds >35 MPH were twice as likely to be diagnosed with TBIs and internal injuries, as compared to pedestrians struck at lower speeds. Open wounds/amputations and fractures were also more common among pedestrian struck at speeds of >35 MPH. On the other hand, injuries associated with lower severity, such as strains/sprains/dislocations and superficial wounds/contusions, were more common among pedestrians struck at lower impact speeds.

Table 26 also displays the relationship between nature of injury and striking vehicle type. The only nature of injury associated with vehicle type was internal injury ($p$ = .01). Pedestrians struck by pickup trucks (16%) were more likely to sustain an internal injury, as compared to SUVs (13%), vans (12%), and passenger cars (11%).

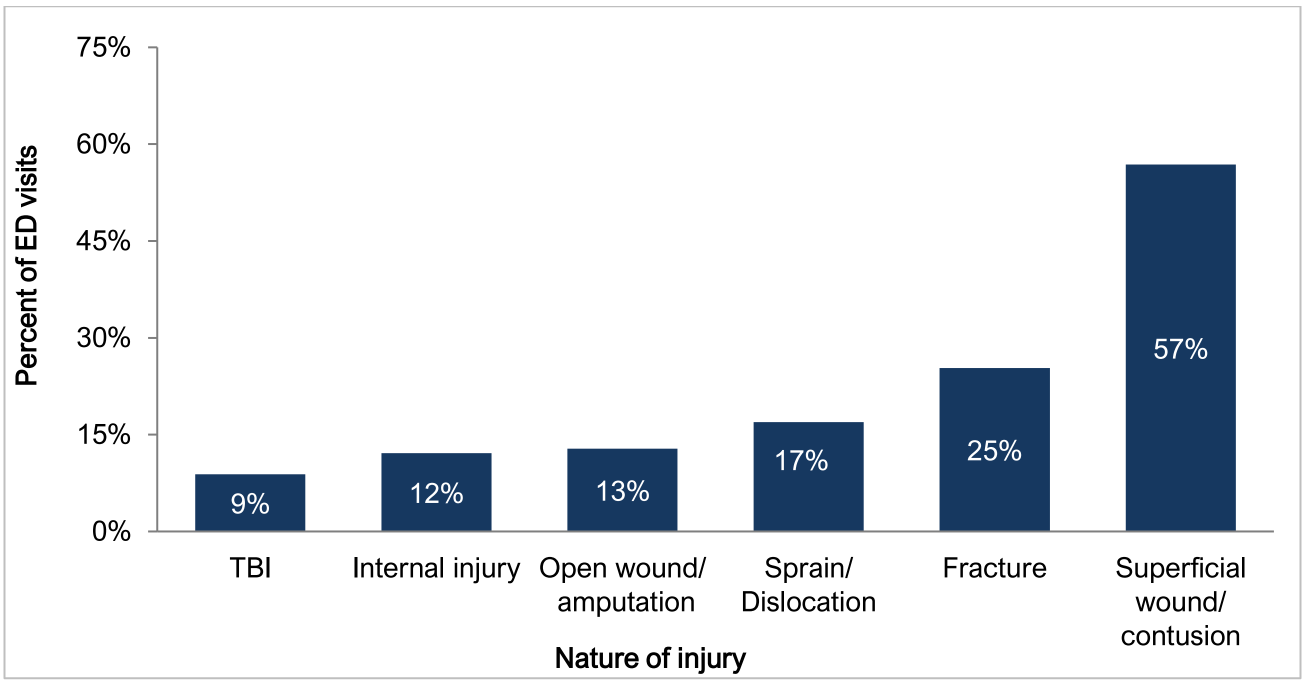


*Figure 25: Frequency of pedestrians treated at NC emergency departments, by nature of injury (N=6,923)[1]*

Abbreviations: TBI, traumatic brain injury
[1]Injured pedestrians may have more than one injury diagnosis; therefore, frequencies do not sum to 100%.

**Table 25: Frequency of pedestrians treated at NC emergency departments, by selected demographic characteristic and nature of injury (N=6,923)[1]**

| Nature of injury | Gender N (%) | | *p* value | Age group N (%) | | | | | *p* value |
|---|---|---|---|---|---|---|---|---|---|
| | Female | Male | | 0-14 | 15-24 | 25-44 | 45-64 | 65+ | |
| TBI | 198 (6.7%) | 414 (10.4%) | <.001 | 87 (11.4%) | 152 (9.7%) | 169 (7.7%) | 150 (8.3%) | 55 (9.5%) | .02 |
| Internal injury | 304 (10.3%) | 533 (13.4%) | <.001 | 110 (14.4%) | 197 (12.6%) | 251 (11.4%) | 201 (11.1%) | 78 (13.5%) | .10 |
| Open wound/ amputation | 277 (9.4%) | 609 (15.3%) | <.001 | 112 (14.7%) | 221 (14.1%) | 242 (11.0%) | 217 (12.0%) | 93 (16.1%) | .001 |
| Fracture | 639 (21.7%) | 1,114 (28.0%) | <.001 | 169 (22.1%) | 358 (22.8%) | 507 (23.0%) | 520 (28.7%) | 197 (34.1%) | <.001 |
| Sprain/ Dislocation | 530 (18.0%) | 642 (16.1%) | .04 | 59 (7.7%) | 279 (17.8%) | 403 (18.3%) | 348 (19.2%) | 82 (14.2%) | <.001 |
| Superficial wound/ contusion | 1,720 (58.5%) | 2,214 (55.6%) | .02 | 480 (62.8%) | 938 (59.9%) | 1,235 (56.1%) | 969 (53.5%) | 311 (53.8%) | <.001 |
| **Total** | **2,939 (100.0%)** | **3,979 (100.0%)** | | **764 (100.0%)** | **1,567 (100.0%)** | **2,200 (100.0%)** | **1,810 (100.0%)** | **578 (100.0%)** | |

Missing: Gender (N=5), age group (N<5).

Abbreviation: SCI, spinal column injury; VCI, vertebral column injury.

[1]Injured pedestrians may have more than one injury diagnosis; therefore, frequencies do not sum to 100%.

**Table 26: Frequency of pedestrians treated at NC emergency departments, by selected crash characteristic and nature of injury (N=6,923)[1,2]**

| Nature of injury | Speed at impact N (%) | | *p* value | Vehicle type N (%) | | | | *p* value |
|---|---|---|---|---|---|---|---|---|
| | <u><</u>35 | >35 | | Car | SUV | Pickup truck | Van | |
| TBI | 377 (7.1%) | 220 (16.8%) | <.001 | 311 (8.6%) | 112 (9.6%) | 86 (10.5%) | 38 (9.8%) | .31 |
| Internal injury | 535 (10.1%) | 278 (21.2%) | <.001 | 415 (11.4%) | 154 (13.2%) | 128 (15.6%) | 47 (12.1%) | .01 |
| Open wound/ amputation | 595 (11.3%) | 266 (20.3%) | <.001 | 463 (12.8%) | 153 (13.1%) | 128 (15.6%) | 53 (13.6%) | .19 |
| Fracture | 1,149 (21.8%) | 546 (41.6%) | <.001 | 918 (25.3%) | 320 (27.4%) | 226 (27.5%) | 88 (22.6%) | .16 |
| Sprain/ Dislocation | 932 (17.7%) | 175 (13.3%) | <.001 | 612 (16.9%) | 190 (16.2%) | 132 (16.1%) | 64 (16.5%) | .92 |
| Superficial wound/contusion | 3,093 (58.7%) | 657 (50.0%) | <.001 | 2,071 (57.1%) | 670 (57.3%) | 451 (54.9%) | 231 (59.4%) | .50 |
| **Total** | **5,273 (100.0%)** | **1,313 (100.0%)** | | **3,626 (100.0%)** | **1,170 (100.0%)** | **821 (100.0%)** | **389 (100.0%)** | |

Missing: Speed at impact (N=337), vehicle type (N=598).
Abbreviation: SCI, spinal column injury; VCI, vertebral column injury.
[1]Injured pedestrians may have more than one injury diagnosis; therefore, frequencies do not sum to 100%.
[2]Due to small numbers, "other vehicle type" not included in analyses.

# Conclusion

During the period October 1, 2010 – September 30, 2015, there were 14,264 pedestrians reported struck by motor vehicles by police in North Carolina. During this same period, there were 19,699 pedestrians treated in NC EDs for their injuries. We linked approximately one-half of all pedestrians with a crash report to an ED visit record, for a study population of 6,923 injured pedestrians. The linked data yielded numerous findings, with some of the highlights bulleted below:

- Police reported crash data underestimate pedestrian injuries. We identified 19,699 pedestrians injured in our NC ED visit data, as compared to 14,264 pedestrians in the crash data: a percent increase of 38%. The largest differences observed in counts of ED visits/crash records was for males, young adults 20-29 years-of-age, and for the nighttime hours of 20:00-23:59.

- Police reported crash data do not always contain accurate measures of pedestrian injury severity. In the crash data, the variable KABCO (K: killed, A: disabling injury, B: evident injury, C: possible injury, O: no injury) indicates pedestrian injury severity as determined by the investigating police officer. After linkage, 50% of "B" injuries, 16% of "C" injuries, and 12% of "O" injuries were reclassified as "serious" based on information present in the ED visit record. Therefore, we recommend using clinical outcomes for pedestrian injury severity, when available.

- In the linked NC crash-ED visit data, 38% of pedestrians sustained a serious or fatal injury, based on information present in the ED visit record. Had we used "K" (fatal) and "A" (disabling) injuries as our indicator of serious pedestrian injury, only 10% of the pedestrian injuries in the linked data would have been classified as "serious".

- There was no temporal trend observed for the annual number of injured pedestrians in the linked data for the period under study. Although NC experienced an increase in pedestrian fatalities over the study period, the number of pedestrians reported injured in the linked crash-ED visit data did not vary significantly by year, with about 1,300-1,400 pedestrians reported injured annually in NC.

- Both the number of pedestrian injuries and the severity of pedestrian injuries differed by crash hour-of-day. The hour with the single greatest number of pedestrian injuries was 17:00 (N=354), while the crash hour with the lowest number of injuries was 4:00 (N=64). However, the hour with the highest frequency of serious pedestrian injuries was 4:00 (61%) and the hour with the lowest frequency of serious pedestrian injuries was 12:00 (26%). There were some differences in hourly trends for weekdays versus weekends.

- The frequency and severity of pedestrian injury varied by pedestrian age group. The age group with the highest number of pedestrian injuries was the group 25-34 years-of-age. This was not the age group with the highest percentage of serious injuries, however. Children 0-4 years-of-age (46%), children 5-9 years-of-age (43%), older adults 65-74 years of age (48%), and older adults ≥75 years-of-age (54%) were the most likely sustain serious injuries.

- Driver demographics also impact the frequency and severity of pedestrian injuries. Young adult drivers 25-34 years-of-age were the age group associated with the highest frequency of pedestrian age groups. They were also the second-highest age group regarding pedestrian injury severity, with 42% of striking drivers in this age group resulting in serious pedestrian injury. The group with highest frequency of serious pedestrian injuries was young adults 20-24 years-of-age (43%).

- Suspected alcohol use among pedestrians and striking drivers was associated with pedestrian injury severity. In our descriptive analyses, a higher proportion of pedestrians (67%) and drivers (49%) suspected of alcohol use was associated with more serious pedestrian injuries.

- Speed demonstrated a strong relationship with pedestrian injury severity. Regardless of whether estimated speed at impact of posted speed limit was used as an indicator of vehicle speed, higher speeds (and speed limits) were associated with greater pedestrian injury severity. Among pedestrians struck at impact speeds of >35 MPH, 57% had serious injuries, as compared with 23% of pedestrians struck at speeds 0-5 MPH. Similarly, 54% of pedestrians struck on roadways with posted speed limits of

≥50 MPH had serious or fatal injuries, as compared to 25% of pedestrians struck on roadways with speed limits of 5-15 MPH.

- Ambient light condition was also associated with higher pedestrian injury severities. Although 57% of pedestrians were injured under daylight conditions, injury severities were highest among nighttime pedestrian MVCs, with 46% of pedestrians injured under dark-lighted conditions and 50% of pedestrians injured under dark-unlighted/unknown conditions having serious injuries, as compared to 32% pedestrians injured under daylight conditions.

- Certain pedestrian crash types were associated with higher injury severities. Among pedestrians injured on roadways, pedestrians struck by vehicles traveling straight while the pedestrian was crossing the roadway, had the highest frequency of serious injuries (55%). Among pedestrians injured on non-roadways, pedestrians involved in a motor vehicle loss of control crash type were the most likely to have a serious injury (34%).

- After adjustment, hour of crash, pedestrian gender, pedestrian age, race/Hispanic ethnicity, documented pedestrian comorbidities, suspected pedestrian alcohol use, striking driver age, ambient light condition, intersection-relatedness, road classification, posted speed limit, estimated impact speed, and pedestrian crash type were identified as significant predictors of pedestrian injury severity among roadway crashes in our multivariate logistic regression model.

- After adjustment, hour of crash, pedestrian gender, pedestrian age, race/Hispanic ethnicity, suspected pedestrian alcohol use, and vehicle type were identified as significant predictors of pedestrian injury severity among non-roadway crashes in our multivariate logistic regression model.

- By linking to ED visit data, we were able to describe in detail injury outcomes among pedestrians. The most common location of injury was the lower extremities. The most common nature of injury was superficial wounds and contusions. Pedestrian age, gender, estimated speed at impact, and vehicle type was related to both location and nature of injury.

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# Appendix I: Literature Review

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| **Outcome** | | | | | | | | |
| *Hospital admission/ death* | Yes* | High | Yes** | High | High | Hospital admission and death are indicators of serious and fatal pedestrian/bicyclist injuries.<br><br>*Crash data contain information on patient death.<br><br>**ED data contain information on patient hospital admission. | Serious injuries requiring hospitalization are costly, may require long-term treatment, and may result in long-term disability. Death is the ultimate negative outcome from a pedestrian/bicyclist crash. | Explore using linked dataset. |
| *Specific injury diagnoses* | No | -- | Yes | High | High | Certain injury diagnoses (e.g., TBI, certain types of fractures, internal injuries) are indicative of more serious injuries and may differ across vehicle type, crash type, and other variables of interest. | The frequency of specific pedestrian/bicyclist patient injury diagnoses is hypothesized to be associated with several explanatory variables. For example, TBIs, thoracic injuries, abdominal injuries, and more severe injuries/deaths are more common among pedestrians | Explore using linked dataset. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | struck by SUVs/PUs/Vans than pedestrians struck by passenger vehicle (Ballesteros et al., 2004; D'elia & Newstead, 2015; Helmer et al., n.d.; Paulozzi, 2005; Roudsari et al., 2004). Pedestrian/bicyclist injury patterns also differ in frequency across the lifespan, with spinal injuries being more common among older pedestrians, pelvic and tibial fractures being more common among working-age adult pedestrians, and femoral fractures being more common among pediatric pedestrians (Demetriades et al., 2004). | |
| *Total number of injury diagnoses* | No | -- | Yes | High | Medium/ Low | Total number of injury diagnoses is another measure of injury severity; patients with multiple injuries tend to have worse outcomes. | Total number of injury diagnoses is another indicator of injury severity. | Possibly explore using linked dataset; this outcome variable may not be as useful as the outcome measures previously described. May incorporate into |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | another outcome measure. |
| **Time** | | | | | | | | |
| *Annual trends* | Yes | High | Yes | High | Medium | While the quality of the data is good and the significance of the factor is high, the study period (10/10-09/15) may not encompass enough years of data to perform a time series analysis. | From 2008-2017, the average annual number of pedestrian fatalities increased by 35% (from 4,414 to 5,977 US deaths) while the average annual number of all other combined traffic deaths decreased by 6% (R. Retting, 2019). | Explore using linked dataset; consider adding additional years of data for future analyses. Consider looking at temporal changes of select explanatory variables (e.g., vehicle type). |
| *Seasonal trends* | Yes | High | Yes | High | Medium | Rates of pedestrian/bicyclist injuries are expected to fluctuate by season. | Seasonal variation (related to hours of daylight, temperature, and adverse weather events) has been demonstrated to decrease cyclist, and to a lesser extent, pedestrian traffic volumes and, therefore, frequencies of injuries/death (Aultman-Hall et al., 2009; Kuzmyak & Dill, 2012). | Time permitting, possibly explore using linked dataset; seasonal temporal variation in pedestrian/bicyclist morbidity/mortality has been well-described using unlinked crash data. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| *Day of week/hour of day trends* | Yes | High | Yes | High | Medium | Rates of pedestrian/bicyclist injuries are expected to fluctuate by day of week, time of day, and holiday versus non-holiday. | Pedestrian/bicyclist traffic volumes fluctuate by day of week, time of day, and holidays (New Year's Day and Halloween have elevated pedestrian mortality rates) (Cejun Liu et al., 2005). While pedestrian/bicyclist morbidity/mortality is often correlated with traffic volume, it is not always. For example, pedestrian/bicyclist traffic volume often peaks during the morning/evening commute, but pedestrian/bicyclist mortality rates are highest at night (Aultman-Hall et al., 2009; National Center for Statistics and Analysis, 2018a). | Time permitting, possibly explore using linked dataset; daily/hourly temporal variation in pedestrian/bicyclist morbidity/mortality has been well-described using unlinked crash data. |
| **Person** | | | | | | | | |
| *Demographics* | Yes | High | Yes | High | High | Demographic characteristics (age, gender, and race/Hispanic ethnicity) are well-captured in both datasets and are | Males, middle-aged adults 50-54 years of age, older adults >69 years of age, and people of color have higher pedestrian fatality rates (Campos-Outcalt et al., 2002; National Center for Statistics and | Explore using linked dataset. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | important descriptors of the patient population. | Analysis, 2018a; C V Zegeer et al., 1996). Males, middle-aged adults 50-64 years of age, and whites have higher cyclist fatality rates (Hamann et al., 2013; National Center for Statistics and Analysis, 2018b). | |
| *Use of safety equipment* | Yes | Medium | No | -- | Low | Use of safety equipment (e.g., helmets) is reported for cyclists; however, this information is often missing (it is also reported for pedestrians, but the quality of these data is poor). | Despite disagreement over the magnitude of the effect size, bicycle helmets have been shown to have a moderate to strong level of effect at preventing injuries to the head and upper face (Attewell et al., 2001; Rune Elvik, 2011, 2013; Olivier & Creighton, 2017). | Data are likely too poor for analysis. |
| *Socioeconomic status* | No | -- | Yes | Good/ Medium | High | Expected source of payment (e.g. insurance status) is often used as a proxy measure for SES with payers of “Medicaid” and “Self-pay” (e.g. uninsured) indicating low SES (Healthcare Cost and Utilization Project, Agency for Healthcare Research | Pedestrian crashes are 4-8 times more common in low-income neighborhoods than median and high-income neighborhoods (Chakravarthy et al., 2010, 2012). Much of this increased risk relates to inferior quality infrastructure and a population that walks and utilizes public transit at greater levels (Cottrill & Thakuriah, 2010). In | Explore using linked dataset. Consider incorporating US Census data to explore other measures of pedestrian/bicyclist SES. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | and Quality, 2019; Marcin et al., 2003). This data element is well-captured in the ED visit data. | addition, uninsured patients may have worse outcomes related to treatment delay and differences in medical care provided (Maybury et al., 2010). | |
| *Homelessness* | No | -- | Yes | Unknown | Medium | In the ED visit data, the chief complaint data may mention lack of housing; however, it is unknown how frequently these terms are used. Syndromic surveillance definitions have been developed to detect patient homelessness (Albert et al., 2019). | The unhoused population have much higher pedestrian fatality rates than the housed population (Hickox et al., 2014). Risk factors are not well-described but may relate to higher levels of exposure, substance use/misuse, and mental health disorders & other comorbidities. | Explore using linked dataset; data quality may be too poor for analysis. |
| *Comorbidities* | No | -- | Yes | Unknown/ Variable | High/ Medium/ Low | A variety of comorbid conditions (e.g., smoking status, hypertension, history of mental health and substance use disorders, etc.) are captured in the ICD-10-CM diagnosis codes. Quality of comorbidity data is | Comorbidities have been associated with increased frailty and poorer outcomes among patients with traumatic injuries, including MVC-related injuries. Comorbidities associated with worse outcomes include dementia, cancer, substance abuse disorders, diabetes, cardiovascular disease, | Explore using linked dataset; data quality may be too poor to examine all hypothesized comorbidities. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | unknown and is likely comorbidity specific. | cerebrovascular disease, asthma/COPD, obesity, vision disorders, and chronic renal failure. In addition, the total number of comorbid conditions can adversely affect outcomes (C. V. R. Brown et al., 2016; Devos et al., 2017; Kirshenbom et al., 2017). As our society ages, comorbid conditions are likely to become more prevalent and may be affecting pedestrian/bicyclist mortality rates. | |
| **Impairment (pedestrian/ bicyclist)** | | | | | | | | |
| *Alcohol* | Yes | Low | Yes | Low | Low | Patient alcohol impairment is not consistently reported in the crash or ED visit data for pedestrian/bicyclists. | Alcohol has been identified as a risk factor for pedestrian/bicyclist crash involvement (Hezaveh & Cherry, 2018; Li et al., 2001; Miles-Doan, 1996). In addition, alcohol retail establishments has been positively associated with pedestrian crash rates (LaScala et al., 2000, 2001; Schuurman et al., 2009). However, | Do not explore using linked dataset; consider adding additional sources of data (e.g., geospatial data of alcohol retail outlets) for future analyses. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | recent trends indicate that pedestrian/bicyclist impairment may have declined (Eichelberger et al., 2018). | |
| *Narcotics (e.g., Opioids)* | Yes | Low | Yes | Low | Low | Patient narcotic impairment is not consistently reported in the crash or ED visit data for pedestrian/bicyclists. | NC has an increasing opioid dependence and overdose problem (Injury Epidemiology & Surveillance Unit, Injury & Violence Prevention Branch, 2016) However, it is unclear what impact this is having on pedestrian/bicyclist morbidity/mortality. | Do not explore using linked dataset; consider adding additional sources of data (e.g., prescription drug monitoring or toxicology data) for future analyses. |
| *Marijuana* | Yes | Low | Yes | Low | Low | Patient marijuana impairment is not consistently reported in the crash or ED visit data for pedestrian/bicyclists. | States have increasingly legalized marijuana for medicinal and recreational purposes (marijuana is not legal in NC) and use has increased. While marijuana increases the risk of being involved in a MVC, the evidence for its role in pedestrian/bicyclist morbidity/mortality is less clear.(Insurance Institute for Highway Safety, 2018; Lane & Hall, 2019) | Do not explore using linked dataset; consider adding additional sources of data (e.g., toxicology data) for future analyses. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| **Driver** | | | | | | | | |
| *Demographics* | Yes | High | Yes | High | Medium | Demographic characteristics (age, gender, and race/Hispanic ethnicity) are well-captured in both datasets and are important descriptors of the drivers involved in MVC-pedestrian/bicyclist interactions. However, the focus on this project will be on the pedestrian/bicyclists, so driver characteristics may not factor heavily in analyses. | Driver demographic characteristics, especially age, affects driving ability. For example, older drivers may have a more difficult time recognizing and responding to pedestrian/bicyclists under dark conditions (Wood et al., 2005). | Time permitting, possibly explore using linked dataset. |
| Impairment (driver*)* | Yes | Low | Yes | Low | Low | Similar issues to pedestrian impairment (see above); driver alcohol impairment may be insufficiently captured to permit inclusion in analyses. | If quality is acceptable, include in analyses as driver alcohol use is associated with pedestrian/bicyclist injury severity (Zajac & Ivan, 2003). | Do not explore using linked dataset. |
| **Crash** | | | | | | | | |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| *Pedestrian/Bicyclist location/ position/ type* | Yes | High | No | -- | High | UNC HSRC has developed a method of classifying pedestrian/bicyclist crashes according to location, position, and type. Data are complete and well-captured. | Over 2012-2016, 16% of pedestrians were killed or seriously injured in MVCs. The most common location, position, and type of pedestrian crashes was (% killed/seriously injured in parentheses): non-intersection (23%), travel lane (20%), and crossing roadway – vehicle not turning (20%) (Thomas, Vann, et al., 2018). Over 2012-2016, 7% of cyclists were killed or seriously injured in MVCs. The most common location, position, and type of bicycle crashes was (% killed/seriously injured in parentheses): non-intersection (9%), travel lane (8%), and motorist overtaking bicycle (12%) (Vann et al., 2018b). | Explore using linked dataset; may need to collapse categories to permit analysis. |
| *Light condition* | Yes | High | No | -- | High | Light condition (e.g., light, dark-lighted, dark-unlighted) at time of crash | Low light conditions have been associated with a higher risk of pedestrian and cyclist morbidity/mortality (Chong et al., 2018; J.-K. Kim et al., 2007; Klop & | Explore using linked dataset. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | is relatively complete in the crash data. | Khattak, 1999; Sullivan & Flannagan, 2002). This variable is of considerable importance because there are several evidence-based countermeasures that can reduce morbidity/mortality related to low light conditions, including street lighting (specifically at intersections and high pedestrian/bicyclist traffic areas), illuminated crosswalks, and pedestrian/bicyclist use of visibility aids (R Elvik, 1995; Kwan et al., 2002; Nitzburg & Knoblauch, 2001; R. A. Retting et al., 2003; Wanvik, 2009). One important countermeasure is adaptive headlights. Currently, the EU and Canada allow 2x's the high beam output allowable in the US and the operation of high beams and low beams simultaneously (illegal in the US) that automatically dim to prevent glare. EU-style headlights have been shown to increase roadway lighting by 86% (American | |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | | | | Automobile Association, Inc., 2019). In the EU, adaptive headlights have been shown to decrease pedestrian/bicyclist injury frequency/ severity (Strandroth et al., 2014). | |
| *Weather condition* | Yes | High | No | -- | Medium | The crash data captures the weather at the time of event and if weather was the cause of the crash. Weather condition at time of crash is relatively complete in the crash data; however, it is anticipated that weather conditions will factor into only a small proportion of pedestrian/bicyclist crashes. | Weather can have an impact on travel patterns and, therefore, pedestrian/bicyclist crash risk (Aultman-Hall et al., 2009; Chengxi Liu et al., 2015). In addition, adverse weather events may also influence pedestrian/bicyclist crash severity (Klop & Khattak, 1999; Zhai et al., 2019). However, a majority of NC pedestrian/bicyclist crashes occur in clear conditions, so the impact on crash risk/injury severity is anticipated to be minimal (Vann et al., 2018a, 2018c). | Time permitting, possibly explore using linked dataset; relationship with outcome variables may be weak. |
| *Speed* | Yes | Medium/ Low | No | -- | High | NC crash data contains posted speed limit, estimated traveling speed, and estimated speed at impact. While these data | The speed at which a MV collides with a pedestrian/bicyclist is the single greatest predictor of injury severity and death. While there is some variability across prediction | Explore using linked dataset; select one indicator of speed for use in analyses. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | are somewhat complete, there are concerns about the accuracy of the speed data, especially for traveling speed/speed at impact. | curves, studies suggest that 7-10% of pedestrians struck at impact speeds of 30 MPH will die, 30-50% of pedestrians struck at impact speeds of 40 MPH will die, and 80-100% of pedestrians struck at 60 MPH will die (there is increased variability at predicting pedestrian/bicyclist mortality at higher speeds) (DC RichardsTransport Research Laboratory, 2010). Speed appears to be an effect measure modifier of the relationship between vehicle type and injury severity (i.e. at higher speeds the relationship between explanatory variable and outcome is attenuated) (Ballesteros et al., 2004). While in theory, impact speed is the most relevant speed variable collected in the crash data for predicting injury severity/death, there are concerns about the accuracy of police reported speed at impact (as well as traveling speed). | |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Therefore, posted speed limit, considered to be a more reliably collected variable, may be used as a proxy measure for impact speed. It should be noted that comparisons between EDR and police reported traveling speeds differed by an average of 3.1, 5.6, and 12.8 MPH, depending on the study (Chung & Chang, 2015; daSilva, 2008; Korpu, 2008). | |
| *Land use* | High | Medium | No | -- | High | In crash data, the investigating police officer assigns a description of crash locality based on the level of development (rural, mixed, and urban). Unclear how well this designation coincides with other common methods of classifying land use. If necessary, may utilize other information about crash | The number of pedestrian/bicyclist crashes are highest in urban areas primarily due to higher population densities and more walking/cycling. While urban areas have the highest population-based rates of pedestrian fatalities, per mile walked, rates are similar (and may even be higher) in suburban and rural communities (Zajac & Ivan, 2003; Zhu et al., 2008). In addition, poorer pedestrian/bicyclist infrastructure, poorer lighting, higher speeds, older populations, and greater distance to | Explore using linked dataset; may incorporate other information about location (e.g., geocoordinates) to assign land use (time permitting). |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | location to determine land use category. | definitive emergency care, may contribute to worse health outcomes among pedestrian/bicyclists in suburban and rural communities (Carter & Council, 2007; Gonzalez et al., 2009; Travis et al., 2012; Charles V Zegeer & Bushell, 2012). | |
| **Roadway** | | | | | | | | |
| *Roadway classification* | Yes | High | No | -- | Medium | Roadway classification (e.g., interstate, state highway, local road) is relatively complete in the crash data. | Roadway classification is an important descriptor of pedestrian/bicyclist crashes, with most pedestrian/bicyclist crashes occurring on local streets; however, it is unclear how much roadway classification will predict injury severity after controlling for speed and other roadway variables (Division of Bicycle and Pedestrian Transportation, North Carolina Department of Transportation, n.d.). | Explore using linked dataset; may not include in final analyses. |
| *Number of lanes* | Yes | High | No | -- | Medium | Number of lanes is relatively complete in the crash data. | The number of through lanes has been associated with an increased likelihood of avoidance maneuvers/ conflicts between MVs and | Explore using linked dataset. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | pedestrian/bicyclists and an increased risk of fatal crashes (Charles V. Zegeer et al., 2006; Charles V Zegeer et al., 2005). | |
| *Road feature* | Yes | Medium | No | -- | Medium | Roadway features (e.g., intersection, bridge, public/private driveway) are moderately well-captured in the crash data; however, the most common feature is "No special feature". | Certain roadway features are of specific interest to the study of pedestrian/bicyclist morbidity/mortality. For example, historically, public/private driveways were the most common sites of pediatric (<5 years of age) pedestrian fatalities in "back over" crashes (Schieber & Vegega, 2002). In addition, intersections are also common sites for pedestrian/bicyclist crashes, especially uncontrolled intersections and intersections with high traffic volumes, high vehicular speeds, right-turn only lanes, longer traffic signal phases and pedestrian/bicyclist wait times, and locations in areas with large scale commercial development (Schneider et al., 2010). However, | Time permitting, possibly explore using linked dataset; may need to collapse categories to permit analysis. Also – pedestrian/bicyclist crash types already incorporate some of this information. |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | this specific variable has many categories that will need to be collapsed prior to analysis. In addition, most pedestrian/bicyclist crashes do not include a specific roadway feature (Vann et al., 2018a, 2018c). | |
| **Vehicle** | | | | | | | | |
| *Type / Year / Make* | Yes | High | No | -- | High | Vehicle type (sedan, SUV, PU) is well-captured in the dataset. The crash data also capture vehicle make (e.g., Volkswagen) and year, but not model type (e.g., Jetta). | As mentioned previously, for "survivable" crashes under certain speeds, vehicle type is a predictor of pedestrian/bicyclist injury severity related to vehicle design (hood height, bumper length, materials, etc.) and weight with pedestrian/bicyclists struck by SUVs and PUs having worse outcomes (Ballesteros et al., 2004; D'elia & Newstead, 2015; Helmer et al., n.d.; Roudsari et al., 2004). Increasing US sales of larger vehicles has been hypothesized as one of the major factors propelling increasing pedestrian/bicyclist mortality rates | Explore using linked dataset; may need to collapse across categories; may need to create composite variable of vehicle type and year (and possibly make). |

| Factor | In crash data? | Quality of crash data | In ED data? | Quality of ED data | Priority level | Reasoning | Significance | Action |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | (JATO, 2019). Ideally, vehicle dimensions and weight would be collected based on the reported vehicle's make, model, and year. However, since model is not available in the NC crash data, proxy groupings will be created based on vehicle type and year, an approach previously used by NHTSA (Martin & Pfeiffer, 2017). | |

Abbreviations: pedestrian/bicyclist, pedestrian/bicyclist; ED, emergency department; MPH, miles per hour; TBI, traumatic brain injury; SUV, sport utility vehicle; PU, pick-up truck; SES, socioeconomic status; US, United States; MV, motor vehicle; MVC, motor vehicle crash; COPD, chronic obstructive pulmonary disease; ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification; NC, North Carolina; UNC HSRC, University of North Carolina Highway Safety Research Center; EU, European Union; EDR, electronic data recorder; NHTSA, National Highway Traffic Safety Administration.

# Appendix II: Comparison of Linked and Unlinked Data Sources

Table 27: Comparison of linked and unlinked pedestrian crash records

| Selected characteristics | Linked records N (%) | Unlinked records N (%) | Total pedestrian crash records N (%) |
|---|---|---|---|
| **Gender** | | | |
| Female | 2,939 (42.5%) | 2,731 (38.0%) | 5,670 (40.2%) |
| Male | 3,979 (57.5%) | 4,448 (62.0%) | 8,427 (59.8%) |
| Total | 6,918 (100.0%) | 7,179 (100.0%) | 14,097 (100.0%) |
| **Age group** | | | |
| 0-9 | 393 (5.7%) | 344 (4.8%) | 737 (5.2%) |
| 10-19 | 1,109 (16.0%) | 993 (13.7%) | 2,102 (14.9%) |
| 20-29 | 1,512 (21.9%) | 1,762 (24.4%) | 3,274 (23.1%) |
| 30-39 | 1,009 (14.6%) | 1,187 (16.4%) | 2,196 (15.5%) |
| 40-49 | 1,026 (14.8%) | 1,115 (15.4%) | 2,141 (15.1%) |
| 50-59 | 949 (13.7%) | 874 (12.1%) | 1,823 (12.9%) |
| 60-69 | 551 (8.0%) | 521 (7.2%) | 1,072 (7.6%) |
| 70-79 | 249 (3.6%) | 216 (3.0%) | 465 (3.3%) |
| 80+ | 121 (1.7%) | 121 (1.7%) | 242 (1.7%) |
| Total | 6,919 (100.0%) | 7,233 (100.0%) | 14,152 (100.0%) |
| **Race/Hispanic ethnicity** | | | |
| White, not Hispanic/Latinx | 3,145 (46.1%) | 3,735 (52.3%) | 6,880 (49.3%) |
| Black, not Hispanic/Latinx | 3,081 (45.1%) | 2,749 (38.5%) | 5,830 (41.8%) |
| Hispanic/Latinx | 374 (5.5%) | 421 (5.9%) | 795 (5.7%) |
| NA/AI | 80 (1.2%) | 61 (0.9%) | 141 (1.0%) |
| Other race[1] | 147 (2.2%) | 169 (2.4%) | 316 (2.3%) |
| Total | 6,827 (100.0%) | 7,135 (100.0%) | 13,962 (100.0%) |
| **Injury severity** | | | |
| K: Killed | 206 (3.1%) | 671 (9.6%) | 811 (6.4%) |
| A: Disabling injury | 490 (7.3%) | 445 (6.3%) | 935 (6.8%) |
| B: Evident injury | 2,871 (42.6%) | 2,163 (30.8%) | 5,034 (36.6%) |
| C: Possible injury | 3,011 (44.7%) | 3,070 (43.8%) | 6,081 (44.2%) |
| O: No injury | 161 (2.4%) | 664 (9.5%) | 825 (6.0%) |
| Total | 6,739 (100.0%) | 7,013 (100.0%) | 13,752 (100.0%) |
| **Hour of crash** | | | |
| 0:00-3:59 | 580 (6.4%) | 580 (7.9%) | 1,025 (7.2%) |
| 4:00-7:59 | 596 (8.6%) | 608 (8.3%) | 1,204 (8.4%) |
| 8:00-11:59 | 974 (14.1%) | 971 (13.2%) | 1,945 (13.6%) |
| 12:00-15:59 | 1,528 (22.1%) | 1,592 (21.7%) | 3,120 (21.9%) |
| 16:00-19:59 | 2,009 (29.0%) | 2,004 (27.3%) | 4,013 (28.1%) |
| 20:00-23:59 | 1,371 (19.8%) | 1,586 (21.6%) | 2,957 (20.7%) |
| Total | 6,923 (100.0%) | 7,341 (100.0%) | 14,264 (100.0%) |

| Selected characteristics | Linked records N (%) | Unlinked records N (%) | Total pedestrian crash records N (%) |
|---|---|---|---|
| **Total** | **6,923 (100.0%)** | **7,341 (100.0%)** | **14,264 (100.0%)** |

Abbreviations: NA, Native American; AI, Alaskan Native

[1]Other race contains “Asian” and “other race”.

### Table 28: Comparison of linked and unlinked pedestrian ED visit records (comparison of ED visit records with a pedestrian-related keyword or ICD-9-CM E-code, only)[1]

| Selected characteristics | Linked records N (%) | Unlinked records N (%) | Total pedestrian crash records N (%) |
|---|---|---|---|
| **Gender** | | | |
| Female | 2,364 (42.9%) | 5,507 (38.9%) | 7,871 (40.0%) |
| Male | 3,150 (57.1%) | 8,663 (61.1%) | 11,813 (60.0%) |
| Total | 5,514 (100.0%) | 14,170 (100.0%) | 19,684 (100.0%) |
| **Age group** | | | |
| 0-9 | 322 (5.8%) | 1,000 (7.1%) | 1,322 (6.7%) |
| 10-19 | 920 (16.7%) | 2,096 (14.8%) | 3,016 (15.3%) |
| 20-29 | 1,220 (22.1%) | 3,640 (25.7%) | 4,860 (24.7%) |
| 30-39 | 796 (14.4%) | 2,486 (17.6%) | 3,282 (16.7%) |
| 40-49 | 787 (14.3%) | 2,107 (14.9%) | 2,894 (14.7%) |
| 50-59 | 756 (13.7%) | 1,514 (10.7%) | 2,270 (11.5%) |
| 60-69 | 429 (7.8%) | 758 (5.4%) | 1,187 (6.0%) |
| 70-79 | 190 (3.4%) | 355 (2.5%) | 545 (2.8%) |
| 80+ | 95 (1.7%) | 188 (1.3%) | 283 (1.4%) |
| Total | 5,515 (100.0%) | 14,144 (100.0%) | 19,659 (100.0%) |
| **Admitted to hospital/died** | | | |
| Yes | 882 (16.0%) | 1,005 (7.4%) | 1,887 (9.8%) |
| No | 4,636 (84.0%) | 12,635 (92.6%) | 17,271 (90.2%) |
| Total | 5,518 (100.0%) | 13,640 (100.0%) | 19,158 (100.0%) |
| **Arrived via ambulance** | | | |
| Yes | 3,235 (69.6%) | 4,501 (37.0%) | 7,736 (46.1%) |
| No | 1,411 (30.4%) | 7,651 (63.0%) | 9,062 (53.9%) |
| Total | 4,646 (100.0%) | 12,152 (100.0%) | 16,798 (100.0%) |
| **Hour of ED visit** | | | |
| 0:00-3:59 | 435 (7.9%) | 1,425 (10.0%) | 1,860 (9.4%) |
| 4:00-7:59 | 342 (6.2%) | 826 (5.8%) | 1,168 (5.9%) |
| 8:00-11:59 | 850 (15.4%) | 2,203 (15.5%) | 3,053 (15.5%) |
| 12:00-15:59 | 1,123 (20.4%) | 2,970 (20.9%) | 4,093 (20.8%) |
| 16:00-19:59 | 1,522 (27.6%) | 3,706 (26.1%) | 5,228 (26.5%) |
| 20:00-23:59 | 1,246 (22.6%) | 3,051 (21.5%) | 4,297 (21.8%) |
| Total | 5,518 (100.0%) | 14,181 (100.0%) | 19,699 (100.0%) |
| **Total** | **5,518 (100.0%)** | **14,181 (100.0%)** | **19,699 (100.0%)** |

Abbreviations: NA, Native American; AI, Alaskan Native

[1]Records for the 1,405 ED visits identified as pedestrian injury-related only through linkage (i.e., did not contain a pedestrian injury-related keyword or ICD-9-MC E-code) were excluded from analyses, as these records were not a subset of the 19,699 pedestrian injury-related ED visits identified prior to linkage.

# Appendix III: Barell Injury Diagnosis Matrix

## Frequency of pedestrians treated at NC emergency departments, categorized according to the Barell Injury Diagnosis Matrix (N=6,923)[1,2]

| Location | Fracture | Dislo-cations | Sprains & strains | Internal | Open wounds | Ampu-tations | Blood vessels | Contusions/ Superficial wounds | Crush | Burns | Nerves | Unsp. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TBI | 165 (2.4) | | | 472 (6.8) | | | | | | | * | | 614 (8.9) |
| Other head | 196 (2.8) | * | * | | 581 (8.4) | | * | 711 (10.3) | 0 (0.0) | * | * | 593 (8.6) | 1,921 (27.7) |
| Spinal cord | 18 (0.3) | | | 10 (0.1) | | | | | | | | | 26 (0.4) |
| Vertebral column | 270 (3.9) | 8 (0.1) | 473 (6.8) | | | | | | | | | | 746 (10.8) |
| Torso | 394 (5.7) | * | 121 (1.7) | 335 (4.8) | 38 (0.5) | | 13 (0.2) | 615 (8.9) | 6 (0.1) | * | 0 (0.0) | 163 (2.4) | 1,415 (20.4) |
| Upper extremities | 519 (7.5) | 41 (0.6) | 177 (2.6) | | 173 (2.5) | * | * | 1,199 (17.3) | 6 (0.1) | * | * | 158 (2.3) | 2,028 (29.3) |
| *Upper arms* | 258 (3.7) | 33 (0.5) | 98 (1.4) | | | * | | 346 (5.0) | 0 (0.0) | *) | | 72 (1.0) | 790 (11.4) |
| *Lower arms* | 180 (2.6) | * | 21 (0.3) | | 93 (1.3) | 0 (0.0) | | 328 (4.7) | * | 0 (0.0) | | | 608 (8.8) |
| *Hands* | 110 (1.6) | 7 (0.1) | 65 (0.9) | | 57 (0.8) | 0 (0.0) | | 288 (4.2) | * | * | | 18 (0.3) | 496 (7.2) |
| *Unsp.* | 0 (0.0) | 0 (0.0) | 0 (0.0) | | 9 (0.1) | * | * | 408 (5.9) | * | 0 (0.0) | * | 77 (1.1) | 497 (7.2) |

| Location | Fracture | Dislo-cations | Sprains & strains | Internal | Open wounds | Ampu-tations | Blood vessels | Contusions/ Superficial wounds | Crush | Burns | Nerves | Unsp. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower extremities | 906 (13.1) | 52 (0.8) | 406 (5.9) | | 152 (2.2) | 5 (0.1) | 10 (0.1) | 1,802 (26.0) | 64 (0.9) | * | 0 (0.0) | 346 (5.0) | 3,205 (46.3) |
| *Hips* | 44 (0.6) | * | 42 (0.6) | | | | | 386 (5.6) | 0 (0.0) | | | | 471 (6.8) |
| *Upper legs* | 109 (1.6) | | | | 0 (0.0) | * | | 168 (2.4) | * | 0 (0.0) | | | 279 (4.0) |
| *Knees* | 17 (0.2) | 38 (0.5) | 22 (0.3) | | | | | 419 (6.1) | 5 (0.1) | 0 (0.0) | | | 491 (7.1) |
| *Lower legs* | 672 (9.7) | 6 (0.1) | 179 (2.6) | | | * | | 316 (4.6) | 15 (0.2) | * | | | 1,154 (16.7) |
| *Feet* | 135 (2.0) | 5 (0.1) | 36 (0.5) | | 40 (0.6) | * | | 253 (3.7) | 41 (0.6) | 0 (0.0) | | | 457 (6.6) |
| *Unsp.* | 19 (0.3) | | 156 (2.3) | | 116 (1.7) | * | 10 (0.1) | 601 (8.7) | * | * | | 346 (5.0) | 1,166 (16.8) |
| Other & unsp. injuries | 20 (0.3) | 0 (0.0) | 53 (0.8) | * | 45 (0.7) | | * | 943 (13.6) | * | 7 (0.1) | * | 310 (4.5) | 1,311 (18.9) |
| **Total** | **1,754 (25.3)** | **105 (1.5)** | **1,080 (15.6)** | **738 (10.7)** | **881 (12.7)** | **7 (0.1)** | **33 (0.5)** | **3,926 (56.9)** | **79 (1.1)** | **11 (0.2)** | **9 (0.1)** | **1,362 (19.7)** | **6,923 (100.0)** |

Abbreviations: TBI, traumatic brain injury; Unsp., Unspecified injuries.
[1]Injured pedestrians may have up to eleven different injury diagnoses; therefore, frequencies do not sum to 100%.
[2]Shaded areas indicate cells containing no corresponding ICD-9-CM diagnosis code.
*1-4 ED visits in cell; data are suppressed.

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