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An investigation of driver, pedestrian, and environmental characteristics and resulting pedestrian injury

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Abstract

Objective: Walking is integral to transportation and physical activity, but safety is a primary concern for pedestrians due to the increasing amount of injuries and deaths per year. To address the need for avenues of pedestrian safety improvements, this study's objective was to determine the association among driver and pedestrian characteristics and behavior, environmental characteristics, and the presence of injury resulting from a pedestrian-vehicle crash.

Methods: Pedestrian crashes were examined in Ohio from 2013–2017 using state crash records. Descriptive statistics as well as univariate and multivariable analysis were performed to estimate the odds of pedestrian injury.

Results: Of the 11,241 pedestrian crashes analyzed, 66% resulted in injury. The odds of pedestrian injury increased when the driver was male, the driver was under the influence of alcohol, the cause of the crash was the pedestrian darting, the pedestrian was struck while in the travel lane, the pedestrian was aged 65 or older, the pedestrian was under the influence of alcohol, or under dark conditions on an unlit roadway. Factors that lowered the odds of injury were pedestrian age 0–4, and vehicle maneuvers other than driving straight ahead, such as backing and turning.

Conclusion: These findings identify several factors associated with pedestrian injury and public health efforts that could influence pedestrian safety are discussed.

Keywords

pedestrian; injury; crash; state crash record

INTRODUCTION

As obesity related diseases and premature death continue to impact the health and well-being of individuals of all ages in the United States (US), objectives such as Healthy People 2020 aim to increase the proportion of walking trips to promote healthy lifestyles (U.S Department of Health and Human Services 2018). Whereas walkable communities have resulted in more physical activity and increased perceptions of safety among community members, in 2016 the National Highway Traffic Safety Administration (NHTSA) reported the highest number of pedestrian fatalities (approximately 6,000) since 1990 (National Center for Statistics and Analysis 2018). In addition, nearly 138,000 pedestrians in 2016 were treated in US emergency departments for non-fatal crash related injuries (Center for Disease Control and Prevention). As walking is not only an integral part of health and fitness but also a primary means of transportation for many individuals in the US, the National Transportation Safety Board in 2018 released recommendations to better investigate pedestrian crashes and promote safety. Of these recommendations, utilizing police crash records to evaluate pedestrian injuries and fatalities at the state-level were of noted interest (National Transportation Safety Board 2018).

Understanding the mechanisms of pedestrian crashes is complex as many factors contribute to these events (daSilva et al. 2003). For children, the built environment has been found to be directly related to the risk of pedestrian injury (DiMaggio and Li 2011). Among adults, more severe injuries have been found to be associated with driver intoxication or speeding, SUV or truck vehicle types, the age of the pedestrian, and travelling in the dark (Kim et al. 2010; Lee and Abdel-Aty 2005). Crashes where pedestrians were at fault were also found to result in more severe injuries than those in which the driver was found to be at fault (Ulfarsson et al. 2010).

While national reports primarily focus on pedestrian fatalities (National Center for Statistics and Analysis 2018), less investigated are the more common non-fatal injuries and their precipitating factors. Although identifying pedestrian fault has been studied (Kim et al. 2010; Lee and Abdel-Aty 2005; Ulfarsson et al. 2010), less is known about the specific precipitating factor of the respective party cited for fault and how those factors relate to subsequent pedestrian injury. Less common in the literature are comprehensive studies which take into account detailed pedestrian, driver, and environmental characteristics and their association with pedestrian injuries across the lifespan (Lee and Abdel-Aty 2005). Lastly, state-level investigations are lacking as states vary in the percentages of pedestrian injuries and fatalities (see Appendix for related literature). Uddin and Ahmed (2018) were the first to investigate the precipitating factors of pedestrian crash-related injury in Ohio, utilizing a 2009–2013 crash database to assess associations between pedestrian, driver, crash, roadway, and vehicle characteristics. While the findings helped establish an empirical insight into pedestrian crashes in Ohio, lacking is an investigation of factors that capture driver and pedestrian behaviors and characteristics of the built environment. Therefore, the objective of this study was to examine these aforementioned gaps in the pedestrian injury literature by investigating the complex and comprehensive associations among driver and pedestrian characteristics and behavior, environmental characteristics, and the presence of injury resulting from a pedestrian crash in Ohio using 2013–2017 data.

METHODS

Data Source

Data for this cross-sectional study were obtained from the Ohio Department of Public Safety (ODPS) Crash Data Extracts for years 2013–2017. When performing a routine crash report, Ohio law enforcement record all cases of traffic-related pedestrian injury, ranging from if there is no reported injury to if the injury is fatal. For each individual involved in the crash, police officers at the scene report injury outcomes on a 5-point scale, demographic characteristics, as well as information about the circumstances precipitating the crash based on first-hand observation and interviews. Ohio crash reports denote “contributing circumstance” rather than “fault”, stating what circumstance the officer determined as the cause of the crash. If the officer could not attribute the contributing circumstance to either the pedestrian or driver, then the contributing circumstance for that party was listed as “none”. Ohio police departments from all 88 counties submit crash forms, which are compiled, verified, and managed by the ODPS. This study was exempt from institutional review board approval as the de-identified data were obtained through public access. Variable values are determined by the law enforcement officer investigating the crash and the ODPS Traffic Crash Reports are in compliance with the NHTSA Model Minimum Uniform Crash Criteria Standards (*Traffic Crash Report Procedure Manual* 2011).

Cases of pedestrian injury were extracted if the individual was identified as a pedestrian and involved in a collision with only one vehicle in transport. Multiple vehicle crashes were removed to minimize uncertainty in assessing driver-vehicle contributing factors for a pedestrian crash. Unique document numbers are assigned to each crash, which allowed for driver information from each pedestrian-related crash to be extracted. There were 10,721

crashes, with 10,279 (95.88%) crashes involving only one pedestrian and 442 (4.12%) involving two or more pedestrians, with 11,241 pedestrians in total.

The outcome for this study was the presence of an injury resulting from a crash. The ODPS defines the injury severities (*Traffic Crash Report Procedure Manual* 2011) as the following:

1. No injury/none reported: No injury or no information about an individual being injured.
2. Possible injury: No visible injury but complaint of pain.
3. Non-incapacitating injury: Any injury that is evident but not an incapacitating or fatal injury.
4. Incapacitating injury: Any injury which prevents the person from continuing the activity they were doing prior to the crash occurring (i.e., walking).
5. Fatal injury: An injury that results in death up to 30-days after the crash occurs.

When assessing the distribution of pedestrian injury severity, 34% of crashes had no injury/possible injury, 43% had non-incapacitating injuries, 19% had incapacitating injuries, and 4% of crashes were fatal. To investigate factors associated with the presence of an injury, no injury/none reported and possible injury were recoded as “no injury present/possible injury,” and non-incapacitating injury, incapacitating injury, and fatal injury were recoded as “injury present”. Combining no injury and possible injury is consistent with previous literature (Kim et al. 2008; Kim et al. 2010; Uddin and Ahmed 2018).

Pedestrian and driver variables examined included age, sex, police suspected alcohol and drug use, pedestrian location prior to impact, pre-crash action, and contributing circumstance. Environmental and crash variables examined were year, day of week, light condition, and weather condition. When necessary, levels of categorical variables that were similar in nature were combined (see Table S1 for more detail).

Statistical Analysis

Frequencies and percentages were summarized for pedestrian, driver, and environmental characteristics by group (injury present vs. no injury present/possible injury; see Table S2). Generalized estimating equations (GEE) with logit link that account for clustering by crashes were included to address if multiple pedestrians were in one crash and to assess univariate associations between potential predictors and pedestrian injury severities. Variables with a p -value <0.10 were entered into a multivariable model. Variables were removed sequentially from the multivariable model using the backward selection method. Unadjusted and adjusted odds ratios (OR) and 95% confidence intervals (CI) were reported. Multiplicity was adjusted using the Dunnett method to compare each level of the independent variables to the reference level in the multivariable models. Complete multivariable models are provided within supplemental documents (Tables S3–S4). Summary-level tables presented in text contain statistically significant factors in the multivariable model with a p -value of <0.05 . Statistical analyses were conducted in SAS version 9.4 (SAS Institute Inc 2015).

RESULTS

The sample included 11,241 pedestrians involved in crashes in Ohio between 2013 and 2017, of these crashes 66% resulted in an injury. Most pedestrians (58%) and drivers (58%) involved in crashes were male. For age, 49% of pedestrians were 26–64 years old, and 65% of the drivers were 20–54 years old (Table S2). Most crashes occurred when the driver was driving straight ahead (58%), the pedestrian was walking, running, or playing, and during clear weather in the daylight (54%). More crashes occurred when the pedestrian was in an intersection at a marked crosswalk (33%) than when the pedestrian was in an unmarked crosswalk (13%) or at a crosswalk midblock (2%). Crashes where a contributing circumstance was assigned to the driver constituted 51% of the sample, and for pedestrians 53% of the sample. Drivers suspected of alcohol or drug use made up 3% of all crashes, and pedestrians suspected of alcohol or drug use made up 8%.

Characteristics with a p -value of <0.10 in the univariate analysis (Table S3) included driver age, driver sex, driver pre-crash action, driver contributing circumstance, driver alcohol status, pedestrian age, pedestrian pre-crash action, pedestrian contributing circumstance, pedestrian alcohol or drug status, pedestrian location, day of week, light condition, and weather condition. Driver, pedestrian, and environmental characteristics were entered into the multivariable analysis. By using the backward selection method driver age, driver sex, driver pre-crash action, driver alcohol or drug use, pedestrian age, pedestrian contributing circumstance, pedestrian alcohol or drug use, pedestrian location, and light condition were included in the final multivariable model (Table S4).

Multivariable Model

Driver Characteristics and Behavior—Compared to the reference group (35–54) the odds of pedestrian injury did not differ statistically in younger (19 and under, 20–34) or older drivers (55–64). Male drivers were not only overrepresented in the sample, but also had higher odds of being involved in a pedestrian crash that caused an injury compared to female drivers (OR: 1.13, 95% CI: 1.02, 1.25). Compared with driving straight ahead, turning right (OR: 0.52, 95% CI: 0.41, 0.66) and backing (OR: 0.62, 95% CI: 0.43, 0.90) were associated with lower odds of injury. Turning left also tended to have lower odds of injury compared to driving straight ahead (OR: 0.82, 95% CI: 0.64, 1.00). The driver being suspected of alcohol or drug use increased the odds of injury by 115% (OR: 2.15, 95% CI: 1.53, 3.01).

Pedestrian Characteristics and Behavior—When assessing age, pedestrians 0–4 years old were at 42% lower odds of injury (OR: 0.58, 95% CI: 0.40, 0.82) than pedestrians 26–64 years old. Furthermore, pedestrians 65 years old and older were at 44% higher odds of injury (OR: 1.44, 95% CI: 1.12, 1.87). The only statistically significant contributing circumstance of the pedestrian was darting, which increased the odds of pedestrian injury by 54% relative to not at-fault pedestrian crashes (OR: 1.54, 95% CI: 1.17, 2.02). The pedestrian being suspected of alcohol or drug use also increased the odds of pedestrian injury by 64% (OR: 1.64, 95% CI: 1.31, 2.05). Pedestrians located at intersections with unmarked crosswalks or at marked crosswalks midblock did not significantly differ in the

odds of injury compared to those struck at intersections with marked crosswalks. Lastly, pedestrians being in a travel lane increased the odds of injury by 27% (OR: 1.27, 95% CI: 1.01, 1.60) relative to the pedestrian being in a marked crosswalks at an intersection.

Environmental Characteristics—The environmental characteristics examined were year, day of week, light condition, and weather condition. After adjusting for other factors, the only environmental characteristic that was statistically associated with the odds of injury was light condition, with pedestrians being struck on dark not lighted roadways increasing the odds of injury by 49% (OR: 1.49, CI: 1.14, 1.93). The other environmental characteristics were no longer statistically associated with the presence of pedestrian injury after the backward selection method and Dunnett's correction.

DISCUSSION

Driver Characteristics and Behaviors

Driver factors, such as sex, pre-crash maneuvers, and alcohol or drug use were associated with pedestrian injury. Previous studies have also found statistically significant associations between the sex of the driver and the odds of pedestrian injury (Lee and Abdel-Aty 2005; Ulfarsson et al. 2010). Male drivers have consistently been found more likely to be involved in a crash resulting in more severe pedestrian injury (Kim et al. 2008; Kim et al. 2010). With the intention of minimizing risky driving behaviors, Lee and Abdel-Aty (2005) propose more intensive driver education and restrictive traffic regulations targeted at middle-aged male drivers as a way to reduce pedestrian crashes. Adjusting for sex differences, we found that other vehicle maneuvers besides driving straight ahead, which are often accompanied by reduced speed, were associated with lower odds of a pedestrian injury occurring. Turning vehicles have been associated with lower pedestrian fatalities and daSilva et al. (2003) explains differences as more likely the result of reduced speed rather than the vehicle maneuver itself. Regarding substance use, alcohol is known to impair driving, and although police-suspected alcohol or drug use among drivers made up a small percentage of crashes involving pedestrians from the current study, it was substantially associated with the increased odds of an injury occurring. Many studies at state and national levels using different data sets have also found a statistically significant association between driver intoxication and pedestrian injuries and crashes (Kim et al. 2008; Uddin and Ahmed 2018; daSilva et al. 2003).

Pedestrian Characteristics and Behaviors

Regarding pedestrian characteristics, location prior to impact, contributing circumstance, and alcohol or drug use were found to impact the odds of injury. Compared to marked crosswalks at intersections, the only pedestrian location prior to the crash that was associated with the odds of injury was the pedestrian being in the travel lane. A high percentage of crashes occurring at both marked and unmarked crosswalks along with mixed findings from other studies regarding crosswalks and odds of injury (see Appendix for related literature) highlight the importance of improving the safety of designated areas that are often the only appropriate route of travel for pedestrians. Both engineering measures, such as the design of

the built environment (Retting et al. 2003), and behavioral differences that occur at marked versus unmarked crosswalks (Mitman et al. 2008) could help explain discrepancies.

Pedestrian age was also found to have a strong association with the odds of injury. The youngest pedestrians (0–4 years old) were associated with lowest odds of injury, while the oldest pedestrians (aged 65 and older) were associated with highest when compared to pedestrians aged 26–64. This suggests a different pattern of injury for the youngest and oldest pedestrians, with both groups representing vulnerable pedestrian populations that disproportionately experience the burden of crash-related injury. Whereas more research is needed on age-dependent injury mechanisms, research has shown death was significantly higher for elderly pedestrians than younger pedestrians when struck at the same speed, which can be partly attributed to anatomic distribution and physiological characteristics, making pelvic fractures and spinal injuries more likely with older age (see Appendix for related literature). Furthermore, old age (65 and older) has also been associated with a higher probability of a pedestrian crash occurring due to cognitive decline and slower walking speed (Dommes and Cavallo 2011), making this population especially vulnerable. Children aged 0–4 may experience a different pattern of crash location, as research has shown that children aged 0–4 were more frequently injured in low-speed vehicle run-overs compared to other age groups of children (see Appendix related literature). The lower odds of injury for this age group may be attributed to children aged 0–4 being more likely to be accompanied by adults, as Schroeder and Wilbur (2013) found that only 1% of parents thought children 4 years old were old enough to cross neighborhood streets alone.

For children older than four years old, crossing the street safely is a learned behavior that must be taught. Children with disabilities have also been found to be more likely to be hit by a motor vehicle than those without a disability (Xiang et al. 2006). Inexperience with road crossing behavior is especially important when combined with the dangers of darting, as findings from daSilva et al. (2003) revealed darting crashes primarily involve children 14 and under. Both younger children and older adults have different cognitive abilities than adults, demonstrating a need for tailored pedestrian interventions.

The degree to which pedestrian alcohol or drug use moderates injury severity still remains inconclusive, yet findings show its association with pedestrian fatalities (National Transportation Safety Board 2018). Contextual factors that may impact alcohol usage and law enforcements' recording of alcohol and drug use may help explain variations within and between states. Alcohol-impaired pedestrians are an area of future intervention as mechanisms are in place at federal and state levels to target this group of road users (see Appendix for related literature). Implementing interventions that target pedestrian crashes at night may be effective as Lee and Abdel-Aty (2005) found that pedestrian alcohol or drug use leads to more crashes at night, compounding the dangers of dark lighting and the potential for the impact to be at a higher speed.

Environmental Characteristics

Of the environmental characteristics investigated, light condition was the only one associated with the odds of pedestrian injury. Our findings revealed that dark conditions without roadway lighting increased the odds of injury compared to daylight conditions.

These findings partly support Kim et al., (2010) who investigated pedestrian injury from North Carolina and found roadways under dark conditions with and without streetlights to be associated with higher risk of severe injury. Findings related to dark conditions and poorly lighted roadways support interventions and research designed to enhance pedestrian visibility with reflective garments placed in biomarker patterns to help drivers better distinguish pedestrian movement in poor lighting conditions (Wood et al. 2017). While this study did not detect an association between weather and the odds of pedestrian injury in Ohio, evidence of weather associations have been cited in pedestrian injury studies from states in the southeast (Kim et al. 2010; Lee and Abdel-Aty 2005). While more investigation is needed, differences in environmental characteristics could be partly dependent on state differences in climate, terrain, rurality, and pedestrian safety culture.

Limitations

Although this study captured many aspects of pedestrian-related crashes, limitations were still present. The population studied was pedestrians in Ohio, therefore discretion is advised when translating these findings to other states with features such as higher population density, distinct traffic patterns, different terrain, or different safety culture. Although state-by-state variations exist, the methodology and results alluded to generalizability of our findings. As we captured both crash-related fatalities and injuries in metropolitan and rural communities, we had similar findings to another state-level study of pedestrian injury in a different US region (Kim et al. 2010). While the current findings only focused on Ohio, having specific state data may be a benefit in situations which allow for localized interventions and can contribute to the goal of creating a state-level national database of pedestrian injuries and fatalities (National Transportation Safety Board 2018). Second, traffic crash reports may be subjected to unaccountable bias. Due to the nature of traffic crash reports, the determination of injury severity relies upon the judgement of the officer at the scene. Additionally, only reported crashes were investigated. While underreporting is a limitation in any study using police crash reports, previous research has shown that both pedestrians and drivers have motivation to report crashes of all impact (Kim et al. 2008). Moreover, we could not investigate all variables of interest such as vehicle weight and speed, which also may influence injury severity. While certain characteristics were not captured, the ODPS emphasizes timely and accurate crash reporting and uses a uniform electronic reporting system across the state, which is compliant with the NHTSA Model Minimum Crash Criteria Standards (*Traffic Crash Report Procedure Manual* 2011). Lastly, it is also important to note that none of the associations have a causal relationship, to better understand associations pedestrian behaviors and exposure should be further considered.

In conclusion, separating the characteristics of a pedestrian crash in this manner provides novel insight on pedestrian safety. The findings from this study, combined with other studies of pedestrian injury and crash frequencies, can help inform pedestrian safety measures that limit both injury and occurrence. These behavioral, demographic, and crash-related factors highlight the need for multidisciplinary interventions to mitigate pedestrian injury. Furthermore, the current study has provided several potential avenues for interventions, particularly targeting pre-crash behaviors, environmental characteristics, and vulnerable age groups, such as children and older adults. Lastly, pedestrian crash investigations similar to

the current study utilizing state crash reports can help support and implement national efforts to link highway crash and hospitalization data (National Transportation Safety Board 2018) to provide a more holistic view of injury data as seen with crash-related injuries and fatalities (Sauber-Schatz et al. 2015).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1:

Summary of statistically significant driver and environmental characteristics

Characteristics	Odds Ratio	95% CI	p-value
Driver Sex (reference: female)			
Male	1.13	(1.02, 1.25)	0.018
Driver Pre-crash action (reference: straight ahead)			
Backing	0.62	(0.43, 0.90)	0.005
Turning Right	0.52	(0.41, 0.66)	<0.001
Other	0.64	(0.49, 0.85)	<0.001
Driver Alcohol/drug suspected (reference: no)			
Yes	2.15	(1.53, 3.01)	<0.001
Environmental Light condition (reference: daylight)			
Dark- roadway not lighted	1.49	(1.14, 1.93)	<0.001*

Table 2:

Summary of statistically significant pedestrian characteristics

Characteristic	Odds Ratio	95% CI	p-value
Pedestrian Age (reference: 26–64)			
0–4	0.58	(0.40, 0.82)	<0.001
65+	1.44	(1.12, 1.87)	0.001
Pedestrian Contributing circumstance (reference: none)			
Darting	1.54	(1.17, 2.02)	<0.001
Pedestrian Alcohol/drug suspected (reference: no)			
Yes	1.64	(1.31, 2.05)	<0.001
Pedestrian Location prior to impact (reference: Marked crosswalk-intersection)			
Travel lane	1.27	(1.01, 1.60)	0.033