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The risk of pedestrian injury and fatality in collisions with motor vehicles, a social ecological study of state routes and city streets in King County, Washington

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A B S T R A C T

This study examined the correlates of injury severity using police records of pedestrian–motor-vehicle collisions on state routes and city streets in King County, Washington. Levels of influence on collision outcome considered (1) the characteristics of individual pedestrians and drivers and their actions; (2) the road environment; and (3) the neighborhood environment. Binary logistic regressions served to estimate the risk of a pedestrian being severely injured or dying versus suffering minor or no injury.

Significant individual-level influences on injury severity were confirmed for both types of roads: pedestrians being older or younger; the vehicle moving straight on the roadway. New variables associated with increased risk of severe injury or death included: having more than two pedestrians involved in a collision; and on city streets, the driver being inebriated.

Road intersection design was significant only in the state route models, with pedestrians crossing at intersections without signals increasing the risk of being injured or dying.

Adjusting for pedestrians' and drivers' characteristics and actions, neighborhood medium home values and higher residential densities increased the risk of injury or death. No other road or neighborhood environment variable remained significant, suggesting that pedestrians were not safer in areas with high pedestrian activity.

1. Introduction

Collisions between pedestrians and motor vehicles are an unfortunate part of modern life, and their outcome is often tragic and costly. Because of their light and fragile bodies and low travel speeds, pedestrians involved in collisions are at a definite disadvantage relative to drivers or vehicle occupants. To wit, nationwide U.S. pedestrian fatalities have loomed between 11% and 12% of all traffic related fatalities (National Center for Statistics and Analysis, 2008).

Estimated societal costs of a fatality or an injury resulting from motor-vehicle crashes have varied because of difficulties in monetizing many of the indirect costs of a collision outcome (e.g., loss of bodily and mental functions, productivity, etc.). In the U.S., low figures are about $300 billion per year for all motor-vehicle crashes (Delucchi, 2006). The Abbreviated Injury Scale puts an individual fatality at $3 million (1994 dollars), a critical injury at $1.98 million, and a severe injury at $0.49 million. Thus at $3 million each, the 4900 U.S. pedestrian deaths would cost about $15 billion per year. Because a disabling injury is poorly measured as a one-off cost associated with the year the person was injured, some studies evaluate the Potential Years of Life Lost or Disability Adjusted Life Years, which accounts for the indirect costs of a collision over a person's entire life cycle (Blincoe et al., 2002; Victoria Transport Policy Institute, 2008).

Most safety programs have aimed at reducing the frequency of pedestrian–vehicle collisions, but few have focused specifically on reducing the risk of severe injury or death (Campbell et al., 2004). Reducing rates of pedestrian mortality and morbidity seems timely, particularly in the many urban and urbanizing areas where the prevalence of people walking and pedestrian exposure to traffic are greatest. More than two-thirds of pedestrian fatalities took place in cities, with only 13% of the cities accounting for more than two-thirds of total pedestrian deaths between 1997 and 2006 (National Center for Statistics and Analysis, 2008). Future population growth alone will lead to increases in the absolute number of people walking. In addition, policy-induced increases in population-wide amounts of walking are expected to address the multiple woes of

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traffic congestion (high fossil fuel consumption and related costs, diminishing air and water quality, and pandemic increases in rates of personal physical inactivity and overweight) through increases in "active travel" (Frumkin et al., 2004).

Precedents show that lowering the number of pedestrian fatalities is an achievable safety goal. Between 1975 and 2001, Germany and the Netherlands have willfully cut the total number of pedestrian deaths by 82% and by 73%, respectively. Traffic injuries fell by an average of 53% in Denmark, England, Germany, and the Netherlands as a result of policies to calm traffic in neighborhoods (Pucher and Dijkstra, 2003).

2. Objectives and rationale

This study examined the factors associated with the severity of injury sustained by or the death of pedestrians involved in collisions with motor vehicles. Specific objectives were (1) to estimate the odds of a pedestrian dying or being disabled as a result of a collision with a motor vehicle; and (2) to identify significant correlates of collision injury severity outcomes, which would inform pedestrian safety policies and shape safety programs to reduce the number of fatal collisions and of severe injuries resulting from a collision.

Predicting and, correspondingly, preventing, collisions ending in a pedestrian's disabling injury or death is in some ways simpler than anticipating collisions between pedestrians and motor vehicles: if a collision does occur, the basic laws of physics apply, whereby (1) the larger and the heavier the vehicle and (2) the faster the speed at which it moves, and (3) the smaller and the more physically fragile the pedestrian, the more severe the injury and the likelihood of the pedestrian dying.

Indeed, research has shown that younger and older pedestrians, with smaller and more feeble bodies, were disproportionately represented in collisions ending in fatality (Kong et al., 1996; Peng and Bongard, 1999; Zajac and Ivan, 2003; Campbell et al., 2004; Demetriades et al., 2004; Lee and Abdel-Aty, 2005). Vehicle size, weight, and design have also been associated with specific injury types and traumas (Ballesteros et al., 2004). And the risk of a pedestrian dying of a collision with a motor vehicle is estimated to jump from 5% to 45% when the speed of the striking vehicle increases from 20 to 30 mph; it is 85% when vehicular speed reaches 40 mph (Limpert, 1994; Leaf and Preusser, 1999; Victoria Transport Policy Institute, 2008).

Of these three primary determinants of severe injury or fatality, vehicular speed is the one that safety programs could readily alter in the short term. Making the young and the old safer entails long-term safety education, and reducing the size or improving the design of vehicles demands structural changes in the automobile industry. But reducing vehicular speeds, especially in areas where there are pedestrians as has been done in Northern Europe, can be achieved by changing and enforcing one traffic regulation.

The determinants of a collision injury outcome are few and clear. Yet the causal path which begins with a collision not being avoided and ends in injury or death is complex, because the three determinants of injury severity interact in different ways to modify outcomes. While, for instance, heavy vehicles such as sport utility vehicles, pickup trucks, and vans are associated with higher rates of fatality than passenger cars, research has shown that the heavier vehicles most affect the risk of severe injury or death for children under 8 years old (Starnes and Longthorne, 2003). And although little is known about the effect of poor vehicle maintenance on injury outcomes, it is likely that faulty headlights or brakes account for many injury crashes (Treat, 1980). The behavior and actions of pedestrians also affect a collision outcome: the fact that in every age category, more male than female die of a collision with a motor vehicle is explained by males exhibiting higher risk behaviors than females (Campbell et al., 2004). In 2000, the fatality rate of male pedestrians was twice that of female pedestrians (National Center for Statistics and Analysis, 2008). Also, pedestrians under the influence of alcohol have been shown to engage in risky road-crossing behaviors (Lee and Abdel-Aty, 2005; Oxley et al., 2006; Spainhour et al., 2006).

Other modifiers of collision outcome include driver and pedestrian perceptive abilities just before collisions take place: fatal pedestrian crashes tend to occur during night time hours. Relative to dark conditions or no street lighting, daylight has been shown to reduce the odds of a fatal injury by 75% at mid-block locations and by 83% at intersections. Street lighting appears to reduce the same odds by 42% at mid-block locations and by 54% at intersections (Guttenplan et al., 2006). Driver's attentiveness and concentration also matter. They are known to affect the frequency of collision, but little research exists that relates these states to injury severity: it is difficult for example to measure how driver's attentiveness is related to increased differential between a vehicle travel speed and speed at impact.

Individual behaviors, perceptions and attentiveness are in turn affected by the environment through which people travel. Weather and light affect drivers' ability to reduce speed, although weather conditions have not been directly related the risk of injury (DiMaggio and Durkin, 2002). Many aspects of road design have also been associated with severity of injury: on a two-lane road, crash severity did not differ significantly for collisions occurring at marked and unmarked crosswalks, but on multi-lane roads, there was evidence of more fatal crashes at marked crosswalks compared to unmarked crosswalks (Zegeer et al., 2002). The width of a street was also found to be positively related to pedestrian injury severity (Zajac and Ivan, 2003). Child pedestrian injury rates were found to be 2.5 times higher on one-way than on two-way streets—46.4 per 100,000 children aged 0–14 per 100 km of one-way street versus 19.6 per 100,000 children on two-way streets (Wazana et al., 2000). A study examining the crash severity levels of all traffic collisions at signalized intersections found that crashes involving a pedestrian or a bicyclist and a motor vehicle turning left had a high probability of resulting in severe injury (Abdel-Aty and Keller, 2005). Finally, a study found that low-speed streets with on-street parking had the lowest fatal and severe crash rates of any road category, suggesting that presence of parking had a measurable effect on vehicle speeds (Marshall et al., 2008).

The characteristics of the area or the neighborhood have mattered as well. Severity of pedestrian injury was found to be higher outside of urban areas (25% of fatal pedestrian crashes occur in rural areas) (Campbell et al., 2004). In standard statistical regions of the U.K., lower income areas and increased per capita expenditure on alcohol were associated with more serious pedestrian injuries (Noland and Quddus, 2004). Also in the U.K., a quadratic relationship was found between urban density (population and employment captured at the scale of a ward) and pedestrian casualties: pedestrian casualties increased with density, but decreased in the most dense wards (Graham and Glaister, 2003).

3. Methods

3.1. Study design

This study included all reported individual pedestrians involved in collisions on state routes (1999–2004) and city streets (2000–2004) in King County, Washington. Derived from the federally mandated Fatality Analysis Report System (FARS) protocols, yet including all reported collisions regardless of injury outcome, these unique state-level data were compatible with detailed data on transportation networks and land uses. Having a full sample of the reported collisions opened opportunities to examine many possible influences on collision occurrences and outcomes. The same data were used to analyze the odds of a collision taking place in a location regardless of its injury outcome (Moudon et al., 2008)

Using the literature on the personal and environmental determinants of walking (Hess et al., 2004; McCormack et al., 2008), on pedestrian safety and on the many factors known to be associated with injury severity, we used three domains of influence to structure the study's conceptual framework:

(1) the individual socio-demographic profiles of pedestrians and drivers, and their behaviors and actions;
(2) the road environment including road design and traffic characteristics; and
(3) the neighborhood environment related to walking and walkability.

The literature review showed that the first domain had been well covered, providing useful information on the relationships between injury severity and pedestrians and drivers' characteristics and actions. The second domain had also been examined, with a focus on the effects of the characteristics of roads on injury severity. In contrast, the third domain remained understudied. We wanted to test the hypothesis that pedestrians colliding with motor vehicles in neighborhood environments known to have more people walking (i.e., densely populated, with pedestrian activity generators, high bus ridership, etc.) were less likely to sustain severe injury or to die than those involved in a collision in areas with low incidence of walking. Furthermore, we investigated this effect by controlling for the characteristics of individual pedestrians and drivers, and their actions, and for the collision temporal and design environment. This analysis would lead to identify the ingredients of safety strategies that aimed at areas with a substantial population of pedestrians, and where walking should be safe.

State routes and city streets were included for comparative purposes because they differed as transportation facilities and in their road environments. While state routes in King County were originally designed as trans-regional vehicular transportation facilities, they have increasingly carried local traffic within growing cities and suburbs and served as principal transit corridors (Hess et al., 2004). Therefore, while state routes typically carried large volumes of traffic at higher speeds than city streets, they also had to accommodate the large numbers of pedestrians who were transit users.

The urbanized area of King County served as the study's spatial extent. The county had slightly more than 28% of the State population (almost 1.8 million in 2005), yet had a disproportionate 44.0% of all statewide pedestrian collisions. It also had 34.4% of the pedestrian fatalities and 41.7% of the disabling injuries in the state. Of the pedestrian collisions on King County's state routes, 6.8% ended in a fatality and 16.6% in a disabling injury. This compared to a relatively low 1.8% of pedestrian collisions on city streets in the county ending in a fatality and 12.6% ending in a disabling injury (Fig. 1).

3.2. Data sources

Collision data came from the Transportation Data Office of the Washington State Department of Transportation's Strategic Planning and Programming Division. They originated from collision reports submitted by police officers and citizens, and included the socio-demographic and behavioral characteristics of pedestrians and drivers; road class, conditions, and design where the collision occurred; and time of day and year and weather conditions when the collision occurred. Individual collision records were compiled in a geocodable flat file containing milepost or address information.

Objective data on the road environment came from the Puget Sound Regional Council (PSRC), which provided average annual weekday daily traffic figures and estimated speed on state routes (AADT and estimated speed were EMME2 modeled data); from King County Metro, which provided bus ridership data; and from WSDOT, which provided traffic signals, intersections, crosswalks, sidewalks, and number of traffic lanes. The PSRC and WSDOT data were available for state routes and major arterials only. Speed limits were used for local and minor streets.

Objective data on the neighborhood environment came from the King County Assessor's office, which provided land use, property assessment values, and residential density data at the parcel or tax lot level. Employment data were generated at the Urban Form Lab (Moudon and Sohn, 2005).

3.3. Measurements

3.3.1. Geocoding

For state routes, 90% of the collisions involving pedestrians could be geocoded by using milepost data with a spatial resolution of 1/10th of a mile. However, the distribution of geocoded and total collisions was similar, with approximately 94% of the reported and geocoded collisions involving one pedestrian, 5% involving two pedestrians, and about 1% involving three pedestrians.

For city streets, 93.5% of the collisions involving pedestrians could be geocoded on the King County street network by using location data on primary traffic way, block number, intersecting traffic way, and/or a reference street. The distribution of geocoded and total collisions was similar, with approximately 96% of the collisions involving one pedestrian, 3.5% involving two pedestrians, and about 1% involving three or more pedestrians. However, poor collision address records meant that 16% of the geocoded collisions were located at the nearest intersection even though they might not have occurred at an intersection.

3.3.2. Dependent variables

The dependent variable was the degree of severity of injury, including death, sustained by a pedestrian involved in a collision with a motor vehicle. Police records on pedestrian injury contained seven categories of severity: dead at scene, dead on arrival, dead at hospital (within 30 days), disabling injury, evident injury, possible injury, and no injury.

Our models aggregated injury severity into two and five classes. The five classes were those of the KABCO injury recording system, which defines injury as "bodily harm to a person" (Hauer, 2006) (citing ANSI D16.1–1996 American National Standard, 1996 Manual on Classification of Motor Vehicle Traffic Accidents, Section 2.3). KABCO stands for the following: K = fatal injury; A = incapacitating injury; B = non-incapacitating evident injury; C = possible injury; O = no injury. The KABCO injury recording system collapses the three subcategories of fatality used in the police records into one. It has been used in a number of studies (Duncan et al., 1998; Zajac and Ivan, 2003; Lee and Abdel-Aty, 2005; Guttenplan et al., 2006). The two-injury class models combined KABCO's categories K and A into one class, and B, C, and O into another. These two classes were called fatal/high injury severity and low/no injury severity. This binary system has been used in previous research (Shankar et al., 2006).

3.3.3. Independent variables from police record variables

Police records provided data for two of the study domains: the individual characteristics of pedestrians and drivers and their actions at the time and location of the collision; and the road environment at the collision location, including the temporal and weather dimensions of collisions, the road surface and lighting conditions, and road classification. Table 1 (columns A through C) lists the variables selected from these data.

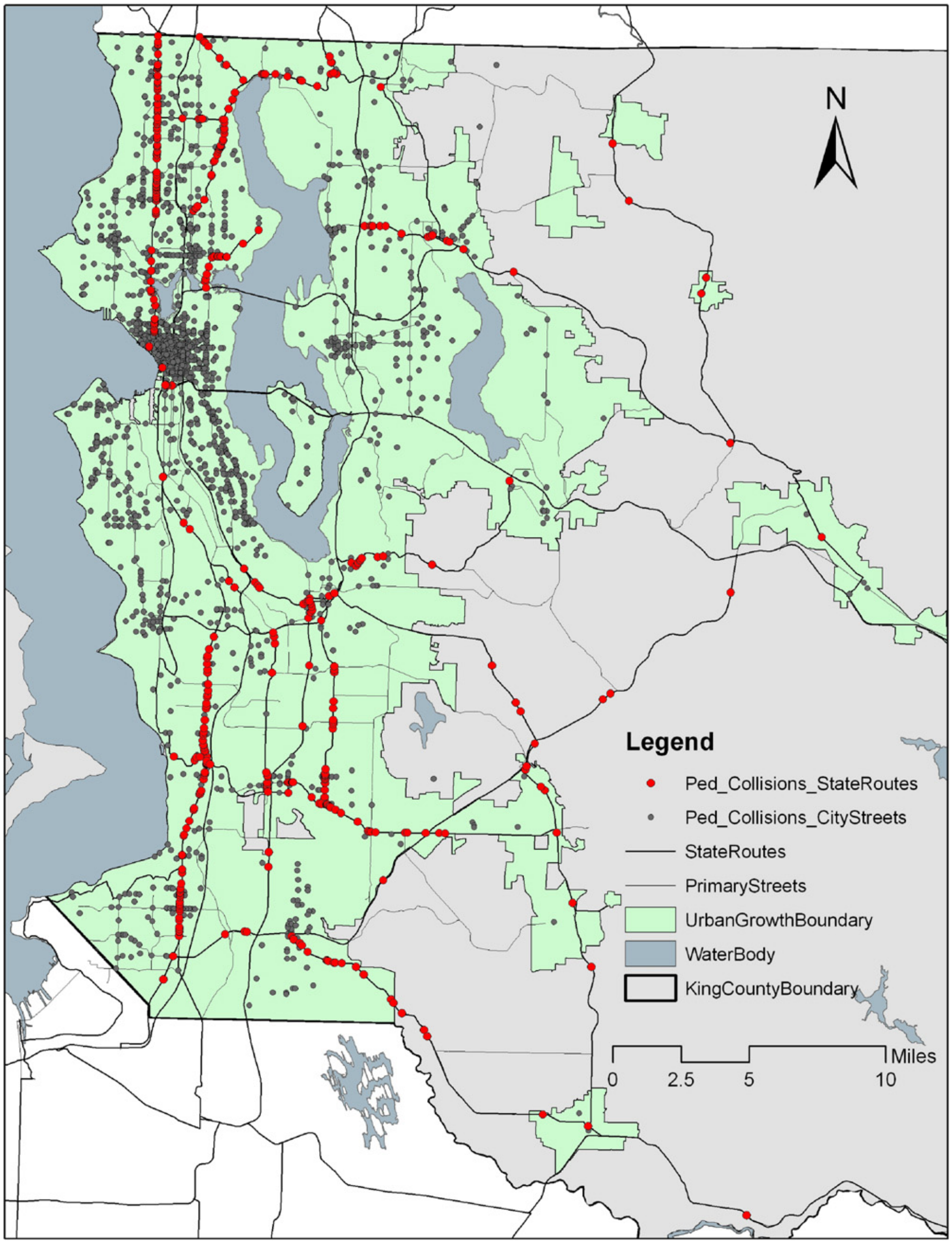

Fig. 1. Pedestrian collision locations on state routes and city streets in King County, Washington (1999–2004).

3.3.4. Objectively measured environment variables

Variables capturing the objectively measured (i.e. using measures of the actual physical environment as different from those based on reported police records) road and neighborhood land use environment were measured by using a 0.5 km airline buffer radius from each collision point (Table 2 columns A through C). A common pedestrian travel “catchment” area, this buffer size was used in previous research (Moudon et al., 2008). For this research, tests were carried out with 1.0 km and 1.5 km buffer, but fewer variables were significant in the bivariate tests than variables measured in the 0.5 km buffer. Both count measures and measures of shortest distance from a collision to attractor destinations were also tested in the models. Measures were taken by using GIS routines developed in previous projects.

Variables portraying the road design environment included the number of lanes at the collision location; the presence of pedestrian infrastructure in the form of sidewalks, crosswalks, street-block size, and traffic signals on all roads or streets within the collision buffer area.

Attributes of neighborhood environment known to be associated with higher probabilities of walking were taken from the results of a previous study, the Walkable and Bikeable Communities project (WBC), which had been validated for King County. Documented elsewhere (Moudon et al., 2007) the study isolated 14 objectively measured land use and transportation infrastructure variables significantly associated with walking at health-enhancing levels. They included shorter distances to grocery stores/markets, restaurants, and retail stores, but longer distances to offices or mixed-use buildings. The density of the respondent’s parcel was also strongly associated with more walking. Other research had supported the WBC study findings. Transit use had been associated with more pedestrian travel as well as with locations of multiple pedestrian collisions (Hess et al., 2004). Neighborhood wealth and neighborhood destinations had been shown to attract

Table 1
Independent variables obtained from the collision reports and selected for the base models.

A Level	B Domain	C Variables	State routes		City streets	
			D Measurement and number of observations for each category	E Type	D Measurement and number of observations for each category	E Type
Individual level	Pedestrian socio-demographic characteristics	Age	Min: 0, max: 92, mean: 36.50, SD: 19.11 Unknown: 29, entered with average age	Continuous	11: 0–4: 37; 12: 5–9: 96; 13: 10-14: 174; 14: 15–24: 460; 15: 25–44: 676; 16: 45–64: 523; 17: 65–74: 106; 18: 75 and above: 124; 19: unknown: 261	Categorical
		Gender	Male: 188; female: 115, unknown: 454	Categorical	Male: 788, female: 685, unknown: 984	Categorical
	Pedestrian behavior characteristics (action)	Inebriety	Have not been drinking: 665, have been drinking: 92	Dummy	Have not been drinking: 2386, have been drinking: 71	Dummy
		Action and location	Walking along roadway: 73, Xing-non-intersection: 207, Xing – at intersection with signal: 253, Xing – at intersection without signal: 92, other actions: 132	Categorical	Walking along roadway: 146, Xing-non-intersection: 413, Xing – at intersection with signal: 442, Xing – at intersection without signal: 940, other actions: 516 (include 11 unknown)	Categorical
		Number of pedestrians	One pedestrian involved: 670, more than one pedestrian involved: 87	Dummy	One pedestrian involved: 2259, more than one pedestrian involved: 198	Dummy
	Driver behavior	Inebriety	Have not been drinking: 721, have been drinking: 36	Dummy	Have not been drinking: 2401, have been drinking: 56	Dummy
	Driver vehicle action	Action and location	Going straight ahead: 419, making right turn: 188, making left turn: 96, other actions: 54	Categorical	Going straight ahead: 1136, making right turn: 480, making left turn: 540, other actions: 301 (include 23 unknown)	Categorical
		Number of vehicles	One vehicle involved: 316, more than one vehicle involved: 441	Dummy	One vehicle involved: 2320 (include 17 unknown), more than one vehicle involved: 120	Dummy
Road environment	Temporal characteristics of collision	Peak times	Morning peak (6–9am): 87 Morning off-peak (9am–12pm): 88 Afternoon off-peak (12–4pm): 181 Afternoon peak (4–7pm): 177 Evening off-peak (7pm–6am): 224	Categorical	Morning peak (6–9am): 407 Morning off-peak (9am–12pm): 349 Afternoon off-peak (12–4pm): 721 Afternoon peak (4–7pm): 566 Evening off-peak (7pm–6am): 414	Categorical
		Light	Daylight/dawn/dusk: 402, dark/unknown/other: 355	Dummy	Daylight/dawn/dusk: 1680, dark/unknown/other: 777	Dummy
	Road characteristics	Road functional class	Principal arterial: 583, minor arterial: 93, interstate highway: 81	Categorical	C: collector road: 265, L: local road: 725, M: minor road: 683, P: primary road:784	Categorical
		Location	At roadway (non-intersection): 329, at intersection/intersection: 428	Dummy	At roadway (non-intersection): 896, at intersection/intersection: 1561	Dummy

Table 2
Independent variables measured objectively and used in the one-by-one tests.

A Level	B Domain	C Variable	State routes		City streets		
			D Measurement and number of observations for each category	E Type	C Variable	D Measurement and number of observations for each category	E Type
Road environment	Road characteristics	Distance to the closest intersection (log)	Min: −7.88, max: −0.6, mean: −4.17, SD: 1.36 Untransformed data: min: 2, max: 2905, mean: 193, SD: 320 (ft.)	Continuous	Distance to the closest intersection	Collisions happened at intersections: 1963, collisions happened outside intersections: 494 Untransformed data min: 0, max: 1056, mean: 35.9, SD: 109.5	Dichotomized
		Distance to the closest traffic signal (log)	Min: −6.09, max: −0.13, Mean: −3.4, SD: 1.14 Untransformed data: min: 12, max: 4634, mean: 354, SD: 597 (ft.)	Continuous			
		Number of lanes	2 lanes or fewer: 50, more than 2 lanes: 707	Dichotomized			
		Count of traffic signal in 0.5 km buffer	11 0–2 traffic signals: 91; 12 3–5 traffic signals: 75; 13 6–8 traffic signals: 121; 14 9–12 traffic signals: 214; 15 13–15 traffic signals: 103; 16 16–25 traffic signals: 101; 17 26+ traffic signals: 52 Untransformed data: min: 0, max: 65, mean: 11.37, SD: 8.5	Ordinal	Count of traffic signals in 0.5 km buffer	11 0 traffic signals: 216; 12 1 traffic signal: 186; 13 2 traffic signals: 263; 14 3 traffic signals: 237; 15 4 traffic signals: 255; 16 5–6 traffic signals: 212; 17 7–9 traffic signals: 208; 18 10–18 traffic signals: 258; 19 19–30 traffic signals: 244; 20 31+ traffic signals: 380 Untransformed data: min: 0, max: 66, mean: 13.59, SD: 17.185	Ordinal
		Total length of sidewalk in 0.5 km buffer	11 0 mile: 70; 12 ≤1 mile: 68; 13 1–2 miles: 123; 14 2–3 miles: 121; 15 3–4 miles: 112; 16 4–5 mile: 77; 17 5–6 miles: 62; 18 6–8 miles: 70; 19 >8+ miles: 54 Untransformed data: min: 0, max: 84,468, mean: 18,277, SD: 14,512 (ft.)	Ordinal	Total length of sidewalk in 0.5 km buffer in mile	Min: 0, max: 17.59, mean: 5.21, SD: 2.97 Untransformed data: min: 0, max: 92,880.1, mean: 27,521, SD: 15,678 (ft.)	Continuous
					Median block size in 0.5 km buffer, in acre and then log	Min: 0.64, max: 5.20, mean: 1.51, SD: 0.68 Untransformed data: min: 82,980, max: 7893,709, mean: 273,880, SD: 379,546 (ft.)	Continuous
	Traffic conditions	Distance to closest bus stop within 1.5 km buffer (log)	Min: 2.48, max: 8.57, mean: 5.35, SD: 1.18 Untransformed data: min: 12, max: 5280, mean: 500, SD: 1003 (ft.)	Continuous	Distance to closest bus stop within 1.5 km buffer (log)	Min: 2.56, max: 8.40, mean: 4.97, SD: 1.03 Untransformed data: min: −99, max: 4434, mean: 259, SD: 389 (ft.)	Continuous
		Median daily boardings and alightings per bus stop in 0.5 km buffer	11. 0 ridership: 138; 12. 1–5: 185; 13. 6–10: 132; 14. 11–20: 140; 15. 21–50: 106; 16. 50+ ridership: 56 Untransformed data: min: 0, max: 180, mean: 15.06, SD: 21.74	Ordinal	Median daily boardings and alightings per bus stop in 0.5 km buffer	0 boardings and alightings: 1579, one or more boardings and alightings: 878 Untransformed data: min: 0, max: 840, mean: 5.84, SD: 40.5	Dichotomized
		Average annual daily traffic in 0.5 km buffer (AADT)	Min: 3.85, max: 11.4, mean: 8.92, SD: 1.36 Untransformed data: min: 0, max: 89,376, mean: 13,825, SD: 12,908.	Continuous	Average daily traffic in 0.5 km buffer (AADT) (log)	Min: 0, max: 11.50, mean: 9.75, SD: 1.856 Untransformed data: min: 0, max: 99,141, mean: 29,757, SD: 21,511	Continuous
		Estimated mean speed in 0.5 km buffer	Min: 23, max: 70, mean: 35.03, SD: 6.97 (mph)	Continuous	Estimated mean speed in 0.5 km buffer	Min: 11, max: 30, mean: 24.91, SD: 2.351 (mph)	Continuous
		Count of collisions in 0.5 km buffer	11 1–2 collision: 136; 12 3–5: 102; 13 6–10: 187; 14 11–15: 122; 15 16–20: 91; 16 21–25: 66; 17 26+: 53 Untransformed data: min: 1, max: 37, mean: 11.07, SD: 8.473	Ordinal	Count of collisions in 0.5 km buffer (log)	Min: 0, max: 5.08, mean: 2.46, SD: 1.47 Untransformed data: min: 1, max: 161, mean: 30.23, SD: 40.242	Continuous

Neighborhood environment	Density	Net residential density in 0.5 km buffer (log)	Min:0, max: 5.63, mean: 2.32, SD: 0.93 Untransformed data: min: 0, max: 278.8, mean: 16.4, SD: 29.7 (units per acre)	Continuous	Net residential density in 0.5 km buffer (log)	Min: −2.25, max: 5.85, mean: 3.47, SD: 1.42 Untransformed data: min: 0, max: 345.547, mean: 63.46, SD: 80.8 (units per acre)	Continuous
					Gross population density in 0.5–km buffer (log)	Min: 0.45, max: 6.50, mean: 3.727, SD: 1.234 Untransformed data: min: 1.57, max: 662.5, mean: 90.1, SD: 115.4 (units per acre)	Continuous
		Net employment density in 0.5 km buffer (log)	Min: 0, max: 7.09, mean: 3.08, SD: 0.95	Continuous			
		Sum of employment in 0.5 km buffer (log)	Min:0, max: 11.45, mean: 6.79, SD: 1.86	Continuous			
					Total residential units in 0.5 km buffer (log)	Min:0, max: 10.33, mean: 7.04, SD: 1.24 Untransformed data: min: 0, max: 30,489, mean: 1844, SD: 1956	Continuous
	Land use destinations	Count of office parcels in 0.5 km buffer	11 0 office parcel: 94; 12 1–2 office parcels: 88; 13 3–5 office parcels: 84; 14 6–8 office parcels: 135; 15 9–11 office parcels: 111; 16 12–14 office parcels: 68; 17 15–20 office parcels: 85; 18 21–30 office parcels: 48; 19 31+ office parcels: 44	Ordinal	Size of closest office parcels in 1.5 km buffer (acre/log)	Min:0, max: 5.93, mean: 0.58, SD: 0.78 Untransformed data: min: 0, max: 16,375,378, mean: 126,177.94, SD: 781,563 ($ft.^2$)	Continuous
		Count of grocery store parcels in 0.5 km buffer	Have no grocery store parcel: 397, have at least one grocery store parcel: 360	Dichotomized	Distance to the closest grocery store (log)	Min: 3.22, max: 8.49, mean: 6.97, SD: 1.20 Untransformed data: min: 0, max: 4880, mean: 1500, SD: 1209 (ft.)	Continuous
		Count of NC_2 in 0.5 km buffer[a]	Have no C2 in 0.5 km buffer: 345, have NC2 in 0.5 km buffer: 412	Dichotomized	Distance to the closest NC_2 center (log)	Min: 2.08, max: 9.50, mean: 6.88, SD: 1.45 Untransformed data: min: 0, max: 4906, mean: 1248, SD: 1225 (ft.)	Continuous
		Acres of retail parcels in 0.5 km buffer	11 0 retail parcel: 81; 12. < 0.5 retail parcel: 70; 13. 0.5–1 retail parcel: 67; 14. 1–2 retail parcels: 85; 15. 2–3 retail parcels: 72; 16. 4–5 retail parcels: 74; 17. 5–7 retail parcels: 64; 18 7–10 retail parcels: 50; 19 10–12 retail parcels: 59; 20 12–13 retail parcels: 80; 21. 13+: 55	Ordinal	Distance to the closest retail parcel (log)	Min: 1.1, max: 8.49, mean: 5.38, SD: 1.40 Untransformed data: min: 0, max: 4842, mean: 526.6, SD: 785.1 (ft.)	Continuous
		Acres of drinking and eating establishments in 0.5 km buffer	11 0 acre: 143; 12 < 0.5 acre: 115; 13 0.5–1 acre: 164; 14 1–3 acres: 125; 15 3–10 acres: 131; 16 10+ acres: 79	Ordinal	Count of restaurant parcels in 0.5 km buffer	11 0 parcel: 487; 12 1–3: 767; 13 4–9:762; 14 10–16: 346; 15 17- above: 95 Untransformed data: min: 0, max: 21, mean: 5.04, SD: 4.99	Ordinal
					Count of high school parcels in 0.5 km buffer	No high school 228, have one or more high schools: 2229 Untransformed data: min: 0, max: 3, mean: 0.13, SD: 0.436	Categorical
	Neighborhood wealth	Median home value in 0.5 km buffer (dollars)	11 0–6000: 76; 12 6001–28,000: 100; 13 28,001–34,000: 109; 14 34,001–47,000: 182; 15 47,001–68,000: 123; 16 68,001–120,000: 105; 17 120001+: 62	Ordinal	Median home value in 0.5 km buffer (dollars)	11 0–6000: 295; 12 6001–28,000: 476; 13 28,001–34,000: 250; 14 34,001–47,000: 394; 15 47,001–68,000: 434; 16 68,001–120,000: 381; 17 120,001+: 227	Ordinal

[a] NC_2 is a measure of "neighborhood commercial center," which is defined as a cluster of at least one grocery store, one restaurant, and one retail outlet within 50 m of each other.

significantly more walking in different locales (McCormack et al., 2008).

Overall, the objectively measured environmental variables covered the social and physical neighborhood determinants of walking and included direct and indirect measures of exposure related to pedestrian and vehicular traffic volumes (Ragland and Mitman, 2007; Moudon et al., 2008).

3.4. Analyses

The unit of analysis was an individual pedestrian who was involved in a collision from 1999 to 2004 on state routes and 2000 to 2004 on city streets in King County.

3.4.1. Independent variable selection

Three criteria were used to select independent variables: (1) their importance based on previous studies that had found the variables to be significantly associated with pedestrian injury severity; (2) their significance in bivariate analyses with the dependent variables ($p < 0.05$); and (3) the availability, quality, or completeness of the data.

Bivariate analyses with the dependent variables used one-way ANOVA for continuous independent variables, Kendall's tau-*c* for ordinal variables, and contingency coefficients for categorical and dummy variables. Tables 1 and 2 (columns D and E) summarize the independent variables selected from the collision reports and from the objective data on the road and the neighborhood environments, respectively.

3.4.2. Statistical models

Binary logistic regression (unordered model) was applied to the model with the two fatal/high and no injury/low pedestrian injury severity categories, and ordinal logistic regression (ordered model) were used in the models with the five KABCO categories of injury severity. These two types of models have been used in previous studies (Shankar and Mannering, 1996; Savolainen and Mannering, 2007; Tay and Rifaat, 2007). Ordinal logistic or probit regression models account for the ordinal nature of injury categories. This model has had several applications since it was first employed in a traffic injury study in the 1990s (O'Donnell and Connor, 1996; Duncan et al., 1998; Quddus et al., 2002; Abdel-Aty, 2003; Austin and Faigin, 2003; Zajac and Ivan, 2003; Abdel-Aty and Keller, 2005; Lee and Abdel-Aty, 2005; Guttenplan et al., 2006).

3.4.3. Modeling process

A three-step process was used for both models. Based on the study's conceptual framework, the process was to examine objective built environmental variables associated with injury severity (in the domains of the road and neighborhood environments), while controlling for other variables found to be associated with pedestrian crashes in previous transportation research (in the domains of the individual characteristics and actions and the road environment). First, a base model was developed using variables from the collision report data and allowing comparisons with prior research findings (in the domains of the individual characteristics and actions and the road environment). Second, supplementary objective environmental variables of the road and neighborhood environments were added to the base model and tested one at a time, to select those that were associated with injury severity. In the third step, final models were estimated that combined all the variables in the base model and those objectively measured environmental variables that showed statistical significance in the one-by-one testing step.

4. Results

4.1. Descriptive statistics

Of the 711 pedestrian collisions on state routes, 670 involved one pedestrian, 36 had two pedestrians, and 5 had three pedestrians, for a total of 757 pedestrians involved in a collision. Of the 2351 collisions on city streets, 2259 involved one pedestrian, 82 had two pedestrians, and 10 had three or more pedestrians, for a total of 2457 pedestrians involved in a collision.

Two hundred out of 757 pedestrians died or sustained disabling injuries on state routes, against 398 out of 2457 on city streets. For state routes and city streets, the distribution was 7.4% fatalities (2.6% on city streets), 19.0% with disabling injury (13.2%), 38.4% with evident injury (42.6%), 31.8.0% with possible injury (39.0%), and 3.3% with no injury or unknown outcomes (2.6%).

Regarding the pedestrian age, 3.8% of the data were missing for state routes and 10.6% for city streets. On state routes, the distribution of fatalities and disabling injury by age was 1.1% (16.1% disabling injury) for pedestrians aged 0–14; 8.3% (18.7%) for age 15–64, and 11.8% (25%) for over 65. On city streets, fatalities and disabling injury were 2% (17.9% disabling injury) for pedestrian's age 0–14; 1.9% (12.7%) for age 15–64; and 11.3% (35%) for over 65.

Data were missing for the gender of 60% and 40% of the pedestrians on state routes and city streets, respectively. Bivariate analyses showed significant gender-based differences in injury severity on city streets, but not on state routes. The age and gender of drivers were not included in the models due to missing data.

Regarding impairment, 13.8% and 3% of the pedestrians involved in a collision were reported to be inebriated, on state routes and city streets, respectively, versus 5% and 2.3% of the drivers, respectively.

On state routes, 26.2% of the pedestrians were involved in a collision within 10 m of an intersection, and 42.5% were within 10–50 m of an intersection. For city streets, almost 80% of the collisions were located at intersections.

For the road environment measured in the in 0.5 km buffer of the collision, the Average Annual Daily Traffic was 13,825 vehicles (SD 12,908) and 29,757 (SD 21,511), for state routes and city streets, respectively; the mean estimated speed 35.03 mph (SD 6.97) and 24.91 mph (SD 2.35); the mean length of sidewalk 3.46 miles (SD 2.75) and 5.21 (SD 2.97); the median daily bus ridership 15.06 boardings and alightings (SD 21.74) and 5.84 (SD 40.5); and the mean count of collisions 11.07 (SD 8.47) and 30.23 (SD 40.24).

Net residential density in 0.5 km buffer was 16.4 units per acre (SD 29.7) on state routes and 63.46 (SD 80.8) on city streets. Tables 1 and 2 (columns C and D) summarize these descriptive statistics.

4.2. Models

For state routes, the binary logit base model (not shown), which included 13 independent variables, had a −2 log likelihood value of 700.026, with a Nagelkerke R^2 of 0.26. The final model, which added seven road and neighborhood environment variables, had a −2 log likelihood value of 682.771 and a Nagelkerke R^2 of 0.29. The Akaike Information Criterion (AIC) test for model selection (with the preferred model having a lower value of AIC) suggested that the final model was the preferred model.

For city streets, the binary logit base model (not shown), which included 9 independent variables, had a −2 log likelihood value of 1957.236, with a Nagelkerke R^2 of 0.13. The final model, which added five road and neighborhood environment variables, had a −2 log likelihood value of 1913.87 and a Nagelkerke R^2 of 0.16 (Table 3). The AIC test confirmed that the final model improved the base model.

Table 3
Final binary logistic model results.

Level	Domain	State route model						City streets model					
		Variables	B	Sig.	Odds ratio	95.0% C.I. for exp(B) (odds ratio)		Variables	B	Sig.	Odds ratio	95.0%C.I. for exp(B) (odds ratio)	
						Lower	Upper					Lower	Upper
Individual level	Pedestrian	Constant	0.789	0.651	2.201			Constant	−4.759	0.001	0.009		
		Age	−0.022	0.252	0.978	0.943	1.016	Age (0–4)	**1.043**	**0.020**	**2.838**	**1.179**	**6.833**
		Age_square (square of age/100)	**0.053**	**0.019**	1.055	1.009	1.103	Age (5–9)	0.557	0.112	1.745	0.878	3.467
								Age (10–14)	0.369	0.231	1.447	0.791	2.647
								Age (15–24)	0.215	0.414	1.240	0.740	2.075
								Age (25–44)	0.240	0.338	1.272	0.778	2.079
								Age (45–64)	**0.719**	**0.004**	**2.053**	**1.253**	**3.362**
								Age (64–74)	**0.908**	**0.007**	**2.479**	**1.280**	**4.802**
								Age (75 and above)	**1.543**	**0.000**	**4.678**	**2.587**	**8.462**
								Age (unknown)[a]					
		Gender (female)	−0.059	0.883	0.943	0.429	2.072	Gender (female)	0.154	0.288	1.167	0.878	1.552
		Gender (male)	−0.135	0.710	0.874	0.430	1.777	Gender (male)	−0.261	0.077	0.770	0.577	1.028
		Gender (unknown)[a]						Gender (unknown)[a]					
		Action (Walking along roadway)	0.414	0.286	1.513	0.708	3.233	Action (Walking along roadway)	**−0.799**	**0.011**	**0.450**	**0.244**	**0.830**
		Action (Xing-non-intersection)	0.555	0.096	1.743	0.906	3.353	Action (Xing-non intersection)	0.208	0.299	1.231	0.832	1.821
		Action (Xing – at intersection with signal)	0.800	0.066	2.226	0.947	5.232	Action (Xing – at intersection with signal)	0.066	0.808	1.069	0.625	1.828
		Action (Xing – at intersection without signal)	**1.360**	**0.003**	3.897	1.608	9.444	Action (Xing – at intersection without signal)	0.024	0.928	1.024	0.613	1.710
		Action (other actions)[a]						Action (other actions)[a]					
		More than one pedestrian involved	**0.661**	**0.034**	1.936	1.051	3.566	More than one pedestrian involved	**0.915**	**0.000**	**2.496**	**1.698**	**3.670**
		One pedestrian involved[a]						One pedestrian involved)[a]					
		Inebriety (have been drinking)	**0.578**	**0.044**	1.782	1.015	3.130	Inebriety (have been drinking)	0.180	0.596	1.197	0.616	2.328
		Inebriety (have not been drinking)[a]						Inebriety (have not been drinking)[a]					
	Driver	Inebriety (have been drinking)	0.352	0.395	1.421	0.633	3.194	Inebriety (have been drinking)	**1.126**	**0.001**	**3.083**	**1.612**	**5.896**
		Inebriety (have not been drinking)[a]						Inebriety (have not been drinking)[a]	0				
		Action (going straight ahead)	**0.809**	**0.038**	2.245	1.045	4.823	Action (going straight ahead)	**0.492**	**0.012**	**1.635**	**1.114**	**2.401**
		Action (making right turn)	−**1.272**	**0.009**	0.280	0.108	0.730	Action (making right turn)	−**1.134**	**0.000**	**0.322**	**0.188**	**0.550**
		Action (making left turn)	−0.772	0.148	0.462	0.162	1.314	Action (making left turn)	−0.446	0.065	0.640	0.399	1.027
		Action (others)[a]						Action (others)[a]					
		More than one vehicle involved	−0.175	0.619	0.839	0.597	2.377						
		One vehicle involved[a]											
Road environment	Temporal characteristics	Light (daylight/dawn/dusk)	−0.225	0.451	0.799	0.445	1.434	Light (daylight/dawn/dusk)	**−0.384**	**0.027**	**0.681**	**0.485**	**0.956**
		Light (dark/unknown/other)[a]						Light (dark/unknown/other)[a]					
		Peak time (morning peak)	0.191	0.627	1.210	0.560	2.612						
		Peak time (morning off-peak)	−0.662	0.156	0.516	0.207	1.287						
		Peak time (afternoon off-peak)	−0.216	0.566	0.806	0.386	1.683						
		Peak time (afternoon peak)	−0.364	0.209	0.695	0.394	1.226						
		Peak time (evening off-peak)[a]											

Table 3 (*Continued*)

Level	Domain	State route model						City streets model					
		Variables	B	Sig.	Odds ratio	95.0% C.I. for exp(B) (odds ratio)		Variables	B	Sig.	Odds ratio	95.0%C.I. for exp(B) (odds ratio)	
						Lower	Upper					Lower	Upper
	Road and traffic characteristics	Junction (at roadway)	0.432	0.257	1.540	0.730	3.249						
		Junction (at intersection/related)[a]											
		SR_Function (principal arterial)	0.023	0.946	1.023	0.523	2.002	Road class (collector)	−0.113	0.588	0.893	0.593	1.345
		SR_Function (minor arterial)	−0.201	0.656	0.818	0.337	1.982	Road class (local)	0.011	0.945	1.011	0.748	1.365
		SR_Function (interstate)[a]						Road class (minor)	−0.201	0.214	0.818	0.596	1.123
								Road class (primary)[a]					
		AADT in 0.5 km buffer	**−0.193**	**0.016**	0.825	0.705	0.964	AADT in 0.5 km buffer	**0.134**	**0.004**	**1.143**	**1.044**	**1.251**
		Number of collisions in 0.5 km buffer	−0.002	0.985	0.998	0.847	1.176						
		Distance to intersection	0.180	0.062	1.197	0.991	1.446						
		More than two lanes	−0.598	0.148	0.550	0.245	1.236						
		Two lanes or fewer[a]											
Neighborhood Environment	Neighborhood wealth	Median home value in 0.5 km buffer	0.075	0.196	1.078	0.962	1.209	Median home value in 0.5 km buffer (0–6000 $)	0.516	0.138	1.676	0.847	3.317
								Med. home value in 0.5 km (6001–28,000 $)	0.437	0.198	1.548	0.796	3.009
								Med. home value in 0.5 km (28,001–34,000 $)	0.277	0.418	1.319	0.674	2.581
								Med. home value in 0.5 km (34,001–47,000 $)	0.422	0.177	1.525	0.827	2.813
								Med. home value in 0.5 km (47,001–68,000 $)	0.499	0.091	1.646	0.923	2.936
								Med. home value 0.5 km (68,001–120,000 $)	**0.669**	**0.018**	**1.953**	**1.120**	**3.406**
								Med. home value in 0.5 km (120,001+ $)[a]					
	Density							Population density	0.282	0.060	1.326	0.989	1.777
								Total residential units in 0.5 km buffer	**0.217**	**0.026**	**1.242**	**0.582**	**1.088**
	Land use	Number of office parcels in 0.5 km buffer	−0.003	0.948	0.997	0.904	1.099	No restaurant in 0.5 km buffer	−0.283	0.466	0.753	0.352	1.612
								1–3 restaurants in 0.5 km buffer	−0.107	0.742	0.899	0.475	1.699
								4–9 restaurants in 0.5 km buffer	−0.039	0.901	0.962	0.525	1.764
								10–16 restaurants in 0.5 km buffer	−0.330	0.307	0.719	0.382	1.354
								17 or more restaurants in 0.5 km buffer[a]					
	NC2	NC2 (at least one NC2)[b]	−0.132	0.597	0.876	0.536	1.431						
		NC2 (no NC2)[a,b]											
		−2 log likelihood	680.771					−2 log likelihood	1913.87				
		Cox and Snell R^2	0.201					Cox and Snell R^2	0.090				
		Nagelkerke R^2	0.292					Nagelkerke R^2	0.155				

Bold values significant at <0.05.

[a] Reference category.

[b] NC_2 is a measure of “neighborhood commercial center,” which is defined as a cluster of at least one grocery store, one restaurant, and one retail outlet within 50 m of each other.

The final models of *both* state routes and city streets yielded one socio-demographic and four action variables significant at the $p < 0.05$: the pedestrian's age (the older the pedestrian the more likely s/he was to die or to suffer a disabling injury); having more than one pedestrian involved in the collision increased the risk of severe injury or death (OR = 1.937 and 2.496 on state routes and city streets, respectively); the vehicle traveling straight ahead on the roadway was positively, and the vehicle making a right turn was negatively associated with severe injury or death. One road environment variable, AADT (average daily traffic), was also significant in both models: however, it was negatively related to injury severity for pedestrians in collisions occurring on state roads, and positively so for those on city streets.

For state routes *only*, two additional action variables were significant: the pedestrian crossing at an intersection without a signal was associated with increased likelihood of a fatality or severe injury (OR = 3.897) and the pedestrian being inebriated (OR = 1.782).

For city streets *only*, one additional action variable decreased the risk of severe injury: the pedestrian walking along the roadway. One action variable increased the risk of severe injury or death: the driver being inebriated (OR = 3.083). One more road environment variable significantly increased the risk of the pedestrian dying or being severely injured: the collision taking place under dark conditions (OR = 1.468). Finally, two neighborhood environment variables were significantly associated with severe injury or death: the collision being located in an area with higher medium home values, and with a higher total number of residential units within the 0.5 km buffer.

In the KABCO models (data not shown), three of the five variables significant in both state routes and city streets binomial models were also significant: the pedestrian age, vehicle driving straight ahead, and AADT. The pedestrian crossing at a non-intersection increased the risk of severe injury in both state route and city streets KABCO models. The pedestrian being inebriated also increased the risk of high injury, but only for state routes. In state routes as well, higher home values were associated with decreased risk of severe injury or death. For city streets, the KABCO model confirmed the significance of having more than one pedestrian in a collision (positive association), and the pedestrian walking along the roadway (negative association). The KABCO models added the following new variables to the city streets models: being female, having sidewalks and restaurants in the 0.5 km radius of a collision.

5. Discussion

The results of the final models estimating the effects of environment on injury severity did not differ substantially from those of the base models. Findings were consistent across the binomial and KABCO models (data not shown), indicating that the model results were stable and robust. The analyses likely suffered from poor measures of vehicular speed and missing data on the types of vehicles involved in many non-fatal collisions, which prevented the inclusion of this variable in the models.

Overall, variables capturing the pedestrians' and drivers' actions offered the most and strongest associations with the risk of high injury or death. Also, differences in results between state routes and city streets models appeared to provide some justification for separate treatment in the analyses, and suggested the need to consider different strategies to increase safety with respect to the two types of facilities.

5.1. Age and gender

The models confirmed the long-documented vulnerability of older pedestrians involved in collisions (Peng and Bongard, 1999; Koepsell et al., 2002; Zajac and Ivan, 2003; Demetriades et al., 2004; Lee and Abdel-Aty, 2005). On state routes, where the variable was treated as continuous, the risk of severe injury or death increased significantly with age. On city streets, the risk doubled for the middle aged category and more than quadrupled for the above 75 year category, relative to the population of pedestrians whose age was unknown. On city streets as well, being four years or younger increased the risk of severe injury or death almost three fold.

The results also suggested that females had a higher risk of more severe injury than males on city streets: gender was significant in the KABCO model and in the base binomial model, but marginally so in the final model. Large percentages of missing data (60% and 40% on state routes and city streets, respectively) limited the validity of this finding.

5.2. Inebriety

The study shed new light on this important predictor of collision. On state routes, the pedestrian being inebriated significantly increased the risk of severe injury or death in the base and the final models. In contrast, while the pedestrian's state of inebriation was not significant in the city street models, inebriated drivers tripled the risk of the pedestrian being severely injured or dying in the final binomial models ($p = 0.001$) (this variable was also significant in the final KABCO models [$p = 0.001$]).

This finding added to the literature on pedestrian collisions, which had emphasized the increased risk associated with pedestrians having been drinking (Oxley et al., 2006). While pedestrians under the influence of alcohol appeared to negatively affect safety on such major facilities as state routes, on city streets, drunk drivers increased the risk of a severe injury or fatal collision.

5.3. Collisions involving more than one pedestrian

Having more than one pedestrian involved in the collision was associated with twice the risk of severe injury or death on both state routes and city streets. The variable was significant in the base model, but was not significant in the final KABCO models for state routes. Although the literature referred to multiple pedestrians involved in the same collision (Lefler and Gabler, 2004; Nance et al., 2004; Pietrantonio and Tourinho, 2006), this variable was not previously tested. Its significance in this study suggested that "there is no safety in numbers" when it comes to the risk of being severely injured. Given that two or more persons on the roadway should be more visible than one, this finding pointed to drivers' lack of attention as a major predictor of lack of safety for pedestrians. It could be that on state routes, drivers traveling at relatively fast speeds were unable to brake in time even for multiple pedestrians on the roadway. Yet this explanation would not hold for city streets, where drivers should be aware and watch for the possible presence of pedestrians.

5.4. Intersections

For pedestrians on state routes, the most dangerous action to take was to cross these routes at intersections without signals, where the likelihood of being severely injured or dying was almost four times that of being anywhere else on the route. This finding supported previous research and suggested that engineering approaches to road design could insure the safety of pedestrians (Koepsell et al., 2002; Zegeer et al., 2002).

In contrast, variables capturing intersection design on city streets were not significant. Ironically, the safest action on the part of the pedestrian was to walk along the street (ostensibly because most city streets have sidewalks or other protective devices separating pedestrians and cars) and not to cross a street, no matter how the intersection was designed. KABCO models showed a significant positive association between injury severity or death and the pedestrian crossing at non-intersections (often called mid-block crossings), corroborating a prior study showing that the probability of a pedestrian dying after being struck by a vehicle was higher for collisions occurring at mid-block locations (Guttenplan et al., 2006).

Adding to previous research, the finding that intersection design and risk of severe injury severity were significantly associated for state routes but not for city streets, could be interpreted as meaning that intersection design mattered for facilities that served as major arterials (Koepsell et al., 2002; Zegeer et al., 2002). They suggested that intersections on major arterials needed to be signalized to insure pedestrian safety. On city streets, intersection design did not appear to either protect pedestrians from severe injury or death, or to expose them to a higher risk of injury or death. However, what represented a "signal" needed further research. Collision records did not consistently report the type of signal existing at collision locations. Likewise, objective data on signalization at intersections did not distinguish among the many varieties of lights and signs.

The findings indicated that, in the short run, pedestrians needed be educated to understand the high risks they took in crossing roadways regardless of intersection design. The findings could also inform the "Warrant System" (Manual on Uniform Traffic Control Devices [MUTCD]), the procedure used by departments of transportation to provide or improve pedestrian crossing "treatments." According to a recent Transportation Research Board study, the MUTCD "does not mention safety considerations. . .[and T]here is no consideration of pedestrian generators, such as transit stops, within the warranting criteria" (Transportation Research Board, 2006).

5.5. Driver's actions

Colliding with a car moving along (versus make turns on) state routes or city streets was associated with about twice the risk of a pedestrian sustaining disabling injuries or dying. A car making a right turn decreased the risk of severe injury or death. These two variables were interpreted as proxies for vehicular speed, as vehicles moved at faster speeds along the roadway than when making turns.

5.6. Vehicular speed

Direct measures of vehicular speed (estimated speed and speed limit), a main determinant of injury severity or death, were only weakly associated with injury severity. On state routes, they were significant in the bivariate analyses, but not significant in the one-by-one testing for the final models. On city streets, speed limit was significant only in the one-by-one test. These unconvincing findings likely only reflected the approximate nature of the available data in terms of both the specific time and location of a collision. However, three of the significant variables capturing individual actions and road conditions appeared to act as possible proxies for speed in the final models: driving straight along the roadway and making a right turn, were strong, respectively positive and negative, predictors of severe injury or death on both state and city streets. Also, AADT was associated with lower and higher risk of severe injury on state routes and city streets, respectively. AADT was a relatively weak predictor, however, which seemed to capture the effect of lower travel speeds on state routes with higher AADT, and the effect of higher exposure to cars for pedestrians using city streets with higher AADT. Recent research based on all collisions in Greater London examined whether congested traffic conditions were associated with lower levels of injury severity. It pointed to some evidence that traffic congestion might mean lower severity of injury to pedestrians on roadways, ostensibly because congestion reduced vehicular speed (Noland and Quddus, 2005).

5.7. Objectively measured environment variables

In the state route model, of the 19 road and neighborhood environment variables found significant in the bivariate analyses and tested in the one-by- one process, 7 variables stayed in the final models. Yet only one road environment characteristic, AADT, remained significant in the final binomial model.

In the city street model, 6 of the same 19 environmental variables stayed in the final model. Three remained significant in the final binomial models: AADT, median home value, and total number of residential units, all measured within the 0.5 km buffer of a collision.

In the city street models, the introduction of environmental variables did not change the results of the base model. In the state route models, however, the introduction of objective environmental variables at the road and neighborhood levels rendered the report data on the collision location (junction and SR function) not significant.

5.7.1. Individual land uses

Neighborhood environment variables considered, which included known pedestrian attractors, had a significant relationship with the dependent variable in the bivariate analyses, with the exception of the presence of elementary and middle schools and other educational facilities near collision locations. The latter land uses were not associated with injury severity even without controlling for individual-level variables. One likely explanation was that speed limits in schools zones were effective means for preventing severe injury or death when collisions do occur near schools.

Having fewer rather than more restaurants within a 0.5 km of a collision was significantly related to high injury severity in the city street KABCO models.

5.7.2. Road environment

Except for AADT, variables characterizing vehicular volumes, such as the number of lanes, were not significant. Only on state routes was intersection design and signalization associated with a safer environment. Neither were pedestrian-related road characteristics such as sidewalks or bus ridership.

5.7.3. Neighborhood characteristics

On city streets, the total number of residential units with the 0.5 km buffer increased the risk of severe injury or death. This continuous measure of neighborhood density had an OR of 1.242 and showed that "safety in numbers" was not found in city street models.

An association was found between residential property values and injury severity on city streets (and in the KABCO models of state routes). A value of $68,000 to $120,000 of median home value (the mean for all city street collisions was $52,884) as compared to a higher residential unit value almost doubled the risk of severe injury or death, indicating that neighborhood wealth could in part explain injury severity. This finding was difficult to explain since lower neighborhood wealth had been associated with many other characteristics, such as more land use mix and more people walking.

The study's main hypothesis was not supported by the limited associations found between injury severity and the collision neighborhood environment: on city streets, residential density increased the likelihood of severe injury or death, suggesting that areas with possibly more pedestrians were not "safer" than less dense areas.

Interesting was the lack of association between injury severity and collision frequency at or near the same location. The one-by-one testing showed a significant negative association between the number of collisions within the 0.5-km buffer and pedestrian injury severity on state routes. On city streets, bivariate analyses showed a positive correlation ($p = 0.46$). These results suggested that the locations of collisions with high severity injury were not necessarily the same locations as those with high collision frequency. Thus safety programs addressing high frequency collision locations would not necessarily help reduce the severity of injury when collisions did occur.

Furthermore, combining the lack of relationship between collision frequency and injury severity and the finding that injury severity was related to few attributes of the surrounding environment, suggested that injury severity might be explained in great part by driver or pedestrian actions and behaviors. Especially on city streets, the research suggested that controlling these behaviors through street engineering design would not be sufficient to reduce fatalities and severe injury, and that regulatory and enforcement measures modifying pedestrian and driver behavior would be necessary. Specifically, reducing and enforcing speed limits would be most effective.

Safety programs to lower the risk of injury and severity should continue to control individual behaviors. In addition, safety programs should focus on more heavily populated areas, reducing speed limits and enforcing these limits; designing intersections for safe crossing to include signalization.

5.8. Limitations

It is important to keep the interpretation of the results strictly within the confines of estimating injury severity and not collision frequency.

Data limitations should be noted. The AADT and estimated speed data did not take into account differences between peak and off-peak traffic. Substantial portions of the data on age and gender of both pedestrians and drivers were missing from the records. So were data on vehicle type, actual vehicular speeds, especially on city streets (Wootton and Spainhour, 2007). This study would support the Transportation Research Board's recommendations for improving safety data collection, quality and accuracy (Transportation Research Board, 2006). Furthermore, studies have noted that motor-vehicle collisions were underreported, and that about 20% of the minor or no injury collisions involving pedestrians were missing from police reports (Hauer and Hakkert, 1988; Blincoe et al., 2002; Sciortino et al., 2005; McGeehan et al., 2006). There was agreement that unreported injuries varied by injury severity, with only critical and fatal injuries being systematically recorded, and that a full census of collisions would entail collecting data not only from police, but also from hospital and insurance records (Elvik and Mysen, 1999; Blincoe et al., 2002).

6. Conclusions

This study examined the relative influence of individual factors and the road and neighborhood environments on the risk of severe injury or death. Individual factors explained most of the risk, followed by characteristics of the road environment. The neighborhood environment was significant only in the city street models, where higher residential densities and medium home values were associated with higher risk of severe injury or death. Safety programs seemed urgently needed to reduce the risk of severe injury or death in densely populated areas where more people are likely to walk.

Correlates of severe injury or death, which were common to both state routes and city streets included: the pedestrian being older; the vehicle moving straight along the roadway; making a right turn had a negative association with the severity of injury; and having two or more pedestrians involved in a collision more than doubled the risk of severe injury or death. This new finding suggested the need for immediate further research.

The two types of roads presented different challenges for safety programs. Intersection design related strongly to risk of severe injury or death on state routes, but were not significant on city streets, suggesting that pedestrian safety on these latter facilities depended on factors other than intersection design or signalization. AADT appeared to be a proxy for vehicular speed. It had positive and negative relationship to injury on state routes and city streets, respectively.

Regarding impairment, inebriated pedestrians were significantly associated with higher risk of severe or fatal injury. However, this finding only applied to state routes, a phenomenon not reported in previous studies. On city streets, inebriated drivers, not pedestrians, were strongly associated with severe injury or death. Attention needed to be paid to recording and monitoring drivers' alcohol levels.

Finally, the study found that collision frequency at the location of a collision was not related to the injury severity of the collision outcome on either state routes or city streets, suggesting that safety programs should devise different approaches to reduce the prevalence of these two aspects of safety.

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