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Demographic and environmental correlates of pedestrian injury collisions: a spatial analysis

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Abstract

Pedestrian injury collisions often occur when and where large numbers of pedestrians travel within complex roadway systems with high traffic flow. The pedestrian injury literature suggests a number of individual and environmental correlates of injury risks, however studies in this area have primarily focused upon demographic differences (e.g. related to age) and a few global characteristics of the roadway system (e.g. aspects of pedestrian traffic). Studies in which the geography of communities has been considered are primarily descriptive, identifying pedestrian injury 'hot spots'. The current study more extensively explores some geographic correlates of pedestrian injury collisions through a spatial analysis of data from the city of San Francisco, CA. A spatial autocorrelation corrected regression model was used to determine factors associated with pedestrian traffic injury in 1990. The study used a geographic information system to map locations of pedestrian injuries, and environmental and demographic characteristics of the city across census tract units. In addition to a number of demographic factors (gender, age, marital status, education, income and unemployment), it was proposed that several environmental features of the city would be related to injury rates (high traffic flow, complex roadway systems, greater population densities and alcohol availability). Results of the study showed that pedestrian injury rates were related to traffic flow, population density, age composition of the local population, unemployment, gender and education. Availability of alcohol through bars was directly related to pedestrian injury collisions in which the pedestrian had been drinking alcohol.

Keywords: Pedestrian; Injury; Demographics; Alcohol availability; Geostatistics

1. Introduction and literature review

Motor vehicle and traffic collisions remain the leading cause of premature death in the United States. Nationwide, pedestrians are the second largest population group to die in motor vehicle related crashes (motor vehicle occupants are the largest), accounting for about 13% of the death toll (Insurance Institute for Highway Safety, 1997). In 1996, 5412 pedestrians (mostly young children, elderly people and intoxicated people) died; an additional 82 000 were injured (National Highway Traffic Safety Administration, NHTSA, 1997). Within the state of California in 1994, 843 pedestrians were killed, representing the highest absolute number in the nation. When adjusted for population, California ranks eighth in the nation for pedestrian injury (NHTSA, 1995a). At the local level, San Francisco has one of the highest pedestrian injury rates among all major US cities. According to the National Highway Traffic Safety Administration, 28 out of the 63 persons killed in San Francisco in 1994 traffic collisions, or 44%, were pedestrians. In comparison, statewide, less than 20% of the 4226 persons killed in California traffic collisions were pedestrians (NHTSA, 1995a). Focusing on census year 1990 (the year for which data was collected for the current study), there were 1137 traffic collisions in which a pedestrian was involved in San Francisco, or 10.9% of the 10 419 total collisions that year. In these collisions, there were a total of 35 persons (30 pedestrians) killed and 1227 (1164 pedestrians) injured.

A variety of characteristics of individuals involved and the collision environment appear to be related to pedestrian injuries. Studies of adult pedestrians have found gender and age differences. For example, males

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and older persons appear more likely to be involved in pedestrian crashes. In 1994, 68% of all pedestrian fatalities in the US were male (NHTSA, 1995b) and almost 23% were 65 or older (NHTSA, 1995a). One study found differences in perceptual judgements between younger and older pedestrians (Oxley et al., 1997). The findings suggested that age-related perceptual and cognitive deficits might play a substantial role in crashes involving older pedestrians. Child pedestrian research has found several environmental factors to be associated with pedestrian injury, including traffic flow, traffic speed, the presence of curbside parking and the presence of pedestrian footpaths (Roberts et al., 1995; Stevenson et al., 1995). Other child pedestrian studies have examined geographic variations such as differences in child pedestrian death rates at the state-level (Baker et al., 1991) and identified characteristics of high frequency collision sites using a geographic information system (Braddock et al., 1994). Another recent study of adult pedestrians estimated the effects of reduced travel speeds on pedestrian fatalities (Anderson et al., 1997).

Alcohol consumption by adult pedestrians has been found to play an important role in pedestrian traffic injury. The NHTSA (1997) found that almost one-third (32.3%) of fatally injured pedestrians had blood alcohol concentrations (BAC) at or above the 0.10 g/dl in 1996, the legal limit for drivers in many states. In the same year, the Insurance Institute for Highway Safety (1997) found that of all pedestrians 16 years of age or older who were killed in night-time crashes, 55% had BACs of 0.10% or more. In contrast, the intoxication rate for drivers was 12%, less than half that for the pedestrians. From 1982 to 1992, there were 56 179 drivers involved in 61 129 pedestrian fatalities in which the pedestrian was older than 14 years of age. Only 15.5% of the drivers had BACs in excess of 0.10 g/dl, while 36.9% of the pedestrians had BACs in excess of that value. Although BACs in excess of 0.10 in these drivers has fallen from 20.0% in 1982 to 11.9% in 1992, it has fallen only from 39.4 to 36.2% among pedestrian fatalities during that time (Centers for Disease Control, 1993).

Research from emergency rooms has suggested that many pedestrians who are injured or killed were under some influence of alcohol at the time they were struck; little is known about injuries that do not require admission to emergency rooms. Profiles of injured pedestrians show many, between 19 and 65%, to have been drinking, often heavily (Bastos and Galante, 1986; Brainard et al., 1989; Middaugh, 1989; Vestrup and Reid, 1989). Pedestrians who are under the influence of alcohol also appear to have more severe injuries (Bradbury, 1991; Mittmeyer, 1991) and face higher mortality (Williams et al., 1995) than those who are not under the influence. Case-control studies have shown that intoxication increases the likelihood that a pedestrian is injured. Honkanen et al. (1976) showed that in the US relative risks of injury increased rapidly with pedestrian BACs in excess of 0.10. These earlier findings have received renewed emphasis in recent studies about the prevalence of alcohol involvement in pedestrian injuries. A study in Australia found that 38% of pedestrian fatalities and 29% of pedestrian emergency room admissions had blood alcohol concentrations at or above 0.10 (Holubowycz, 1995). Another study in Florida found that alcohol use increased by at least fourfold the risk of a pedestrian dying in a traffic collision (Miles-Doan, 1996).

As this review suggests, although the current literature on pedestrian injury includes studies of individual and global environmental characteristics related to injury rates, specific geographic components of pedestrian injury have seldom been introduced; this despite the fact that pedestrian injuries, like all traffic related injuries, have specific geographic correlates (e.g. local traffic flows and locations of pedestrian walk ways, Roberts et al., 1995; Stevenson et al., 1995) and have been shown to geographically cluster (Braddock et al., 1994). Thus, noting the substantial involvement of alcohol in pedestrian injury, it is reasonable to consider the extent to which the geography of retail alcohol availability is related to the geography of pedestrian injuries.

Several geographic studies have suggested that locations of alcohol outlets are associated with alcohol use and alcohol-related crashes (Gruenewald et al., 1993; Van Oers and Garretsen, 1993; Scribner et al., 1994). Gruenewald et al. (1993) suggests that alcohol-related traffic collisions exhibit geographically measurable relationships with the density of and distance from alcohol outlets. Gruenewald et al. (1996) demonstrated that physical availability was related to rates of single vehicle night-time crashes (SVNs) between 20:00 and 04:00 h (a surrogate for alcohol-related crashes). Uniquely, this study used geostatistical modeling techniques to identify a spreading pattern of crashes radiating away from sources of alcohol.

1.1. Spatial analysis

Gruenewald et al. (1996) used geostatistical modeling techniques to study the relationships between the spatial distribution of alcohol outlets and alcohol-related traffic collisions. These statistical techniques allowed the researchers to correct for spatial autocorrelations between rates of crash events due to their relative proximity in space, while at the same time providing a means to explore the relationships between the availability of alcohol in one area and rates of crashes in adjacent areas (i.e. spatial lags). Spatial autocorrelations between adjacent geographic units introduce bias into statistical analyses due to the violation of the assumption of unit independence. Two spatial units that are physically close together can be expected to exert some effect on each other. Therefore, these units, if taken as separate observations, are not truly independent.

One correction for spatial autocorrelation involves deriving a matrix which shows which geographic units are adjacent to each other (a binary connection matrix, **W**, an $n \times n$ matrix indicating connections between adjacent spatial units with 0 and 1) and calculating the degree of spatial autocorrelation, ρ, between adjacent units. Generalized least squares estimators are available to provide unbiased tests of regression effects in these spatial contexts (Griffith, 1987). Thus, Levine et al. (1995) used a spatial autoregressive lag model of the form:

$$\boldsymbol{Y} = \rho \mathbf{W}\mathbf{Y} + \mathbf{X}b + \boldsymbol{\varepsilon} \quad (1)$$

to adjust for spatial autocorrelation in traffic collision data, where $\boldsymbol{Y}$ is an $n \times 1$ vector of dependent variables observed across n units, and ρ is the coefficient of the spatial lag term. The scalar multiplication ρ by **WY** provides an estimate of the weighted effects of the dependent variable measured on adjacent units upon each target unit, **X** is an $n \times k$ matrix of k exogenous measures, b the $n \times 1$ coefficients for each measure, and $\boldsymbol{\varepsilon}$ an $n \times 1$ vector of error terms. Although correcting for one form of spatial autocorrelation, this model is consistent with arguments that collision rates in one location are directly related to those in adjacent areas. If such direct effects are not to be expected, use of this model results in biased estimates of the statistical significance of observed effects. Only in the very rare instance where a collision in one location might set off subsequent collisions in another location, such as a large traffic 'pile-up', would this be the case.

An alternative model used by Gruenewald et al. (1996) makes a somewhat different assumption in which, using similar notation, errors in estimation between geographic units are spatially autocorrelated:

$$\boldsymbol{Y} = \mathbf{X}b + (\mathbf{I} - \rho \mathbf{W})^{-1}\boldsymbol{\varepsilon} \quad (2)$$

where **I** is an $n \times n$ identity matrix. This model suggests that other unmeasured factors related to the clustering of pedestrian injuries (e.g. common patterns of pedestrian traffic between units) cause the rates of pedestrian collisions to exhibit spatial autocorrelation (in the form of spatially correlated measurement error). Should these factors be included in the model, it is expected that the degree of spatial autocorrelation, ρ, would go to 0. In the current study these kinds of factors would cause pedestrian injuries to cluster together and this model is used to correct for any resulting spatial autocorrelation.

As a technical point, the consequence of this argument is that the error variance–covariance matrix used to test statistical effects in the current study is consistent with a model that, quite reasonably, implies the absence of any direct relationship between rates of pedestrian injury collisions across areas. Tests of effects using the error variance–covariance matrix implied by model (1), quite unreasonably, implies the existence of some direct relationship between rates of pedestrian injury collisions across these same areas. It should not surprise the reader that the results of the misapplication of these different statistical models, each consistent with a different set of assumed relationships between measured outcomes, results in biased statistical tests of effects.

1.2. Study goal

The goal of the current study was to elucidate the relationships between observed rates of pedestrian injury traffic collisions and measures of environmental and demographic characteristics of the City and County of San Francisco. It was expected that rates of pedestrian injury would be greatest in those areas of the city that provided greatest access to alcohol via restaurants, bars and retail outlets. It was also expected that this relationship would be strongest among pedestrians who had been drinking. Additional demographic and environmental measures of roadway complexity, traffic flow and population density were included to control for known effects of these variables in geographic studies of traffic related outcomes (Gruenewald et al., 1996).

2. Methods

The study examined rates of pedestrian injuries across 149 census tracts in the city of San Francisco. Over a single annual period, 1990, numbers of motor vehicle collisions in which a pedestrian was injured or killed were aggregated within these geographic units. The traffic injury data were obtained from the California Highway Patrol's Statewide Integrated Traffic Record System (SWITRS) for San Francisco County in 1990. This dataset includes all traffic collisions reported to the California Highway Patrol, and consists of both highway and city street collisions[1]. All crashes in which a pedestrian was listed as a party involved in the incident were included. In 1990, there were 1137 such incidents in which 1227 persons were injured. Of these 1137 collisions, 1113 (97.9%) were successfully geocoded. These incidents were used to derive two

[1] Collisions could be reported by the San Francisco Police Department, the Sheriff's Office, or the California Highway Patrol. The design of SWITRS is such that only one reporting agency reports on any collision.

dependent measures: total injuries in pedestrian collisions ($n = 1227$) and injuries in pedestrian collisions in which the pedestrian was determined to have been drinking by police at the scene ($n = 102$, 8.3%). The sample size of the latter measure was constrained by the one year of available data, but did not pose a significant problem in the analysis (see below). The sample size of the latter measure, however, did constrain the selection of geographic units. Smaller units of analysis (e.g. census blocks) would have obviated application of current methods for the assessment of spatial autocorrelation.

Alcohol outlet data for 1990 were obtained from state licensing records provided by California Alcohol Beverage Control. Alcohol outlets were mapped by premise address and categorized by type of license into bars (license types 40, 42, and 48; $n = 505$, 88.7% of which were successfully geocoded), restaurants that serve alcohol (license types 41 and 47; $n = 1986$, 82.9% of which were successfully geocoded), and establishments licensed to sell alcohol that is carried off the premise ('off-premise outlets', license types 20 and 21; $n = 1246$, 89.4% of which were successfully geocoded.

Traffic flow data were obtained from a dataset used by the San Francisco Department of Public Works (DPW) to monitor street use (average daily traffic flow, ADT) and mapped by nearest street intersection ($n = 12\,710$, 78.6% of which were successfully geocoded). These data were created using computerized traffic count apparatus that counted the number of vehicles traveling through the street in a 24-h period at many intersections throughout the city. These measurements were limited to weekday measurements, and therefore may not reflect weekend traffic patterns and may result in some over-estimation of the b-value relating traffic flow to crash rates. Streets were categorized by DPW according to street type (arterial, residential) and according to whether there was a bus route. ADT values for all city intersections for which there was no direct measurement were then calculated using the average of actual ADT measurements for that street type. There were several weaknesses to the use of this dataset. First, extrapolation from measured traffic flows to approximating 'average' traffic flows for each type of street is problematic, overstating traffic flow for low flow streets and understating traffic flow for high flow streets. Second, intersections at which traffic flows are known are not randomly distributed geographically, leaving some areas of San Francisco unmeasured. Traffic flow measurements are performed as deemed necessary by the Department of Parking and Traffic (DPT), usually because the intersections are considered either high volume or otherwise problematic (e.g. a location at which many motor vehicle collisions occur). The dataset is, nonetheless, viewed to be the best and most complete available, providing representative averages across some 85 intersections per census tract.

Population data were obtained from the 1990 Census (US Department of Commerce, 1992) for each of the 149 census tracts. Cross-street density was calculated using a Map-Basic subroutine that counts all the street intersections within a census tract (based on America.dbf Digital MapFiles, MapInfo, 1994). The census data files contained numbers of Blacks, Hispanics, Asians, and non-Hispanic whites, in addition to the populations of various age cohorts, number of males, marital status, and education by census tract. These values were converted into proportions using the total population of the census tract as the denominator. In addition, a median income variable was used, which was calculated by the Census Bureau for each census tract. Persons in three age cohorts were also counted (0–15, 16–29 years, and 55 years or older) and proportions were calculated using the total population in the census tract. Ethnic group variables were examined in preliminary analyses, found to be unrelated to rates of pedestrian injury, and so excluded from the final analyses.

The dependent measures were transformed to provide estimates of the densities of pedestrian injuries within the geographic units of the city. Each variable was transformed by dividing the length of the roadway in each census tract (e.g. numbers of pedestrian injury collisions per kilometer of roadway). Since pedestrian collisions occur exclusively on or near streets, traffic flow takes place upon these streets, and community populations use these routes to move from place-to-place within the community, this was assumed to be a natural metric for the examination of rates of these events. The same metric was also applied to the alcohol availability measures and two other environmental variables (i.e. numbers of cross-streets and population). This procedure provided estimates of the numbers of bars, restaurants and off-premise establishments per kilometer of roadway, the number of cross-streets per kilometer of roadway and total population per kilometer of roadway. Thus, it was assumed that for a given aggregate rate of traffic flow, greater availability of alcohol per unit roadway length, greater road network complexity per unit roadway length, and greater population per unit roadway length would be related to greater pedestrian collisions per unit roadway length. The roadway system itself is assumed to be the link between traffic flow, alcohol availability, and exposure to the risks of pedestrian injury collisions. Reasonably, if there are few or no roads in an area, there will be few or no pedestrian injury collisions, regardless of resident population. In rural areas, more wide ranging roadway systems and small populations imply a low pedestrian injury rate per unit roadway length. As suggested by Gruenewald et al. (1996), the use of roadway length as the denominator for these measures reflects the obvious fact that exposure to possible pedestrian injury, access to alcohol, and the packing of roadways and people within urban areas take place along the roadway system[2]. A final logarithmic transformation of the dependent measures:

$$\ln[1 + (\text{pedestrian injuries})/(\text{roadway length})] \quad (3)$$

provided conditional normal distributions for analysis. This log-normal transform is appropriate for analyses of non-negative positively skewed rates and has been widely applied in geostatistical analyses of such outcome data (e.g. Scribner et al., 1994).

San Francisco County consists of 152 census tracts. Two census tracts are assigned to individual locations (prisons), and were removed from analysis because they had no roads. Another census tract is assigned to San Francisco Bay, which although it has a population, has no roads. During preliminary analyses two census tracts, those representing the Presidio and Golden Gate Park, were found to have extremely high leverage (i.e. observations taken on those units strongly skewed effects estimates from the models, Cooks distances exceeding 1.00, Cook and Weisberg, 1982; see also Gruenewald et al., 1996). The original observations for these areas were smoothed by averaging with observations from all adjacent census tracts. Prior to smoothing, these census tracts exhibited rather extreme characteristics. Each had a high traffic volume but very low population and roadway length (in 1990, the Presidio was a US Naval base with high vehicle traffic volume directly to and from the Golden Gate Bridge; Golden Gate Park is a large park with very low residential population, but very high vehicle and pedestrian traffic). An analysis of the Cook's distances of the residuals from preliminary analyses also revealed one other census tract as a high leverage observation, the Civic Center and performing arts area of the city. Here population densities were very small, but roadway length very large. In the final analyses, including those for the small sample of pedestrian injuries in which the police determined the pedestrian to have been drinking, no significant outliers or highly leveraged cases were detected.

Datasets were managed using Microsoft Excel and SPSS for Windows software packages. Data were aggregated by census tract using MapInfo GIS software. Pedestrian injuries were geocoded to the nearest street intersections, as reported in SWITRS data, and alcohol outlets were geocoded according to street address. MapInfo was used to calculate variables such as number of cross-streets and length of roadway. It was also used to create a connection matrix indicating the spatial relationships between census tracts, considering as adjacent only those census tracts connected by some portion of the roadway system.

All geostatistical analyses were performed using proprietary Spatial Statistical System software developed at Prevention Research Center (Ponicki and Gruenewald, 1998). The analysis procedure consisted of, first, an examination of the correlation matrix among all variables and, second, a spatial regression analysis relating the dependent to the independent variables. Examination of the correlation matrix for all models revealed little collinearity among the independent measures (Pearson's $r \leq 0.30$). The spatial analysis model is actually a regression model that has been corrected for the error associated with spatial autocorrelation (Eq. (2) above). For each model, an ordinary least squares (OLS) regression analysis was conducted to obtain starting values for a generalized least squares (GLS) procedure that estimated the effects of the independent measures with a simultaneous statistical correction for autocorrelated error (ρ). For both dependent measures (all pedestrian injuries and alcohol-related pedestrian injuries), the performance of each group of variables was first measured (alcohol availability, environment, demographics without age, and age), then the results from the full model reported. The coefficients from the models are interpretable in a similar way as linear regression coefficients; coefficients that are significantly different from zero are said to be linearly associated with the dependent measure.

3. Results

Stepped into the model one at a time, Table 1 presents the performance of each group of variables in predicting pedestrian injuries in the City of San Francisco. Columns one and two present the name of each group of variables and their contribution to the model (Rao's likelihood ratio Chi-Square, ΔG^2). Using the spatial analysis (GLS) procedure discussed above, columns three, four and five, present the effects estimates for the environmental measures of bar, restaurant and off-premise alcohol outlet densities (effects indicated by 'b (bars)', 'b (rest's)', and 'b (off-premise)'). Column 6 presents the estimate from each model of the degree of spatial autocorrelation using the GLS estimator ('GLS ρ'). Column 7 presents a similar diagnostic based upon residuals from the OLS analysis without correction for spatial autocorrelation ('OLS Moran coefficient'). As shown, the spatial autocorrela

[2] This approach to analyzing pedestrian injury rates is intended to reflect the process by which individuals come to be involved in these events. Thus, the greater packing of people about the roadway system is assumed to increase the exposure of people to traffic related mishaps. The greater availability of alcohol along the roadway system is assumed to increase the numbers of drinking pedestrians and drivers at risk of involvement in pedestrian injury collisions.

tions observed in every analysis were positive and quite substantial. Without correction, this failure of unit independence would have led to considerable Type I errors. That is, many of the observed statistical relationships would have been identified as 'significantly different from 0' when, in truth, no such 'significant' relationships existed.

With regard to all pedestrian injuries, each class of variable (availability, environment, demographics and age) provides a significantly better fit to these data. This indicates that each group of variables, each taken as a whole, helps predict pedestrian injury rates. In addition, two types of alcohol availability, bars and off-premise outlets, when considered alone, are associated with pedestrian injuries. However, the addition of the environmental variables reduces these apparent effects, and subsequent addition of demographic variables and age further diminishes these associations.

Table 2 shows the coefficients of the full model relating each of the independent measures to the dependent variable, all pedestrian injuries. The table presents the name of each variable group, the specific measure tested, its coefficient, the asymptotic t-statistic testing its association to the dependent measure, and the P-value for each test. Six variables had significant associations with pedestrian injuries. Population density and the proportion of males both had significantly positive associations; higher population density and a predominance of males within geographic units were associated with higher rates of pedestrian injuries. Persons aged 0–15 and higher education had significantly negative associations; greater proportions of children and better educated populations were associated with lower rates of pedestrian injuries. Average daily traffic flow had a positive association with rates of injury; greater traffic flow was related to greater pedestrian injury rates. Unemployment had a positive association with injury density; greater unemployment was related to greater pedestrian injury rates.

The analysis presented in Table 2 was repeated for the dependent measure: all injuries in pedestrian collisions in which the pedestrian was reported to have been drinking. These collisions included any pedestrian who had been drinking, regardless of whether the police reported an extent of impairment. This analysis was conducted to uncover specific relationships between alcohol availability and alcohol involvement in pedestrian injury collisions. Table 3 shows a significant relationship between bars per kilometer of roadway and had been drinking pedestrian collisions. This observation supports the expectation that increased outlet densities would be specifically related to increased alcohol-related pedestrian injuries.

4. Discussion

The results of this study demonstrate significant geographically based relationships between specific environmental and demographic characteristics of the City and County of San Francisco and pedestrian injuries. Injuries in pedestrian-involved collisions were most likely to occur in areas of the city with greater population density, with greater proportions of males, with lower proportions of children 0–15 years of age as residents, proportionately greater unemployment, and lower proportions of well educated residents (high school degree or better). In addition, injuries in pedestrian collisions were greater in areas of the city with greatest traffic flow and, in the case of injuries in which alcohol use by the pedestrian was implicated, where densities of bars were greatest. Specifically, the presence of a greater number of bars in a neighborhood was related to a greater rate of 'had been drinking' pedestrian injuries, regardless of whether the police reported an extent of obvious impairment.

The results of this study clearly demonstrate that geographically based studies may have significant problems with spatial autocorrelation. In this paper, an OLS regression model was initially used to estimate parameters and test the significance of relationships between variables. Then a Moran coefficient was used to test for the significance of spatial autocorrelated errors in the analyses and found to be significant in each case. The positive Moran coefficients in Table 1 indicate that Type I errors were more likely to result. For this reason, each analysis was again performed using a

Table 1
Geographic analysis results for pedestrian injuries in San Francisco by census tracts ($N = 149$)

Model	ΔG^2	b (bars)	b (rest's)	b (off-premise)	GLS ρ	OLS Moran coefficient
Constant	–	–	–	–	0.763[a]	0.519[a]
+Alcohol availability	41.323[a]	0.290[a]	0.062	0.268[a]	0.578[a]	0.230[a]
+Environment	11.463[a]	0.197	0.073	0.141	0.416[a]	0.143[a]
+Demographics without age	11.749[a]	0.133	0.076	0.097	0.448[a]	0.150[a]
+Age	9.752[a]	0.083	0.977	0.064	0.408[a]	0.135[a]

[a] P-value < 0.05.

Table 2
b Coefficients for full model in analysis of all injuries in pedestrian collisions

Type of variable	Variable	*b* coefficient	*t*-statistic	*P*-value
Alcohol availability	Bars per kilometer roadway	0.083	0.634	0.263
	Restaurants per kilometer roadway	0.077	1.555	0.060
	Off-premise outlets per kilometer roadway	0.064	0.525	0.300
Environment	Cross-streets per kilometer roadway	0.103	1.429	0.077
	Average daily traffic flow × 1000	0.042	1.691	0.045[a]
	Population per kilometer roadway × 1000	0.826	2.543	0.006[a]
Demographics: age	Persons age 0–15 (proportion)	−3.935	−2.056	0.020[a]
	Persons age 16–29 (proportion)	0.931	1.003	0.158
	Persons age 55 and up (proportion)	−0.880	−0.887	0.188
Demographics: other	Persons unemployed (proportion)	2.945	1.643	0.050[a]
	Never married persons (proportion)	−1.122	−1.141	0.127
	Median income × 10 000	−0.022	−0.317	0.376
	Males (proportion)	2.432	2.208	0.014[a]0
	High school graduate or higher (proportion)	−1.614	−2.262	0.012[a]

[a] $P \leq 0.05$.

regression model that provided a statistical correction for spatial autocorrelation. As shown in Table 1, with this correction, each additional set of explanatory variables improved the fit of the model. The positive Moran coefficient coupled with the systematic improvement in the fit of the model provides strong support for models that go beyond an examination of alcohol availability and injuries alone.

The interpretation of the individual and demographic effects observed in the study, as well as the suggestion of mechanisms by which certain population groups may experience higher rather than lower rates of pedestrian injuries, must proceed with caution. For example, lower education may be associated with work that takes place outside in the community, including a variety of occupations that require physical labor, thus exposing workers to more roadway hazards. Likewise, the positive relationship between unemployment and rates of pedestrian injury may be associated with a greater level of outdoor activity and exposure to traffic risks by individuals who are unemployed. While this kind of reasoning may be appealing, especially in a highly urbanized setting such as San Francisco, it is purely speculative. Support for such arguments must be based upon clearly articulated theory, explicit measurement of the postulated variables and appropriate causal analyses.

The interpretation of the expected environmental effects observed in the study is more intuitively compelling. For example, the positive relationships of population density and traffic flow to pedestrian injury rates suggests that a greater focus on regulating both pedestrian activities and other roadway use in areas of

Table 3
b Coefficients for full model in analysis of all injuries in pedestrian collisions in which pedestrian had been drinking

Type of variable	Variable	*b* coefficient	*t*-statistic	*P*-value
Alcohol availability	Bars per kilometer roadway	0.399	1.910	0.028[a]
	Restaurants per kilometer roadway	0.001	0.005	0.499
	Off-premise outlets per kilometer roadway	−0.049	−0.242	0.405
Environment	Cross-streets per kilometer roadway	0.151	1.412	0.079
	Average daily traffic flow × 1000	0.002	0.055	0.478
	Population per kilometer roadway × 1000	0.626	1.261	0.104
Demographics: age	Persons age 0–15 (proportion)	−3.822	−1.219	0.112
	Persons age 16–29 (proportion)	−0.106	−0.070	0.472
	Persons age 55 and up (proportion)	−1.000	−0.597	0.276
Demographics: other	Persons unemployed (proportion)	10.954	3.681	<0.001[a]
	Never married persons (proportion)	−0.103	−0.064	0.475
	Median income × 10 000	−0.131	−1.155	0.124
	Males (proportion)	1.102	0.630	0.189
	High school graduate or higher (proportion)	1.035	0.882	0.189

[a] $P \leq 0.05$.

the city where population and traffic flow are greatest may lead to a reduction in injuries. Similarly, the positive relationship of bar densities to pedestrian injury in 'had been drinking' collisions suggests that regulation of the availability of alcohol through neighborhood bars could have beneficial effects for the community at large. While it is feasible that investigating officers may be more likely to check the 'had been drinking box' when a bar is located near the collision site, the association of pedestrian injuries with bars suggests that pedestrians who had been drinking may be struck leaving or while spending time outside and around these establishments. It also suggests that pedestrian intoxication or impairment is a factor in causing these collisions. In both these cases, future research should elucidate in more detail the precise relationships between outlets and pedestrian collisions (e.g. estimating the proximity of one to the other). In any case, the results of the current research suggest that education and environmental prevention efforts intended to reduce rates of pedestrian injury should focus on aspects of traffic flow, neighborhood alcohol availability and raising community awareness about the risks associated with pedestrian alcohol impairment.

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