Environmental Characteristics Associated With Pedestrian–Motor Vehicle Collisions in Denver, Colorado

Anne K. Sebert Kuhlmann, PhD, John Brett, PhD, Deborah Thomas, PhD, and Stephan R. Sain, PhD

Objectives. We examined patterns of pedestrian–motor vehicle collisions and associated environmental characteristics in Denver, Colorado.

Methods. We integrated publicly available data on motor vehicle collisions, liquor licenses, land use, and sociodemographic characteristics to analyze spatial patterns and other characteristics of collisions involving pedestrians. We developed both linear and spatially weighted regression models of these collisions.

Results. Spatial analysis revealed global clustering of pedestrian–motor vehicle collisions with concentrations in downtown, in a contiguous neighborhood, and along major arterial streets. Walking to work, population density, and liquor license outlet density all contributed significantly to both linear and spatial models of collisions involving pedestrians and were each significantly associated with these collisions.

Conclusions. These models, constructed with data from Denver, identified conditions that likely contribute to patterns of pedestrian–motor vehicle collisions. Should these models be verified elsewhere, they will have implications for future research directions, public policy to enhance pedestrian safety, and public health programs aimed at decreasing unintentional injury from pedestrian–motor vehicle collisions and promoting walking as a routine physical activity. (*Am J Public Health.* 2009;99:1632–1637. doi:10.2105/AJPH.2007.131961)

In response to the rising prevalence of obesity, diabetes, and other chronic diseases in the United States, public health campaigns promote walking among adults for pleasure, exercise, and everyday errands; children are encouraged to walk to and from school.[1,2] Walking, however, can be a risky activity. Pedestrians are up to 9 times as likely as those traveling in cars to be killed per kilometer traveled.[3,4] Both walking and bicycling are more dangerous than motor vehicle travel in the United States per kilometer traveled.[5] Clearly, safety and perceptions of safety should be important components of campaigns to promote and increase pedestrian activity.

Pedestrian–motor vehicle collisions are not, however, random events—either geographically or demographically. Among more developed countries, the United States has among the highest rates of pedestrian accidents per kilometer traveled[5,6] and incidents of pedestrian–motor vehicle collisions.[7] Cities in the south and west of the United States tend to have the highest rates of pedestrian–motor vehicle collisions per 100 000 population[8] and per capita when calculations are controlled for the amount people walk in a given metro area.[9,10] Geographic concentrations of pedestrian–motor vehicle collisions within cities have been reported in the United States[11,12] and elsewhere.[13,14] For example, pedestrian and bicyclist accidents among children in Montreal, Quebec, are concentrated in just a handful of census tracts, and incidence is markedly lower in higher-income census tracts.[13] In Mexico City, Mexico, where pedestrians account for the majority of all fatalities involving a motor vehicle, pedestrian fatalities are concentrated around 6 intersections.[14]

Certain population groups are also disproportionately affected by pedestrian–motor vehicle collisions. In the United States, Blacks account for more than 20% of all pedestrian fatalities, despite making up only about 12% of the total population.[9] In a study in Atlanta, Georgia, the pedestrian fatality rate per 100 000 for Hispanics was 6 times as high and for non-Hispanic Blacks twice as high as for non-Hispanic Whites.[15] Reports from Los Angeles, California,[16] and Washington, DC,[17] found a higher number of pedestrian fatalities among Latinos than would be expected from their proportion of these cities' populations.

To date, much of the work on pedestrian–motor vehicle collisions has used the national Fatality Accident Reporting System database.[8–10] Although these data provide useful insights into pedestrian–motor vehicle collisions, they record only pedestrian fatalities, which tend to occur in certain types of collisions (e.g., high velocity, head-on impact).[18] Published studies estimate pedestrian injuries to be 13[19] to 16[20] times as common as fatalities. Exploratory work indicated that fewer than 5% of pedestrian–motor vehicle collisions in Denver, Colorado, resulted in a pedestrian fatality (A.K.S.K., unpublished data, 2004). Similarly, 2005 data from the Centers for Disease Control and Prevention's Web-based Injury Statistics Query and Reporting System suggest that pedestrian fatalities account for fewer than 5% of all pedestrian injuries, calculated by comparing pedestrian fatalities from all causes (6074) with pedestrian injuries from all causes (165 512).[21] These findings highlight the importance of comprehensive examinations of all types of pedestrian–motor vehicle collisions, not just those that result in fatalities. Therefore, we incorporated data from all pedestrian–motor vehicle collisions (fatality, injury, and other) on public roadways in Denver and integrated this information with several other data sources for environmental characteristics.

We sought to examine pedestrian–motor vehicle collisions comprehensively and to explore the association between pedestrian–motor vehicle collisions and environmental characteristics by analyzing publicly available data. We captured all reported pedestrian–motor vehicle collisions during the study period, not just those resulting in fatalities. To assess whether some areas of the city presented a greater risk to pedestrians than others, we analyzed spatial patterns of pedestrian–motor vehicle collisions. We integrated data on pedestrian–motor vehicle collisions with data on liquor licenses, land use, and sociodemographic characteristics to investigate 2 main questions about pedestrian–motor vehicle collisions within the City and County of Denver (hereafter, Denver): What are the spatial patterns of pedestrian–motor vehicle collisions? What is the relationship between pedestrian–motor vehicle collisions and environmental characteristics by census tract?

METHODS

Our cross-sectional study integrated publicly available secondary motor vehicle collision data from Denver for a 4-year period, January 1, 2000, through December 31, 2003, with data on liquor license outlets, land use, and sociodemographic characteristics (Table 1).

Variables

We selected the independent variables on the basis of previous research findings. Table 1 provides a summary of the study variables.

Liquor license outlets. Both the number and type of liquor license outlets in an area have been associated with the number of drinking drivers and the number of drinking pedestrians.[22,23] The Department of Revenue, State of Colorado, database of liquor license outlets listed the address and type of license awarded to 1368 outlets in Denver. Of the 33 types of liquor licenses issued, some were excluded because the type of license was not relevant to the study (e.g., wholesale manufacturer); some outlets were excluded because their address mapped to jurisdictions just outside of Denver. After exclusion, 1245 outlets (91.0%) were categorized by the type of license issued (e.g., on-premise versus off-premise consumption), geocoded, and aggregated by census tract.

Land use. Previous research showed type of land use to be an important component of the environment affecting physical activity.[24] Our data came from the Technology Services Department, City and County of Denver, land use database that contained location and descriptive information for more than 166 000 land parcels in a format compatible with a geographic information system (GIS). Land parcels were categorized by their primary use: residential, business, industrial, or institutional. Summary scores were calculated in the GIS, indicating the proportion of land dedicated to each use by census tract.

Sociodemographic factors. Pedestrian safety and physical activity level can be affected by characteristics such as population density, which has been found to be associated with frequency of walking and pedestrian injuries at the individual level.[25–28] A study of neighborhood factors associated with physical activity used place-based economic status and educational attainment variables.[27] Children and older adults were shown to be disproportionately affected by pedestrian–motor vehicle collisions.[25,26] Similarly, Hispanics and Blacks were disproportionately affected by pedestrian–motor vehicle collisions in the United States.[9,15–17]

Pedestrian activity. At the time of the study, our review of the literature on pedestrian accidents and safety revealed no research that used mode of transportation to work as reported by the US Census as an explanatory or independent variable. Walking or taking public transportation to work was the only information collected during the 2000 US Census that provided an indicator of potential pedestrian exposure to motor vehicles. To the best of our knowledge, there were no publicly available data about the amount of walking by area or neighborhood in Denver at the time of our study. Therefore, we relied on a composite variable from the 2000 US Census of walking or taking public transportation to work as a proxy, on the assumption that taking public transportation requires at least some pedestrian activity.

Collision Data

We defined pedestrian–motor vehicle collisions as events involving a collision between a motor vehicle and a person walking or jogging on a public roadway. The motor vehicle

TABLE 1—Definitions and Data Sources for Variables Related to Pedestrian–Motor Vehicle (PMV) Collisions: Denver, CO, 2000–2003

	Variable Type	Definition	Source
Density of PMV collisions	Dependent	Total PMV collisions per 1 000 000 sq ft in tract	Department of Public Works, City and County of Denver
Population density	Independent	Total population per 1 000 000 sq ft in tract	US Census Bureau
Economic indicator	Independent	Proportion of labor force aged ≥16 y unemployed in tract	US Census Bureau
Educational attainment	Independent	Proportion of population aged ≥25 y with a high school degree as highest level of education in tract	US Census Bureau
		Proportion of population aged ≥25 y with a college degree or higher in tract	
Age structure	Independent	Proportion of population aged <18 y in tract	US Census Bureau
		Proportion of population aged >64 y in tract	
Hispanic ethnicity	Independent	Proportion of population identifying as Hispanic in tract	US Census Bureau
Walking to work	Independent	Proportion of labor force aged ≥16 y who walk or take public transport as their main mode of transportation to work in tract	US Census Bureau
Business land use	Independent	Proportion of total land dedicated to business use in tract	Technology Services Department, City and County of Denver
Density of liquor license outlets	Independent	Total liquor license outlets per 1 000 000 sq ft in tract	Department of Revenue, State of Colorado

collision database we used from the Department of Public Works, City and County of Denver, did not register pedestrian–motor vehicle collisions involving public transport vehicles (e.g., buses, light rail trains). We excluded collisions on limited-access highways because public health efforts to promote walking do not encourage pedestrian activity on highways and interstates. Therefore, our results likely present a conservative picture of total pedestrian–motor vehicle collisions in Denver, although it is more comprehensive than analyses restricted to collisions that result in pedestrian fatalities.

Traffic Accident Report forms are completed by law enforcement officers in Colorado when they respond to reports of motor vehicle collisions.[29] The Denver Department of Public Works maintains a database of these forms, which we queried for date of event and first harmful event (the event when injury or damage first occurred). We selected only forms in which the first harmful event field listed a collision with a pedestrian. Although this second selection criterion likely excluded a few motor vehicle collisions involving pedestrians in which the first harmful event was not a collision with a pedestrian (e.g., 2 motor vehicles collide and then 1 ricochets to hit a pedestrian), first harmful event is the variable that most reliably identifies motor vehicle collisions involving pedestrians.

Our query yielded 1892 pedestrian–motor vehicle collisions from January 1, 2000, through December 31, 2003. After exclusions, 1811 pedestrian–motor vehicle collisions (95.7%) were geocoded in ArcGIS 9.1[30] with the TIGER/Line (Topographically Integrated Geographic Encoding and Referencing system) street file for Denver from the 2000 US Census.[31] Additional pedestrian–motor vehicle collisions were then excluded by census tract either because they could not be assigned to a tract or because the entire tract was excluded. Two census tracts with residential populations of fewer than 5 people during the 2000 US Census—incorporating the airport and the county jail—were excluded, leaving 134 census tracts for analysis.

Pedestrian–motor vehicle collision locations were assigned to a census tract by tract assignment provided by the US Census Bureau's Web site.[32] Although many collisions occurred on streets that served as census tract boundaries, the bureau assigned a specific tract to a location depending on how the location was entered. Denver's accident report data set provided a primary street and closest cross street for every pedestrian–motor vehicle collision. The primary street was entered first in the census database, followed by the secondary or closest cross street. More than half of all accidents (52.0%) fell on a census tract border; large, arterial streets often serve as boundaries between census tracts, and the majority of pedestrian–motor vehicle collisions occurred on arterial streets. However, because some independent variables were derived from 2000 US Census data, we used the bureau's tract assignment of a location instead of an alternative assignment method. Employing the spatial analyses helped mitigate bias that might arise from this assignment method.

Analyses

We combined all data within a GIS and analyzed them with spatial techniques, which facilitated an exploration of relationships that would not be possible with traditional approaches.

We first produced descriptive analyses on the characteristics of pedestrian–motor vehicle collisions. Then we carried out geographic analyses of the patterns of pedestrian–motor vehicle collision locations by census tract and analyzed spatial statistics for significant global clustering of collisions. Finally, we conducted statistical modeling of environmental characteristics associated with density of pedestrian–motor vehicle collision. These linear models were then verified with a weighted regression model (conditional autoregressive) to account for the spatial relationships within the data.[33,34]

RESULTS

On average, law enforcement officials in Denver received more than 1 report of a pedestrian–motor vehicle collision per day. More than half of the pedestrian–motor vehicle collisions (55%) occurred at an intersection or were intersection related; another 37% occurred midblock. Just over 77% of collisions occurred on an arterial street or at an intersection with an arterial street. Approximately 90% of collisions involved a single motor vehicle. Nearly 9 out of 10 pedestrian–motor vehicle collisions resulted in an injury (83.7%) or fatality (4.4%) to a pedestrian.

Total pedestrian–motor vehicle collisions per census tract ranged from 0 to 110 (median=9.0; mean=12.9). Seven tracts had no pedestrian–motor vehicle collisions; 6 of these were suburban tracts on the southwest or southeast edge of the county. Census tracts with the most pedestrian–motor vehicle collisions tended to cluster around downtown and a contiguous neighborhood (Lower Downtown) that is a revitalized area with residential, entertainment, business, and retail mixed use. The few additional neighborhoods that had exceptionally high pedestrian–motor vehicle collision rates all bordered major arterial streets of the city (Figure 1). A global Moran index (I) calculation, which estimates whether there is overall, or global, clustering within the data, indicated statistically significant global clustering of pedestrian–motor vehicle collisions by census tract ($I=0.19$; $P<.01$).

After exploratory and bivariate analyses, we included 5 of the original variables in multivariate analyses: population density, Hispanic ethnicity, walking to work, liquor license outlet density, and business land use. We excluded other variables either because of their poor relationship with the outcome variable (density of pedestrian–motor vehicle collisions) or to reduce multicollinearity.

Linear regression analysis tested the relationship between the 5 selected variables and density of pedestrian–motor vehicle collisions. Initial model fit suggested that business land use and Hispanic ethnicity should be dropped from the model. A linear combination of walking to work, population density, and liquor license outlet density significantly predicted density of pedestrian–motor vehicle collisions by census tract ($F_{3,130}=115.23$; $P<.001$). The adjusted R^2 indicated that the model explained approximately 72.0% of the variance in density of pedestrian–motor vehicle collisions by census tract (Table 2). This is a relatively large effect size.[35] Although some correlations between independent variables were significant in bivariate analyses, tolerance levels for all variables in the final multivariate models were acceptable.

Both the dependent and the independent variables in this model were transformed with natural log transformations, enabling

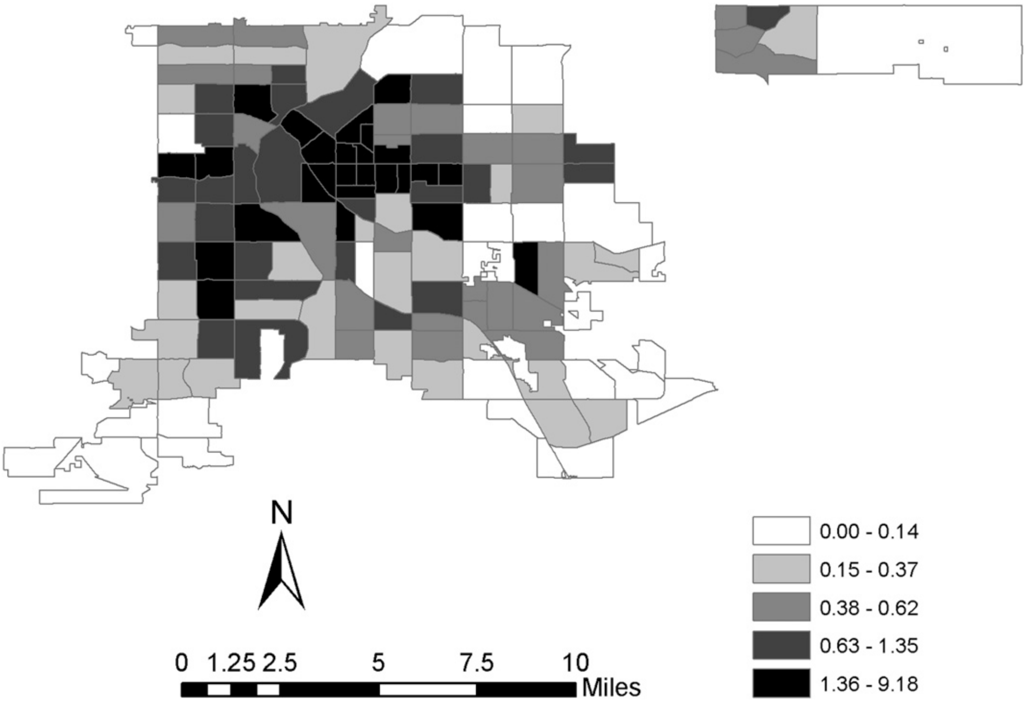

Figure 1—Pedestrian-motor vehicle collisions per 1 000 000 square feet by census tract, in quintiles: Denver, CO, 2000–2003.

interpretation as an elasticity, in which a 1% increase in the independent variable corresponded to a percentage change in the dependent variable. Therefore, a 1% increase in population density was associated with a 0.42% increase in density of pedestrian–motor vehicle collisions. A 1% increase in walking to work was associated with a 0.59% increase in density of pedestrian–motor vehicle collisions. A 1% increase in liquor license outlet density was associated with a 0.45% increase in density of pedestrian–motor vehicle collisions. This linear model should be interpreted with caution, however, because it did not account for spatial dependence within the data. A global Moran index calculation from the studentized residual of the linear regression model[33] indicated remaining spatial correlation in the linear model (I=0.02; z=3.03; P<.01).

A weighted conditional autoregressive (CAR) model was then calculated to account for the residual spatial correlation, with area of the census tract in square feet as the weight. In the CAR model, all variables significantly contributed to the model. The regression coefficients for the variables in the CAR model (Table 3) were very similar to the coefficients produced by the linear model. A likelihood ratio test indicated the presence of only a modest spatial structure in the CAR model (Φ=0.09; P=.09).

TABLE 2—Simultaneous Linear Regression Model of Density of Pedestrian–Motor Vehicle Collisions by Census Tract: Denver, CO, 2000–2003

	Unstadardized Parameter Estimate, b (SE)	Standardized Parameter Estimate, B	*P*
Population density	0.42 (0.10)	0.21	<.001
Walking to work	0.59 (0.10)	0.36	<.001
Liquor license outlet density	0.45 (0.07)	0.45	<.001
Constant	−3.82 (0.59)	. . .	<.001
Model statistics			<.001
Adjusted R^2	0.72		
$F_{3,130}$	115.23		

Note. b = unstandardized coefficient; B = standardized coefficient. Two census tracts were excluded, leaving 134 for the analysis.

DISCUSSION

We used Denver as a model to explore patterns of pedestrian–motor vehicle collisions and associated environmental characteristics that could be discerned in publicly available data. We captured all reported pedestrian–motor vehicle collisions in Denver during the study period, not just those resulting in a pedestrian fatality, and integrated the incident

TABLE 3—Conditional Autoregressive Model of Density of Pedestrian–Motor Vehicle Collisions by Census Tract: Denver, CO, 2000–2003

	Parameter Estimate, b (SE)	*z*	*P*
Population density	0.28 (0.10)	2.69	<.01
Walking to work	0.61 (0.12)	4.98	<.001
Liquor license outlet density	0.46 (0.07)	6.24	<.001
Intercept	–3.11 (0.61)	–5.07	<.001
Model statistics			.09
Φ (range)	0.09 (–0.31 to 0.15)		
Likelihood ratio	2.96		

Note. Two census tracts were excluded, leaving 134 for the analysis.

location information with other publicly available data about environmental characteristics within a GIS, thus providing a comprehensive picture of pedestrian–motor vehicle collisions. Consistent with other research on pedestrian injuries and fatalities,[11–14,19] our results showed a definitive pattern of spatial clustering of pedestrian–motor vehicle collisions within Denver. Pedestrian–motor vehicle collisions cluster in downtown, in the revitalized Lower Downtown neighborhood, and in neighborhoods that border a few of the major arterial streets.

Three environmental characteristics, in combination, were significantly associated with the density of pedestrian–motor vehicle collisions by census tract: density of liquor license outlets, population density, and walking to work. Despite their significance in previous studies,[12,27] economic indicator variables were not included in the final model because of concerns regarding multicollinearity. Environmental characteristics appeared to have strong relationships with place-based density of pedestrian–motor vehicle collisions in Denver. Attention to such place-based factors, as well as to individual pedestrian and driver factors, could improve pedestrian safety and promote pedestrian activity.

Strengths and Limitations

These analyses should be reproducible relatively economically elsewhere because we used publicly available data. Although the specific models presented here apply to Denver and would need to be tested elsewhere for generalizablity, they can inform policy and programmatic decisions, potentially helping to save lives and improve quality of life for pedestrians. For example, targeted, place-based interventions could help reduce pedestrian–motor vehicle collisions. Certain geographic areas experience much higher numbers of pedestrian–motor vehicle collisions than do most other areas. Improving pedestrian safety in these geographic areas first could reduce the overall number of pedestrian–motor vehicle collisions, thus reducing unintentional injuries and fatalities. With limited resources available for pedestrian safety and unintentional injury prevention, targeted interventions could be the most cost effective.

Furthermore, these models could help municipalities be proactive in determining geographic areas at risk for elevated numbers of pedestrian–motor vehicle collisions and in monitoring changes that might identify geographic areas with potentially increasing or decreasing numbers of pedestrian–motor vehicle collisions. Such proactive monitoring could assist municipalities in focusing resources and targeting interventions to geographic areas most at risk for elevated numbers of pedestrian–motor vehicle collisions.

Our results also suggest future research directions that would enhance our understanding of pedestrian–motor vehicle collisions and pedestrian safety. Qualitative studies informed by and supplementing quantitative studies such as ours should investigate resident perceptions of pedestrian safety. In this way, municipalities could proactively target specific neighborhoods to enhance pedestrian safety. Census tracts might not be a geographic unit particularly relevant to community members, but studies by neighborhood in a place such as Denver, which has fairly well-defined neighborhood units that correspond relatively well to aggregate census boundaries, could be informative. In cities where neighborhoods are not so well defined, alternatives might be identified, such as elementary school catchment areas.

Looking more specifically at the relationship between liquor license outlets and pedestrian–motor vehicle collisions would also be useful. Despite previous research indicating a significant association between the type of liquor license outlet and various public health outcomes,[22,23,36,37] we did not observe a significant association between the type of liquor license outlet and pedestrian–motor vehicle collisions in this study. Instead, density of liquor license outlets—irrespective of type—was significantly associated with pedestrian–motor vehicle collisions. Further investigation into the relationship between liquor license outlets and pedestrian–motor vehicle collisions would help municipalities make planning decisions and allocate liquor licenses. Such information might also help municipalities plan pedestrian infrastructure enhancements and make policy decisions for geographic areas with elevated numbers or specific types of liquor license outlets.

Although our study provided useful insights into the spatial patterns and place-based relationships of environmental characteristics associated with pedestrian–motor vehicle collisions in Denver, it had some limitations. The exploratory, cross-sectional nature of the study facilitated the investigation of associations that may lead to new hypotheses and inform future studies, but it did not permit causal inferences. The exclusion of 2 census tracts that had very low residential populations during the 2000 US Census (<5) isolated a group of census tracts in the northeast corner of the city. This isolation may have affected the CAR model, which relied on a proximity matrix, although each of the tracts in this groups still bordered at least 2 other tracts.

Finally, our data were limited to pedestrian–motor vehicle collisions on public roadways, which often serve to subdivide geographic areas of a city. Analyses of pedestrian–motor vehicle collisions must determine how to assign collisions that occur along roads that serve as geographic unit boundaries. We relied on the US Census Bureau tract assignment because place-based census data composed a critical portion of the data of interest.

Conclusions

We combined publicly available data from several sources and integrated the information in a GIS to provide a unique look at the spatial patterns of pedestrian–motor vehicle collisions and associated environmental characteristics. The insights gained through such place-based analyses may help spur future research as well as programmatic decisions and policy development to help protect pedestrians and promote walking as a means to combat obesity, diabetes, and other chronic diseases. ■

About the Authors

At the time of the study, Anne K. Sebert Kuhlmann was with the Health and Behavioral Sciences Program, University of Colorado Denver. John Brett was with the Department of Anthropology, University of Colorado Denver. Deborah Thomas was with the Department of Geography and Environmental Sciences, University of Colorado Denver. Stephan R. Sain was with the Department of Mathematics, University of Colorado Denver.

Correspondence should be sent to John Brett, PhD, Department of Anthropology, University of Colorado Denver, Campus Box 103, P.O. Box 173364, Denver, CO 80217-3364 (e-mail: John.Brett@ucdenver.com). Reprints can be ordered at http://www.ajph.org by clicking on the "Reprints/Eprints" link.

This article was accepted November 27, 2008.

Contributors

A.K. Sebert Kuhlmann originated the study and supervised all aspects of its implementation. J. Brett assisted with the conceptualization and design of the study. D. Thomas assisted with the GIS analyses. S.R. Sain assisted with the statistical analyses. All authors contributed ideas, interpreted findings, and reviewed drafts of the article.

Human Participant Protection

No protocol approval was necessary because data were obtained from publicly available secondary sources.

References

1. Staunton CE, Hubsmith D, Kallins W. Promoting safe walking and biking to school: the Marin County success story. *Am J Public Health.* 2003;93(9):1431–1434.

2. Walk to School Day—USA. Available at: http://www.walktoschool-usa.org. Accessed November 9, 2004.

3. Koornstra MK, ed. 2003. Transport safety performance in the EU. Available at: http://www.etsc.be/documents/statoverv.pdf. Accessed November 18, 2004.

4. Miller TR, Spicer RS, Lestina DC, Levy DT. Safest to travel by bicycle, car or big truck? *Traffic Inj Prev.* 1999;1:25–34.

5. Pucher J, Dijkstra L. Promoting safe walking and cycling to improve public health: lessons from the Netherlands and Germany. *Am J Public Health.* 2003;93(9):1509–1516.

6. Peden M, Scurfield R, Sleet D, et al., eds. *The World Report on Road Traffic Injury Prevention.* Geneva, Switzerland: World Health Organization; 2004.

7. Fletcher T, McMichael AJ, eds. *Health at the Crossroads: Transport Policy and Urban Health.* Chichester, UK: John Wiley & Sons; 1997.

8. National Highway Traffic Safety Administration, US Department of Transportation. *Pedestrian Roadway Fatalities.* Springfield, VA: National Center for Statistics and Analysis; 2003.

9. Ernst M, McCann B. *Mean Streets 2002.* Washington, DC: Surface Transportation Policy Project; 2002.

10. Ernst M. *Mean Streets 2004: How Far Have We Come?* Washington, DC: Surface Transportation Policy Project; 2004.

11. Lightstone AS, Dhillon PK, Peek-Asa C, Kraus JF. A geographic analysis of motor vehicle collisions with child pedestrians in Long Beach, California: comparing intersection and midblock incident location. *Inj Prev.* 2001;7:155–160.

12. LaScala EA, Gruenewald PJ, Johnson FW. An ecological study of the locations of schools and child pedestrian injury collisions. *Accid Anal Prev.* 2004;36:569–576.

13. Joly MF, Foggin PM, Pless IB. Geographical and socio-ecological variations of traffic accidents among children. *Soc Sci Med.* 1991;33(7):765–769.

14. Hijar M, Trostle J, Bronfman M. Pedestrian injuries in Mexico: a multi-method approach. *Soc Sci Med.* 2003;57:2149–2159.

15. Centers for Disease Control and Prevention. Pedestrian fatalities—Cobb, DeKalb, Fulton, and Gwinnett counties, Georgia, 1994–1998. *MMWR Morb Mortal Wkly Rep.* 1999;48(28):601–605.

16. Marosi R. Pedestrian deaths reveal O.C.'s car culture clash. *Los Angeles Times.* November 28, 1999:A1.

17. Moreno S, Sipress A. Fatalities higher for Latino pedestrians: area's Hispanic immigrants apt to walk but unaccustomed to urban traffic. *Washington Post.* August 27, 1999:A1.

18. Anderson RW, McLean AJ, Farmer MJB, Lee BH, Brooks CG. Vehicle travel speeds and the incidence of fatal pedestrian crashes. *Accid Anal Prev.* 1997;29:667–674.

19. Hijar M, Vazquez-Vela E, Arreola-Risa C. Pedestrian traffic injuries in Mexico: a country update. *Inj Control Saf Promot.* 2003;10:37–43.

20. Ewing R. Is Los Angeles–style sprawl desirable? *J Am Plann Assoc.* 1997;63(1):107–126.

21. Centers for Disease Control and Prevention, National Center for Injury Prevention and Control. Web-based Injury Statistics Query and Reporting System (WISQARS). 2005. Available at: http://www.cdc.gov/ncipc/wisqars. Accessed March 19, 2008.

22. Gruenewald PJ, Stockwell T, Beel A, Dyskin EV. Beverage sales and drinking and driving: the role of on-premise drinking places. *J Stud Alcohol.* 1999;60:47–53.

23. Scribner RA, MacKinnon DP, Dwyer JH. Alcohol outlet density and motor vehicle crashes in Los Angeles County cities. *J Stud Alcohol.* 1994;55:447–453.

24. Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: views from urban planning. *Am J Prev Med.* 2002;23(2 suppl):64–73.

25. LaScala EA, Gerber D, Gruenewald PJ. Demographic and environmental correlates of pedestrian injury collisions: a spatial analysis. *Accid Anal Prev.* 2000;32:651–658.

26. LaScala EA, Johnson FW, Gruenewald PJ. Neighborhood characteristics of alcohol-related pedestrian injury collisions: a geostatistical analysis. *Prev Sci.* 2001;2(2):123–134.

27. Craig CL, Brownson RC, Cragg SE, Dunn AL. Exploring the effect of the environment on physical activity: a study examining walking to work. *Am J Prev Med.* 2002;23(2 suppl):36–43.

28. Frank LD, Pivo G. Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. *Transportation Res Rec.* 1994;1499:44–52.

29. Motor Vehicle Division. Traffic accident report form. DR 447. In: *Investigating Officer's Traffic Accident Reporting Manual.* Rev ed. Denver: State of Colorado; 1997.

30. *ArcGIS: Release 9.0.* Redlands, CA: Environmental Systems Research Institute; 2004.

31. US Census Bureau. TIGER, TIGER/Line and TIGER-related products. Topographically integrated geographic encoding and referencing system. Available at: http://www.census.gov/geo/www/tiger. Accessed March 1, 2009.

32. US Census Bureau. American FactFinder. Available at: http://factfinder.census.gov/servlet/AGSGeoAddressServlet?_lang=en&_programYear=50&_treeId=420. Accessed March 1, 2005.

33. Waller LA, Gotway CA. *Applied Spatial Statistics for Public Health Data.* New York, NY: John Wiley; 2004:227–236, 367–380.

34. Rue H, Held L. *Gaussian Markov Random Fields: Theory and Applications.* Boca Raton, FL: Chapman and Hall/CRC; 2005:28–29, 72–73.

35. Cohen J. *Statistical Power and Analysis for the Behavioral Sciences.* 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

36. Lipton R, Gruenewald P. The spatial dynamics of violence and alcohol outlets. *J Stud Alcohol.* 2002;63:187–195.

37. Gruenewald PJ, Freisthler B, Remer L, LaScala EA, Treno A. Ecological models of alcohol outlets and violent assaults: crime potentials and geospatial analysis. *Addiction.* 2006;101:666–677.