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A GIS-based spatiotemporal analysis of violent trauma hotspots in Vancouver, Canada: identification, contextualisation and intervention

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ABSTRACT

Background: In 2002, the WHO declared interpersonal violence to be a leading public health problem. Previous research demonstrates that urban spaces with a high incidence of violent trauma (hotspots) correlate with features of built environment and social determinants. However, there are few studies that analyse injury data across the axes of both space and time to characterise injury–environment relationships. This paper describes a spatiotemporal analysis of violent injuries in Vancouver, Canada, from 2001 to 2008.

Methods: Using geographic information systems, 575 violent trauma incidents were mapped and analysed using kernel density estimation to identify hotspot locations. Patterns between space, time, victim age and sex and mechanism of injury were investigated with an exploratory approach.

Results: Several patterns in space and time were identified and described, corresponding to distinct neighbourhood characteristics. Violent trauma hotspots were most prevalent in Vancouver's nightclub district on Friday and Saturday nights, with higher rates in the most socioeconomically deprived neighbourhoods. Victim sex, age and mechanism of injury also formed strong patterns. Three neighbourhood profiles are presented using the dual axis of space/time to describe the hotspot environments.

Conclusions: This work posits the value of exploratory spatial data analysis using geographic information systems in trauma epidemiology studies and further suggests that using both space and time concurrently to understand urban environmental correlates of injury provides a more granular or higher resolution picture of risk. We discuss implications for injury prevention and control, focusing on education, regulation, the built environment and injury surveillance.

Strengths and limitations of this study

- High-resolution multidimensional patterns of violent trauma are identified using a population-based trauma registry.
- Neighbourhood characteristics are used to describe context-specific urban violent spaces in a high-income country.
- Owing to data recording procedures and confidentiality regulations, this study is limited to severe trauma and excludes cases where the patient expired prior to arrival at a trauma centre.

BACKGROUND

In 2008 over two million people in the USA were injured as a result of interpersonal violence.[1] As a result there were 19 200 deaths; this mortality rate is more than 13 times the number of American 'War on Terror' casualties that same year.[2 3] While medical and criminal perspectives tend to dominate the public discourse on violent injury, incidents have social, economic, political and personal repercussions.[4] For example, the total cost of violence in the USA is estimated to be nearly 10% of the gross domestic product.[5 6] Such figures fail to include the extensive psychological and emotional impacts of victimisation.[7] This multifaceted burden of violent injury presents a significant challenge to public health policymakers and practitioners. To contribute to injury prevention and control efforts, we employ a spatial epidemiology approach that emphasises the role of urban geographies in this multivariate temporal analysis of violent injury.

Within cities, violent injury incidence has been shown to vary between neighbourhoods. For example, Brantingham and Brantingham[8] point to dense, elevated violence rates along the edges of entertainment districts, contrasting low rates in larger, nearby residential areas. In order to identify high-risk urban areas (hotspots), many researchers use geographic information systems (GIS).[9–11] GIS technologies and methods constitute a powerful toolset for

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analysing spatial data, and have been pivotal in identifying the links between violent injury and features of social and physical environments.[9 12 13]

Research has demonstrated that injury is strongly correlated in space-time, and is related to features of the social and physical urban environments.[12 14–16] These relationships can be further refined by including a temporal variable. Cusimano *et al* identified peaks in violent injury incidence at night and early morning, tending to cluster around alcohol-serving establishments, low-income housing and homeless shelters.[9 10 17–21] This work differs in that we expand our analysis to include victim characteristics, the weapon of injury and a measure of social deprivation.

Social structure and deprivation are shown to be correlated with violent injury.[16] Socioeconomic indicators and indices (eg, income inequality and employment status) tend to be strong predictors of injury risk.[22 23] We examine this relationship using a deprivation index developed by Bell *et al*.[24]

In this work, we focus on severe trauma as the result of interpersonal violence in Vancouver, Canada. Specifically, we investigate how these incidents cluster in space-time, and examine how these patterns are reflected in the nature of the victim, the injury, the physical environment and the socioeconomic deprivation level of the neighbourhood where the incident took place.

DATA AND METHODS

Injury data were acquired from the British Columbia Trauma Registry comprising the location, date, time and cause of every injury that was treated in a trauma centre in the Metro Vancouver area between 2001 and 2008, inclusive. Owing to data recording protocols, confidentiality regulations, and to eliminate minor incidents, only cases with an injury severity score (ISS)[25] greater than 15 were included. As such, only severe injuries and injuries to multiple body parts were included; sports injuries and self-inflicted injuries were excluded. Cases where the patient had expired prior to arrival at a trauma centre were not recorded in the trauma registry and are therefore excluded from this analysis.

The data were classified into seven injury mechanisms: gunshot wound; sharp object trauma; blunt object trauma; bodily force (eg, punch); and other assault. A total of 575 incidents were mapped, each represented as a point in space and time. In order to determine whether an incident took place during the day or night, civil dawn and civil dusk were calculated for every day in the data period.

The following variables were used in this analysis: injury location (mapped); victim age; victim sex; date and time of incident; and mechanism of injury. Pearson's χ^2 test was used to determine the independence of variables against day/night, and the data were graphed in relation to time of day, day-night contrast, time of year, and day of the week. These relationships were mapped in order to identify multivariate clusters (eg, night time gunshot injuries).

The data were imported into geographic information systems and kernel density estimation was used to produce hotspot maps to contrast hotspots for men and women. As these data constitute a population, kernel density estimation was selected as a non-inferential interpolation method for visualising the spatial distribution of cases. Natural breaks (Jenks' algorithm) was selected to identify areas of high concentration, and the cut-off was manually adjusted to obscure several cases' locations. To identify spatial-temporal hotspots, the spatial scan statistic with a space-time permutation model was used.[26–28] In the interest of patient confidentiality, the kernel density bandwidth parameter and spatial scan window size are withheld to prevent reverse calculation.

In order to explore the relationship between violent injury hotspots and socioeconomic deprivation, we used the Vancouver Area Neighbourhood Deprivation Index (VANDIX), constructed by Bell *et al*.[24] VANDIX is a single quantitative metric constructed from numerous census variables in consultation with regional health specialists. The deprivation score for every census dissemination area was calculated, and classified into quintiles and the violent injury locations were queried in GIS to identify the proportion within each deprivation quintile.

FINDINGS

The violent injury data comprise 518 male and 57 female victims. This disparity corresponds with findings in the literature.[14] However, trauma data are certainly skewed due to the under-reporting of domestic violence.[29] When categorised by day/night, we found that 75% of injuries among men occurred at night, compared with 56% of injuries among women; the association between victim sex and day/night was significant (χ^2 p=0.002). Figure 1 displays the temporal distribution.

One in every three injuries in this dataset was caused by a firearm. However, weapon of choice and time/location do not significantly correlate, matching findings in the literature.[30] Figure 2 divides each mechanism of injury into day/night incidence. The difference of day/night ratios suggests that the severity of a mechanism is related to its proportional daytime prevalence. That is, an offender may feel more secure using a firearm under the cover of darkness, whereas the distinction is less consequential if throwing a punch. Note that because these data only include severe trauma cases, blunt object and bodily force injuries are under-represented.

In figure 3, incidents are categorised by day of the week. Each night is defined as continuous until the following dawn; that is, Saturday night continues until sunrise on Sunday. This is done in order to account for alcohol consumption initiated in the evening and prolonged through the night. This weekend spike is to be

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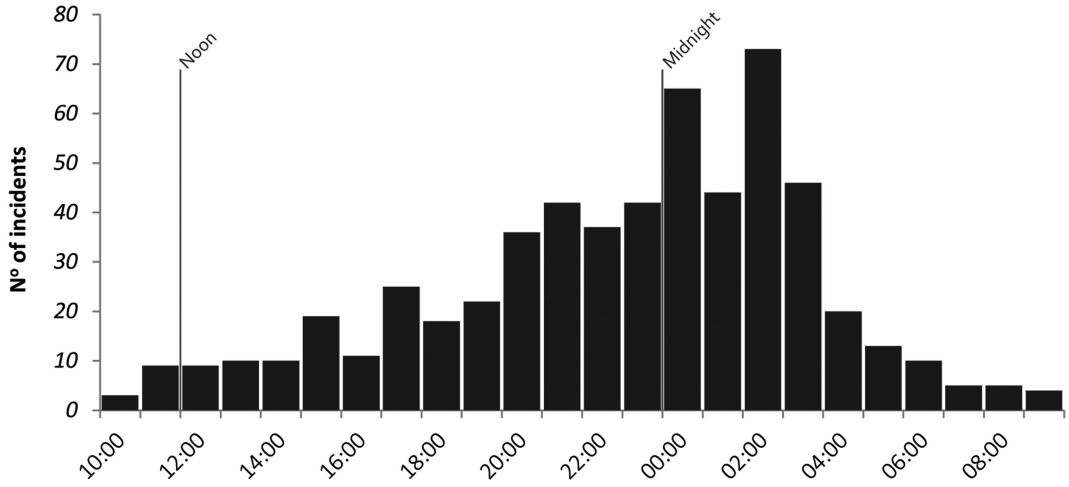

Figure 1 Temporal distribution of violent injuries through 24 h period. Seventy-three per cent of incidents took place at night. Note the bimodal peaks at midnight and 2:00. These peaks clustered spatially within the nightclub district (23:00–3:00) and the Downtown Eastside (00:00–4:00). The peak between 2:00 and 3:00 coincides with required bar closing times.

expected, but note the 'hangover effect': relative peace on Saturday and Sunday during daylight hours.

Figure 4, below, displays violent injury hotspots in the Metro Vancouver area. This pattern is similar to the distribution of low-income, high-density housing in the region. The most prominent hotspot (bright red) occurs in the Downtown Eastside, and some minor hotspots are found in commercial zones of the outer suburbs. The linear trend from Downtown to New Westminster features a series of minor hotspots which occur close to Skytrain stations (light rail transit) and a major shopping centre.

Also evident are spatial differences in female (red) and male (blue) victim hotspots. While the sample size for women is comparatively small, when mapped, some geographic differences are notable. The club district, Commercial Drive and the stadium feature only male victims, while victims in Chinatown are all women.

The circles represent cluster locations detected using the space-time permutation model of the spatial scan statistic, with the time window in which the cluster occurs. The nightclub district, the Downtown Eastside and Commercial Drive contain night-time hotspots that are particularly active on Friday and Saturday nights. These neighbourhoods have a high concentration of alcohol-serving establishments that feature live music and late closing times. The stadium and arena also appears as a hotspot. That this occurs during the night suggests that these cases may also be attributed to the high concentration of alcohol-serving establishments surrounding, and including, the stadium.

When violent injury locations were compared with the VANDIX[24] we found that 77% of all severe violent injuries occurred within neighbourhoods in these two most deprived quintiles. There are two notable exceptions: the club district and Metrotown. While the cluster in the club district is explained by the high night-time incidence in proximity to alcohol-serving establishments, the case in Metrotown is more complex and better explained by features of the built urban environment.

DISCUSSION

The findings point towards several patterns of violent injury embedded in neighbourhood characteristics. To illustrate, we thematically examine three neighbourhoods identified in the maps above: Metrotown; the Downtown Eastside; and the nightclub district/stadium.

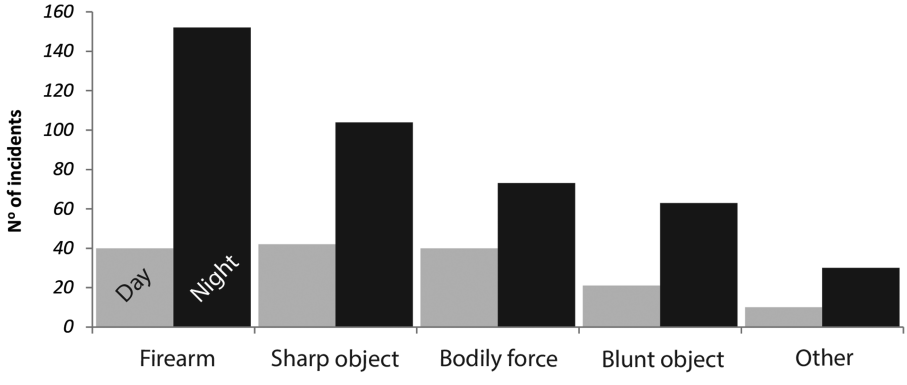

Figure 2 Day/night comparison of violent injury counts by mechanism of injury. All injuries are more prevalent at night while firearms and injuries from sharp objects (eg, knives) are much more prevalent. The increase between day and night incidence of firearm injury is 380%, compared with 247% for sharp object and only 183% for bodily force.

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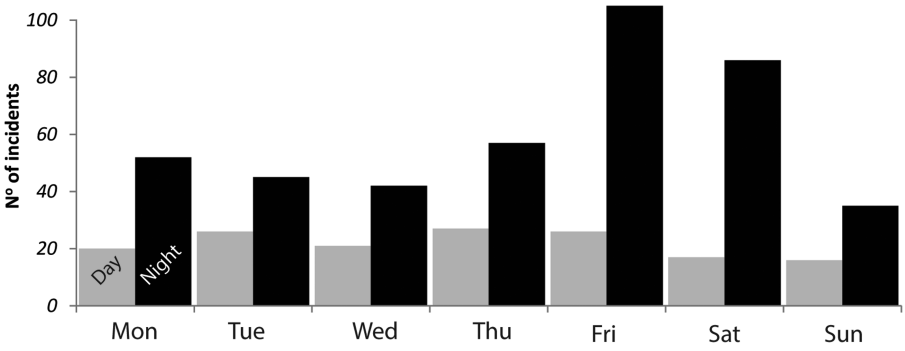

Figure 3 Day/night contrast of violent injury counts by day of week. There is a clear spike on Friday and Saturday nights with daytime figures remaining relatively constant throughout the week. Friday night and Saturday night account for one-third of all injuries. While the median age for all injuries in the dataset is 30, it drops to 25 on Friday and Saturday nights. This spike clusters around the nightclub district.

Metrotown: the built environment

Metrotown is a high-density commercial/industrial neighbourhood with a large shopping centre, cinema and major transit node at its core. These features are encircled by upscale, high-density housing, primarily condominium towers. Similar to the club district, this neighbourhood does not have low incomes, high unemployment or a high deprivation index. It does not, however, have a high concentration of alcohol-serving establishments. Metrotown's appearance as a violent injury hotspot in this study may be explained by the built environment. Shopping centres, transit nodes and high-density commercial development has been linked to violent injury in the literature.[21 29 31 32] While the median victim age city-wide is 30, the Metrotown injury cluster has a median age of 25. This may be explained by the presence of the shopping centre and cinema complex, both popular youth recreation sites. The Metrotown case underscores the role of the built environment,[8 18] a powerful driver of violent injury that socioeconomic and demographic indicators of a neighbourhood's residents fail to represent.

Conversely, features of the built environment perceived as signs of urban decay have been linked to

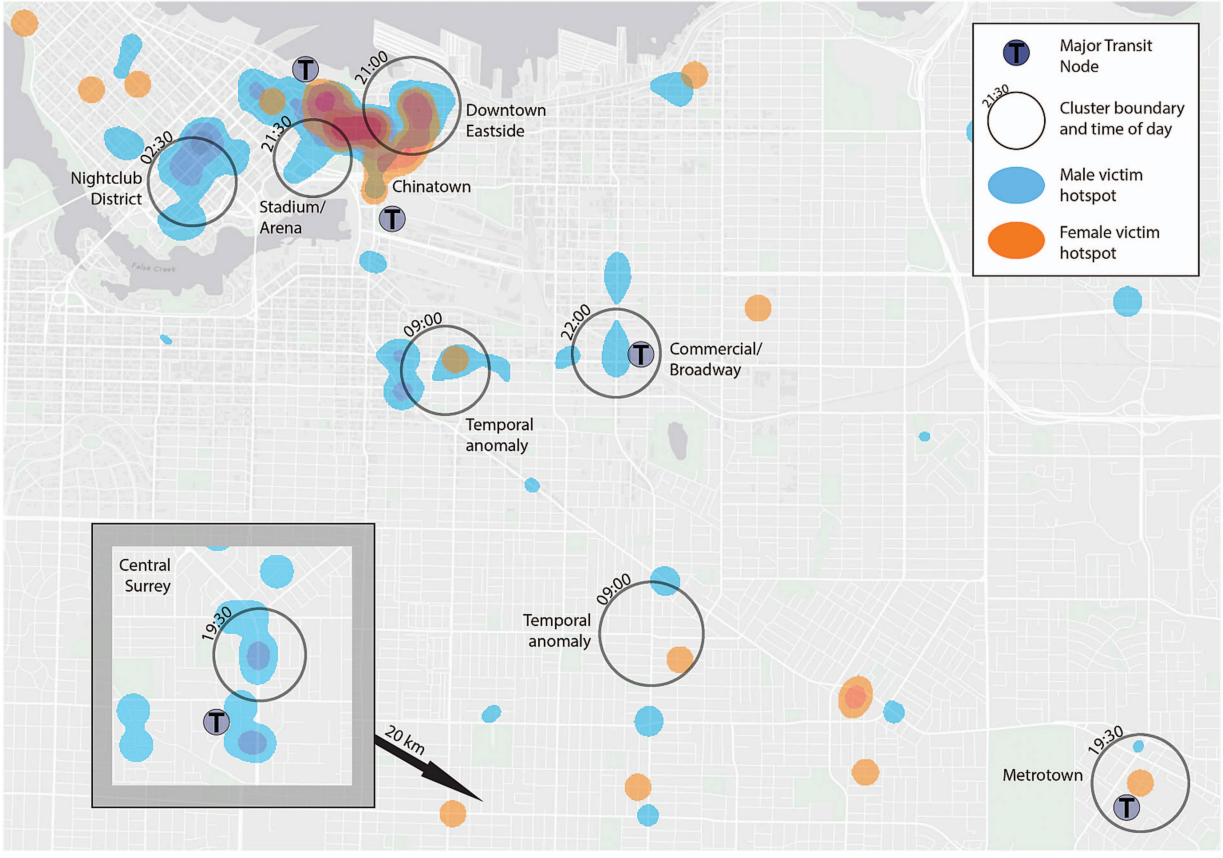

Figure 4 Injury hotspots by subcategory. Note that the Downtown Eastside is an injury hotspot regardless of the breakdown of victims. However, male victims of violent injury are spread along other corridors (eg, Commercial Drive) as are night-time injuries. Note also the clustering of cases in the Downtown Eastside, a neighbourhood in the top quintile of socioeconomic deprivation.

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violent behaviours. Examples include adult businesses,[29] abandoned buildings[20] and homeless shelters.[21 31] While these features are not found in Metrotown, they exist in high concentration in the Downtown Eastside.

Downtown eastside, socioeconomic deprivation

With an average income of $C6282 (before government subsidy), Vancouver's Downtown Eastside has over twice the unemployment rate of Vancouver and less than half the educational attainment.[33] These figures do not account for the substantial homeless population.[34] The Downtown Eastside is adjacent to the central business district, marking a stark economic divide; Wilkinson and Pickett[23] demonstrate the extent to which inequality is a strong driver of interpersonal violence and vice versa. This strong association between socioeconomic deprivation and violent injury incidence coincides with similar findings in the literature.[20 21]

The median age of victims in the Downtown Eastside is 38, 8 years older than that of victims city-wide. This corresponds with the high number of elderly poor who reside in the area, and the near-absence of children. Open drug and alcohol consumption are endemic, both of which have been shown in the literature to correlate with an elevated risk of experiencing violent trauma.[35] There is also an extremely high number of female victims relative to the rest of the study area. Given the high proportion of First Nations population in the Downtown Eastside, relative to the remainder of the study area, this may be explained by the high rates of violence experienced by First Nations women, compared with the general population.[36 37] The sole female-only hotspot bordered the Downtown Eastside, in Chinatown. While this finding certainly merits further examination, an insufficient number of observations precludes the inference that this is a significant effect. The Chinatown corridor, extending south from the Downtown Eastside, runs along a main street with heavy pedestrian traffic. As such, the observed female-only hotspot may rather be a 'spill over' from the Downtown Eastside, reflecting the high proportion of female victims in that area. In addition, it should be noted that Chinatown hosts a large number of First Nations residents (formal and informal). Future research may examine each case independently to determine whether it is a similar pattern of injury.

Club district and stadium, alcohol consumption

The links between alcohol consumption and interpersonal violence are well established in the literature.[9 10 18 20 30 38 39] A 2012 study of violent trauma reports from 14 countries found that over 60% of cases were related to alcohol consumption.[40] Accordingly, many of the incidents in our data occurred at public binge drinking sites; Brantingham and Brantingham[8] found a similar cluster using police data. The stadium also appeared as a hotspot, which may point towards the high concentration of alcohol-serving establishments along its perimeter; other studies have found sports stadiums to be places of high alcohol consumption and violence.[41 42] While the spatial association between alcohol availability and violent trauma was anticipated, the degree to which this was observed was beyond expectation; spaces of excess alcohol consumption appear to be the most prevalent predictor.

IMPLICATIONS FOR PREVENTION AND CONTROL

To examine these findings within an injury prevention and control context, we consider potential interventions actions within education, regulation, the built environment and injury surveillance, recommending a comprehensive comparative study of their effectiveness in other settings.

Physicians occupy a valuable position to discuss violence with patients and refer them to community and health resources.[43] A 1995 study, Hedges *et al*[44] found that nearly half of all repeat trauma patients were injured by the same mechanism that caused their first visit. As such, point-of-care interventions may prove useful in behaviour modification. However, upstream interventions hold strong potential; in this case, information posters could be placed in nightclub washrooms, a technique used in antismoking campaigns.[45] However, offender-targeted campaigns have been shown in the literature to have minimal effect on offender opinions or behaviours, and the management at alcohol-serving establishments may be reluctant to engage in campaigns that may discourage consumption.[46 47] Conversely, the WHO recommends campaigns targeting the cultural norms that promote violence, with an emphasis on youth education.[48] Such programmes would require broader policy support and an acknowledgement of the 'lag effect' of youth education on adult health outcomes.

The most prominent temporal spike in violent injury found in this analysis data points towards the 'closing-time' debate. There is strong evidence that 'last call' policy can reduce excessive consumption and resulting harms,[1 48 49] although the Licensing Act 2003, which allowed for longer serving hours in England and Wales, appeared to have no significant effect.[50] Standardised closing times may contribute to increasingly rapid drinking as last call approaches, leading to higher peak levels of intoxication. One policy alternative is the 'staggered closing' strategy, where venues may purchase liquor licenses priced along a range of closing times. This is intended to prevent high concentrations of intoxicated patrons at closing time. The WHO recommends strategic pricing to reduce alcohol-related harms, which has been shown both in England[51] and British Columbia[52] to be an effective policy tool for reducing negative health outcomes.[48]

There were 192 gunshot trauma cases in this dataset, more than any other mechanism. However, the exclusion of minor injuries in our dataset inflates the

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proportion of severe trauma, limiting any inference. The WHO global report on violence prevention points towards a widespread weapons availability, pointing towards background checks, safe storage regulations and more restrictive regulation.[48] While Canada has relatively strong firearms legislation, the majority of illegal firearms in the Metro Vancouver region are smuggled from the USA or overseas.[53] Improved border checks are therefore a potential avenue for intervention.

While increased police presence in hotspots is often recommended,[31 32 54] Goldstein proposes *problem-oriented policing* as a method that emphasises the role of the police officer to identify underlying drivers of crime, build relationships with the citizenry and acknowledge the limits of the criminal justice system to address problems.[55] This approach has been tested in the field with promising results,[29 31] including 'community policing' in Vancouver.

Planning and modification of the built environment provide another direction through which violent trauma can be prevented.[31] Stevenson describes urban violence with the enclosure/encounter models.[15] A crowded bar is an example of a built enclosure, while the crowded street at closing time causes numerous encounters, both of which can contribute to interpersonal violence. Modifications could include improved nightclub design and wider sidewalks.

Effective injury surveillance programmes can facilitate goal-tracking[43]; social web technologies are a promising asset in this regard, particularly in deprived urban areas where mobile phone usage is rapidly growing.[56] High-quality trauma data were vital in this and other studies. Research and subsequent interventions would benefit from the implementation of a broad violence surveillance programme that combines data from police, medical, schools, community resources (such as women's shelters), legal records and other sources.

In this study, we found several distinct patterns of violent injury with varying characteristics between neighbourhoods. As such, surveillance and intervention programmes should be custom-designed for individual neighbourhoods.[31 55] While education, regulation, the built environment and surveillance programmes hold strong potential to reduce violent injury in urban space, successes based on policing and accessible medical services have been quantitatively demonstrated.[31 54] With the ultimate aim of injury control, a successful campaign will encompass a range of strategies to confront the issue upstream (eg, liquor policy and education) and downstream (eg, policing and ample ambulatory resources). This study is limited by the exclusion of cases with a severity score below 15; as a result, these findings are applicable only to severe trauma. Further, the inclusion of patients who expired prior to arrival at a trauma centre may have an impact on the distribution of hotspots. Their exclusion may have led to an underrepresentation of gang-related violence, which caused numerous deaths during the study period. Future spatial analyses of violent trauma may benefit from the integration of multiple data sources to include a broader range of severity and an extended temporal period.

In this paper, we identified spatial–temporal patterns of violent trauma in Vancouver, Canada, described the neighbourhood-specific contexts within which the examined hotspots are found, and discussed some potential intervention strategies. While this analysis was limited to severe trauma in one city, the findings and implications may prove useful for enriching research efforts in other urban places. However, further research should examine ways to refine the GIS-based methods used herein, conduct more place-specific contextual investigation and examine the efficacy of intervention strategies in other study areas.

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Contributors BBW conducted the analysis, interpreted the findings and drafted the manuscript; and is the guarantor. NS managed the data agreements, interpreted the findings and edited the manuscript. SMH managed the data agreements and reviewed the manuscript.

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REFERENCES

1. Centers for Disease Control and Prevention. WISQARS nonfatal injury reports (Dataset). 2010.
2. United States Department of Defense. *Active duty military deaths by year and manner*. Washington, DC: United States Department of Defense, 2011.
3. World Health Organization. *Disease and injury country estimates, 2008*. Geneva, Switzerland: World Health Organization, 2011.
4. Polinder S, Haagsma J, Lyons R, *et al*. Measuring the population burden of fatal and nonfatal injury. *Epidemiol Rev* 2012;34:17–31.
5. World Health Organization. *The economic dimensions of interpersonal violence*. Geneva, Switzerland: World Health Organization, 2004.
6. Smartrisk. *The economic burden of injury in Canada*. Toronto: Smartrisk, 2009.
7. Papachristos A, Braga A, Hureau D. Social networks and the risk of gunshot injury. *J Urban Health* 2012;89:992–1003.
8. Brantingham P, Brantingham P. Criminality of place: crime generators and crime attractors. *Eur J Crim Policy Res* 1995;3:5–26.
9. Gorman D, Speer P, Gruenewald P, *et al*. Spatial dynamics of alcohol availability, neighborhood structure and violent crime. *J Stud Alcohol* 2001;62:628–37.
10. Livingston M. Alcohol outlet density and assault: a spatial analysis. *Addiction* 2008;103:619–28.
11. Bell N, Schuurman N. GIS and injury prevention and control: history, challenges, and opportunities. *Int J Environ Res Public Health* 2010;7:1002–17.
12. Walker BB, Schuurman N. Environmental correlates with violent injury. *Geomatica* 2012;66:103–11.

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13. Nelson A, Bromley R, Thomas C. Identifying micro-spatial and temporal patterns of violent crime and disorder in the British city centre. *Appl Geogr* 2001;21:249–74.
14. Murray S. Global injury and violence. *Can Med Assoc J* 2006;174:620–1.
15. Stevenson M. Building safer environments: injury, safety, and our surroundings. *Inj Prev* 2006;12:1–2.
16. Sparks C. Violent crime in San Antonio, Texas: an application of spatial epidemiological methods. *Spat Spatiotemporal Epidemiol* 2011;2:301–9.
17. Bellis M, Hughes K, Hughes S. *Alcohol and interpersonal violence: policy briefing*. Geneva: World Health Organization, 2005.
18. Branas C, Elliot M, Richmond T, *et al*. Alcohol consumption, alcohol outlets, and the risk of being assaulted with a gun. *Alcohol Clin Exp Res* 2009;33:906–15.
19. Cunradi C, Mair C, Ponicki W, *et al*. Alcohol outlets, neighbourhood characteristics, and intimate partner violence: ecological analysis of a California city. *J Urban Health* 2011;88:191–200.
20. Gruenewald P, Remer L. Changes in outlet densities affects violence rates. *Alcohol Clin Exp Res* 2006; 30:1184–93.
21. Cusimano M, Marshall S, Rinner C, *et al*. Patterns of urban violent injury: a spatio-temporal analysis. *PLoS ONE* 2010;5:1–9.
22. Bell N, Schuurman N, Hameed SM. A multilevel analysis of the socio-spatial pattern of assault injuries in Greater Vancouver, British Columbia. *Can J Public Health* 2009;100:73–7.
23. Wilkinson R, Pickett K. *The spirit level: why equality is better for everyone*. Toronto, Canada, Penguin, 2009.
24. Bell N, Schuurman N, Oliver L, *et al*. Towards the construction of place-specific measures of deprivation: a case study from the Vancouver metropolitan area. *Can Geogr* 2007;51:444–61.
25. Baker S, O'Neill B, Haddon W, *et al*. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma* 1974;14:187–96.
26. Kulldorff M, Heffernan R, Hartman J, *et al*. A space-time permutation scan statistic for the early detection of disease outbreaks. *PLoS Med* 2005;2:216–24.
27. Kulldorff M. Information Management Services Inc. SaTScan v8.0: Software for the spatial and space-time scan statistics, 2009.
28. Schuurman N, Cinnamon J, Crooks VA, *et al*. Pedestrian injury and the built environment: an environmental scan of hotspots. *BMC Public Health* 2009;9:233.
29. Taylor B, Koper C, Woods D. A randomized controlled trial of different policing strategies at hot spots of violent crime. *J Exp Criminol* 2011;7:149–81.
30. Erickson P, Butters J, Cousineau M-M, *et al*. An international study of the perpetration of violence. *J Urban Health* 2006;83:788–801.
31. Braga A, Weisburd D, Waring E, *et al*. Problem-oriented policing in violent crime place: a randomized controlled experiment. *Criminology* 1999;37:541–80.
32. Piza E, Kennedy L, Caplan J. *Risk clusters, hotspots, and spatial intelligence: risk terrain modeling as an algorithm for police resource allocation strategies*. Newark: Rutgers Center on Public Security, 2010.
33. Statistics Canada. *Census of population*. Ottawa, 2006.
34. Roe G. Fixed in place: Vancouver's Downtown Eastside and the community of clients. *BC Studies* 2009;164:75–101.
35. Korcha R, Cherpitel C, Witbrodt J, *et al*. Violence-related injury and gender: the role of alcohol and alcohol combined with drugs. *Drug Alcohol Rev* 2014;33:43–50.
36. Farley M, Lynne J, Cotton A. Prostitution in Vancouver: violence and the colonization of First Nations women. *Transcult Psychiatry* 2005;42:242–71.
37. Brownridge D. Male partner violence against Aboriginal women in Canada: an empirical analysis. *J Interpers Violence* 2003;18:63–83.
38. Zhu L, Gorman D, Horel S. Alcohol outlet density and violence: a geospatial analysis. *Alcohol Alcohol* 2004;39:369–75.
39. Cunningham R, Walton M, Maio R, *et al*. Violence and substance use among an injured emergency department population. *Acad Emerg Med* 2003;10:764–75.
40. Cherpitel C, Ye Y, Bond J, *et al*. Attribution of alcohol to violence-related injury: self and other's drinking in the event. *J Stud Alcohol Drugs* 2012;73:277–84.
41. Roberts J, Benjamin C. Spectator violence in sports: a North American perspective. *Eur J Crim Policy Res* 2000;8:163–81.
42. Sànchez À, Krafty R, Puyana J, *et al*. Football events and thier association with interpersonal violence deaths. *Panam J Trauma Crit Care Emerg Surg* 2013;2:26–32.
43. Anderson R, Taliaferro E. Injury prevention and control. *J Emerg Med* 1998;16:487–98.
44. Hedges B, Dimsdale J, Hoyt D, *et al*. Repeat trauma patients, San Diego County. *Am J Public Health* 1995;85:1008–10.
45. Prothrow-Stith D. The epidemic of violence and its impact on the health care system. *Henry Ford Hosp Med J* 1990;38:175–7.
46. Flexon J, Guerette R. Differential effects of an offender-focused crime prevention media campaign. *J Crim Justice* 2009;37:608–16.
47. Hawkins N, Sanson-Fisher R, Shakeshaft A, *et al*. Differences in licensee, police and public opinions regarding interventions to reduce alcohol-related harm associated with licensed premises. *Aust N Z J Public Health* 2009;33:296.
48. World Health Organization. *Violence prevention: the evidence*. Geneva: World Health Organization, 2010.
49. Hahn R, Kuzara J, Elder R, *et al*. Effectiveness of policies restricting hours of alcohol sales in preventing excessive alcohol consumption and related harms. *Am J Prev Med* 2010;39:590–604.
50. Hough M, Hunter G. The 2003 Licensing Act's impact on crime and disorder: an evaluation. *Criminol Crim Justice* 2008;8:239–60.
51. Purshouse RC, Meier PS, Brennan A, *et al*. Estimated effect of alcohol pricing policies on health and health economic outcomes in England: an epidemiological model. *Lancet* 9723;375:1355–64.
52. Stockwell T. Does minimum pricing reduce alcohol consumption? The experience of a Canadian province. *Addiction* 2012;107:912–20.
53. Ball D. *American guns, Canadian deaths*. Vancouver, 2012 [updated 4 Jan 2012]. http://www.vancouverobserver.com/politics/investigations/2012/01/04/american-guns-canadian-deaths
54. Warburton A, Shepherd J. Tackling alcohol related violence in city centres: effect of emergency medicine and police intervention. *Emerg Med J* 2006;23:12–17.
55. Goldstein H. Imporving policing: a problem-oriented approach. *Crime Delinquency* 1979;25:236–58.
56. Cinnamon J, Schuurman N. Injury surveillance in low-resource settings using geospatial and social web technologies. *Int J Health Geogr* 2010;24:25.

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