

Spatial-Temporal Epidemiology of Violent Trauma in Urban Environments

by

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Abstract

The World Health Organization has declared violence to be a significant public health problem (2002). This thesis uses a spatial epidemiology approach to investigate clusters of violent injury in the Metro Vancouver area.

Trauma registry data were analysed using a visually-enhanced ranking method in geographic information systems to identify violent injury hotspots. The identified hotspots were then examined using environmental, spatial-temporal, victim, and deprivation variables. Data from hotspot observations, victim and incident records, and the use of a Vancouver-specific deprivation index were included.

Alcohol availability, time of day, and social deprivation are several of the factors found to be strongly related to violent injury hotspots. However, the hotspots were found to occur in several disparate geographical contexts, each of which is characterised to produce a series of multidimensional profiles of urban spaces of violent injury. To conclude, the emergence of a non-statistical, exploratory paradigm in geographic information science is promoted.

Keywords: violent injury; spatial epidemiology; temporal; urban environment; geographic information systems

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Chapter 1

Introduction

Since the industrial revolution, significant advances in medicine and sanitation have been made, leading to the decline of infectious disease prevalence around the globe (Omran 1971). With this decline came the rise of chronic disease as the primary cause of mortality, particularly in the global north (WHO 2011). This epidemiological transition is also transpiring in the global south, alongside the adoption of liberal economic and political models, rapid urbanisation, and access to medical technology (Albala, et al. 1997; Amuna and Zotor 2008; Agyei-Mensah 2010). In Canada, the mortality rate in 2004 from non-communicable disease was over nineteen times the mortality from communicable, maternal, perinatal, and nutritional diseases combined (WHO 2011). Also causing more deaths than this combined total is the oft-overlooked 'invisible epidemic', injury (Smartrisk 2005; WHO 2011).

In Canada, injury is the fourth overall leading cause of death; however, it is the number one cause of death for Canadians aged 1 to 44 years (Smartrisk 2005; Public Health Agency of Canada 2006). While the majority of injury-related mortality is unintentional or self-inflicted, interpersonal violence is a significantly prevalent cause. The World Health Organization (2011) estimated Canadian mortality caused by interpersonal violence to be 1.4 per 100 000 in 2004; and while this is less than one quarter that of the United States of America, interpersonal violence still poses a significant public health problem here in Canada (Smartrisk 2005; Health Canada 2010).

This thesis begins with a background on violent injury, the study area, and injury data. Also provided is a primer on violent injury's patterns in space-time and its links to the social and physical urban environments. Subsequently introduced is the spatial epidemiology approach employed in this research coupled with a background on the use of GIS as an exploratory tool. An example of how this approach is used to synthesise

evidence is then provided, using one of the most prevalent drivers of violent trauma: alcohol consumption.

Burden of violent injury

While often thought of as a medical issue or public health care expense, an injury may incur upon its victim financial losses, emotional trauma, decreased work productivity, and other knock-on effects. These burdens may also place strain upon personal and professional relationships. Furthermore, injuries can trigger medical complications, resulting in additional conditions requiring treatment.

The total impact of an incident, as its effects echo and accumulate through society, is referred to as the burden of injury. While previously applied to other diseases, the total burden concept was first applied to injury by Gordon (1949), who was one of the first researchers to promote an epidemiological approach to injury. The burden of injury is often estimated as a cost in monetary units. For example, the 2004 estimate in Canada was published as 871 million dollars, greater than those of drowning, burns, and sports injuries combined (Smartrisk 2009).

Such conceptualisations omit other quality-of-life factors such as social, psychological, and emotional wellbeing. However, the publishing of dollar figures as a valuation metric may have a greater effect on public perception and policy priority, as dollars are more widely understood than, for example, disability-adjusted life-years (Polinder, et al. 2012). Reducing the burden of disease is one of the primary goals of public health practice (Walley, et al. 2001); the ultimate purpose of this thesis is to inform that practice by examining interpersonal violence in urban space.

Contrasting urban and rural violence

Rural Canada has been shown to experience lower levels of overall crime, but higher rates (cases per capita) of homicide and interpersonal violence than its urban counterparts (Osgood and Chambers 2000; Francisco and Chénier 2007). For example, in 2005 the homicide rate [per 100 000, as are all rates given hereforth] was 2.5 in rural areas, versus 2.0 in large urban areas. That same year, the violent crime rate was 830

in large urban areas, 1232 in small urban areas, and 1067 in rural areas (Francisco and Chénier 2007). Conversely, 19 per cent of violent crime in large urban areas features a weapon, versus only 12 per cent in rural (Francisco and Chénier 2007). Similarly, Shaw-Taylor (2002) found the highest rates of homicide in the USA to be in low-income urban areas. However, such figures include only reported crimes. Domestic violence often goes unreported, and higher rates are experienced in rural areas (Logan, et al. 2003; Taylor, et al. 2011; Kim, et al. 2012).

This thesis focuses on urban settings, because while rural areas may experience higher rates of interpersonal violence, urban areas contain the greatest total number of incidents, thus comprising the largest portion of the burden of injury (Nelson, et al. 2001). For example, 65 per cent of all homicides in Canada in 2005 took place in large urban areas. Furthermore, injury has been found to cluster strongly in space-time, particularly in urban areas (Dovey 2000). Focus on these clusters assists researchers in search of factors that may be drivers behind violent injury.

Geographical context

In British Columbia in 2005 the homicide rate was 2.6, higher than the Canada-wide rate of 2.0 (Francisco and Chénier 2007). These figures suggest higher rates of all violence (as opposed to only reported violent crime) within the populations of British Columbia, emphasising the need for additional research in this area. Given that Vancouver has the largest population in British Columbia, it is reasonable to infer that the Metro Vancouver area is also host to the greatest number of violent incidents in the province. As such, Metro Vancouver, formerly known as the Greater Vancouver Regional District, was selected as the study area. This agglomeration comprises the city of Vancouver and surrounding municipalities, home to a population of 2.46 million people (estimate for the year 2012; Statistics Canada 2013).

The study period is from January 1, 2001 to December 31, 2008. During this time, there were approximately 300 000 violent crimes in Metro Vancouver (calculated using Statistics Canada 2012b). Figure 1, below, compares violent crime rates of Metro Vancouver to those of Canada.

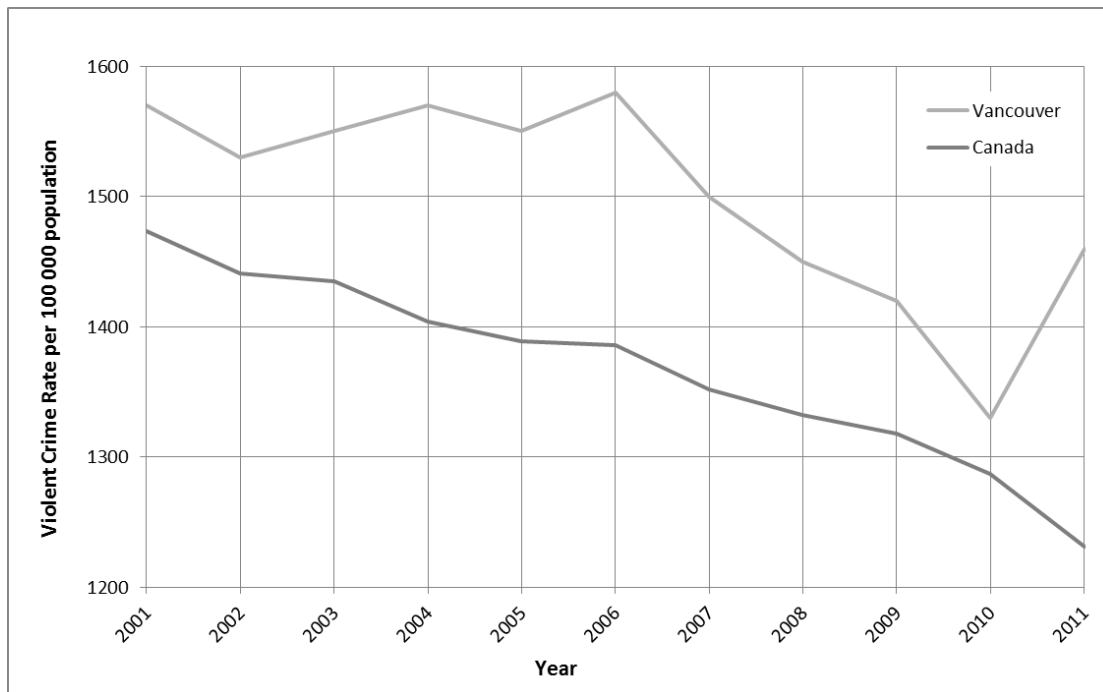


Figure 1: Violent crime rate comparison between Canada and Metro Vancouver, 2001-2011. Vancouver has slightly higher rates than Canada, but follows a similar temporal trend. Note the 2011 spike, possibly due to the 'hockey riots' and a spike in gang-related violence that year. Data: Statistics Canada (2012a; b).

Approximately 19 per cent of all violent crime in Canada features the use of a weapon (Francisco and Chénier 2007). According to the Uniform Crime Reporting Survey (2012), 3.2 per cent include firearms, 7.0 per cent include sharp objects, and 8.7 per cent feature blunt objects or other mechanisms (e.g., malicious burn, explosion). This means that 81 per cent of violent crimes are committed exclusively using bodily force. Intuitively, there is an hierarchy of severity along the axis of mechanism, suggesting a greater danger associated with firearms than fists. In chapter 3 of this thesis, the spatial-temporal distribution of mechanisms is examined.

In the popular media, firearm violence is frequently portrayed as linked to gang activity, and bodily force is often associated with alcohol consumption or intimate partner violence (for examples, see the British Library's topical bibliography on youth gangs, knife, and gun crime¹, and the Royal Canadian Mounted Police's 2006 environmental

¹ <http://www.bl.uk/reshelp/findhelpsubject/socsci/topbib/gang/knifecrimeitalics.pdf>

scan of youth gangs and guns²; Woodruff 1996; Buskirk, et al. 2012). While there is an abundance of evidence in the literature to support these connections, closer examination suggests that gang-related violence in Canada is overrepresented in the popular media and intimate partner violence underreported in trauma data (Fagan and Wilkinson 1998; Phillips 1999; Logan, et al. 2003; Cunradi 2007; Ratcliffe 2008; Children's Defence Fund 2012; Kim, et al. 2012; Papachristos, et al. 2012). Much of the focus in the literature concerns the social identities of the victims and perpetrators. However, rather than examining the *who* or *to whom*, this thesis seeks to fill some of the knowledge gaps concerning the *where*, *when*, and *how* of urban interpersonal violence.

Approach: an alternative spatial epidemiology

Spatial epidemiology can be loosely defined by a focus on the geographical patterns of disease in search of environmental, social, and other categorical determinants of health events (Elliot and Wartenberg 2004; Rothman 2012). Credit for the birth of the discipline is often given to John Snow, whose 1854 map of cholera events in central London led to the discovery of waterborne cholera transmission (although some authors have questioned the veracity of this tale: Koch and Denike 2009; Brody, et al. 2000; McLeod 2000). Since those early days of disease mapping, cartography has played a central role in the discipline.

Over a century later, the quantitative revolution in geography provided the basis for a union with the extant biostatistical model of epidemiology practice, resulting in a domination of the field by quantitative methods (Elliot, et al. 2001; Lawson 2006; Pfeiffer, et al. 2008). While Bayesian methods, fuzzy logic, and complex cellular automata provide detailed insight into epidemiological studies, purely quantitative methods lack the human intuition required for making the logical and intuitive syntheses often required to identify pathways of causation and suitability of interventions (Scheutz and Poulsen 1999; Clavien and Dindo 2007; Braude 2009). For example, the famous John Snow cholera map, when analysed spatio-temporally, does not readily lead to the cause of the problem, the Broad Street water pump (Koch and Denike 2009; Le Comber, et al. 2011).

² <http://www.rcmp-grc.gc.ca/pubs/yg-ja/gangs-bandes-eng.pdf>

Only once he went into the hotspot to investigate the built environment was he able to identify the culprit.

What this emphasises is the role of contextualisation beyond exclusively quantitative methods in spatial epidemiology. In this thesis, violent trauma incidents are mapped and analysed using geographic information systems, but hotspots are visited in-person to make observations of the built urban environment. Also used is prior knowledge about an area (for example, the location of pubs and nightclubs) and social knowledge (for example, social deprivation in Vancouver's Downtown Eastside). A quantitative index of social deprivation, used in chapters 2 and 3, was developed using the crucial expertise of public health officials (Bell, et al. 2007).

This work pursues a broader approach to spatial-epidemiological methods that is inclusive of non-quantitative methods and modes of knowing. Tentative steps are taken in this direction through the use of geographic information systems, not exclusively as a tool for testing statistical hypotheses, but also as a way to explore and interact with spatial-temporal datasets.

GIS as an exploratory tool

Geographic information systems provide the computational power and algorithmic ability to conduct spatial-statistical analysis, seen by many as the pinnacle achievement of modern geography practice (Schuurman 2004b). Tools like hotspot analysis, geographically-weighted regression, and kriging can provide insight into the spatial dependency of injury with other factors. These quantitative capabilities have proven their worth in injury research (e.g., Zhu, et al. 2004; Chakravarthy, et al. 2007; Schuurman, et al. 2009; Piza, et al. 2010).

While the spatial-analytical abilities of GIS continue to be improved upon, there have also been parallel advancements stemming from efforts within the geographic information science community to disengage from statistical conceptualisations of geographic realities and embrace other ways of knowing (Kwan 2004; Elwood 2010). Barnes (2010) points towards this concept in describing the growing use of quantitative techniques blended with a 'sensitivity' informed by critical geographers' contributions to

the discipline. Such advancements include the increasing prominence of feminist theory (Schuurman 2009), rejections of positivist epistemologies (Pavlovskaya 2006), criticisms of traditional statistical theory (Sheppard and Barnes 2011), the consequent 'qualitative turn' in geography (Poon 2003), and concerns about the social effects of using GIS technologies (Schuurman 2002a). One of the fruits of these efforts is the growing use of qualitative data to refine quantitative models (e.g., Crooks, et al. 2011). This requires the researcher to balance Poon's 'imperfect empiricism' (2003, 760) with an acceptance of the situatedness of geographic information, the assumptions of spatial analysis techniques, and problems of representation. Further yet, many steps have been taken towards a fully qualitative GIS (Cope and Elwood 2009).

In this thesis, GIS are used as a tool for managing, mapping, and analysing data, but not exclusively within the traditional quantitative realm of hypothesis tests. This pragmatic approach recognises the value of spatial statistics for examining relationships, but also derives benefit from the user-tool interaction, through which much knowledge can be gained. For example, in chapter 2, injury locations are used to produce a three-dimensional 'injury terrain' model, overlaid on satellite imagery and street maps of Vancouver. The user can 'fly' around this terrain in a virtual environment to explore hotspots, and use prior knowledge about an area to refine the hotspot locations. In this way, the spatial-analytical abilities of GIS are used to produce outputs that can be analysed qualitatively through users' experiencing them in virtual space.

This user-GIS interaction is characterised by Schuurman (2002b; 2004a) as the 'cyborg', the human-machine interface through which GIS practice is mediated. Rather than attempting to reject quantitative GIS or relying exclusively upon it, this thesis works towards embracing the cyborg as an opportunity to gain knowledge of the spatial-temporal nature of violent injury and its multiple relationships to the built environment and social deprivation.

Injury data

Injury surveillance is the systematic collection of injury data to conduct analyses and inform public health decision makers, and a vital element of the effort to reduce the burden of injury (Graitcer 1987; Hanrahan and Moll 1989; Halperin and Horan 1998;

Horan and Mallonee 2003; Krug 2004; Bayer and Fairchild 2010). This research uses spatially-referenced violent trauma data alongside census figures, field observations, index values incorporating expert opinion, qualitative findings from the literature, and the researchers' prior knowledge about the study area.

While Statistics Canada data, including census results, are openly available through institutional access to databases, retrieving high-resolution incident and victim data is significantly more challenging due to ethics and security considerations (Bayer and Fairchild 2010; Bell and Schuurman 2010; Huang, et al. 2012). Fears of Orwellian informatics permeate the debate, certainly encouraged by unfortunately coincident notions stemming from the term 'surveillance' (from French *to survey*; usage in French also readily conjures 'big brother' imagery). Throughout the dialogue concerning health informatics are utilitarian echoes about governments' obligations to disseminate health information, diametrically pressured by the responsibility to protect those represented by it, including health care workers (Dauphinee and Frecker 2005; Habermann 2006; Wainwright and Sambrook 2010). With the increasing prominence of information technology in health informatics also come increasing patient concerns about contributing their information to epidemiological studies (Goodman 2010).

While health records have been in use for millennia, the recent transition from paper to digital has presented numerous challenges to health institutions (Patel 2005; Bassam, et al. 2010). Database construction, record transcription, access to technology, user training, and ever-evolving security procedures all weigh against the benefits of a surveillance programme (Schuurman, et al. 2010; Govender, et al. 2012). These barriers are most prominent in low-resource settings (Cinnamon and Schuurman 2010; Schuurman, et al. 2010), but the study area for this research benefits from a permanent surveillance programme. The injury data used for this work is from the British Columbia Trauma Registry, a provincial surveillance programme whose data have been used in other similar studies (Bell, et al. 2009; Schuurman, et al. 2009; Hameed, et al. 2010).

Social deprivation and environmental patterns of injury

The academic literature strongly suggests that social deprivation as defined using measurable demographic variables often conforms to spatial patterns (Pacione 1995;

Pearce, et al. 2006; Bell, et al. 2007; Maroko, et al. 2009; Green, et al. 2011). For example, the tendency of similar-income populations is to residentially cluster. Early injury research demonstrated the spatial dependency between victim demographics and injury rates (Goodwin and Hutchinson 1977; Todd and Walker 1980; Wolfe and O'Day 1981). The development of compound measurements of socio-economic disadvantage provided more comprehensive quantitative metrics of the complex nature of deprivation. Such deprivation indices have been shown to explain a large proportion of the variation in injury incidence within urban settings; injuries tend to cluster in deprived neighbourhoods (Schuurman, et al. 2007; Bell, et al. 2009; Schuurman, et al. 2010; Green, et al. 2011). Furthermore, residents of these neighbourhoods have been shown to have less access to health service (Kawakami, et al. 2011).

Such neighbourhoods are often seen or imagined as decaying urban spaces, associated in the popular imagination with various facets of deprivation (Wilson and Kelling 1982; Doran and Lees 2005; Andersen 2008). To provide a basic example: while walking through a neighbourhood with buildings in disrepair, abundant graffiti, and street litter, one may easily infer that the locals are not wealthy (ethical complications of such judgements notwithstanding). Researchers have proven this preconception to be rooted in some degree of fact, that deprivation is concentrated in urban residential neighbourhoods where the built environment is in a state of decay (Andersen 2008; Baing and Wong 2012; Bertotti, et al. 2012). The built environment, in this thesis, is defined as any stationary, fabricated, physical thing constructed by a person or people. Furthermore, it has been shown that residing in such spaces is linked to behaviours that put one at a higher risk of injury (Wilson and Kelling 1982; Stevenson 2006; Maghelal and Capp 2011). However, researchers have gone beyond this basic association to discover numerous specific features of the built urban environment that correlate with injury incidence (Brantingham and Brantingham 1993; Koepsell, et al. 2002; Retting, et al. 2003; Schuurman, et al. 2009; Caplan, et al. 2010; Maghelal and Capp 2011). Some efforts have also included visits to injury hotspots to observe and record features of the built environment (Schuurman, et al. 2009; Dai, et al. 2010; Wilson 2011), one of the methods presented in chapter 2 of this thesis.

In addition to social and physical features of urban environments, the temporal dimension is also examined in chapter 3. Researchers have demonstrated how injuries

also cluster in space-time (Anderson 2009; Mountrakis and Gunson 2009); for example, peaks in violent injury are found on Friday and Saturday nights around nightclubs and other alcohol-serving establishments (Cusimano, et al. 2010; this thesis, chapter 3). Such findings, in conjunction with observations of the built environment and literature review, allow researchers to narrow in on specific drivers of injury. In this particular example to follow, alcohol consumption appears to play a key role.

Synthesising evidence

Perhaps the most prominent factor in violent injury incidence is alcohol consumption (Scribner, et al. 1995; Scribner, et al. 1999; Norstrom 2000; Gorman, et al. 2001; Zhu, et al. 2004; Bellis, et al. 2005; Gruenewald and Remer 2006; Warburton and Shepherd 2006; Cunradi 2007; Livingston 2008; Branas, et al. 2009; Casswell and Thamarangsi 2009; Hahn, et al. 2010; Taylor, et al. 2011; Keyes, et al. 2012). In addition to being one of the primary focus areas of the upcoming World Health Organization *Global Status Report on Violence Prevention* (scheduled for publication in 2014), alcohol merits a standalone section, as it also provides an example of how social deprivation, the built environment, and temporal clusters of violent injury can be used to identify a suspect cause.

Using GIS to explore the trauma registry data, a strong cluster of violent injury was found in Vancouver's Downtown Eastside. This is one among Canada's most socioeconomically deprived neighbourhoods, where open liquor consumption on the street is a common sight (Statistics Canada 2006; Brethour 2009; Roe 2009; Schuurman, et al. 2009). Additionally, there are numerous alcohol-serving establishments targeting a low-income clientele. By making direct observations of this neighbourhood, one can easily hypothesise the link between alcohol consumption and the high injury incidence found in the trauma data (described in chapters 2 and 3). This direct observation method is referred to in this thesis as 'environmental scan'. The literature is searched for coincident findings; in this case, socioeconomic deprivation has been linked to high rates of alcohol consumption at individual and aggregate scales, providing additional support for the alcohol hypothesis (van Oers, et al. 1999; Baumann, et al. 2007; Mulia and Karriker-Jaffe 2012; Redonnet, et al. 2012).

Another example comes from examining the temporality of the trauma registry data using GIS. When violent injuries were sorted by days of the week; strong clusters were found on Friday and Saturday nights in an area of downtown Vancouver known widely as the nightclub district. A [daytime] visit to this location confirmed this finding, further supported by a literature review and experiential knowledge. By examining patterns of violent injury along multiple axes, the findings in chapters 2 and 3 can be synthesised into hypotheses about the nature of violent trauma in urban environments.

Significance of contribution

Positioned as a response to the call for more research in the World Health Organization's *World Report on Violence and Health* (2002), this thesis seeks to answer the question: where are violent injury hotspots along the axes of space, time, weapon, victim age and sex, and neighbourhood social deprivation? To answer this question, the following objectives are achieved: hotspots are identified using GIS; environmental scans of the top-ranked hotspots are conducted; the temporal distribution of incidents is examined within 24-hour and 7-day scales; the relationship between weapon, victim age, and victim sex is examined; each of these preceding variables is mapped; and the findings are examined with reference to the literature. The literature, as reviewed above and in the following chapters, cumulatively provides significant insight on these relationships. However, no research has been found to date that combines all three dimensions using real-world data to provide a set of hypotheses about the patterns of violent injury in urban space. This work is intended to address this gap by offering an evidence-based series of profiles of spaces of violent injury in an urban geographical context. The unique contribution of this research is that it synthesises social deprivation, the built environment, and the temporality of violent trauma into narratives guided by surveillance data, field observations, and the literature. While explicit policy implications exceed the intended scope of this thesis, the hope remains that these findings may prove useful in the development of policies that seek to make our cities safer.

Thesis outline

This thesis is composed of four chapters. This first chapter provided a background on violent trauma, the Metro Vancouver area, and some of the challenges in health

surveillance. Literature on the geography of violent injury was introduced, and the approach used in this thesis was outlined. The terminal example of alcohol demonstrated how this approach is put into use in the following chapters.

Chapter 2 is a paper published in the peer-reviewed journal *Geomatica* (Walker and Schuurman 2012), the purpose of which is to identify features of the built urban environment that spatially correlate with violent injury hotspots. Chapter 3 is a paper submitted to a peer-reviewed journal and is under review at the time of this writing. This chapter introduces the temporal dimension and mechanism of injury, identifying three distinct, multivariate patterns embodied in neighbourhood characteristics in Metro Vancouver. Chapter 4 summarises the findings from chapters 2 and 3 and reflects on the approach and methods used. The thesis concludes with comment on opportunities for further research.

Chapter 2

Environmental Correlates with Violent Injury

Falls, cuts, burns, gunshot wounds, and punches comprise only a few of the myriad ways in which a person can be injured. Altogether, injuries cause 30% more deaths than tuberculosis, malaria, and HIV combined, and representing 10% of total global mortality (WHO 2006). Injury is also the fourth leading cause of death in Canada and the leading cause of death for Canadians ages 1 to 44, constituting a significant, yet often overlooked, public health problem (Nantulya and Reich 2002; Smartrisk 2005; Public Health Agency of Canada 2006). In this paper, we expand upon geographic methods for identifying drivers of injury and present the results of our findings in the Metro Vancouver region.

Contrary to common perception, injury is not a random occurrence; it is strongly correlated in space and time (Dovey 2000). Areas of high injury incidence, known as hotspots, have been directly linked to features of the built environment (Dovey 2000; Schuurman et al. 2009). For example, high numbers of injuries are found near alcohol-serving establishments (Taylor, et al. 2011). The built environment has been shown to have significant effects on human behaviours and events (Maghelal and Capp 2011). As such, injury can be driven both by human behaviours (e.g., a bar fight) and inherent environmental risk (e.g., high traffic levels at an intersection). An enhanced understanding of how these phenomena manifest in space is necessary to inform proactive, targeted policy interventions to reduce the economic, social, political, personal, and medical dimensions of the burden imposed by injury.

Injury and the social-physical environment

Social deprivation has often been shown to conform to geographical patterns (e.g., Pacione 1995; Pearce, et al. 2006; Bell, et al. 2007; Maroko, et al. 2009; Green, et al.

2011). Furthermore, it has been shown in the literature that areas of social deprivation experience higher relative rates of injury (Bell, et al. 2009; Hameed, et al. 2010; Schuurman, et al. 2010). Among early investigations of injury found in the literature (notably, Read 1969), the majority focus is on victim demographics (e.g., Goodwin and Hutchinson 1977; Todd and Walker 1980; Wolfe and O'Day 1981). Other researchers have examined the relationship between injury and features of the built environment. However, the social and physical perspectives intersect in urban space, where they are widely recognised as being covariates; that is, the built urban environment tends to reflect socio-economic characteristics of its denizens and vice-versa.

Research examining features of the built environment has accelerated in recent decades, with numerous potential correlates to injury identified and potential patterns of causation described (Brantingham and Brantingham 1993; Koepsell et al. 2002; Retting, et al. 2003; Schuurman, et al. 2009; Caplan, et al. 2010). In tandem, efforts are being made to conceptualise features of the built environment in methodological terms, that is, how our understanding and perception of the environment can produce meaningful findings towards reducing the burden of injury. For example, Maghelal and Capp (2011) present a list of variables related to features of the built urban environment that affect pedestrian behaviours, but also include a classification of variables. Their classification scheme distinguishes between objective (e.g., lighting, land-use), subjective (e.g., odour, noise, sense of security), and distinctive (e.g., pedestrian-friendly area, clear line of sight) observable phenomena. This is particularly useful for determining which potential correlates to injury can be objectively assessed.

Environmental scan

In this work, we identify features of the built environment present in areas of high injury incidence. Following the protocol established by Schuurman, et al. (2009) we refer to this process as an 'environmental scan'. Originating in the business literature (e.g., Gordon and Narayanan 1984; Bryson 1989), this term has come to encompass a range of methods for identifying and evaluating external factors influencing a variety of organisations (Abels 2002; Graham, et al. 2008). Schuurman, et al. (2009) apply this concept within a geographical realm to contextualise pedestrian injury as influenced by features of the built environment; this method was also used by Dai, et al. (2010). In this

work, we apply the environmental scan technique to interpersonal violence hotspots, detected using a visually-enhanced method. This environmental scan methodology can be conceptualised using Wilson's (2011) framework, where 'street subjects' (observers, characterised as cyborgs [Schuurman 2002b; 2004a]) examined the built urban environment to code (classify) 'street objects' (features of the built environment). An immediate limitation is the definition and interpretation of street objects as subjective functions of an observer's own perception of objects in space-time. That is, one's classification of an object may differ from another's. As such, the prescription of well-defined criteria is of benefit, as is observer training (Wilson 2011).

Interpersonal violence

In this work, we focus on injury as the result of interpersonal violence, which has been shown to be a significant contributor to the global burden of injury (Nantulya 2002; Mair and Mair 2003; Smartrisk 2005). Interpersonal violence is defined in the literature as "intentionally inflicted bodily harm, injury, or death" (Brink 1998, 38). Every year, over 1.6 million people die as the result of interpersonal violence, and in 2000 the global mortality rate attributable to interpersonal violence was 8.8 per 100 000 (WHO 2002). Homicide alone accounts for at least eleven per cent of injury-related deaths worldwide (WHO 2006). Such statistics fail to include unreported violent incidents; the true figures are certainly much greater. Regardless, it is indisputable that violence is a significant public health problem (Mair and Mair 2003).

Significant geographical disparities in interpersonal violence risk exist at multiple scales. Globally, the highest homicide rates are concentrated in Latin America and Africa, where regionally, the highest rates are found in low-income urban areas (Shaw-Taylor 2002; WHO 2006). Violence incidence is significantly higher in urban areas than suburban and rural areas, due largely to uneven population distribution (Nelson, et al. 2001). However, some authors provide evidence of higher rates (i.e., per capita) of violence in rural areas (Osgood and Chambers 2000; Logan, et al. 2003).

In the literature, violence is primarily studied from four general disciplinary orientations. The psychological, sociological, and criminological approaches often use qualitative methods to describe the various dimensions of violence (e.g., Casteel and Peek-Asa

2000; Grossman 2009). Critical, feminist, and activist approaches are often driven by Marxist-normative interpretations of violence and extrapolation of these concepts beyond medically-defined phenomena. For example, the notion of 'structural violence' provides a term for forms of real and perceived oppression through social inequity (Galtung 1969; Meth 2004). Medical and epidemiological perspectives on violence comprise quantified clinical analyses of violence, including spatial-analytical approaches (e.g., Brink 1998). Drawing upon these three orientations is the fourth: public health and policy is concerned with the use of social and medical health knowledges to inform decision making (e.g., WHO 2010). We position this work within the spatial-epidemiological realm, drawing upon previous research in the GIScience paradigm.

Sherman, et al. (1989) identified hotspots of criminal activity and spatially associated features of the built environment, signalling an emergent focus on urban form in the criminology literature. Several years later, Brantingham and Brantingham (1993) found that cognitive maps are useful tools for investigating criminal decision making. Their study identified perceived surveillance and anonymity as factors in opportunistic crime, concluding that the built urban environment has a significant impact on these factors and the overall geometry of criminal activity. In 1995, they expanded upon this study to generate a list of crime generators and attractors. Braga, et al. (1999) provide an extensive set of environmental features found within their study of fifty-six violent injury hotspots. These include recreation facilities, high-density housing, transit nodes, convenience stores, and homeless shelters. Alcohol availability is widely considered to be a significant factor in interpersonal violence incidence (e.g., Norstrom 2000; Gorman, et al. 2001; Gruenewald and Remer 2006; Livingston 2008; Mabunda, et al. 2008; Branas, et al. 2009; Taylor, et al. 2011). Zhu, Gorman, and Horel (2004) examined the effectiveness of alcohol outlet density and socio-economic status as predictors of interpersonal violence, finding both to be effective at census tract resolution. They also found strong covariation, additional evidence of the codependence between social and physical urban geographical features. Lighting is also associated with interpersonal violence, although other factors tend to confound its apparent effect (Farrington and Welsh 2002; Loomis, et al. 2002; Staunton, et al. 2007). Furthermore, in urban areas, lighting tends to be highly localised (streetlights may have an effect size of only ten metres).

Interpersonal violence is a significant contributor to the burden of injury locally and globally, societally and personally. For policymakers to address this burden, the spatial nature of injury as the result of interpersonal violence must be better understood. Features of the built environment associated with interpersonal violence are found in the literature, but in order to observe them the injury hotspots must first be located. For this, we present a visually-enhanced analysis method to identify and rank hotspots.

Hotspot identification

Geographic information systems and the associated quantitative and qualitative spatial analysis techniques provide powerful tools to examine geographical data, identify trends, and create predictive models. Such approaches have been used extensively in epidemiological research, including studies of injury (e.g., Gorman, et al. 2001; Livingston 2008; Bell and Schuurman 2010; Cusimano, et al. 2010). Numerous techniques can be used to examine the spatial-temporal distribution of injury. If an injury is represented as a point in space-time, GIS can be used to identify areas of high point density. The resulting 'density map' can then be interpreted to identify areas of high incidence (hotspots). Caplan, et al. (2010) create a three-dimensional representation of firearm violence, where density values are projected as elevations to produce a three-dimensional terrain. On this type of map, the peaks represent centroids of firearm violence. We expand upon this method to rank hotspots, as described below. While several tools exist for this purpose, kernel density estimation (KDE) is used herein. This is the most commonly used spatial analysis technique for identifying hotspots in the literature. KDE interpolates points using a kernel function to produce an output raster surface, where high pixel values correspond to high point densities, and low values to low densities. In three-dimensional space, this point density function around each incident location can be thought of as a hill. The peak of the hill corresponds to the exact location of the incident and has the highest density value (elevation). As distance from the peak increases, density value decreases until a user-specified distance, at which point the density value reaches zero. When executed for multiple points, these 'hills' vertically accumulate to produce an interpolated terrain.

In order to determine which hotspots are significant, the Jenks algorithm can be used. This technique examines the resulting density values (elevations) and identifies natural

breaks in their distribution. A natural break can be thought of as a sudden change in a frequency distribution, for example, a gap in the histogram of pixel values. The user selects a number of desired classes, and the algorithm determines at which values breaks occur. This allows the user to identify densities reflecting an independent pattern from the rest of the data. However, selection of the number of classes poses challenges. North (2009) presents an algorithm for determining the optimal the number of classes, but also argues that ultimately, the user should select exogenous classes that reflect the number of influences the user is trying to identify. For example, if the literature indicates that there are two census income classes that have a strong relationship to injury hotspots, then three natural breaks could be selected (two for those income class, and one for 'no relationship').

While the hotspot detection literature is mature, there appears to be an emphasis on sophisticated statistical modelling and a deficit in the operationalisation of specific parameters. While algorithms for the optimal bandwidths, natural breaks, and other inputs are calculable, these are vulnerable to the methodological fallacy of data driving data. An understanding of the phenomena comprising the data is crucial to selecting the most appropriate method and parameters. Often the selection of these is arbitrary or not thoroughly explained. This work uses a unique method to identify the most significant injury hotspots, as explained in the methods section.

This literature review points toward a persistent gap in methodological definition; that is, whether a hotspot is a precise point in space-time, a statistically-delineated region in Cartesian space (e.g., Di Martino and Sessa 2011), or an exogenously-defined area (e.g., an administrative district as per Bharti, et al. 2010). Patil, et al. (2008) define a hotspot as an area with some unusual characteristic of interest. While spatial-statistical methods provide powerful visual tools for identifying hotspots, contextual information is crucial to interpreting and validating the results. Expert opinion holds value in examining the spatial-temporal distribution of data and identifying hotspots. Unfortunately, there appears to be a gap in the literature between research dependent on statistical modelling and research focussing on qualitative information. That said, some authors do bridge the gap. For example, Taylor, et al. (2011) consulted the Jacksonville police, who identified hotspots and provided valuable contextual information. In spatial epidemiology, doctors and other medical personnel are often listed authors, implying a contextualising

role in a publication. Authors' prior knowledge about interpersonal violence and the study area was used to refine hotspot detection parameters and locations.

Data and methods

This work follows the protocol developed by Schuurman, et al. (2009): hotspot identification and environmental scan. Interpersonal violence hotspots are found separately within Metro Vancouver (formerly known as the Greater Vancouver Regional District). Data were obtained from the British Columbia Trauma Registry and include all recorded injuries resulting from an assault, including intentional gunshot. Excluded are sports injuries, accidental firearms discharge, or self-inflicted injury. Only injuries with an injury severity score (ISS) greater than 15 are used. The ISS scale (Baker et al. 1974) ranges from 0 to 75 and is derived by assessing the severity of the worst injury to each body section (head, face, chest, abdomen, extremities, external structures) using an abbreviated injury score (AIS ranges from 1 to 6, with 1 being minor and 6 being unsurvivable). The top AIS score from each of the three most severely injured body sections is squared, the sum of which is the patient's ISS score. One key limitation with this measure is that it includes only the worst injury on a body section, so if a patient is assessed with two projectile wounds through the chest, only the worst is considered, even though both may have damaged vital organs. The data comprise points representing each location at which an injury incident took place between January 1, 2001, and December 31, 2008, inclusive. Following data cleaning, 1332 interpersonal violence injury points were mapped.

Control points (i.e., randomly-generated spots to conduct environmental scans) were not included, because this work is concerned with the burden of injury from a public health perspective. That is, hotspots should identify spaces where the greatest numbers of violent injuries occur so that the findings may be used to address the total burden of injury. Hotspots were identified using kernel density estimation in ArcGIS. Ripley's K function was used to determine the optimal bandwidth. The resulting density map was reprojected as a 3D 'injury terrain'. The hotspot ranking system is best explained by analogy, where the injury terrain is flooded like a virtual lake, until all peaks (hotspots) are submerged. The water level is gradually lowered until one island appears, representing the 'hottest' injury hotspot. This first peak to appear is ranked number one.

The water level is gradually lowered, and each subsequently emerging peak is given a rank. In this way, each hotspot was ranked according to its peak density value. The top thirteen hotspots were selected for further investigation, as a large break was observed between the thirteenth and fourteenth hotspot peak density values, identified using the Jenks algorithm in ArcGIS.

Injury and violence literatures were consulted to produce lists of suspected environmental correlates to interpersonal violence, listed in Table A, following page. These features are used to construct matrices of known potential correlates. The matrices were then taken into the field to record which features are present at each of the thirteen hotspots (within 100 metres Manhattan distance from the hotspot centroid). This phase was conducted in teams of four, each member of which made independent observations. In order to test the aforementioned association between injury and social deprivation, injury hotspots were classified using the Vancouver Area Neighbourhood Deprivation Index (VANDIX), developed by Bell, et al. (2007). This index was developed in consultation with medical health officers, who ranked socio-economic indicators of deprivation in Vancouver (for more information, see Bell, et al. 2007). The thirteen hotspots were mapped over neighbourhoods classified into quintiles according to their overall VANDIX score. The findings were tested against random distributions using randomly-generated points created using ArcGIS.

Feature	References					
Alcohol service	Branas, et al. 2009	Gorman, et al. 2001	Gruenewalk & Remer 2006	Livingston 2008	Norstrom 2000	Scribner, et al. 1999
Alcohol service cont'd	Virtanen & Pernanen 2001	Ingemann-Hansen & Brink 2004	Homel, et al. 2001	Bellis, et al. 2005	Taylor, et al. 2011	Sherman, et al. 1989
Alcohol service cont'd	Braga, et al. 1999	Cusimano, et al. 2010	Nelson, et al. 2001	Warburton & Shepherd 2006	Sparks 2011	Scribner, et al. 1995
Alcohol service cont'd	Zhu, et al. 2004	Green & Plant 2007	Macintyre & Homel 1997	WHO 2010		
Lighting	Loomis, et al. 2002	Farrington & Welsh 2002	Staunton, et al. 2007			
Street Access	Newman 1996					
Recreation facility/park	Peterson & Mark 2000	Taylor, et al. 2011	Sherman, et al. 1989	Braga, et al. 1999		
High-density residential	Piza, et al. 2010	Butchart 2004	Taylor, et al. 2011	Sherman, et al. 1989	Braga, et al. 1999	Cusimano, et al. 2010
Land use type	Williams & Poynton 2006	Sparks 2011				
Transit nodes	Taylor, et al. 2011	Sherman, et al. 1989	Braga, et al. 1999			
Parking lot	Taylor, et al. 2011	Sherman, et al. 1989				
Shopping centre/large store	Taylor, et al. 2011	Sherman, et al. 1989	Nelson, et al. 2001			
Hotels/motel	Taylor, et al. 2011					
Adult business	Taylor, et al. 2011	Sherman, et al. 1989				
Public restrooms	Sherman, et al. 1989					
Convenience store	Taylor, et al. 2011	Sherman, et al. 1989	Braga, et al. 1999			
Major street	Braga, et al. 1999	Nelson, et al. 2001	Sparks 2011			
Homeless shelter	Braga, et al. 1999	Cusimano, et al. 2010				

Table A: Suspected positive correlates to interpersonal violence

Results

Interpersonal violence injury locations appear to cluster in low-income neighbourhoods and dense urban areas. Ripley's K function was used to estimate the optimal bandwidth for kernel density estimation for the injury points. Measuring clustering at five metre intervals, from zero to 1000 metres, this method found a logarithmic increase difference between observed and expected clustering, extending far beyond 1000 metres, meaning that spatial clustering becomes increasingly significant as bandwidth increases. However, larger bandwidths were found to produce hotspots that do not accurately reflect injury locations. That is, many derived hotspots appeared between incident clusters, not accurately reflecting actual areas of high injury incidence. Additionally, because this work concerns features of the built environment, small, observable areas must be identified. A disturbance in the clustering pattern was found for bandwidths between 90 and 105 metres. This may be indicative of an underlying scalar variable attributable to heterogeneity between neighbourhoods or the built structure of urban areas. (e.g., intersection spacing/block size). As such, a bandwidth of 100 metres was selected for KDE. The resulting output was projected as a 3D 'injury terrain', where the peaks represent violent injury hotspots (as shown in figure 2, following page).

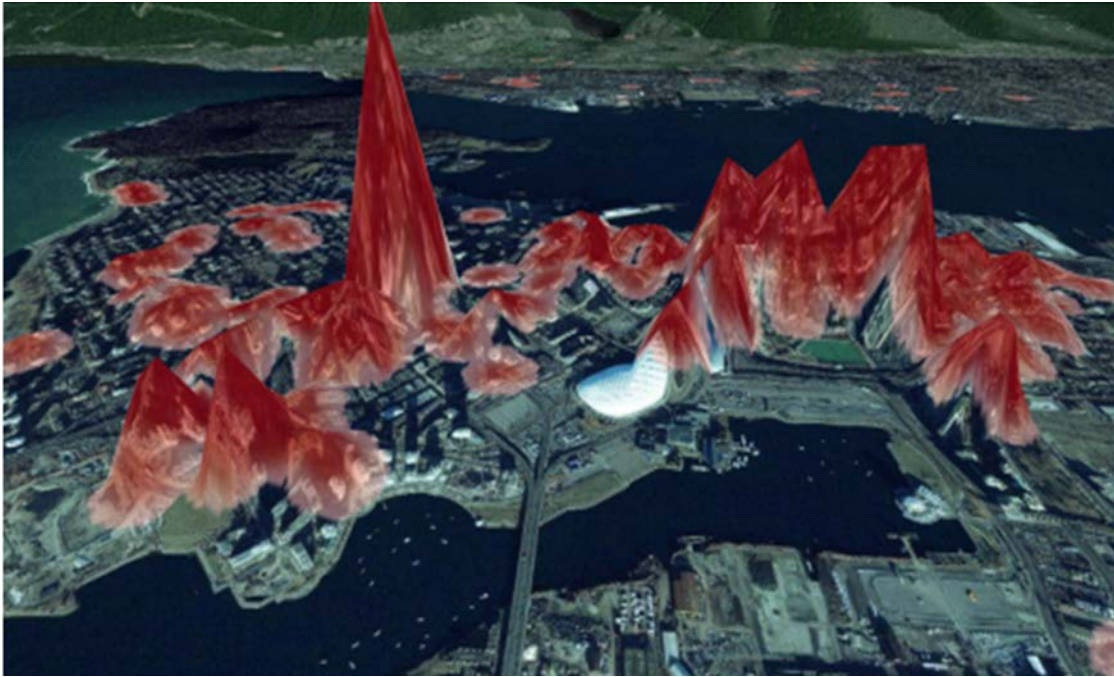


Figure 2: Violent injury terrain, downtown Vancouver. The tallest hotspot is over the nightclub district. The ‘range’ to the right is the Downtown Eastside.

Environmental scans were conducted in the top thirteen interpersonal violence injury hotspots. It was found that twelve of the thirteen violent injury hotspots contained at least one alcohol-serving establishment. Over three-quarters of all interpersonal violence hotspots were near high-density residential housing, and 84% of were near commercial and mixed commercial/residential land use parcels. Twelve of the thirteen hotspots were contained a transit node (bus stop or metro station). Adult businesses (e.g., sex shops, dedicated pornography outlets, exotic cabarets) were found within six hotspots, and public restrooms within ten. Homeless shelters were also found in 38% of the interpersonal violence hotspots. In combination, these features illustrate the quintessential economically marginalised inner-city neighbourhood (Brantingham and Brantingham 1995; Taylor, et al. 2011). These findings coincide with those in the literature.

To examine the relationship between violent injury and socioeconomic deprivation, the VANDIX was used. All thirteen hotspots were mapped over neighbourhoods classified into quintiles according to their overall VANDIX score. It was found that twelve of thirteen hotspots are within or border neighbourhoods in the two most deprived quintiles. This,

when compared to an average of three randomly-generated hotspots, indicates significance in the spatial association between neighbourhood deprivation and violent injury incidence. However, there is no direct evidence in the data suggesting that the residents of deprived neighbourhoods are those engaging in violent behaviours, so caution must be made to avoid this inference. A more suitable basis for explanation lies in the broken windows cycle (Doran and Lees 2005), where people within a decaying urban environment (not necessarily residents) are more likely to engage in destructive or antisocial behaviours.

There was one noteworthy exception to this emerging geographical pattern of violent spaces. Vancouver's nightclub district features the second hottest violent injury hotspot. However, it does not contain any adult businesses, homeless shelters, or abandoned housing, nor does it border any socially deprived neighbourhoods. This case is attributable to the spatially and temporally concentrated nature of alcohol supply, consumption, and patronage, further elevating violent injury risk. Additional analysis contrasting time of day may provide further insight into this pattern. Such spaces form a second urban profile of violent injury, suggesting that another important feature may be the spatial/temporal concentration of pedestrian traffic.

Limitations

The data include only incidents reported at local trauma hospitals. As such, these data certainly underrepresent domestic violence. Excluded are injuries with an injury severity score less than 15 and those injuries that resulted in a fatality prior to admission to a trauma centre. As the incidental difference between injury and severe injury is often an arbitrary difference of millimetres or milliseconds, fatal and non-fatal injuries were equally weighted. Another concern rests with the temporality of the data, in that they comprise an eight-year range. Features observed in March 2012 may not have been present when a particular incident took place.

GIS-based hotspot detection incurs implicit assumptions about space, which may affect the validity of resulting representations. For example, kernel density estimation assumes a uniform Cartesian space and no directionality. Steenberghen, et al. (2010) discovered that KDE tends to overdetect clustering along roadways (and Okabe, et al. 2008

developed a network-constrained GIS tool to counteract this problem, used by Dai, et al. 2010). It cannot be assumed that the standard kernel is an appropriate model for injury density (Okabe, et al. 2009 also counteract this problem, but it is not addressed in this thesis).

The only hotspot not containing an alcohol-serving establishment was found to be across the street from a prison. However, the prison population is not included in our dataset, nor does this neighbourhood fit the profile of a violent urban space. It would appear that this hotspot may have been the result of a detection anomaly, as it had fewer injury points in its vicinity than the others. However, it is possible that social or environmental correlates exist as the hotspot region but are simply not yet identified by researchers. Further analysis of this hotspot may reveal a missing variable, although the sample size within this dataset is not sufficient to support any inferences. The presence of this hotspot illustrates the potential fallibility of KDE as a hotspot detection method. However, further research could examine the use of KDE at multiple scales to identify finer patterns of violent injury. Further research will compare KDE to other methods to determine which is most appropriate for identifying injury clusters.

Significance of findings

Through this work, we have confirmed the spatial association between violent injury and suspected features of the built environment from the literature. Most prevalent are alcohol-serving establishments, high-density housing, and transit nodes; social deprivation also appears to be a key predictor. However, characterisation of violent spaces in the Canadian city requires a more holistic view of the built and social urban landscape. Subsequent work will examine combinations of features and socio-economic indicators to expand upon and refine profiles of violent urban spaces. However, caution must be taken not to automatically assume causation between features of the built environment, social deprivation, and violent injury. Furthermore, one must not overstate the presence of violence in deprived neighbourhoods, at peril of further marginalising these spaces and contributing to the broken windows cycle.

Most disconcerting was the extreme violent injury incidence found in the Downtown Eastside neighbourhood of Vancouver. This skews the entire distribution of densities,

leading to an underrepresentation of hotspots in other areas. More importantly, the sheer volume of injury that occurs in this neighbourhood injects urgency into this research.

This work is intended to underscore the value of GIScience methodologies in public health. Such approaches not only allow researchers to study spatial-temporal patterns, but also comprise a multidimensional, integrative vision of space that lends itself to informing decisions about urban policy.

Chapter 3

Spatial-temporal dimensions of interpersonal violent injury in urban environments

Introduction

In 2008, over two million people in the United States were injured as the result of interpersonal violence (CDC 2010). 19 200 of them died as a result, more than thirteen times the number of American 'War on Terror' casualties that same year (USDOD 2011, WHO 2011). The World Health Organization has declared violence to be a leading public health problem (WHO 2002). While medical and criminal perspectives tend to dominate the public discourse on violent injury, the effects of an incident echo through social, economic, political, and personal spheres (Polinder et al. 2012). For example, the total cost of violence in the USA is estimated to be nearly 10% of the gross domestic product (WHO 2004). Such figures fail to include the extensive psychological and emotional impacts of victimisation (Clark et al. 2007, Grossman 2009, Papachristos, Braga and Hureau 2012). This multifaceted burden of violent injury presents a significant challenge to public health policymakers and practitioners.

While the myth that injury is a random accident persists in the popular imagination, there is a growing body of evidence in the literature that speaks to the contrary. Research has demonstrated that injury does not occur at random, rather, it is strongly correlated in space-time, and is related to features of the built environment and socio-economic deprivation (Dovey 2000, Murray 2006, Stevenson 2006, Sparks 2011). In this work, we focus on severe injury 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 social deprivation of a neighbourhood, and the built environment.

Background

This problem is addressed from a public health perspective, which provides a framework encompassing injury surveillance, investigation of risk, evaluation of interventions, and policy implementation (VPA 2012). Through this lens, we can conceptualise violence as a public health issue, rather than the traditional criminal view (Mair and Mair 2003; Sparks 2011). While definitions of interpersonal violence vary between disciplines, generally they include intentional harm leading to injury or death (Brink 1998; Feil and Mollen 1999; Kazdin 2011). Within this framework, we employ a spatial epidemiology approach, emphasising the role of urban geographies in this multivariate temporal analysis of violent injury.

Significant disparities in the risk of violent injury have been found globally (WHO 2006). At a regional scale, increasingly nuanced patterns become apparent. An example is provided by differences between urban and rural violence, the latter of which is characterised by higher rates of domestic assault, stronger links to substance abuse, and lower levels of social support (Osgood and Chambers 2000; Nelson, et al. 2001; Logan, et al. 2003). Within cities, violent injury incidence has been shown to vary between neighbourhoods. For example, Brantingham and Brantingham (1995) 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; Sherman, et al. 1989; Gorman, et al. 2001; Livingston 2008; Anderson 2009; Bell and Schuurman 2010). GIS technologies and methods constitute a powerful toolset for analysing spatial data, and have been pivotal in identifying the links between violent injury, the built environment, and social deprivation. For example, the presence of alcohol-serving establishments in low-income neighbourhoods is a strong predictor of violent crime (Norstrom 2000; Zhu, et al. 2004; Cusimano, et al. 2010; Taylor, et al. 2011).

Ideally, hotspots of violent injury represent highly localised spaces that are representative of the surrounding neighbourhood, termed 'micro-spaces' in the literature (Nelson, et al. 2001; Groff, et al. 2010; Taylor, et al. 2011). This is predicated upon Jane Jacobs' (1961) call to examine urban spatial patterns at the 'subneighbourhood' scale. However, GIS-based analyses can be data-driven and statistical and thus inherently

subject to error (Monmonier 2006; Sheppard and Barnes 2011), underscoring the need for field observation and contextualisation. This involves visiting hotspots and recording features of the built environment (Schuurman, et al. 2009; Walker and Schuurman 2012), as well as the use of ancillary data sources.

Investigations of the geography of violent injury can further be refined by including a temporal variable (Anderson 2009; Mountrakis and Gunson 2009). Cusimano, et al. (2010) identified peaks in violent injury incidence at night and early morning, tending to cluster around alcohol-serving establishments, low-income housing, and homeless shelters. This work differs in that we expand our analysis to include victim characteristics, the weapon of injury, and a measure of social deprivation.

While these findings in the literature are invaluable for health, policing, and social policy, they serve also to underscore the significance of social structure and deprivation as drivers of violent injury, a relationship well-demonstrated in the literature (Shaw-Taylor 2002; Messer, et al. 2006; Sparks 2011). Socioeconomic indicators (e.g.: income inequality; employment status; educational attainment) tend to be strong predictors of injury risk (Elliot and Wartenberg 2004; Bell, et al. 2009; Wilkinson and Pickett 2009). We examine this relationship using a deprivation index developed by Bell, et al (2007).

Data and methods

Metro Vancouver (formerly the Greater Vancouver Regional District) was selected as the study location. This urban area has a population of approximately 2.2 million, and is an agglomeration of twenty-one municipalities covered by two separate public health authorities. 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. However, only injuries with an injury severity score (ISS) greater than 15 were included. The ISS is a compound measurement on a scale of 0 to 75, where 1 is minor and 75 is unsurvivable (Baker, et al. 1974). Due to this limitation, only severe injuries and injuries to multiple body parts are included in the data; cases where the victim expires prior to arrival at a trauma centre are excluded. Sports injuries and self-inflicted injuries were also excluded.

The data were classified into seven injury types, termed 'mechanisms': gunshot wound; sharp object trauma; blunt object trauma; bodily force (e.g., punch); and other assault. The 'other assault' category comprises malicious burns, explosions, and unspecified mechanisms. Altogether, 575 incidents were mapped, each represented as a point in space and time. In order to determine whether an incident took place during day or night, civil dawn and civil dusk were calculated for every day in the data period. Civil dawn and dusk were selected because these are widely recognised as the times at which artificial lighting is [not] required for outdoor activity.

The following variables are used in this analysis: injury location (mapped); victim age; victim sex; date and time of incident; and mechanism of injury. Pearson's chi-squared 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. Furthermore, these relationships were mapped in order to identify multivariate clusters (for example, night time gunshot injuries).

Due to data confidentiality regulations, the violent injury locations are not shown herein. GIS was used to produce hotspot maps (shown in the following section). This procedure displays the spatial patterns while obscuring the original locations of individual incidents. Specifically, kernel density estimation was used with a 250 metre bandwidth. This method was selected not for its statistical robustness, rather, to produce a useful visualisation of the spatial distribution of the original data.

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 (2007). 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 is calculated, and the results were mapped with relation to the injury locations.

Findings

The violent injury data comprise 518 male and 57 female victims. This disparity in injury risk corresponds with findings in the literature; violent injury is responsible for 14% of all

male deaths and 7% of female deaths (Murray 2006). However, trauma data are certainly skewed due to the underreporting of domestic violence (Taylor, et al. 2011, Kim, et al. 2012)

When categorised by day/night, we found that 75% of male injuries occurred at night, compared to 56% of female injuries; the association between sex and day/night was found to be highly statistically significant using Pearson's chi-squared test for independence ($p=0.002$). Of the 575 violent injuries in this dataset, 73% took place at night. Figure 3 on the following page displays the distribution of injury counts across each hour. Between midnight and 04:00, there is a consistently strong cluster in downtown Vancouver's Downtown Eastside, a neighbourhood well known for its large low-income and homeless populations, as well as high rates of drug use. The peak between 02:00 to 03:00 can be attributed to the time at which bars, pubs, and nightclubs are required to close. This is confirmed by mapping the data for this time, which form a strong cluster of violent injuries in the club district. After 03:00, the injury locations appear to disperse throughout the downtown area; this pattern may be a reflection of nightclub patrons leaving the district after closing time.

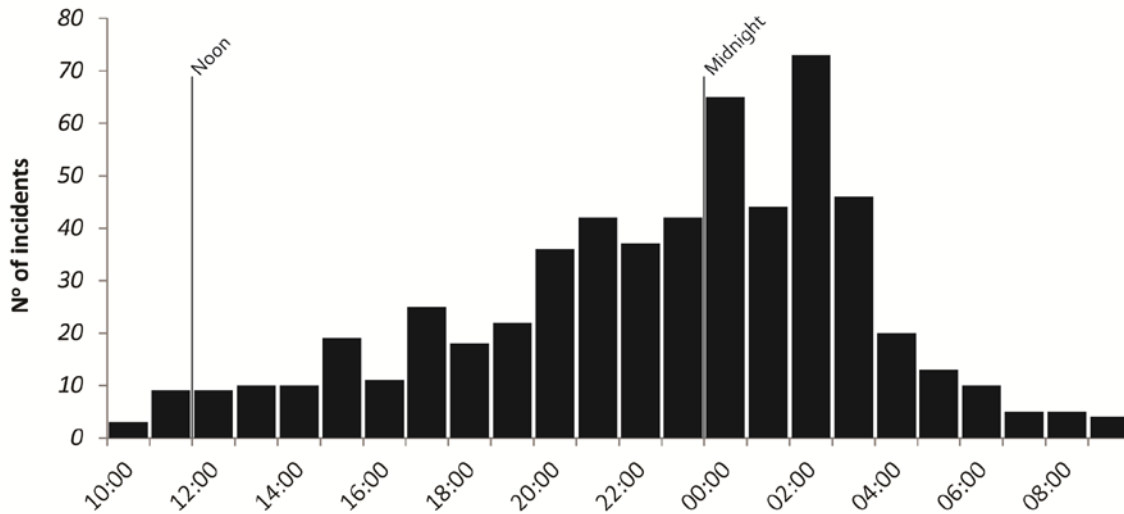


Figure 3: Temporal distribution of violent injuries through 24-hour period. Note the bimodal peaks at midnight and 2 A.M. These injuries are clustered spatially as well with consistent clustering in the downtown eastside. The peak between 2 and 3 A.M. coincides with bar and pub closing hours.

One in every three injuries in this dataset was caused by a firearm. However, weapon choice and time/location do not significantly correlate, matching findings in the literature (Erickson, et al. 2006). Figure 4 on the following page divides each mechanism of injury into day/night incidence. A clear increase from day to night is noted for each mechanism; however, there is also a distinct difference within each group. The increase between day and night incidence of firearm injury is 380%, compared to 247% for sharp object and only 183% for bodily force. This pattern suggests that the degree of violence, severity, or illegality of a mechanism is related to the time of day at which it is used. That is, one may feel more secure using a firearm to commit a violent assault under the cover of darkness. This is a less important distinction when throwing a punch, as the consequences of which are generally less severe. Note that because these data only include severe injuries, blunt object and bodily force injuries are underrepresented.

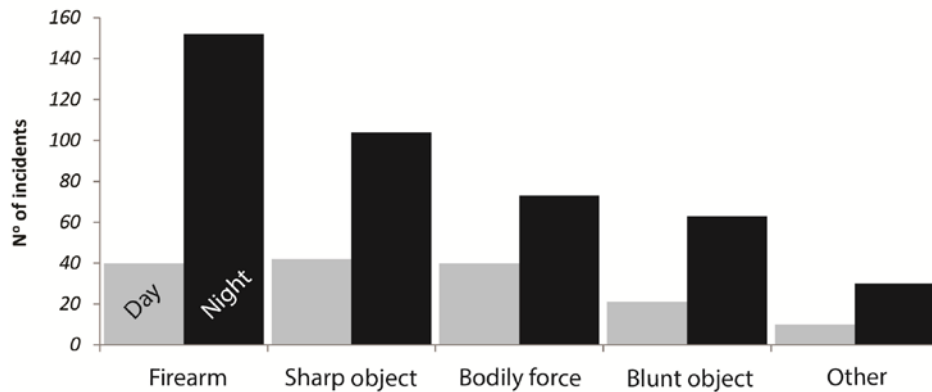


Figure 4: Day/night comparison of violent injury counts by mechanism of injury. All injuries are more prevalent at night while firearms and injuries from sharp objects (e.g. knives) are significantly more prevalent after dark.

To categorise the data by day of the week, we define each night 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. 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 weekend spike shown in figure 5, below, is to be expected, but note the ‘hangover effect’: relative peace on Saturday and Sunday during daylight hours.

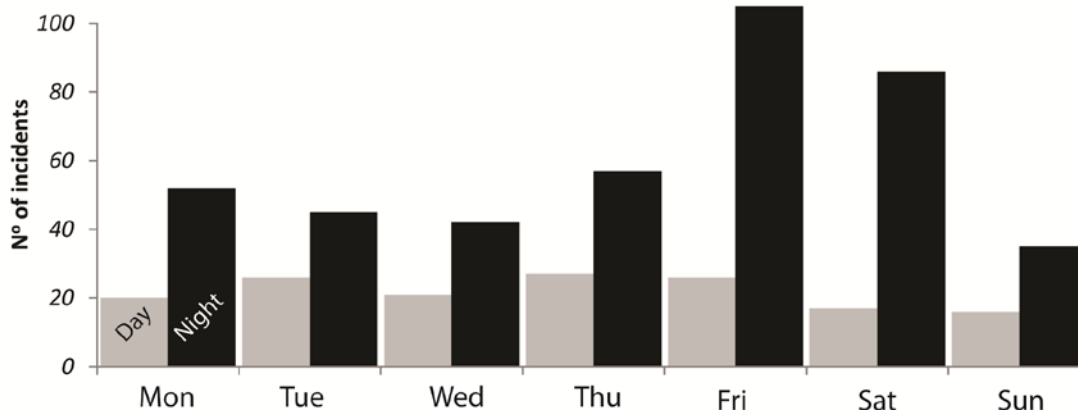


Figure 5: Day/night contrast of violent injury counts by day of week. As might be expected there are more injuries on Friday and Saturday nights with daytime figures remaining relatively constant throughout the week.

Map A, below, displays violent injury hotspots in the Metro Vancouver area for all mechanisms of injury. 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 Westminister features a series of minor hotspots which occur close to Skytrain stations (light rail transit) and a major shopping centre.

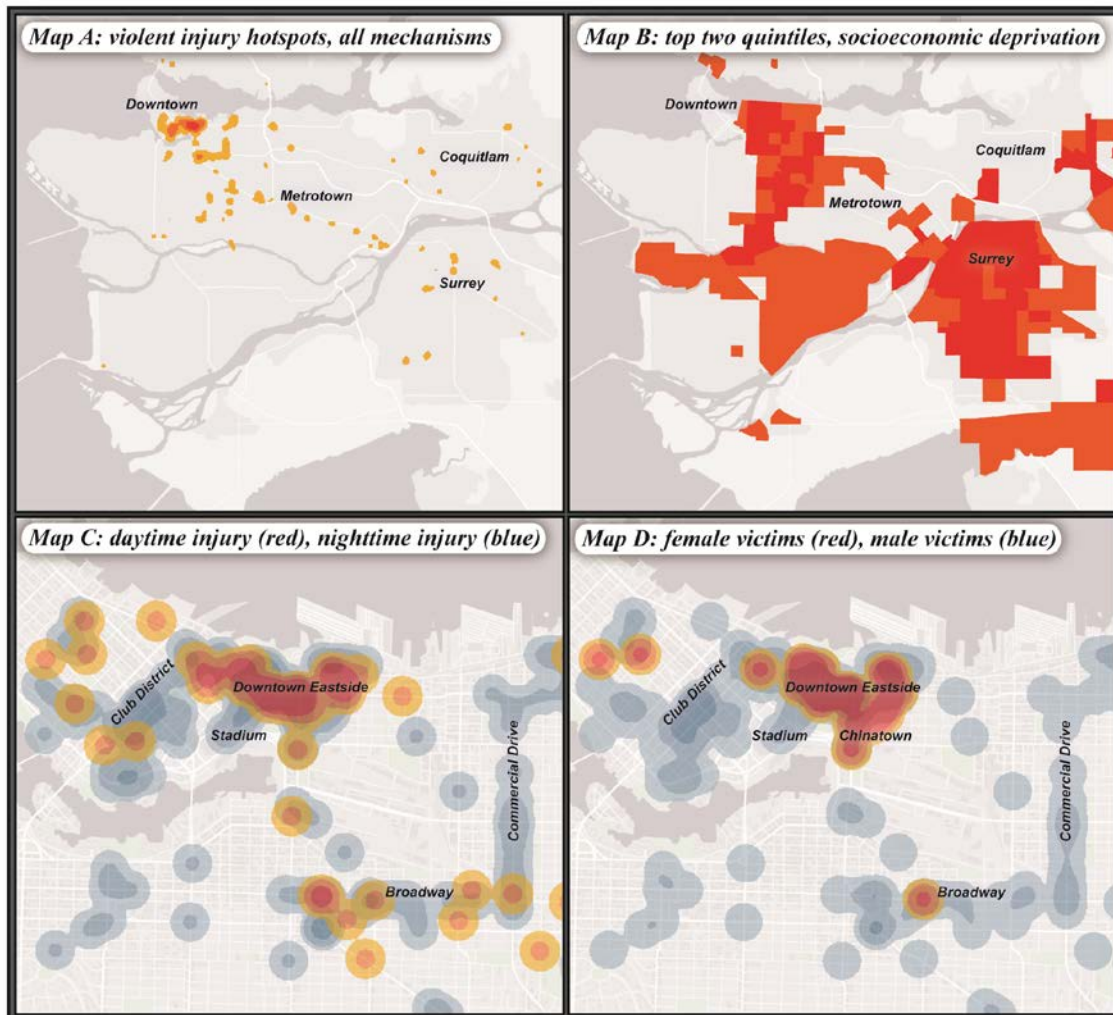


Figure 6: Injury hotspots by sub-category. Note that the Downtown Eastside is an injury hotspot regardless of the breakdown of victims. However male victims of violent injury are spread along other corridors (e.g. Commercial Drive) as are night time injuries.

Map B displays the two highest quintiles of socioeconomic deprivation using the Vancouver Area Neighbourhood Deprivation Index. Here, a spatial pattern similar to the hotspots that appear in Map A is visible; 77% of all severe violent injuries occurred within neighbourhoods in these two most deprived quintiles. This is further evidence of the link between spaces of socioeconomic deprivation and elevated risk of interpersonal violence. There are, however, two notable exceptions: the club district and Metrotown (labelled on Map B). While the cluster in the club district is explained by the high nighttime incidence in proximity to alcohol-serving establishments, the case in Metrotown is more complex and better explained by features of the built urban environment.

Map C focuses on central Vancouver, contrasting day and night hotspots. A significant overlap is noted in the Downtown Eastside. The club district, the Downtown Eastside, and Commercial Drive contain nighttime 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 where football, soccer, and hockey matches are played also appears as a hotspot. That this occurs during the night suggests that the majority of incidents occur after a match, further evidence towards the significance of alcohol consumption in interpersonal violence. Mixed day/night clusters occur along Broadway, a high-traffic corridor lined with restaurants and retail, but featuring a less active nightlife than the club district or Commercial Drive.

Map D compares hotspots of male and female victims. While the sample size for females is comparatively small, when mapped, some geographic differences are notable. The club district, Commercial Drive, and the stadium feature only male victims of severe violent injury, while victims in Chinatown are all female. Further research should seek to examine this finding in greater depth.

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 Club District/Stadium.

Metrotown: the built environment

This neighbourhood does not have low incomes, high unemployment, or a high deprivation index. In fact, it is very similar demographically and socioeconomically to the surrounding suburbs of Burnaby. However, this regional shopping centre and major transit node is surrounded by high-density housing; all three of these urban features have been linked to violent injury in the literature (Sherman, et al. 1989; Braga, et al. 1999; Nelson, et al. 2001; Butchart 2004; Cusimano, et al. 2010; Piza, et al. 2010; Taylor, et al. 2011). Metrotown draws large numbers of people from across the Metro Vancouver area, producing a noisy, crowded setting. Such conditions have been shown to increase incidence of violent behaviours (Evans 2003). 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 hangout options. However, the minimum age in the data is 16, limiting any useful inference. Regardless, what the Metrotown case underscores is the role of the built environment (Brantingham and Brantingham 1995; Brink 1998; Branas, et al. 2009), 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 violent behaviours (Wilson and Kelling 1982; Doran and Lees 2005). Examples include adult businesses (Taylor, et al. 2011; Sherman, et al. 1989), abandoned buildings (Gruenewald and Remer 2006), and homeless shelters (Braga, et al. 1999; Cusimano, et al. 2010). While these features are found in the Downtown Eastside, they are nowhere to be found in the second-highest violent injury hotspot, the Club District.

Club District and Stadium, alcohol consumption

The links between alcohol consumption and interpersonal violence are well-established in the literature (Scribner, et al. 1995; Norstrom 2000; Gorman, et al. 2001; Zhu, et al. 2004; Bellis, et al. 2005; Erickson, et al. 2006; Gruenewald and Remer 2006; Livingston 2008; Branas, et al. 2009; Govender, et al. 2012; Keyes, et al. 2012). That strong clusters of violent injury are found around nightclubs suggests that our findings are concordant. Indeed, many of the incidents occurred at nightclubs, bars, and pubs;

Brantingham and Brantingham (1995) found a similar cluster using police data. While the presence of alcohol-serving establishments was observed in chapter two using the environmental scans, the strength of this relationship was unexpected. Furthermore, different types of alcohol-serving establishments were readily distinguished between hotspots; for example, the nightclubs on Granville Street are very different in character from the bars found in the Downtown Eastside. Another violent injury cluster was found near the stadium/arena, also a space of high alcohol consumption. Another factor may be the use of illicit drugs, although nothing in the data points towards this in the nightclub or stadium districts. While drug use in these areas is generally confined to nightclub washroom stalls and back alleys, it is front-and-centre in what is commonly referred to as 'Canada's poorest postal code' (Christoff and Kalache 2007)

Downtown Eastside, socioeconomic deprivation

With an average income of \$6 282 (before government subsidy), Vancouver's Downtown Eastside has over twice the unemployment rate of Vancouver and less than half the educational attainment (Statistics Canada 2006; Brethour 2009). Four of every five residents live alone (Statistics Canada 2006). These figures are certainly underestimations, as they do not account for the substantial homeless population (Wadsworth, et al. 2008; Metro Vancouver 2009; Roe 2009). The epicentre of this hotspot is at the intersection of two major streets where one can witness openly conducted drug deals, purchase bicycles and electronics off the sidewalk, and watch sex workers ply their wares. Buses pass through this area into the nearby central business district. From the bus, Vancouver's bankers, lawyers, and the otherwise well-employed can catch glimpses of the Downtown Eastside. This contrast highlights deep socioeconomic inequalities; in their 2009 book 'The Spirit Level', Wilkinson and Pickett demonstrate the extent to which inequality is a strong driver of interpersonal violence and vice-versa (Hawkins 1993; Kramer 2000; McCaughan 2001; Cramer 2003; Iadicola and Shupe 2003)

In our analysis, the strong association between socioeconomic deprivation and violent injury incidence coincides with similar findings in the literature (Gruenewald and Remer 2006; Cusimano, et al. 2010). Yet, while high socioeconomic deprivation appears to be a strong predictor of violent injury, Papachristos, et al. (2012) provide evidence that

social networks are a more direct cause. Enhanced patient data and qualitative methods could help with further investigation of this relationship.

The median age of victims in the Downtown Eastside is 38, a full eight years older than the median of victims city-wide. According to the 2006 census, only 7% of the population is under 20 years old, compared to 25% city-wide (Statistics Canada 2006). Perhaps the most striking of our findings in this neighbourhood is the extremely high prevalence of female victims, relative to the rest of the study area. Within the extensive literature examining violence against women (Yonas, et al. 2005; Clark, et al. 2007; Ali, et al. 2011), many authors have found that there is a high probability of experiencing violent trauma among female drug users (Fullilove, et al. 1993; Kelly, et al. 1996; Brewer, et al. 1998; Braitstein, et al. 2003). Curiously, the only hotspot comprising only female victims was found in the southern corner of the Downtown Eastside, in Chinatown. This finding is not explained in the literature, suggesting a need for further research.

In this work, we identified hotspots using a combination of GIS techniques and a priori knowledge of the study area. This represents a departure from the traditional quantitative implementation of GIS, rather, using it more as an exploratory tool to search for patterns in the data. This methodology emphasises the role of the user in choosing how to analyse data and present the results (Monmonier 2006). For example, the scale at which a neighbourhood is delineated has been shown to influence health metrics (Schuurman, et al. 2007). Ultimately, GIS may have its greatest value in helping researchers to distil geographic information in order to make it accessible to a non-expert audience (Buckley 2004; Slocum, et al. 2004), rather than presenting p-values for hypothesis tests. For example, GIS can be a powerful tool for producing visualisations to identify and communicate complex patterns in space and time (MacEachren 1995; Monmonier 2006; Dykes, et al. 2005). Furthermore, map-based platforms have shown strong potential for facilitating group decision making and engaging multiple stakeholders (MacEachren 2000; Jankowski and Nyerges 2001; Craig, et al. 2002). GIS thus offers a powerful toolset for communicating geographic information about urban health and engaging policy makers (Miller 2001; Tatem and Hay 2004; Zapata, et al. 2011; Fobil, et al. 2012)

A recipe for policy

Stevenson argues that due to the short-term nature of political impetus, long-term solutions require short-term milestones (Stevenson 2006). Effective injury surveillance programmes can facilitate goal-tracking; social web technologies are a promising asset in this regard, particularly in deprived urban areas (Cinnamon and Schuurman 2010). In this study, we found distinct patterns of violent injury within different neighbourhoods. As such, we agree with Goldstein (1979), Clarke (1992), and Braga, et al. (1999) that surveillance and intervention programmes must be custom-designed for individual neighbourhoods, considerate of the specific contexts within which violent injury is cached. To this end, participatory methods may hold significant potential.

The concentration of hotspots around high densities of alcohol-serving establishments, combined with the most prominent temporal spike in our data points towards the ongoing debate concerning mandatory closing times for alcohol-serving establishments. There is strong evidence that 'last call' policy can reduce excessive consumption and resulting harms (Casswell and Thamarangsi 2009; Morelo et al. 2009; Hahn et al. 2010; CDC 2010). However, Johnco, et al. (2010) discuss the 'scarcity effect', which may contribute to increasingly rapid drinking as last call approaches, leading to higher peak levels of intoxication. When the Licensing Act was introduced to England and Wales in 2003, allowing for 24 hour liquor sales, consumption and violence rates actually decreased, albeit not significantly (Hough and Hunter 2008; Kirby and Hewitt 2011). The application of our methods to violent injury in cities where 24-hour service is available may allow for comparative analysis of this problem. 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 a mass exodus at closing time and the resulting disorder from high concentrations of intoxicated patrons.

Stevenson attributes violence in relation to urban space through the enclosure model and the encounter model (Stevenson 2006). A crowded bar is an example of a built enclosure, while the crowded street at closing time causes numerous encounters, both of which can trigger interpersonal violence. This perspective places the onus on the built environment, arguing that modification of engineered urban space can reduce violent injury incidence (Sherman, et al. 1989; Braga, et al. 1999; Mair and Mair 2003;

Stevenson 2006; Caplan, et al. 2010). However, the role of policing and accessible medical services cannot be understated, both have been shown to reduce rates of violent injury (Braga et al. 1999; Warburton and Shepherd 2006). Ultimately, the aim is injury control, encompassing a range of strategies to confront the issue upstream (e.g., liquor policy, social programmes) and downstream (e.g., ample ambulatory resources).

As demonstrated in this chapter, GIS constitutes a powerful tool for analysing and communicating multidimensional data to elucidate patterns through space-time, the characteristics of a violent injury, the built environment, and social deprivation. Through the illustration of distinct spatial and temporal patterns inherent in injury surveillance data, we present the argument that enhanced understanding of micro-environmental patterns such as diurnal patterns, spatial patterns, and contextual framing of socio-economic status are bases for making injury surveillance interpretation useful to policy and decision makers.

Chapter 4 Conclusion

The burdens imposed by violent injury extend beyond the monetary, impacting victims and those around them in immeasurable ways. This thesis sought to answer the question: where are violent injury hotspots along the axes of space, time, weapon, victim age and sex, and neighbourhood social deprivation? To answer this, chapter two identifies hotspots of violent injury in Vancouver and presents the findings from the environmental scan of hotspots. The social deprivation score from VANDIX was also checked for each hotspot location. Chapter three examines the patterns in these hotspots between space, time, mechanism, victim age and sex, and expands on the links between neighbourhood social deprivation and the nature of a hotspot. The resulting three profiles of spaces of violent injury (nightclub district, Downtown Eastside, and Metrotown) point towards different patterns of injury identified through these two chapters. In this concluding chapter, the effectiveness, limitations, and resulting contributions of this thesis are discussed in terms of the knowledge gained, methods used, and approach developed.

Chapter 2 contributions

Chapter 2 focussed on the built environment and socioeconomic deprivation. The purpose of that peer-reviewed paper, published in *Geomatica* (December 2012), is to determine which features of the built urban environment correlate with violent injury hotspots. Contributions to the literature are summarised as follows.

The hotspot identification and environmental scan technique used in this chapter was developed by Schuurman, et al. (2009). Incident locations provided by the British Columbia Trauma Registry were mapped, and kernel density estimation was used to identify clusters. To better visualise, refine, and rank hotspot locations, the resulting density surface was then projected into a three-dimensional injury terrain, which was

then virtually flooded to rank hotspots by their intensity (elevation). The top thirteen hotspots were then visited in teams to identify which features of the built environment were present.

To analyse the results and determine which features were significant, this work did not use the traditional case-control approach (testing a statistic against a random distribution). Correlation was inferred intuitively; for example, twelve out of thirteen hotspots border deprived neighbourhoods, therefore it is inferred that there is a spatial relationship. This approach produces more widely legible findings than statistical test results, and also avoids some of the pitfalls of error statistical theory and inference. The findings in chapter 2 were supported by similar findings in the literature, suggesting the validity of this method used herein.

Social deprivation was measured using VANDIX; all but one of 13 hotspots was within or bordering a neighbourhood of high deprivation; the only exception was the nightclub district. Once the environmental scans had been conducted, alcohol-serving establishments were also found to be present at all but one hotspot, suggesting their strong connection to violent injury; this finding is widely demonstrated in the literature and examined further in chapter 3. Transit nodes, high-density residential, public restrooms, adult businesses, homeless shelters were other factors found to be present in many or most hotspots.

From these findings two profiles of urban violent space were generated. The first is the deprived inner-city neighbourhood, characterised by the features listed above, plus social deprivation, unmaintained urban structures, and an abundance of graffiti. The connection is made via the literature to the broken windows theory as a possible causal pathway, although further research is required in this direction. The second profile of urban violent geography comprises spaces of high levels of alcohol consumption. The most prominent hotspots found in this work correspond to these two profiles: the Downtown Eastside (also a deprived inner-city neighbourhood); and the nightclub district. Both of these neighbourhoods are examined in greater detail in chapter 3.

Chapter 3 contributions

Chapter 3 expands upon the findings of chapter 2, using data about the time and mechanism of injury, as well as victim age and sex to refine our understanding of patterns of violent injury in urban space. This chapter used a subset of the data from chapter two, as many of the original data were missing the temporal variables (date and time). As in chapter two, kernel density estimation is used to generate hotspots of temporal and categorical variables in the injury data (e.g., time of day, mechanism of injury, sex of victim). The resulting patterns were not analysed quantitatively; the graphs and maps are presented and interpreted using the literature and the researchers' prior knowledge of the study area. Pearson's chi-square statistic was used to test the independence of categorical variables in once instance (victim sex and day/night). This was the only statistical hypothesis test used in this thesis, selected in order to provide additional evidence to the male/female divide between day and night injuries, as mapped. The temporal and categorical hotspots were compared also to social deprivation using the VANDIX.

Through this analysis, three distinct patterns emerged to complement and refine the hotspot profiles found in chapter 2. These are organised along the three most prevalent themes found in the literature. The first uses the example of injury patterns in Metrotown and the Downtown Eastside to illuminate the significance of the relationship between the built environment and violent injury. The second focuses on the nightclub district and the stadium as spaces of high alcohol consumption. The third is the Downtown Eastside, as an example of the two themes above combine with socioeconomic deprivation to explain Metro Vancouver's most severe violent injury hotspot. The improved three profiles that resulted provide more detail about how the variables included in this research combine and relate to the character of a violent injury hotspot.

Broader contributions

The findings in chapters 2 and 3 were consistent with those from the literature. While providing additional evidence, the papers comprising this thesis (one published, one under review at the time of this writing) will also provide additional evidence. Uniquely, this thesis synthesises the various influences to provide a more holistic description of the

environment-injury relation. To this end, the neighbourhood profiles, emerging from chapter 2 and honed in chapter 3, are used to demonstrate the interdependency of the numerous factors involved in this analysis. Furthermore, these contributions are intended to highlight the significance of the built environment, social deprivation, and spaces of high alcohol consumption as drivers of violent injury, improving awareness of the severity of this phenomenon within academic circles. Ideally, this awareness will permeate policy-making through initiatives such as the World Health Organization's *Global Campaign for Violence Prevention*.

Through this thesis, it is shown how temporal data can provide clues about patterns of injury, illuminating possible causal pathways. When implemented in a GIS environment with an exploratory approach, the user is able to analyse patterns in unique, interactive ways to enrich our geographical understanding of violent injury. While this work does not use mixed-methods, it attempts to embrace a post-positivist epistemology while remaining pragmatic in methodological decision-making. For example, the selection of a kernel density estimation bandwidth in chapter 2 was made using intuitive terms first, then explored algorithmically with Ripley's K function. The bandwidth was selected using experiential knowledge about the urban environment, in this case, block length and approximate 'effect range' of a feature of the built urban environment. Multiscalar KDE within different neighbourhoods may prove useful for local detection of micro-hotspots.

The resulting calculated hotspots in chapter two were the result of a purely quantitative function; this thesis does not challenge their value, nor the value of any quantitative test, rather focussing on the utility of such tools outside of the strictly quantitative realm as tools for exploring relationships within datasets. In this case, the density maps were projected into three-dimensional injury terrains. While this was done by Caplan, et al. (2010) for the purposes of visualising risk, in this thesis the user was able to explore the injury terrain to adjust hotspot locations and incorporate prior knowledge about the urban environment.

The approach used in this work embraces GIS not only as a quantitative tool, but also as a way to explore and interact with data to gain knowledge in ways that the traditional hypothesis testing model cannot. By not adhering strictly to quantitative methods, onus

is placed on the researcher to demonstrate rigour in their methods. However, this instance was a cursory exploration of this approach, which will require further development in the future, as in-depth methodological discussion is beyond the scope of this thesis.

Alcohol and Policy

To conclude, the question of how to convert these findings into actionable solutions is reflected upon, taking the case of alcohol. Through this thesis, particular attention has been drawn to the significance of alcohol consumption as a driver of violent injury, as it was surprisingly prevalent in injury hotspots, as determined through the environmental scans.

Not addressed in this thesis are the numerous other negative effects of alcohol consumption, including non-violent injury, acute and chronic health effects, and social, psychological, and economic turmoil (Baumann, et al. 2007; Buskirk, et al. 2012). In the USA, a person's odds of dying from alcohol-related injury or disease in 2008 were 1 in 150 681, over 3.4 times higher than the odds of dying from a firearm (including accidental and self-inflicted gunshot; The Economist 2013). Yet comparatively, there is little focus on the perils of excessive alcohol consumption. Indeed, it is often glorified through romanticised imagery. Woodruff (1996) and Buskirk, et al. (2012) provide discussions of how portrayals of alcohol consumption in the media may contribute to its negative societal effects. Both authors point towards the potential for policy intervention, as was also discussed in chapter 3.

There may be value in comparison to tobacco controls; increasing restrictions on alcohol advertising may help to prevent the propagation of imagery promoting consumption among young and vulnerable populations (Richards, et al. 1996). Another popular policy option in effect in many polities is the 'last call' rule, discussed in chapter 3. A third option, not discussed earlier, is the use of price controls. Stockwell, et al. (2012) found that as the price of alcohol increased in British Columbia, cases of alcohol poisoning, gastritis, and other dependency-related deaths decreased. While the effect on alcohol-related injury was not determined, it may have a similar effect, ultimately reducing the

alcohol-related health burden in Canada, estimated to be 14.6 billion dollars in 2012 (Torres 2012).

In order to contribute knowledge to policy decisions, such findings as those discussed in this thesis must be communicable to decision-makers. Whether this is the responsibility of the researcher is up for debate, and largely a matter of personal preference. However, this work will ideally contribute to a growing body of knowledge about the need for action to reduce the alcohol-related burden of injury in society, as called for by the World Health Organization (2002).

Limitations

Access to British Columbia Trauma registry data was vital to the analysis conducted in this thesis. While not an explicit topic within this thesis, the value of effective, comprehensive injury surveillance programmes cannot be understated. However, a balance must be struck between respect for the confidentiality of patients and health care workers and the broader societal benefits of data provision for health research. Underreporting of intimate partner violence and violence in the home is an urgent, yet colossal, challenge for researchers who rely on surveillance data, and was certainly a factor in the underrepresentation of residential areas in this thesis.

The exploratory spatial epidemiology approach leveraging quantitative GIS, as proposed in this work, requires development. This is a broader methodological challenge that will require dedicated study of its potential. Further application of this approach may provide deeper insight into the nature of violent injury. Experimentation with multiple scales, hotspot identification tools, and visualisation techniques may prove fruitful for this purpose.

There is a gap in the literature concerning the reconciliation of perceived risk of violence with actual individual risk, which is certainly embedded in a person's subject position and lived experience (Ali, et al. 2011). In chapter 3, the only violent hotspot to include only female victims was near the Downtown Eastside, in Chinatown. While no potential explanations are presented in this work, this problem certainly presents an opportunity

for further research. Future efforts may benefit from qualitative methods, such as interviews with victims, offenders, medical personnel, and law enforcement officers.

Closing remarks

In its initial stages, the purpose of this work was to explore the links between violent injury hotspots and the built environment. However, exploration of the rich dataset provided by the British Columbia Trauma Registry provided additional lanes of inquiry, leading to the inclusion of temporality and victim characteristics. The Vancouver Area Neighbourhood Deprivation Index further enriched this investigation and the resulting neighbourhood profiles. While additional work is certainly required, this thesis' contributions to the geography of violent injury will ideally be used to construct solutions to the greater problem: the broad and deep burdens of violent injury in society, locally and globally.

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