Int J Public Health (2012) 57:467–475
DOI 10.1007/s00038-012-0331-7

ORIGINAL ARTICLE

Geospatial analyses to prioritize public health interventions: a case study of pedestrian and pedal cycle injuries in New South Wales, Australia

Roslyn G. Poulos · Shanley S. S. Chong · Jake Olivier · Bin Jalaludin

Received: 8 June 2011 / Revised: 28 October 2011 / Accepted: 5 January 2012 / Published online: 24 January 2012

Abstract
Objectives Pedestrian and pedal cycle injuries are important causes of child morbidity and mortality. The combination of Bayesian methods and geographical distribution maps may assist public health practitioners to identify communities at high risk of injury.
Methods Data were obtained on all hospitalizations of children from NSW (Australia), for pedestrian and pedal cycle injuries, from 2000–2001 to 2004–2005. Using Bayesian methods, posterior expected rate ratios (as an estimate of smoothed standardized hospitalization ratios for each injury mechanism) were mapped by local government area (LGA) across the state.
Results There were over 7,000 hospitalizations for pedestrian and pedal cycle injuries. High risk LGAs accounted for more than one third of hospitalized pedestrian and pedal cycle injuries in NSW.
Conclusions LGAs at high risk for pedestrian injury tended to be urbanized metropolitan areas with a high population density, while high risk LGAs for pedal cycle injury tended to be either in urban regional areas, or on the margin of urbanized metropolitan areas. Geospatial analyses can assist policymakers and practitioners to identify high risk communities for which public health interventions can be prioritized.

Keywords Child · Wounds and injuries · Accidents, traffic · Bicycling · Pedestrian · Bayesian method

R. G. Poulos (✉) · B. Jalaludin
School of Public Health and Community Medicine,
The University of New South Wales,
Sydney NSW 2052, Australia
e-mail: r.poulos@unsw.edu.au

S. S. S. Chong · J. Olivier
The NSW Injury Risk Management Research Centre,
The University of New South Wales, Sydney UNSW, Australia

J. Olivier
The School of Mathematics and Statistics, The University
of New South Wales, Sydney UNSW, Australia

B. Jalaludin
Centre for Research, Evidence Management and Surveillance,
Clinical Support Cluster (Western), NSW Health,
Sydney, Australia

Introduction

Walking and cycling are popular activities for children both for recreational purposes and as a means of transport. In modern society where environmental factors appear to promote overweight and obesity (World Health Organisation 2000), the health benefits offered by these forms of physical activity are well known, and promoted (Mason 2000). While research in Britain has indicated that rates of pedestrian and pedal cycling deaths have declined in recent decades, indications are that a substantial amount of this decline is due to a decrease in the distances that children walk and cycle, and an increase in car travel, rather than safer walking and cycling (DiGuiseppi et al. 1997; Roberts et al. 1995).

Despite reported declines (Doukas et al. 2010), pedestrian and pedal cycling injuries remain important causes of child morbidity and mortality in developed countries. In Australia in 2003–04, 59.3 and 42.4% of hospitalizations due to unintentional transport-related injuries in boys and girls (0–14 years) respectively were accounted for by pedestrian and pedal cycle injuries (Berry 2007). Road traffic injuries are also well recognized as a cause of health inequalities in the international literature (Hassleberg et al.

2001); (Moustaki et al. 2001) (Hippisley-Cox et al. 2002). In New South Wales (NSW), transport-related injuries in children were among those most strongly related to socioeconomic disadvantage (Poulos et al. 2007).

While it has been suggested that targeted preventative programs are required to reduce differentials in injury risk (Plasencia and Borrell 2001), it can be difficult to direct interventions to individual children at greatest need, and it may be more practical to target high risk communities. This is particularly so in the case of road traffic injury, where effective interventions often include engineering modifications to the built environment (Retting et al. 2003).

Consequently, this study was undertaken to assess the usefulness of geospatial methods in identifying communities at high risk of child injury for which targeted interventions may be warranted. The strengths of geospatial analysis include the ability to obtain robust rates of disease incidence or prevalence even with low case numbers or small populations, and of accounting for spatial correlation between areas. Thus, there are significant advantages over the reliance on crude rates, which have been used as a way of examining geographic differences in injury across small areas (Ekman et al. 2005; Van Niekerk et al. 2006). Further, by incorporating the results of the models into maps, we sought to provide a method by which communities at greatest need could be readily identified.

Methods

Data were obtained on all hospitalizations of NSW children aged 1–14 years for pedestrian and pedal cycle injuries, for the financial period 2000–2001 to 2004–2005 inclusive. Hospitalizations were identified from the NSW Admitted Patients Data Collection (APDC), which is a routinely collected census of all hospitalizations from NSW public and private hospitals. To minimize multiple counting which may occur when a child has more than one episode of care for a given injury, episodes relating to transfers and changes in hospitalization status were excluded.

Hospitalizations were selected on the basis of the 10th edition of the International Classification of Diseases (ICD-10-AM) codes, if the principal diagnosis was injury or poisoning (ICD-10-AM range S00-T98), and the first external cause of morbidity was assigned as pedestrian (ICD-10- AM range V01–V09) or pedal cyclist (ICD-10-AM range V10–V19) injured in transport accident. Demographic information extracted from the APDC included age and gender of child, and local government area (LGA) of residence.

Australian Standard Geographical Classification was used, which divides NSW into 175 LGAs (Australian Bureau of Statistics 2001). For each LGA, cases were aggregated by the total number of hospitalizations for pedestrian or pedal cycle injury for children during the study period. As the data were collected by financial year (July–June), end-of-year (mid-point) population estimates for each LGA were used to determine the population denominator (Population Health Division 2006).

Statistical analysis

Hospitalization rates for pedestrian and pedal cycle injury by age group (1–4, 5–9, and 10–14 years) were calculated using the end-of-year population estimates as the denominator. Indirect standardisation, whereby we applied NSW age-specific rates to LGAs, was used to calculate standardised hospitalization ratios for each LGA. We used SAS version 9.1 (SAS Institute, Cary, NC, USA).

Area-based estimates may be unstable where there are low counts and small populations, so we undertook statistical smoothing using Bayesian methods. The Besag, York and Mollie model was applied (Lawson et al. 2000), as this model accounts for both the variation in injury rates in immediately adjacent LGAs (i.e. spatially correlated variation) and the variability occurring across the entire state (i.e. uncorrelated variation), to produce a posterior distribution of the expected standardized hospitalization ratio for an LGA compared to NSW (Population Health Division 2006). The statistical program, BRugs, was used to fit a Bayesian model for each injury mechanism (Thomas 2004). The mean of the posterior distribution for each LGA was taken as the best estimate of the smoothed standardized hospitalization ratio, and the proportion of the probability distribution greater than one was used as an estimate of the statistical significance of the smoothed standardized hospitalization ratio for an LGA compared to the NSW average. The models were checked using the Gelman and Rubin diagnostic, and spatial autocorrelation of the residuals was examined using Moran's I statistic (Lawson et al. 2003). The results of the models were incorporated into choropleth maps using MapInfo Version 8.5 (MapInfo Corporation). An estimated smoothed standardized hospitalization ratio (SHR) of more than 20% greater than the state average (that is, SHR > 1.2) was considered important; and we considered that identifying LGAs with a probability of more than 80% that the estimated smoothed standardized hospitalization ratio was greater than the state average would likely ensure selection of those LGAs most at risk. LGAs meeting both of these criteria where highlighted in the maps.

Results

There was a total of 1,455 and 5,695 hospitalizations for pedestrian and pedal cycle injuries, respectively, for NSW children during the 5-year period 2000–01 to 2004–05

(Table 1). The majority of hospitalizations were for children aged 10–14 years (52.4%) followed by children aged 5–9 years (35.5%). The proportion of hospitalizations was greater for boys (74.1%) than for girls (25.9%).

Figure 1 shows pedestrian injuries by cause. The majority of injuries (77.1%) involved collision with motor vehicles; 4.5% involved collision with a pedal cycle, or other non-motor vehicle (0.5%). Most injuries (67.0%) were reported as traffic related; 22.1% were reported as non-traffic; 10.9% were unspecified.

For pedal cycle injuries, the majority of injuries (50.5%) were non-collision events; 6.3% of injuries involved a collision with a motor vehicle. Most injuries (59.8%) were reported as non-traffic; with 36.7% reported as traffic and 3.5% as unspecified (Fig. 2).

Figures 3, 4 show the geographic distribution of LGAs with high estimated smoothed standardized hospitalization ratios for pedestrian and pedal cycle injuries in children aged 1–14 years, respectively. Of the 175 LGAs in the state, 19 were identified as high risk for pedestrian injury and 28 for pedal cycle injury. These LGAs accounted for 35.0% of all pedestrian injuries, and 36.9% of all pedal cycle injuries. LGAs at high risk for pedestrian injury tended to be urbanized metropolitan areas with a high population density, while those at high risk for pedal cycle injury tended to be in LGAs classified as urban regional town/city, or LGAs on the margin of a metropolitan developed or regional urban centre (Fig. 5) (Department of Infrastructure, Transport, et al. 2008).

Discussion

Pedestrian and pedal cycle injuries accounted for over 7,000 hospitalizations in children in NSW in a 5-year period. The rate of pedestrian injury was highest in young children, while the rate of pedal cycle injury was highest in older children. Males predominated across the age groups, with about a 50% increased risk of pedestrian injury, and about double the risk of pedal cycle injury, than girls. The majority of pedal cycle injuries were non-traffic related and resulted from non-collision events, indicating the need to better understand non-roadway and non-motor vehicle injury events in order to create and implement effective prevention strategies (Meuleners et al. 2006; Stutts and Hunter 1999). In contrast, we found the majority of pedestrian injuries resulted from collisions with motor vehicles.

The LGAs at high risk as identified through the geospatial analysis accounted for more than one third of pedestrian and pedal cycle injuries leading to hospitalization in NSW. Interestingly, the spatial distribution of LGAs at high risk of pedestrian injury was quite different to that of pedal cycle injury. For example, there was a clustering of LGAs at high risk of pedestrian injury in the Sydney metropolitan region, and a clustering of LGAs at high risk of pedal cycle injury around the margins of the Sydney metropolitan region. Statistical analysis, which provides only numeric results does not readily convey these geospatial patterns of injury, and potential epidemiological associations with location may be missed. For example, there may be differences in environmental factors across LGAs, which impact on risk. Traffic volume (Roberts et al. 1995), vehicle speed, presence of traffic calming (Jones et al. 2005), road surface lighting (Macpherson et al. 2004), street configuration (Morency and Cloutier 2006), need to cross roads to reach facilities, lack of off-street parking and safe areas to play (Posner et al. 2002), have all been associated with increased road traffic injury in children. The differences in risk may also reflect the different

Table 1 Number of hospitalizations and crude hospitalization rates per 100,000 children aged 1–14 years by injury mechanism and age group, 2000–2001 to 2004–2005, NSW, Australia

	1–4 years		5–9 years		10–14 years	
	Number of hospitalizations	Hospitalization rate	Number of hospitalizations	Hospitalization rate	Number of hospitalizations	Hospitalization rate
Pedestrian injury						
Male	266	29.8	335	29.1	319	27.3
Female	168	19.9	177	16.2	190	17.1
Total	434	25.0	512	22.8	509	22.3
Pedal cycle injury						
Male	307	34.4	1,382	120.2	2,688	230.0
Female	121	14.3	647	59.3	550	49.5
Total	428	24.6	2,029	90.5	3,238	142.1
Total	862		2,541		3,747	

Source: NSW Admitted Patient Data Collection. Centre for Epidemiology and Research, NSW Department of Health

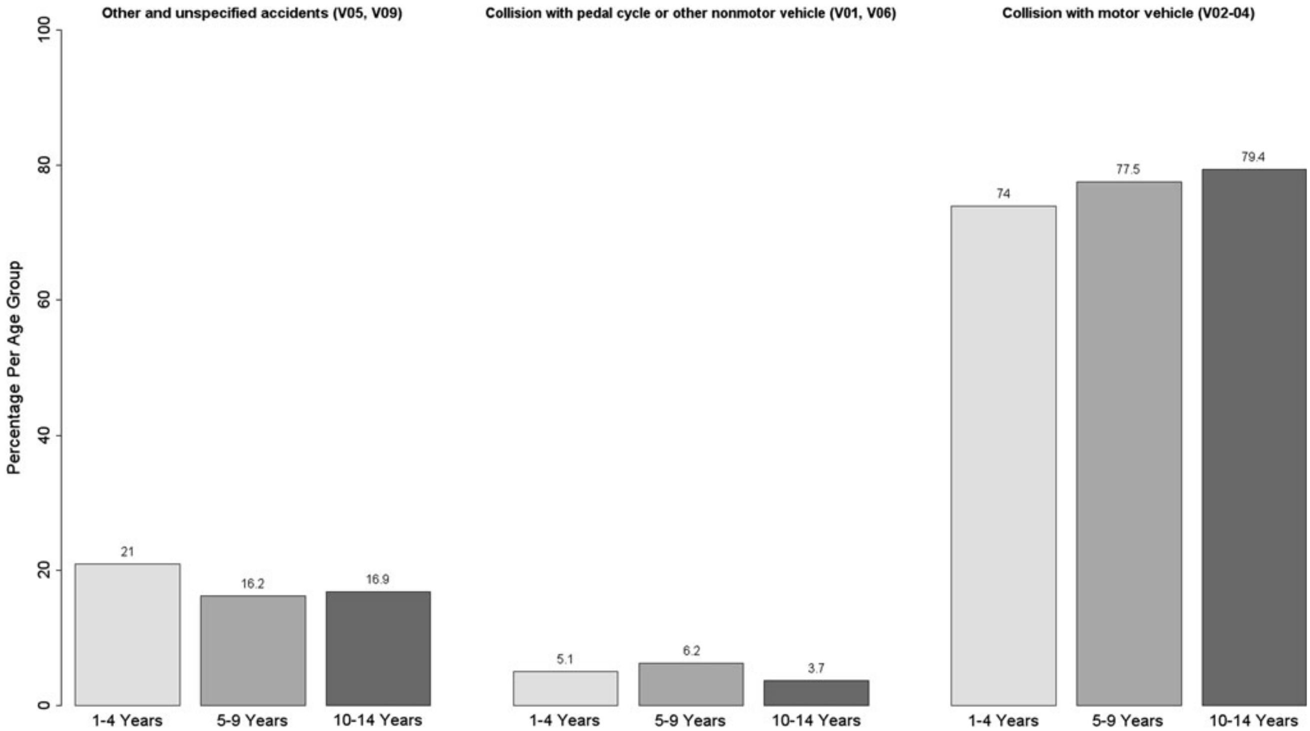

Fig. 1 Distribution of pedestrian injuries by cause and age group, 2000–01 to 2004–05, NSW Australia. Source: NSW Admitted Patient Data Collection (HOIST), Centre for Epidemiology and Research, NSW Department of Health

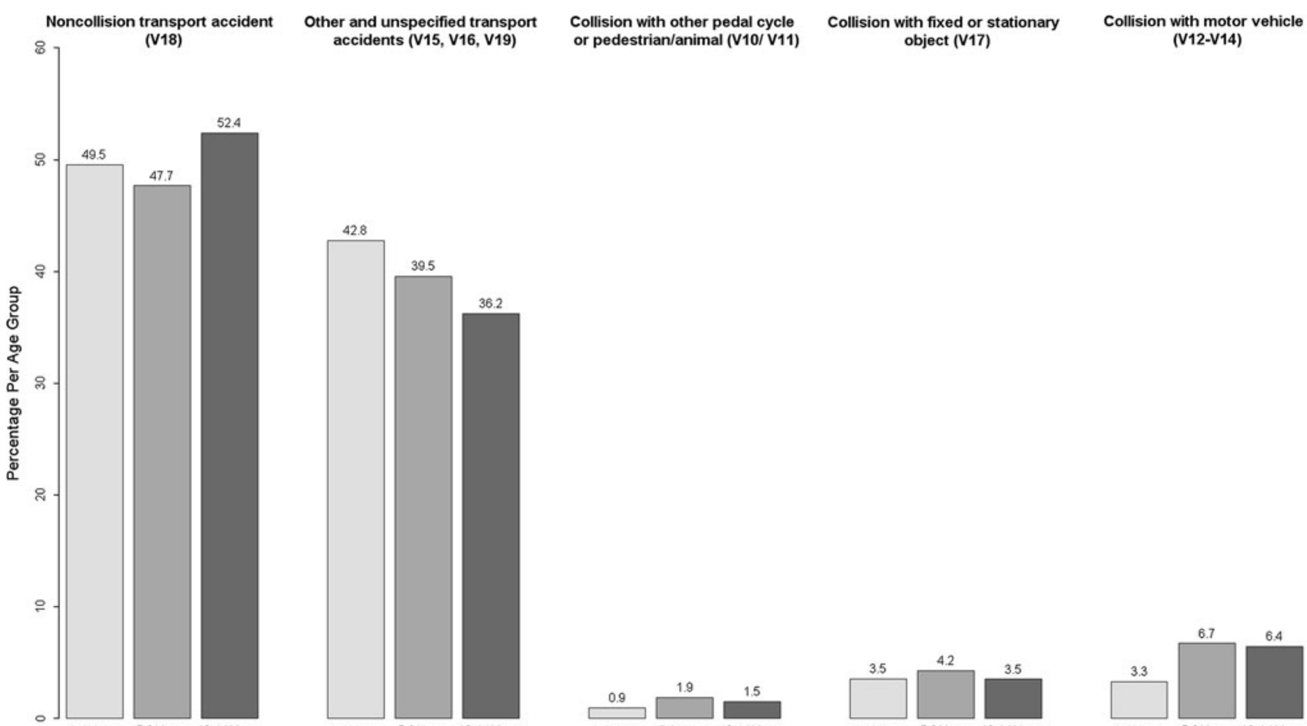

Fig. 2 Distribution of pedal cycle injuries by cause and age group, 2000–01 to 2004–05, NSW Australia. Source: NSW Admitted Patient Data Collection (HOIST), Centre for Epidemiology and Research, NSW Department of Health

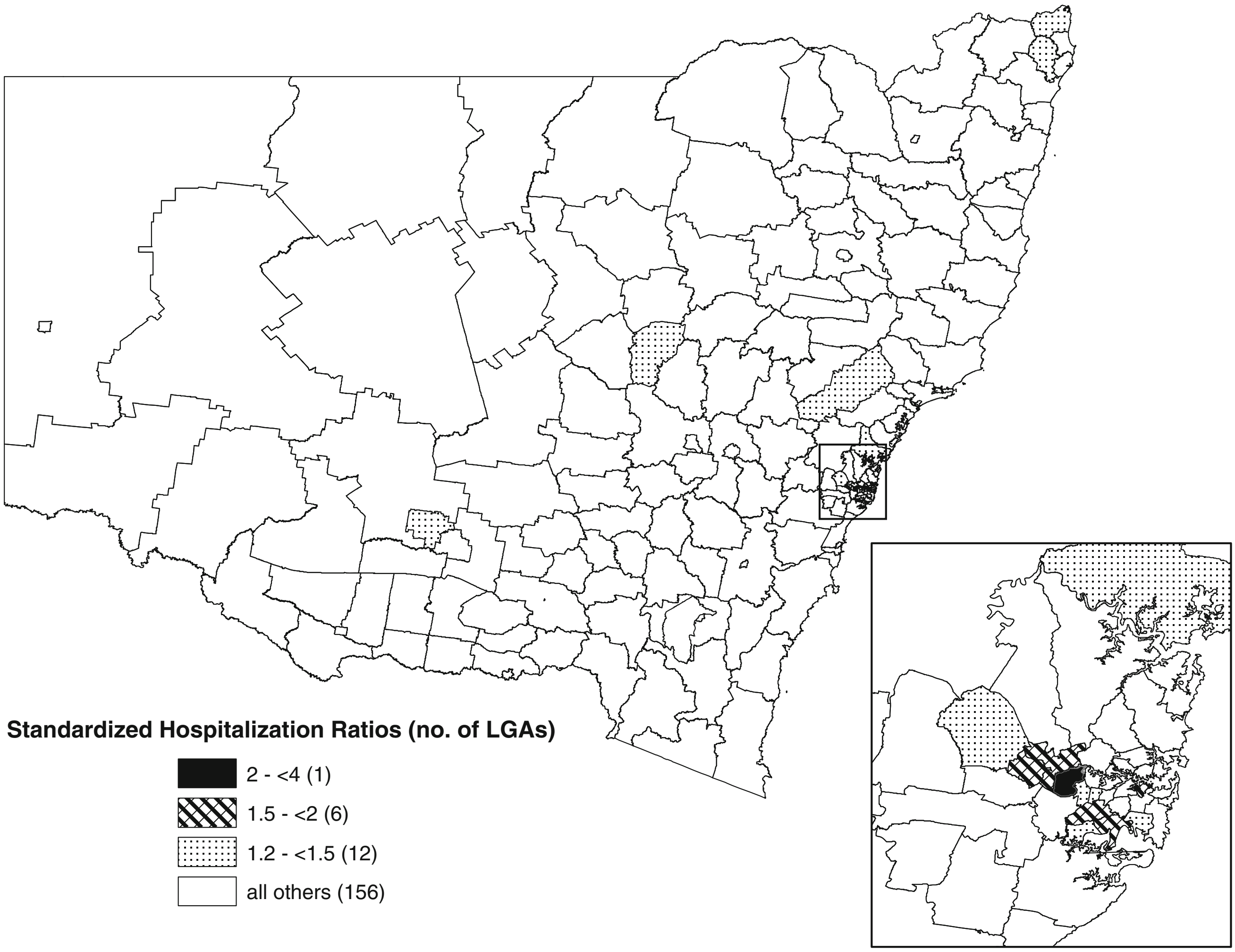

Fig. 3 NSW Local Government Areas (LGAs) with a high estimated smooth standardized hospitalization ratio (SHR) for pedestrian injury in children aged 1–14 years (SHR > 1.2; posterior probability > 0.8), 2000–01 to 2004–05. Source: NSW Admitted Patient Data Collection (HOIST), Centre for Epidemiology and Research, NSW Department of Health

activities of children, and therefore exposure, in these locations. For example, metropolitan areas may encourage more pedestrian activity in children, while more open spaces in outer metropolitan areas may encourage more recreational cycling in children.

Having identified the location of high risk communities the opportunity now exists to work with these communities to enhance the surveillance of risk factors and hazards, and to identify and evaluate locally applicable injury prevention interventions to reduce the disparity. Effective interventions will address the relevant injury mechanism, and will require an understanding of underlying causes within the community. For example, if the deficit is informational, then education will be required (e.g. bicycle safety courses); if economic barriers exist, then a solution may be the provision of free or subsidized safety equipment (e.g. cycle helmets); if it is exposure to high traffic volumes for example, then area-wide environmental and policy measures will be necessary (Dowswell and Towner 2002).

We have used injury hospitalizations to demonstrate how geospatial methods can be useful as a tool for identifying geographic areas for intervention. These methods largely overcome problems with traditional methods (such as crude rates or unsmoothed standardized mortality ratios), which are very variable in situations of low case numbers or small populations, and which do not allow for spatial correlation in the data. Incorporating spatial correlation into the model leads to more robust estimates of hospitalization ratios in each LGA and uses the surrounding LGAs to smooth out the extra variation in LGAs with low numbers. The results of the Besag, York and Mollie model are usually plotted on separate maps showing posterior expected rate ratios or posterior probabilities (Jarup et al. 2002; Best et al. 2002) (Bergamaschi et al. 2006, Montomoli et al. 2006). However, maps of posterior

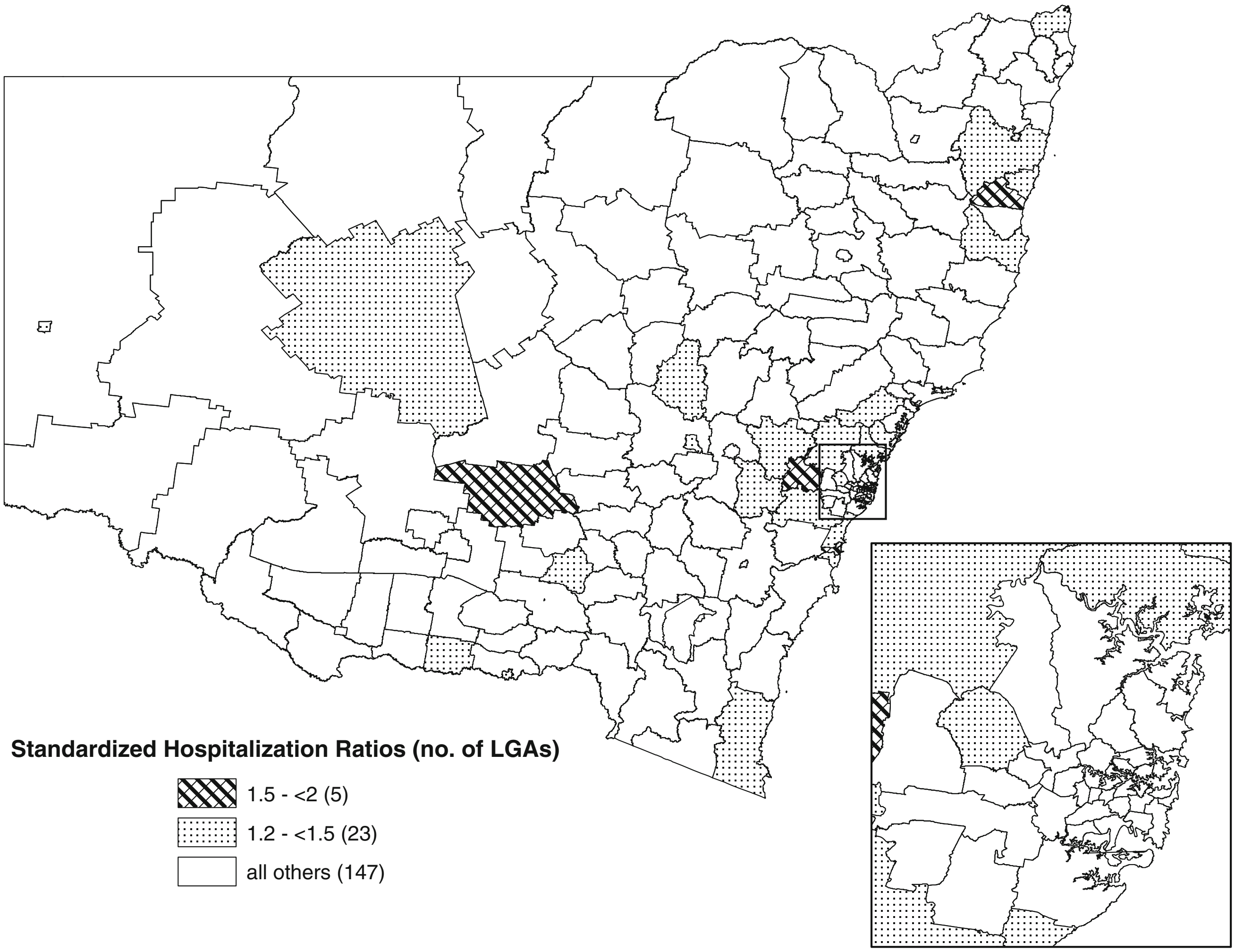

Fig. 4 NSW Local Government Areas (LGAs) with a high estimated smooth standardized hospitalization ratio (SHR) for pedal cycle injury in children aged 1–14 years (SHR > 1.2; posterior probability > 0.8), 2000–01 to 2004–05. Source: NSW Admitted Patient Data Collection (HOIST), Centre for Epidemiology and Research, NSW Department of Health

expected rate ratios tend to be dominated by areas with small populations where random fluctuation is greatest, and maps showing posterior probability tend to be dominated by areas with large populations, where small differences are likely to be statistically significant. Therefore, we chose to combine information on both risk and probability on a single map, making interpretation easier for policy makers and practitioners and focusing attention only on those areas most in need. We believe that such a combined measure, which is not widely used, provides a simpler and more useful index of increased risk.

Spatial statistical models allow researchers to use data from small areas to determine risk. Although hospitalization data were also available at smaller spatial levels in our dataset (at the postcode level), our analysis for this case study was conducted at the LGA level. LGAs are not homogeneous areas, and may contain areas of both high and low risk. However, since the organization and delivery of many services is on the basis of LGA (for example, the local government road safety program (Roads and Traffic Authority (NSW) 2010)), analysis at this level makes operational sense. This is particularly important for larger scale environmental interventions. Further, local government has many statutory town planning powers that it can exercise to implement changes to the environment. For example, local government in NSW has control over local roads and therefore it can implement traffic calming strategies if necessary. However, if it was necessary to compare injury rates over smaller geographical areas to pinpoint, for example, hot spots for injuries, these geospatial models will be equally effective in providing robust risk estimates.

Nonetheless, the usefulness of these geospatial methods is only as good as the quality of the data that are available,

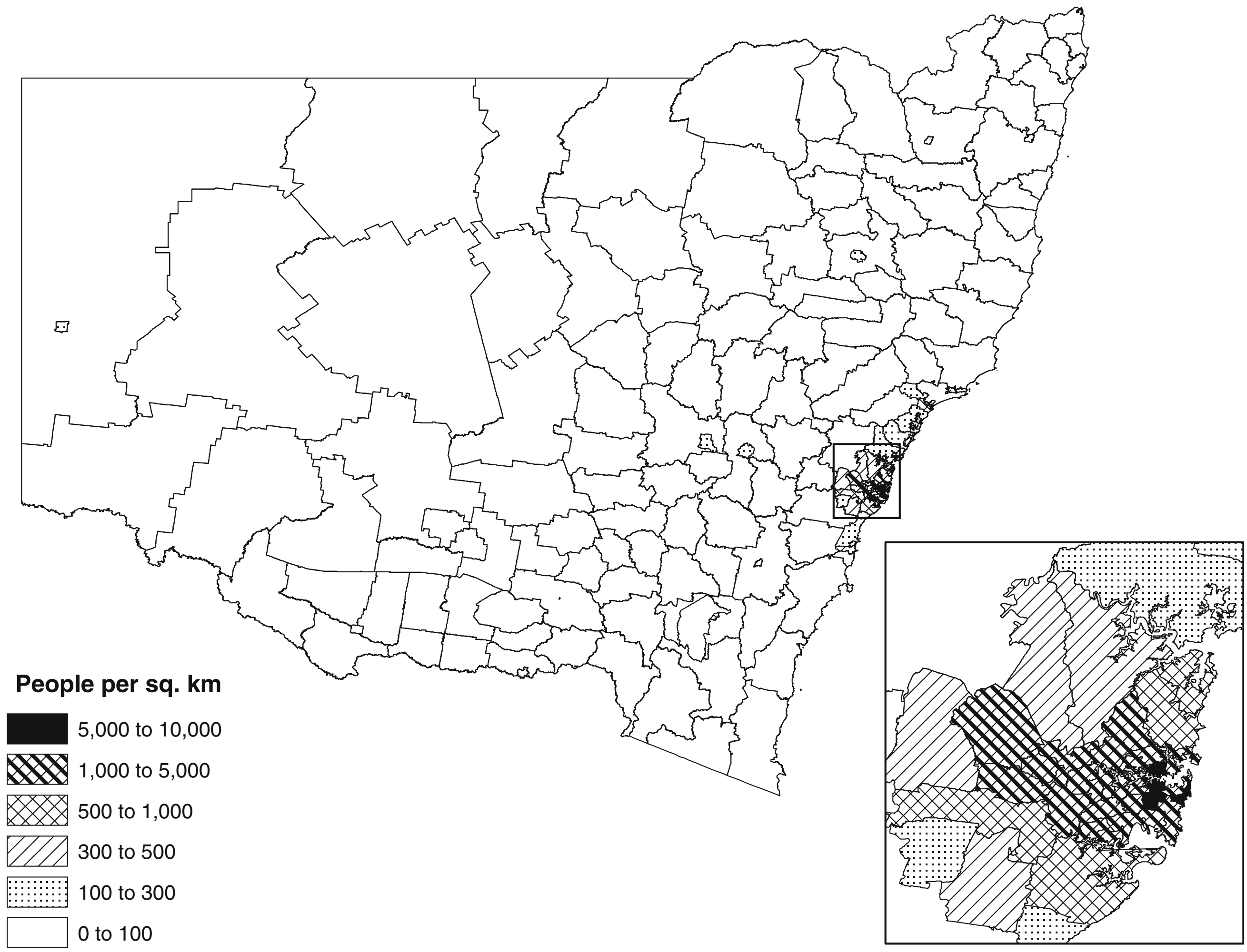

Fig. 5 NSW Local Government Areas by average population density, 2000–01 to 2004–05. Source: ABS Population Estimates (HOIST), Centre for Epidemiology and Research, NSW Department of Health

and the interpretation of the results should acknowledge the limitations of the data. For example, while the hospitalization data has more complete case ascertainment than police crash records for pedestrian and pedal cycle injuries(Lujic, Finch et al. 2008), it does not capture deaths occurring before hospitalization or injuries presenting only to general practitioners or emergency departments, thus underestimating the true incidence of injury (Leonard et al. 1999; Beattie et al. 1999). However, these hospitalization data do capture the majority of the severe injuries (Australian Institute of Health and Welfare 2010). Further, the location of an injury event is not collected in our routine hospitalization data, so injury rates relate to the LGA of a child's place of residence. The impact of this on our findings is unknown, although other research indicates that children are frequently injured in or near their homes (Jones et al. 2005; Hewson 2005; Joly et al. 1991).

Conclusion and implications

Pedestrian and pedal cycle injuries are significant and potentially avoidable causes of injury in children in NSW, thus, continued investment in statewide interventions to promote safety remain important. Our findings using geospatial analyses suggest that injury prevention interventions could also be differentially targeted in NSW to achieve greater population impact. For example, it appears that further investment in interventions that promote safety in pedestrians should be directed to a number of metropolitan areas, while further investment in interventions that result in safe cycling (particularly in non-road, non-traffic environments) are required in some of the outer metropolitan areas, if disparities are to be redressed.

The visual impact of mapped data may be a more effective means of highlighting need and promoting action when working with communities or government, than the associated numeric data (Rezaeian et al. 2004). Maps are relatively easy to understand despite the complicated statistical analyses underlying them, and they are therefore suitable for wide dissemination. For example, researchers in Sweden report that maps of child and youth injury rates by municipality gained the attention of the media and local authorities leading to local action (Ekman et al. 2005). Potentially, maps can be compared with a range of spatially distributed variables (such as socioeconomic indices for areas (Adhikari 2006), which can aid in the generation of hypotheses about causal relationships, which can be further investigated (Lawson et al. 2000). They can also be overlaid with other maps showing the location of health, emergency, and other community facilities, which is useful for planning services to respond to the higher rates of injuries. Finally, they can assist policymakers and practitioners to prioritize public health interventions to communities at greatest risk.

Acknowledgments RP is supported by a National Health and Medical Research Council Capacity Building Grant in Injury, Trauma and Rehabilitation. SC and JO are supported by the NSW Injury Risk Management Research Centre (IRMRC), with core funding provided by the NSW Health Department, the NSW Roads and Traffic Authority and the Motor Accidents Authority. The authors would like to thank the Centre for Epidemiology and Research at the NSW Health Department for providing the NSW APDC data from the Health Outcomes and Information Statistical Toolkit (HOIST) analyzed in this study. The authors are also grateful to Dr Andrew Hayen (now at University of Sydney) for the statistical and methodological advice he provided to an earlier phase of this research.

References

Adhikari P (2006) Socio-economic indexes for areas: Introduction, use and Future directions

Australian Bureau of Statistics (2001) Statistical geography. Australian Standard Geographical Classification. Volume 1 Australian Bureau of Statistics, Canberra

Australian Institute of Health and Welfare (2010) Australia's health 2010. Australia's health series no. 12. Cat. no. AUS 122. Canberra, AIHW

Bergamaschi R, Montomoli C, Candeloro E et al (2006) Bayesian mapping of multiple scleroisis prevalence in the province of Pavia, northern Italy. J Neurol Sci 244:127–131

Berry J, Harrison J (2007) Hospital separations due to injury and poisoning, Australia 2003-04. Injury research and statistics series no. 30. AIHW cat. no. INJCAT 88. Australian Institute of Health and Welfare, Adelaide

Department of Infrastructure, Transport et al (2008) Appendix F: Australian classification of local governments. http://www.infrastructure.gov.au/local/publications/reports/2002_2003/appendix_f.aspx. (Accessed 1 Nov, 2010)

DiGuiseppi C, Roberts I, Li L (1997) Influence of changing travel patterns on child death rates from injury: trend analysis. BMJ 314:710

Doukas G, Olivier J, Poulos R et al (2010) Exploring differential trends in sever and fatal child pedestrian injury trends in New South Wales, Australia (1997–2006). Accid Anal Prev 42:1705–1711

Dowswell T, Towner E (2002) Social Deprivation and the prevention of unintentional injury in childhood: a systematic review. Health Educ Res 17(2):221–237

Ekman R, Svanstrom L, Langberg B (2005) Temporal trends, gender, and geographic distributions in child and youth injury rates in Sweden. Inj Prev 11:29–32

Hassleberg M, Laflamme L, Weitoft G (2001) Socioeconomic differences in road traffic injuries during childhood and youth: a closer look at different kinds of road user. J Epidemiol Community Health 55:858–862

Hewson P (2005) Epidemiology of child pedestrian casualty rates: can we assume spatial independence? Accid Anal & Prev 37:651–659

Hippisley-Cox J, Groom L, Kendrick D et al (2002) Cross-sectional survey of socioeconomic variations in severity and mechanism of childhood injuries in Trent 1992–7. BMJ 324:1132

Jarup L, Best N, Toledana M et al (2002) Geographical epidemiology of prostate cancer in Great Britain. Int J Cancer 97:695–699

Joly M-F, Foggin P, Pless I (1991) Geographical and socio-ecological variations of traffic accidents among children. Soc Sci Med 33:765–769

Jones S, Lyons R, John A et al (2005) Traffic calming policy can reduce inequalities in child pedestrian injuries: a database study. Inj Prev 11:152–156

Lawson A, Biggeri A, Boehning D et al (2000) Disease mapping models: an empirical evaluation. Stat Med 19:2217–2241

Lawson A, Browne W, Vidal Rodeiro C (2003) Disease mapping with WinBUGS and MLwin. Wiley, Chichester

Leonard P, Beattie T, Gorman D (1999) Under representation of morbidity from paediatric bicycle accidents by official statistics—a need for data collection in the accident and emergency department. Inj Prev 5:303–304

Lujic C, Finch S Boufous et al (2008) How comparable are road traffic crash cases in hospital admissions data and police records? An examination of data linkage rates. ANZ J Pub Health 32:28–33

Macpherson A, To T, Parkin P et al (2004) Urban/rural variation in children's bicycle-related injuries. Accid Anal Prev 36:649–654

Mason C (2000) Transport and health: en route to a healthier Australia? MJA 172:230–232

Meuleners L, Haworth C, Lee A (2006) Emergency presentations by vulnerable road users: implications for injury research. Inj Prev 12:12–14

Morency P, Cloutier M-S (2006) From tageted "black spots" to area-wide pedestrian safety. Inj Prev 12:360–364

Moustaki M, Petridou E, Trichopoulos D (2001) Person, time and place co-ordinates of pedestrian injuries: a study in Athens. Acta Paediatr 90:558–562

Plasencia A, Borrell C (2001) Reducing socioeconomic inequalities in road traffic injuries: time for a policy agenda. J Epidemiol Community Health 55:853–854

Population Health Division (2006). The Health of the people of New South Wales—Report of the Chief Health Officer NSW Department of Health. Sydney

Posner J, Liao E, Winston F et al (2002) Exposure to traffic among urban children injured as pedestrians. Inj Prev 8:231–235

Poulos R, Hayen A, Finch C et al (2007) Area socioeconomic status and child injury morbidity in New South Wales, Australia. Inj Prev 13:322–327

Retting R, Ferguson S, McCartt A (2003) A review of evidence-based traffic engineering measres designed to reduce pedestrian-motor vehicle crashes. Am J Public Health 93:1456–1463

Rezaeian M, Dunn G, St Leger S, Appelby L (2004) The production and interpretation of disease maps. Soc Psychiatry Psychiatr Epidemiol 39:947–954

Roads and Traffic Authority (NSW) (2010) Local government road safety program, from http://www.rta.nsw.gov.au/doingbusinesswithus/lgr/downloads/programs/lgrsp.html Accessed on October 2010

Roberts I, Norton R, Jackson R et al (1995) Effect of environmental factors on risk of injury of child pedestrians by motor vehicles: a case-control study. BMJ 310:91–94

Stutts J, Hunter W (1999) Motor vehicle and roadway factors in pedestrian and bicyclist injuries: an examination based on emergency department data. Accid Anal & Prev 31:505–514

Thomas A (2004) BRugs User Manual, Version 1.0. University of Helsinki, Dept of Mathematics and Statistics

Van Niekerk A, Reimers A, Laflamme L (2006) Area characteristics and determinants of hospitalised childhood burn injury: a study in the city of Cape Town. Public Health 120:115–124

World Health Organisation (2000) Obesity: preventing and managing the global epidemic. Report of a WHO Consultation: WHO technical report series 894. World Health Organisation, Geneva