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Vector fields of risk: A new approach to the geographical representation of childhood asthma

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ABSTRACT

One of the major challenges in health studies with a spatial dimension is to produce valid and meaningful geographical representations of risk. This issue has arisen in our research on childhood asthma and proximity to traffic in Perth, Western Australia. To illustrate the spatial variation in risk over the study area, we developed a method for constructing a "risk field" map and applied this method to our study population. Cases and controls aged 0–19 years were defined using emergency department presentations from 2002 to 2006. For each asthma case, two matched controls were obtained. Geocoded residential addresses were used to calculate "vectors" or arrows of risk across the study area. This allows a rapid interpretation, with the risk of asthma greatest in the direction of the head of the vector relative to the vector's tail. This approach clearly indicated that the risk of asthma presentation at hospital emergency departments is higher for children living closer to the major urban city centers. Application of our method to the study population suggests that the "vector" approach may be useful as an exploratory tool for the spatial investigation of risk of other health outcomes.

1. Background

One of the major challenges in epidemiological studies with a spatial dimension is to produce a valid and meaningful geographical representation of risk. The issue of mapping risks has arisen in our current research on childhood asthma and proximity to traffic in Perth, Western Australia. Despite earlier conflicting opinions (Heinrich et al., 2004), recent reviews have highlighted associations between asthma and traffic exposure and possible causal mechanisms (Brugge et al., 2007; Holguin, 2008; Salam et al., 2008). This health issue is of increasing concern in parts of Perth following recent rapid population growth of the city.

For our study, we sought to explore the risk of asthma Emergency Department (ED) presentation of children and young adults living in the south-west metropolitan area of Perth. Typically, a spatial analysis would begin with an exploratory investigation of asthma risk, then proceed to formal statistical tests. To visualize how asthma varies with residential location, we instead developed a new method for constructing a "risk field" map. The risk field is best conceptualized as a field of vectors that "point" in the direction of maximal risk, analogous to other vector fields in the physical sciences (e.g. electro-magnetic fields). The use of vector fields in geographic information analysis has already been identified, and vector fields such as velocity fields, electromagnetic fields and gravitational fields are commonly used to model phenomena having a location, magnitude and direction (O'Sullivan and Unwin, 2003). For instance, velocity fields can be constructed by modeling of the speed and direction of fluid flow such as wind flow in a street canyon (DePaul and Sheih, 1986).

Our risk field was constructed by modeling the odds ratio using the latitude and longitude coordinates corresponding to the residential addresses. Each of the vectors in the risk field is anchored at a reference subject's residential address, and the head of the vector ("the tip of arrow") points in the direction of elevated risk. In other words, there is a greater risk of the adverse health outcome for subjects that reside at locations *in this direction* based on the locations of neighboring subjects. An illustration of risk vectors for a simplified hypothetical situation is shown in Fig. 1. This figure uses relative risk but the odds ratio could equally be applied as a descriptor of risk. There are two aspects to any vector: a direction and a length. From the illustration it is evident that the vectors point in the direction of greatest risk and that the length of the vectors are proportional to the increase in risk in this direction.

More traditional scalar fields such as density surfaces, contour maps, and choropleth maps of risk do not explicitly display the

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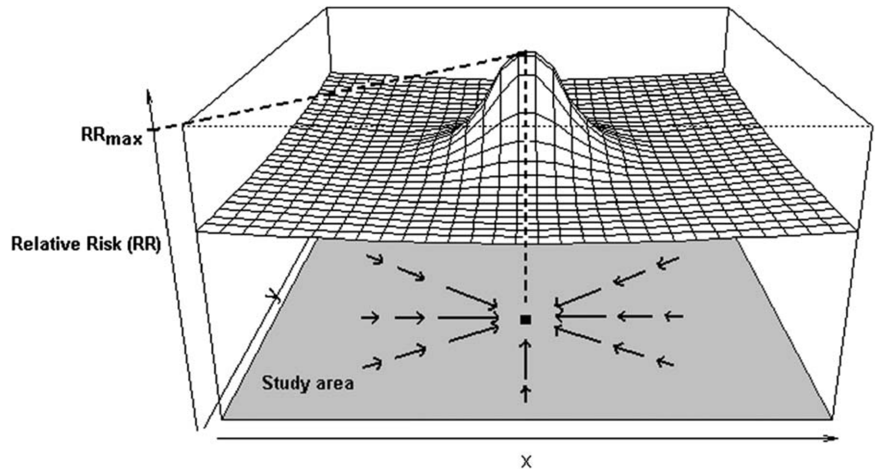

Fig. 1. Each of the vectors (arrows) plotted on the study area have a DIRECTION and a LENGTH. DIRECTION: the vectors point to the location in the study area at which RR is highest. LENGTH: the length of the vectors are proportional to the increase in RR in that DIRECTION.

magnitude of risk in a particular direction from a particular reference location, such as residential address. These forms of visualization are also less useful than a vector field of risk for making comparisons with other predominantly two-dimensional fields of exposure, such as prevailing wind and vehicle traffic flow in the context of asthma risk. Alternative approaches have been developed that are based on the ratio of case and control kernel intensities (Bithell, 1990; Kelsall and Diggle, 1995). However, such methods are not always suitable for spatial epidemiological studies in which cases are matched to controls. Moreover, an inherent assumption of many methods is that the 'population at risk' of the disease has a continuous spatial distribution (Lawson and Kleinman, 2005). This assumption is typically violated if the study area contains sections of no resident population, such as within industrial areas. A less obvious violation occurs when sections of the study area contain a resident population, none of whom are at risk of the disease.

This paper describes the development of "risk field" maps and provides an application of this method to asthma ED presentations. Many weaknesses of cluster identification studies and those incorporating statistical tests have been identified (Rothman, 1990). For this reason, the risk field map was developed as an exploratory spatial tool to visually assess hypotheses formed a priori and provide a visual summary of the observed locations of adverse health events. The method could also be applied more generally to other spatial analyses to enable visualization of how risk varies geographically by subject location.

2. Method

2.1. Study design

This study is a record-based n:m matched case–control study using geocoded ED presentation data on children and young adults living in the study area.

2.2. Study area

The study area included 613 census Collection Districts (CDs), encompassing eight Statistical Local Areas, within the south-western region of the Perth metropolitan area. CDs are the smallest available geographical areas for which demographic statistics are disseminated by the Australian Bureau of Statistics, and on average included 225 dwellings. This particular study area was chosen because, being traversed by major metropolitan vehicle corridors and less-trafficked local roads, it provided a sufficient degree of exposure contrast. It was also representative of the wider metropolitan area. The total population in the area was 269,734 (2006 Census of Population and Housing).

Table 1
Prevailing wind direction and wind speed in Perth.

	Annual	Summer	Autumn	Winter	Spring
	Prevailing wind direction[a]				
9 AM	East	East	North-east	North-east	East
3 PM	South-west	South-west	South-west	South-west	South-west
	Wind speed[a]				
9 AM	14.1	17.3	13.3	11	14.8
3 PM	18.6	21.5	16.4	16.1	20.4

Source: Bureau of Meteorology. Climate Statistics for Australian Locations. Commonwealth of Australia, 2008.

[a] Measured at Perth Airport.

2.3. Summary of climatic conditions

Perth is located on a narrow coastal plain between the Indian Ocean to the west and the 300 m high Darling Scarp to the east. Perth has a Mediterranean climate with hot, dry summers, and mild wet winters (Sturman and Tapper, 2006). During the summer, Perth is influenced mainly by morning easterly winds blowing across the inland desert, shifting to strong south-westerly sea breezes dominating during the afternoon (Hurley and Manins, 1995) (Table 1).

2.4. Study population

The cases were all individuals aged 0–19 years with residential addresses in the study area, who presented at the ED of any Perth metropolitan hospital in 2002–2006, with a principal diagnosis of asthma (J45) or status asthmaticus (J46). Each case was matched to a gastroenteritis (A00–A09) control and an upper limb injury (S40–S69) control. Gastroenteritis and upper limb injuries were chosen as control conditions because they had no known or suspected association with proximity to air pollution from motor vehicle traffic. Previous case–control studies have also used