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Synoptic weather types and aeroallergens modify the effect of air pollution on hospitalisations for asthma hospitalisations in Canadian cities

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A B S T R A C T

Pollution levels and the effect of air pollution on human health can be modified by synoptic weather type and aeroallergens. We investigated the effect modification of aeroallergens on the association between CO, O_3, NO_2, SO_2, PM_{10}, $PM_{2.5}$ and asthma hospitalisation rates in seven synoptic weather types. We developed single air pollutant models, adjusted for the effect of aeroallergens and stratified by synoptic weather type, and pooled relative risk estimates for asthma hospitalisation in ten Canadian cities. Aeroallergens significantly modified the relative risk in 19 pollutant-weather type combinations, reducing the size and variance for each single pollutant model. However, aeroallergens did not significantly modify relative risk for any pollutant in the DT or MT weather types, or for PM_{10} in any weather type. Thus, there is a modifying effect of aeroallergens on the association between CO, O_3, NO_2, SO_2, $PM_{2.5}$ and asthma hospitalisations that differs under specific synoptic weather types.

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1. Background

Associations between individual climatological variables, such as temperature, and human health outcomes have been well studied, and while this approach can draw meaningful associations between weather predictors and mortality or morbidity, it can fail to capture the complex effects of interrelated weather factors on human health outcomes. To account and understand how humans respond to a combination of meteorological variables simultaneously, spatial synoptic classification (SSC) can be used to group weather patterns using a suite of meteorological parameters into distinct categories (Sheridan, 2002). The SSC is becoming more widely used to investigate associations between pollutant levels and mortality; for example, a study based in North Carolina, USA found that ozone in conjunction with dry tropical (DT) and moist tropical (MT) weather types increased the risk of hospitalisation for asthma and myocardial infarction (Hanna et al., 2011).

Synoptic weather patterns have been found to affect concentrations of air pollutants (Davis et al., 2010; Greene et al., 1999; Rainham et al., 2005); however, the implications for human health are not clear. One study looked at 19 years of data for Toronto, finding no systematic modification of the pollution–mortality association by weather type but observing that variation in pollutant concentrations was in part dependent on the synoptic category (Rainham et al., 2005). Weather types can affect human health outcomes in their own right due to their intrinsic meteorological characteristics: the so called "offensive" SSCs, DT, dry tropical, and MT, moist tropical, have been found to increase mortality rates, and this effect increases with the duration of exposure to the weather type (Kyselý, 2007; Sheridan and Kalkstein, 2010).

Our recent work has found that air pollution modifies the effect of aeroallergens on asthma, increasing the rate of hospitalisations on days of high air pollution (Cakmak et al., 2012). These findings are consistent with both animal model and human studies that suggest biological interactions between pollutants and aeroallergens (Farraj et al., 2006; Kehrl et al., 1999; Peden, 2001; Whitekus et al., 2002). Airways damaged by air pollutants may be more susceptible to allergen exposure (Amato et al., 2010), while

Abbreviations: PM_{10}, Particulate matter with a median aerodynamic diameter less than or equal to 10 μm; $PM_{2.5}$, Particulate matter with a median aerodynamic diameter less than or equal to 2.5 μm; AIC, The Akaike Information Criterion; SSC, Spatial Synoptic Classification.

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population level studies support an interactive effect between pollution and aeroallergens, without suggesting a causal mechanism (Atkinson and Strachan, 2004; Johnston and Sears, 2006).

There is some evidence that aeroallergen levels can be increased by synoptic weather conditions such as low height and stability in the nocturnal boundary layer (Gassmann and Gardiol, 2007) or low surface pressures (Hart et al., 2007). The relationship between pollution, aeroallergens, and asthma is therefore complex, and there is potential for further modification of this relationship by weather type, due to intrinsic characteristics of the weather type itself that can directly affect human health or by affecting pollutant and aeroallergen levels.

Forecasting that incorporates synoptic conditions, aeroallergen levels and air pollutants could be useful for managing the respiratory health of susceptible populations (Hondula et al., 2013; Jamason et al., 1997). Health officials can be warned of the potential for increased admissions and at-risk individuals can take measures to mitigate their risk of respiratory exacerbations (Lee et al., 2012). In this study we explore the relative risk of asthma hospitalisation from single air pollutants and the modifying effect of aeroallergens, pooled for ten cities to obtain an overall risk estimate for Canada, in the presence of seven synoptic scale weather types. The study design tests the association between daily changes in aeroallergens and asthma hospitalisations, where changes in asthma hospitalisations can only be contributed by individuals with susceptibility to aeroallergens; members of the population that are not susceptible to aeroallergens would therefore not be considered.

2. Methods

The study population comprised hospitalisations where asthma was recorded as the principal reason for admission, obtained from the Canadian Institute for Health Information (CIHI), for ten cities across Canada for which aeroallergen data were also available: Calgary, Edmonton, Halifax, London, Ottawa, Saint John, Toronto, Vancouver, Windsor, and Winnipeg. Data were obtained for the period April 1, 1994, to March 31, 2007, with city population data centred on 2000. Asthma hospitalisations were coded 493 or J45 and J46 by using the International Classification of Disease, 9th or 10th revision (http://www.who.int/classifications/icd/en/).

Air pollution data for each city were obtained from the National Air Pollution Surveillance (NAPS) network as one hour maximum daily ozone concentrations, 24 h concentrations of carbon monoxide, nitrogen dioxide, and sulphur dioxide, and particulate matter with mean aerodynamic diameters of 10 (PM_{10}) and 2.5 μm ($PM_{2.5}$).

Aeroallergens were collected by Aerobiology Research Laboratories, using a standardised method for all cities for the study period of April to October, 1994 to 2007. Rotational impact methods were used to obtain 24 h collections of pollen grains and fungal spores and estimate the number of particles present per cubic meter of air sampled. Aeroallergens show large day to day variations and therefore we log transformed the data for analysis.

Spatial Synoptic Classification combines routinely collected meteorological variables (air temperature, dew point, wind velocity, pressure, and cloud cover) in order to classify a weather situation into one of six weather types, dry moderate (DM), dry polar (DP), dry tropical (DT), moist moderate (MM), moist polar (MP), moist tropical (MT), plus a transition category (TR) where one weather type transitions into a different type. MT+ (moist tropical plus) and MT++ occur rarely in Canada, and when found were classified into the MT. The SSC is a semi-automated classification system (2002) developed and maintained by Sheridan (http://sheridan.geog.kent.edu/ssc.html). The data used for classification are obtained from the Meteorological Service of Canada from airport weather stations in each of the ten cities. Daily synoptic weather classifications for each city are available at the SSC archive.

Generalised additive models (S-Plus, Professional Edition Version 6.0.2 (1) for Microsoft Windows; Insightful Corp, Seattle, Wash) with stringent convergence criteria ($\varepsilon < 10-14$) were used to test the association between asthma hospitalisations and individual pollutants, adjusting for the modifying effect of aeroallergens. Each model was developed for days corresponding to one of seven synoptic scale weather types. We assumed that the hospitalisation data was Poisson-distributed. The effect of each pollutant on asthma hospitalisation was tested for the day of admission and five days preceding admission (lags 0, 1, 2, 3, 4, 5), selecting the lag period which optimised the observed effect size. Relative risks were estimated for an interquartile increase (25th to 75th) in hospitalisation for asthma, stratified by weather type. The relative risks of asthma hospitalisation for each pollutant were tested with and without adjustment for the effect of aeroallergens for days in the presence of each weather type.

The model can be summarised as follows:

$$LogE(Y_t / X_t, Z_t) \sim \beta X_{t-l} + \delta Z_{t-l} + \text{ns(time, knot)} + DOW_t$$

Where Y_t is the daily count of hospital asthma admissions, X_{t-l} is the pollutant level on day t with 0–5 days of lag, Z_{t-l} is the aeroallergen level on day t with 0–5 days of lag, β and δ are the regression coefficients linking the pollutant and the aeroallergen to daily asthma hospitalisations, respectively, ns(time, knot) is the natural spline of time with knots at 13, 25, 49 and 145 days of observation, the number of knots selected based on minimization of Akaike's Information Criterion (AIC) and the Bartlett test for autocorrelation; and DOW_t is an indicator for the day of the week on time t. Effect estimates for each pollutant, adjusted and unadjusted for aeroallergens, in each weather type were obtained by replacing β by $\beta_{(dm)}I_{dm}$, where I_{dm} is an indicator of the DM weather type (Vanos et al., 2014).

Data was pooled for the ten cities using a random effects model with a random intercept to account for between-city inhomogeneity, and the effect estimates were weighted using the inverse sum of within and between-city variance, as in Cakmak et al. (2012). Single-pollutant-specific regression coefficients were combined using the restricted maximum likelihood method. A t-test was used to test for significant differences ($P < 0.05$) in RR before and after adjustment by aeroallergens for each single-pollutant model within each weather type.

Table 1
Weather type frequency (%) per city and the average frequency for all cities during the study period, for seven weather types: DM (dry moderate), DP (dry polar), DT (dry tropical), MM (moist moderate), MP (moist polar), MT (moist tropical), and TR (transitional). NA indicates that weather type not present.

	DM	DP	DT	MM	MP	MT	TR
Calgary	31	23	3	9	19	1	8
Edmonton	21	32	2	8	22	1	12
Halifax	23	18	1	18	13	8	9
London	27	11	4	19	7	20	8
Ottawa	29	11	5	21	9	14	9
Saint John	18	13	NA	21	26	6	11
Toronto	34	8	7	17	5	18	10
Vancouver	44	3	NA	28	13	1	9
Windsor	26	12	5	18	5	23	7
Winnipeg	27	16	2	16	13	12	11
All-city average	28	15	3	17	13	10	10

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