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Are children's asthmatic symptoms related to ambient temperature? A panel study in Australia

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ABSTRACT

Objectives: To examine the short-term effects of ambient temperature on respiratory symptoms for school children with asthma across Australia.
Methods: A panel of 270 children (7–12 years) with asthma was recruited from six Australian cities. They were asked to record their respiratory symptoms every day in the morning (for night-time symptoms) and evening (for daytime symptoms) for four weeks. Daily ambient temperature, relative humidity and air pollution data were obtained from fixed monitors nearby. A mixed logistic regression model was used to examine the effects of ambient temperature on respiratory symptoms adjusted for children's sex, age, standing height, weight and air pollution. Subjects were specified as random effects.
Results: The relationships between ambient temperature and respiratory symptoms were linear. Increasing temperatures induced the risks of children's asthmatic symptoms, especially for "wheeze/chest tightness" and to a lesser extent for "cough/phlegm". The effects were acute and lasted for four days (lag 0–3) in general. With increasing ambient temperature, boys were more at risk than girls.
Conclusions: High ambient temperature is a risk factor for respiratory symptoms in children with asthma. As ambient temperature increases, policies and strategies for rising temperatures will be necessary to protect asthmatic children.

1. Introduction

Asthma accounts for about one percent of all disability-adjusted life years lost worldwide, which reflects the severity and high prevalence of this disease. It is estimated that there are currently about 300 million people with asthma in the world (Masoli et al., 2004). The prevalence of asthma in Australian children is amongst the highest (about 1 in 8 children) in the world, and is continuing to increase (Australian Centre for Asthma Monitoring, 2009). Therefore, the causes and/or risk factors for the onset of asthma need to be urgent to identify so that effective control and prevention strategies can be developed.

Previous studies have documented that a variety of environmental factors, for example, air pollution, aero-allergen exposure and ambient temperature are related to the onset of asthma attacks (Gruchalla et al., 2005; Guo et al., 2012a; Trasande and Thurston, 2005). Some studies have also reported that there are long-term effects of climate (especially temperature) on asthma prevalence. Warmer regions have higher asthma prevalence than cooler regions (de Marco et al., 2002; Guo et al., 1999; Hales et al., 1998). International studies have shown a positive association of asthma and asthma-like symptoms prevalence with the average non-summer temperature (Verlato et al., 2002; Zanolin et al., 2004). Both extreme cold and hot temperatures are related to hospitalization and emergency department visitors for respiratory diseases including asthma (Lin et al., 2009; Michelozzi et al., 2009; Nastos et al., 2008). Previous studies have shown that high temperature and diurnal temperature range are associated with decreases of lung function in children with asthma in Australia

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(Li et al., 2014a, 2014b). However, the effects of ambient temperature on mild asthmatic symptoms have been rarely studied and deserve more attention. Understanding the temperature-induced asthma symptoms through early childhood may have important implications for children with asthma.

In this study, to inform and help increase awareness of the effects of weather change, we assessed the short-term effects of ambient temperature on respiratory symptoms for children with asthma, using a panel study designed in six Australian cities.

2. Methods

2.1. Ethics statement

The study protocol was approved by the Universities of Queensland and Sydney, Departments of Education in the Australian Capital Territory, New South Wales, Queensland, South Australia, Victoria and Western Australia. Ethics approval was also obtained from the Catholic Education Office of Victoria to perform the study at selected Victorian Catholic primary schools. All subjects and parents or guardians gave written informed consent before participation in the study.

2.2. Study location

This study was conducted in six Australian cities: Sydney, Melbourne, Brisbane, Adelaide, Perth and Canberra (Fig. 1). We selected at least two schools near the air monitoring stations for each city. Participants' homes were located around the air monitoring stations. Air monitoring stations were located to measure background concentrations rather than point sources of air pollutants. The study period for each location is described in Supplemental material Table S1.

2.3. Data on weather conditions and air pollution

We obtained daily ambient levels of temperature (average, maximum and minimum) and ozone from each of the selected air monitoring stations for 2007–2008. We used average ozone of the previous 8 h for each hour of the day (8-hour rolling average O_3, parts per billion, ppb) in this study.

We downloaded daily mean relative humidity from "Weather Underground" (http://www.wunderground.com/) for each city, as data on relative humidity were unavailable at the monitoring stations. These data were measured by the local weather monitoring stations. We assumed that any differences in spatial distribution of relative humidity would be small, and therefore we conducted sensitivity analysis to confirm the main findings by excluding relative humidity from the final models.

2.4. Study subjects

First, we sampled primary schools that were within 3 km of selected air monitoring stations. Children in school years three to five (aged 7–12 years) in the selected schools were invited to participate in a cross-sectional study. In the cross-sectional study conducted during 2007–2008, parents were asked to complete a baseline questionnaire which asked about children's lung health and potential environmental factors related to asthma. There were 781 children with a parent report of doctor-diagnosed asthma and symptoms of asthma within the preceding year, that is, with current asthma. Those who lived within a 3 km radius of the corresponding air monitoring station were invited to take part in the panel study. Finally, 270 children were recruited to the panel study. The children were recruited in Melbourne, Brisbane, Adelaide, Perth, and Canberra during 2007 and in Sydney during 2008.

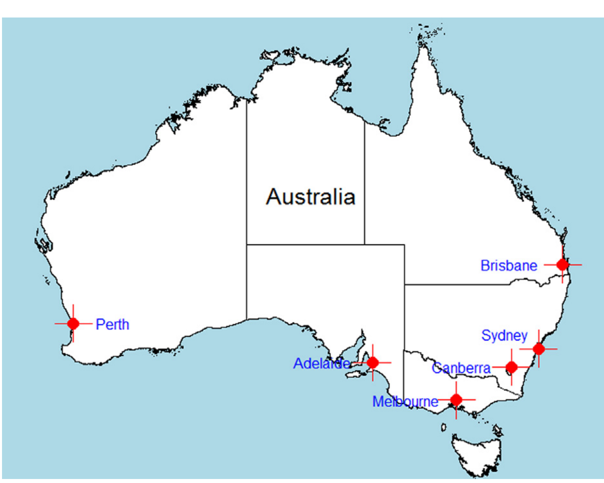

Fig. 1. Location of study cities in Australia.

2.5. Respiratory symptoms

Research staff made face to face appointments with parents and children after school or at their home to discuss the panel study. During these face to face meetings, research staff taught parents/guardian and children how to complete a diary for respiratory symptoms and medication use every morning and evening for four weeks. Respiratory symptoms include cough and/or phlegm, wheeze and/or chest tightness and shortness of breath ("Yes"/"No"). The use of asthma medications— relievers and preventers—was also recorded ("Yes"/"No"). Symptoms and medications used during the night were recorded in the morning, while symptoms and medications used during the day were recorded in the evening.

2.6. Statistical analyses

Mixed logistic regression models were used to examine the effects of ambient temperature (daily average, maximum and minimum) on respiratory symptoms. The mixed logistic regression model contains both fixed and random effects for independent variables. This model is particularly useful in studies where repeated measurements are made on the same statistical units (e.g., on subjects in a panel study). In addition, this model has advantages when dealing with missing values (Jaeger, 2008; Zuur, 2009). The final sample included 270 children and 8691 diary days. There were 1671 missing values for any night-time symptoms, 1684 missing values for night-time cough and/or phlegm, and 1687 missing values for night-time wheeze and/or chest tightness. There were 1642 missing values for any daytime symptoms, 1666 missing values for daytime cough and/or phlegm, and 1665 missing values for daytime wheeze and/or chest tightness.

In this study, we examined the effects of ambient temperature on whole day (either night-time or daytime), night-time and daytime symptoms. Whole day, night-time and daytime symptoms were stratified into three types: any symptoms, cough and/or phlegm, wheeze and/or chest tightness.

We used a natural cubic spline with three degrees of freedom for ambient temperatures (Fig. 2) to examine whether the effects of ambient temperatures on respiratory symptoms were linear. Preliminary results showed that the association between ambient temperature and children's respiratory symptoms was linear-shaped, and also produced the smallest values of both the Akaike information criterion (AIC) and Bayesian information criterion (BIC) (results not shown). Therefore, a linear function was used for temperature in the final analyses.

As children's sex, age, standing height and weight are well-known factors that are related to respiratory symptoms and children may adapt to each city's characteristics, in the basic model, ambient temperature, children's sex, age, standing height, weight and city (categorical variable) were specified as fixed effects. Subject was included as a random effect which also successfully controlled for the effects of season and location.

After establishing the basic model, we sequentially introduced 8-hour rolling average O_3 concentration, relative humidity and asthma medication use into the regression model. By comparing the AIC and BIC values for all models, the best model was selected as the final model that gave the lowest AIC and BIC values. The final model was used to separately assess the effects of ambient temperature on children's respiratory symptoms for girls and boys.

As previous studies have reported effects of ambient temperature not only on the same day, but also on several following days (Guo et al., 2011; Michelozzi et al., 2009), the lagged effects of ambient temperature for up to three days on children's respiratory symptoms were also examined.

Our initial results showed that average temperature was a better predictor than maximum and minimum temperatures as judged by model fit (AIC and BIC) (results not shown). In addition, average temperature represents the exposure throughout whole day and night-time and can be easily interpreted for decision making purposes. Therefore, average temperature was included in the final models. The results for minimum and maximum temperatures are also reported in Supplemental material.

Sensitivity analyses were conducted to check the robustness of our findings. We used other air pollution exposures, for example, particulate matter less than 2.5 μm ($PM_{2.5}$) and sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) to replace O_3. We did not put two pollutants or three pollutants in the same model, because they had a strong co-linearity, which may influence the model fit and interpretation of the results. We also used the relative humidity data from Australia Bureau of Meteorology to replace that from the Weather Underground. In addition, we included time and time squared into the models to control for the learning effects, because it is assumed that the recorded lung function for the first few days could be inaccurate because the children were still learning the proper use of the peak flow meters (Guyatt et al., 1985; Penttinen et al., 2001).