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Acute effects of air pollution on influenza-like illness in Nanjing, China: A population-based study

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HIGHLIGHTS

- A study in China to quantify effects of air pollution on influenza-like illness.
- Wavelet coherence analysis and generalized additive models were used.
- The strongest effects were observed for the same day exposure.
- The effect estimated for people aged 15–24 was most significant.

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ABSTRACT

Influenza-like illness causes substantial morbidity and mortality. Air pollution has already been linked to many health issues, and increasing evidence in recent years supports an association between air pollution and respiratory infections. It is a pioneer study in China to quantify the effects of air pollution on influenza-like illness. This study used wavelet coherence analysis and generalized additive models to explore the potential association between air pollution (including particulate matter with aerodynamic diameter ≦2.5 μm ($PM_{2.5}$), particulate matter with aerodynamic diameter ≦10 μm (PM_{10}) and nitrogen dioxide (NO_2)) and influenza-like illness (a total of 59860 cases) in Nanjing, China from January 1, 2013 to December 31, 2013. The average concentrations of $PM_{2.5}$, PM_{10} and NO_2 were 77.37 μg/m^3, 135.20 μg/m^3 and 55.80 μg/m^3. An interquartile range increase in $PM_{2.5}$ concentration was associated with a 2.99% (95% confidence interval (CI): 1.64%, 4.36%) increase in daily influenza-like cases on the same day, while the corresponding increase in NO_2 was associated with a 3.77% (95% CI: 2.01%, 5.56%) increase in daily cases. People aged 0–4 were proved to be significantly susceptible to PM_{10} and NO_2; 5–14 ages were significantly susceptible to $PM_{2.5}$ and PM_{10}; and 15–24 ages were significantly susceptible to all the analyzed air pollutants. Air pollution effects tended to be null or negative for patients aged over 25, which might be due to the small number of influenza-like cases in this age group. This study can be useful for understanding the adverse health effects of air pollution and the cause of influenza-like illness.

1. Introduction

Influenza-like illness, a common respiratory syndrome, poses a great threat to worldwide economy as well as public health, which leads to substantial morbidity and mortality each year (Laguna-Torres et al., 2009; Silva et al., 2014; Ng and Gordon, 2015). A wide range of respiratory viruses may cause influenza-like illness, such as influenza viruses, respiratory syncytial viruses and para-influenza viruses (Coiras et al., 2003; Druce et al., 2005; Peng et al., 2012). Numerous studies have confirmed that short- and long-term exposures to ambient air pollutants are associated with a wide range of adverse health outcomes, such as higher mortality rates, greater hospital admissions and increased outpatient visits (Dockery et al., 1993; Bremner et al., 1999; Kan and Chen, 2003).

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The relationship between air pollution and respiratory infections has become an increased public health concern in recent years. Although air pollution has not been shown as the sole cause of respiratory infections, it has been reported that air pollutants such as nitrogen dioxide (NO_2), ozone (O_3), and particulate matter (PM), were correlated with increased morbidity of respiratory infections (Burnett et al., 2001; Hwang, 2002; Lin et al., 2005; Tolbert and Peel, 2005). However, the epidemiological studies for the association between air pollution and the incidence of influenza-like illness are relatively few and have not been performed in China before.

Nanjing, with an area of 6587 km^2 and a resident population of 8.18 million by the end of 2013 (Nanjing Bureau of Statistics (2014)), is the capital of Jiangsu Province, China (see Supplementary Information, Fig. S1). Located at the lower reaches of the Yangzi River, the city is recognized as a national transportation hub as well as the economic, financial, cultural, and educational center of eastern China. Nanjing is surrounded by mountains on three sides, which is not conducive to the dispersion of air pollutants. Due to the rapid economic development and topographical enclosure, the concentrations of air pollutants measured in Nanjing area are relatively higher than the national average. Data from years of influenza-like illness surveillance in Nanjing have demonstrated a typical pattern for southern China areas: a bimodal increase in summer and winter−spring (Shu et al., 2010).

This study provides data to characterize the effects of air pollutants on respiratory infections in Nanjing area. We assessed the acute effects of air pollutants on influenza-like illness. Results of this study will give a better understanding about the adverse health effects of air pollution and the cause of influenza-like illness. It can also help identify the significant lag time and susceptible age groups.

2. Materials and methods

2.1. Data

Data of daily influenza-like cases of all of the five national influenza sentinel hospitals in Nanjing between January 1, 2013 and December 31, 2013 were obtained from Jiangsu Provincial Center for Disease Control and Prevention. All the patients with diagnosis of influenza-like illness (defined as the one with body temperature $\geq$38 °C and cough or sore throat) from the outpatient and emergency departments of Jiangsu Provincial People's Hospital, Nanjing First Hospital, Nanjing Children's Hospital, Nanjing Gulou Hospital and the Second Affiliated Hospital of Nanjing Medical University were included, and then compiled as different age groups: 0−4, 5−14, 15−24, 25−59 and over 60 years old. Locations of the five hospitals were shown in Supplementary Information, Fig. S2.

Daily mean temperature and relative humidity data in Nanjing for the same period were obtained from Nanjing Meteorological Bureau to control for the potential confounding effects of weather.

Daily air pollution data, including particulate matter with aerodynamic diameter $\leqq$2.5 μm ($PM_{2.5}$), particulate matter with aerodynamic diameter $\leqq$10 μm (PM_{10}) and NO_2 were downloaded from China Environmental Monitoring Centre (CEMC) (http://113.108.142.147:20035/emcpublish/). The calculation of daily average pollutant concentrations was based on data from nine fixed-site monitoring stations covering the whole geographical area of Nanjing (see Supplementary Information, Fig. S3). We extracted the 24-h average concentrations for $PM_{2.5}$, PM_{10} and NO_2. For the calculation of 24-h average concentration of a particular monitoring station, at least 75% of the 1-h values on that particular day have to be available. The missing values in the time-series were replaced by linear interpolation.

2.2. Statistical methods

Descriptive statistical analyses were performed to characterize the distributions of meteorological data, air pollutants and influenza-like cases. The Pearson correlation coefficients between air pollutants and weather variables were also calculated.

We used wavelet coherence approach to explore the possible association between air pollution and influenza-like illness. Wavelet coherence is a useful tool to measure how coherent the cross wavelet transforms of two time series are in time frequency space. The definition of squared wavelet coherence closely resembles that of a traditional correlation coefficient, and it is useful to think of the squared wavelet coherence as a localized correlation coefficient in time frequency space. High coherence suggests the capability of one time series to predict the other one (Grinsted et al., 2004). In wavelet coherence analysis, wavelet transforms have to be normalized to ensure that they are comparable to each other (Torrence and Compo, 1998). The statistical significance level of the wavelet coherence is estimated using Monte Carlo methods. The cross wavelet angle is used to assess the phase difference between components of the two time series. We are able to quantify the lag period between two time series by calculating the phase difference (Grinsted et al., 2004). Wavelet coherence analysis were conducted in Matlab using a package downloaded from: http://noc.ac.uk/using-science/crosswavelet-wavelet-coherence. The detailed theory has been described by Grinsted et al. (Grinsted et al., 2004).

Daily influenza-like cases are countable events that typically follow a Poisson distribution; and the confounding variables often exhibit a nonlinear relationship with health outcomes. Therefore, Poisson regression in a generalized additive model was used to investigate the association between influenza-like illness and air pollutants for the total population and different age groups.

The daily number of influenza-like cases was the dependent variable, and the daily mean levels of each air pollutant were the independent variables. Cubic regression spline functions of nonlinear terms, including time trend, mean temperature and relative humidity were incorporated into the generalized additive models. Day of the week (DOW) was also included as dummy variable to control for the short-term trend. It is known that exposure to air pollutants may cause harm to human health with some lags (Kan et al., 2007). To determine the possible lag effect between the increase in air pollutant concentration and the onset of influenza-like illness, the models with different lag structures, including both single-day lag (lag0-lag5, e.g., lag0 corresponds to the current day concentration, lag1 corresponds to the concentration of the day before hospital visit) and multi-day lag (lag01-lag05, e.g., lag01 corresponds to the two-day moving averages of current and previous day concentrations of air pollutants) were fitted. Current day temperature and relative humidity (lag = 0) were used in models with different lag structures of air pollutants. Two-pollutant models were also fitted to assess the stability of individual effect.

The model used is shown as follows:

$$\log[E(y_t)] = \beta X_i + as.factor(DOW) + s_{(time,df)} + s_{(temperature,df)} + s_{(humidity,df)} + intercept \quad (1)$$

Where

$E(y_t)$ is the expected value of the daily count of influenza-like cases;
β is the regression coefficient for each air pollutant;
X_i are the air pollutants such as $PM_{2.5}$, PM_{10} and NO_2;