Ambient air quality and the effects of air pollutants on otolaryngology in Beijing

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Abstract. To investigate temporal patterns, pollution concentrations and the health effects of air pollutants in Beijing we carried out time-series analyses on daily concentrations of ambient air pollutants and daily numbers of outpatient visits for otolaryngology over two years (2011–2012) to identify possible health effects of air pollutants. The results showed that PM_{10} was the major air pollutant in Beijing and that air quality was slightly better in 2012 than in 2011. Seasonal differences were apparent for SO_2 and NO_2. Both the background and urban areas of Beijing experienced particulate matter pollution in 2011. In addition to local air pollution, Beijing was also affected by pollutants transported from other regions, especially during heavy air pollution episodes. PM_{10}, NO_2 and SO_2 concentrations showed positive associations with numbers of outpatient visits for otolaryngology during winter. NO_2 and SO_2 also had adverse ear, nose and throat health effects outside of winter. The ear, nose and throat health risks caused by air pollutants were higher during the winter than during the summer. NO_2 had stronger influence on increased the likelihood of outpatient visits than SO_2. The findings provide additional information about air quality and health effects of air pollution in Beijing.

Keywords: Air pollutant, temporal pattern, pollutant concentration, health effect, Beijing

1 Introduction

Research on air pollution is attracting significant interest worldwide (Lave and Seskin 2013; Leung et al. 2012). Air pollution has been found to have serious effects on public health in China (Chen et al. 2013). In a move to improve air quality, protect the climate and reduce the health burden of air pollution, the Chinese Government issued a new National Ambient Air Quality Standard (GB3095-2012) in 2012 to replace an older one (GB3095-1996). The new air quality standard will be carried out step-by-step until 31 December 2015. Air quality assessments based on GB3095-2012 are urgently needed for further implementation of the standard.

Much research has shown that air pollution exposure increases the risk of mortality (Welty and Zeger 2005; Breitner et al. 2011), morbidity (Schleicher et al. 2011; Gold and Samet 2013), hospital admissions (Lall et al. 2011), outpatient visits (Guo et al. 2010), and diminished life expectancy and longevity (Wang et al. 2014). Early-life exposure to ambient air pollution may increase the risk of upper and lower respiratory tract infections in infants (Aguilera et al. 2013). Modest, but consistent, associations were found between some measures of air pollution and otitis media in a large birth cohort exposed to relatively low levels of ambient air pollution (MacIntyre et al. 2011). Consistent evidence was also found for an association between air pollution and pneumonia during early childhood; as well as some evidence for an association with otitis media (MacIntyre et al. 2014). Elevated levels of air pollutants increased respiratory tract complaints in children (Altuğ et al. 2014). Air pollution exposure has also been associated with olfactory dysfunction and olfactory bulbs pathology (Calderón-Garcidueñas et al. 2010). Higher particulate matter (PM_{10}), SO_2 and NO_2 concentrations were associated with increased likelihood of hospital visits for allergic rhinitis in Beijing (F. Zhang et al. 2013; F. Y. Zhang et al. 2011). Better air quality was significantly associated with low prevalence of pediatric frequent ear infections and improvements in air quality have been implicated in decreased rates of pediatric ear infections over time (Bhattacharyya and Shapiro 2010). Though these studies indicated that air pollutants influence an individual's ear, nose and throat health, systematic studies focused on air quality and the health of adults' ears, noses and throats (ENTs) are rare.

Beijing is the capital city of China and local air quality has attracted much concern (M. Zhang et al. 2007; Breitner et al. 2011). We carried out time-series analyses on daily concentrations of ambient air pollutants and daily numbers of outpatient consultations for otolaryngology in Beijing from 1 January 2011 to 31 December 2012. A non-parametric generalized additive model (GAM) was used to analyze exposure-response relationships between three air pollutants (PM_{10}, SO_2 and NO_2) and daily outpatient visits for otolaryngology. The objective of this study was to characterize temporal variations of ambient air pollutants, evaluate the ambient air quality of Beijing and identify possible health effects of air pollutants on individuals' ENTs.

2 Data and Methodology

2.1 Air pollutant monitoring and meteorological data

Daily PM_{10}, SO_2 and NO_2 concentrations were obtained from the Beijing Municipal Environmental Protection Monitoring Center. The data was available as averages derived from the monitoring data of 11 state-controlled monitoring stations distributed across Beijing.

To quantify the air quality and air pollution concentrations in Beijing, daily monitoring data from one of the stations mentioned above (Dongsi) and one background monitoring station (Dingling) were obtained. The Dongsi air quality monitoring station is located in the Dongcheng District and is an urban environmental assessment site which is mainly used to assess regional air quality and its variations. Dingling is the urban background site for Beijing and is used to for quantifying pollution concentrations that are not influenced by the urban environment.

Daily temperatures, relative humidities and other meteorological data for Beijing were obtained from the Beijing Meteorological Bureau.

2.2 Outpatient visits for otolaryngology

The numbers of outpatient consultations for otolaryngology from 1 January 2011 to 31 December 2012 were obtained from the Department of Otolaryngology-Head and Neck Surgery, Beijing Hospital, Ministry of Public Health. Beijing Hospital is a leading Class-Three, Grade A-level hospital located in the Dong Cheng District that serves a large catchment within central Beijing. The hospital is open to the general public, providing large-scale, comprehensive, integrated health services, including medical treatment, teaching and education, scientific research and disease prevention.

Only one visit per individual patient per day was included in the tabulation of daily visit counts. Subsequent follow-up visits that occurred within 30 days of the initial consultation were also not included in the count.

The Ethics Review Board of Beijing Hospital, Ministry of Public Health, and the Ethics Review Board of the Institute of Geographic Sciences and Natural Resources Research, CAS approved this study. Our study did not involve any patient's personal information.

2.3 Data analysis

Spatio-temporal patterns of air pollutants

Statistical analyses were used to study the temporal patterns of air pollutants in Beijing. Daily concentrations of air pollutants from 1 January 2011 to 31 December 2012 at the two monitoring stations discussed in the air pollutant monitoring and meteorological data section were evaluated.

Health effect of air pollutants on individual's ENT

Consistent with other time-series studies (Bhaskaran et al. 2013; F. Y. Zhang et al. 2011), we used the generalized additive model (GAM) to analyze outpatient visits, air pollutant concentrations and covariates (meteorological factors, time trend, day of the week). Because the daily number of outpatient visits for otolaryngology were small and typically followed a Poisson distribution (Dominici et al. 2002; Caillaud et al. 2014), the core analysis involved GAM using log-link and Poisson uncertainty that accounted for smooth fluctuations in the daily numbers of consultations for otolaryngology.

$$\log[E(Y_t)] = \alpha + \sum_{i=1}^{q} \beta_i (X_i) + \sum_{j=1}^{p} f_j (Z_j, df) + W_t(week) \quad (1)$$

Here *E(Yt)* represents the expected numbers of outpatient visit at day t; β represents the log-relative rate of outpatient visit associated with an unit increase of air pollutants; *Xi* indicates the concentrations of pollutants at day t; *Wt(week)* is the dummy variable for day of the week. $\sum_{j=1}^{p} f_j (Z_j, df)$ is the non-parametric spline function of calendar time, temperature and humidity. A detailed introduction to the GAM has been described in previous studies (S. N. Wood and Augustin 2002; S. Wood 2006).

We performed sensitivity analyses using Welty's method (Welty and Zeger 2005). We initialized the df as 7 df/year for time, 3 df for temperature and barometric pressure, 5 df for humidity. We fitted both single-pollutants models and multi-pollutant models (models with a different combination of two or three pollutants per model) to assess the stability of pollutants' effect.

We examined the effect of air pollutants with different lag (L) structures consisting of single-day lag (from L0–L3) and multi-day lag (L01–L03), where a lag of 0 days (L0) corresponded to pollution on the day and a lag of one day (L1) referred to pollution on the previous day. In multi-day lag models, L03 corresponded to four-day moving averages of pollutant concentrations for the current and previous three days (Lall et al. 2011). The meteorological factors used in the lag models were those from the present day.

Seasonality was differentiated on the basis of heating/non-heating periods over the winter (heating period) in Beijing (from October to the following March) and the summer (non-heating period; from April to September). Because major parts of Beijing are still provided with central heating from coal burning power plants, air pollution loads during the heating season increased significantly. Our seasonal analysis followed the method introduced by Peng et al. (Peng et al. 2005).

All statistical analyses were conducted in R 3.1.0 using the MGCV package. The results obtained were expressed as the relative risk (RR) percentage change in the number of consultations for otolaryngology per 10 μg/m^3 increase in air pollutant concentrations. The calculation of RR is presented in Equation 2:

$$RR = e^{\beta x \Delta C}, \quad (2)$$

where ΔC is the change in air pollutant concentration. In this study we used 10 μg/m^3 for comparison with similar studies conducted in other locations across China

3 Results

3.1 Overview and statistical results

Table 1 provides a statistical summary of the air pollutants studied, meteorological variables and outpatient numbers on an annual and seasonal basis.

Table 1 Statistical characteristic of air pollutants, meteorological factors and outpatient numbers

Variables		Average			SD	percentage				
		All year	Winter	Summer		min	25%	median	75%	max
Air Pollutants $\mu g/m^3$	SO_2	28.4	41.9	15	27	5	9.1	18	38	166.8
	NO_2	53.9	61.8	46	22.5	14	38	49.2	66.1	160.2
	PM_{10}	110.6	109.5	111.7	74.9	7	55	95	150	573
Temperature ºC	ave	13.2	3.3	23	11.5	-9.5	1.7	15.5	23.8	31.3
	max	18.2	8.3	28.1	11.8	-5.8	6.9	20.9	28.8	38
	min	8.4	-1.2	18	11.4	-13.7	-2.3	10.2	19	26.7
Pressure hPa	ave	1012.6	1021.1	1004.2	10.5	990.4	1003.5	1012.6	1021.4	1037.3
	max	1015.2	1024	1006.5	10.8	992.6	1005.5	1015.5	1024.1	1040.3
	min	1009.6	1017.8	1001.3	10.4	987.7	1001	1009.1	1017.8	1034.5
Humidity %	ave	50.4	44.8	55.9	20.9	9	31	52	67	97
	min	30.1	25.9	34.2	18.2	5	15	25	42	85
Wind speed m/s	ave	2.2	2.2	2.3	0.9	0.6	1.6	2.1	2.6	5.8
	max	4.9	4.8	5	1.8	1.7	3.5	4.6	6.1	12
Daily numbers of outpatient		198	192	205	39	87	173	199	224	314

During the study period, the annual average temperature and humidity were 13.2 °C and 50.4 %, respectively. Daily temperatures ranged from −9.5–31.3 °C and daily relative humidities ranged from 9–97 %, reflecting the sub-humid, warm temperate, continental monsoon climate of Beijing.

Figure 1 presents the temporal variability of the three air pollutants studied and the daily number of outpatient visits for otolaryngology. Over the two years, average daily concentrations of PM_{10}, SO_2 and NO_2 were 110.6$\mu g/m^3$, 28.4$\mu g/m^3$ and 53.9$\mu g/m^3$, respectively. Concentrations of SO_2 and NO_2 showed clear seasonal differences, with higher concentrations occurring during the winter. Though PM_{10} concentrations had some peak values, there was no seasonality apparent.

A total of 145 085 outpatients attended the Department of Otolaryngology-Head and Neck Surgery, Beijing Hospital. Daily patient numbers ranged from 87–314. Average daily outpatient numbers were higher during the summer than during the winter and the highest number of outpatient visits occurred in April and May.

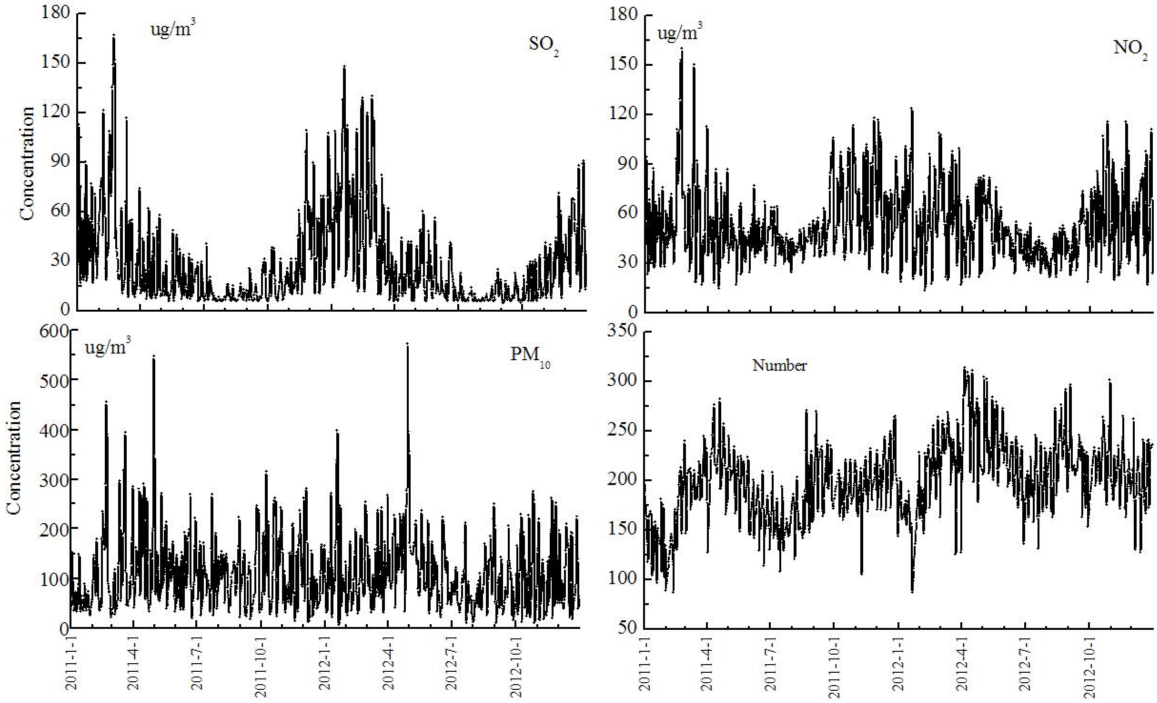

Figure 1. Daily concentrations of air pollutants and numbers of outpatient visits for otolaryngology

Pearson correlation coefficients among different air pollutants and meteorological factors are presented in Table 2. Significant correlations were identified among the three air pollutants, probably because emissions from domestic heating are a common source.

Table 2 Correlation coefficients between air pollutants and meteorological factors

	SO_2	NO_2	PM_{10}	Temperature	Pressure	Humidity	Wind speed
SO_2	1						
NO_2	0.698*	1					
PM_{10}	0.460*	0.662*	1				
Temperature	-0.587*	-0.259*	0.054	1			
Pressure	0.414*	0.182*	-0.144*	-0.888*	1		
Humidity	-0.050	0.251*	0.237*	0.376	-0.369*	1	
Wind speed	-0.240	-0.418*	-0.157*	-0.010	-0.040	-0.449*	1

*Correlation is significant at the 0.01 level (2-tailed).

3.2 Assessments of air quality

In this study we assessed daily ambient air quality based on GB3095-2012 and the results were expressed as the air quality class. The annual air quality was worse than Class 2 in 2011 and the annual average concentrations of PM_{10}, SO_2 and NO_2 were 113, 28 and 56μg/m^3, respectively. There were 101 days when air pollutant concentrations exceeded the Class 2 limits. The annual average concentrations of PM_{10}, SO_2 and NO_2 were 109, 28 and 52μg/m^3, respectively, and the annual air quality was worse than Class 2 in 2012. There were 91 days when air pollutant concentrations exceeded the GB3095-2012 standard limits. By any measure, air quality showed some improves from 2011 to 2012 in Beijing.

Over the 2 years studied, PM_{10} was the major air pollutant in Beijing. Overall, 181 days featured heavy PM_{10} pollution where daily PM_{10} concentrations exceeded 150μg/m^3. PM_{10} concentration ranges were wide and the largest concentrations were higher than the recommended limits in this study. The maximum daily PM_{10} concentration (573μg/m^3) was three times greater than the Class 2 limit (150μg/m^3). SO_2 and NO_2 concentrations were also high at times and exceeded the Class 2 limits occasionally.

Figure 2 presents time-series analyses of air pollutant concentrations at Dingling and Dongsi in 2011.

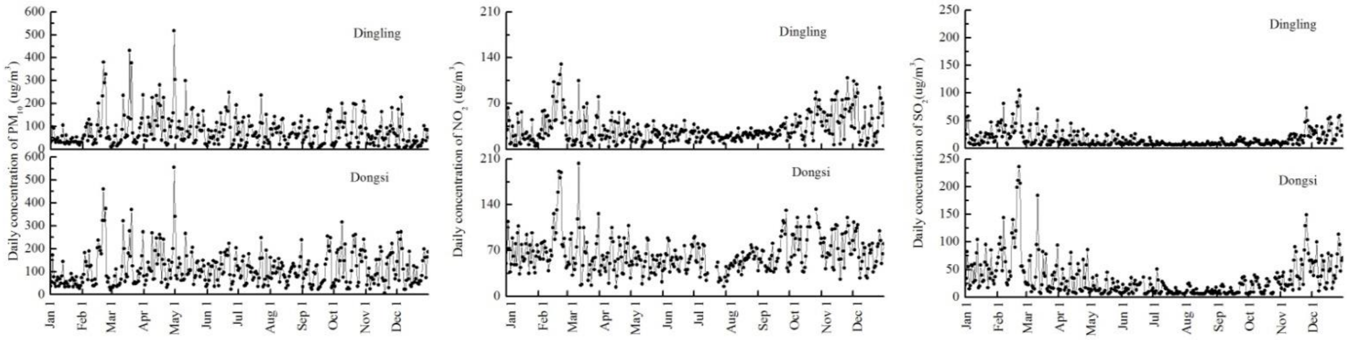

Figure2. Daily concentrations of SO_2, NO_2 and PM_{10} at Dingling and Dongsi in 2011

Daily air pollutant concentrations at Dongsi were higher than at Dingling, indicating that urban air pollution sources were present in the Dongsi area. According to GB3095-2012, 25.2 % days in 2011 had heavy air pollution at Dongsi, and Dingling also experienced some heavy air pollution days, suggesting that pollution from outside the urban area was being transported into the city. The annual average NO_2 and SO_2 concentrations at Dingling met Class 2 Standards (60μg/m^3 for SO_2 and 40μg/m^3 for NO_2). The annual average SO_2 concentration at Dongsi met the Class 2 Standard, but the annual average NO_2 concentration failed to meet the Class 2 Standard. Annual average PM_{10} concentrations at Dingling and Dongsi failed to meet the Class 2 Standard. Statistical results and air quality classifications for the two sites are presented in Table 3.

Table 3 Statistical data and air quality classifications at the two monitoring stations in 2011

Pollutants	Dingling μg/m^3					Dongsi μg/m^3				
	Min	Max	Ave	> C1	> C2	Min	Max	Ave	> C1	> C2
SO_2	6	105	16.7	4.1%	0	6	236	33.7	20.9%	1.4%
NO_2	4	130	31.6	4.1%	0	14	203	65.2	24.9%	0
PM_{10}	3	518	80.7	59.7%	10.1%	6	555	112.3	78.4%	25.2%

Note: > C1, percentage of days worse than Class 1; > C2, percentage of days worse than Class2

3.3 Associations among air pollutants and individuals' ENTs issues

Table 4 presents the RRs (95 % confidence intervals (CI)) of outpatient visits for ENT issues with every 10 μg/m^3 increase in air pollutant concentrations.

To identify any possible time-delays of air pollutants on health effects in the clinical manifestation of symptoms, we analyzed the lag effects of air pollutants on daily numbers of outpatient visits. Changes in RRs for the numbers of outpatient visits for otolaryngology with a 10 μg/m^3 increase in pollutant concentrations for single-day measures (L0–L3) and moving average measures (L01–L03) are also provided in Table 4. While running the models we also considered lags of more than three days for each of the pollutants, but very few associations were identified and these results have been excluded from further analyses.

Over the whole study period, there was no obvious relationship between PM_{10} concentration changes and the number of outpatient visits. NO_2 and SO_2 concentration changes showed positive associations with increases in daily numbers of outpatient visits for otolaryngology. The largest relative risks were for elevated pollutant concentrations on day zero, and the relative risks of these two air pollutants decreased as lag days increased for the single lag day and moving average lag day models. Compared with SO_2, NO_2 had a stronger influence on the likelihood of outpatient visits for ENT issues.

Table 4 RRs for outpatient visits with every 10μg/m^3 increase in air pollutant concentrations

Lag day/Season	PM_{10}		NO_2		SO_2	
	RR	95% CI	RR	95% CI	RR	95% CI
L0	-0.082	-0.166~0.003	0.977	0.940~1.014	0.659	0.624~0.695
L1	-0.184	-0.368~0.001	0.334	0.303~0.365	0.100	0.069~0.132
L2	-0.135	-0.270~0.001	-0.088	-0.181~0.005	-0.154	-0.310~0.003
L3	-0.127	-0.257~0.003	-0.234	-0.471~0.002	-0.229	-0.459~0.002
L01	-0.201	-0.403~0.001	0.889	0.848~0.93	0.519	0.479~0.560
L02	-0.268	-0.538~0.001	0.637	0.592~0.681	0.317	0.272~0.361
L03	-0.333	-0.666~0.001	0.357	0.308~0.405	0.099	0.050~0.147
Summer	-0.167	-0.341~0.006	-0.649	-1.301~0.003	0.021	-0.073~0.114
Winter	0.035	0.022~0.049	1.325	1.280~1.370	0.113	0.073~0.152

Seasonal differences in RRs on individuals' ENTs are shown in Table 4. For each of the air pollutants the RRs during winter were higher than during summer. Though no obvious ENT effects of PM_{10} could be identified over the whole research period, a positive association between PM_{10} concentrations and daily numbers of outpatient visits for otolaryngology were observed during the winter. We did not consider the effects of all three pollutants together in one model.

4 Discussion

In this study we analyzed the temporal patterns of air pollutant concentrations in Beijing from 1 January 2011 to 31 December 2012. We also performed time-series analyses on daily concentrations of ambient air pollutants and daily numbers of outpatient visits for otolaryngology to identify possible ENT effects on exposed individuals. The results provide additional information about air quality and the health effects of air pollution in Beijing.

Over the 2 years studied, daily PM_{10} concentrations ranged from 7–573μg/m^3, with an average concentration of 110.6μg/m^3. Daily NO_2 concentrations ranged from 14–160.2μg/m^3, with an average concentration of 53.9μg/m^3. SO_2 had minimum, maximum and average daily concentrations of 5μg/m^3, 166.8μg/m^3 and 28.4μg/m^3, respectively. Daily SO_2 and NO_2 concentrations had clear seasonality, with peak concentrations occurring during the winter. Daily patterns for the concentrations of SO_2 and NO_2 in this study were consistent with previous studies (F. Zhang et al. 2011; J. Zhang et al. 2011). The pollutant concentrations were typically higher during the winter from November to the following March (J. Zhang et al. 2011). Daily PM_{10} concentrations did not show much seasonal variation. This could be because the pollution sources for PM_{10} were varied and included traffic exhaust and coal-related pollution that have important impacts on air quality (J. Zhang et al. 2011). The average concentrations were higher than the median concentrations for the air pollutants studied, indicating that extremely high pollution episodes were driving the average concentrations. Significant correlations among the three air pollutants indicate emissions from domestic heating are a common source.

Compared with 2011, annual air pollutant concentrations and number of pollution days decreased slightly in 2012, indicating that ambient air quality in Beijing had improved slightly. According to GB3095-2012, PM_{10} was the major air pollutant in Beijing during the study period and 25% of days featured heavy PM_{10} pollution where daily PM_{10} concentrations exceeded 150μg/m^3.

In 2011, the annual average PM_{10} concentration was 80.7μg/m^3 at Dingling and 112.3μg/m^3 at Dongsi. PM_{10} concentrations at these two sites failed to meet the Class 2 Standard. In 2011, 25.2% of days were classified as heavy pollution days and daily air pollutant concentrations at Dongsi were higher than Dingling, which indicated extra urban air pollution sources existed at Dongsi. There were also some heavy air pollution days at the background site, which indicated that regional sources were influencing air quality in Beijing at these times.

Daily numbers of outpatient visits for otolaryngology ranged from 87–314 at Beijing Hospital, with an average of 198 per day. The average number of outpatient visits was higher during the summer than during the winter.

Associations between atmospheric pollutants and otitis media has been well documented and statistically significant associations between improvements in air quality and reductions in the frequency of ear infection prevalence has been reported (Bhattacharyya and Shapiro 2010). Exposure to ambient air pollution also increases the risk of upper and lower respiratory tract infections (Aguilera et al. 2013; Altuğ et al. 2014), and increases olfactory dysfunction and olfactory bulb pathology (Calderón-Garcidueñas et al. 2010).

In our study we combined ear, nose and throat issues together and found positive associations between air pollutant concentrations (NO_2 and SO_2) and daily numbers of outpatient visits for otolaryngology, which is consistent with previous studies (Aguilera et al. 2013; Altuğ et al. 2014; Bhattacharyya and Shapiro 2010). The largest relative risks were found for day zero and the relative risks posed by these two air pollutants decreased by lag day when concentrations were considered for single lag day and moving average lag day analyses. Compared to SO_2, NO_2 had a stronger influence on increased likelihood of outpatient visits. There was no obvious relationship between PM_{10} concentration changes and number of outpatient visits. RRs during winter were higher than those during the summer for the three air pollutants. A positive association between PM_{10} concentrations and daily numbers of outpatient visits for otolaryngology was identified only during winter. Pearson correlation coefficients between air pollutants and patient numbers also indicated that the numbers of outpatient visits for otolaryngology were significantly correlated with the three air pollutants during winter, indicating that the air pollutants had short-term effects on individuals' ENTs that exacerbated ENT symptoms and increased hospital visits.

Though the average daily numbers of outpatient visits for otolaryngology were higher during summer, the daily average concentrations of SO_2 and NO_2 were higher during winter. RRs during winter were higher than during summer for the three air pollutants studied. One possible explanation for this result is that besides the air pollutants studied, other factors, like pollen concentrations, could influence the health of ENTs during the summer (Caillaud et al. 2014). Air pollutants can trigger the release of allergen-containing granules from grass pollen and increase the bioavailability of airborne pollen allergens (F. Y. Zhang et al. 2011). Combinations of air pollutants and pollen can accelerate the occurrence of allergic rhinitis and increased pollen levels were significantly associated with hospital outpatient visits for allergic rhinitis (F. Zhang et al. 2012; F. Y. Zhang et al. 2011). Daily numbers of outpatient visits for allergic rhinitis showed a similar time-series to that of pollen levels during the summer (F. Zhang et al. 2012).

Our study also had some limitations. We were only able to obtain data from one major hospital in Beijing. Because the catchment boundaries of hospitals in central Beijing are not clearly defined, it was not possible to establish population characteristics within the catchment area. Because $PM_{2.5}$ pollution data were not yet available we had to limit our analysis to PM_{10}. Average values derived from the monitoring data of 11 state-controlled monitoring stations distributed across Beijing were used as exposure concentrations, but a more accurate exposure assessment and proper catchment boundaries for the hospital are important factors that should be considered further. Further investigations on the relationships among meteorological factors, air pollutants, time-series activity, personal pollutant exposure, socioeconomics and human health at a city-level are required.

5 Conclusion

PM_{10} was the major air pollutant in Beijing and 25% of days had heavy air pollution over the 2 years studied (2011 and 2012). Beijing's air quality improved slightly in 2012. Seasonal differences were identified for SO_2 and NO_2 concentrations, and no seasonality was apparent for PM_{10}. During air pollution episodes, concentrations of all three air pollutants studied were high. Both the background and urban areas of Beijing had high particulate matter pollution in 2011 and the city suffered from regional pollution in addition to local emissions on some occasions. PM_{10}, NO_2 and SO_2 showed positive associations with daily numbers of outpatient visits for otolaryngology during winter. NO_2 and SO_2 also had effects on individuals' ENTs during summer. The health risks on an individual's ENT caused by air pollutants were higher during the winter than during the summer, and NO_2 had a stronger influence on the increased likelihood of outpatient visits than SO_2. Our study provides evidence to health services policy makers for the need to be more proactive and to insure that sufficient resources are available to provide real-time public health alerts based on air quality so that those affected can be advised.

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Conflicts of interest

The authors declare that they have no competing interests.

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