Associations between daily outpatient visits for respiratory diseases and ambient fine particulate matter and ozone levels in Shanghai, China

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Abstract

Air pollution in China has been very serious during the recent decades. However, few studies have investigated the effects of short-term exposure to PM2.5 and O3 on daily outpatient visits for respiratory diseases. We examined the effects of PM2.5 and O3 on the daily outpatient visits for respiratory diseases, explored the sensitivities of different population subgroups and analyzed the relative risk (RR) of PM2.5 and O3 in different seasons in Shanghai during 2013–2016. The generalized linear model (GLM) was applied to analyze the exposure-response relationship between air pollutants (daily average PM2.5 and daily maximum 8-h average O3), and daily outpatient visits due to respiratory diseases. The sensitivities of males and females at the ages of 15–60 yr-old and 60+ yr-old to the pollutants were also studied for the whole year and for the cold and warm months, respectively. Finally, the results of the single-day lagged model were compared with that of the moving average lag model. At lag 0 day, the RR of respiratory outpatients increased by 0.37% with a 10 μg/m³ increase in PM2.5. Exposure to PM2.5 (RR, 1.0047, 95% CI, 1.0032–1.0062) was more sensitive for females than for males (RR, 1.0025, 95% CI, 1.0008–1.0041), and was more sensitive for the 15–60 yr-old than that in the 60+ yr-old group (RR, 1.0041, 95% CI, 1.0027–1.0055) than the 60+ yr-old group (RR, 1.0031, 95% CI, 1.0014–1.0049). O3 was not significantly associated with respiratory outpatient visits during the warm periods, but was negatively associated during the cold periods. PM2.5 was more significantly in the cold periods than that in the warm periods. The results indicated that control of PM2.5, compared to O3, in the cold periods would be more beneficial to the respiratory health in Shanghai. In addition, the single-day lagged model underestimated the relationship between PM2.5 and O3 and outpatient visits for respiratory diseases compared to the moving average lag model.

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1. Introduction

Air pollutants, for instance particulate matter (PM) and ozone (O3), can lead to various health problems (Costa et al., 2014; Lichtman et al., 2016; Mimura et al., 2014; Tam et al., 2015; Tsangari et al., 2016), among which respiratory diseases are very common (Lim et al., 2012; Tam et al., 2014). Studies on the association between air pollutants and respiratory health effects have been performed, but mainly focused on some developed countries (Pope, 1989; Waldott, 1972; Wise, 2016). Many developing countries, such as India and China, are suffering from serious air pollution problems (Guo et al., 2017; Hu et al., 2014; Verma et al., 2003; Wang et al., 2014). However, few health effects studies have been conducted and most of them were based on the exposure-response correlations found in developed countries (Gurjar et al., 2010). Due to the severity of air pollution, high population density, and lack of...
local exposure-response correlations in developing countries, the assessment has large uncertainties. Recent studies (Mehta et al., 2013; Phung et al., 2016) in Vietnam found that the increased concentration of air pollutants (PM_{10}, NO_{2}, SO_{2}) can lead to elevated risk of hospital admission among young children and adult residents. Such studies should be conducted to assess the health risks of air pollutants in other countries/regions with severe air pollution. Understanding the relationship between air pollutants and human health helps identify the pollutants and sources that have the largest negative impacts on human health, provides valuable information for clinical and public health interventions, and is the basis for developing effective policies and regulations to improve air quality and protect human health. It has been well recognized that the relationship between air pollutants and human health can vary in different regions, due to differences in the degree and nature of air pollution, as well as differences in population (Burnett et al., 2000; Hu et al., 2015; Shang et al., 2013). Therefore, directly applying the relationship established mostly in developed countries to Shanghai or other cities in China would lead to large bias and it is necessary to conduct studies with local data of air pollutants and health outcomes.

China is facing severe air pollution problems (Chan and Yao, 2008), especially in the more populous regions, for instance Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta and Sichuan Basin (Cheng et al., 2013; Tan et al., 2016; Tao et al., 2013, 2014a). The major air pollutants include PM_{2.5}, SO_{2}, NO_{2}, and O_{3}. Some studies in China (Cui et al., 2016; Kan and Chen, 2003; Tao et al., 2014b) have demonstrated that air pollutants caused respiratory and cardiovascular disease contribute to the increasing mortality and morbidity in China (Hu et al., 2017).

Shanghai is the most populous megacity with a population of 24 million in 2015 in China. It is also one of the heaviest polluted cities in China (Li et al., 2009). During the study period, there are 256 days exceeding theCAAQS Grade II standard for PM_{2.5}, 115 days for O_{3}. Several studies have investigated the relationships between air pollution and death rate and morbidity in Shanghai (Cai et al., 2014, 2015; Cao et al., 2009; Chen et al., 2010; Hua et al., 2014; Huang et al., 2009; Kan and Chen, 2003; Kan et al., 2007; Zhao et al., 2013). For example, Cai et al. (2014) found that air pollution was an important contributor to asthma development and exacerbation. Cao et al. (2009) found air pollution had a significant effect on increased risk of hospital outpatient and emergency room visits, and a 10\mu g/m^3 increase in concentrations of PM_{10}, NO_{2}, and SO_{2} corresponded to 0.11%, 0.34%, and 0.55% increase of outpatient visits and 0.01%, 0.17%, and 0.08% increase of emergency room visits, respectively. Chen et al. (2010) found outdoor air pollution also had an effect on increased risk of total and cardiovascular hospital admission in Shanghai. Hua et al. (2014) found the PM_{2.5} and the BC had a significant influence on childhood asthma admissions using a single-pollution model. Kan and Chen (2003) found that a 10\mu g/m^3 increase over a 48-h moving average concentrations of PM_{10}, SO_{2} and NO_{2} corresponded to 1.003 (95%CI 1.001–1.005), 1.016 (95%CI 1.011–1.021), and 1.020 (95%CI 1.012–1.027) RR of non-accident mortality, respectively.

Previous studies have discussed the effects of air pollutants in China, mostly focusing on PM_{10}, NO_{2}, and SO_{2}. Recent studies have suggested that the major pollutants in urban cities of China are PM_{2.5} and O_{3}. (Hu et al., 2015; Wang et al., 2014). Regulatory monitoring network of PM_{2.5} and O_{3}, as well as other four criteria pollutants (i.e., CO, SO_{2}, NO_{2}, and PM_{10}), has been gradually built up in major cities of China since 2013. In this study, we took advantages of four-year ambient measurements of PM_{2.5} and O_{3} in 2013–2016, and assessed the relationships between different air pollutants and outpatient visits of respiratory diseases in Shanghai.

2. Materials and methods

2.1. Data collection

Daily data of outpatient visits for respiratory diseases were collected from Shanghai Tenth People’s Hospital between March 1, 2013 and December 31, 2016. Respiratory diseases include upper respiratory and lower respiratory tract diseases. The upper respiratory tract diseases mainly include sinusitis, acute upper respiratory tract infection, and the lower respiratory tract diseases include pneumonia, asthma, bronchitis, and chronic obstructive pulmonary disease. These records contained the date of outpatient visit, age, gender, and discharge diagnosis from the 10th revision of the international classification of diseases (ICD-10). The records had 99.4% with age above 15 years, therefore, the outpatient visits were classified into two age groups: 15–60 yr-old age group and 60+ yr-old age group.

Four criteria air pollutants data in the same period were collected from the website published by the National Environmental Monitoring Center of China (http://eansi.aemet.es). SO_{2}, NO_{2}, PM_{2.5}, and O_{3} with hourly concentrations in Shanghai were obtained. SO_{2} and NO_{2} were used to test the stability of the model. In a previous study, the measurement method for each pollutant, and the quality control on the data set were described (Wang et al., 2014). Hourly concentrations were then averaged to 24-h averaged concentrations for PM_{2.5}, SO_{2}, NO_{2} and daily maximum 8-h mean ozone (8-h O_{3}).

To consider the effects of meteorological conditions, meteorological parameters were obtained from the National Climate Data Center (NCDC) (ftp://ftp.ncdc.noaa.gov/pub/data/noaa/). In this study, daily average temperature and daily average relative humidity were used.

All the data were classified into two time periods, i.e. the warm periods and the cold periods, according to the mean temperature of every month. Months with mean temperature above 20\degree C (the median value of temperature in Shanghai during 2013–2016) were classified into the warm periods and months with mean temperature below 20\degree C were classified into the cold periods. As a result, the warm periods were ranged from May to October, and the cold periods include the rest.

2.2. Statistical analysis

Daily outpatient visits for respiratory diseases and four criteria air pollutants concentrations (i.e., PM_{2.5}, O_{3}, NO_{2} and SO_{2}) were recorded by date information and could be analyzed with a time-series analysis. Because counts of daily outpatient visits for respiratory diseases data roughly subordinate to the Poisson distribution and the relationship between outpatient visits for respiratory diseases and explanatory variables are mostly nonlinear (Bhaskaran et al., 2013), a generalized linear model (GLM) was used to quantify the relationships, in which the main exposure variables were the daily averages of individual air pollutants. The GLM model combines the time-series regression analysis with the family of Poisson distribution and natural splines, and estimates both the short-term and the long-term relationship between the PM_{2.5}, O_{3} and the outpatient visits for respiratory diseases. We used a flexible spline function to control long-term trend and seasonal effects with 8 degrees of freedom (Qiu et al., 2013; Tian et al., 2014), and natural cubic spline functions with 4 degrees of freedom to adjust the influences of relative humidity (Phung et al., 2016), and with 3 degrees of freedom to adjust the effects of temperature. Sensitivity analyses were performed to examine the stability of the model by selecting different degrees of freedom, described in the Discussion section. The day of the week (DOW), flu days and public holidays
where, $Y_{ts}$ is the observed daily count of outpatient visits for respiratory diseases on day $t$ or $s$; $t$ and $s$ represent current and lagged days, respectively; $Z_{ts}$ is the daily level of air pollutant (daily average PM$_{2.5}$ and daily maximum 8-h average O$_3$) with a coefficient of $b_2$; DOW represents day of the week, with a coefficient of $b_3$; Holiday is a public holiday on day $t$ (0 for no holiday, and 1 for a holiday), with a coefficient of $b_4$; Flu indicates the days of flu, obtained from Wang et al. (2015), with a coefficient of $b_5$; ns represents the natural cubic splines; time indicates long-term trends and seasonality using the calendar time days; $T$ represents the daily mean temperature; and RH is the daily mean relative humidity.

Once $b_1$ is determined by Eq (1), the RR is calculated using Eq (2).

$$RR = e^{b_1+c}$$  \hspace{1cm} (2)

Where C is the increase concentration of a certain pollutant. The RR represents as the relative risk when PM$_{2.5}$, O$_3$ increases by C. The C value is 10 µg/m$^3$ for both PM$_{2.5}$ and O$_3$. All analyses were performed by using the ‘mgcv’ package in the statistical software R, version 3.2.4.

3. Results

Table 1 summarizes the descriptive statistics of the outpatient visits, meteorological conditions of temperature and relative humidity, and concentrations of four pollutants. There were a total of 247,514 patients visits for respiratory diseases (1402 days from March 1, 2013 to December 31, 2016, and no visits on holidays and weekends), with an average daily outpatient visits of 226 cases. Daily mean values of male and female patients were 108 (45.1%) and 118 (54.9%), respectively. The number of outpatient visits for respiratory diseases was higher in 15–60 yr-old age group (60.8%) than in 60+ yr-old age group (38.6%).

During the study period, the daily levels of PM$_{2.5}$, ranged from 5.599 to 473.238 µg/m$^3$ with an annual mean of 48.729 µg/m$^3$. The annual mean PM$_{2.5}$ was 39.2% higher than the Grade II Annual PM$_{2.5}$ Standard of CNAAGS (35 µg/m$^3$) but 4.8 times of the WHO guideline of annual average PM$_{2.5}$ (10 µg/m$^3$). The numbers of days exceeding the Grade II CNAAGS (75 µg/m$^3$) and the WHO guideline of 24-h PM$_{2.5}$ (25 µg/m$^3$) were 256 and 1060 days (18.3% and 75.6% of the observational days), respectively. The daily levels of gaseous pollutants ranged from 5.777 to 96.136 µg/m$^3$ (annual mean, 17.571 µg/m$^3$) for SO$_2$, 5.367–143.177 µg/m$^3$ (annual mean, 59.785 µg/m$^3$) for NO$_2$, and 11.475–256.534 µg/m$^3$ (annual mean 73.488 µg/m$^3$) for O$_3$. The numbers of days exceeding the Grade II CNAAGS of 24-h SO$_2$ (150 µg/m$^3$), NO$_2$ (80 µg/m$^3$) and 8 h average O$_3$ (160 µg/m$^3$) were 0, 97, and 115 days, respectively.

The average daily temperature ranged from −6.319−35.208 °C (annual average, 7.564 °C) during the study period. The average daily relative humidity ranged from 50 to 97.569% (annual average, 77.604%).

Fig. 1 displays the temporal variations of outpatient visits for respiratory diseases and air pollutants. Fig. 1(a) presents the time series of four pollutants of PM$_{2.5}$, NO$_2$, SO$_2$, and O$_3$. During the whole period, PM$_{2.5}$ had higher concentrations in the cold periods and lower concentrations in the warm periods. The concentrations of SO$_2$ and NO$_2$ were also higher in the cold periods. The concentrations of O$_3$ were higher in the warm periods. Fig. 1(b) presents the outpatient visits for respiratory of different groups. The outpatient visits for respiratory diseases decreased from Monday to Friday, and had two peaks in the spring and winter, respectively. The peak corresponded to the occurrence of the flu during this period and could be due to the flu. Meanwhile, the outpatients for respiratory diseases for 15-60 yr-old group increased substantially during the flu period, which might be related to the more outdoor activities in this sub-group than other groups.

Fig. 2 shows the associations between PM$_{2.5}$, O$_3$ and respiratory disease outpatients in different genders in a single-pollutant model. At lag 0 day, PM$_{2.5}$ had a significant impact on the risk of outpatients in different subgroups of respiratory diseases and the risk of the total outpatient visits for respiratory diseases increased by 0.37% (RR, 1.0037, 95% CI, 1.0026–1.0048) for a 10 µg/m$^3$ increase in PM$_{2.5}$. The effect of PM$_{2.5}$ on outpatient visits for respiratory diseases in females (RR, 1.0047, 95% CI, 1.0032–1.0062) was slightly higher than that of men (RR, 1.0025, 95% CI, 1.0008–1.0041).

Fig. 3 presents the associations between each air pollutant and respiratory disease outpatient visits in different age groups in a single-pollutant mode. For 60+ yr-old group, the effect of PM$_{2.5}$ on the risk of respiratory disease outpatients was significant, and the risk of the total outpatient visits for respiratory diseases increased by 0.31% (RR of PM$_{2.5}$, 1.0031, 95%CI, 1.0014–1.0049). The effect of PM$_{2.5}$ for the 15-60 yr-old group (RR 1.0041, 95%CI, 1.0027–1.0056) was higher than the effect for the 60+ yr-old group.

Table 1

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>First quartile</th>
<th>Media</th>
<th>Third quartile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1402</td>
<td>225.5</td>
<td>2.121</td>
<td>1</td>
<td>172</td>
<td>203</td>
<td>247</td>
</tr>
<tr>
<td>Female</td>
<td>1402</td>
<td>118</td>
<td>8.485</td>
<td>0</td>
<td>93</td>
<td>111</td>
<td>136</td>
</tr>
<tr>
<td>Male</td>
<td>1402</td>
<td>107.5</td>
<td>10.607</td>
<td>1</td>
<td>78</td>
<td>92</td>
<td>111</td>
</tr>
<tr>
<td>0-15 yr-old</td>
<td>1402</td>
<td>1</td>
<td>1.355</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>15-60 yr-old</td>
<td>1402</td>
<td>147</td>
<td>12.728</td>
<td>0</td>
<td>106</td>
<td>125</td>
<td>147</td>
</tr>
<tr>
<td>60+ yr-old</td>
<td>1402</td>
<td>78</td>
<td>11.314</td>
<td>0</td>
<td>61</td>
<td>79</td>
<td>99</td>
</tr>
<tr>
<td>Air pollutants concentrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$ (µg/m$^3$)</td>
<td>1402</td>
<td>48.729</td>
<td>1.302</td>
<td>5.599</td>
<td>27.585</td>
<td>43.488</td>
<td>66.795</td>
</tr>
<tr>
<td>SO$_2$ (µg/m$^3$)</td>
<td>1402</td>
<td>17.517</td>
<td>6.530</td>
<td>5.777</td>
<td>11.052</td>
<td>14.079</td>
<td>20.142</td>
</tr>
<tr>
<td>NO$_2$ (µg/m$^3$)</td>
<td>1402</td>
<td>59.785</td>
<td>41.353</td>
<td>5.367</td>
<td>29.234</td>
<td>39.660</td>
<td>54.600</td>
</tr>
<tr>
<td>8-h-O$_3$ (µg/m$^3$)</td>
<td>1402</td>
<td>73.488</td>
<td>56.575</td>
<td>11.475</td>
<td>71.540</td>
<td>96.979</td>
<td>125.426</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>1402</td>
<td>5.764</td>
<td>1.866</td>
<td>−6.319</td>
<td>10.694</td>
<td>19.028</td>
<td>24.514</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>1402</td>
<td>77.604</td>
<td>13.995</td>
<td>50.000</td>
<td>64.236</td>
<td>74.653</td>
<td>83.681</td>
</tr>
</tbody>
</table>
From Figs. 2 and 3, lag effects were observed for effects of air pollutants on the respiratory disease visits in Shanghai. Effects of air pollutants including PM$_{2.5}$ and O$_3$ on the total outpatient visits for respiratory diseases were significant at different lag days. For PM$_{2.5}$, single-day lag effects for all people were the most significant on lag5 (for 15-60 yr-old group: single-day lag effects were the most significant on lag5, for 60+ yr-old group: single-day lag effects were the most significant on lag0, for males: single-day lag effects were the most significant on lag5, for females: single-day lag effects were the most significant on lag5).

From the moving average lagged model, the RR values for O$_3$ were not significant for all people group. All RR values of PM$_{2.5}$ were significant, with the maximum RR on lag05. The RR values for PM$_{2.5}$ were the most significant on lag05 and kept a same increasing trend from lag01 to lag05 for the male and female groups and the 15-60 yr-old group and 60+ yr-old group.

### 4. Discussion

Table 2 presents the percent increase (95% confidence interval) in mortality for PM$_{2.5}$ and O$_3$ (increased by 10µg/m$^3$) in sensitivity analyses with different values of degrees of freedom for time trends and meteorological parameters. Changing the degrees of freedom for time trend from 7 to 9 and degrees of freedom for meteorological factors with a value of 3 and 4, respectively, the estimated effects of PM$_{2.5}$ (0.310%–0.372%) and O$_3$ (−0.220%–0.396%) were not substantially affected, indicating that results of this study are relatively stable.

In addition to the single pollutant models of PM$_{2.5}$ and O$_3$, we also examined the multiple pollutant models and investigated the effects of inclusion of other pollutants (O$_3$, NO$_2$ and SO$_2$ for PM$_{2.5}$, and PM$_{2.5}$, NO$_2$, and SO$_2$ for O$_3$). As shown in Fig. 4, the results of PM$_{2.5}$ model did not change much after adding O$_3$ (0.372% vs 0.375%) as a risk factor, which was in line with the previous studies.
For NO₂ and SO₂ as a risk factor, the effects of PM₂.5 decreased as well as for all pollutants, with a value decreased by 0.327% and 0.681% respectively, which indicated that there is a strong correlation between these pollutants and PM₂.5, but there was no synergy between the pollutants. When O₃ as the main role for the single pollutant model and other pollutants as the adjust factors, the result of O₃ model did not change much after adding one pollutant or all pollutants as a risk factor, with a value of \(\frac{0.365}{0.001}\), \(\frac{0.433}{0.001}\), \(\frac{0.385}{0.001}\), \(\frac{0.309}{0.001}\) and \(\frac{0.237}{0.001}\) for O₃, PM₂.5, NO₂, SO₂ and all pollutants respectively.

It was found that air pollutants in Shanghai were closely related to outpatient visits for respiratory diseases from March 2013 to December 2016. Women were more sensitive to air pollutants than men, and the risks of people in the 15-60 yr-old age group were significantly higher than the 60+ yr-old age group. The relationships of air pollutants and respiratory diseases in the present work were consistent with the study of other time series studies (Díaz-Robles et al., 2014; Phung et al., 2016; Xu et al., 2016a). For example, a study showed that increase of 10 \(\mu g/m^3\) air pollutant could cause RR of 1.019 for PM₂.5 and 0.968 for O₃ (Hwang and Chan, 2002; Liu et al., 2017). However, our values were relatively lower. The exposure-response curves were non-linear and the curves flattens at the high concentration, which might be the reason for our low RR value (Burnett et al., 2014). Meanwhile, a study from European multicenter panel also showed that the relationship between PM₂.5 and the respiratory outpatient admission was not significant (Karakatsani et al., 2012). It is opposite to our results, which showed that the RR with an increase of 0.37% for an increase of 10 \(\mu g/m^3\) in PM₂.5. Those differences were due to multiple factors. Firstly, in our study, most of the outpatients were above 15-year old, while Liu et al. focused on children. Other possible reasons included the sources of air pollutant, the levels of air pollutant or the chemical composition in different study areas. A previous study in Yichang, China showed that major sources, such as industrial exhaust, coal combustion, biomass burning and some secondary inorganic sources, made a dominant contribution to PM₂.5 mass (Liu et al., 2017). Studies indicated that traffic exhaust was a major source of air pollution in Shanghai (jiang et al., 2009).
Different sources to PM$_{2.5}$ mass between Yichang City and Shanghai City lead to the different chemical compositions in PM$_{2.5}$ in the two cities. PM$_{2.5}$ contains a large fraction of aerosols, has high toxicity, and has a great impact on human health (Wang et al., 2006).

This study also found that women appear to be more susceptible to PM$_{2.5}$ than men, which was in line with previous studies (Kan et al., 2010). It might be related to different physical conditions and working conditions for men and women (Cesaroni et al., 2008; Jacquemin et al., 2004; Sunyer et al., 2006). For example, a study showed that women had lower smoking rates than men (0.6% vs. 50.8%) (Li et al., 2013), and non-smokers might be more likely affected by air pollution (Phung et al., 2016). Card et al. (2007) argued that male sex hormones promote cholinergic airway responses through male-specific vagal-mediated reflex mechanisms, which made a difference to women in response to different pollutants. The effect of PM$_{2.5}$ for the 15-60 yr-old group was higher than the effect for the 60+ yr-old group. The reason might be attributed to that old people tend to stay indoor more than younger ones, and in China indoor air concentrations were generally less than outdoor (Li and Zhao, 2015; Yuan et al., 2018).

O$_3$ was negatively associated with respiratory outpatient visits in Shanghai during the entire studying period, and the association at lag0 was significant. Air pollutants had distinct seasonal variations. The O$_3$ had high concentrations in summer and low concentrations in winter due to high photochemical production under summer intensive sunlight and high temperature. While the concentration variation of PM$_{2.5}$ was opposite to that of O$_3$. So we analyzed the effects of O$_3$ and PM$_{2.5}$ in the warm periods (i.e., May–October) and the cold periods (November–April). Fig. 5 presents the associations between O$_3$ and respiratory disease outpatient visits during the warm periods and the cold periods. At lag 0 day, no significant association was found in the warm periods, which is consistent with previous studies (Atkinson et al., 1999; Chang et al., 2005; Phung et al., 2016). But O$_3$ was significantly and negatively associated with outpatient visits in the cold periods. During the cold period, the photochemical formation was weak and ground O$_3$ levels were mainly determined by consuming reactions of O$_3$ with NO$_x$. Therefore, O$_3$ concentrations were low and were negatively correlated with NO$_2$ concentrations. NO$_2$ was found to be positively correlated to the outpatient visits of respiratory diseases in our study and many other studies (Cai et al., 2014, 2015; Cao et al., 2009; Chen et al., 2010; Hua et al., 2014; Huang et al., 2009; Kan and Chen, 2003; Kan et al., 2007; Zhao et al., 2013).

Significant associations were also found in the single-day lagged model at lag2 to lag5, and in the moving average lagged model at lag01 to lag05. PM$_{2.5}$ had a significant and positive correlation with the respiratory outpatient visits in Shanghai during the entire studying period. However, the association in the warm and cold periods was different. Fig. 6 presents the associations between PM$_{2.5}$ and respiratory disease outpatient visits during the warm periods and the cold periods. PM$_{2.5}$ and respiratory disease outpatient visits were positively associated in the cold periods but negatively associated in the warm periods. Female respiratory disease patients were more sensitive to PM$_{2.5}$ than male respiratory diseases during the cold periods. As for 15-60 yr-old age group, the RR for PM$_{2.5}$ were higher than those for 60+ yr-old people. The association was stronger in the cold periods. 15-60 yr-old people were more sensitive to O$_3$ than 60+ yr-old, and females were more sensitive than males. Compared to the moving averages lag model, single-day delayed model underestimated the RR values. In the multi-pollutant model, there was a significant correlation between NO$_2$, SO$_2$ and PM$_{2.5}$, and the result of O$_3$ model did not change much after adding one pollutant or all pollutants as a risk factor. The findings provide insights on the effects of air pollution in highly polluted areas with dense population and may

**Table 2**
Percent increase (95% confidence interval) in mortality for PM$_{2.5}$ 10-µg/m$^3$ and O$_3$ 10 µg/m$^3$ in sensitivity analysis.

<table>
<thead>
<tr>
<th></th>
<th>PM$_{2.5}$</th>
<th>O$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Increase</td>
<td>95% CI</td>
</tr>
<tr>
<td>The Core Model</td>
<td>0.372</td>
<td>0.262,0.481</td>
</tr>
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<td>Specification of the degrees of freedom (df)</td>
<td>dftime – 8, dmeteorological factors – 3</td>
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</tr>
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<td></td>
<td>dftime – 9, dmeteorological factors – 3</td>
<td>0.394</td>
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<td></td>
<td>dftime – 10, dmeteorological factors – 3</td>
<td>0.321</td>
</tr>
<tr>
<td></td>
<td>dftime – 8, dmeteorological factors – 5</td>
<td>0.354</td>
</tr>
<tr>
<td></td>
<td>dftime – 9, dmeteorological factors – 5</td>
<td>0.380</td>
</tr>
<tr>
<td></td>
<td>dftime – 10, dmeteorological factors – 5</td>
<td>0.310</td>
</tr>
</tbody>
</table>

**Fig. 4.** Percentage increase of daily outpatient visits for respiratory diseases associated with a 10-µg/m$^3$ increase in PM$_{2.5}$ and O$_3$ concentrations using the single- and multiple pollutant models.
Fig. 5. RR of outpatient visits for respiratory disease for an increase of 10\(\mu\)g/m\(^3\) in \(\text{O}_3\) during the warm periods (May–October) and the cold periods (November–April).
have implications for local government to develop air pollution control measures. Further research on associations between different compositions of PM$_{2.5}$, environmental and social factors, and respiratory health is needed in the future.

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