Environmental Pollution 230 (2017) 974–980

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Short-term effects of ambient air pollution on emergency room admissions due to cardiovascular causes in Beijing, China☆

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ARTICLE INFO

Article history:
Received 15 January 2017
Received in revised form
19 June 2017
Accepted 19 June 2017
Available online 24 July 2017

Keywords:
Air pollution
Emergency room admissions
Cardiovascular diseases
Time-series

ABSTRACT

Ambient air pollution has been a major global public health issue. A number of studies have shown various adverse effects of ambient air pollution on cardiovascular diseases. In the current study, we investigated the short-term effects of ambient air pollution on emergency room (ER) admissions due to cardiovascular causes in Beijing from 2009 to 2012 using a time-series analysis. A total of 82430 ER cardiovascular admissions were recorded. Different gender (male and female) and age groups (15yrs $\leq$ age <65 yrs and age $\geq$ 65 yrs) were also examined by single model and multiple-pollutant model. Three major pollutants (SO_2, NO_2 and PM_{10}) had lag effects of 0–2 days on cardiovascular ER admissions. The relative risks (95% CI) of per 10 $\mu g/m^3$ increase in PM_{10}, SO_2 and NO_2 were 1.008 (0.997–1.020), 1.008(0.999–1.018) and 1.014(1.003–1.024), respectively. The effect was more pronounced in age $\geq$65 and males in Beijing. We also found the stronger acute effects on the elderly and females at lag 0 than on the younger people and males at lag 2.

1. Introduction

In recent years, a number of studies have demonstrated the association between ambient air pollution and cardiovascular diseases (Brook et al., 2010; Miller et al., 2007; Poloniecki et al., 1997; Rodriguez et al., 2015). Ambient air pollution was responsible for approximately 17.5 million people death from cardiovascular diseases per year (WHO, 2016). The estimated effects of air pollution on cardiovascular complications were higher than the effects on respiratory disorders (Chin, 2015). In China, cardiovascular disease is the first leading cause of death and results 3.5 million people death every year, accounting for 41% of the total death (Wang et al., 2012).

Numerous epidemiological studies on air pollution causing cardiovascular diseases have been reported, including gaseous pollution on cardiovascular emergency admissions (Cao et al., 2009; Zheng et al., 2013), and particulate matters on cardiovascular mortality and hospital admissions (Adar et al., 2014; Franck et al., 2011; Zhou et al., 2014; Yu et al., 2012). Previously, short effects of air pollution on cardiovascular diseases have been reported in Europe (Chiusolo et al., 2011; Sunyer et al., 2003; Barnett et al., 2006), the United States (Dominici et al., 2005) and Canada (Vanos et al., 2014). Analitis et al. (2006) working in Europe, found that increase in the concentration of PM_{10} resulted increased mortality of cardiovascular diseases. Study by Poloniecki et al. (1997) found that the number of admission for acute myocardial infarction showed positive correlation with SO_2 and NO_2 in London. Researches also have reported adverse effects of air pollution in Asia (Ueda et al., 2012; Khaniabadi et al., 2016). In mainland China, associations of air pollution with cardiovascular diseases have been performed in some large cities, including Beijing (Yang and Pan, 2008; Su et al., 2016), southern cities of Shanghai (Chen et al., 2010a; Cao et al., 2009), Guangzhou (Yu et al., 2012) and Wuhan (Liu et al., 2015). An earlier study in Hong kong also reported that increase of the daily concentrations of PM_{10}, SO_2 and NO_2 associated with the total number of cardiovascular hospital admissions (Wong et al., 1999).

☆ This paper has been recommended for acceptance by David Carpenter.

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http://dx.doi.org/10.1016/j.envpol.2017.06.104

In the current study, a time-series analysis was performed to evaluate the short effects of air pollution on emergency room admissions due to cardiovascular causes in Beijing, the capital of China, from 2009 to 2012. Gender and age modification were also considered to examine the adverse health effects of air pollution on different groups.

2. Materials and methods

2.1. Study area

This study was performed in Beijing (116°23′E, 39°54′N), the capital of China. Our study is limited in the urban district and high-density residential area of Beijing. There were 21.7 million of permanent residents and 8.23 million of floating population at the end of 2013. Mean daily temperature and relative humidity are 13.1 °C and 50.8% respectively, and that mean wind speed is 2.2 m/s and average rainfall is around 480 mm, reflecting the typical temperate and semi-humid continental monsoon climate in Beijing.

2.2. Material sources

2.2.1. Daily cardiovascular admissions

Daily number of emergency room (ER) admissions due to cardiovascular causes were collected from Jan 1st, 2009 to Dec 31st, 2012 from four comprehensive top-level hospitals in Beijing. The records were extracted according to the information of date of hospital admissions, age, sex and residential address. The records were classified according the International Classification of Diseases, Tenth Revision (ICD-10) for cardiovascular diseases (ICD 10:I00-I99). We also divided the total cardiovascular admissions to different gender (male and female) and age (15yrs ≤ age <65yrs and age ≥ 65yrs) groups. Cardiovascular disease is the main health problem for adults and elder people, therefore, we removed the admissions of age <15yrs because of the small sample.

2.2.2. Air pollution data and meteorological data

Daily air pollution data and meteorological data from Jan 1st, 2009 to Dec 31st, 2012 were obtained from Beijing Environmental Monitoring Center and Beijing Meteorological Bureau respectively. Air pollution data included SO_2, NO_2 and PM_{10}. Meteorological data were daily average temperature, relative humidity, hours of sun shine and wind speed.

2.2.3. Methods

The daily number of ER cardiovascular admissions were analyzed using time-series methods, by generalized addictive Poisson regression model. Age and gender specific models were also constructed.

A generalized additive model (GAM) was used to construct a basic model to explore the relationships between ER cardiovascular admissions and air pollutants. The cubic smoothing functions were applied to control the confounding effects of long-term trend, day of the week (DOW), holiday and weather factors (temperature and relative humidity). We used the partial autocorrelation function (PACF) to select the degree of freedom by the minimization of the absolute values of the sum of PACF for lags up to 30. Holiday and DOW were included as subvariables. We fitted the final model according to the Akaike's Information Criterion (AIC) (Akaike, 1987). We also revealed the lag effects (from L0 to L6) of air pollutants (PM_{10}, SO_2 and NO_2) on ER cardiovascular admissions. The model is as following:

$$\log[E(Yt)] = \alpha + s(time, df) + DOW + Holiday + s(temperature, df) + s(humidity, df) + \beta Zt \qquad (1)$$

Where t denotes the day of the observation; E(Yt) refers to expected ER cardiovascular admissions counted on day t; α denotes the intercept; s() represents a spline smoothing function for nonlinear variables; time is the days of calendar time on day t; df is the degree of freedom; DOW refers to the day of the week on day t; β indicates the log-relative rate of ER cardiovascular admissions associated with per unit increment of air pollutants; Zt denotes concentrations of air pollutants on day t.

We introduced the air pollutants one by one each time into the basic model to examine the relative risk of cardiovascular diseases posed by each pollutant. All results were presented as relative risks (RRs) of cardiovascular admissions and their 95% Confidence Interval (95%CI). RR was calculated for a 10 $\mu g/m^3$ increase in each air pollutant's concentration. In addition, we also examined the effects of air pollutants on age (15yrs ≤ age <65 yrs and age ≥ 65 yrs) and gender (female and male). All analyses were performed using MGCV package in the R software (R 3.1.3).

3. Results

Table 1 presents the descriptive statistics for weather, air pollutants and ER cardiovascular admissions in Beijing. From 2009 to 2012, a total of 82430 ER cardiovascular admissions were recorded in Beijing, accounting for 23.1% of the total admissions. The daily cardiovascular admissions per day for all cardiovascular, male, female, age <65 yrs and age ≥65 yrs were approximately 56.5, 30.3, 26.2, 32.9 and 23.6 respectively. The mean daily concentrations of air pollutants were 114.4 $\mu g/m^3$, 26.6 $\mu g/m^3$ and 57.5 $\mu g/m^3$ respectively for PM_{10}, SO_2 and NO_2. PM_{10} is the primary contamination during study period. The PM_{10} and NO_2 concentrations were exceeded the annual mean of National Grade II standard level (PM_{10}: 70 $\mu g/m^3$, NO_2: 40 $\mu g/m^3$) (Table 1) and SO_2 concentration exceeded the 24-h mean of the WHO air quality guidelines (SO_2: 20 $\mu g/m^3$). Mean daily air temperature is 13.1 °C, relative humidity and mean wind speed are 50.8% and is 2.2 m/s, respectively.

Table 2 provides the correlative coefficients between daily air pollutants and meteorological factors. PM_{10}, SO_2 and NO_2 were correlated with each other with statistical significance ($P < 0.01$). PM_{10} was significantly positively correlated with SO_2 ($r = 0.355$) and NO_2 ($r = 0.609$), and SO_2 was also significantly positively correlated with NO_2 ($r = 0.550$). Both SO_2 and NO_2 were negatively correlated with temperature, sunshine duration and weed speed. A negative correlation was found between SO_2 and relative humidity, and a positive correlation was found between NO_2 and relative humidity. Significantly positive correlations were found between PM_{10} and temperature and relative humidity. And negative correlations were found between PM_{10} and sunshine duration and weed speed.

Table 3 presents the relative risk and their 95% Confidence Interval (95%CI) for ER cardiovascular admissions at 10 $\mu g/m^3$ increments in air pollutants concentrations in different lag days (0–6). For PM_{10}, the maximum effect was found at lag 0, and the greatest effects for SO_2 and NO_2 both occurred at lag 2 (bold in Table 3). The RR (95% CI) of per 10 $\mu g/m^3$ increment in PM_{10}, SO_2 and NO_2 were 1.008 (0.997–1.020), 1.008(0.999–1.018) and 1.014(1.003–1.024), respectively. The effects of NO_2 was the strongest among the three pollutants.

The relative risk for ER cardiovascular admissions at 10 $\mu g/m^3$ increments in each pollutant concentrations varied by age and gender group (Fig. 1). The greatest effects of PM_{10} and NO_2 were

Table 1
Descriptive statistics for weather factors, air pollutants and cardiovascular ER admissions from Jan 1, 2009 to Dec 31, 2012 in Beijing.

Variables	Mean + SD	Min	P25	Median	P75	Max	IQR
Weather factors							
Temperature(°C)	13.1 + 11.6	−12.5	1.7	15.1	24.0	34.5	22.2
Hours of sunshine(h)	6.7 + 4.0	0	3.4	7.8	9.9	14.0	6.5
Relative humidity(%)	50.8 + 20.1	9.0	34.0	52.0	67.0	97.0	33.0
Wind speed(m/s)	2.2 + 0.92	0.5	1.6	2.1	2.7	6.4	1.1
Air pollutants							
SO_2(μg/m^3)	26.6	0	8.0	17.0	34.7	234.0	26.7
NO_2(μg/m^3)	57.5	11.0	38.4	52.5	71.3	242.0	33.0
PM_{10}(μg/m^3)	114.4	0	62.0	104.4	153.8	544.0	92.0
Cardiovascular admissions							
All	56.5 ± 14.7	16	46	57	66	101	20
Male	30.3 ± 8.31	10	24	30	36	61	12
Female	26.2 ± 8.37	5	20	26	32	60	12
15 yrs ≤ age < 65 yrs	32.9 ± 8.98	9	27	33	39	68	12
Age ≥65 yrs	23.6 ± 7.78	4	18	23	29	49	11

SD: Standard deviation; Min: minimum; P25: 25th percentile; P75: 75th percentile; Max: maximum; IQR: Inter quartile range.

Table 2
Correlation coefficients for meteorology factors and air pollutants.

Elements	PM_{10}	SO_2	NO_2	T(°C)	RH(%)	SSD(h)	WS(m/s)
PM_{10}	1						
SO_2	0.355**	1					
NO_2	0.609**	0.550**	1				
T(°C)	0.130**	−0.619**	−0.220**	1			
RH(%)	0.325**	−0.167**	0.225**	0.360**	1		
SSD(h)	−0.320**	−0.222**	−0.298**	0.181**	−0.585**	1	
WS(m/s)	−0.246**	−0.218**	−0.510**	0.012	−0.451**	0.293**	1

AbbreviationsT: daily average temperature; RH: relative humidity; SSD: sunshine duration.
WS:wind speed. **P < 0.01.

Table 3
RR and their 95% Confidence Interval for ER cardiovascular admissions for each 10 μg/m^3 increment in air pollutant concentrations at different lag days.

Relative risk and 95%CI			
Lag days	PM_{10}	SO_2	NO_2
0	**1.008(0.997~1.020)***	1.003(0.992–1.014)*	1.012(0.999–1.026)*
1	1.005(0.995–1.016)*	0.999(0.989–1.009)	1.007(0.996–1.019)*
2	1.004(0.994–1.014)*	**1.008(0.999~1.018)***	**1.014(1.003~1.024)***
3	0.998(0.989–1.008)	0.997(0.988–1.006)	1.000(0.99–1.010)
4	0.997(0.987–1.006)	0.992(0.983–1.002)	0.994(0.984–1.004)
5	0.987(0.978–0.996)**	0.985(0.976–0.995)**	0.982(0.973–0.992)**
6	0.992(0.982–1.001)	0.992(0.983–1.002)	0.986(0.976–0.996)**

**p < 0.01, *p < 0.05.

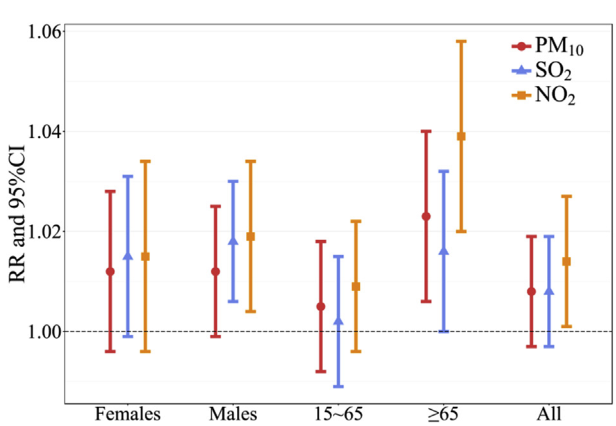

Fig. 1. RR and 95% with a 10 μg/m^3 increase in air pollutants by age and gender.

observed in age ≥65 yrs and the effect of SO_2 was found the greatest in males. Regarding gender, greater effects of SO_2 and NO_2 were more pronounced in males, while the effect of PM_{10} was slightly greater in females than in males.

Fig. 2 indicates the RR (95% CI) for ER cardiovascular admissions with per 10 μg/m^3 increase in air pollutants concentrations at different lags by age and gender. For females, the greatest impacts of PM_{10}, SO_2 and NO_2 were all discovered at lag 0, and for males the greatest effects were found at lag 2 for three pollutants. For those 15 yrs ≤ age <65yrs, the greatest effects of three pollutants were similar with males, all occurred at lag 2. For those aged ≥65yrs, the maximum effects were observed all at lag 0 for three pollutants. And for the total ER cardiovascular admissions, we found the highest influences at lag 0 for PM_{10} and SO_2, and lag 2 for NO_2.

Table 4 presents the single model and multi-pollutant model by gender and age groups. PM_{10}, SO_2 and NO_2 had lag effects on age and gender, all pollutants with a lag of 0–2 days. . For age groups, the relative risk of each pollutant estimates tended to be greater for the elderly (age ≥ 65 yrs) than those patients 15yrs ≤ age < 65 yrs. The relative risk of ER cardiovascular admissions for age ≥65 yrs in single model were 1.023(1.006–1.040), 1.016(1.000–1.032) and

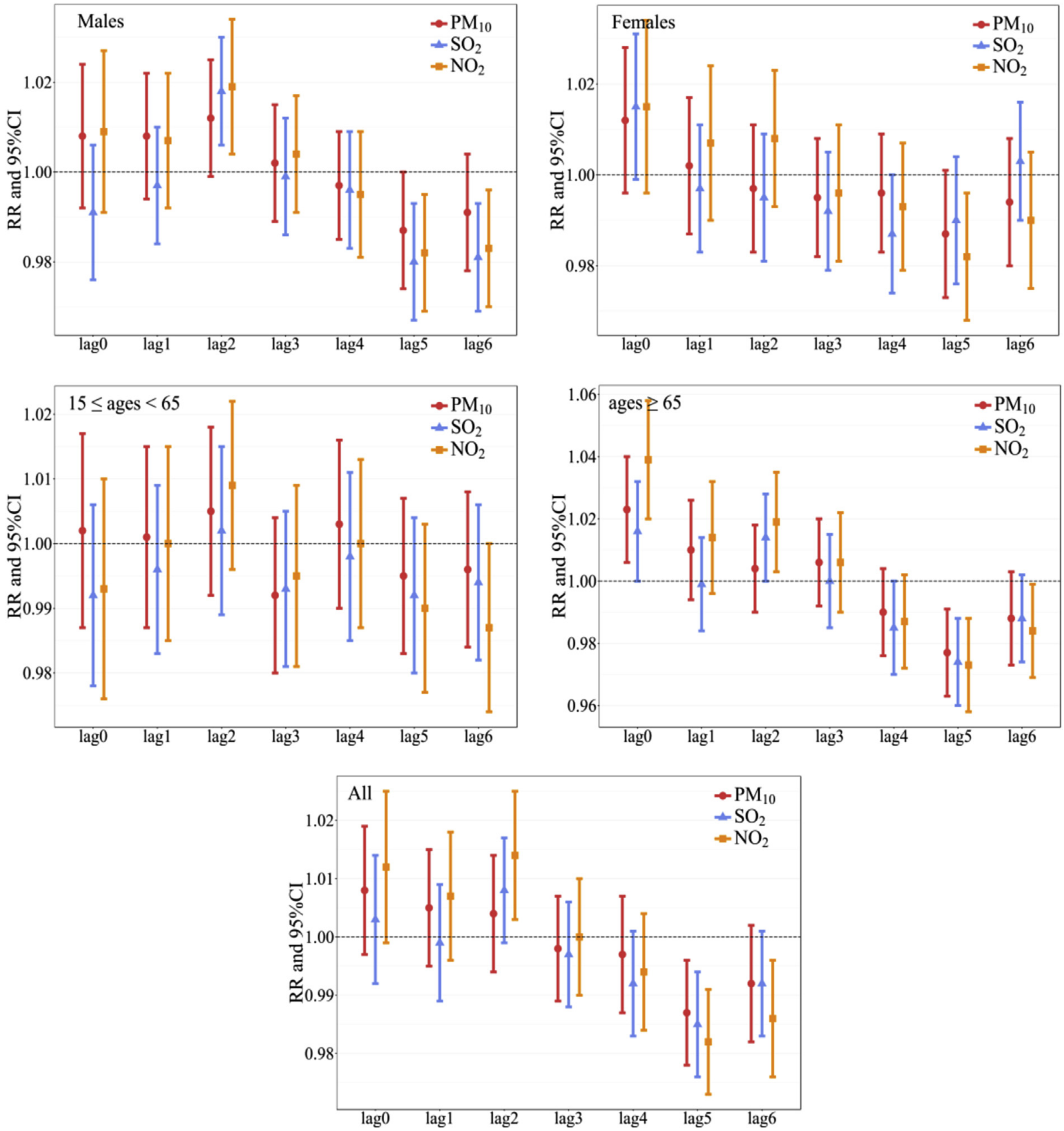

Fig. 2. RR and 95% with per 10 increase for different groups at different lag days.

1.039(1.020–1.059) with a 10 μg/m^3 increase in PM_{10}, SO_2 and NO_2 respectively. Regarding gender, the effects of SO_2 and NO_2 estimated to be stronger for males than for females, but there was no significant differences existing for males and females due to PM_{10}. The relative risk associated with per 10 μg/m^3 increase in PM_{10}, SO_2 and NO_2 for males were 1.012(0.999–1.025), 1.018(1.006–1.031) and 1.019(1.004–1.033) respectively. The relative risk estimates for different groups in multi-pollutant models were reduced and most values had no significant meaning.

4. Discussion

Results obtained in this time-series analysis proved the short effects of air pollution on emergency room admissions due to cardiovascular causes in Beijing, 2009–2012. In the present study, a 10 μg/m^3 increase in PM_{10} increased cardiovascular ER admissions by 0.8%, 1.2%, 1.2%, 0.5% and 2.3% respectively for the total, male, female, 15yrs ≤ age <65yrs and age ≥65yrs, respectively. A 10 μg/m^3 increment in SO_2 corresponded to 0.8%, 1.8%, 1.5%, 0.2% and 1.6% increase respectively for the total, male, female, 15yrs ≤ age <65yrs and age ≥65yrs. Per 10 μg/m^3 increment in NO_2 associated with increase of 1.4%, 1.9% 1.5%, 0.9% and 3.9% respectively for the total, male, female, 15yrs ≤ age <65yrs and age ≥65yrs. The effects of three pollutants on ER cardiovascular admissions were much stronger in the elderly than in the younger people, and regarding gender, they were higher in males than in females but PM_{10}.

Previous studies have reported varied results of adverse effects of air pollution on cardiovascular morbidity and mortality (Liang

Table 4
Single model and multiple-pollutant model by age and gender.

Pollutant	Class	Lag day	Single model	Multiple model
PM_{10}	All	0	1.008(0.997–1.020)*	0.998(0.996–1.001)
	male	2	1.012(0.999–1.025)*	1.000(0.996–1.003)
	Female	0	1.012(0.996–1.029)*	0.997(0.993–1.000)
	<65 yrs	2	1.005(0.992–1.018)	1.000(0.997–1.003)
	≥65yrs	0	1.023(1.006–1.040)**	0.996(0.993–1.000)*
SO_2	All	2	1.008(0.999–1.018)	1.000(0.999–1.000)
	male	2	1.018(1.006–1.031)**	1.000(0.999–1.001)
	Female	0	1.015(0.999–1.031)*	0.999(0.998–1.000)
	<65 yrs	2	1.002(0.989–1.014)	1.000(0.999–1.001)
	≥65yrs	0	1.016(1.000–1.032)*	0.999(0.998–1.000)*
NO_2	All	2	1.014(1.003–1.024)*	0.999(0.999–1.000)
	male	2	1.019(1.004–1.033)*	1.000(0.999–1.001)
	Female	0	1.015(0.996–1.034)*	0.999(0.998–1.000)
	<65 yrs	2	1.009(0.996–1.023)*	1.000(0.999–1.001)
	≥65yrs	0	1.039(1.020–1.059)**	0.999(0.997–1.000)*

$^{**}p < 0.01$, $^{*}p < 0.05$.

et al., 2009; Shahi et al., 2014; Zanobetti and Schwartz, 2006). A study in French reported that the daily number of hospitalization for cardiovascular diseases increased by 0.8% and 1.1% with a 10 μg/m^3 increase in PM_{10} and NO_2 respectively (Larrieu et al., 2007). A similar study conducted in Canada suggested 1.9% increase in emergency department visits for myocardial infraction with a 20.6 μg/m^3 increase in PM_{10} (Stieb et al., 2009). A study in western part of Iran reported that per 10 μg/m^3 increase in PM_{10} and NO_2 resulted excess relative risks of 6.6% and 1.2% respectively for cardiovascular mortality (Khaniabadi et al., 2016). A previous study in Guangzhou, China suggested 1.29%, 2.3% and 1.8% increases in cardiovascular mortality associated with a 10 μg/m^3 increase in PM_{10}, SO_2 and NO_2 respectively (Yu et al., 2012). Chen et al. (2010b) working in Anshan, China reported 0.67%, 0.38% and 2.11% increases in cardiovascular mortality associated with per 10 μg/m^3 increase in PM_{10}, SO_2 and NO_2 respectively. Numerous studies also have reported short-term effect of dust events on cardiovascular mortality and morbidity (Perez et al., 2012; Neophytou et al., 2013; Middleton et al., 2008; Kwon et al., 2002; Tao et al., 2014). In the present study, we did not take into account the modifying effects of dust events because the data of dust events in Beijing were not available for the study period. But our findings confirmed those earlier results of strong effects of air pollutants on ER cardiovascular diseases.

Lag effects were found in the influence of air pollutants on daily ER cardiovascular admissions in Beijing. The results revealed that the effects of three pollutants on ER cardiovascular admissions were the strongest at lag0 and lag2. Similar with our finding, earlier studies have reported lag effects on the same day, or in 1–2 previous days (Guo et al., 2009; Yu et al., 2012; Kim et al., 2012). But some other studies reported the highest effects of air pollutants at lag 5 - lag 8 (Zhang et al., 2015; Su et al., 2016). In the present study, the same day (lag 0) triggered the largest RR for females and the elderly (age ≥ 65yrs), while the maximum effects for total, males and the adults (15yrs ≤ age < 65yrs) were observed at lag 2, indicating that females and the elderly people have a more acute response to air pollution, whereas males and the younger people need longer time to be affected.

Age-stratified analysis showed significant higher effects of air pollutants in age ≥65yrs than in the younger people, this result was consistent with other studies conducted in Europe (Larrieu et al., 2007; Katsouyanni et al., 2001), Australian and New Zealand cities (Barnett et al., 2006) and mainland China (Su et al., 2016; Zheng et al., 2013). This probably because the elderly were found the mostly vulnerable to air pollution (Gouveia and Fletcher, 2000; Katsouyanni et al., 2001). And preexisting heart problems are more prevalent in the elder people than in the younger people (Barnett et al., 2006; Kan et al., 2008). Elderly people are also considered to be more susceptible to the effects of air pollution than other groups also because of their physiological processes are gradually declining over time (Sacks et al., 2011).

We observed stronger effects of SO_2 and NO_2 on males than on females, which is consistent with the previous study conducted in Wuhan China (Liu et al., 2015), but not consistent with the results of a study in Shanghai (Kan et al., 2008). The effect of PM_{10} was slightly greater in females than in males, this result was in accordance with observed effects of PM in previous studies (Yorifuji et al., 2014; Lin and Kuo, 2013; Zeka et al., 2006; Zhang et al., 2015). But the results were not consistent. Some studies reported slightly stronger effects of PM on cardiovascular admissions for males compared to females (Middleton et al., 2008; Zanobetti and Schwartz, 2005). A study by Cakmak et al. (2006) found that gender had no modification effect on the hospitalization of cardiac diseases due to air pollution. In our study, higher effects of gaseous pollutants on males than on females might be due to higher potential exposure of men to SO_2 and NO_2 because outdoor workers are males in general in Beijing. The findings of gender-specific are still unclear and need more further investigation.

In the multi-pollutant models, the statistically significant associations were observed only for age ≥65yrs, but the relative risks were reduced after adjusting other pollutants. Previous studies also reported significant associations between air pollution and daily cardio-cerebrovascular hospital admissions (Zheng et al., 2013; Chang et al., 2005) in multiple - pollutant models. But some other studies (Guo et al., 2009; Zhang et al., 2015) reported no significant associations between air pollutants and cardiovascular emergency visits in multiple - pollutant models. The differences existing among the results might be explained by the selection bias of air pollutants and hospital admissions data in the studies (Sheppard et al., 2005), and also might be due to the different data length.

Some limitations in our study should be taken into account. We used the daily average level of air pollutants of different monitoring stations as proxy for population exposure level. Measurements error might exist between monitoring stations (Sheppard et al., 2005), possibly introducing bias to estimated results. But these bias could not be quantified because that the personal exposure information were not available. In addition, as other previous studies, because the pollutants were highly correlated in Beijing (Table 2), we could not separate the effects for each pollutant. Moreover, some studies estimated effect modification by season, socioeconomic status and personal characteristics (Gouveia and Fletcher, 2000; Qiu et al., 2015; Kan et al., 2008; Wilson et al., 2007), but our study did not collect data on socioeconomic status and personal information such as occupation, married and educational status. Therefore, further research is needed to evaluate the potential modifiers effects on ER admissions due to ambient air pollution in Beijing.

5. Conclusion

In the present study, we found significant association between air pollutants and ER cardiovascular admissions in Beijing, 2009–2012. The effects were obviously stronger in males and age ≥65 yrs. Results of delayed effect showed more acute effects on age ≥65 yrs and females at lag 0 than on males and the younger people at lag 2. Our results provide insights of short-term effects of air pollution on cardiovascular diseases. The findings have important implications to local public and environmental strategy and policy.

Conflict of interest

The authors declare they have no competing financial interests.

Acknowledgments

We thank the Professional Services for Meteorology, Environment and Public Health of the National Scientific Data Sharing Platform for Population and Health for collecting data. The study was supported by Shanghai Key Laboratory of Meteorology and Health (Grant No: QXJK201608), National Natural Science Foundation of China (41475095) and the Fundamental Research Funds for the Central Universities (lzujbky-2017-69). Parts of this work were funded by a Scholarship being awarded to Yuxia Ma (File No. 201308625022) supported by the China Scholarship Council (CSC).

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