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Effect of Air Pollution on Hospital Admissions of Respiratory, Dermatological, Ophthalmic Diseases in a Coastal City, China

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Abstract

Recent studies have shown associations between particulate matter and respiratory diseases for children in some heavy air pollution areas in China. However, few investigations have focused on the potential effects of chronic exposure to low-moderate levels on health symptoms among children. In this study, the effect of air quality on pediatric hospital admissions for respiratory disease, dermatological illness and ophthalmic diseases in Zhoushan were characterized by data from different lag structures, single-pollutant models and multi-pollutant models (Generalized additive model, GAM). Under lag0, a 36 μ g/m^3 increased in PM_{10} and a 5 μ g/m^3 increased in SO_2 with associated with a 1.050% risk increased (95% confidence interval [CI] 1.037 to 1.064) and with a 1.030% increased (95% CI 1.016 to 1.044) in respiratory hospitalization, respectively. A positive association between SO_2 with the increased risk of dermatological hospitalization was found: 1.139% (95% CI 0.977 to 1.328) at lag2. A detrimental effect was found at lag0 of ophthalmic illness with ambient air pollution. Seasonal differences were found for air pollution for pediatric respiratory and dermatology. This study indicates that air pollution has an impact on pediatric health, even in a high air quality area, we should control the concentrations strictly to prevent environmental health problem.

Keywords: Children's health; Hospital admission; Particulate matter; Zhoushan; Generalized additive model

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Introduction

During the last two decades, numerous studies have documented that ambient air pollutants is related to asthma hospitalizations [1], chronic obstructive pulmonary disease (COPD) [2,3], lower respiratory infections [4,5] and some other respiratory illness [6-8] and cardiovascular diseases [9-11]. Many researchers pay their attention to the relationship between air pollutant and children's health [12-17]. Lin et al. [18] suggested a detrimental effect of relatively low levels of coarse particulate matter and NO_2 on hospitalization for respiratory infections in children. Silverman et al. [15] investigated the associations between severe asthma morbidity and $PM_{2.5}$ and ozone in the warm season, and revealed warm weather patterns of ozone and $PM_{2.5}$ disproportionately affected children with asthma in New York. Ostro et al. [19] observed associations between several components (like EC, OC) of $PM_{2.5}$ and respiratory admissions for children under 19 years of age. Hua et al. [20] found $PM_{2.5}$ and the BC were significantly associated with childhood asthma visits in single-pollution model in Shanghai. Mehta et al. [12] assessed the effects of exposure to air pollution on hospitalization for acute lower respiratory infection among children in Ho Chi Minh City and found the increased of NO_2 and SO_2 were associated with increased admissions in the dry season. Chinese experts has investigated the health effect in Beijing [21], Shanghai [20], Lanzhou [22], but only few studies focused on children's health.

The main adverse effects of atmospheric pollutants are: ophthalmic illness, skin injuries, cardiovascular diseases and respiratory illness and lung cancer [23]. Children are vulnerable to outdoor air pollutants on health because their respiratory tract may be sensitive to the stimulation of pollutants. More time to stay outside lead to a long time of exposure that may cause their uncomfortable on eyes [24-26]. In this report, we not only examined the relationship between air pollutants and respiratory, but also tried to find some association between air pollutants and dermatological illness and ophthalmological disease using the statistical methods.

Many researchers have studied the effect of air quality in heavy polluted area or megacities on Children's health [3,20,27,28]. However, the health effect on Children who exposed to low-moderate levels of particulate matter and gaseous pollutants is still lack of consideration. We chose Zhoushan as our study area. It is located in East China Sea, about 140 kilometers away from Shanghai and 58 kilometers away from Ningbo (**Figure 1**). The mean of PM_{10}, $PM_{2.5}$, SO_2, NO_2 and O_3 in Zhoushan was 54 μ g/m³, 31 μ g/m³, 6 μ g/m³, 23 μ g/m³, 91 μ g/m³, respectively. Some researches showed that the respiratory health damage threshold of the $PM_{2.5}$ concentration was mainly within the range of 20-60 μ g/m³, and the adverse effect of excessively high $PM_{2.5}$ concentration maintained a stable level [29]. So taking Zhoushan as a study area is meaningful and it also can be a contrast case to other Chinese cities.

Materials and Methods

Study area

Zhoushan, has a population of 1.13 million by the end of 2010, which composed of 1400 islands, with a total area of 220 km². Annual average temperature of Zhoushan is about 16°C, and rainfall is ranged from 927 ml to 1,620 ml every year. It has a subtropical oceanic monsoon climate, with a mildly winter and moderate summer. The harbor is the main anthropogenic source of pollution. Influenced by the strong wind and superior surroundings, the Zhoushan air quality ranked top in China.

Health and environmental data observation: The primary emergency diagnoses were recorded according to the International Classification of Disease 10th Revision (ICD-10) (World Health Organization) by Zhoushan Center for Diseases Control and Prevention from January 1, 2014, to December 31, 2015 (**Table 1**). Diseases include respiratory illness, dermatology illness and ophthalmic illness.

Air pollution data, including hourly concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter with aerodynamic diameter less than 10 μ m (PM_{10}), particulate matter with aerodynamic diameter less than 2.5 μ m ($PM_{2.5}$), and ozone (O_3) were acquired by a real-time air quality monitoring station located in Linchen district (122.20E, 29.98N). The Linchen district monitoring station was fully automated and provided hourly readings of SO_2, NO_2, PM_{10}, $PM_{2.5}$ and O_3. Particulate matters were measured in μ g/m³ while gas pollutants were measured in μ g/m³.

Meteorological data were obtained from NOAA climate government. The daily weather data were measured at Linchen

Figure 1 The location of Zhoushan Island.

Table 1 Descriptive statistics on air pollutants, daily hospital admissions, meteorological factors in Zhoushan, 2014 to 2015.

Air pollutants levels		N	Mean	SD	Min	Max	IQR
PM_{10} (μ g/m^3)	All year	730	53.4	34.1	7	256	36
	Dry	181	70.5	40.4	13	256	49
	Wet	368	42.3	23.7	10	93	24
$PM_{2.5}$ (μ g/m^3)	All year	730	31.3	21.8	3	163	22
	Dry	181	40.4	26.2	6	163	29
	Wet	368	24.9	14	3	93	16
SO_2 (μ g/m^3)	All year	730	6.1	4.2	2	42	5
	Dry	181	6.3	4.1	3	23	5
	Wet	368	5.8	3	3	19	5
NO_2 (μ g/m^3)	All year	730	23	13	2	42	15
	Dry	181	28.7	15.3	2	100	20
	Wet	368	18.9	9.7	3	63	12
O_3 (μ g/m^3)	All year	728	92.2	31.9	2	231	38.8
	Dry	181	84.8	25.6	22	171	34
	Wet	367	100.9	35	18	231	37
Meteorological data							
Temperature (°C)	All year	730	17.1	7.5	0.1	30.4	
	Dry	181	10.6	4.8	0.1	22.5	
	Wet	368	23.3	3.4	14.5	30.4	
Relative humidity (%)	All year	730	80.2	12.2	35.9	194	
	Dry	181	73.8	12.8	35.9	98	
	Wet	368	83.4	8.7	50.9	99.3	
Sea level Pressure (Pa)	All year	730	1016.6	8.7	983.2	1035.7	
	Dry	181	1023.1	6.3	1002.8	1034.7	
	Wet	368	1010.2	5.8	983.2	1028.3	
Daily admissions	Total	730	2863	879	355	4438	
	Pediatric Clinic	730	238.7	260.7	57	1505	
	Respiratory	730	52.9	51	7	140	
	Dermatology	730	1	1.5	0	11	
	Ophthalmology	730	0.2	0.6	0	7	

district during the inspection period, including temperature, relative humidity and sea level pressure.

Statistical analysis: The quality of data was checked. First, we set a domain between 0 and 500 to exclude outliers. Then interpolate to fill the null in the air pollution data and meteorological data. Final daily average concentrations (DAC) of SO_2, NO_2, PM_{10}, $PM_{2.5}$ and O_3 were calculated from hourly observations. The following statistical analysis was all based on DAC. A correlation analysis was performed to identify the relationship among each variable (**Table 2**), including PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, temperature (temp°, relative humidity (RH) and sea level pressure (slp). A single-pollutant model was built, the effect of metrological factor such as temp, RH, slp and time; and day of week including weekday and workday were entered to the model as a confounding factor using smooth function to calculate the effect of one pollutant on number of hospitalizations. We used lag structures (from a lag of 0 day corresponding to the current day (L0) to a lag of 6 day corresponding to the previous day concentration (L6)) to estimate the lag effect of disease. The multi-pollutant models were built as the same way, only one different was bringing all pollutants into the model at the same time.

The distribution of respiratory disease was followed by Poisson distribution, while dermatological illness and ophthalmic disease were followed by negative binomial distribution. Generalized additive model (GAM) was used with log link to compute the effects of air pollution on daily hospital admission.

$$\text{Log}[E(Y_i)]=\beta_0+\beta_1 \times X_i+S(\text{time, df})+S(Z_k\text{, df})+\text{DOW} \quad (1)$$

Where Y refers to the number of children daily hospital admission; E(Y) represents the expected number of children hospital admissions at day i; X_i represents the air pollutant concentration at day i; Z_k indicates meteorological factors, which can be temperature, relative humidity, etc; S means smooth functions and df means the degree of freedom, df was not limited and the function gave an optimal value; DOW is a dummy variable for day of the week.

General calculations were performed in SPSS. GAM models were developed using R statistical software with ”mgcv” package and the results were expressed as the percent change in daily hospital admissions for IQR change in pollutant concentration.

Results

A total of 2,089,722 hospital visits were recorded for the analysis in Zhoushan hospital from January 1, 2014 to December 31,

Table 2 Pearson correlation coefficients between environmental variables in Zhoushan. **Correlation is significant at the 0.01 level.

	PM_{10}	$PM_{2.5}$	SO_2	NO_2	O_3
$PM_{2.5}$	0.906**				
SO_2	0.640**	0.615**			
NO_2	0.639**	0.609**	0.485**		
O_3	0.119**	0.126**	0.101**	-0.109**	
Temp	-0.393**	-0.326**	-0.166**	-0.238**	0.218**
RH	-0.492**	-0.327**	-0.405**	-0.206**	-0.116**
Slp	0.400**	0.304**	0.225**	0.196**	-0.168**

Table 3 Percentage increase in daily hospital admissions and 95% CIs associated with IQR increase in air pollutants in multi-pollutant models (***p<0.01, **p<0.05, *p<0.01).

		lag=0	lag=1	lag=2
Respiratory	PM_{10}	↑ 1.12***	↑ 1.11***	↑ 1.08***
		(1.07–1.15)	(1.07–1.14)	(1.047–1.114)
	$PM_{2.5}$	↓ 0.92***	↓ 0.91***	↓ 0.91***
		(0.89–0.95)	(0.88–0.94)	(0.88–0.93)
	SO_2	↓ 0.99	↓ 1.008	↓ 1.01
		(0.97–1.01)	(0.988–1.028)	(0.99–1.03)
	NO_2	↓ 1.05***	↓ 1.04***	↑ 1.05***
		(1.03–1.06)	(1.02–1.057)	(1.03–1.07)
	O_3	↓ 0.997	↓ 1.003	↑ 1.02***
		(0.99–1.01)	(0.987–1.019)	(1.006–1.038)
Dermatology	PM_{10}	↑ 1.07	↑ 1.06	↑ 1.04
		(0.75–1.54)	(0.75–1.49)	(0.74–1.45)
	$PM_{2.5}$	↓ 0.9	↓ 0.75*	↓ 0.92
		(0.66–1.22)	(0.56–1.02)	(0.68–1.22)
	SO_2	↓ 0.905	↑ 1.28**	↑ 1.24**
		(0.71–1.14)	(1.02–1.59)	(1.0–1.53)
	NO_2	↑ 1.12	↑ 1.01	↓ 0.93
		(0.92–1.36)	(0.83–1.21)	(0.78–1.12)
	O_3	↑ 1.07	↑ 1.06	↓ 0.95
		(0.906–1.26)	(0.9–1.25)	(0.81–1.12)
Ophthalmology	PM_{10}	↓ 1.12	↓ 0.94	↑ 1.002
		(0.55–2.29)	(0.46–1.93)	(0.47–2.12)
	$PM_{2.5}$	↓ 1.18	→ 1.14	↓ 0.54*
		(0.66–2.13)	(0.63–2.04)	(0.27–1.05)
	SO_2	↓ 1.15	↓ 0.84	↑ 1.84
		(0.68–1.93)	(0.48–1.49)	(1.07–3.19)
	NO_2	↓ 0.94	↑ 1.29	↑ 1.02
		(0.57–1.56)	(0.78–2.12)	(0.61–1.7)
	O_3	↓ 0.84	↑ 1.05	↑ 1.23
		(0.56–1.24)	(0.71–1.56)	(0.82–1.86)

2015. There were 174,248 pediatric cases, of which 22.17% was respiratory causes, 0.43% was dermatological causes and 0.06% was ophthalmic causes. The calculation of air pollutants, meteorological factors, and hospital visits were summarized in **Table 1**. The correlation matrix among five pollutants and meteorological factors were showed in **Table 2**. PM_{10} was highly correlated with $PM_{2.5}$ (correlation coefficient r=0.906) and moderately correlated with SO_2 (r=0.64) and NO_2 (r=0.639). O_3 was lowly correlated with PM_{10} (r=0.119), $PM_{2.5}$ (r=0.126), SO_2 (r=0.101) and NO_2(r=–0.109).

Figure 2 showed the results from single-pollutant for respiratory, dermatology and ophthalmology at different time lags. The concentrations of PM_{10}, NO_2 affected the hospitalization risk consistently for respiratory diseases strongly for the single lags from 0 to 6 with the peak value 1.050 (95% CI, 1.037, 1.064) at lag0 and 1.065 (95% CI, 1.052, 1.079) at lag4, respectively. The RR of SO_2, $PM_{2.5}$ and O_3 were reached high at lag1 (RR=1.038, 95% CI, 1.025, 1.052), lag0 (RR=1.026, 95% CI, 1.014, 1.037) and lag2 (RR=1.0159, 95% CI, 1.001, 1.030), respectively. NO_2 as the biggest factor which influenced the children respiratory visits was

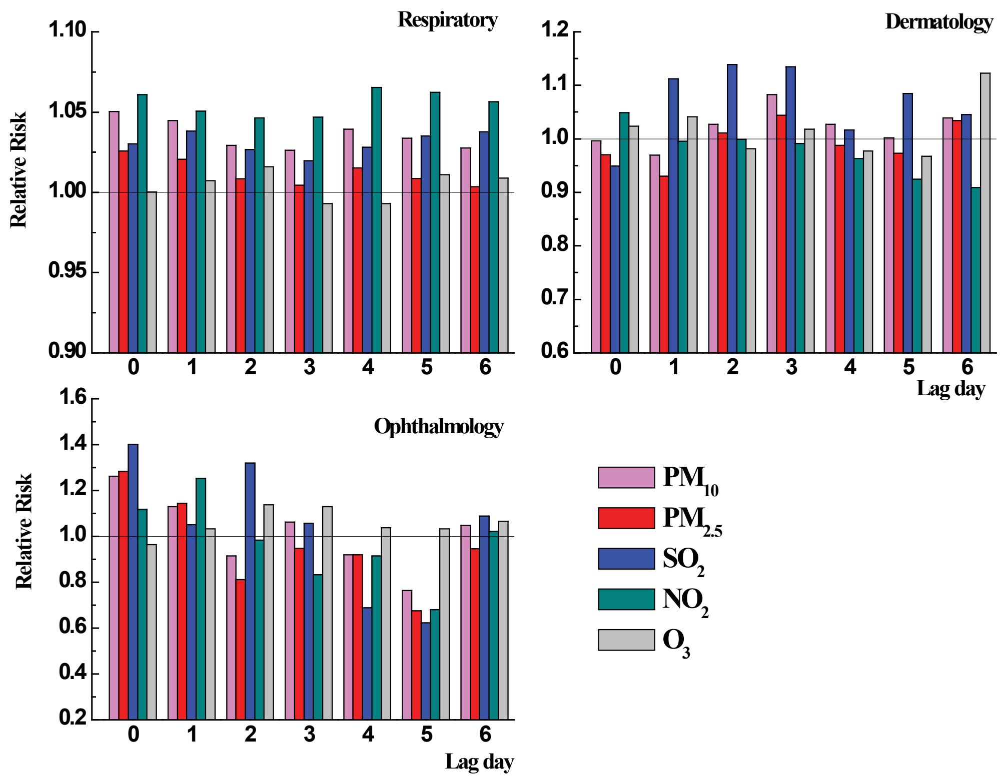

Figure 2 Percentage increase in daily hospital visits for pediatric illness per IQR increase in air pollutants for single lags 0 to 6. Note: (1) A statistical significant association with PM_{10}, SO_2, NO_2 for respiratory at lag0 to lag6 ($p<0.05$). (2) A statistical significant association with $PM_{2.5}$ for respiratory at lag0, lag1, lag4 ($p<0.05$). (3) A statistical significant association with O_3 for respiratory at lag2 ($p<0.05$).

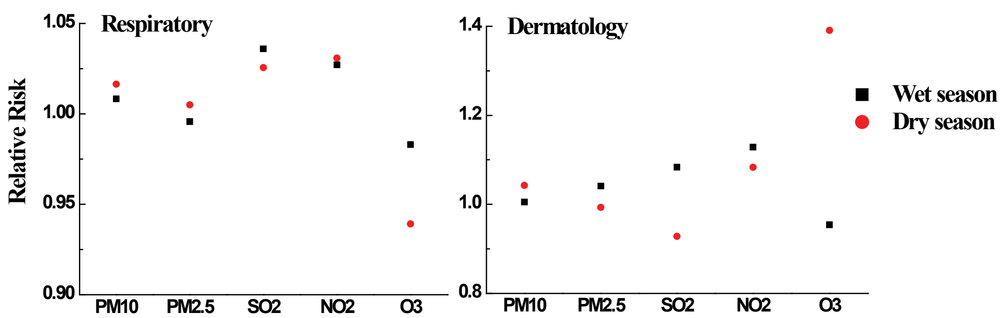

Figure 3 Relative risk in air pollutants with pediatric respiratory and dermatological disease at different season.

decreased from lag0 to lag3, then climbing a peak value at lag4. It showed that NO_2 has a lag effect. There was obvious relationship between SO_2 and dermatological illness with relative risk 1.112 (95% CI, 0.949, 1.302) at lag1, 1.139 (95% CI, 0.977, 1.328) at lag2 and 1.134 (95% CI, 0.974, 1.321) at lag3. For ophthalmic disease, the RR of PM_{10}, $PM_{2.5}$, SO_2, NO_2 remain a high value at lag0 with 1.261 (95% CI, 0.828, 1.922), 1.283 (95% CI, 0.899, 1.829), 1.401 (95% CI, 0.885, 2.220), 1.117 (95% CI, 0.718, 1.738), respectively.

To test whether any pollutant effects were dependent on season, an analysis of different pediatric illness at lag0 were separated into a wet season of May to October, and a dry season of November to April in **Figure 3**. Because the number of ophthalmic hospitalization visits was zero at most, the seasonal difference of relative risk was not estimated. As it is presented, the RR of PM_{10} and $PM_{2.5}$ for respiratory in dry season were higher than in wet season, while SO_2 and O_3 were opposite. For pediatric dermatology, $PM_{2.5}$, SO_2 and NO_2 have greater effect in wet season than in dry season.

Considering the seasonal differences, we estimated the RR in different season using lag structure in **Figures 4** and **5**. Relative risk with pediatric respiratory illness in wet season and dry season were showed in **Figure 5**. SO_2 showed mainly effect on hospital admission at lag6 (1.089, 95% CI, 1.052 to 1.027) in wet season, while PM_{10}, $PM_{2.5}$, SO_2, NO_2 showed weak effects at lag0, lag1 and

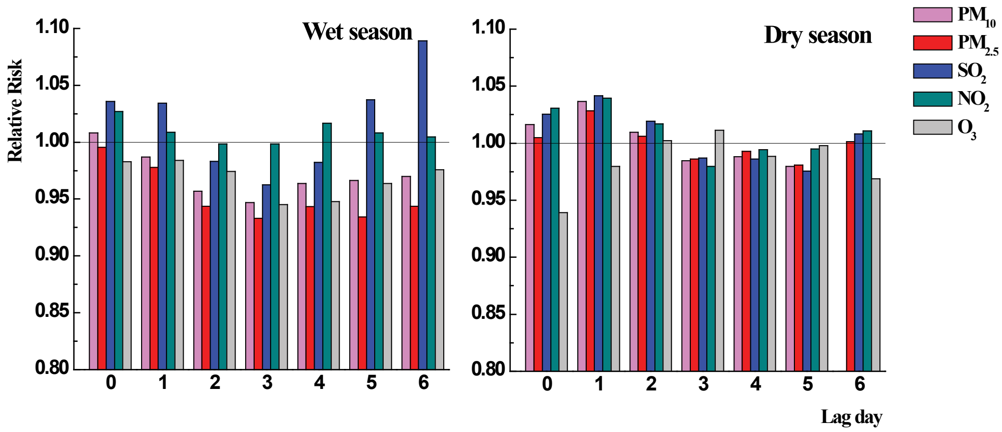

Figure 4 Relative risk of respiratory hospitalization visits at wet season and dry season.

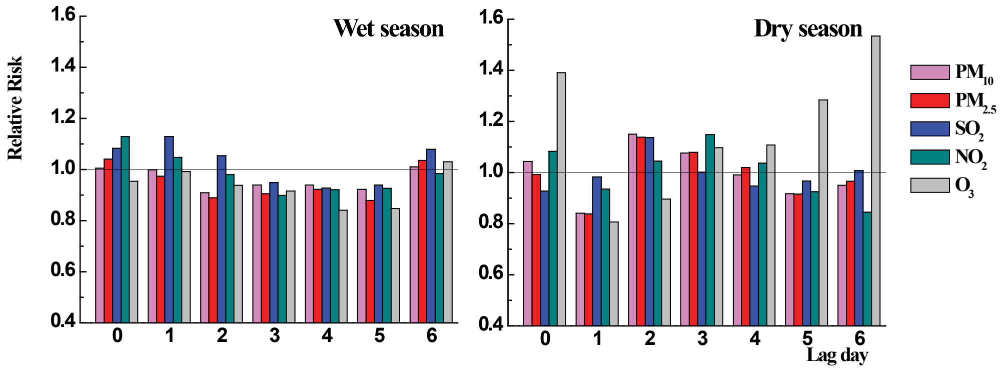

Figure 5 Relative risk of dermatological hospitalization visits at wet season and dry season.

lag2. In dry season, both pollutants have effect on respiratory illness for children at lag0, lag1 and lag2, especially at lag1, the relative risk of PM_{10}, $PM_{2.5}$, SO_2, NO_2 was 1.036 (95% CI, 1.005, 1.068), 1.028 (95% CI, 1.001, 1.056), 1.041 (95% CI, 1.010, 1.073) and 1.039 (95% CI, 1.002, 1.078), respectively.

O_3 presented strongly effect for dermatological disease at lag0, lag5 and lag6 in dry season with relative risk increased was 1.39 (95%CI, 0.701 to 2.758), 1.285 (95% CI, 0.663 to 2.484), 1.53 (95% CI, 0.774 to 3.039), respectively. NO_2 and SO_2 have some associations with pediatric dermatological disease at lag0 (1.128, 95% CI, 0.892 to 1.426) and lag1 (1.129, 95%CI, 0.732 to 1.739), respectively.

Results from GAM model with all pollutants to estimate the association for different illness at different lags (0 to 2) were presented in **Table 3**. The RR of PM_{10} was increased in multi-pollutant model for respiratory which means the adverse effect of PM_{10} was a slightly enhanced among air pollutants. SO_2 were increased among air pollutants while $PM_{2.5}$ was decreased for dermatological illness. PM_{10}, NO_2, SO_2, O_3 were raised at lag2 among air pollutants for ophthalmic disease.

Discussion

In this study, we analyzed the effects of air pollutants on hospital admissions for respiratory disease, dermatological disease and ophthalmic disease for children from January 1, 2014 to December 31, 2015 in Zhoushan.

PM_{10} and $PM_{2.5}$ showed robust associations with respiratory illness for children in this study. For PM_{10}, there were consistent averse effect from lag0 to lag6 and the highest relative risk was 1.050% with the increment of 36 $\mu g/m^3$ at lag0, which was in line with Lin et al. [18], who showed that the corresponding OR for PM_{10} with an increment of 12.5 $\mu g/m^3$ for respiratory infection was 1.25% in boys in children. However, Zhang et al. [7] carried out an analysis on ambient air pollutants and daily number of outpatient visits for otolaryngology during 2011 to 2013 and showed there was no obvious relationship between PM_{10} concentration changes and the number of outpatient visits. The incompatible results might be explained by: 1) different groups. Children were not able to avoid the particulate matters to get into their respiratory tract; 2) different components [19]. A higher proportion of sea salt might exist in the particulate matters in the studied area since it is a coastal city composed by many islands, and chronic exposure to sea salt PM may affect the vulnerable respiratory tract of children. For $PM_{2.5}$, the statistically significant was found at lag0, lag1 and lag4, and the effect reached the highest at lag0 with relative risk 1.026% for per 22 $\mu g/m^3$. Furthermore, many researches showed the detrimental association between $PM_{2.5}$

and respiratory diseases at different ages [2,29], which are in line with our research.

For gaseous pollutants, both NO_2 and SO_2 have consistently positive association with respiratory from lag0 to lag6, with the highest relative risk 1.065% for 15 µ g/m³ at lag4 and 1.016% for 5 µ g/m³ at lag1, respectively. López-Villarrubia et al. [2] presented NO_2 showed mainly its effect on hospital admission for all respiratory diseases in S/C de Tenerife. Tao et al. [22] showed that total respiratory disease hospitalization was increased by the increases of SO_2, NO_2 in Lanzhou, China. Several previous studies have linked respiratory infection to NO_2, SO_2, which had similar results with our study. The statistical significant effect of O_3 concentration was only found at lag2 with the relative risk 1.016%, which was in line with Middleton et al. [9]. The RR value for O_3 effect on respiratory from our study were not able to compare with other studies due to the different measuring technologies of risk.

In multi-pollutant models, we estimated the association between all air pollutants and daily hospital respiratory admission for children from lag0 to lag2. Contrasting with the single-pollutant model, the adverse effect of PM_{10} was increased while NO_2 was decreased. We also estimated the association between dermatological diseases and air pollutants, and between ophthalmic diseases and air pollutants. We observed statistical significant association on dermatological disease with SO_2 at lag1 and lag2 in multi-pollutant model. It demonstrated that other pollutants may stimulate the adverse effect of SO_2 on dermatological disease at lag days. This result was contributed to that it took some time for SO_2 to act on surface skin under the other air pollutants. We found no statistical significant on ophthalmic disease in multi-pollutant model.

Conclusion

Our study revealed a detrimental effect of low to moderate levels of air particulate matter and gaseous pollutants on hospital admissions for respiratory infection, dermatological disease and ophthalmic illness of children in Zhoushan area. We observed the consistent adverse effect with PM_{10} on respiratory disease from lag0 to lag6 and the higher RR were at lag0 and lag4. $PM_{2.5}$ had statistical significant association on respiratory at lag0, lag1 and lag4. Both SO_2 and NO_2 had statistical significant relationship with respiratory disease, while O_3 showed significant relationship only at lag2. We identified the season effect of association between air pollutant and children respiratory disease and dermatological illness and found the RR of PM_{10} and $PM_{2.5}$ for respiratory in dry season were higher than in wet season, while for pediatric dermatology, $PM_{2.5}$, SO_2 and NO_2 have greater effect in wet season than in dry season. We examined the relationship between particulate matter, gaseous pollutants and dermatological diseases, ophthalmic diseases, but in this article, we only found the robust relationship between them but no statistical significant. In multi-pollutant models, particulate matter and NO_2 had a great influence on respiratory. SO_2 is a factor that influenced the increased hospital admissions of dermatological disease when all pollutants were taken into account. Our study provides evidences to policy maker the importance of inducing the air pollution level.

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