The Effect of Air Pollution and Temperature on Pulmonary Function in Healthy People in Xi'an, China

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Research

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Abstract

Background: Temperature and air pollution has been reported to be associated with respiratory diseases. However, little is known about these effects on healthy people, and the potential interaction between the two factors is still uncertain. This study aims to estimate the effects of air pollution combined with temperature on lung function in healthy people.

Methods: The lung function of 428 healthy people was measured in Xi'an, Shaanxi province of Northwest China in summer and winter. Meanwhile, the daily concentrations of air pollution and temperature were obtained from monitoring stations. Statistical analyses were assessed by generalized estimating equations (GEEs).

Results: In winter, Every 10μg/m 3 increase of PM 2.5 concentration, PEF change amount is -0.015L/S(-0.028,-0.002), FEV1 is -0.007 L/S(-0.012,-0.001). The change is -0.022(-0.043,-0.001) and -0.010(-0.011,-0.009) after adjusting for SO 2 . In summer, PEF and FEV1 were were negatively correlated with the concentration of O3. We also found that temperature weaken the adverse effect of PM 2.5 on lung PEF in winter but aggravated effect of O3 on FEV1 in summer. Lag effects showed that Lag0 of FEV1, FEV1/FVC and FEF25-75% were more strongly associated with PM 2.5 .

Conclusions: Our findings indicate that Lung function was significantly negative correlated with O3 in summer and PM 2.5 in winter, and a higher temperature has a greater impact on lung function in both summer and winter in Xi'an.

Introduction

The pulmonary function test (PFT) is an effective tool to evaluate the respiratory system including airway resistance, lung compliance and diffusing capacity [1-3]. Clinically, it is a golden standard for physicians to diagnose some lung diseases, such as chronic obstructive pulmonary disease (COPD), asthma [4, 5].However, lung function is affected by many inner and extrinsic factors. Especially, extrinsic factors may damage the lung function.

Many studies have founded that climate change is related to respiratory health. TORCH (Towards a Revolution in COPD Health) studies showed that COPD exacerbations and hospitalization were more frequent in winter[6].Studies have also reported the acute effects of air pollution in patients with respiratory diseases[7-9].Epidemiological studies have reported associations between particulate matter or temperature and human health[10].However, the results are inconsistent even conflicted. Zhang's study[11]showed that $PM_{2.5}$ had acute adverse effect on lung function of healthy people, and it had antagonistic effect on temperature. Zheng[12]also performed a study on temperature and air pollution on lung function, but come to the opposite conclusion. They founded synergistic effects of PM and high temperatures on cardiopulmonary mortality. Therefore, it is necessary to clarify the relationship between air pollution, temperature and lung function. Besides, few studies have investigated the effects in healthy adults, and even fewer have examined the effects of air pollution combined with climate on lung function simultaneously.

This study therefore aimed to investigate the effects of temperature and air pollution on lung function among healthy people in Xi'an. Therefore, test of pulmonary function were repreatedly performed in 428 healthy adult volunteers, We hypothesized that $PM_{2.5}$ interacted with temperature on lung function, and the effects of different temperature levels on lung function were different, based on published findings of previous study[13].

Materials And Methods

Study participants and design

The study was conducted in 11 communities of Xi'an city (34°15'44"N,108°56'16"E) with the adult residents by multistage cluster sampling in summer (from July 23th to August 23th) and in winter (November 26th to December 27th). Participation in the survey was voluntary. 428 of expected 531 person-tines of lung function test were performed from 11 communities in summer, among these, 296 adults could not be traced in winter, Finally, 132 adults participanted in the study in winter. The inclusion criteria for eligible residents were as follows: Adult, and residence>3 years in Xi'an city. Patients with history of respiratory diseases, allergic constitution and smoking history were excluded.. A flowchart is presented in Fig.1

Air pollution exposure

The concentrations of air pollutants and the meterological date were derived from the regional observing system of the ministry of the environment and Meterological Date Sharing Service System, respect, respectively (generated from the 11 state-controlled monitoring stations across Xi'an). The 11 communities included in this study are the closest to the monitoring station, and the distance is within 1 kilometers. The averages of $PM_{2.5}$ (particulate matter with an aerodynamic diameter<2.5 μm), nitrogen dioxide (NO_2), and SO_2 concentrations and temperature were included. we divide the temperature into three classes: low, normal and high temperature.The low and high temperature were defined as those days on which the higheset or lowest daily average temperature were >95% or <5% of the study date, respectively[14].

Lung function were measured by spirometry

Date on lung function status, including peak expiratory flow rate (PEF, L/sec), forced expiratory volume in 1s(FEV1,L), forced vital capacity (FVC,L), FEV1/FVC and FEF25-75%(L/S) were determined using a portable electronic FGC-A+ spirometer (Spirobank, GTM, Medical International Research, Rome Italy) three times a day. All the researchers in this study follow the guideline of ATS/ERS. Pulmonary function test is conducted under the guidance of two professional respiratory therapists. At the time of examination, the subjects took an end sitting position and ensured that their heads did not lean back or look down excessively. First of all, the forced expiratory test was carried out. Under the guidance of two respiratory therapists trained in standard portable pulmonary function test, the correct way for patients to breathe completely and forcefully and continuously was adopted. Stop breathing for 1s after the maximum deep inspiratory till no further inspiratory, put the breathing filter into the inlet, then exhale quickly and forcefully until no further exhalative; after the heart rate is stable, carry out the same operation, repeat 3 times, and select the best value.Then forced inspiratory test was performed, take the abdominal breathing, put the breathing filter into mouth. make the maximum exhalation, operation again after the heart rate and breathing are stable, and repeat three times. lung functoin was measured 3 times and the optimal value was selected.

Statistical analysis

All the statistical date was analysis by SPSS17.0 software (SPSS Inc., Chicago, IL, USA). Pearson correlation was used to analyze the correlation between pollutants concentrations and temperature. The lung function data of these volunteers were self-control in summer and winter. Since there is autocorrelation between the individual lung function data measured repeatedly in this study, the generalized estimating equations (GEES) were using to evaluate the multivariable correlation. This method is a statistical model for fitting the dependent variables of various distributions such as normal distribution and binomial distribution, which can better solve the problems related to the dependent variables in the longitudinal data[15]. The estimated value of parameters was calculated, and the difference was statistically significant when $P < 0.05$).

For parameter estimation, the daily measured pulmonary function of each subject was taken as the dependent variable. Single-pollutant and two pollutant models were used to estimate the effects of $PM_{2.5}$ and temperature on summer and winter, the covariates included (gender, height, season, BMI, 24h average temperature and age). SO_2 or NO_2 was also adjusted for in the two-pollutant models. The effect of increase of pollution concentration per 10ug/m^3 on PEF, FEV1, FVC, FEF25-75 and FEV1/FVC of participants was studied. β value is used as the index to measure the change of lung function index for every 10 ug/m^3 increase of particle concentration. Considering the lag effect of air pollution on health, the impact of pollution level with a lag of 3 days is also analyzed.

Results

Descriptive statistics of exposure and health data

During the year 2018, the basic information of subjects was shown in Table1. Of the 428 participants, 43% were female. Mean age of total participants was 56.24±16.52. The age ranged from 18 to 86. Mean height and weight were 166.28±8.65 and 60.27±8.82, respectively. Besides, BMI was 24.15±3.12. The PEF in summer and winter were 5.17±3.29 and 4.32±1.88, respectively. And FEV1 were 2.63±0.73 and 2.21±0.75.The detailed characteristics and FVC, FEV1/FVC and FEF25-75 index were also summarized in Table2. The difference of FEV1, FEV1/FVC and FEF25-75 were statistically significant in summer and winter (P<0.01).

The associations between temperature and air pollution

Daily average concentrations of air pollutants during this study period are shown in Fig2.The concentrations of SO_2, NO_2 , $PM_{2.5}$ and O3 were highest on 27th, 22th,27th Dec and 8th Aug,respectively. Characteristics of temperature and air pollutants during the two periods are presentd in Table 3 and Table 4. The daily mean temperature was 30.35±2.24℃ in summer and 1.02±3.29℃ in winter. And the daily mean concentrations of $PM_{2.5}$, SO_2 ,NO_2 and O3 were 31.13±10.07μg/m^3, 7.64±1.39μg/m^3 ,142.79±32.98 and 32.78±6.72μg/m^3 in summer and 105.56±51.38μg/m^3, 23.58±9.66μg/m^3, 27.94±10.41 and 69.45±25.45μg/m^3 in winter, respectively. The temperature and concentrations of O3 in summer were higher than those in winter. The concentrations of SO_2, NO2 and $PM_{2.5}$ were higher in winter than in summer (P<0.01). Both $PM_{2.5}$ concentrations were exceeding WHO guideline for $PM_{2.5}$ (25μg/m^3).

The spearman correlation coefficients for pollutans and temperature are presented in Table 5. In summer, $PM_{2.5}$ were high positively correlated with NO2(r_s=0.286) and negative with O3(r_s=-0.244). In winter, $PM_{2.5}$ were positively correlated with NO2(r_s=0.705), SO_2 (r_s=0.588) and temperature(r_s=0.23) and negetive with O3(r_s=-0.495) in winter. Temperature were positively correlated with O3 and negative with NO2 both in summer and winter. 4.

Correlation between lung functon and air pollutants in different temperature classes

We divided temperature into three classes. In summer, As shown in Table 6, for every 10μg/m^3 increase of O3 concentration, PEF, FEV1 and FVC change are -0.149 L/S (-0.351,-0.052,) -0.021 L/S (-0.034,-0.008), and -0.019L/S (-0.033,-0.006) in normal group. PEF, FEV1 and FVC change amount are -0.011 L/S (-0.005,-0.026), -0.012 L/S (-0.006,-0.017) and 0.01 L/S (0.004,0.016) in higher temperature group. In Winter (Table 7), For every 10μg/m^3 increase of $PM_{2.5}$, PEF, FEV1 and FVC change amount are -0.052 L/S (-0.015,-0.088), -0.008 L/S (-0.014,-0.002) and -0.008 L/S (-0.0001,-0.016) in higher temperature group. FEV1 change is -0.007 L/S (-0.015,-0.001) in normal temperature group.

Analysis of the effects of PM2.5 and Temperature on lung function in different pullutant model

Table 8. shows the relationship between air pollutants ($PM_{2.5}$, SO_2 ,NO_2 and O3) and temperature on lung function, In winter, a 10 μg/m^3 increase of $PM_{2.5}$ was associated with a decrease of -0.015 L/S(-0.028,-0.002) and -0.007 L/S (-0.012,-0.001) in PEF and FEV1, respectively. After adjusting for SO_2, change of -0.022 L/S (-0.043,-0.001) and -0.010 L/S (-0.011,-0.009) respectivly, in two-pollutant model. In summer, a 10 μg/m^3 increase of O3 was associated with a decrease of -0.005 L/S (-0.009,-0.002) and -0.062 L/S (-0.093,-0.031) in PEF and FEV1, respectively. A 1 °C increase in temperature and 10 μg/m^3 increase of O3 were accosiated with a -0.122 L/S (-0.160,-0.084) decreas in FEV1.Moreover, the interactive effects between temperature and $PM_{2.5}$ in winter PEF and FEV1 were found to be significantly positive, an increae in temperature reduced the adverse effect of $PM_{2.5}$ on lung function. A 1 °C increase in temperature and 10 μg/m^3 increase of $PM_{2.5}$ were accosiated with a 0.007 L/S (0.001,0.012) increase in PEF.

Lagged effects of $PM_{2.5}$ and Temperature on Lung function

Fig. 3 shows the lag effect of $PM_{2.5}$ and temperature on PEF, FEV1and FEV1/FVC. The change in PEF was significantly negatively associated with the concentrations of $PM_{2.5}$. The change was greatest on lag1(-0.006[95% CI:-0.012,-0.001]).For FEV1,FEV1/FEVC and FEF25-75,the effect of $PM_{2.5}$ was greatest on Lag 0(-0.003[95% CI:-0.005,0.000],-0.058[95%CI:-0.095,-0.022 and-0.002[95% CI:-0.003,0.000]), and the different were significantly.

In addition, the cumulative lags of temperature (Lag0) were more corelated with both PFE and FEV1/FVC. The temperature of Lag 1 was related to FEV1 and FEF25-75.

Discussion

Air pollution has become a major threat of public health worldwide, causing up to 7 million premature deaths annually[16, 17]. In recent years, the developing countries in Asia, such as India and China, have begun large-scale industrialization of urbanization process, so they have been struggling with serious air pollution[18-20]. Besides, Xi'an is located in the lowest part of Guanzhong Basin, which makes it difficult for pollutants to be discharged, just like a “garbage bags”[21, 22]. In addition, as an important industrial center, Xi'an bears the responsibility of poor air quality in the area with serious air pollution. Therefore, the research on the relationship between air pollutants and public health in Xi’an is more important and urgent. Moreover, this study is still in the development stage in Northwest China and has not been studied in Xi'an.

In this study we recruited 428 healthy people from 11 communities in Xi’an city to estimate the air pollution combined with temperature on lung function. We founded that there was a negative correlation between $PM_{2.5}$ and lung function index (PEF and FEV1)in winter. This results is consisting with previous studies conducted in Tangerang and Makassar[23], exposure to $PM_{2.5}$ showed association with decreased lung function. This study also found that there was a negative correlation between lung function and ozone concentration in summer. O3 is a secondary pollutant generated by the reaction of oxygen, nitrogen oxides and volatile organic compounds under the action of light. It has become the main source of air pollution in summer, Studies have shown that O3 exposure is associated with airway inflammation. Therefore, we hypothesized that lung function deficits is related to airway inflammation caused by O3 in summer. A study conducted by Hwang BF also come to the some conclusion [24].

However, it seems too hasty to conclude that $PM_{2.5}$ concentration is related to lung function, because the influence of temperature is ignored, which is also an important factor on lung function. In order to make up for this defect. We also analyzed the relationship between temperature and lung function. The results demonstrated that there was significant correlation between high temperature and lung function in both summer and winter. To explain this conclusion, the following factors may take into consideration. In summer, It has been proposed that impaired thermoregulation in the setting of higher temperatures may trigger physiologic changes that ultimately reduce lung function[25]. In addition, high temperature in winter is related to ariway drying, which leading to bronchoconstriction and decrement of lung function. Furthermore, In this study we founded that greater pollution especially O3 and $PM_{2.5}$, were exposured to relatively warm days. Two study conducted in china also come to the same conclusion[26,11].

Some previous studies have reported about the effects of pullution and temperature on lung function[27,11]. However, The results are inconsistent, In this study we found that temperature and O3 had synergistic effect on FEV1 in summer, but it weakened the effect of $PM_{2.5}$ on PEF in winter. The possible unifying explanation is related to the frequency of outdoor activities, A previous study of COPD patients found that higher outdoor temperature was associated with worse respiratory symptoms, this association was only present on dats when participants went outdoors[28]. We also found that SO_2 and $PM_{2.5}$ have synergistic effect on lung function, in winter. This may be due to excessive coal combustion caused by heating, which aggravates the pollution of SO_2. Therefore, the seasonal variation of the impact of pollutants on lung function is explained by the changes of pollutant sources and pollutant contents.

There are two major strengths in this study. This is the first article to study the effect of $PM_{2.5}$ and temperature on lung function in healthy people in Northwest China. Second, Other articles usually refer to PEF and FEV1 as indicators of lung function. In this study, five indicators were included which are more comprehensive.

However, the limitations of this study worth noting. First, the population participated in the study are mainly yellow, middle-aged men and women living in Northwest China, which limits the universality of the population. Secondly, measurement of community temperature and pollutants ignores the potential significant differences that may affect individual residential temperature. Third, research period is relatively short, only 30 days are included in each quarter, which is not enough to represent the temperature change of the whole season. Last, our study focuses on two extreme temperature seasons, summer and winter, and ignores the seasons with mild climate conditions in spring and autumn.

Conclusions

In conclusion, our research suggests that exposure to O3 in summer and $PM_{2.5}$ in winter have an acute adverse effect on lung function and there was significant correlation between high temperature and lung function among healthy people in both summer and winter in Xi’an.Further big number of subjects from different countries needed to be included to confirm these findings.

Abbreviations

GEEs=generalized estimating equations; $PM_{2.5}$=particulate matter with an aerodynamic diameter<2.5 μm; NO_2=nitrogen dioxide; SO_2=sulfur dioxide; PEF= peak expiratory flow; FEF25-75= forcedexpiratory flow from 25-75%; FEV1/FVC=; PET= pulmonary function test; COPD= chronic obstructive pulmonary disease; TORCH= towards a revolution in COPD Health; BMI= Body Mass Index.

Declarations

AcknowledgmentsNo

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due other analyses are proceeding but are available form the corresponding author on reasonable request.

Ethics approval and consent to participate

The study protocol was approved by the Institutional Ethics Committee of the First Affiliated Hospital of Xi'an Medical College (No.XYYFY2017LSK-017).All participants signed the consent form before entering the study.

Author contributions: Y.Y. designed the study, conducted analysis, and drafted the work; J.Z made substantial contribution to design of the work , interpretation of the work, and revising the draft for important intellectual contant; Y.T. made substantial contribution to analysis and interpretation of the work; X.D. revised the draft for important intellectual content; H.C. ,H.M.Z and J.Z.Z. helped with access to the data, data management, and analysis; S.Y.W made substantial contributions to the conception of the work, revising the draft for important intellectual content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests: The authors declared that they have no conflicts of interest.

Patient consent for publication Not required.

Ethics approval: The study was deemed form ethical approval by the institutional review board of the first affiliated hospital of Xi’an medical university (No. **XYYFY2017LSK-017**).

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Tables

Table 1. Summary statistics and comparison of characteristics between genders.

Characteristic	Male(n=245)	Female(n=183)	Total (n=428)
Age(year)	59.32±13.21	52.79±11.56	56.24±16.52
Height(cm)	172.25±7.68	160.45±6.67	166.28±8.65
Weight(kg)	63.65±6.28	57.35±9.26	60.27±8.28
BMI (kg/m^2)	25.58±2.15	22.42±2.43	24.15±3.12

Table 2 Index of Lung function in Summer and winter

Characteristic	Summer (n=428)	Winter(n=132)	*P*
PEF(L/S)	5.17±3.29	4.32±1.88	0.616
FEV1(L)	2.63±0.73	2.21±0.75	<0.01
FVC(L)	4.58±0.41	2.97±0.38	0.346
FEV1/FVC(%)	84.99±4.91	83.24±5.27	<0.01
FEF25-75%((L/S)	2.52±0.79	1.57±0.86	<0.01

Table 3. Descriptive statistics of air pollutant concentrations and temperature.

Characteristic	Summer	Winter	*P*
Temp(℃)	30.35±2.24	1.02±3.29	<0.01
SO_2(μg/m^3)	7.64±1.39	23.58±9.66	<0.01
NO_2(μg/m^3)	32.78±6.72	69.45±25.45	<0.01
$PM_{2.5}$(μg/m^3)	31.13±10.07	105.56±51.38	<0.01
O3(μg/m^3)	142.79±32.98	27.94±10.41	<0.01

Table 4 Descriptive statistics for the air pollutants in different temperature classes

Pollutant	Summer			Winter		
	Low Tem	Normal Tem	High Tem	Low Tem	NormalTem	High Tem
PM2.5	29.78±10.76	32.46±8.28	29.85±11.8	100.06±47.04	100.00±66.45	114.6±51.78
SO2	7.61±0.91	8.01±1.61	7.29±1.19	26.61±9.28	27.67±13.16	18.3±6.13
NO2	33.93±4.72	34.3±6.22	29.86±6.74	70.33±21.77	72.00±35.99	67.5±26.77
O3	135.63±17.83	154.09±32.89	130.86±34.7	26.85±11.04	38.00±3.38	27.5±9.67

Table 5. Spearman correlation coefficients between daily ambient air pollutant and temperature in summer and winter

	Summer					Winter				
	PM2.5	NO2	SO2	O3	Tem	PM2.5	NO2	SO2	O3	Tem
PM2.5	1	0.286**	0.032	-0.244**	-0.027	1	0.588**	0.705**	-0.495**	0.23**
NO2		1	0.575**	0.032	-0.146**		1	0.575**	0.032	-0.146**
SO2			1	0.150**	0.025			1	0.150**	0.025
O3				1	0.111*				1	0.111*
Tem					1					1

Table 6 Correlation coefficients of lung functon and air pollutants in different temperature classes in summer

Pollutant	**Temperature**					
	Low		**Normal**		**High**	
	β (95%CI)	***P***	**β (95%CI)**	***P***	**β (95%CI)**	***P***
PEF						
PM2.5	0.744(-1.138,2.627)	0.438	0.011(-0.014,0.036)	0.406	0.009(-0.026,0.043)	0.619
SO2	-2.384(-6.875,2.106)	0.127	-0.004(-0.010,0.001)	0.109	-0.359(-0.931,0.213)	0.262
NO2	-0.291(-3.866,3.283)	0.873	0.013(-0.026,0.053)	0.513	0.061(-0.007,0.128)	0.079
O3	0.633(-0.857,0.983)	0.893	-0.149(-0.351,-0.052)	0.046	-0.011(-0.005,-0.026)	0.005
FEV1						
PM2.5	-0.025(-0.059,0.010)	0.163	-0.001(-0.004,0.002)	0.482	0.012(-0.006,0.030)	0.194
SO2	-0.198(-0.372,0.023)	0.076	-0.108(-0.185,-0.031)	0.006	-0.161(-0.345,0.024)	0.097
NO2	0.434(-0.137,1.005)	0.054	0.052(0.014,1.054)	0.061	0.027(-0.007,0.062)	0.120
O3	-0.017(-0.035, 0.001)	0.074	-0.021(-0.034,-0.008)	0.001	-0.012(-0.006,-0.017)	0.0001
FVC						
PM2.5	0.544(-1.411,2.499)	0.585	0.002(-0.001,0.005)	0.267	0.017(-0.002,0.035)	0.075
SO2	-1.203(-11.061,8.656)	0.811	-0.082(-0.195,0.032)	0.077	-0.194(-0.386,-0.002)	0.052
NO2	-0.385(-4.098,3.328)	0.839	0.524(0.002,1.045)	0.067	-0.008(-0.044,0.029)	0.684
O3	0.368(-0.588,1.323)	0.451	-0.019(-0.033,-0.006)	0.005	0.01(0.004,0.016)	0.001
FEF25-75						
PM2.5	-0.027(-0.063,0.009)	0.143	0.006(-0.009,0.020)	0.490	-0.011(-0.029,0007)	0.226
SO2	-0.157(-0.339,0.025)	0.091	-0.017(-0.103,0.070)	0.708	0.187(-0.013,0.387)	0.136
NO2	-0.065(-0.134,0.003)	0.062	0.0001(-0.003,0.003)	0.922	0.020(-0.016,0.055)	0.275
O3	-0.175(-0.039, 0.004)	0.118	-0.023(-0.054,0.008)	0.537	0.002(-0.004,0.007)	0.619
FEV1/FVC						
PM2.5	0.744(-1.138,2.627)	0.438	-0.035(-0.124,0.054)	0.447	0.005(-0.127,0.138)	0.935
SO2	-2.385(-6.875,2.106)	0.127	-0.229(-0.761,0.303)	0.398	0.869(-0.018, 1.757)	0.067
NO2	-0.292(-3.866,3.283)	0.873	0.689(0.049,1.328)	0.058	-0.123(-0.381,0.134)	0.348
O3	0.063(-0.857,0.983)	0.893	-0.012(-0.032,0.008)	0.244	-0.011(-0.052,0.031)	0.620

Table 7 Correlation coefficients of lung functon and air pollutants in different temperature classes in winter

Pollutant	Temperature					
	Low		Normal		High	
	β (95%CI)	*P*	β (95%CI)	*P*	β (95%CI)	*P*
PEF						
PM2.5	-0.009(-0.031,0.013)	0.412	-0.072(-0.425,0.282)	0.690	-0.052(-0.015,-0.088)	0.006
SO2	0.024(-0.077,0.125)	0.638	-0.092(-0.563,0.380)	0.545	-0.015(-0.166,0.137)	0.851
NO2	-0.008(-0.064,0.047)	0.770	-0.085(-0.185,0.016)	0.099	0.014(-0.023,0.051)	0.461
O3	-0.004(-0.044,0.037)	0.884	0.077(-0.048,0.202)	0.230	0.081(-0.014,0.175)	0.093
FEV1						
PM2.5	-0.065(-0.090,0.219)	0.413	-0.007(-0.015,-0.001)	0.045	-0.008(-0.014,-0.002)	0.008
SO2	0.025(-0.011,0.062)	0.176	-0.282(-1.144,0.581)	0.522	-0.030(-0.138,0.078)	0.499
NO2	-0.003(-0.023,0.017)	0.790	-0.027(-0.071,0.017)	0.223	-0.002(-0.016,0.012)	0.771
O3	-0.006(-0.021,0.008)	0.407	-0.011(-0.065,0.044)	0.705	0.013(-0.003,0.028)	0.121
FVC						
PM2.5	-0.009(-0.021,0.002)	0.105	-0.077(-0.138,0.291)	0.484	-0.008(-0.0001,-0.016)	0.050
SO2	0.051(-0.002,0.103)	0.060	-0.342(-1.538,0.852)	0.574	0.031(-0.049,0.110)	0.451
NO2	-0.004(-0.033,0.025)	0.773	-0.028(-0.089,0.033)	0.375	-0.004(-0.023,0.016)	0.735
O3	-0.012(-0.033,0.010)	0.288	-0.033(-0.108,0.043)	0.398	0.048(-0.001,0.097)	0.057
FEF25-75						
PM2.5	-0.005(-0.010, 0.0001)	0.077	0.49(-0.024,0.123)	0.189	0.565(0.002,1.129)	0.442
SO2	-0.003(-0.026,0.020)	0.807	-0.299(-0.710,0.113)	0.154	0.020(-0.013,0.053)	0.240
NO2	0.006(-0.007,0.019)	0.343	0.012(-0.009,0.033)	0.273	-0.005(-0.013,0.003)	0.240
O3	-0.008(-0.017,0.001)	0.088	-0.003(-0.029,0.023)	0.817	0.543(0.022,1.063)	0.526
FEV1/FVC						
PM2.5	-0.053(-0.196,0.091)	0.473	0.261(-2.623,3.146)	0.859	0.845(0.027,1.662)	0.233
SO2	-0.305(-0.967,0.357)	0.366	-1.267(-17.359,14.82)	0.877	-0.04(-0.548,0.468)	0.878
NO2	0.022(-0.342,0.386)	0.906	-0.121(-0.942,0.701)	0.774	-0.006(-0.13,0.118)	0.925
O3	-0.068(-0.334,0.198)	0.615	0.215(-0.804,1.230)	0.679	0.043(-0.009,0.096)	0.102

Table 8 The effect of PM2.5 and temperature and interaction term on lung function in different pollutant model

	Summer				Winter			
	PEF		FEV1		PEF		FEV1	
	β (95%CI)	*P*	β (95%CI)	*P*	β (95%CI)	*P*	β (95%CI)	*P*
Single-pollutant model								
PM2.5	0.988 (-0.799,2.775)	0.278	0.012(-0.008,0.032)	0.247	-0.015(-0.028,-0.002)	0.028	-0.007(-0.012,-0.001)	0.014
Temp	-0.114(-0.266, 0.038)	0.126	-0.079(-0.457, 0.298)	0.119	0.122(-0.718,0.962)	0.776	0.084(-0.238,0.406)	0.610
PM2.5*Tem	-0.371(-1.039,0.297)	0.276	-0.006(-0.015,0.002)	0.152	0.007(0.001,0.012)	0.025	0.003(0.0001,0.005)	0.090
Two-pollutant model (SO_2)								
SO2	-0.297(-3.211,2.617)	0.246	-0.062(-0.160,0.036)	0.217	-0.039(-0.128,0.051)	0.398	-0.017(-0.051,0.017)	0.331
PM2.5	-0.110(-0.306,0.086)	0.273	-0.001(-0.001,0.004)	0.313	-0.022(-0.043,-0.001)	0.016	-0.010(-0.011,-0.009)	0.013
Temp	1.005(-0.671,2.680)	0.240	0.031(-0.007,0.069)	0.110	0.018(-0.027,0.064)	0.433	0.009(-0.009,0.026)	0.332
PM2.5*Tem	-0.040(-0.11,0.031)	0.270	-0.001(-0.002,0.0001)	0.313	0.001 (0.0001,0.001)	0.655	0.001(0.0001,0.001)	0.735
Two-pollutant model (NO_2)								
NO2	-0.723(-2.391,0.945)	0.101	-0.009(-0.030,0.012)	0.400	-0.014(-0.05,0.022)	0.44	-0.010(-0.024,0.004)	0.142
PM2.5	-0.054(-0.167,0.060)	0.272	-0.007(-0.025,0.001)	0.137	-0.006(-0.012,0.001)	0.434	-0.001(-0.001, 0.0001)	0.375
Temp	0.150(-0.087,0.387)	0.215	0.511(0.001,1.020)	0.065	0.006(-0.008,0.019)	0.426	0.002(-0.003,0.007)	0.360
PM2.5*Tem	-0.007(-0.019,0.005)	0.266	0.0001(-0.001,0.001)	0.056	-0.0001(-0.0001,0.001)	0.359	0.0001(-0.0001,0.0001)	0.456
Two-pollutant model (O_3)								
O_3	-0.005(-0.009,-0.002)	0.012	-0.062(-0.093,-0.031)	0.021	0.023(-0.038,0.085)	0.458	0.008(-0.015,0.031)	0.510
PM2.5	0.008(-0.007,0.024)	0.284	0.0001(-0.001,0.0001)	0.114	-0.001(-0.001,0.0001)	0.359	-0.001(-0.001,0.001)	0.491
Temp	-0.043(-0.221, 0.134)	0.069	-0.122(-0.160,-0.084)	0.039	-0.003(-0.033,0.026)	0.822	0.001(-0.011,0.012)	0.875
PM2.5*Tem	-0.003(-0.010,0.003)	0.286	-0.0001(0.0001,0.001)	0.091	0.0001(0.0001,0.0010)	0.039	0.0001(-0.001,0.0001)	0.059

Figures

Fig.1

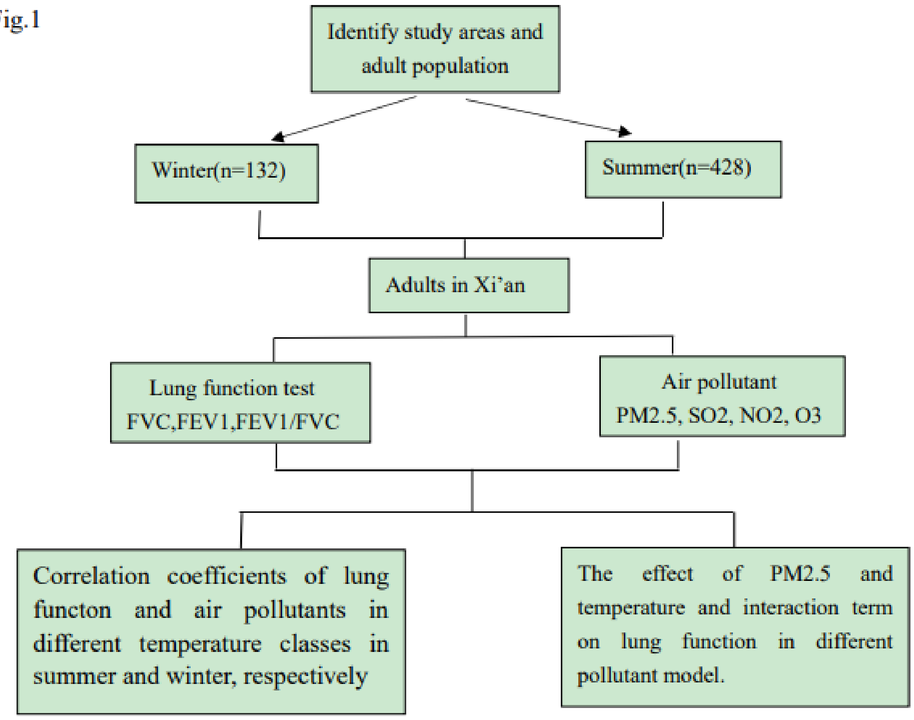

Figure 1

Research flowchart

Fig.2

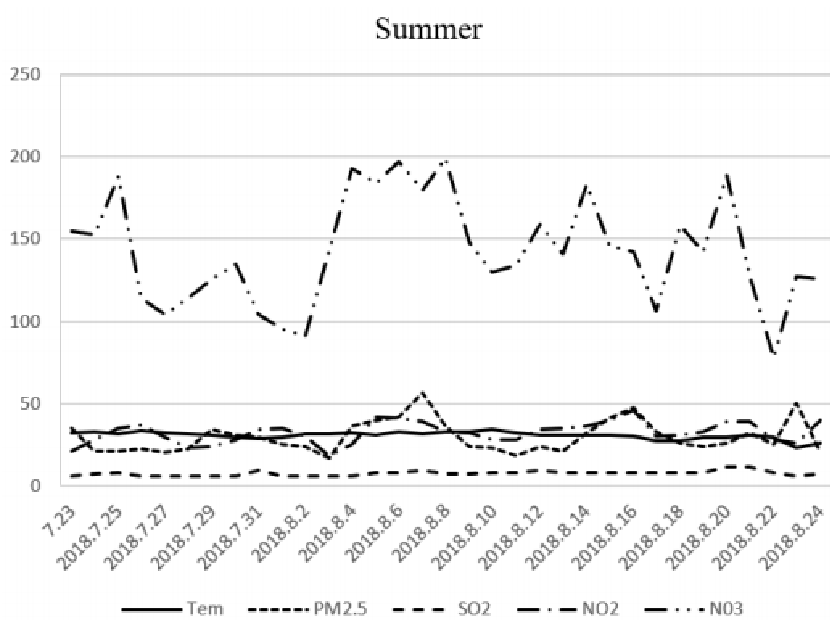

Figure 2

The concentrations of Temperature, PM2.5, SO2 and NO2 for each subject during the study period.

Fig.3

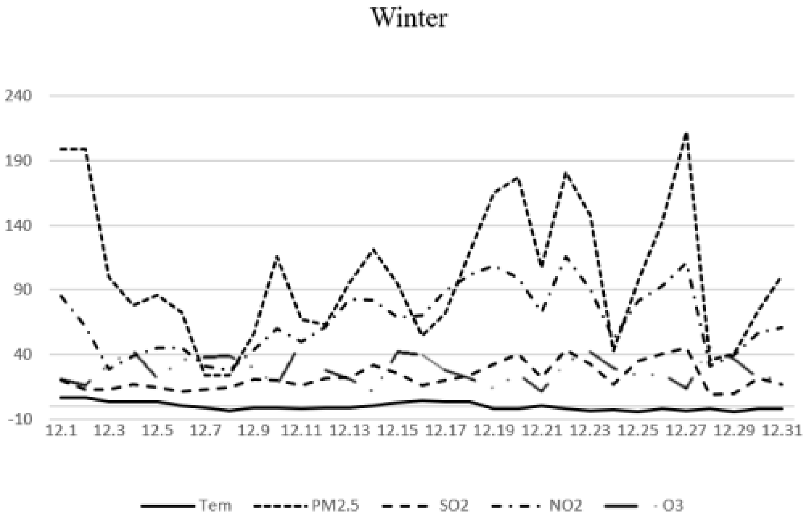

Figure 3

Lagged effects of PM2.5 and Temperature on PEF, FEVA and FEF25-75 in single-pollutant model.

Fig.4

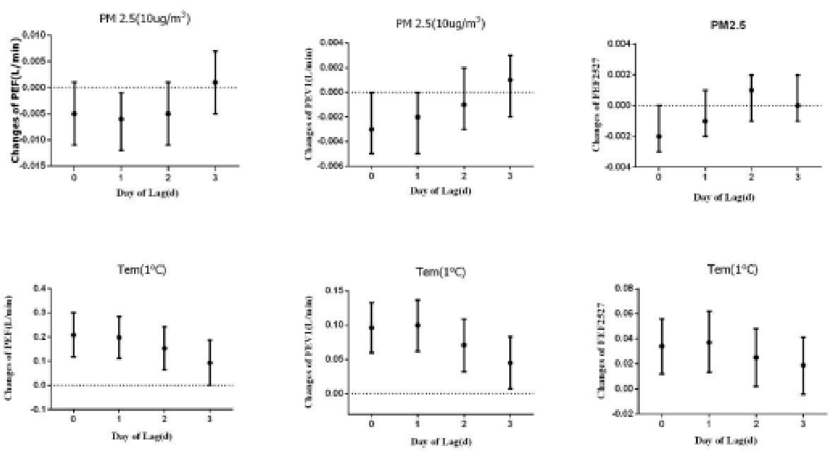

Figure 4

[No caption provided for this figure.]