High-normal blood pressure (prehypertension) is associated with PM2.5 exposure in young adults

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Abstract

We aimed to examine $PM_{2.5}$ exposure, blood pressure (SBP and DBP) measurement, hypertension risk factors and to assess the association between $PM_{2.5}$ exposure and hypertension among young adults. The mean SBP was 117.78 mmHg, with 11.22% high-normal blood pressure (prehypertension) and 2.51% hypertension (≥ 140 mmHg). DBP was 75.48 mmHg with 26.37% prehypertension and 4.53% hypertension (≥ 90 mmHg). The median $PM_{2.5}$ in the past year was 31.79 μg/m^3, with highest in winter (49.33 μg/m^3), followed by spring (37.34 μg/m^3), autumn (29.64 μg/m^3) and summer (24.33 μg/m^3). Blood pressure was positively correlated with age, height, weight, BMI, daily smoking, alcohol consumption, mental stress and stay-up in the past 1 year. After adjustment for the covariates, each 10 μg/m^3 increase in $PM_{2.5}$ was associated with SBP (Day 1 = 1.07 mmHg, Day 3 = 1.25 mmHg, Day 5 = 1.01 mmHg) and DBP (Day 1 = 1.06 mmHg, Day 3 = 1.28 mmHg, Day 5 = 1.29 mmHg, Day 15 = 0.87 mmHg, Day 30 = 0.56 mmHg). Exposure in winter was associated with 1.17 mmHg increase in SBP. Logistic models showed for every 1 μg/m^3 increase of $PM_{2.5}$, SBP in Day 1 and Day 5 was increased by 6% and 4%, and DPB by 3% and 16%, respectively. SBP was increased by 13% in spring and 7% in winter, and DBP was increased by 12% in winter. Our data suggest a certain prevalence of pre- or hypertension among young population, which is associated with short-term fluctuation and season-specific exposure of $PM_{2.5}$.

1. Introduction

Cardiovascular disease is the leading cause of deaths worldwide. It is estimated that 17.8 million people die for it globally in 2017, among which hypertension is the main risk factor for cardiovascular disease and is considered the most important cause of disability and death worldwide (Zhang et al., 2020). A recent study finds that compared with data in 1958 ~ 1959, 1979 ~ 1980, 1991, 2002 and 2012, the crude prevalence rate of hypertension among Chinese residents aged 18 years and above ranges from 18.0 to 44.7% between 2012 to 2015, and the overall prevalence is increasing (Yin et al., 2021). China Health and Nutrition Survey shows that teenagers aged from 6 to 17 years old suffer an increased risk of hypertension from 7.1% in 1991 to 13.8% in 2009, and 6.4% of school-age children have abnormally high blood pressure, and a considerable part of them will develop hypertension in adulthood (Wang et al., 2019b). These results indicate that the incidence of hypertension is gradually becoming younger and has become an important public health problem.

The pathogenesis of hypertension is complex and has many influencing factors. In addition to genetics, diet, and lifestyle, changes in blood pressure are also related to air pollution (Braziene et al., 2020; Zeng et al., 2021). Air pollutant-associated health effects have long been concentrated and studied. It can promote or induce the development of hypertension through imbalance of the autonomic nervous system, oxidative stress, immune inflammation, and endothelial dysfunction (Zhao et al., 2019a). In recent years, epidemiological studies have reported that air pollution, especially $PM_{2.5}$, may be one of the pathogenic factors of hypertension, and is related to the incidence and mortality of cardiovascular diseases (Yan et al., 2021). However, the differences between the levels of $PM_{2.5}$ and the research design in different regions make the conclusion inconsistent (Rabito et al., 2020). This study aims to investigate $PM_{2.5}$ level at a fixed-point monitoring site, blood pressure changes in young adults and the related risk factors, to confirm the relationship between blood pressure and $PM_{2.5}$ exposure by adjusting individual lifestyle and behavior.

2. Methods

2.1 Study population

As undergraduates are from different department and classes, a cluster stratified sampling method was adopted to recruit the participants of different ages between October 2019 and November 2019 in Jiaxing University, Jiaxing City, China. The sampling area (30°77' N, 120°76' E) is located in the northern part of Zhejiang province. Those who lived in the local area for more than one year, with no family history of hypertension, pulmonary, cardiovascular, and other chronic diseases were included in the study. This study was approved by the institutional review boards of all participating institutions including the Human Ethical Committee of Jiaxing University Medical College (JUMC-IRB-2018)

2.2 Questionnaires

An initial number of 900 questionnaires were delivered and the final collected number was 838 (93%). The questionnaire was designed according to the research purpose, domestic and foreign related literature and the actual situation of the preliminary survey. The reliability and validity of the preliminary questionnaire were tested in order to improve the existing problems. The content of the questionnaire involves three aspects: i) demographic information including gender, birth date, family income per year, residence time living in local, family history of hypertension, pulmonary, cardiovascular, diabetes and other acute or chronic diseases; ii) cognitive behavior of hypertension including diagnostic criteria, how to control hypertension, complications and treatment of hypertension, checking blood pressure regularly at home or in the hospital, etc. iii) lifestyle and activities such as intake of salty foods, smoking, excessive drinking, exercise, mental stress, and stay-up, etc.

2.3 Blood pressure measurement

The blood pressure measurement including systolic blood pressure (SBP) and diastolic blood pressure (DBP) was scheduled from 08:00 to 10:00 every morning, which was performed under the trained professional researchers. Before the measurement, participants are required to sit still for at least 5 minutes. The blood pressure of the right brachial artery was measured via a medical-grade arm digital automatic sphygmomanometer BA-806 with a testing error of 3 mmHg (± 0.4 kpa) (Panasonic, Japan). The measurement is repeated for 3 times each. The interval between measurements was at least half a minute. Clinical hypertension standard was set at ≥ 140/90 mmHg, and high-normal blood pressure (prehypertension) at 130–139/80–89 mmHg (Lurbe et al., 2019).

2.4 $PM_{2.5}$ data monitoring

The sampling site of Jiaxing University was one of the environmental monitoring sites in Jiaxing City (Fig. 1). Air pollution indicators including $PM_{2.5}$ exposure were measured every day. We collected $PM_{2.5}$ data from the National Environmental Monitoring Center (http://www.cnemc.cn/). In this study, the length of exposure for participants were divided into short-term exposure based on the exposure accumulation in the past 1 month (Day 1, 3, 5, 7, 15, 30) (Li et al., 2016; Wellenius et al., 2013), and relative long-term exposure in the past one year (spring, summer, autumn, winter) (Tan et al., 2018).

2.3 Statistical analysis

Microsoft Excel and SPSS22.0 software were applied to manage and analyze the data. Measurement data were expressed as mean ± standard deviation (SD), and categorical data were described as the number of cases (%). $PM_{2.5}$ level was skew distribution and presented as median ± SE (min ~ max), and the comparison between multiple groups was performed by the Kruskal-Wallis H test with a further comparison by post hoc test. Cognitive and behavioral factors related to hypertension were multi-class data, and the comparisons between groups were analyzed by χ^2 test. Pearson and Spearman correlations were used to analyze the risk factors of hypertension. Generalized linear mixed model was further used to analyze the relationship between blood pressure and $PM_{2.5}$ levels (Ren et al., 2019). In the model, SBP and DBP were respectively used as dependent variables, $PM_{2.5}$ normally distributed after logarithmic transformation was as factors, and the observed individual number was used as the main variable in the random effect model, with statistically significant risk factors as covariates (confounding factors) to be adjusted. Factors and covariates were included in the main effects of the fixed model, with results of the model effect test to determine whether it was statistically significant (β; 95% confidence). β coefficient indicated a unit change in blood pressure caused by every 10 $\mu g/m^3$ increase of $PM_{2.5}$ exposure. The binary logistic regression model was applied to analyze the relationship between $PM_{2.5}$ exposure and the risk of hypertension. Because of the quite limited number of hypertension subjects, the model used a binary classification of high-normal blood pressure (SBP ≥ 130 mmHg or DBP ≥ 80 mmHg) as the dependent variable, and short-term or long-term $PM_{2.5}$ as a covariate with adjustment for confounding factors (Curto et al., 2019). OR value represented the risk of a unit change in blood pressure for an increase of 1 $\mu g/m^3$ of $PM_{2.5}$ concentration. A p value less than 0.05 or 0.01 in a two-tailed test was considered to be statistically significant.

3. Results

3.1 Characteristics of the study population

The general characteristics were shown in Table 1. The average age of subjects was 19.19 ± 1.35 (years), and there were 327 male (39.02%) and 511 female (60.98%). The average systolic blood pressure (SBP) was 117.78 mmHg with high-normal blood pressure accounting for 11.22%, and ≥ 140 mmHg accounting for 2.51%. The diastolic blood pressure (DBP) was 75.48 with high-normal blood pressure accounting for 26.37%, and ≥ 90mmHg accounting for 4.53%. There were 354 participants (42.24%) having a family history of hypertension.

Table 1
General information of study subjects (n = 838).

	Cases (n, %)	Mean ± SD
Age, years		19.19 ± 1.35
Gender		
Males	327 (39.02)	
Females	511 (60.98)	
Family income per year		
< 3	116 (13.84)	
3 ~ 10	399 (47.61)	
> 10	323 (38.55)	
Height, m		1.66 ± 0.84
Weight, kg		58.65 ± 6.63
BMI		21.26 ± 3.40
Systolic blood pressure (SBP), mmHg		117.78 ± 4.75
130–139	94 (11.22)	
≥ 140	21 (2.51)	
Diastolic blood pressure (DBP), mmHg		75.48 ± 5.03
80–89	221 (26.37)	
≥ 90	38 (4.53)	
Family history of hypertension		
No	351 (41.89)	
Yes	354 (42.24)	
Not sure	133 (15.87)	

3.2 Cognition and behavior of hypertension

There were statistical differences in the awareness rate of hypertension ($p < 0.001$) (Table 2). Further analysis found that the correct rate of the diagnostic criteria for hypertension was the highest (41.41%), and the correct rate of hypertension treatment accounted for 90.33%. Among the behavioral factors, blood pressure measured at least half a year accounted for 44.03%, and at least once a week accounted for only 4.06%; eating greasy food, smoking daily, excessive drinking, regular physical exercise, mental stress and staying up late in the past year were all statistically different ($p < 0.001$). Among them, 25.54% like to eat greasy food, 35.08% to eat salty food, only 17.18% without mental stress in the past year, and 7.76% without frequent staying up late.

Table 2
Factors associated with cognition and behavior of hypertension.

Factors	**Cases n (%)**	χ^2	***p***
Diagnostic criteria		259.73	< 0.001
140/90 mmHg	347 (41.41)		
160/95 mmHg	123 (14.68)		
130/80 mmHg	103 (12.29)		
Unknown	265 (31.62)		
Complications		670.40	< 0.001
Stroke/coronary heart disease/tumor	684 (81.62)		
Unknown	154 (18.38)		
Regular check at home or in the hospital		562.43	< 0.001
At least once a week	34 (4.06)		
Once in a quarter	91 (10.85)		
At least half a year	369 (44.03)		
Uncertainty	344 (41.06)		
Treatment		2574.74	< 0.001
Medicine treatment only	25 (3.00%)		
Non-medical treatment	19 (2.27%)		
Both	757 (90.33%)		
Unknown	37 (4.40%)		
Whether the lower the blood pressure, the better hypertension is		1976.67	< 0.001
Yes	9 (1.07%)		
No	774 (92.36%)		
Unknown	55 (6.57%)		
Eating salty food		39.11	< 0.001
Like	294 (35.08%)		

Factors	Cases n (%)	χ^2	*p*
Dislike	331 (39.50%)		
Anyway	213 (25.42%)		
Eating oily food		210.34	< 0.001
Like	214 (25.54%)		
Dislike	440 (52.50%)		
Anyway	184 (21.96%)		
Smoking every day		2791.92	< 0.001
0 cigarette	783 (93.44%)		
1 ~ 5 cigarettes	28 (3.34%)		
6 ~ 10 cigarettes	15 (1.79%)		
> 10 cigarettes	12 (1.43%)		
Excessive alcohol consumption (≥ 2 bottles of beer or wine		1679.99	< 0.001
Always	26 (3.10%)		
Sometimes	172 (20.53%)		
None	640 (76.37%)		
Regular exercise		714.33	< 0.001
Frequently	216 (25.78%)		
Sometimes	563 (67.18%)		
None	59 (7.04%)		
Mental stress in the past year		676.83	< 0.001
Frequently	125 (14.92%)		
Sometimes	569 (67.90%)		

Factors	Cases n (%)	χ^2	*p*
None	144 (17.18%)		
Stay-up		431.25	< 0.001
Frequently	311 (37.11%)		
Sometimes	462 (55.13%)		
None	65 (7.76%)		

3.3 $PM_{2.5}$ concentrations

$PM_{2.5}$ level was statistically different within short-term periods (χ^2 = 30.82, $p < 0.001$) (Fig. 2A). The level in the past 30 days (Day 30: Median ± SE = 27.87 ± 0.32 μg/m3) was significantly lower than that of the past 1 day (38.00 ± 0.65 μg/m^3), 5 (38.20 ± 0.68 μg/m^3) and 15 Days (31.70 ± 0.52 μg/m^3) (All $p <$ 0.001). Long-term $PM_{2.5}$ levels between different seasons were statistically different (χ^2 = 1970.59, $p <$ 0.001), with a median level of 31.79 μg/m^3 (SE: ± 0.32) (Fig. 2B). Further analysis found that the highest level of $PM_{2.5}$ was in winter (49.33 ± 0.65 μg/m^3), followed by spring (37.34 ± 0.26 μg/m^3), autumn (29.64 ± 0.30 μg/m^3) and summer (24.33 ± 0.15 μg/m^3).

3.4 Potential factors related with blood pressure

Pearson and spearman correlation analyses showed that both SBP and DBP were positively associated with age, height, weight, BMI, smoking every day, and stay-up (Table 3). Smoking every day, excessive alcohol consumption and mental stress in the past year had weak association with SBP and DBP. Gender showed an opposite association with SBP and DBP, indicating gender as an influencing factor.

Table 3
Correlation analysis of various factors of blood pressure.

Relevant factors	SBP		DBP	
	r	*p*	*r*	*p*
Age	0.399	< 0.001	0.230	< 0.001
Gender	− 0.404	< 0.001	− 0.328	< 0.001
Height	0.301	< 0.001	0.263	< 0.001
Weight	0.345	< 0.001	0.280	< 0.001
BMI	0.228	< 0.001	0.171	< 0.001
Family income	0.000	0.997	− 0.046	0.168
Family history of hypertension	− 0.004	0.899	0.010	0.758
Eating salty food	− 0.006	0.862	0.027	0.424
Eating oily food	0.028	0.400	0.073	0.028
Smoking every day	0.070	0.034	0.073	0.028
Excessive alcohol consumption	0.127	< 0.001	0.131	< 0.001
Regular exercise	− 0.059	0.076	− 0.034	0.264
Mental stress in the past year	0.090	0.007	0.124	< 0.001
Stay-up	0.253	< 0.001	0.179	< 0.001

Further we examined the relationship between $PM_{2.5}$ exposure and blood pressure via generalized linear mixed model and adjusted the potential covariates including age, gender, height, weight, BMI, smoking every day, eating oily food, excessive alcohol consumption, mental stress and stay-up (Fig. 3). Short-term $PM_{2.5}$ at Day 1 (β: 1.07; 95%CI: 0.86, 1.82), Day 3 (β: 1.25; 95%CI: 1.14, 2.03), Day 5 (β: 1.01; 95%CI: 0.78, 1.89) were related to SBP changes; Day 1 (β: 1.06; 95%CI: 0.12, 2.24), Day 3 (β: 1.28; 95%CI: 0.89, 2.46), Day 5 (β: 1.29; 95%CI: 0.95, 2.40), Day 15 (β: 0.87; 95%CI: 0.08, 1.94) and Day 30 (β: 0.56; 95%CI: 0.07, 1.63) were related to changes in DBP. In regard to long-term exposure, $PM_{2.5}$ level in winter (β: 1.17; 95%CI: 0.25, 2.31) was associated with SBP.

3.5 Risk of hypertension

Binary logistic regression models for the association of short-term or long-term exposure with SBP and DBP were assessed, in which the blood pressure was classified into normal blood pressure and high-normal blood pressure as the dependent variable. The models were adjusted for age, gender, height, weight, BMI, eating greasy food and salty food, every day smoking, excessive alcohol consumption and mental stress in the past year (Table 4). An increment of 1.06 mmHg (95% CI: 1.01, 2.11) and 1.04 mmHg (95% CI: 0.97, 1.71) in SBP, and 1.03 (95% CI: 1.01, 1.79) and 1.16 (95% CI: 1.02, 2.01) in DBP was positively associated with short-term $PM_{2.5}$ exposure at Day 1 and Day 5, respectively. $PM_{2.5}$ exposure in spring and winter increased the risk of SBP per unit increase of 1.13 mmHg (95% CI: 0.94, 9.70) and 1.07 mmHg (95% CI: 0.86, 7.26), respectively. $PM_{2.5}$ exposure in winter increased the risk of DBP per unit increase of 1.12 mmHg (95% CI: 0.74, 5.38).

Table 4
Binary logistic regression analysis of $PM_{2.5}$ exposure for hypertension risk.

Variables	SBP				DBP			
	Wald	**OR**	**95% CI**	***p***	**Wald**	**OR**	**95% CI**	***p***
Model 1								
Day 1	8.80	1.06	(1.01, 2.11)	0.001	5.47	1.03	(1.01, 1.79)	0.011
Day 3	1.08	0.98	(0.39, 2.44)	0.965	1.29	1.07	(0.95, 1,81)	0.258
Day 5	8.97	1.04	(0.97, 1.71)	0.001	7.15	1.16	(1.02, 2,01)	0.001
Day 7	2.48	0.37	(0.11, 1.28)	0.110	0.11	1.06	(0.75, 1.49)	0.744
Day 15	1.56	0.53	(0.20, 1.43)	0.211	0.86	0.85	(0.61, 1.18)	0.353
Day 30	1.45	0.52	(0.19, 1.41)	0.227	0.82	0.86	(0.57, 1.19)	0.341
Model 2								
Spring	5.80	1.13	(0.94, 9.70)	0.016	0.64	1.14	(0.82, 1.59)	0.423
Summer	0.75	1.85	(0.46, 7.49)	0.386	0.36	0.68	(0.20, 2.31)	0.546
Autumn	0.49	1.04	(0.33, 3.23)	0.945	0.41	1.13	(0.77, 1.66)	0.520
Winter	10.37	1.07	(0.86, 7.26)	0.001	6.23	1.12	(0.74, 5.38)	0.001
Year average	0.15	1.21	(0.45, 3.30)	0.700	0.92	1.18	(0.84, 1.68)	0.337

4. Discussion

$PM_{2.5}$ has become the primary air pollutant affecting public health. Studies have shown that the current $PM_{2.5}$ exposure in most areas of China is still at a relatively high level, and the improvement in health benefits attributed to the decline of the exposure level is less than the decline itself (Zhang et al., 2019). The daily limit of $PM_{2.5}$ for Grade-I is 35 μg/m^3, 70 μg/m^3 for Grade-II, and over 250 μg/m^3 indicating serious pollution (Zhou et al., 2016). Results of this study show that the daily average level in the past week was as high as 40.33 μg/m^3, and the lowest 34.50 μg/m^3 was close to Grade-I. The average $PM_{2.5}$

level in the past year was 31.79 μg/m^3, and the highest was in winter up to 49.33 μg/m^3. Our data has similar trend with a previous study that $PM_{2.5}$ concentration in winter of Jiaxing city is more serious with obvious differences in different seasons, which is greatly affected by pollutant transportation from surrounding cities (Zhao et al., 2019b). This indicates that there are still certain problems in the air quality in local. Though overall $PM_{2.5}$ in long term is low, the exposure level exceeds the national standard limit within days, and season-specific especially for winter should be alerted. Therefore, the monitoring in this place should be continuously strengthened.

Hypertension is one of the risk factors for cardiovascular disease. There is 23.2% (≈ 244.5 million) of the Chinese adult population ≥ 18 years of age having hypertension, and 41.3% (≈ 435.3 million) having high-normal blood pressure (prehypertension) according to the Chinese guideline (Wang et al., 2018). Data in this study found that the average SBP was 117.78 mmHg, and the prehypertension accounted for 11.22%, and hypertension (≥ 140 mmHg) for 2.51%. The average DBP level was 75.48 mmHg with prehypertension 26.37%, and hypertension (≥ 140 mmHg) 4.53%. The prevalence of prehypertension and hypertension is lower than that in other studies according to a prior investigation in 2017 in China showing that the hypertension prevalence ≥ 18 years among 14, 220 permanent residents is up to 46.9% (Shen et al., 2017). A recent study from a cohort of 20 year-follow-up in China manifests that compared with the young and middle-aged population with no cardiovascular disease at baseline BP or lower than 120/80 mmHg, the risk of cardiovascular disease including coronary atherosclerotic heart disease (coronary heart disease), stroke, and cardiovascular death is significantly increased in the pre-hypertensive stage at 130–139/80–89 mmHg, and more than 60% of the pre-hypertensive middle-aged and young people has blood pressure progressed to ≥ 140/90 mmHg after 15 years, with their cardiovascular disease risk three times higher than that of normal BP (Qi et al., 2018). In addition, we found that the accuracy of response to the diagnostic criteria of hypertension among young individuals was no more than a half (41.41%). Among the behavioral factors, BP measurement at least once a week accounted for only 4.06%, but quite a few liked to eat oily food (25.54%) and salty food (35.08%). A small number of young students (17.18%) had mental stress in the past year, and most students stayed up late (versus 7.76% no stay-up). These results suggest that young adults are under unreasonable diet and lifestyle with little awareness of the risk of hypertension. Health promotion and education of hypertension for young people should be paid attention, and those with high-normal blood pressure should receive clinical check.

In the study, both SBP and DBP to varying degrees were positively associated with age, height, weight, BMI, smoking every day, smoking every day, excessive alcohol consumption, mental stress in the past year and stay-up. Studies have shown that the occurrence and development of hypertension is closely related to age, overweight and obesity, family history of hypertension, alcohol consumption, high uric acid, and high C-reactive protein (Flack and Adekola, 2020). This demonstrates that diet, lifestyle, and mental state are related to changes in blood pressure, and unreasonable diet, lifestyle, and mental stress are potential risk factors for hypertension. In recent years, studies have found that $PM_{2.5}$ exposure levels are related to hypertension, but there are differences between the research conclusions. Ren et al. (Ren et al., 2019) used a general linear model to analyze the association between daily and fixed monitoring point $PM_{2.5}$ exposure and blood pressure among young people in short-term 1 to 3 days, exhibiting that $PM_{2.5}$ exposure is related to the reduction of ambulatory blood pressure, and after adjusting for age and other confounding factors, SBP and DBP was decreased by 0.54 mmHg and 0.22 mmHg for an increase of 10 μg/m^3 $PM_{2.5}$, respectively, while decreased by 0.95 mmHg and 0.74 mmHg at fixed monitoring stations, respectively. Baumgartner et al. (Baumgartner et al., 2011) analyzed the relationship between 24-h $PM_{2.5}$ exposure and blood pressure among female adults ≥ 25 years by mixed linear models, and find that an elevation of 10 μg/m^3 increase in $PM_{2.5}$ is associated with an increase of 2.2 mmHg in SBP and 0.50 mmHg in DBP. Our study found that SBP was increased by 1.07, 1.25, and 1.01 mmHg for every 10 μg/m^3 increase in $PM_{2.5}$ at Day 1, Day 3, and Day 5, respectively, and DBP increased by 1.06, 1.28, 1.29, 0.87 and 0.56 mmHg at Day 1, 3, 5, 15, and 30, respectively. For long-term exposure, an increase of 1.17 mmHg in SBP was associated with each 10 μg/m^3 increase in $PM_{2.5}$ level in winter. These results show that the $PM_{2.5}$ exposure level in this area is related to the increase in blood pressure. Further we adjusted the potential confounding factors, finding that for every 1 μg/m^3 increase in $PM_{2.5}$, the risk of SBP was increased by 6% and 4% at Day 1 and Day 5, respectively, and DBP risk increased by 3% and 16%, respectively. SBP risk was increased by 13% and 7% in spring and winter, respectively, and DBP in winter increased by 12%. Some studies have shown that by modifying blood pressure–related factors such as psychosocial stress (Hicken et al., 2014), gender and age (Baumgartner et al., 2011), the influence of short-term $PM_{2.5}$ on blood pressure is changed, suggesting that potential risk factors should be considered when assessing the exposure association with $PM_{2.5}$. The concentration of $PM_{2.5}$ also plays a critical role as exposure in winter or spring is relatively higher than other seasons, and makes a significant change in SBP or DPB. We also tried to explore the detailed linkage between $PM_{2.5}$ exposure and blood pressure by stratification of gender or age, but the model failed to distinguish due to the limited sample size of subjects when separating into different gender or age. Thus we adjusted the gender and age in the whole model. The mechanism of $PM_{2.5}$ exposure for blood pressure change also has been extensively studies. $PM_{2.5}$ exposure can activate the inflammatory response in the arcuate nucleus of the thalamus in the acute blood pressure response, leading to up-regulations of pro-inflammatory factors and inhibitory factors kappaB kinase (IKK)/nuclear factor kappaB (NF-κB), which is related to abnormal activation of the cerebral sympathetic nervous system (Ying et al., 2014). $PM_{2.5}$ exposure can also induce inflammation and oxidative stress in the circulatory system of hyperlipidemia rats, activating the JNK/P53 pathway and promoting hypercoagulability and cardiomyocyte apoptosis (Wang et al., 2019a). Therefore, $PM_{2.5}$ exposure can affect blood pressure by activating oxidative stress or inflammation.

This study also has certain limitations. First of all, the scope and time of indoor or outdoor activities of subjects are different, and the $PM_{2.5}$ monitoring at a fixed station cannot accurately reflect their daily exposure level, and there is a certain bias. Secondly, the clinical recommendation of blood pressure measurement is to maintain a resting state when you wake up in the morning, and the measured blood pressure is relatively accurate. This study selected a time period in the morning which had little effect on the stable blood pressure individuals, but it might bring some changes to those with significant fluctuating people. Air pollutant exposure is quite complex posing a wide range of health effects on the population, but we did not include all such as PM_{10}, SO_2, NO, etc. We only focused on the relationship between $PM_{2.5}$ exposure and blood pressure changes since the concentration of $PM_{2.5}$ pollutant is highlighted and typical in this area.

5. Conclusions

In summary, there is certain prevalence of prehypertension and hypertension among young college students in local. In addition to age, gender, height, weight, BMI, eating oliy and salty food, smoking every day, excessive alcohol consumption and mental stress in the past year, $PM_{2.5}$ in short-term periods or season-specific exposure is related to changes in blood pressure, which can increase the risk of prehypertension. Therefore, attention should be paid to the early prevention of prehypertension and hypertension, to effectively reduce the incidence of hypertension in the young population.

Declarations

Ethics approval and consent to participate

This study was approved by the Human Ethical Committee of Jiaxing University Medical College (JUMC-IRB-2018), and the informed consent was given to all subjects prior to research.

Consent to publish

All participants consented to publish.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no conflict of interest.

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Authors' contributions

Huaze Ye: Questionnaire design, survey, collection and project implementation; Jie Tang: Conceptualize the idea, statistical analysis, paper draft; Leiqin Luo: Questionnaire design, survey, collection, project implementation, data analysis; Tianjian Yang: Questionnaire collection, PM2.5 data collection; Kedi Fan: Questionnaire collection, PM2.5 data collection; Long Xu: Conceptualize the idea, financial support, statistical analysis, editing the paper.

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Figures

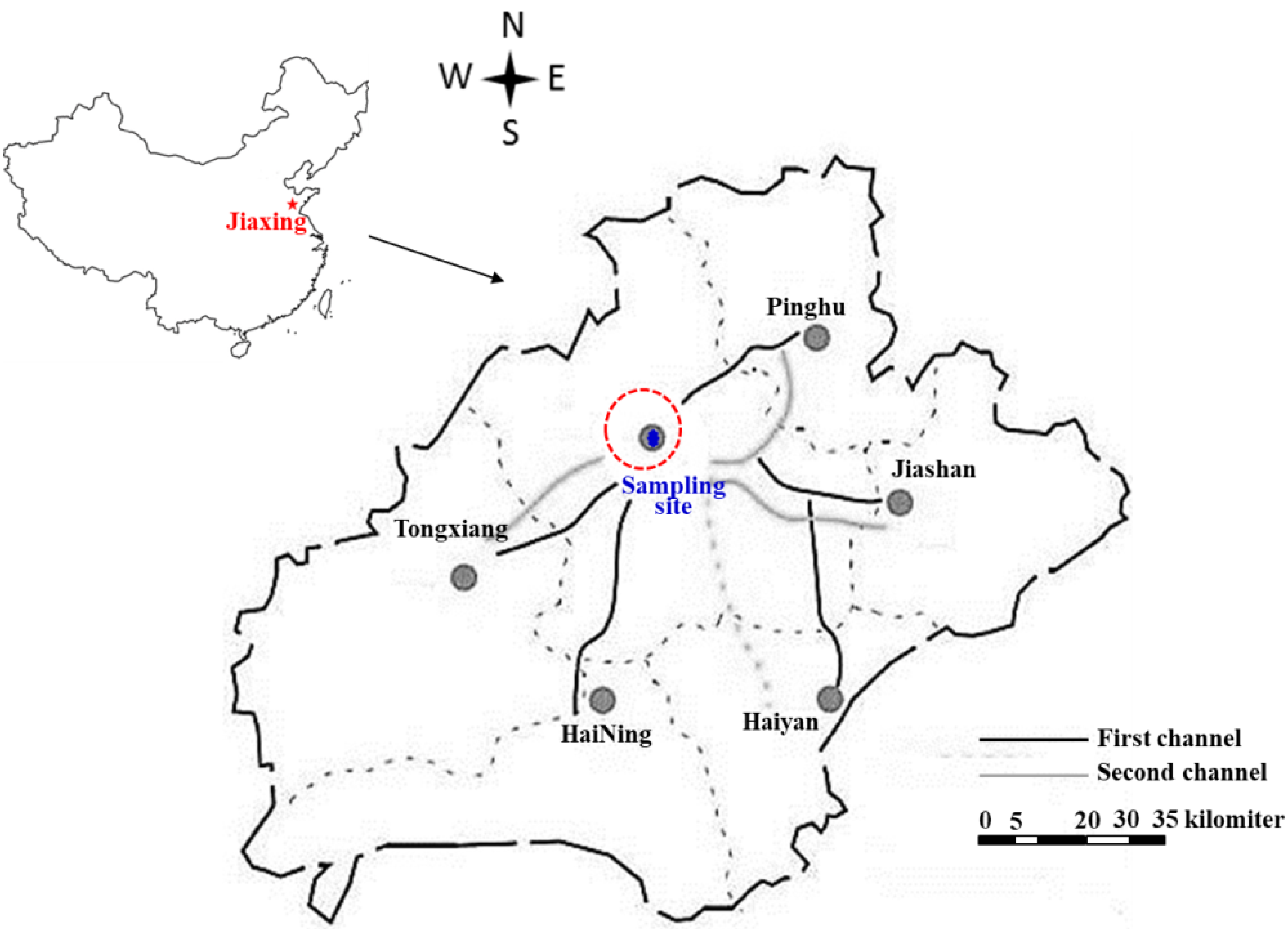

Figure 1

The geographic distribution of sampling area in this study

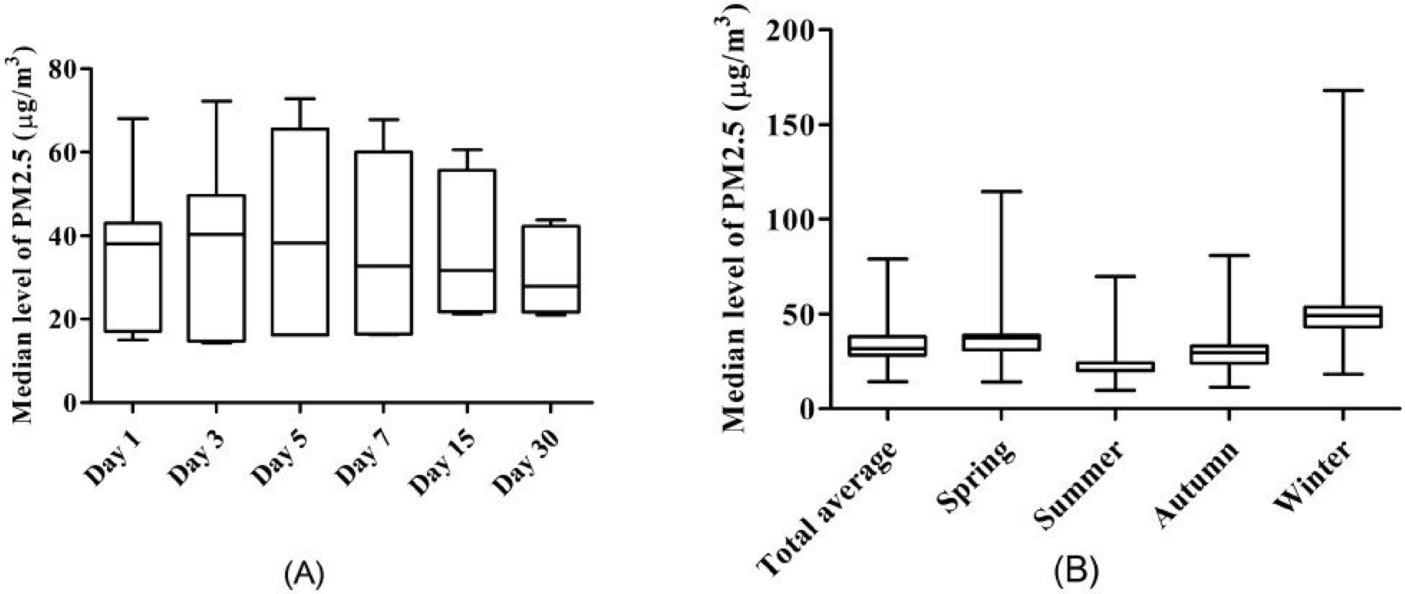

Figure 2

PM2.5 levels in the past year. (A) Short-term PM2.5 concentrations in Day 1, 3, 5, 7, 15 and day 30; (B) Long-term PM2.5 changes in different seasons. Box plot was applied, and the upper line of the box was maximum value, the lower line for the minimum value and the inside line for the median value.

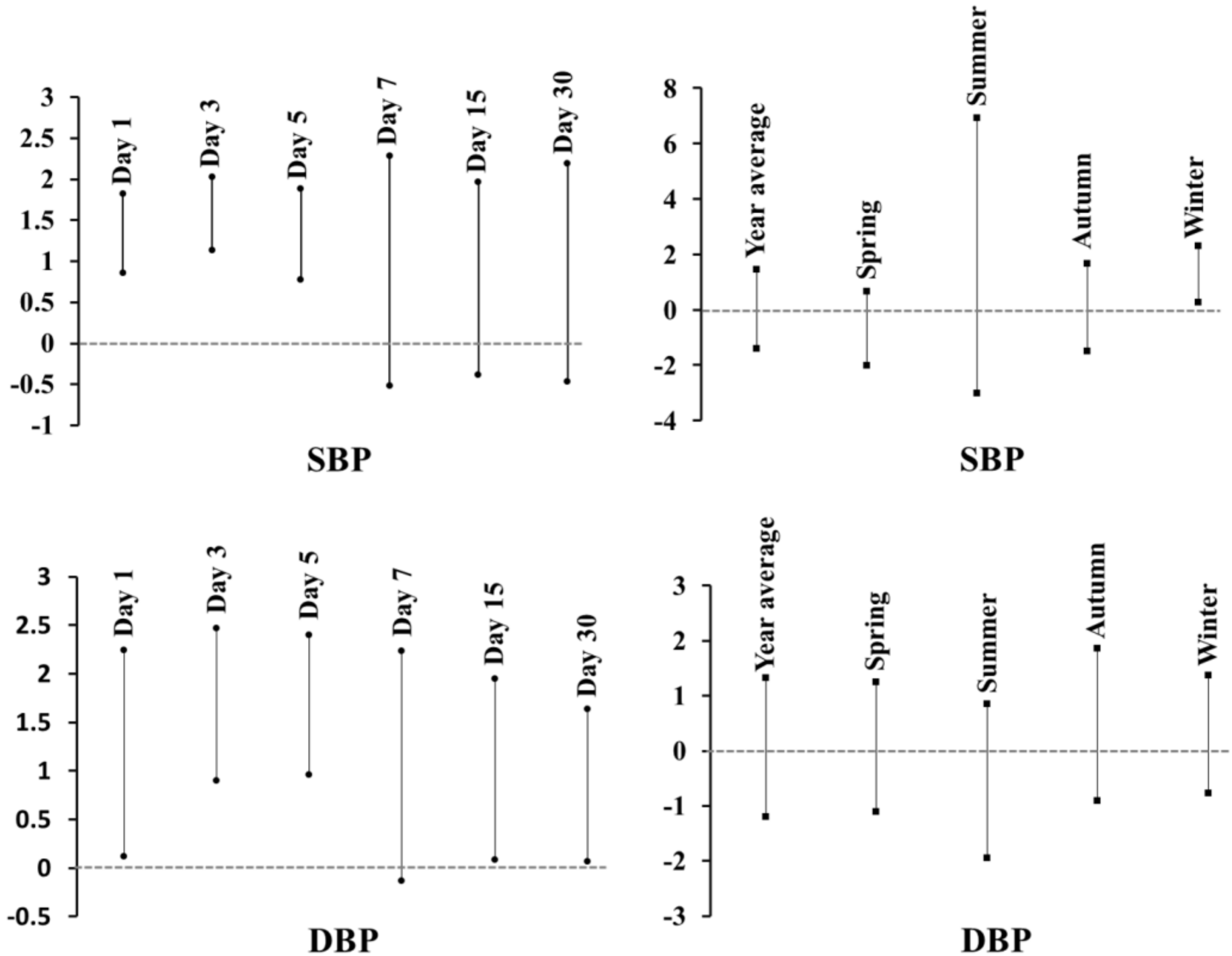

Figure 3

Estimating of blood pressure changes per 10 µg/m3 increase of PM2.5 exposure by generalized linear mixed model analyses (β; 95% CI). Models were adjusted for age, gender, height, weight, BMI, smoking every day, eating oily food, excessive alcohol consumption, mental stress and stay-up.