



Is smaller worse? New insights about associations of PM₁ and respiratory health in children and adolescents

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ARTICLE INFO

Handling Editor: Xavier Querol

Keywords:

PM₁
Asthma
Allergic predisposition
Children and adolescents
China

ABSTRACT

Background and objectives: Little is known about PM₁ effects on respiratory health, relative to larger size fractions (PM_{2.5}). To address this literature gap, we assessed associations between PM₁ exposure and asthmatic symptoms in Chinese children and adolescents, compared with PM_{2.5}.

Methods: A total of 59,754 children, aged 2–17 years, were recruited from 94 kindergartens, elementary and middle schools in the Seven Northeast Cities (SNEC) study, during 2012–2013. We obtained information on asthma and asthma-related symptoms including wheeze, persistent phlegm, and persistent cough using a standardized questionnaire developed by the American Thoracic Society. PM₁ and PM_{2.5} concentrations were estimated using a spatial statistical model matched to the children's geocoded home addresses. To examine the associations, mixed models with school/kindergarten as random intercept were used, controlling for covariates.

Results: Odds ratios (ORs) of doctor-diagnosed asthma associated with a 10-μg/m³ increase for PM₁ and PM_{2.5} were 1.56 (95% CI: 1.46–1.66) and 1.50 (1.41–1.59), respectively, and similar pattern were observed for other outcomes. Interaction analyses indicated that boys and the individuals with an allergic predisposition may be vulnerable subgroups. For example, among children with allergic predisposition, the ORs for doctor diagnosed asthma per 10 μg/m³ increase in PM₁ was 1.71 (95% CI: 1.60–1.83), which was stronger than in their counterparts (1.46; 1.37–1.56) ($p_{\text{for interaction}} < 0.05$).

Conclusions: This study indicated that long-term exposure to PM₁ may increase the risk of asthma and asthma-related symptoms, especially among boys and those with allergic predisposition. Furthermore, these positive associations for PM₁ were very similar to those for PM_{2.5}.

Abbreviations: ATS, American Thoracic Society; CI, Confidence intervals; IQR, Interquartile range; OR, Odds ratios; PM, Particulate matter; SNEC, Seven Northeastern Cities

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<https://doi.org/10.1016/j.envint.2018.08.027>

Received 1 May 2018; Received in revised form 27 July 2018; Accepted 9 August 2018

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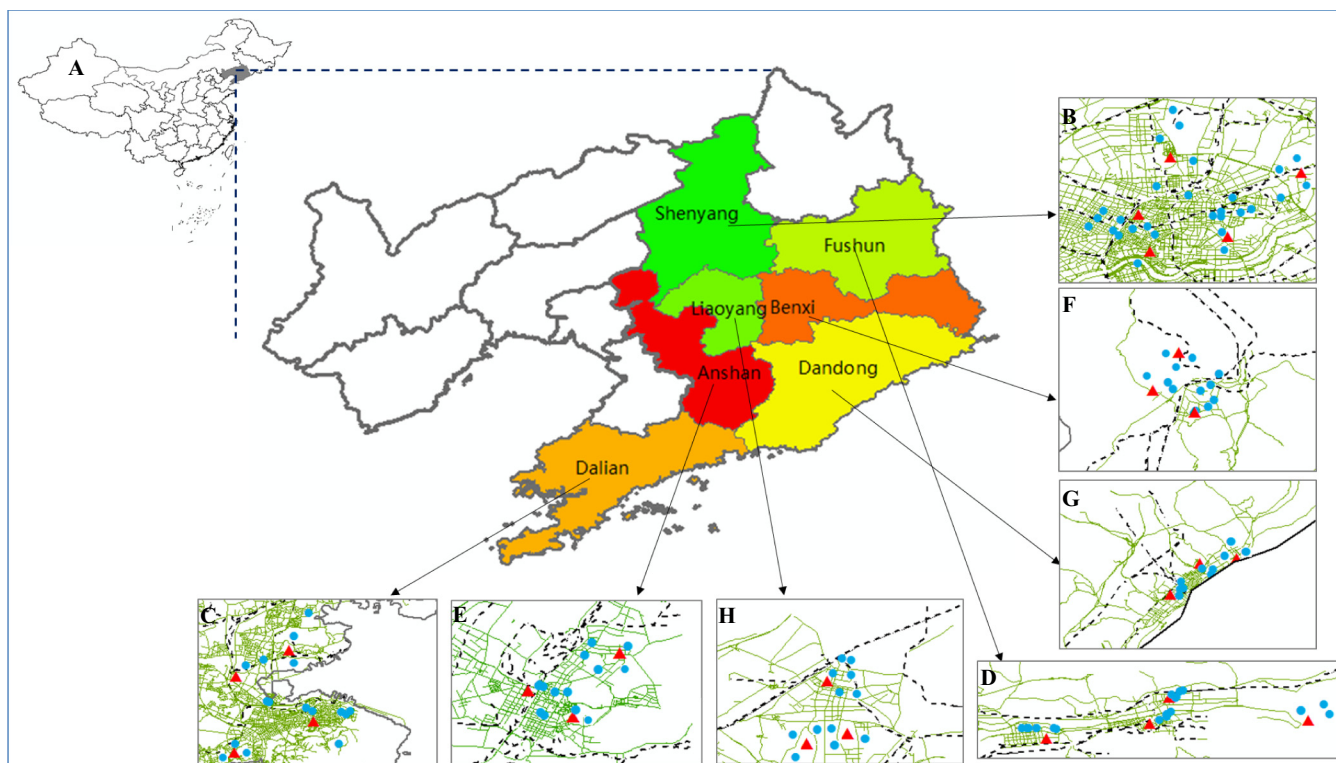


Fig. 1. Map of the study area and locations of districts and schools A: China; B: Shenyang; C: Dalian; D: Fushun; E: Anshan; F: Benxi; G: Dandong; H: Liaoyang. Red triangles represent air monitoring stations, blue dots represent selected schools. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1. Introduction

Several recent reviews on associations between ambient air pollution and respiratory health such as asthma and allergic rhinitis showed controversial conclusions (Anderson et al., 2013; Bowatte et al., 2015; Fuertes and Heinrich, 2015; Gowers et al., 2012; Guarnieri and Balmes, 2014; Heinrich et al., 2016; Khreis et al., 2017; Jacquemin et al., 2015). Reviews that included both cross-sectional and longitudinal studies supported a positive association between air pollution and respiratory health (Khreis et al., 2017), while those based exclusively on longitudinal studies did not show these associations (Bowatte et al., 2015; Fuertes and Heinrich, 2015; Heinrich et al., 2016; Jacquemin et al., 2015). One hypothesis attributes these differences, at least partially, to regional differences in air pollution composition and concentrations (Burbank and Peden, 2018; Cheng et al., 2016; Guarnieri and Balmes, 2014; Jirík et al., 2017; Liu et al., 2017; Rice et al., 2018; Watanabe et al., 2017). Since most existing studies are from European and North American areas with comparatively low exposures, there is a need to study associations between air pollution and respiratory health in high exposure settings, such as in Asia (Doğruel et al., 2017; Gerez et al., 2010; Kou et al., 2018; Pinart et al., 2017). In China, high rates of population growth, coupled with rapid industrial development and urbanization, have led to well-publicized air quality concerns due to the coexistence of intense coal smoke and motor vehicle emissions. Therefore, China presents an ideal opportunity to examine the effects of ambient air pollution on respiratory health.

While the effects of airborne particulate matter (PM) with aerodynamic diameters $< 2.5 \mu\text{m}$ ($\text{PM}_{2.5}$) on asthma and allergies have been widely investigated (Bose et al., 2018; Khalili et al., 2018; Keet et al., 2018; Lavigne et al., 2018; Pennington et al., 2018), few studies have characterized respiratory health impacts for the smaller, and potentially more toxic PM size fraction $< 1 \mu\text{m}$ aerodynamic diameter (PM_1). $\text{PM}_{2.5}$ can penetrate the small airways and alveoli of the lower respiratory

tract, leading to potentially more pronounced health effects (Chen et al., 2017; Mei et al., 2018). PM_1 particles are even smaller, and are characterized by high surface area to volume ratio, having an even greater potential for deleterious biological interactions with respiratory tissues and risks for adverse health outcomes (Mei et al., 2018; Borm et al., 2006; Seaton et al., 2010). However, PM_1 is not routinely measured because it is not subject to air quality standards in most countries and limited data are available to characterize exposure (Chen et al., 2017; Krzyzanowski, 2008).

In a systematic Medline search, we identified only six relevant human studies examining the effect of PM_1 exposure on human health (Chen et al., 2017; Hassanvand et al., 2017; Lin et al., 2016; Wang et al., 2018; Chen et al., 2015; Yang et al., 2018a, 2018b), but none of these studies looked at respiratory outcomes. Furthermore, among these six human-related studies, two studies were panel studies (Chen et al., 2015; Hassanvand et al., 2017), and three studies were both based on Chinese disease monitoring data (Chen et al., 2017; Wang et al., 2018). Only our 33 Communities Chinese Health Study (33CCHS) previously provided a large general population investigation to evaluate the associations of PM_1 with diabetes and metabolic syndrome (Yang et al., 2018a, 2018b). To begin to address the absence of evidence on ambient PM_1 and children's respiratory health, we used data from the Seven Northeastern Cities (SNEC) Study. Our primary aim was to evaluate the effects of $\text{PM}_{2.5}$ and PM_1 on asthma, asthma-related symptoms, and allergic rhinitis in children aged 2 to 17 years. As a secondary aim, we explored whether these associations were modified by sex and allergic predisposition.

2. Material and methods

2.1. Study population and participants

The SNEC was a large population based study designed to examine

health outcomes in association with ambient PM exposure among children residing in Liaoning Province, a highly industrialized area in northeastern China. To maximize the contrasts of ambient PM concentrations, in April 2012, we selected 27 urban districts in seven cities as study sites, based on mean air pollution levels during 2009–2012. In total, we selected six districts in Shenyang, five districts in Dalian, four districts in Fushun, three districts in Anshan, three districts in Benxi, three districts in Dandong, and three districts in Liaoyang (Fig. 1). Each district had only one available municipal central air monitoring station. We randomly selected one or two kindergartens, one or two elementary schools, and one or two middle schools, located ≤ 1.5 miles from each study district's air monitoring station. Students in the resulting total 94 kindergartens/schools were eligible for participation in the study, if they had resided at their current address for at least 2 years. We secured approval from each school's principal, and disseminated study descriptions, consents, and questionnaires to selected school teachers, for delivery to the children's parents. We also invited parents or guardians to participate in study information sessions. Parents filled in the study questionnaires at a study information session or at home. The study ran from April 2012 to January 2013.

Of 68,647 parents of children and adolescents invited to participate, 63,910 (32,395 for boys and 31,515 for girls) returned the study questionnaire, with a response rate of 93.10% (92.05% in boys and 94.19% in girls). This study was conducted according to the World Medical Association Declaration of Helsinki-Ethical Principles for Medical Research Involving Human Subjects. The Human Studies Committee of Sun Yat-sen University approved the study protocol. Written informed consent was obtained from each participant and a parent or guardian before starting data collection.

2.2. Study questionnaire

We collected residential addresses from each participant, and captured respiratory health related questions using the Epidemiologic Standardization Project Questionnaire of the American Thoracic Society (ATS-DLD-78-A) (Ferris, 1978), which has been widely validated (Dong et al., 2011; Hwang and Lee, 2010; Peters et al., 1999; Zhang et al., 2002). The Chinese language version of the ATS questionnaire was also validated and used for epidemiologic investigations in other Chinese cities (Dong et al., 2011; Hwang and Lee, 2010; Liu et al., 2016; Zhang et al., 2002). We collected detailed information on respiratory diseases and symptoms based on the results of our prior investigations (Dong et al., 2011, 2013), including: Doctor diagnosed asthma, Wheeze, Current wheeze, Current asthma, Persistent phlegm, Persistent cough, and Allergic rhinitis. A detailed description of these respiratory diseases and symptoms can be found in the Supplementary Material Table S1.

A family history of allergies was defined as any biological parent or grandparents in whom hay fever or allergies (including allergic dermatitis, allergic conjunctivitis, and eczema) had been diagnosed. A family history of asthma was defined as any biological parent or grandparent ever having been diagnosed with asthma or bronchial asthma. If participants answer 'yes' to family history of allergy or family history of asthma, then they were defined as having an allergic predisposition.

2.3. Ambient particulate matter measures exposure assessment

Daily PM₁ and PM_{2.5} concentrations were predicted at a $0.1^\circ \times 0.1^\circ$ spatial resolution for mainland China during 2009–2012 by a machine learning method with higher predictive ability than previous studies (Chen et al., 2018a, 2018b). In brief, the results from two types of Moderate Resolution Imaging Spectroradiometer (MODIS) data algorithms that processed aerosol optical depth data, Dark Target (<https://darktarget.gsfc.nasa.gov/>) and Deep Blue (<https://deepblue.gsfc.nasa.gov/>), were combined. A spatiotemporal model was developed to link ground-monitored PM₁ and PM_{2.5} data with the aerosol optical depth

data and with other spatial and temporal predictors (e.g., urban cover, forest cover, weather data, and calendar month). A 10-fold cross-validation procedure showed that the R² and root mean squared error (RMSE) for monthly and daily PM₁ predictions were 71% and 13.0 $\mu\text{g}/\text{m}^3$, and 59% and 22.5 $\mu\text{g}/\text{m}^3$, respectively, and that the R² and RMSE for monthly and daily PM_{2.5} predictions were 75% and 15.1 $\mu\text{g}/\text{m}^3$, and 83% and 18.1 $\mu\text{g}/\text{m}^3$, respectively. Briefly, each participant's home address was geocoded as a geographical longitude and latitude, and superimposed over the predicted daily PM₁ and PM_{2.5} concentrations' grids, and then the exposure parameters were calculated by averaging the daily concentrations for PM₁ and PM_{2.5} over the four-year period of 2009–2012.

2.4. Statistical analysis

As described previously (Dong et al., 2013) and in the Supplementary Material, a two-level mixed model with districts as random intercept were used to evaluate individual associations between PM₁ and PM_{2.5} as independent continuous or categorical (quartiles) predictor variables and asthma and asthma-related symptoms as dependent variables. Models were adjusted for age (years), sex (male/female), parental education (defined as the highest level of education completed by either parent; high school or higher/middle school or lower), body mass index (BMI: calculated as weight in kilograms divided by height in meters squared (kg/m^2)), breast fed status (exclusively 4 months, yes/no), low birth weight (birth weight < 2500 g), preterm delivery (< 37 weeks' gestation), caesarean delivery (born by caesarean section), average household income (≤ 9999 Yuan, 10,000–29,999 Yuan, 30,000–100,000 Yuan, > 100,000 Yuan), environmental tobacco smoke exposure (yes/no, defined as living with someone who smokes cigarettes daily in the house; smoking by visitors or guests was not ascertained), exercise time per week (hours), area of residence per person (m^2 , calculated as residence area divided by the number of people living in the home), family history of asthma (yes/no), average ambient temperature during investigation, and district. If the estimated regression effects for PM changed by at least 10% upon inclusion in the base model, the covariate was included in the final model as a confounding variable.

We also investigated effect modification according to sex or allergic predisposition, by including the interaction terms for these variables with PM in joint regression models (i.e., models including girls and boys, with and without allergic predisposition, respectively). Finally, the same two-level logistic regression models were used to estimate associations with respiratory diseases in PM quartiles, with the lowest PM quartile (1) as a reference group, and adjusted for covariates mentioned above. Associations are presented as odds ratios (ORs) with 95% confidence intervals (CI), for a $10 \mu\text{g}/\text{m}^3$ change in ambient airborne particulate concentration. To evaluate the robustness of our estimates, we conducted a number of sensitivity analyses, including stratifying by child's age, and by excluding the participants with colds or other infections. Regression analyses were conducted using the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, North Carolina). All statistical tests were two-sided. A p -value < 0.05 was considered statistically significant.

3. Results

3.1. Characteristics of the study population

From the 63,910 participants, we excluded 4156 children and adolescents (6.50%) that had resided in their current residential address for < 2 years. In the final sample of 59,754 children and adolescents, the average age was 10.31 years, and 50.64% were boys. As shown in Table 1, the overall prevalence of doctor-diagnosed asthma (9.51% vs. 6.07%), current asthma (3.50% vs. 1.98%), current wheeze (4.61% vs. 3.31%), wheeze (12.79% vs. 10.07%), persistent phlegm

Table 1
Characteristics of children and adolescents participating in the Seven Northeastern Cities (SNEC) Study.

Variables	Boys (n = 30,260)	Girls (n = 29,494)	Total (n = 59,754)
Age (years), mean (SD)	10.28 (3.61)	10.34 (3.58)	10.31 (3.60)
Height (cm), mean (SD)*	145.15 (22.74)	142.74 (20.58)	143.96 (21.73)
Weight (kg), mean (SD)*	41.78 (17.36)	38.21 (14.70)	40.02 (16.20)
Exercise time per week (hour), Mean (SD)*	6.81 (8.13)	6.32 (7.80)	6.56 (7.97)
Area of residence per person (m ²), Mean (SD)	23.70 (12.52)	23.51 (12.35)	23.60 (12.44)
Time from home to school by walking (minutes), Mean (SD)	11.68 (6.59)	11.52 (6.50)	11.60 (6.54)
Breastfeeding*	19,403 (64.12)	20,353 (69.01)	39,756 (66.53)
Low birth weight*	1032 (3.14)	1155 (3.92)	2187 (3.66)
Premature delivery*	1753 (5.79)	1464 (4.96)	3217 (5.38)
Caesarean delivery*	15,129 (50.00)	13,748 (46.61)	28,877 (48.33)
Parental education < high school	8157 (26.96)	7811 (26.48)	15,968 (26.72)
Family income per year			
≤ 9999 RMB	6291 (20.79)	6168 (20.91)	12,459 (20.85)
10,000–29,999 RMB	11,329 (37.44)	10,841 (36.76)	22,170 (37.10)
30,000–100,000 RMB	10,531 (34.80)	10,467 (35.49)	20,998 (35.14)
> 100,000 RMB	2109 (6.97)	2018 (6.84)	4127 (6.91)
Environmental tobacco smoke exposure	14,153 (46.77)	13,669 (46.35)	27,822 (46.56)
Family asthma history	2114 (6.99)	1999 (6.78)	4113 (6.88)
Allergic predisposition	6676 (22.06)	6512 (22.08)	13,188 (22.07)
Asthma and asthma-related symptoms			
Doctor-diagnosed asthma*	2879 (9.51)	1790 (6.07)	4669 (7.81)
Current asthma*	1059 (3.50)	584 (1.98)	1643 (2.75)
Current wheeze*	1394 (4.61)	975 (3.31)	2369 (3.96)
Wheeze*	3869 (12.79)	2969 (10.07)	6838 (11.44)
Persistent phlegm*	1039 (3.43)	826 (2.80)	1865 (3.12)
Persistent cough*	2171 (7.17)	1833 (6.21)	4004 (6.70)
Allergic rhinitis*	3403 (11.25)	2263 (7.67)	5666 (9.48)

Values are n (%) except where indicated.

RMB, Chinese Renminbi Yuan; SD, standard deviation.

* Significant difference between boys and girls ($p < 0.05$), as tested by χ^2 test for categorical variables and Student's t -test for continuous variables.

(3.43% vs. 2.80%), persistent cough (7.17% vs. 6.21%), and allergic rhinitis (11.25% vs. 7.67%) were significantly higher in boys than in girls ($p < 0.05$). The age and sex distribution of children from each city were shown in Supplementary Table S2.

3.2. Ambient air particulates

Table 2 shows the distributions of average particulate air pollutant concentrations, from 2009 to 2012. The median (IQR) values of predicted concentrations was 46.57 (6.05) $\mu\text{g}/\text{m}^3$ for PM_{10} , and 54.47

Table 2
Average PM_{10} and $\text{PM}_{2.5}$ concentrations ($\mu\text{g}/\text{m}^3$) for 94 schools in northeast of China, 2009–2012.

Air pollutant	PM_{10}	$\text{PM}_{2.5}$	Temperature ($^{\circ}\text{C}$) ^a
Mean (SD)	46.57 (6.05)	54.47 (6.59)	14.19 (6.13)
Median	44.92	52.01	15.25
25th percentile	41.05	48.76	9.00
75th percentile	52.69	60.39	19.00
Interquartile range (IQR)	11.64	11.63	10.00
Minimum	38.15	46.04	1.50
Maximum	56.20	65.58	24.00

PM_{10} , airborne particulates with aerodynamic diameter $< 10 \mu\text{m}$; $\text{PM}_{2.5}$, airborne particulates with aerodynamic diameter $< 2.5 \mu\text{m}$.

IQR: Range from 25th to 75th percentile of district-specific concentrations.

^a The levels during time of investigation.

(6.59) $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$. The ratio of $\text{PM}_{10}:\text{PM}_{2.5}$ in the 94 schools ranged from 0.79 to 0.89, and for most schools (79 of 94 schools), the $\text{PM}_{10}:\text{PM}_{2.5}$ ratios exceeded 0.85. There was a significant and strong positive correlation between PM_{10} and $\text{PM}_{2.5}$ (γ spearman correlation coefficient = 0.936).

3.3. Associations between PM and asthma and asthma-related outcomes

Overall, we found positive associations between both PM_{10} and $\text{PM}_{2.5}$ and asthma and asthma-related symptoms in boys, girls, and all participants combined with or without adjusting co-variables (Table 3, Supplementary Table S3 and S4). We identified the strongest associations for PM exposure with ever having doctor-diagnosed asthma (Table 3). Furthermore, the magnitude of the significant and positive associations for PM_{10} was very similar to those for $\text{PM}_{2.5}$. For example, the adjusted ORs of doctor diagnosed asthma in association with a 10- $\mu\text{g}/\text{m}^3$ increases in PM_{10} and $\text{PM}_{2.5}$ were 1.56 (95% CI: 1.46–1.66) and 1.50 (95% CI: 1.41–1.59), respectively. Associations were consistently stronger in boys than in girls (Table 4). The analysis treating air pollutants as quartiles of exposure demonstrated significant trends, in which adjusted ORs increased with increasing pollutants levels (Fig. 2). The shapes of the exposure-response relationships of PM_{10} and $\text{PM}_{2.5}$ exposure with asthma and asthma-like symptoms are shown in Supplementary Material Figs. S1 and S2.

When further stratifying sex-specific associations by allergic predisposition, PM exposure showed stronger associations among children and adolescents with allergic predisposition than among children and adolescents without allergic predisposition, with statistically significant interactions between allergic predisposition and PM. For example, among children and adolescents with allergic predisposition, the adjusted ORs for doctor diagnosed asthma per 10 $\mu\text{g}/\text{m}^3$ increase in PM_{10} was 1.76 (95% CI: 1.60–1.83), which was much stronger than in their counterparts (1.46; 95% CI: 1.37–1.56) (p for interaction < 0.05). Adjusted ORs for asthma and asthma-like symptoms expressed for an IQR increase of PM_{10} and $\text{PM}_{2.5}$ are shown in Supplementary Tables S5 and S6.

3.4. Sensitivity analyses

We found similar results when excluding participants with colds or infections during a sensitivity analysis (Fig. 3). Adjusted ORs (95% CI) for a 10 $\mu\text{g}/\text{m}^3$ increase in PM_{10} were 1.14 (0.99–1.33) for wheeze without colds/infections and 1.29 (1.07–1.55) for current wheeze without colds/infections. Furthermore, stratified analyses also showed that the associations were generally greater in boys (Fig. 3A), those individuals with allergic predisposition (Fig. 3B). When stratifying the analysis by the child's age (< 6 years of age, 6–10 years of age, and > 10 years of age), we found similar effect estimates (online Supplementary Table S7).

4. Discussion

In this large population-based study in northeastern China, we detected associations between higher concentrations of ambient PM_{10} and $\text{PM}_{2.5}$ and greater odds for clinical asthma diagnosis and self-reported asthma-like symptoms. All the associations were more pronounced in boys than girls and in those with allergic predisposition than in their non-allergy predisposed counterparts.

4.1. PM_{10} and respiratory health

In contrast to the abundance of studies demonstrating adverse effects of $\text{PM}_{2.5}$ exposure on respiratory health (Bose et al., 2018; Khalili et al., 2018; Lavigne et al., 2018; Pennington et al., 2018), to the best of our knowledge, there is no published research on such associations with PM_{10} . Although the associations with PM_{10} were slightly and consistently

Table 3

Adjusted ORs and 95% CIs for associations between a 10- $\mu\text{g}/\text{m}^3$ increase in PM_{10} and $\text{PM}_{2.5}$ with asthma and asthma-like symptoms for the total study population and stratified by sex^a.

	Boys (n = 30,260)		Girls (n = 29,494)		Total (n = 59,754)		Interaction p-value ^b
	OR	95% CI	OR	95% CI	OR	95% CI	
Doctor-diagnosed asthma							
PM ₁₀	1.62	1.51–1.72	1.47	1.38–1.58	1.56	1.46–1.66	< 0.001
PM _{2.5}	1.55	1.46–1.64	1.43	1.35–1.52	1.50	1.41–1.59	< 0.001
Current asthma							
PM ₁₀	1.50	1.34–1.68	1.34	1.19–1.51	1.44	1.28–1.61	< 0.001
PM _{2.5}	1.48	1.34–1.65	1.35	1.21–1.50	1.43	1.29–1.59	< 0.001
Current wheeze							
PM ₁₀	1.25	1.13–1.38	1.17	1.06–1.29	1.22	1.10–1.34	< 0.001
PM _{2.5}	1.24	1.13–1.36	1.17	1.07–1.28	1.21	1.11–1.33	< 0.001
Wheeze							
PM ₁₀	1.20	1.13–1.27	1.14	1.07–1.21	1.17	1.11–1.24	< 0.001
PM _{2.5}	1.19	1.13–1.25	1.14	1.08–1.20	1.16	1.11–1.23	< 0.001
Persistent phlegm							
PM ₁₀	1.24	1.13–1.37	1.20	1.09–1.33	1.22	1.11–1.35	< 0.001
PM _{2.5}	1.22	1.11–1.33	1.18	1.08–1.30	1.20	1.10–1.32	< 0.001
Persistent cough							
PM ₁₀	1.24	1.16–1.34	1.22	1.13–1.31	1.23	1.15–1.32	< 0.001
PM _{2.5}	1.22	1.14–1.30	1.19	1.12–1.28	1.21	1.13–1.29	< 0.001
Allergic rhinitis							
PM ₁₀	1.32	1.24–1.40	1.21	1.14–1.29	1.27	1.19–1.35	< 0.001
PM _{2.5}	1.27	1.20–1.35	1.18	1.11–1.25	1.23	1.16–1.31	< 0.001

^a Adjusted for age, sex, BMI, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, temperature during investigation, and district.

^b p-Value for interaction between PM $\times$ Sex.

Table 4

Adjusted ORs and 95% CIs for associations between a 10- $\mu\text{g}/\text{m}^3$ increase in PM_{10} and $\text{PM}_{2.5}$ with asthma and asthma-like symptoms for the total study population and stratified by sex and allergic predisposition^a.

	Boys		Girls		Total	
	Allergic predisposition (n = 6676)	Non-allergic predisposition (n = 23,584)	Allergic predisposition (n = 6512)	Non-allergic predisposition (n = 22,982)	Allergic predisposition (n = 13,188)	Non-allergic predisposition (n = 46,566)
Doctor-diagnosed asthma						
PM ₁₀	1.69 (1.56–1.84)	1.45 (1.33–1.57)*	1.73 (1.56–1.91)	1.47 (1.33–1.62)*	1.71 (1.60–1.83)	1.46 (1.37–1.56)*
PM _{2.5}	1.61 (1.49–1.73)	1.40 (1.30–1.51)*	1.64 (1.49–1.79)	1.42 (1.30–1.56)*	1.62 (1.53–1.73)	1.42 (1.33–1.51)*
Current asthma						
PM ₁₀	1.59 (1.38–1.82)	1.31 (1.14–1.50)*	1.51 (1.26–1.79)	1.23 (1.03–1.47)*	1.57 (1.40–1.76)	1.29 (1.15–1.45)*
PM _{2.5}	1.55 (1.37–1.76)	1.32 (1.16–1.49)*	1.46 (1.25–1.71)	1.23 (1.05–1.44)*	1.54 (1.39–1.71)	1.30 (1.17–1.44)*
Current wheeze						
PM ₁₀	1.30 (1.15–1.47)	1.12 (0.99–1.27)*	1.25 (1.08–1.45)	1.09 (0.94–1.26)*	1.31 (1.19–1.45)	1.13 (1.03–1.25)*
PM _{2.5}	1.28 (1.14–1.43)	1.12 (1.01–1.26)*	1.23 (1.08–1.41)	1.09 (0.95–1.25)*	1.29 (1.18–1.41)	1.14 (1.04–1.24)*
Wheeze						
PM ₁₀	1.25 (1.16–1.35)	1.10 (1.02–1.19)*	1.27 (1.16–1.38)	1.10 (1.01–1.19)*	1.27 (1.19–1.34)	1.11 (1.04–1.17)*
PM _{2.5}	1.23 (1.15–1.32)	1.10 (1.03–1.18)*	1.24 (1.15–1.34)	1.10 (1.02–1.19)*	1.24 (1.18–1.31)	1.11 (1.05–1.17)*
Persistent phlegm						
PM ₁₀	1.22 (1.07–1.39)	1.12 (0.98–1.28)*	1.38 (1.20–1.60)	1.22 (1.06–1.41)*	1.30 (1.18–1.44)	1.18 (1.07–1.30)*
PM _{2.5}	1.20 (1.06–1.35)	1.11 (0.99–1.25)*	1.33 (1.17–1.52)	1.20 (1.05–1.37)*	1.27 (1.16–1.39)	1.16 (1.06–1.27)*
Persistent cough						
PM ₁₀	1.24 (1.13–1.36)	1.12 (1.02–1.23)*	1.40 (1.26–1.56)	1.26 (1.13–1.39)*	1.31 (1.22–1.41)	1.18 (1.10–1.27)*
PM _{2.5}	1.21 (1.11–1.32)	1.11 (1.02–1.21)*	1.35 (1.22–1.48)	1.23 (1.11–1.35)*	1.28 (1.19–1.36)	1.17 (1.09–1.24)*
Allergic rhinitis						
PM ₁₀	1.43 (1.32–1.55)	1.17 (1.08–1.28)*	1.42 (1.29–1.56)	1.14 (1.03–1.26)*	1.43 (1.34–1.53)	1.17 (1.09–1.24)*
PM _{2.5}	1.36 (1.10–1.15)	1.15 (1.00–1.04)*	1.34 (1.23–1.47)	1.11 (1.02–1.22)*	1.36 (1.28–1.44)	1.14 (1.07–1.21)*

^a Adjusted for age, sex, BMI, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, temperature during investigation, and district.

* $p < 0.05$ for interaction between PM $\times$ Allergic predisposition.

stronger than $\text{PM}_{2.5}$ in our study, the differences in effects were not statistically significant. Our findings are consistent with the results of our previous work, the 33 Communities Chinese Health Study, which indicated an adjusted odds of metabolic syndrome per 10 $\mu\text{g}/\text{m}^3$ increase in PM that was slightly stronger for PM_{10} (ORs = 1.12; 95% CI: 1.00–1.24) than for $\text{PM}_{2.5}$ (1.09; 95% CI: 1.00–1.18), although the

difference was not statistically significant (Yang et al., 2018b). Another nationwide study in China, that investigated PM_{10} in relation to emergency hospital visits in 26 Chinese cities based on diseases monitoring data also found similar effects on emergency hospital visits for PM_{10} (OR = 1.011; 95% CI: 1.006–1.017) and $\text{PM}_{2.5}$ (OR = 1.010; 95% CI: 1.005–1.016) (Chen et al., 2017).

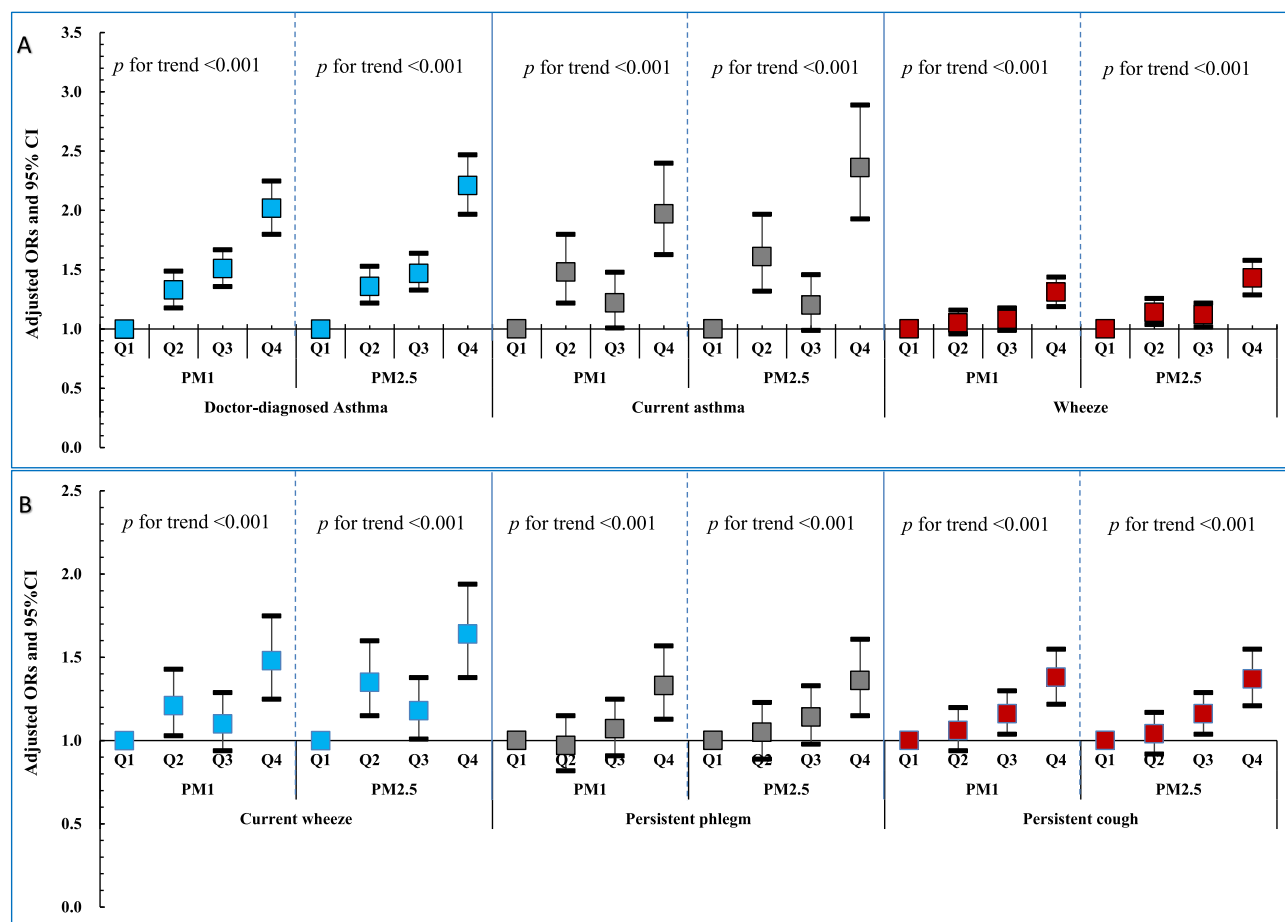


Fig. 2. Association between air pollutants and respiratory diseases. A, for doctor-diagnosed asthma, current asthma, and wheeze; B, for current wheeze, persistent phlegm, persistent cough. The associations are adjusted for age, sex, obesity, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, and district. *p*-Values for trend were calculated using categories representing the median values of corresponding quartiles (Q1: quartile 1 - reference category; Q2: quartile 2; Q3: quartile 3; Q4: quartile 4 with boxes representing the median of each quartile and whiskers representing the 95% confidence interval).

In the present study, PM_1 contributed > 85% of ambient $PM_{2.5}$, with the $PM_1:PM_{2.5}$ ratio ranging from 0.79 to 0.89, suggesting that the smaller PM_1 particle fraction, is a key driver of PM air pollution, and accounts for the majority of $PM_{2.5}$ concentrations (Chen et al., 2017). The $PM_1:PM_{2.5}$ ratios in our study were consistent with those of previous studies in China (Chen et al., 2017; Li et al., 2016; Wang et al., 2015), but higher than in other countries (Deshmukh et al., 2011; Koulouri et al., 2008; Vecchi et al., 2004). Chen and colleagues reported that, across China, the $PM_1:PM_{2.5}$ ratios ranged from 0.67–0.97, and for most areas, the $PM_1:PM_{2.5}$ ratios exceeded 0.80 (Chen et al., 2017). Studies conducted in Milan, Durg, India, and in Athens in Greece showed that $PM_1:PM_{2.5}$ ratios ranged from 0.48 to 0.75 (Deshmukh et al., 2011; Koulouri et al., 2008; Vecchi et al., 2004). From these findings, we could infer that most of the adverse effects of $PM_{2.5}$ in China could be attributed to PM_1 (Chen et al., 2017), which may account in great part for the similar associations from PM_1 and $PM_{2.5}$ exposure in our study. Additional studies comparing the effects of PM_1 and $PM_{2.5}$ are needed to shed light on how different PM sizes and composition affect human health.

Although the exact biological mechanisms for the asthma- PM_1 association we detected are not entirely clear, experimental studies suggest that inflammatory processes and oxidative stress responses may play important roles (Chen et al., 2018; Habertzettl et al., 2016; Van Den Heuvel et al., 2016). Compared to the larger $PM_{2.5}$ and PM_{10} , PM_1 has a much smaller molecular diameter and so is capable of entering the deeper respiratory tract and adsorbing to the cell surface. After

internalization by respiratory epithelial cells, PM could elicit the oxidative stress leading to a secondary inflammatory responses (Gong et al., 2014; Yang et al., 2017). Other studies reported elevated inflammatory factors such as IL-8, IL-6, and TNF_α , along with dysfunction of the cytokine net, suggesting that the effects of airborne PM on pulmonary function might depend primarily on the pro-inflammatory response (Feng et al., 2016; Watanabe et al., 2017). Furthermore, several studies have demonstrated that PM exposure was associated with abnormal global DNA methylation as well as for specific genes involved in the pulmonary immune function (Wei and Tang, 2018; Yang et al., 2017).

4.2. PM_1 , sex, and allergic predisposition

We observed that boys were more susceptible to the respiratory effects of PM than girls, and PM showed stronger associations in those predisposed to allergic diseases than those without an allergic predisposition. A study of twelve Southern California communities evaluated associations between ambient air pollution and asthma, and asthma related symptoms, among 3676 children, and the results showed significant positive associations in boys, but not in girls (Peters et al., 1999). Lavigne et al. (2018) examined whether infant characteristics modified the association between perinatal air pollution exposure and childhood asthma development among 761,172 births in Ontario, Canada. The authors found statistically significant effect modification by infant sex, with males having higher risk of developing asthma when

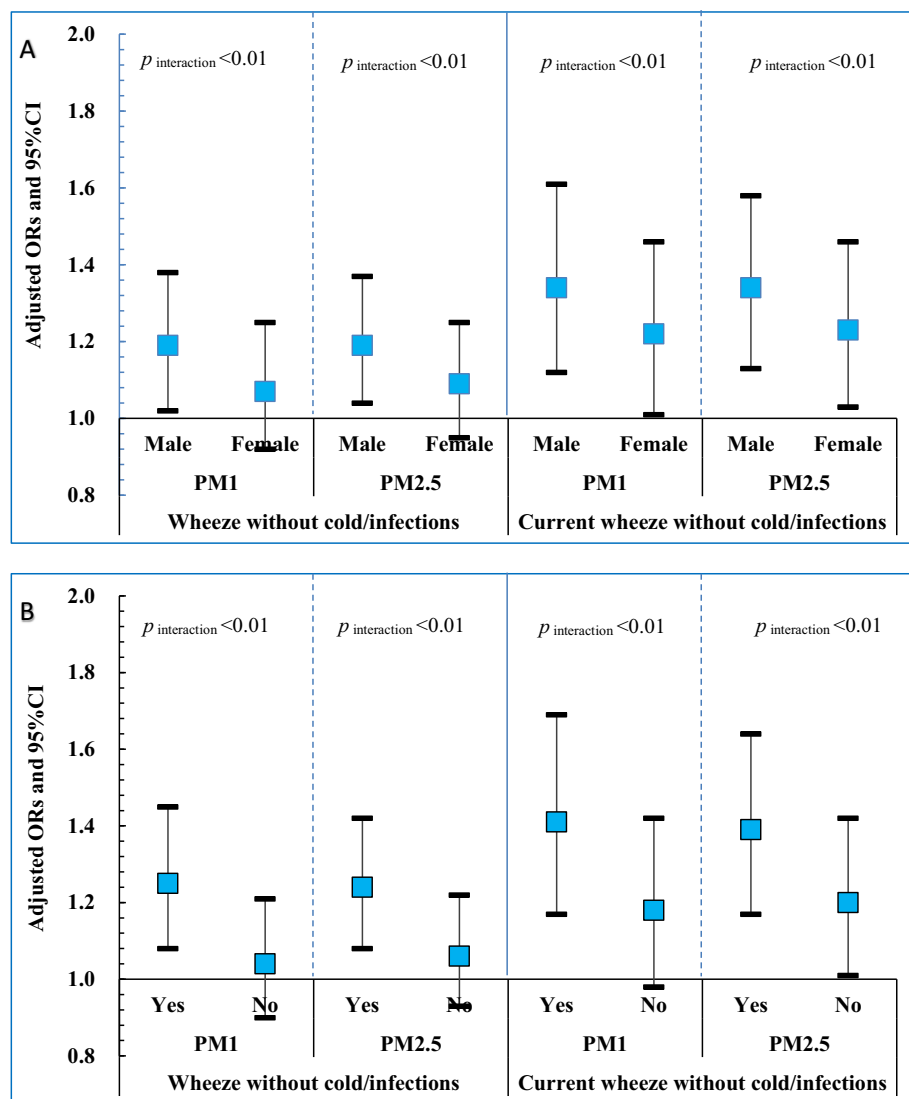


Fig. 3. Associations between air pollutants and respiratory diseases among participants excluding colds or infections. A, for interaction between PM $\times$ Sex; B, for interaction between PM $\times$ Allergic predisposition (Yes: subjects with allergic predisposition; No: non-allergic predisposition). The associations were adjusted for age, sex, obesity, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, and district. Adjusted ORs and 95% CIs were estimated per $10\text{-}\mu\text{g}/\text{m}^3$ increase in PM_{10} and $\text{PM}_{2.5}$ for respiratory diseases. p -Values for interaction between PM $\times$ Sex (A) or PM $\times$ Allergic predisposition (B).

mother was exposed to high $\text{PM}_{2.5}$ in trimesters one and two. It has been reported that human fetal lung development is sexually dimorphic, with girls developing surfactant earlier than boys, and, with boys developing larger lungs than girls, yet with smaller airway diameters relative to volume (Berhane et al., 2000). This leads to sex-based differences in the deposition of PM (Kim and Hu, 2006), gas absorption (Jones and Lam, 2006), and gas-blood barrier permeability (Bräuner et al., 2009). In addition, other sex related traits, such as hormonal status and body size, influence the biological transport of environmental chemicals, potentially leading to different effects between sexes (Clougherty, 2010; Gobinath et al., 2017; Krieger, 2003). In addition, boys in our study spent more time exercising outdoors than girls (6.81 ± 8.13 h per week vs. 6.32 ± 7.80 h per week, $p < 0.05$), which possibly led to higher inhaled PM doses than those experienced by the girls, and stronger apparent PM effects in boys.

With respect to stronger PM effects among participants with allergic predisposition, increased PM levels enhance the allergic inflammatory response, leading to eosinophilic inflammation and mucoid hyperplasia throughout the respiratory system, from the nasal turbinates to the small pulmonary airways (Lee et al., 2007). PM also absorbs aero-allergens released by pollen grains, which is another mechanisms contributing to the enhanced immunoglobulin E (IgE) antibody-mediated immune response with the prolonged retention of the allergen (Zhou et al., 2011). Our finding on higher susceptibility of the children

and adolescents with allergic predisposition may be explained by these mechanisms.

4.3. Study strengths and limitations

The large sample size, which covered 94 kindergartens and schools in 27 districts in Northeastern China, is a strength of this study. The sample size of 59,754 children and adolescents, is one of the largest published studies to date evaluating the association between children's respiratory health and ambient air pollution. Furthermore, in China, primary schools restrict student admissions according to geographical boundaries, preventing children from attending trans-regional schools. The average time walking from home to school was 11.6 min, indicating that the children's PM exposure assessment may represent both school and home exposure levels. Thus, our results may provide more robust conclusions on the health effects of ambient air pollution exposure than studies estimating exposures only at the home. Although novel in geographic context, sample size, and exposure assessment, our study has some limitations and therefore the results should be interpreted with caution. The PM exposure assessment was based on a comprehensive satellite-based model and exposures were assigned to the children's home addresses, which may have misclassified exposure for some participant. Nevertheless, the misclassification is unlikely to have varied by study outcome producing a bias towards the null

hypothesis. In addition, PM contains chemicals, metals, and ions from urban or industrial pollutant emissions in many regions, and the different composition of PM may produce different associations with respiratory diseases. Unfortunately, we were unable to measure PM composition in the present study, so we were unable to identify the various effect of PM composition in different cities. Secondly, given the cross-sectional design of our study, we were unable to establish a temporal relationship in which PM exposure preceded the onset of asthma or asthma-like symptoms. Thus, ‘reverse causality’ is possible, although we believe it to be unlikely given our objective assessment of air pollution exposure. Thirdly, we captured outcome data by self-report using parental questionnaires. This approach may have introduced recall bias, in which parents misreported their children's symptoms and diagnoses, although it is unlikely to have been differential in relation to PM exposure, and so we may have underestimated the associations. However, it is a common procedure to gather self-report information on recent symptom history and physician diagnosis of asthma in large epidemiological studies: self-reported measures are practical and cost-efficient, and their repeatability tends to be good (Bornehag et al., 2005; Oie et al., 1997). Furthermore, we were unable to capture data for additional, potential environmental confounders, such as time-activity patterns for study participants, and thus residual confounding is possible. Despite the limitations, our study included a large sample of children and adolescents, sufficient to allow for a robust statistical analysis stratified by sex, and to detect modest associations for PM with asthma and asthma-like symptoms, and a comprehensive panel of covariates for adjustment.

In conclusion, our results indicate that ambient PM₁ air pollution was associated with asthma and asthma-like symptoms in children and adolescents. PM₁ appeared to have slightly stronger effects than PM_{2.5} although the differences were not significant. Boys appeared to be more sensitive to PM toxicity than girls, as well as children and adolescents with an allergic predisposition than those without, representing potentially vulnerable subgroups. Our results provide further support for previously published findings linking higher ambient air pollution concentrations to a higher risk for respiratory conditions in children and adolescents. Our results will hopefully inform implementation of regulations protective of children's health, and the health of vulnerable groups in China and globally, and also will play a pivotal part in regulatory policy making and standards for PM₁ proposed by WHO or other government agencies in the future.

Acknowledgement

This work was supported by Major Program of National Natural Science Foundation of China (91543208), Science and Technology Program of Guangzhou (201807010032), the National Natural Science Foundation of China (81872582, 81673128, 81703179, 81472936), National Key Research and Development Program of China (2016YFC0207000), Fundamental Research Funds for the Central Universities (16ykd02, 17ykpy14, 17ykpy16), Science and Technology Planning Project of Guangdong Province (2014A050503027, 2016A030313342, 2017A050501062, 2017A090905042), Career Development Fellowship of Australian National Health and Medical Research Council (APP1107107), and Early Career Fellowship of Australian National and Medical Research Council (APP1109193).

Competing financial interests

The authors declare they have no actual or potential competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envint.2018.08.027>.

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Online Supplement

Is smaller worse? New insights about associations of PM₁ and respiratory health in children and adolescents

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Figure S2. Correlation analysis between $\text{PM}_{2.5}$ concentrations and prevalence of asthma diagnosed by doctor (A), current asthma (B), wheeze (C), current wheeze (D), persistent phlegm (E), and persistent cough (F).

Questionnaire in Chinese version

eAppendix.

Sampling procedures:

We used the GIS software to estimate distances between each school and the nearest air pollution monitoring station. For each monitoring station, we randomly selected one school from all schools within a 1.5 km radius around that station. The map below shows an area covering the 1.5 km radius around one air monitoring stations, as indicated by a small, blue circle in the center of the map. As shown in the map, nine elementary schools marked as 1-9 fell within a 1.5 km radius around that station, and we randomly selected schools 1 and 9. In China, each city district is assigned an administrative code; we selected the last two non-zero digits of the city's administrative code as the number of the district, and then we randomly selected two schools within each district based on a random numbers table. For example, the administrative code of Heping district is "02" from Shenyang city's administrative code "210102000000". We then used a random number table to select "1" and "9" as shown below. The resulting schools with labels 1 and 9 in the figure below were included in the study. These randomization procedures ensured that the schools selected provided a sample of children and adolescents representative of the study area.



Figure. The area covered up to a 1.5 km radius around one of our monitoring stations, as indicated with a small blue circle in the center of the map. Then elementary schools marked with 1-9 were within a 1.5 km radius around that station, and we randomly selected school 1 and 9.

随机数字表

编号	1~10	11~20	21~30	31~40	41~50
1	22 17 68 65 81	68 95 23 92 35	87 02 22 57 51	61 09 43 95 06	58 24 82 03 47
2	19 36 27 59 46	13 79 93 37 55	39 77 32 77 09	85 52 05 30 62	47 83 51 62 74
3	16 77 23 02 77	09 61 84 25 21	28 06 24 25 93	16 71 13 59 78	23 05 47 47 25
4	78 43 76 71 61	20 44 90 32 64	97 67 63 99 61	46 38 03 93 22	69 81 21 99 21
5	03 28 28 26 08	73 37 32 04 05	69 30 16 09 05	88 69 58 28 99	35 07 44 75 47

Statistical Analysis

We described distributions for continuous variables as the mean $\pm$ standard deviation (SD) and categorical variables as n (%), comparing girls to boys by using Student's *t*-test or χ^2 -test, as appropriate. To investigate the relationship between the respiratory health conditions and ambient air pollution, we considered a two-level mixed model in which participants were the first-level units and the districts were the second-level units. At the participant level, we modeled the logit of the prevalence of respiratory diseases and related symptoms as a function of *k* covariates ($X_1, \dots, X_k$) as follows:

$$\text{logit} [\text{Probability} (Y_{ij})] = \alpha_j + \beta_1 X_{1ij} + \dots + \beta_k X_{kij} + e_{ij} \quad (1)$$

where the outcome variable (Y) is respiratory health outcomes diagnosis criteria described previously, the subscript i indicates the participant ($i=1, \dots, n_i$), the subscript j is for districts ($j=1, \dots, 24$), α_j is the intercept at the district level, $\beta_1 \dots \beta_k$ are the regression coefficients of the covariates, and e_{ij} is the random error assumed to have means of zero and constant variance. In general, a district with a higher α_j predicts higher respiratory health outcomes prevalence rate than a district with a lower α_j .

At the district level, we regressed the district-specific intercepts α_j on the district-specific pollutant level (Z_j) to explain the variations of α_j , as follows:

$$\alpha_j = \alpha + \gamma_j Z_j + u_j \quad (2)$$

Equation (2) predicts the prevalence in a district by Z_j . If γ_j is positive, then adjusting for covariates, the prevalence of respiratory health outcomes is higher in districts with a higher pollutant levels. If γ_j is negative, then adjusting for covariates, the prevalence is lower in districts with a higher pollutant levels. The random error at the district level, u_j , is assumed to be independent and to follow a normal distribution with a mean of zero and constant variance. These random errors represent the between-district variation and are assumed independent from e_{ij} at the participant level. It should be noted that α , $\beta_1, \dots, \beta_k$, and γ_j are not assumed to vary across districts. Therefore, they have no subscript j to indicate to which district they belong. They are therefore referred to as fixed effects as they apply to all districts.

We used a single regression (3) to simplify the above description by substituting model (2) into model (1):

$$\text{logit}[P(Y_{ij})] = (\alpha + \gamma_j Z_j + \beta_1 X_{1ij} + \dots + \beta_k X_{kij}) + (u_j + e_{ij}) \quad (3)$$

Effects were expressed as odds ratios (OR) with 95% confidence intervals (CI), for a 10 µg/m³ or an interquartile range (i.e., IQR = 75th% tile - 25th% tile) change in ambient airborne particulate concentration.

Models were adjusted for age (years), sex (male/female), parental education (defined as the highest level of education completed by either parent; high school or higher/middle school or lower), body mass index (BMI: calculated as weight in kilograms divided by height in meters squared (kg/m²)), breast fed status (exclusively 4 months, yes/no), low birth weight (birth weight <2500 g), preterm delivery (<37 weeks' gestation), caesarean delivery (born by caesarean section), average household income (≤9,999 Yuan, 10,000-29,999 Yuan, 30,000-100,000 Yuan, >100,000 Yuan), environmental tobacco smoke exposure (yes/no, defined as living with someone who smokes cigarettes daily in the house; smoking by visitors or guests was not ascertained), exercise time per week (hours), area of residence per person (m², calculated as residence area divided by the number of people living in the home), family history of asthma (yes/no), average ambient temperature during investigation, and district.

We also investigated effect modification according to sex or allergic predisposition, by including the interaction terms for these variables with PM in joint regression models (i.e., models including girls and boys, with and without allergic predisposition, respectively). Finally, the same two-level logistic regression models were used to estimate associations with respiratory diseases in PM quartiles, with the lowest PM quartile (1) as a reference group, and adjusted for covariates mentioned above. Associations are presented as odds ratios (ORs) with 95% confidence intervals (CI), for a 10 µg/m³ change in ambient airborne particulate concentration. To evaluate the robustness of our estimates, we conducted a number of sensitivity analyses,

including stratifying by child's age, and by excluding the participants with colds or other infections. Regression analyses were conducted using the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, North Carolina). All statistical tests were two-sided. A p -value < 0.05 was considered statistically significant.

Table S1 Definition of respiratory diseases and symptoms in children (N=59,754)

Respiratory Health	Definition	Prevalence (%)
Doctor diagnosed asthma	A positive response to the question “Has a doctor ever diagnosed asthma in your child?”	7.81
Current asthma	Doctor diagnosed asthma and a positive response to “Has this child experienced an asthma attack in the past two years?” or “Does this child take medicine or treatment for asthma or asthmatic bronchitis?”	2.75
Wheeze	A positive response to “Does this child's chest ever sound wheezy or whistling, including times when he or she had a cold?”	11.44
Current wheeze	Diagnosed with wheeze and a positive response to “Has this child had 2 or more such episodes in last 12 months?”	3.96
Persistent phlegm	Using the responses to several phlegm-related questions, which indicated congestion or presence of chest phlegm, sputum, or mucus on most days (i.e., ≥ 4 days per week), for ≥ 3 months, with or without an infection, during the last 12 months.	3.12
Persistent cough	Using the responses to several cough-related questions, which indicated a cough on most days (i.e., ≥ 4 days per week), for ≥ 3 months, with or without an infection, during the last 12 months.	6.70
Allergic rhinitis	A positive response to the question ‘Has a doctor ever diagnosed allergic rhinitis in this child?’	9.48

Table S2 the age and sex distribution of children from each city

	Shenyang	Dalian	Fushun	Anshan	Benxi	Dandong	Liaoyang	Total
	n=14012	n=9576	n=17280	N=4580	N=5504	N=4221	N=4581	N=59754
Age (years)								
Means	10.17	10.57	10.96	10.14	9.62	11.14	10.75	10.52
SD	3.90	4.00	3.19	3.71	2.86	3.73	2.88	3.57
Boys; %	50.54	51.55	51.33	51.00	49.00	49.14	49.49	50.64

Table S3 the unadjusted ORs and 95% CIs for associations between a 10- $\mu\text{g}/\text{m}^3$ increase in PM_{10} and $\text{PM}_{2.5}$ with asthma and asthma-like symptoms for the total study population and stratified by sex

	Boys (n=30,260)		Girls (n=29,494)		Total (n=59,754)	
	OR	95%CI	OR	95%CI	OR	95%CI
Doctor-diagnosed asthma						
PM_{10}	1.83	1.69-1.98	1.83	1.66-2.02	1.85	1.73-1.96
$\text{PM}_{2.5}$	1.73	1.61-1.87	1.73	1.58-1.90	1.75	1.65-1.85
Current asthma						
PM_{10}	2.19	1.92-2.50	2.15	1.80-2.55	2.20	1.98-2.44
$\text{PM}_{2.5}$	2.07	1.84-2.33	2.01	1.72-2.35	2.07	1.88-2.27
Current wheeze						
PM_{10}	1.88	1.68-2.10	1.85	1.62-2.11	1.88	1.72-2.05
$\text{PM}_{2.5}$	1.78	1.60-1.97	1.74	1.54-1.96	1.77	1.64-1.92
Wheeze						
PM_{10}	1.69	1.58-1.81	1.70	1.57-1.83	1.70	1.62-1.79
$\text{PM}_{2.5}$	1.61	1.51-1.72	1.61	1.50-1.73	1.62	1.55-1.70
Persistent phlegm						
PM_{10}	1.55	1.34-1.78	1.29	1.13-1.46	1.40	1.28-1.54
$\text{PM}_{2.5}$	1.48	1.30-1.69	1.26	1.12-1.41	1.36	1.25-1.48
Persistent cough						
PM_{10}	1.64	1.49-1.80	1.39	1.26-1.51	1.50	1.41-1.60
$\text{PM}_{2.5}$	1.56	1.42-1.70	1.34	1.24-1.46	1.44	1.36-1.53
Allergic rhinitis						
PM_{10}	1.14	1.05-1.24	1.12	1.04-1.20	1.14	1.07-1.20
$\text{PM}_{2.5}$	1.13	1.04-1.22	1.11	1.04-1.19	1.13	1.07-1.19

Table S4 comparing the effects of PM on respiratory health without adjusting any co-variables (crude), adjusting co-variables without age, and adjusting co-variables including age.

Diseases and symptoms	Crude		Adjusted co-variables without age ^a		Adjusted co-variables including age ^a	
	OR	95%CI	OR	95%CI	OR	95%CI
Doctor-diagnosed asthma						
PM ₁	1.85	1.73-1.96	1.82	1.70-1.95	1.56	1.46-1.66
PM _{2.5}	1.75	1.65-1.85	1.73	1.63-1.85	1.50	1.41-1.59
Current asthma						
PM ₁	2.20	1.98-2.44	2.35	2.07-2.67	1.44	1.28-1.61
PM _{2.5}	2.07	1.88-2.27	2.26	2.01-2.54	1.43	1.29-1.59
Current wheeze						
PM ₁	1.88	1.72-2.05	2.18	1.96-2.43	1.22	1.10-1.34
PM _{2.5}	1.77	1.64-1.92	2.08	1.88-2.30	1.21	1.11-1.33
Wheeze						
PM ₁	1.70	1.62-1.79	1.74	1.63-1.85	1.17	1.11-1.24
PM _{2.5}	1.62	1.55-1.70	1.68	1.59-1.78	1.16	1.11-1.23
Persistent phlegm						
PM ₁	1.40	1.28-1.54	1.51	1.36-1.68	1.22	1.11-1.35
PM _{2.5}	1.36	1.25-1.48	1.46	1.32-1.61	1.20	1.10-1.32
Persistent cough						
PM ₁	1.50	1.41-1.60	1.59	1.47-1.71	1.23	1.15-1.32
PM _{2.5}	1.44	1.36-1.53	1.53	1.42-1.64	1.21	1.13-1.29
Allergic rhinitis						
PM ₁	1.14	1.07-1.20	1.03	0.97-1.10	1.27	1.19-1.35
PM _{2.5}	1.13	1.07-1.19	1.02	0.96 -1.09	1.23	1.16-1.31

^aAdjusted for sex, BMI, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, temperature during investigation, temperature during investigation, and district.

Table S5 Adjusted ORs and 95% CIs for associations between IQR increase in PM₁ and PM_{2.5} with asthma and asthma-like symptoms for a total study population and stratified by sex^a

	Boys (n=30,260)		Girls (n=29,494)		Total (n=59,754)		Interaction <i>P</i> -value ^c
	ORs ^b	95%CI	ORs ^b	95%CI	ORs ^b	95%CI	
Doctor-diagnosed asthma							
PM ₁	1.75	1.62-1.89	1.57	1.45-1.69	1.67	1.55-1.81	<0.001
PM _{2.5}	1.66	1.55-1.78	1.52	1.41-1.63	1.60	1.50-1.72	<0.001
Current asthma							
PM ₁	1.60	1.40-1.83	1.41	1.23-1.61	1.53	1.34-1.74	<0.001
PM _{2.5}	1.58	1.40-1.79	1.42	1.25-1.60	1.52	1.34-1.72	<0.001
Current wheeze							
PM ₁	1.30	1.16-1.46	1.20	1.07-1.35	1.26	1.12-1.41	<0.001
PM _{2.5}	1.28	1.16-1.43	1.20	1.08-1.34	1.25	1.13-1.39	<0.001
Wheeze							
PM ₁	1.24	1.16-1.32	1.16	1.09-1.24	1.20	1.12-1.28	<0.001
PM _{2.5}	1.22	1.15-1.30	1.16	1.09-1.23	1.19	1.12-1.27	<0.001
Persistent phlegm							
PM ₁	1.29	1.15-1.45	1.24	1.10-1.39	1.27	1.13-1.42	<0.001
PM _{2.5}	1.26	1.13-1.40	1.22	1.09-1.35	1.24	1.11-1.38	<0.001
Persistent cough							
PM ₁	1.29	1.19-1.40	1.26	1.15-1.36	1.27	1.17-1.38	<0.001
PM _{2.5}	1.26	1.17-1.36	1.23	1.14-1.33	1.24	1.15-1.34	<0.001
Allergic rhinitis							
PM ₁	1.32	1.24-1.40	1.21	1.14-1.28	1.32	1.23-1.42	<0.001
PM _{2.5}	1.27	1.20-1.35	1.18	1.11-1.25	1.28	1.19-1.37	<0.001

^aAdjusted for age, sex, BMI, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, temperature during investigation, and district.

^bEffect expressed for a 1 interquartile range (i.e., 75th % tile - 25th % tile) change in ambient concentration for each pollutant (11.64 µg/m³ for PM₁, and 11.63 µg/m³ for PM_{2.5}).

^c*p*-value for interaction between PM × Sex.

Table S6 Adjusted ORs and 95% CIs for associations between IQR increase in PM₁ and PM_{2.5} with asthma and asthma-like symptoms for a total study population and stratified by sex and allergic predisposition^{a,b}

	Boys		Girls		Total	
	Allergic predisposition (n=6,676)	Non-allergic predisposition (n=23,584)	Allergic predisposition (n=6,512)	Non-allergic predisposition (n=22,982)	Allergic predisposition (n=13,188)	Non-allergic predisposition (n=46,566)
Doctor-diagnosed asthma						
PM ₁	1.84 (1.68-2.03)	1.54 (1.40-1.68)*	1.89 (1.68-2.13)	1.56 (1.39-1.76)*	1.87 (1.73-2.02)	1.55 (1.44-1.67)*
PM _{2.5}	1.74 (1.59-1.89)	1.48 (1.36-1.62)*	1.77 (1.59-1.97)	1.51 (1.35-1.68)*	1.76 (1.64-1.89)	1.50 (1.40-1.61)*
Current						
PM ₁	1.71 (1.46-2.00)	1.36 (1.16-1.60)*	1.61 (1.31-1.97)	1.27 (1.04-1.56)*	1.69 (1.48-1.93)	1.35 (1.18-1.54)*
PM _{2.5}	1.67 (1.44-1.93)	1.38 (1.19-1.59)*	1.56 (1.30-1.87)	1.27 (1.06-1.53)*	1.65 (1.46-1.86)	1.36 (1.20-1.53)*
Current						
PM ₁	1.36 (1.18-1.57)	1.14 (0.99-1.32)*	1.30 (1.10-1.54)	1.10 (0.93-1.31)*	1.37 (1.22-1.54)	1.16 (1.03-1.30)*
PM _{2.5}	1.33 (1.17-1.52)	1.15 (1.05-1.30)*	1.27 (1.09-1.49)	1.11 (0.95-1.29)*	1.34 (1.21-1.49)	1.16 (1.04-1.28)*
Wheeze						
PM ₁	1.30 (1.19-1.42)	1.12 (1.02-1.22)*	1.32 (1.19-1.45)	1.12 (1.01-1.23)*	1.31 (1.23-1.41)	1.12 (1.05-1.20)*
PM _{2.5}	1.27 (1.17-1.38)	1.12 (1.03-1.21)*	1.29 (1.18-1.41)	1.12 (1.02-1.22)*	1.29 (1.21-1.37)	1.12 (1.06-1.20)*
Persistent						
PM ₁	1.26 (1.09-1.47)	1.14 (0.98-1.33)*	1.46 (1.23-1.73)	1.26 (1.07-1.49)*	1.36 (1.21-1.53)	1.21 (1.07-1.36)*
PM _{2.5}	1.23 (1.07-1.42)	1.13 (0.98-1.30)*	1.40 (1.20-1.63)	1.24 (1.06-1.44)*	1.32 (1.19-1.47)	1.19 (1.07-1.32)*
Persistent						
PM ₁	1.28 (1.15-1.43)	1.14 (1.02-1.27)*	1.48 (1.31-1.67)	1.31 (1.16-1.47)*	1.37 (1.26-1.49)	1.22 (1.12-1.32)*
PM _{2.5}	1.25 (1.13-1.39)	1.13 (1.02-1.25)*	1.41 (1.27-1.58)	1.27 (1.13-1.41)*	1.33 (1.23-1.43)	1.20 (1.11-1.29)*
Allergic						
PM ₁	1.43 (1.32-1.55)	1.17 (1.08-1.28)*	1.42 (1.29-1.56)	1.14 (1.03-1.26)*	1.52 (1.41-1.63)	1.20 (1.11-1.29)*
PM _{2.5}	1.36 (1.26-1.47)	1.15 (1.07-1.24)*	1.34 (1.23-1.47)	1.11 (1.02-1.22)*	1.43 (1.34-1.53)	1.17 (1.09-1.25)*

^aAdjusted for age, sex, BMI, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, temperature during investigation, and district.

^bEffect expressed for a 1 interquartile range (i.e., 75th % tile - 25th % tile) change in ambient concentration for each pollutant (11.64 µg/m³ for PM₁, and 11.63 µg/m³ for PM_{2.5}).

**p* < 0.05 for interaction between PM × Allergic predisposition.

Table S7 Adjusted ORs and 95% CIs for associations between 10 μ g/m³ increase in PM₁ and PM_{2.5} with asthma and asthma-like symptoms for a total study population and stratified by age^a

	Age<6 years (n=9,823)		6-10 years of age (n=16,121)		Age>10 years (n=33,810)	
	ORs	95%CI	ORs	95%CI	ORs	95%CI
Doctor-diagnosed asthma						
PM ₁	1.64	1.50-1.79	1.68	1.55-1.82	1.66	1.54-1.79
PM _{2.5}	1.57	1.45-1.70	1.61	1.50-1.73	1.59	1.48-1.71
Current asthma						
PM ₁	1.65	1.42-1.91	1.54	1.34-1.76	1.54	1.35-1.76
PM _{2.5}	1.61	1.41-1.83	1.52	1.34-1.71	1.52	1.34-1.72
Current wheeze						
PM ₁	1.44	1.28-1.64	1.30	1.15-1.45	1.22	1.09-1.38
PM _{2.5}	1.39	1.24-1.55	1.27	1.14-1.41	1.21	1.08-1.34
Wheeze						
PM ₁	1.28	1.19-1.38	1.23	1.15-1.32	1.19	1.11-1.28
PM _{2.5}	1.25	1.17-1.34	1.21	1.14-1.29	1.18	1.11-1.26
Persistent phlegm						
PM ₁	1.40	1.23-1.60	1.29	1.15-1.46	1.27	1.14-1.43
PM _{2.5}	1.34	1.19-1.51	1.26	1.13-1.40	1.24	1.12-1.38
Persistent cough						
PM ₁	1.38	1.26-1.52	1.29	1.19-1.41	1.28	1.18-1.40
PM _{2.5}	1.33	1.22-1.44	1.26	1.16-1.36	1.25	1.16-1.35
Allergic rhinitis						
PM ₁	1.29	1.18-1.40	1.32	1.22-1.43	1.32	1.22-1.41
PM _{2.5}	1.24	1.15-1.34	1.27	1.19-1.37	1.27	1.19-1.36

^aAdjusted for age, sex, BMI, breast feeding status, low birth weight, premature delivery, caesarean delivery, parental education, income, environmental tobacco smoke exposure, exercise time per week, area of residence per person, family asthma history, temperature during investigation, and district.

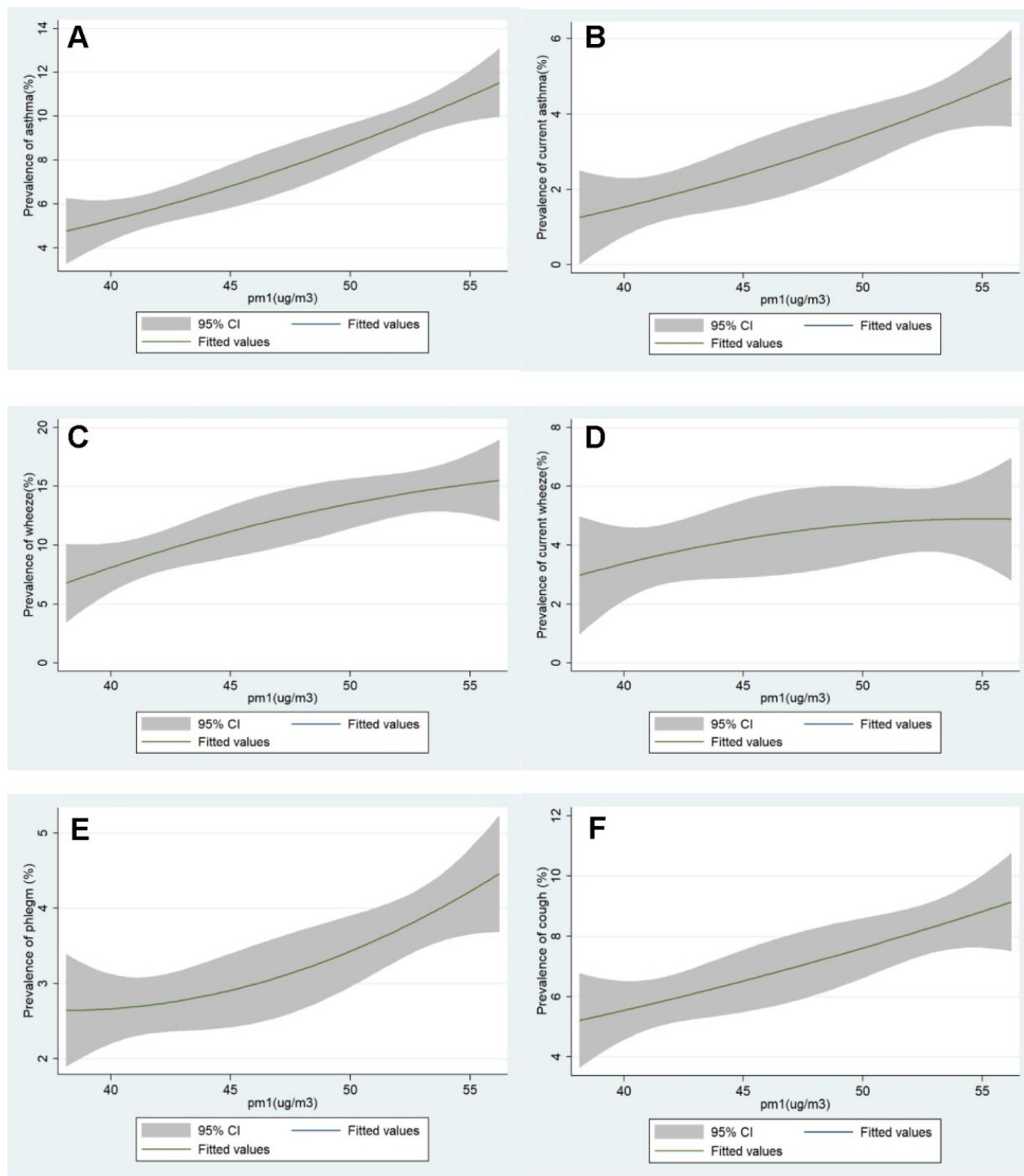


Figure S1. Correlation analysis between PM₁ concentrations and prevalence of asthma diagnosed by doctor (A), current asthma (B), wheeze (C), current wheeze (D), persistent phlegm (E), and persistent cough (F).

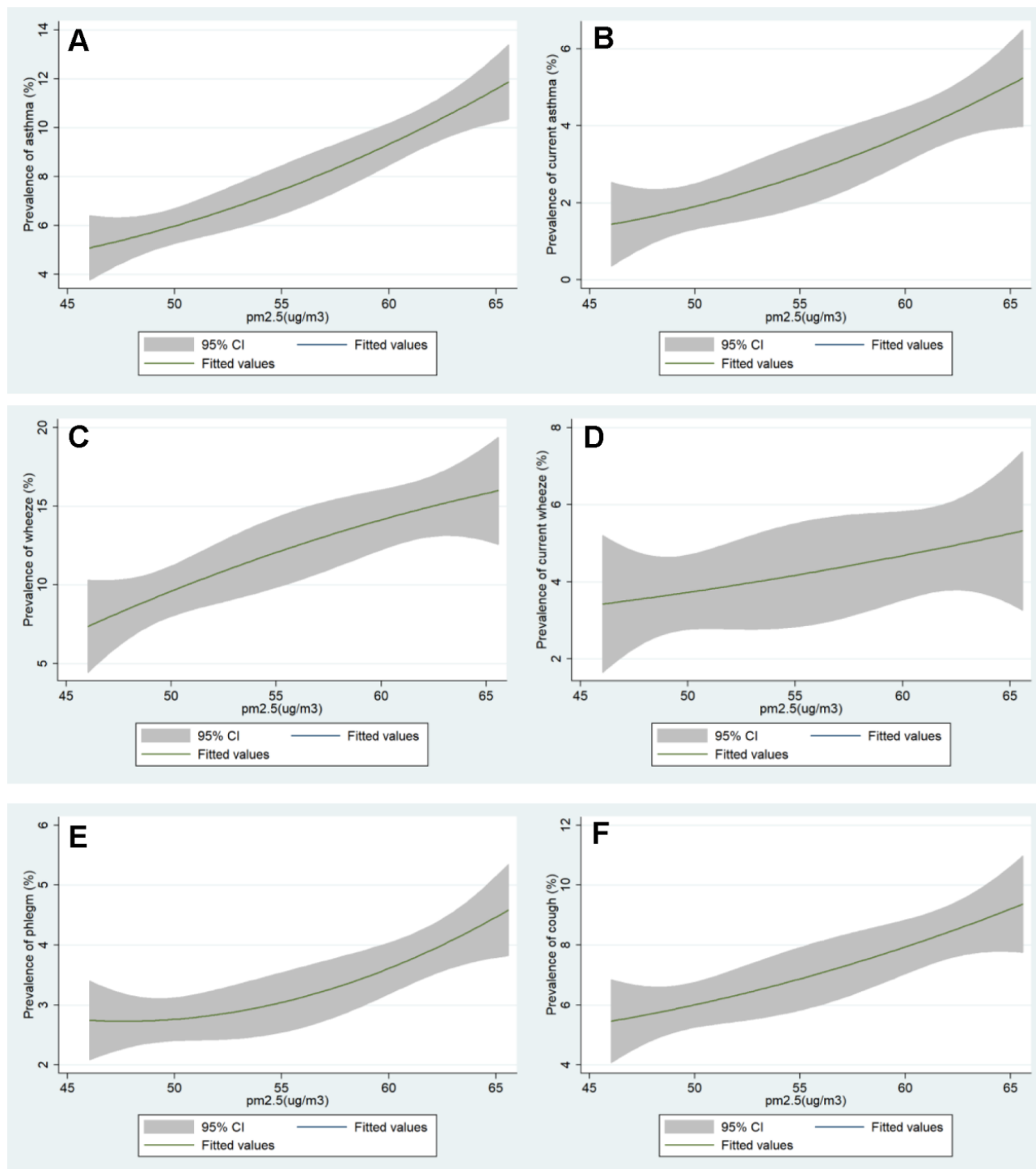


Figure S2. Correlation analysis between PM_{2.5} concentrations and prevalence of asthma diagnosed by doctor (A), current asthma (B), wheeze (C), current wheeze (D), persistent phlegm (E), and persistent cough (F).

辽宁省学生健康调查表

1. 学生姓名_____ 2. 性别_____
3. 所在学校_____ 年级_____ 班级_____
4. 出生日期_____年_____月_____日 5. 身高: _____厘米 体重: _____公斤
6. 现住址: _____市_____区_____街道办事处
7. 家长联系电话_____
8. 调查表填写人与学生的亲属关系是:
 1. 父亲 2. 母亲 3. 爷爷(姥爷) 4. 奶奶(姥姥) 5. 其他
9. 填表人的最高学历是:
 1. 小学 2. 初中 3. 高中(中专) 4. 大学(大专)及以上 5. 其他
10. 这个孩子目前与下列哪些亲人住在一起的时间最长
 1. 父亲 2. 母亲 3. 爷爷(姥爷) 4. 奶奶(姥姥) 5. 其他
11. 这个孩子所在家庭的年收入是:
 1. 5000 元以下 2. 5 千-1 万 3. 1-3 万 4. 3-10 万 5. 10 万以上 9. 不知道
12. 您为孩子购买了下面哪种医疗保险?
 1. 社会基本医疗保险 2. 商业医疗保险 3. 两者都有 4. 没有
13. 您们对这个孩子主要采用以下哪一种家庭教育方式(可以多选)?
 1. 说服教育 2. 管教严厉 3. 顺其自然 4. 其它(请注明)_____
14. 您的这个孩子平时认为作业负担是(幼儿不需填写): 1. 轻松 2. 一般 3. 过重
15. 填表日期_____年_____月_____日

下面对您的这个孩子进行有关呼吸道症状方面的调查。请您在各问题答案前的数字上打“○”或在“___”上填写数字及文字说明,并请调查中的提示跳过某些不必回答的问题,若对某一提问不明白或因记不清楚而无法回答时,请在“否”前的数字上打“○”。

[咳嗽]

- 1.1 您的这个孩子患感冒时经常咳嗽吗? 1. 是 2. 否
- 1.2 即使不感冒也经常咳嗽吗? 1. 是 2. 否
(若回答“否”,请直接回答第 2.1 项问题)
- 1.3 有过一年 3 个月以上,每天(一周 4 天以上)咳嗽的情况吗? 1. 是 2. 否
- 1.4 多大时开始出现一年 3 个月以上,每天(一周 4 天以上)咳嗽的情况? _____月或____周岁
- 1.5 一年 3 个月以上,每天咳嗽的情况已有几年了? _____年
- 1.6 通常哪几个月咳嗽最严重?请在相应的月份上打“○”

1	2	3	4	5	6	7	8	9	10	11	12	与月份无关
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[呼哧呼哧与咳痰]

- 2.1 您的这个孩子患感冒时，总是呼哧呼哧的并且咳痰吗？ 1. 是 2. 否
- 2.2 即使不感冒，也总是呼哧呼哧的并且咳痰？ 1. 是 2. 否
- (若对此问题的答案为“否”，请直接回答第 3.1 项问题)
- 2.3 像这种呼哧呼哧和咳痰的症状，有过一年 3 个月以上、每天（每周 4 天以上）发生的情况吗？ 1. 是 2. 否
- 2.4 多大时开始出现这种一年 3 个月以上、每天（每周 4 天以上）呼哧呼哧和咳痰的症状？ _____月或_____周岁
- 2.5 这种一年 3 个月以上、每日呼哧呼哧和咳痰的情况已经有几年了？ _____年
- 2.6 通常哪几个月咳痰最严重？请在相应的月份上打“○”
- | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|----|----|----|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 与月份无关 |
|---|---|---|---|---|---|---|---|---|----|----|----|-------|

[喘鸣]

- 3.1 您的这个孩子是否有过呼吸时胸中发出咝咝或呼呼的鸣笛声或口哨声（即喘鸣音）的情况？ 1. 是 2. 否
- (若对此问题的答案为“否”，请直接回答第 4.1 项问题)
- 3.2 出现上面（问题-3.1）所说的那种喘鸣音时正在患感冒吗？ 1. 是 2. 否
- 3.3 不感冒时也时常出现上面（问题-3.1）所说的那种喘鸣音吗？ 1. 是 2. 否
- 3.4 这个孩子近两年来出现上面（问题-3.1）所说的那种喘鸣音是否超过两次？ 1. 是 2. 否
- 3.5 这个孩子从小到现在是否有过呼吸时胸中发出咝咝或呼呼的鸣笛声或口哨声（即喘鸣音）并伴有急性呼吸困难的发作？ 1. 是 2. 否
- (若对此问题的答案为“否”，请直接回答第 3.7 项问题)
- 3.6 到现在为止，上面（问题-3.5）所说的那种情况的发作出现过 2 次以上吗？ 1. 是 2. 否
- 3.7 这个孩子长时间玩耍或跑步后是否出现上面（问题-3.1）所说的那种喘鸣音？ 1. 是 2. 否
- 3.8 通常哪几个月喘鸣最严重？请在相应的月份上打“○”
- | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|----|----|----|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 与月份无关 |
|---|---|---|---|---|---|---|---|---|----|----|----|-------|

[打喷嚏、流鼻涕、鼻塞]

- 4.1 您的这个孩子患感冒时经常打喷嚏、流鼻涕、鼻塞吗？ 1. 是 2. 否
- 4.2 您的这个孩子不感冒时也经常打喷嚏、流鼻涕、鼻塞吗？ 1. 是 2. 否

[感冒及呼吸道疾病史]

5.1 近3年来,您的这个孩子是否有因感冒、肺病或气管不好而在家休息超过三天的情况(包括学龄前)? 1. 是 2. 否

5.2 因上述原因(问题5.1)这个孩子三年间平均每年在家休息几次? _____次

5.3 近3年来,您的这个孩子是否有因感冒、肺病或气管不好而在家休息超过一周以上的情况(包括学龄前)? 1. 是 2. 否

(若对此问题的答案为“否”,请直接回答第5.5项问题)

5.4 因上述原因(问题5.3)这个孩子三年间平均每年在家休息几次(包括学龄前)? _____次

5.5 您的这个孩子两岁前是否因感冒而患过严重的呼吸道疾病(如气管炎、肺炎)? 1. 是 2. 否

(若对此问题的答案为“否”,请直接回答第5.8项问题)

5.6 请您回忆一下孩子患病时大夫诊断的病名(若得病超过一次请逐个填写)?
1. _____ 2. _____ 3. _____

5.7 两岁前因患严重的呼吸道疾病而住过几次医院(未住过的请填“0”)? _____次

5.8 您的这个孩子两岁前是否有过呼吸时胸中发出咝咝或呼呼的鸣笛声或口哨声(即喘鸣音)的情况? 1. 是 2. 否

(若对此问题的答案为“否”,请直接回答第5.10项问题)

5.9 第一次出现喘鸣音时孩子多大? _____月或_____周岁

5.10 您的这个孩子两岁前是否有过呼吸时胸中发出咝咝或呼呼的鸣笛声或口哨声(即喘鸣音)并伴有呼吸困难的情况? 1. 是 2. 否

(若对此问题的答案为“否”,请直接回答第5.12项问题)

5.11 第一次出现喘鸣音并伴有呼吸困难时孩子多大? _____月或_____周岁

5.12 医生曾给您这个孩子下过哮喘(或哮喘性支气管炎或者小儿哮喘)的诊断吗? 1. 是 2. 否

(若对此问题的答案为“否”,请直接回答第6.1项问题)

5.13 被诊断当时,孩子呼吸是否有咝咝或呼呼鸣笛声或口哨声(即喘鸣音)? 1. 是 2. 否

5.14 被诊断当时,孩子呼吸是否喘鸣并伴有呼吸困难? 1. 是 2. 否

5.15 孩子多大时由医生诊断为哮喘(或哮喘性支气管炎或者小儿哮喘)? _____月或_____周岁

5.16 孩子的哮喘通常在哪几个月发作?请在相应的月份上打“○”

1 2 3 4 5 6 7 8 9 10 11 12 与月份无关

- 5.17 近两年中，孩子的哮喘发作过吗？ 1. 是 2. 否
- 5.18 近两年中，孩子因哮喘或喘息性支气管炎或小儿喘息而接受治疗吗？ 1. 是 2. 否
- 5.19 孩子最后一次哮喘发作时是多大年龄？ _____月或_____周岁

[其他疾病史]

- 6.1 医生曾诊断您这个孩子患过敏性鼻炎吗？ 1. 是 2. 否
- 6.2 孩子多大时由医生诊断为患过敏性鼻炎？ _____月或_____周岁
- 6.3 孩子的过敏性鼻炎通常在哪儿几个月发作？请在相应月份上打“○”
- | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|----|----|----|-------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 与月份无关 |
|---|---|---|---|---|---|---|---|---|----|----|----|-------|
- 6.4 这两年中，孩子的过敏性鼻炎发作过吗？ 1. 是 2. 否
- 6.5 这两年中，孩子因过敏性鼻炎而接受过治疗吗？ 1. 是 2. 否
- 6.6 孩子最后一次过敏性鼻炎发作时是多大年龄？ _____月或_____周岁
- 6.7 医生是否检查出您这个孩子为过敏性体质？ 1. 是 2. 否
- 6.8 医生是否检查出您这个孩子对某种物质过敏（请逐项选择）？
1. 食物 2. 药物 3. 灰尘 4. 花粉 5. 洗涤剂 6. 其他 7. 否
- 6.9 请回忆一下医生是否曾诊断过您这个孩子患有下列疾病？如果有，请填上第一次患病的年龄。

病名	是否患过		首次患病的年龄
1. 麻疹	1. 是	2. 否	_____周岁
2. 百日咳	1. 是	2. 否	_____周岁
3. 支气管炎	1. 是	2. 否	_____周岁
4. 肺炎或支气管肺炎	1. 是	2. 否	_____周岁
5. 鼻窦炎	1. 是	2. 否	_____周岁
6. 湿疹	1. 是	2. 否	_____周岁
7. 过敏性结膜炎	1. 是	2. 否	_____周岁
8. 中耳炎	1. 是	2. 否	_____周岁
9. 心脏病	1. 是	2. 否	_____周岁
10. 支气管哮喘	1. 是	2. 否	_____周岁
11. 其他	1. 是	2. 否	_____周岁

- 6.10 近一年内，医生曾诊断您这个孩子患支气管炎吗？ 1. 是 2. 否
- 6.11 近一年内，医生曾诊断您这个孩子患肺炎或支气管肺炎吗？ 1. 是 2. 否
- 6.12 您的这个孩子曾做过扁桃体手术吗？ 1. 是 2. 否

[其他问题]

7.1 孩子出生后3个月内采用下列哪种哺乳方式（可以多选）？

1. 母乳 2. 牛奶或奶粉 3. 其他

7.2 若孩子是母乳喂养，那么孩子多大时断乳？ _____月或_____周岁

7.3 您的这个孩子出生时采用的是剖腹产吗？ 1. 是 2. 否

7.4 您的这个孩子是否属于早产？ 1. 是 2. 否

7.5 您的这个孩子出生时是否曾经送到过新生儿监护病房？ 1. 是 2. 否

7.6 母亲在怀孕这个孩子的时候心情如何？ 1. 好 2. 不好

7.7 母亲在怀孕这个孩子的时候年龄多大？ _____周岁

7.8 孩子的出生体重是多少？ _____斤_____两

7.9 您的这个孩子是独生子或独生女吗？ 1. 是 2. 否

7.10 孩子在近三年内接种过流感疫苗吗？ 1. 是 2. 否

7.11 这个孩子平时每周在户外活动的的时间是多少？ _____分钟或_____小时

[有关家庭成员的问题]

8.1 与这个孩子经常住在一起的亲属中有在家中吸烟的吗？ 1. 是 2. 否

（若对此问题的答案为“否”，请直接回答第8.3项问题）

8.2 他和孩子在一起的时候吸几支烟？如果他与孩子在一起时不吸烟请填上“0”支。

吸烟者与孩子的关系	和孩子在一起时吸烟支数	
	平日	节假日
父亲	_____支/日	_____支/日
母亲	_____支/日	_____支/日
爷爷	_____支/日	_____支/日
奶奶	_____支/日	_____支/日
姥爷	_____支/日	_____支/日
姥姥	_____支/日	_____支/日
其他（ ）	_____支/日	_____支/日

注：“其他”指伯父、叔父、姑母、舅父、姨母

8.3 母亲在怀这个孩子到出生这段时间内，家庭中或与孩子一起居住的人是否有经常在母亲面前吸烟的？ 1. 是 2. 否

8.4 孩子从出生到两岁这段时间内，家庭中或与孩子一起居住的人是否有经常在孩子面前吸烟的？ 1. 是 2. 否

8.5 怀这个孩子时母亲是否吸烟？ 1. 是 2. 否

8.6 怀这个孩子时母亲是否饮酒？ 1. 是 2. 否

[家族史]

9.1 这个孩子的父亲、母亲、(外)祖父、(外)祖母、叔父(舅父)、姑母(姨母)等是否患过以下疾病。若患病的话请在表中相应的空格内画“√”。

病名	父亲	母亲	爷爷	奶奶	姥爷	姥姥	其他
哮喘（支气管哮喘）							
慢性支气管炎							
肺气肿							
湿疹							
过敏性鼻炎							
过敏性结膜炎							

注：“其他”指伯父、叔父、姑母、舅父、姨母

[孩子的居住环境]

10.1 这个孩子现在的住房是哪种建筑类型？

1. 平房 2. 楼房 3. 其它

10.2 这个孩子现在的住房是哪年的建筑? 年

10.3 孩子的住房是在几楼? 楼

10.4 孩子现在居住的住房位于下列哪类区域内？

1. 居住区 2. 工业区 3. 商业区 4. 其他

10.5 孩子现在居住的住房沿街吗? 1. 是 2. 否

10.6 孩子现在居住的住房与主要交通干线相距大约多少米?

- 1) <5 米 2) 5-19 米 3) 20-100 米 4) >100 米

10.7 孩子的住房与工厂的距离？

- 1) <20 米 2) 20-100 米 3) >100 米 4) 附近没有工厂

10.8 孩子的住房与大烟囱的距离？

- 1) <20 米 2) 20-100 米 3) >100 米 4) 附近没有大烟囱

10.9 孩子的住房最近 3 年内是否装修过? 1. 是 2. 否

(若对此问题的答案为“否”，请直接回答第 10.11 项问题)

10.10 室内装修时采用了下列哪些方式（可以多选）？

- 1.油漆 2.地板革 3.地板 4.地毯 5.墙壁粉刷涂料或壁纸 6.购买新家具 7.其它

10.11 孩子家中有几个房间（含门厅，不含卫生间和壁橱）？ 间

10.12 住房面积是多少平方米? 平方米

10.13 孩子家中共有几个人居住? _____ 人

- 10.14 孩子家中冬天是否经常开窗换气？
1. 经常 2. 偶尔 3. 很少
- 10.15 孩子家中是否使用加湿器？ 1. 是 2. 否
- 10.16 孩子自己或与家人同住的居室的地面是什么材料（可以多选）？
1. 水泥 2. 地板 3. 地毯 4. 地砖 5. 地板革 6. 土地面
- 10.17 孩子现在在家中冬季里用什么方式取暖（可以多选）？
1. 暖气 2. 煤炉或火炕 3. 电暖气 4. 煤气取暖器 5. 其他
- 10.18 孩子家中做饭主要用哪种燃料或能源（可以多选）？
1. 煤 2. 煤气或液化气 3. 电 4. 木材 5. 煤油 6. 其他
- 10.19 厨房内是否安装了抽油烟机、排风扇等排气设备？ 1. 是 2. 否
- 10.20 做饭时，厨房内的烟对做饭者眼睛是否产生刺激症状？ 1. 是 2. 否
- 10.21 做饭时，家里（除了厨房以外）有多少烟？
1. 没有 2. 轻度 3. 中度 4. 重度
- 10.22 这个孩子家中现在是否饲养了小动物（宠物）？ 1. 是 2. 否
（若对此问题的答案为“否”，请直接回答第 10.26 项问题）
- 10.23 这个孩子家中现在饲养的各种小动物（宠物）的数量是多少？ _____个
- 10.24 这个孩子家里现在饲养了下列小动物吗？
1. 猫 2. 狗 3. 鸟 4. 鸡、鸭、鹅 5. 其他 6. 未养任何小动物
- 10.25 这个孩子晚上睡觉时是否经常与小动物睡在一起？ 1. 是 2. 否
- 10.26 孩子从出生到 2 岁这段时间内家中是否饲养了小动物（宠物）？ 1. 是 2. 否
- 10.27 母亲在怀孕这个孩子时家中是否饲养了小动物（宠物）？ 1. 是 2. 否
- 10.28 这个孩子家里的墙壁上是否因屋漏雨或漏水而出现发霉或长毛？ 1. 是 2. 否
（若对此问题的答案为“否”，请直接回答第 10.29 项问题）
- 10.29 家里的墙壁共有几处地方出现发霉或长毛？ _____处
- 10.30 这个孩子家里是否有蟑螂出现？ 1. 是 2. 否
- 10.31 这个孩子是否自己睡单独房间？ 1. 是 2. 否
- 10.32 这个孩子是否自己睡一床？ 1. 是 2. 否
- 10.33 您的这个孩子是否曾经到游泳馆游泳？ 1. 是 2. 否
- 10.34 您的这个孩子第一次到游泳馆游泳的年龄是多大？ _____周岁
- 10.35 这个孩子睡觉的房间里是否安装了电视？ 1. 是 2. 否
- 10.36 您的这个孩子平时每天看电视的时间大约是多少？ _____分钟或_____小时
- 10.37 这个孩子每天上学采用何种交通工具？
1. 步行 2. 自行车（包括成人接送） 3. 摩托车 4. 公共汽车 5. 小汽车 6. 其它
- 10.38 孩子从家到学校在路上需用多长时间？ _____分钟

〔孩子的睡眠状况〕

睡眠是影响学生身体健康的重要因素，充足的睡眠可保证儿童具有良好的学习状态。以下 26 个问题是了解您的孩子在过去 6 个月中的睡眠状况，请您从“从不”、“偶尔”、“有时”、“经常”、“总是”五个答案中选择一个最合适您孩子情况的答案。请在相应答案上打“○”。

1. 平时您的孩子晚上睡眠一般多少时间（小时）？	>9	8-9	7-8	5-7	<5
2. 平时您的孩子上床后需要多少分钟才能入睡？	<15	15-30	30-45	45-60	>60
以下问题选项注释： “从不=从来没有出现过”；“偶尔=每月出现 1-2 次”； “有时=每周出现 1-2 次”；“经常=每周出现 3-5 次”；“总是=每周出现次数>5 次”					
3. 该上床睡觉的时候，您的孩子很不情愿上床睡觉	从不	偶尔	有时	经常	总是
4. 晚上睡觉时，您的孩子比较难以入睡或入睡比较困难	从不	偶尔	有时	经常	总是
5. 孩子在入睡过程中感到焦虑或害怕	从不	偶尔	有时	经常	总是
6. 孩子在入睡过程中出现突然惊跳或抽动身体某个部位	从不	偶尔	有时	经常	总是
7. 孩子在入睡过程中总是重复某个动作如摇摆或翻身	从不	偶尔	有时	经常	总是
8. 孩子在入睡过程中头脑中出现梦境般的场景	从不	偶尔	有时	经常	总是
9. 孩子在入睡过程中身上出许多汗	从不	偶尔	有时	经常	总是
10. 每晚孩子醒来超过两次	从不	偶尔	有时	经常	总是
11. 孩子半夜睡醒后很难再次入睡	从不	偶尔	有时	经常	总是
12. 孩子在睡觉时经常翻身或踢腿把被踹掉	从不	偶尔	有时	经常	总是
13. 晚上睡觉时孩子出现呼吸困难或呼吸不畅	从不	偶尔	有时	经常	总是
14. 晚上睡觉时孩子出现张口呼吸或呼吸暂停现象	从不	偶尔	有时	经常	总是
15. 孩子睡觉时打呼噜	从不	偶尔	有时	经常	总是
16. 在晚上睡觉时，孩子身上过度出汗	从不	偶尔	有时	经常	总是
17. 您曾经看到孩子梦游	从不	偶尔	有时	经常	总是
18. 您曾经听到孩子睡觉时说梦话	从不	偶尔	有时	经常	总是
19. 孩子睡觉时磨牙	从不	偶尔	有时	经常	总是
20. 孩子突然尖叫着或表情迷茫的醒来，而你无法与他（她）交谈，但孩子早上醒来却忘记了	从不	偶尔	有时	经常	总是
21. 孩子晚上睡觉时做噩梦，但第二天醒来后却不记得	从不	偶尔	有时	经常	总是
22. 早上孩子很难醒来	从不	偶尔	有时	经常	总是
23. 早上醒来，孩子感到非常疲倦	从不	偶尔	有时	经常	总是
24. 早上孩子醒来后感到无法活动	从不	偶尔	有时	经常	总是
25. 孩子白天打瞌睡	从不	偶尔	有时	经常	总是
26. 孩子在不适合睡觉的环境中能够突然入睡	从不	偶尔	有时	经常	总是

〔孩子的学习行为〕

孩子的日常行为举止可影响学习态度和学习效率，以下 20 个问题是了解您的孩子平时或一贯表现情况的描述，请您根据了解的信息从“无”、“稍有”、“较多”、“很多”四个答案中选择一个最合适您孩子情况的答案。请在相应答案上打“○”。

1. 上课时坐立不安	无	稍有	较多	很多
2. 上课时经常讲话	无	稍有	较多	很多
3. 上课时小动作多	无	稍有	较多	很多
4. 发言不举手	无	稍有	较多	很多
5. 不专心，东张西望，易因外界干扰而分心	无	稍有	较多	很多
6. 情绪变化快，容易与别人争吵	无	稍有	较多	很多
7. 常激惹别人，干扰别人活动	无	稍有	较多	很多
8. 不能平心静气玩耍	无	稍有	较多	很多
9. 做事心血来潮，想做什么就做什么，往往有始无终	无	稍有	较多	很多
10. 做事不计后果如何	无	稍有	较多	很多
11. 随便拿父母钞票，或在外偷窃	无	稍有	较多	很多
12. 丢三落四，记忆力差	无	稍有	较多	很多
13. 学习成绩差	无	稍有	较多	很多
14. 说谎、骂人打架	无	稍有	较多	很多
15. 在游戏或集体活动时不能耐心地排队等候上场	无	稍有	较多	很多
16. 常常别人问话未完即抢着回答	无	稍有	较多	很多
17. 难以按照别人的指示去做事	无	稍有	较多	很多
18. 在做作业或游戏中难以保持注意力	无	稍有	较多	很多
19. 别人和他讲话时常似听非听	无	稍有	较多	很多
20. 常常参与危险活动而不考虑后果，如乱跑到街上而不顾周围等	无	稍有	较多	很多

调查到此结束，请您从头检查一下是否有遗漏和错误。

非常感谢您认真帮助我们完成这次调查。