

The Effect of Residential Environment on Respiratory Diseases and Pulmonary Function in Children from a Community in Jilin Province of China

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Purpose: Respiratory disease is a major and increasingly global epidemic that has a great impact on humans, especially children. The purpose of this study was to identify environmental risk factors for respiratory diseases and pulmonary function in children.

Patients and Methods: A population-based, cross-sectional survey of respiratory diseases and environmental risk factors was conducted in Jilin Province, China. Complete questionnaire information was available for 2419 children, while adequate pulmonary function data were available for a subgroup of 627 children.

Results: Our study found that environmental risk factors for respiratory health in children were mainly concentrated indoors. After adjusting for demographic factors, insecticide exposure and passive smoking were risk factors for respiratory disease and industrial pollutant sources, insecticide exposure and the use of a fume exhauster may be independent risk factors for recurrent respiratory infections. The main fuel for cooking in the winter and passive smoking were the main influencing factors of pulmonary function indicators.

Conclusion: The primary risk factors differ in different respiratory diseases. Passive smoking remains a critical adverse factor for respiratory illness and pulmonary function in children, and it is important to reduce children's exposure to passive smoking to increase pulmonary health. Insecticide exposure may be a neglected environmental risk factor, and further investigations are still needed to explore the relationship and mechanisms between insecticide exposure and children's respiratory health.

Keywords: respiratory diseases, lung function, environmental risk factors

Introduction

Environmental factors play an essential role in the health and development of children. A safe and healthy environment contributes to children's growth and health but is absent in some countries.¹ According to reports, environmental risk factors remain a major risk factor affecting children's health, causing various short- and long-term damage to children.² Meanwhile, poor health among children places a financial strain on the children's families, in terms of medical costs, and the national public health care systems.^{3,4} It is worth noting that respiratory diseases are a major cause of poor health in children.

Pulmonary development and function can be easily altered by early exposure to environmental risk factors in children, whose lungs are still growing and

developing. Environmental risk factors might have adverse effects on children's respiratory system, leading to a decline in lung function.^{5,6} For example, exposure to traffic pollutants may cause children coughing, sneezing, asthma, and decreased lung function in children.^{7–11} Concurrently, phthalates, pesticides, and bisphenol-A (BPA) are known to be important risk factors for the development and exacerbation of asthma.^{12,13} In addition, environmental tobacco smoke (ETS), air pollution and the family environment may be associated with respiratory infection.^{14–16} Notably, ETS exposure may cause an increase in symptoms of respiratory disease.^{17,18} To date, the effects of some environmental factors on the respiratory system of children have been demonstrated. For example, passive smoking is considered a risk factor for many respiratory diseases, such as asthma and rhinallergosis.^{19,20} However, except for passive smoking, there is still limited research on the impact of environmental risk factors in the living environment on respiratory diseases. We examined associations between environmental risk factors in the living environment and children's respiratory health, as assessed by a questionnaire and pulmonary function measurements, in a cross-sectional study of a predominantly Chinese community in Jilin Province, China.

Patients and Methods

Study Population

Considering the regional characteristics of air pollution and ethnic minorities, we chose Changchun, the provincial capital city, and Yanji, a minority gathering area, as the study cities. In each city, two primary schools were randomly selected, and at least 200 students each from grades 3rd through 5th were selected using the cluster random sampling method in October 2016. We assessed the impact of environmental factors on respiratory health in children (n=2419).

Exposure Assessment

The environmental impact factors were assessed through the parental questionnaire. The parental questionnaire was based on a review of the literature and designed to identify the demographic information and environmental factors to be assessed. The questionnaire was further refined by a presurvey, and it was developed jointly by epidemiologists and environmental health experts. Trained investigators applied the questionnaire, and the

main environmental variables were as follows. Outdoor environmental exposures: industrial pollutant sources (exposure to garbage stations, foul ditches, heating companies or noise with 100 meters around home); and distance from home to main traffic roads (<20 m, 20–150 m, >150 m). Indoor environmental exposures: insecticide exposure (exposure to insecticides, anopheli-fuges or moth repellent); other organic solvent exposure (exposure to air fresheners or disinfectants); indoor furnishings (decorated the house within three years or bought new furniture within a year); presence or absence of pets; passive smoking (smoke inhaled every day for more than 15 minutes); (No, <1 day/week, 1–2 day/week, >2 days/week); main heating mode (central heating, household gas heating, heating via spontaneous combustion of coal, others); main fuel used for cooking (electric power, natural gas, liquid gas, pipeline gas, others); and use of a fume exhaustor or air cleaner. Moreover, information about the frequency of opening the windows in winter (No, 1–3 times/week, >3 times/week) was collected.

Health Outcome Assessment

Children's health outcomes included recurrent respiratory tract infection, pneumonia, asthma, tracheitis/bronchitis and rhinallergosis; these outcomes were also ascertained by the parental questionnaire. The main outcome, respiratory disease, was defined as at least one of the following: recurrent respiratory tract infections, pneumonia, asthma, tracheitis/bronchitis or rhinallergosis. All diseases were clinically confirmed and had a clear diagnosis report. Limited funds were available to select 25% of the primary school students for assessment of pulmonary function. In each school, at least 50 primary school students from grades 3 to 5 were randomly selected for pulmonary function testing in each grade (generally one class as a whole using the cluster random sampling method); in principle, both sexes were equally represented. A subset of the selected study population underwent analysis of pulmonary function (Chestgraph HI-101, Japan) at a designated hospital or medical examination center after the children's weight and standing height were obtained (n = 627). The pulmonary function analysis included forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), FEV₁/FVC, peak expiratory flow velocity (PEF), forced expiratory flow at 25% FVC (V₂₅) and forced expiratory flow at 75% FVC (V₇₅).

Ethics Statement

This study was conducted in accordance with the Declaration of Helsinki. The Ethics Committee of Jilin Provincial Center for Disease Control and Prevention approved this study, and informed consent was obtained from all pupils and parents before the study was conducted. Written informed consent from the parents was obtained for each participant.

Quality Control

All investigators were trained before the investigation. Reviewers examined the questionnaires on the same day that they were completed (to check whether the questionnaire was completed and whether there were logical errors); if necessary, unqualified questionnaires were corrected, and omissions eventually completed by contacting the investigator or the subjects. The data were double-entered in parallel and corrected according to the consistency test report. The measurement instruments for pulmonary function assessment were calibrated according to the same standard provided in the CHESTGRAPH HI-101 User's Manual.

Statistical Analysis

The database was established by EpiData 3.1, and statistical analysis was carried out using SPSS 17.0 and R version 3.6.2 statistical software. Categorical variables are described as numbers and frequencies, and continuous variables are described as $\bar{x} \pm s$ (mean \pm standard deviation). The χ^2 test and *t*-test were adopted for comparisons between two groups. The least significant difference (LSD) procedure and one-way ANOVA were used to compare the means of three groups. To analyze the environmental risk factors for respiratory diseases and pulmonary function, we used multivariate logistic regression analysis and stepwise multiple linear regression analysis. In addition, different models were constructed by adjusting for demographic variables. A *P*-value <0.05 (two-tailed) was considered to be statistically significant.

Results

Characteristics of the Study Population

A total of 2419 subjects were included in the study, and the characteristics of the study population are listed in Table 1. The sex ratio of the study population was close to 1. The educational background of most children's parents was junior high school or above. The prevalence

of respiratory diseases was 14.8%, and the prevalence of the five different respiratory diseases evaluated was 6.2% for recurrent respiratory tract infection, 1.1% for pneumonia, 0.9% for asthma, 4.4% for tracheitis/bronchitis, and 4.9% for rhinallergosis (Table 2). Almost all families used a fume exhauster during cooking, nearly half of the households used natural gas, and some families were exposed to other environmental factors (Table 1). There were few differences between the pulmonary function testing subset and the larger study sample in selected demographics, health outcomes, and environmental exposures ($P>0.05$). Therefore, the subset can reasonably represent the study population.

Univariate Analysis of the Environmental Risk Factors for Respiratory Diseases

Significant differences were found in industrial pollutant sources, insecticide exposure, other organic solvents and passive smoking between the population with respiratory diseases and the population without respiratory diseases ($P<0.05$) (Table S1). In the four respiratory diseases other than pneumonia, insecticide exposure and passive smoking were significantly different between those with and without disease. The distribution of the main fuel for cooking in winter was significantly different only between those with and without pneumonia. Other detailed univariate analysis results are shown in Table S2.

Multivariable Analysis of the Environmental Risk Factors for Respiratory Diseases

Taking respiratory diseases as the dependent variables, the significant factors in the univariate analysis (industrial pollutant sources, insecticide exposure, other organic solvents and passive smoking) were entered as the independent variables, and multivariate logistic regression was conducted to analyze the environmental risk factors for respiratory diseases. The valuation of variables is listed in Table S3.

As shown in Figure 1, exposure to industrial sources of pollutants, pesticides, other organic solvents, and passive smoking were risk factors for respiratory disease in model 1 (unadjusted) and model 2 (adjusted for sex and highest parental education). After adjusting for sex, parental education, allergic history, past history of respiratory diseases and family history of respiratory diseases, only insecticide exposure and passive smoking were risk factors for respiratory disease ($P<0.05$).

Table 1 Characteristics of Study Population [n(%)]

Factors		Study Population (n=2419)	Subset (n=627)	χ^2	P
Demographics					
Sex	Female Male	1125(46.5) 1294(53.5)	293(46.7) 334(53.3)	0.010	0.920
Father's highest degree	Primary school and below Junior middle school High school College degree Bachelor or above	118(4.9) 706(29.2) 709(29.3) 471(19.5) 415(17.2)	22(3.5) 158(25.2) 196(31.3) 144(23) 107(17.1)	8.474	0.076
Mother's highest degree	Primary school and below Junior middle school High school College degree Bachelor or above	137(5.7) 756(31.3) 670(27.7) 462(19.1) 394(16.3)	26(4.1) 181(28.9) 178(28.4) 133(21.2) 109(17.4)	4.648	0.325
Respiratory diseases	No Yes	2060(85.2) 359(14.8)	543(86.6) 84(13.4)	0.835	0.361
Allergic history	No Yes	2089(86.4) 330(13.6)	530(84.5) 97(15.5)	1.381	0.240
Past history of respiratory diseases	No Yes	2049(84.7) 370(15.3)	535(85.3) 92(14.7)	0.150	0.699
Family history of respiratory diseases	No Yes	2308(95.4) 111(4.6)	603(96.2) 24(3.8)	0.681	0.409
Outdoor environmental exposures					
Distance from home to main traffic road	<20m 20–150m >150m	377(15.6) 992(41) 1050(43.4)	103(16.4) 263(41.9) 261(41.6)	0.697	0.706
Industrial pollutant sources	No Yes	1533(63.4) 886(36.6)	385(61.4) 242(38.6)	0.829	0.363
Indoor environmental exposures					
Insecticide exposure	No Yes	2100(86.8) 319(13.2)	542(86.4) 85(13.6)	0.059	0.808
Other organic solvent exposure	No Yes	2028(83.8) 391(16.2)	512(81.7) 115(18.3)	1.705	0.192
Indoor furnishings	No Yes	1989(82.2) 430(17.8)	517(82.5) 110(17.5)	0.018	0.892
Pet	No Yes	2181(90.2) 238(9.8)	567(90.4) 60(9.6)	0.041	0.840
Window opening in winter	No 1–3 times/week >3 times/week	218(9) 856(35.4) 1345(55.6)	60(9.6) 221(35.2) 346(55.2)	0.188	0.910

(Continued)

Table 1 (Continued).

Factors		Study Population (n=2419)	Subset (n=627)	χ^2	P
Passive smoking	No <1 day/week 1–2 day/week >2 day/week	2020(83.5) 167(6.9) 109(4.5) 123(5.1)	530(84.5) 45(7.2) 24(3.8) 28(4.5)	1.025	0.795
Main heating mode	Central heating Household gas heating Heating of spontaneous combustion coal Others	2198(90.9) 82(3.4) 89(3.7) 50(2.1)	565(90.1) 19(3) 21(3.3) 22(3.5)	4.754	0.191
The main fuel for cooking in winter	Electric power Natural gas Liquid gas Pipe-line gas Others	247(10.2) 1039(43) 700(28.9) 384(15.9) 49(2)	57(9.1) 286(45.6) 190(30.3) 84(13.4) 10(1.6)	4.221	0.377
Fume exhauster	No Yes	162(6.7) 2257(93.3)	40(6.4) 587(93.6)	0.081	0.776
Air cleaner	No Yes	2105(87) 314(13)	536(85.5) 91(14.5)	1.015	0.314

Table 2 The Prevalence of the Different Respiratory/Allergic Diseases

Respiratory Diseases	Yes [n(%)]	No [n(%)]
Recurrent respiratory tract infection	151(6.2)	2268(93.8)
Pneumonia	27(1.1)	2392(98.9)
Asthma	22(0.9)	2397(99.1)
Tracheitis/ bronchitis	107(4.4)	2312(95.6)
Rhinallergosis	119(4.9)	2300(95.1)

In addition, we performed individual multivariate analyses for the five different respiratory/allergic diseases. After adjusting for demographic factors, we found that passive smoking may be an independent risk factor for tracheitis/bronchitis and rhinallergosis, and industrial pollutant sources, insecticide exposure, and the use of a fume exhauster may be independent risk factors for recurrent respiratory infections. No environmental risk factors were found for pneumonia or asthma (Figure 2).

Pulmonary Function Under Different Environmental Conditions

As shown in Table S4, the FVC of children whose homes were >150 m from the main traffic road was significantly lower than those whose homes were <20 m from the main traffic road ($P<0.05$). Compared to children whose homes were >150 m from the main traffic road, children whose homes were <20 m and 20–150 m from the main traffic road had lower FEV₁/FVC. The V₂₅ of children whose homes had windows open in winter >3 times/week was significantly higher than that among children whose windows were open 1–3 times/week ($P<0.05$). FVC values were all significantly different among children exposed to passive smoking <1 day/week, passive smoking 1–2 day/week and no passive smoking ($P<0.05$); the FEV₁ among children exposed to passive smoking 1–2 day/week was lower than that among children who were not exposed to passive smoking ($P<0.05$); The FVC, FEV₁ and V₇₅ values for children exposed to electric power, liquid gas and pipeline gas were all higher than those for children

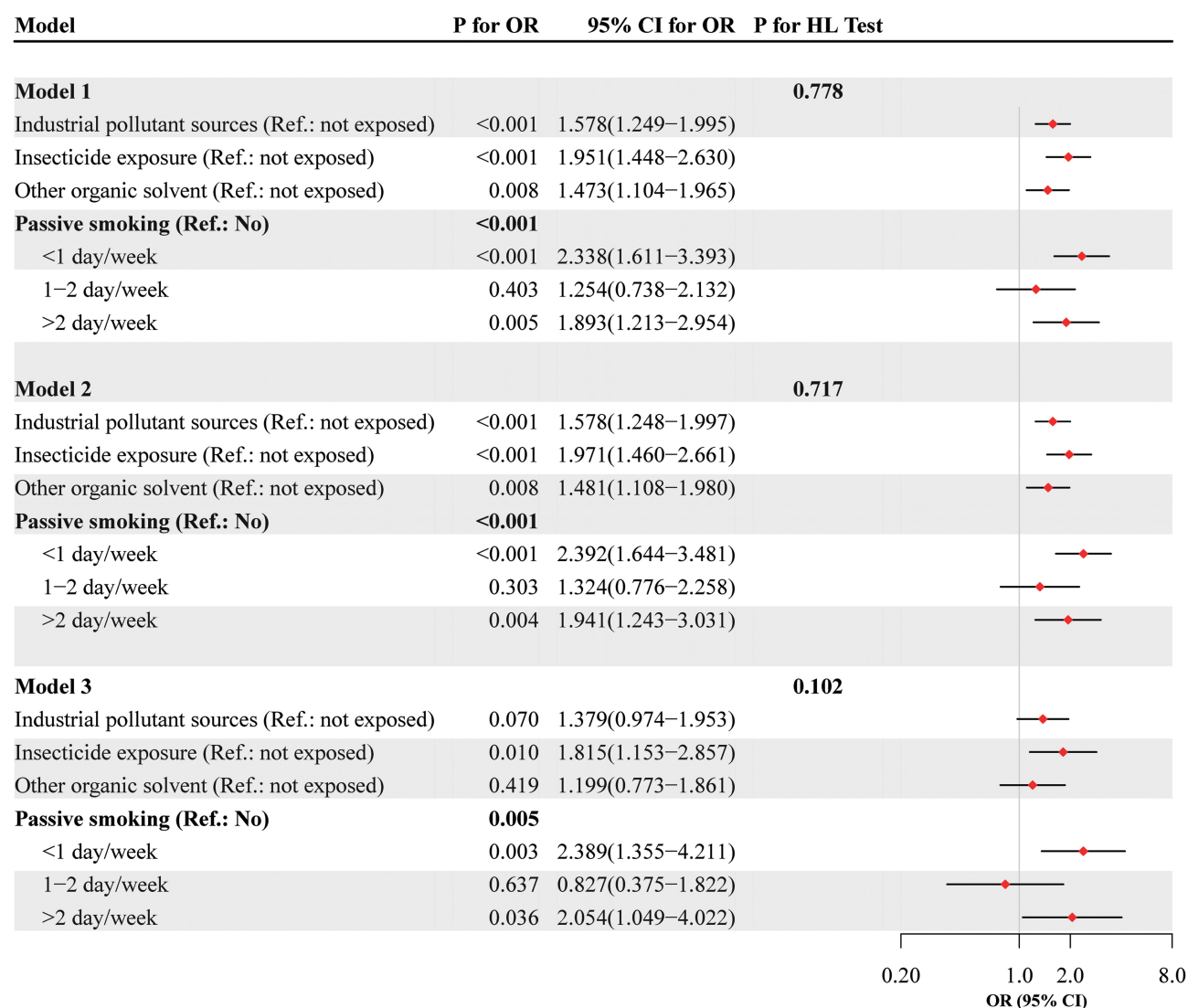


Figure 1 Multivariable analysis of the environmental risk factors for respiratory diseases.

Notes: Model 1: unadjusted; Model 2: adjusted for sex, father's highest degree and mother's highest degree; Model 3: adjusted for sex, father's highest degree, mother's highest degree, allergic history, past history of respiratory diseases and family history of respiratory diseases.

Abbreviations: HL Test, Hosmer and Lemeshow Test; OR, odds ratio; CI, confidence interval.

exposed to natural gas, while the opposite was true for FEV_1/FVC ($P < 0.05$).

Stepwise Multiple Linear Regression Analysis of Pulmonary Function Indicators

As shown in Table 3, the potential environmental impact factors differed for different pulmonary function indicators. The main fuel used for cooking in winter affected FEV_1/FVC , FVC and FEV_1 in children. In addition, FVC and FEV_1 might be influenced by passive smoking; the distance from home to the main road also influenced FEV_1/FVC and FVC in children; and window opening in winter

impacted children's V_{25} . Lower V_{25} was seen with a high frequency of window openings per week. After adjusting for demographic factors, no environmental variables significantly affected PEF in our current study.

Discussion

The use of questionnaires allowed us to collect and analyze information on children's respiratory health and their living environment easily, quickly, efficiently and economically. The aim of this study was to investigate some environmental risk factors for respiratory diseases and lung function through the analysis of children's indoor

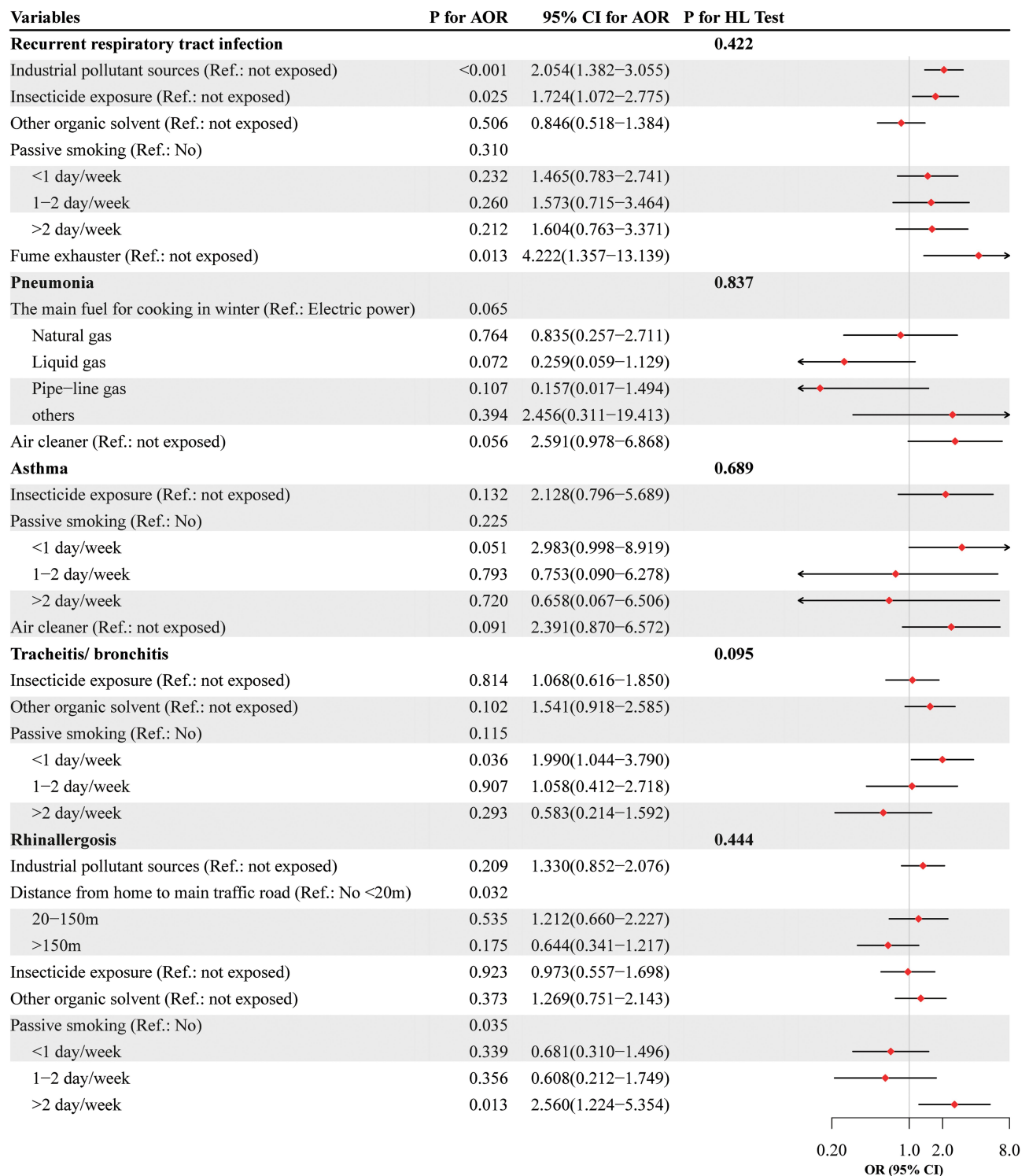


Figure 2 Multivariable analysis of the environmental risk factors for five respiratory diseases. Adjusted for sex, father's highest degree, mother's highest degree, allergic history, past history of respiratory diseases and family history of respiratory diseases.

Abbreviations: HL Test, Hosmer and Lemeshow Test; AOR, adjusted odds ratio; CI, confidence interval.

and outdoor environments by using a questionnaire. The respiratory health effect of environmental smoke exposure is an important issue worldwide. We found that passive smoking could influence respiratory disease and lung

function in children, even after adjusting for demographic factors. The analysis of five different respiratory diseases showed that the environmental risk factors also differed among the different respiratory diseases. In addition, the

Table 3 Stepwise Multiple Linear Regression Analysis for Pulmonary Function Indices in the Subset Population (n =627)

Variables and Model		SE	β	P	VIF	Durbin-Watson
FEV ₁ /FVC	Model 1					1.872
	Distance from home to main traffic road (Ref.: <20m)	0.003	0.111	0.005	1.001	
	The main fuel for cooking in winter (Ref.: Electric power)	0.003	-0.086	0.031	1.001	1.870
	Model 2					
FVC	Distance from home to main traffic road (Ref.: <20m)	0.003	0.110	0.006	1.008	1.931
	The main fuel for cooking in winter (Ref.: Electric power)	0.003	-0.085	0.033	1.007	
	Model 1					1.914
	Distance from home to main traffic road (Ref.: <20m)	0.028	-0.094	0.017	1.006	
	Passive smoking (Ref.: not exposed)	0.027	-0.104	0.009	1.013	
	The main fuel for cooking in winter (Ref.: Electric power)	0.022	0.131	0.001	1.009	
FEV ₁	Model 2					1.942
	Distance from home to main traffic road (Ref.: <20m)	0.027	-0.082	0.034	1.014	
	Passive smoking (Ref.: not exposed)	0.027	-0.115	0.004	1.045	1.937
	The main fuel for cooking in winter (Ref.: Electric power)	0.022	0.128	0.001	1.014	
	Model 1					1.937
	Passive smoking (Ref.: not exposed)	0.023	-0.100	0.012	1.008	
PEF	The main fuel for cooking in winter (Ref.: Electric power)	0.019	0.130	0.001	1.008	2.083
	Model 2					
	Passive smoking (Ref.: not exposed)	0.023	-0.113	0.004	1.039	2.072
	The main fuel for cooking in winter (Ref.: Electric power)	0.019	0.127	0.001	1.013	
V ₇₅	Model 1					2.083
	Window opening in winter (Ref.: >3 times/week)	0.047	-0.081	0.044	1.000	
	Model 2					2.072
	Window opening in winter (Ref.: >3 times/week)	0.047	-0.068	0.088	1.028	
V ₂₅	Model 1					1.988
	The main fuel for cooking in winter (Ref.: Electric power)	0.027	0.091	0.023	1.000	
	Model 2					1.990
	The main fuel for cooking in winter (Ref.: Electric power)	0.027	0.087	0.029	1.006	
V ₂₅	Model 1					2.132
	Window opening in winter (Ref.: No)	0.048	-0.104	0.009	1.000	
	Model 2					2.101
	Window opening in winter (Ref.: No)	0.048	-0.092	0.021	1.028	

Notes: Model 1: unadjusted. Model 2: adjusted for sex, father's highest degree, mother's highest degree, allergic history, past history of respiratory diseases and family history of respiratory diseases. Bold values mean P<0.05.

Abbreviations: FVC, forced vital capacity; FEV₁, forced expiratory volume in 1 s; PEF, peak expiratory flow velocity; V₇₅, forced expiratory flow at 75%FVC; V₂₅, forced expiratory flow at 25%FVC; SE, standard error; VIF, variance inflation factor.

factors that affect pulmonary function indicators in children were nearly all indoor environmental factors. Appropriate reduction or elimination of these environmental risk factors could help reduce the effect of this risk.^{21,22}

The detrimental effects of passive smoke exposure on pulmonary function are well documented.^{23,24} Our findings also further confirm that passive smoking is a significant environmental risk factor for respiratory

disease and lung function in children. Additionally, rhinallergosis and tracheitis/bronchitis were influenced by passive smoking. This may be because environmental tobacco smoke may generate certain adverse effects on ciliary activity and the function of mucociliary cilia in the respiratory mucosa, leading to changes in some structures that may disrupt or weaken defense mechanisms.²⁵ Mucus produced by secretory cells in

the mucosa effectively protects the respiratory tract by clearing hazardous particles.²⁶ As a result of the body's defense mechanisms, tobacco smoke may facilitate mucus production, but it may also alter the mucus glycoprotein content and reduce its viscoelasticity.²⁷ Furthermore, submicron particles and nanoparticles are also responsible for the negative effect of PM on children's lung health.²⁸

A study conducted in Italian children concluded that passive smoking was a trigger for asthma-like symptoms and increased FEV₁/FVC, which was different from our findings.²⁹ In the multivariate results of pulmonary function indicators, only FVC and FEV₁ were impacted by passive smoking in children, while passive smoking was not significantly associated with FEV₁/FVC. Passive smoking was found to reduce FVC and FEV₁ in children, which was consistent with the study by Tager IB.³⁰

Few studies have investigated the effects of insecticide use on respiratory disease in children, and a relatively novel finding of this study was that insecticide exposure was an independent risk factor for respiratory disease. After human exposure to insecticides occurs in the home, these substances can enter the body^{31,32} through the diet or respiratory tract and create physical harm. In contrast to the findings of Yang,³³ we found that insecticide exposure could contribute to respiratory disease in children beyond just cough symptoms. An animal study³⁴ suggested that exposure to some pesticides over time could be connected to diaphragmatic contractility and altered breathing patterns in rats. The lungs are not fully developed in children; therefore, they may be more susceptible to environmental toxins inhaled via the respiratory tract.³⁵ Preventing children from the hazards of pesticide exposure should therefore be brought to the attention of parents.

Exposure to industrial pollutants could also interfere with recurrent respiratory tract infection. Garbage stations and foul ditches produce irritating gases through fermentation,^{36–38} and the combustion of garbage and the emission of pollutants from heating companies produce large amounts of polycyclic aromatic hydrocarbons (PAHs) and inhalable particulate matter (IPM) contents in the air.³⁹ PAHs compromise the normal developmental process of respiratory airways; mutagenicity can activate the activity of PAHs, and they are associated with depressed lung function in children.^{40,41} Similarly, the IPM was more strongly associated with respiratory diseases.^{42–44} In this study, we did not observe

environmental risk factors for asthma or pneumonia, which may be due to the low prevalence of asthma and pneumonia (approximately 1%).

Exposure to roadway air pollution adversely affected childhood lung function. In this study, the increase in distance from home to the main road adversely affected FEV₁/FVC, consistent with the findings of several studies,^{45,46} but may have the opposite association with FVC. Robert⁴⁷ found that close proximity to a major road was negatively associated with FVC and FEV₁, but these associations were not statistically significant. Therefore, the relationship between children's FVC, FEV₁ and the distance from home to the main road still needs to be evaluated by more studies. It is desirable to detect each contaminant's concentration at different distances to analyze its relationship with the indicators of lung function in children.

Questionnaires facilitate access to larger sample sizes and are less limited by location and distance. When combined with electronic questionnaires and web-based reporting systems,⁴⁸ they also allow for more comprehensive and accurate analysis by utilizing regional surveillance data. Our study has several advantages over previous studies, including (1) a large sample size, which made the results more reliable and allowed us to analyze a wide range of respiratory diseases; (2) detailed information about the environmental exposure factors and the selection of a subset for lung function measurements; and (3) new evidence for insecticide exposure as an indoor risk factor for respiratory disease in children. However, some limitations still exist in our study: (1) the cross-sectional design used in our research may have biased and limited the interpretation of causality; (2) environmental risk factors were determined by questionnaire rather than on-site exposure assessment; and (3) there may be some residual miscellaneous factors that were not captured on the questionnaire. Further studies for these additional risk factors, with detailed exposure assessments, are needed.

Conclusions

The primary risk factors differ among the different respiratory diseases. Passive smoking remains an essential adverse factor for respiratory disease and pulmonary function in children, and it is important to reduce exposure to passive smoking for children's pulmonary health. Insecticide exposure may be a neglected environmental risk factor, and further investigations are still needed to

explore the relationship and mechanisms between insecticide exposure and children's respiratory health.

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Disclosure

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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