

Respiratory symptoms in relation to residential coal burning and environmental tobacco smoke among early adolescents in Wuhan, China: a cross-sectional study

Päivi M. Salo ¹, Jiang Xia ², C. Anderson Johnson ³, Yan Li ⁴, Edward L. Avol ⁵, Chunhong Liu ²,
Stephanie J. London ^{*1}

¹ Epidemiology Branch, National Institute of Environmental Health Sciences, National Institutes of Health, MD A3-05, PO Box 12233, Research Triangle Park, NC 27709, USA

² Wuhan Public Health and Anti-Epidemic Station, No. 24 N. Jiangnan Road, Wuhan, Hubei 430022, China

³ Institute for Health Promotion & Disease Prevention Research, USC Keck School of Medicine, 1000 South Fremont Ave., Unit 8, Alhambra, CA 91803, USA

⁴ Wuhan Health Bureau, 2 YiYuan Road, Wuhan, Hubei 430014, China

⁵ Department of Occupational & Environmental Health, USC Keck School of Medicine, CHP 236, 1540 Alcazar St., Los Angeles, CA 90089, USA

* Corresponding author

E-mail:	Päivi M. Salo	salol@niehs.nih.gov
	Jiang Xia	xiajiang@public.wh.hb.cn
	C. Anderson Johnson	carljohn@hsc.usc.edu
	Yan Li	yanli@public.wh.hb.cn
	Edward L. Avol	avol@hsc.usc.edu
	Chunhong Liu	liups@public.wh.hb.cn
	Stephanie J. London	london2@niehs.nih.gov

Abstract

Background: Cigarette smoking and coal burning are the primary sources of indoor air pollution in Chinese households. However, effects of these exposures on Chinese children's respiratory health are not well characterized.

Methods: Seventh grade students (N=5051) from 22 randomly selected schools in the greater metropolitan area of Wuhan, China, completed an in-class self-administered questionnaire on their respiratory health and home environment.

Results: Coal burning for cooking and/or heating increased odds of wheezing with colds [odds ratio (OR)=1.57, 95% confidence interval (CI): 1.35-1.82, $p<0.001$] and without colds (OR=1.44, 95% CI: 1.15-1.81, $p<0.01$). For smoking in the home, the strongest associations were seen for cough (OR=1.74, 95% CI: 1.11-2.75, $p<0.05$) and phlegm production (OR=2.25, 95% CI: 1.47-3.46, $p<0.001$) without colds among children who lived with two or more smokers.

Conclusions: Chinese children living with smokers or in coal-burning homes are at increased risk for respiratory impairment. While economic development in China may decrease coal burning by providing cleaner fuels for household energy use, the increasing prevalence of cigarette smoking is a growing public health concern due to its effects on children. Adverse effects of tobacco smoke exposure were seen despite the low rates of maternal smoking (3.6%) in this population.

Background

Residential coal burning and cigarette smoking are the most common sources of indoor air pollution in Chinese households [1-3] . Although use of coal stoves and smoking have been linked to respiratory morbidity among adult populations in mainland China [1, 4-6], little is known about how these exposures affect Chinese children's respiratory health. Children's developing lungs are especially vulnerable to indoor air pollution because children spend much of their time indoors at home [7, 8].

Coal is widely used for cooking and heating in China [1, 9]. Domestic coal stoves and boilers produce high indoor concentrations of sulfur dioxide (SO₂), carbon monoxide (CO), particulate matter, and other pollutants [2, 3, 10, 11]. Some studies indicate that residential concentrations of these pollutants may even exceed international guidelines and national ambient air pollution standards in China [1, 2].

An increasing proportion of Chinese children are exposed to tobacco smoke because smoking prevalence in China has increased rapidly, especially among men, during the last decades [1, 12]. Over two thirds of the Chinese population is currently exposed to environmental tobacco smoke (ETS) in the home [12]. Literature from Western populations has generally shown that maternal smoking is more strongly associated with children's respiratory symptoms than paternal smoking [13, 14]. China provides a unique opportunity to examine effects of parental smoking because prevalence of smoking remains very low among women.

We examined the associations between respiratory symptoms and exposure to residential coal burning and environmental tobacco smoke in a cross-sectional study of seventh grade students in the greater metropolitan area of Wuhan, China.

Methods

Participants and study procedure

In the spring of 1999, 5231 seventh grade students at 22 public schools in and around Wuhan, China were invited to complete a self-administered questionnaire on respiratory symptoms and home environment. Two schools were randomly selected from each of the 11 administrative units governed by the city of Wuhan, the capital of Hubei Province. The resulting schools included 14 schools from urban (53.0% of the students), three schools from suburban (25.1%), and five schools from rural areas (21.9%). Of the 5231 students, 5051 (97 %) provided parental consent and completed the questionnaire in class with study staff in attendance. Before completing the questions students viewed a video demonstrating wheezing [15]. The study protocol was approved by the Institutional Review Boards at the Wuhan Public Health and Anti-Epidemic Station and the National Institute of Environmental Health Sciences.

Questionnaire data

The questionnaire included questions on respiratory health and potential risk factors such as exposure to cooking and heating fuels, smokers in the home, and personal smoking. We incorporated respiratory health items from a standardized questionnaire (ATS-DLD-78-C)

translated into Chinese for a previous study in Wuhan and other Chinese cities [16]. Our primary outcome measures were responses to questions regarding respiratory symptoms in the past 12 months. We asked whether children had cough and/or phlegm production almost everyday during the past 12 months, with and without colds. Additionally, we asked whether children had wheezing over the past 12 months, with and without colds.

We assessed exposure to residential coal burning by questions defining the types of fuels used for cooking and heating in the child's home. We combined information on cooking and heating with coal into a single variable with the following categories: no coal stove, coal stove used only for heating, coal stove used only for cooking, and coal stove used for both cooking and heating. To assess environmental tobacco smoke exposure, we asked the child to list all household members and indicate whether each person currently smoked. We created three exposure categories: no smokers in the home, one smoker (1) in the home, and two or more smokers (2+) in the home.

Statistical analysis

We calculated prevalence odds ratios (95% confidence intervals) for each of the six outcome measures (cough, phlegm production and wheezing in the past 12 months, each with colds and without colds) by unconditional logistic regression (Proc Logistic in SAS System for Windows, Version 8.01). Although the odds ratio is the most common measure of association in cross-sectional studies [17], difficulties in interpretation may arise when outcomes are common [18, 19]. We present odds ratios as our effect measures to estimate the associations between respiratory symptoms and residential exposures (coal burning and environmental tobacco smoke)

because using the log-binomial model (Proc Genmod in SAS System for Windows, Version 8.01) [20] to estimate prevalence proportion ratios for the outcomes did not alter any of our conclusions.

We excluded 521 subjects with missing data on any of the outcome or exposure variables leaving 4,530 subjects for the analysis. The following covariates were assessed as potential confounders: gender, animals in the household, presence of pests (cockroaches, ants, rodents), crowding in the household, older siblings, parental asthma, physical activity, and time spent indoors and outdoors. The multivariate models are adjusted for coal use, smokers in the home, and child's sex because inclusion of the other variables did not appreciably change the associations. Due to strong correlation between coal use and living area (coal use 22.2% in urban areas, 67.6–77.9% in non-urban areas, $p < 0.001$), living area was not included in the multivariate models.

Results

Characteristics of the study population are presented in Table 1. The mean age of the seventh grade students was 13.6 years (SD = 0.7 years). Majority of the students (94.2%) were life-long residents of the Wuhan area. Although 7.1% of the students reported wheezing without colds, doctor-diagnosed asthma was relatively uncommon in this population (3.2%). Coal was used for cooking and/or heating almost in half of the homes. Few children smoked (0.6%), but 73.2% of

the students lived with household members who smoked. Fathers (69.1%) were much more likely to smoke than mothers (3.6%).

Residential coal burning was primarily associated with wheezing in the past 12 months as opposed to cough or phlegm production (Table 2). For those who used coal only for cooking or only for heating, wheezing was more strongly associated with cooking. However, the association between coal use and recent wheezing strengthened when coal was used for both cooking and heating (OR=1.78, 95% CI: 1.41-2.23 for wheezing with colds; OR=1.57, 95% CI: 1.11-2.23 for wheezing without colds).

Living with smokers (Table 3) was significantly associated with chronic cough and phlegm production in the past 12 months. The strongest associations were seen for cough (OR=1.74, 95% CI: 1.11-2.75) and phlegm production (OR=2.25, 95% CI: 1.47-3.46) without colds among children who lived with two or more smokers. Living with smokers was not appreciably associated with wheezing.

Discussion

Domestic coal use and exposure to ETS in the home were both associated with adverse respiratory effects in this population of Chinese adolescents. Coal burning increased the odds of wheezing, whereas living with smokers was associated with cough and phlegm production.

Coal burning produces high concentrations of particulate matter, SO₂, and other pollutants [2, 3, 11]. Exposure to these pollutants may impair clearance mechanisms, and lead to airway inflammation [21, 22]. Decreased pulmonary function has been associated with exposure to particulate matter and SO₂ in several air pollution studies during the past decades [21]. Although residential coal burning has been linked to decreased pulmonary function and asthma among children [23-25], conflicting data exist. In two European studies, domestic coal burning has been associated with lower risk for childhood asthma and allergic diseases [26, 27]. The findings in these two studies, however, may reflect some early life or other lifestyle factors related to coal use in Europe.

In our study, residential coal burning was predominantly associated with wheezing. Coal cooking was a stronger risk factor for wheezing than was coal heating. This may be explained by relatively low heating use in the Wuhan area, whereas cooking is a year around activity. The greater association with coal use for both cooking and heating suggests an exposure-dependent relationship.

The harmful effects of ETS in children, primarily from living with smokers, have been widely studied [14, 28-31]. In general, evidence that ETS causes cough, phlegm, and wheezing has not been as strong for school-aged children as it has been for infants and preschool children [28]. There are few data among Chinese populations where smoking behavior differs from Western populations. *In utero* exposure, via a smoking mother, that is believed to contribute to adverse effects of ETS in children [32, 33] is uncommon in China. Thus, it is of interest that in this cohort of middle school children, where maternal and personal smoking were low, exposure to

ETS in the home was clearly associated with chronic cough and phlegm production, with and without colds.

Our results indicated an exposure dependent response to ETS; having two or more smokers in the household increased the odds of cough and phlegm production compared to having only one smoker in the household. We did not find strong evidence suggesting differences in effect by gender, although the effect of ETS on persistent cough without colds was more pronounced among boys than girls (data not shown). Exposure levels may be influenced by time-activity patterns that can differ by gender. Boys may be more likely to spend time in close proximity with their smoking fathers or male relatives than girls.

Mechanisms responsible for the respiratory effects of ETS have been proposed in the literature [28]. In addition to decreased mucociliary clearance and goblet cell hypertrophy/hypersecretion, local and central nervous system components are thought to be involved in cough and phlegm production [28, 34]. Although exposure to ETS may affect childhood lung growth and result in lower pulmonary function [14, 35], wheezing was not appreciably related to the presence of smokers in our study. Genetic susceptibility may influence the effects of ETS on bronchial obstruction. For example, parental atopy was found to modify the effects of ETS on bronchial obstruction and asthma considerably in a Norwegian birth cohort study [36]. However, we were unable to examine potential interactions between family history and ETS in relation to atopic illness in our population because, consistent with previously published data on Chinese children [37, 38], the prevalence of asthma (3.2%) and hay fever (1.8%) was very low.

The composition of pollutants produced by residential coal burning and smoking can be highly variable, but both exposures contribute substantially to inhalable and respirable particulate matter in indoor environments [2, 3, 39]. Existing data suggests that coal burning and smoking may have synergistic effects on respiratory symptoms [5]. In our data, we did not find consistent evidence of interaction between coal burning and ETS exposure.

Our outcome and exposure measures were determined by questionnaire alone, which is a limitation of the study. Nonetheless, large epidemiological studies of respiratory health often rely on reports on recent symptom history because self-reported measures are cost efficient, practical and their repeatability is good [40, 41]. Generally, respiratory symptoms have been reported consistently across populations [41]. To improve the quality of our self-reported outcomes we included audiovisual presentation of wheezing symptoms [15]. Because the temporal relationship between outcome(s) and exposure(s) can be difficult to determine in cross-sectional studies we focused on respiratory symptoms in the past 12 months to minimize recall bias. We did not use parents as source of information on child's symptoms. Some studies suggest that Chinese parents may deny or underreport child's symptoms or illnesses [42, 43]. Therefore, adolescents' reports on their own symptoms and health status may be more accurate than their parents'. Given that questionnaires have limited ability to quantify exposures, the possibility of exposure misclassification cannot be excluded. However, serious differential misclassification either of the exposures or outcomes is unlikely because health hazards of indoor air pollutants were not widely known among Chinese school children at the time when the survey was conducted [44].

Although indoor air quality is influenced by infiltration of outdoor air [1], we do not believe that outdoor air pollution could explain the observed associations. Exposures to indoor air pollutants are likely to dominate the total exposure burden [45], especially among children, who spend much of their time at home [8]. In Chinese homes with coal stoves and smokers, not only levels of particulate matter, but also levels of many other air pollutants, including concentrations of SO₂, often exceed the levels outdoors [2, 3]. In Wuhan, where coal stoves are not usually vented via flue, concentrations of respirable particulate matter (291 µg/m³) and SO₂ (173 µg/m³) can reach high levels indoors [2]. Concentrations of these pollutants have been found to be lower in ambient air. For example, a study investigating long-term air pollution in Wuhan estimated that the annual means for PM_{2.5}, PM₁₀, and SO₂ in urban areas were 73 µg/m³, 129 µg/m³, and 73 µg/m³, respectively [46].

The major strength of this study is that the public school system ensured a large and representative sample of rural, suburban, and urban populations in the Wuhan area. Our study is one of the few studies that have examined effects of major indoor pollutants in relation to children's respiratory health in mainland China [16, 23-25].

Conclusions

Coal burning and living with smokers contributed to persistent respiratory symptoms in this cohort of Chinese adolescents. Adverse effects of tobacco smoke in the home were seen despite the very low prevalence of maternal smoking. Even if exposure to residential coal burning

declines in response to economic changes in China, the increasing prevalence in smoking augur an increase in children's exposure to environmental tobacco smoke. Because many men initiate smoking during adulthood, and the rate of quitting and desire to quit smoking are low [47], future prospects for children's health are worrisome. The rise in cigarette smoking in China is a growing public health concern, not only in the adult population but because its effects on children. Although rates of childhood asthma have remained low in China, common indoor air pollutants, coal and tobacco smoke, impair children's respiratory health.

List of abbreviations

CI = confidence interval

CO = carbon monoxide

ETS = environmental tobacco smoke

OR = odds ratio

PM₁₀ = particulate matter with an aerodynamic diameter less or equal to 10 µm

PM_{2.5} = particulate matter with an aerodynamic diameter less or equal to 2.5 µm

SO₂ = sulfur dioxide

Competing interests

None declared.

Authors' contributions

Contributors: PMS analyzed the data and wrote the manuscript with input from all investigators. YL, JX and CL are key investigators for the data collection. ELA assisted with data collection. CAJ was involved in design of the study. SJL is the principal investigator and guarantor of the manuscript.

Acknowledgements

This study was supported by the National Cancer Institute / National Institute of Drug Abuse Transdisciplinary Tobacco Use research Center grant (1 P50 CA84735-01) awarded to the University of Southern California and the project Z01 ES 49019 of the Division of Intramural Research, National Institute of Environmental Health Sciences.

We wish to acknowledge the contribution of the Wuhan Education Committee and the Wuhan Public Health and Anti-Epidemic Station for their assistance with data collection and entry, and Ms. Gong Jie for her help with data management. We thank Dr. Chris Lai from The Chinese University of Hong Kong, China, for sharing questionnaire materials, and Dr. Grace Chiu from Westat Inc, Research Triangle Park, NC, for assistance with programming.

References

1. Florig HK: **China's Air Pollution Risks.** *Environ Sci Technol* 1997, **31**:274-279.
2. Qin YH, Zhang XM, Jin HZ, Liu YQ, Fan DL, Yin XR, Li Z, Fang W, Wang GF: **Indoor air pollution in four cities in China.** *Biomed Environ Sci* 1991, **4**:366-372.
3. Wang JN, Zhang Y: **CO and particle pollution of indoor air in Beijing and its elemental analysis.** *Biomed Environ Sci* 1990, **3**:132-138.
4. Du YX, Cha Q, Chen XW, Chen YZ, Huang LF, Feng ZZ, Wu XF, Wu JM: **An epidemiological study of risk factors for lung cancer in Guangzhou, China.** *Lung Cancer* 1996, **14 Suppl 1**:S9-37.
5. Pope CA, 3rd, Xu X: **Passive cigarette smoke, coal heating, and respiratory symptoms of nonsmoking women in China.** *Environ Health Perspect* 1993, **101**:314-316.
6. Xu X, Wang L: **Association of indoor and outdoor particulate level with chronic respiratory illness.** *Am Rev Respir Dis* 1993, **148**:1516-1522.
7. Silvers A, Florence BT, Rourke DL, Lorimor RJ: **How children spend their time: a sample survey for use in exposure and risk assessments.** *Risk Anal* 1994, **14**:931-944.
8. Xu Y, Cuie S, Ji X, Hanping W: **Effects of indoor pollution on pulmonary function and COHb of school pupils in Wuhan city (China).** In *Proceedings of the 6th International Conference on Indoor Air Quality and Climate: July 4-8 1993*; Helsinki, Finland. Edited by Jaakkola JJK, Ilmarinen R, Seppänen O. Helsinki, Finland: Indoor Air '93; 1993:505-510.
9. **Indoor Air Pollution Database for China**
[http://whqlibdoc.who.int/hq/1995/WHO_EHG_95.8.pdf]
10. Finkelmann RB, Belkin HE, Zheng B: **Health impacts of domestic coal use in China.** *Proc Natl Acad Sci U S A* 1999, **96**:3427-3431.
11. Zhang J, Smith KR: **Emissions of Carbonyl Compounds from Various Cookstoves in China.** *Environ Sci Technol* 1999, **33**:2311-2320.
12. Yang G, Fan L, Tan J, Qi G, Zhang Y, Samet JM, Taylor CE, Becker K, Xu J: **Smoking in China: findings of the 1996 National Prevalence Survey.** *JAMA* 1999, **282**:1247-1253.
13. Cook DG, Strachan DP: **Health effects of passive smoking. 3. Parental smoking and prevalence of respiratory symptoms and asthma in school age children.** *Thorax* 1997, **52**:1081-1094.
14. Jaakkola JJ, Jaakkola MS: **Effects of environmental tobacco smoke on the respiratory health of children.** *Scand J Work Environ Health* 2002, **28 Suppl 2**:71-83.
15. Lai CK, Chan JK, Chan A, Wong G, Ho A, Choy D, Lau J, Leung R: **Comparison of the ISAAC video questionnaire (AVQ3.0) with the ISAAC written questionnaire for estimating asthma associated with bronchial hyperreactivity.** *Clin Exp Allergy* 1997, **27**:540-545.
16. Zhang JJ, Hu W, Wei F, Wu G, Korn LR, Chapman RS: **Children's respiratory morbidity prevalence in relation to air pollution in four Chinese cities.** *Environ Health Perspect* 2002, **110**:961-967.

17. Bland JM, Altman DG: **Statistics notes. The odds ratio.** *BMJ* 2000, **320**:1468.
18. Altman DG, Deeks JJ, Sackett DL: **Odds ratios should be avoided when events are common.** *BMJ* 1998, **317**:1318.
19. Zocchetti C, Consonni D, Bertazzi PA: **Relationship between prevalence rate ratios and odds ratios in cross-sectional studies.** *Int J Epidemiol* 1997, **26**:220-223.
20. Skov T, Deddens J, Petersen MR, Endahl L: **Prevalence proportion ratios: estimation and hypothesis testing.** *Int J Epidemiol* 1998, **27**:91-95.
21. **Health effects of outdoor air pollution. Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society.** *Am J Respir Crit Care Med* 1996, **153**:3-50.
22. MacNee W, Donaldson K: **Exacerbations of COPD: environmental mechanisms.** *Chest* 2000, **117 Suppl 2**:390S-397S.
23. Qian Z, Zhang J, Korn LR, Wei F, Chapman RS: **Factor analysis of household factors: are they associated with respiratory conditions in Chinese children?** *Int J Epidemiol* 2004, **33**:582-588.
24. Shen S, Qin Y, Cao Z, Shang J, Liu Y, Yang X, Deng Y, Huang J, Fu Z, Song X: **Indoor air pollution and pulmonary function in children.** *Biomed Environ Sci* 1992, **5**:136-141.
25. Zheng T, Niu S, Lu B, Fan X, Sun F, Wang J, Zhang Y, Zhang B, Owens P, Hao L, Li Y, Leaderer B: **Childhood asthma in Beijing, China: a population-based case-control study.** *Am J Epidemiol* 2002, **156**:977-983.
26. Duhme H, Weiland SK, Rudolph P, Wienke A, Kramer A, Keil U: **Asthma and allergies among children in West and East Germany: a comparison between Munster and Greifswald using the ISAAC phase I protocol. International Study of Asthma and Allergies in Childhood.** *Eur Respir J* 1998, **11**:840-847.
27. von Mutius E, Illi S, Nicolai T, Martinez FD: **Relation of indoor heating with asthma, allergic sensitisation, and bronchial responsiveness: survey of children in south Bavaria.** *BMJ* 1996, **312**:1448-1450.
28. Cook DG, Strachan DP: **Health effects of passive smoking-10: Summary of effects of parental smoking on the respiratory health of children and implications for research.** *Thorax* 1999, **54**:357-366.
29. Mannino DM, Moorman JE, Kingsley B, Rose D, Repace J: **Health effects related to environmental tobacco smoke exposure in children in the United States: data from the Third National Health and Nutrition Examination Survey.** *Arch Pediatr Adolesc Med* 2001, **155**:36-41.
30. U.S. Environmental Protection Agency: *Respiratory Health Effects of Passive Smoking: Lung Cancer and Other Disorders.* Washington, DC; 1992.
31. U.S. Department of Health and Human Services, Public Health Service, Office on Smoking and Health: *The health consequences of involuntary smoking: A report of the Surgeon General.* Rockville, Maryland; 1986.
32. London SJ, James GW, Avol E, Rappaport EB, Peters JM: **Family history and the risk of early-onset persistent, early-onset transient, and late-onset asthma.** *Epidemiology* 2001, **12**:577-583.
33. Morgan WJ: **Maternal smoking and infant lung function. Further evidence for an in utero effect.** *Am J Respir Crit Care Med* 1998, **158**:689-690.

34. Joad JP, Munch PA, Bric JM, Evans SJ, Pinkerton KE, Chen CY, Bonham AC: **Passive smoke effects on cough and airways in young guinea pigs: role of brainstem substance P.** *Am J Respir Crit Care Med* 2004, **169**:499-504.
35. Venners SA, Wang X, Chen C, Wang B, Ni J, Jin Y, Yang J, Fang Z, Weiss ST, Xu X: **Exposure-response relationship between paternal smoking and children's pulmonary function.** *Am J Respir Crit Care Med* 2001, **164**:973-976.
36. Jaakkola JJ, Nafstad P, Magnus P: **Environmental tobacco smoke, parental atopy, and childhood asthma.** *Environ Health Perspect* 2001, **109**:579-582.
37. **Worldwide variations in the prevalence of asthma symptoms: the International Study of Asthma and Allergies in Childhood (ISAAC).** *Eur Respir J* 1998, **12**:315-335.
38. **Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. The International Study of Asthma and Allergies in Childhood (ISAAC) Steering Committee.** *Lancet* 1998, **351**:1225-1232.
39. IEH: *Airborne particles: Exposures in the home and Health Effects.* Leicester, UK: MCR The Institute for Environment and Health; 2000.
40. Britton J: **Symptoms and objective measures to define the asthma phenotype.** *Clin Exp Allergy* 1998, **28 Suppl 1**:2-7.
41. Sunyer J, Basagaña X, Burney P, Anto JM: **International assessment of the internal consistency of respiratory symptoms. European Community Respiratory Health Study (ECRHS).** *Am J Respir Crit Care Med* 2000, **162**:930-935.
42. Leung R, Ho P: **Asthma, allergy, and atopy in three south-east Asian populations.** *Thorax* 1994, **49**:1205-1210.
43. Leung R, Jenkins M: **Asthma, allergy and atopy in southern Chinese school students.** *Clin Exp Allergy* 1994, **24**:353-358.
44. Lam TH, Chung SF, Betson CL, Wong CM, Hedley AJ: **Respiratory symptoms due to active and passive smoking in junior secondary school students in Hong Kong.** *Int J Epidemiol* 1998, **27**:41-48.
45. Burke JM, Zufall MJ, Özkaynak H: **A population exposure model for particulate matter: case study results for PM(2.5) in Philadelphia, PA.** *J Expo Anal Environ Epidemiol* 2001, **11**:470-489.
46. Qian Z, Zhang J, Wei F, Wilson WE, Chapman RS: **Long-term ambient air pollution levels in four Chinese cities: inter-city and intra-city concentration gradients for epidemiological studies.** *J Expo Anal Environ Epidemiol* 2001, **11**:341-351.
47. Gong YL, Koplan JP, Feng W, Chen CH, Zheng P, Harris JR: **Cigarette smoking in China. Prevalence, characteristics, and attitudes in Minhang District.** *JAMA* 1995, **274**:1232-1234.

Tables

Table 1. Characteristics of the study population of 4530 seventh grade students at 22 schools in greater Wuhan, China

Characteristic	%
Subjects	
Gender	
Male	52.5
Female	47.5
Respiratory symptoms	
Wheezing with colds	19.4
Wheezing without colds	7.1
Bringing up phlegm with colds	16.7
Bringing up phlegm without colds	5.7
Coughing with colds	24.7
Coughing without colds	4.5
Exposures	
Smokers in child's household	
No smokers	26.8
1 smoker	62.3
2+ smokers	10.9
Father smokes	69.1
Mother smokes	3.6
Personal smoking by students	0.6
Exposure to coal burning	
No coal use	54.2
Coal used only for heating	8.8
Coal used only for cooking	25.9
Coal used for cooking and heating	11.1

Table 2. Respiratory symptoms in relation to residential coal burning

Exposure	Cough with colds					Cough without colds				
	No	Yes	OR*	(95% CI)	p-value	No	Yes	OR*	(95% CI)	p-value
	N	N				N	N			
Total	3413	1117				4327	203			
Coal use										
No	1833	622	1.00			2347	108	1.00		
Yes	1580	495	0.92	(0.81,1.06)	0.242	1980	95	1.03	(0.78,1.37)	0.817
Heating	300	99	0.97	(0.76,1.23)	0.774	381	18	1.02	(0.61,1.71)	0.930
Cooking	926	249	0.79	(0.67,0.94)	0.006	1120	55	1.04	(0.75,1.45)	0.815
Both	354	147	1.22	(0.98,1.51)	0.071	479	22	0.99	(0.62,1.58)	0.960
	Phlegm with colds					Phlegm without colds				
	No	Yes	OR*	(95% CI)	p-value	No	Yes	OR*	(95% CI)	p-value
	N	N				N	N			
Total	3772	758				4274	256			
Coal use										
No	2051	404	1.00			2315	140	1.00		
Yes	1721	354	1.04	(0.89,1.22)	0.626	1959	116	0.96	(0.75,1.24)	0.760
Heating	331	68	1.04	(0.79,1.39)	0.764	376	23	1.02	(0.64,1.61)	0.944
Cooking	994	181	0.92	(0.76,1.11)	0.379	1114	61	0.87	(0.63,1.18)	0.359
Both	396	105	1.35	(1.06,1.71)	0.016	469	32	1.12	(0.75,1.67)	0.585
	Wheeze with colds					Wheeze without colds				
	No	Yes	OR*	(95% CI)	p-value	No	Yes	OR*	(95% CI)	p-value
	N	N				N	N			
Total	3652	878				4210	320			
Coal use										
No	2058	397	1.00			2309	146	1.00		
Yes	1594	481	1.57	(1.35,1.82)	<0.001	1901	174	1.44	(1.15,1.81)	0.002
Heating	329	70	1.10	(0.83,1.45)	0.520	368	31	1.35	(0.91,2.03)	0.141
Cooking	892	283	1.66	(1.40,1.97)	<0.001	1077	98	1.42	(1.09,1.86)	0.010
Both	373	128	1.78	(1.41,2.23)	<0.001	456	45	1.57	(1.11,2.23)	0.011

* Odds ratios (OR) adjusted for smokers in the home and gender. Dichotomous and multilevel odds ratios are computed separately.

Table 3. Respiratory symptoms in relation to living with smokers

Exposure	Cough with colds		OR*	(95% CI)	p-value	Cough without colds		OR*	(95% CI)	p-value
	No	Yes				No	Yes			
	N	N				N	N			
Total	3413	1117				4327	203			
Smokers in the home										
No	954	259	1.00			1165	48	1.00		
Yes	2459	858	1.29	(1.10,1.51)	0.002	3162	155	1.19	(0.86,1.66)	0.294
1 smoker	2105	717	1.26	(1.07,1.48)	0.005	2700	122	1.10	(0.78,1.55)	0.584
2+ smokers	354	141	1.47	(1.16,1.87)	0.002	462	33	1.74	(1.11,2.75)	0.017
	Phlegm with colds		OR*	(95% CI)	p-value	Phlegm without colds		OR*	(95% CI)	p-value
	No	Yes				No	Yes			
	N	N				N	N			
Total	3772	758				4274	256			
Smokers in the home										
No	1036	177	1.00			1164	49	1.00		
Yes	2736	581	1.24	(1.04,1.49)	0.020	3110	207	1.60	(1.16,2.20)	0.004
1 smoker	2327	495	1.25	(1.04,1.50)	0.020	2657	165	1.49	(1.08,2.07)	0.017
2+ smokers	409	86	1.23	(0.93,1.63)	0.150	453	42	2.25	(1.47,3.46)	<0.001
	Wheeze with colds		OR*	(95% CI)	p-value	Wheeze without colds		OR*	(95% CI)	p-value
	No	Yes				No	Yes			
	N	N				N	N			
Total	3652	878				4210	320			
Smokers in the home										
No	993	220	1.00			1125	88	1.00		
Yes	2659	658	1.11	(0.93,1.31)	0.245	3085	232	0.96	(0.74,1.24)	0.749
1 smoker	2265	557	1.10	(0.93,1.31)	0.278	2619	203	0.99	(0.76,1.28)	0.942
2+ smokers	394	101	1.13	(0.86,1.47)	0.382	466	29	0.78	(0.51,1.20)	0.274

* Odds ratios (OR) adjusted for coal use and gender. Dichotomous and multilevel odds ratios are computed separately.