CHEST

Original Research

Air Pollution and Prevalence of Bronchitic Symptoms Among Children in Taiwan

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Background: **There were limited studies concerning ambient air pollution exposure on development of bronchitic symptoms among children. These studies provided suggestive but inconclusive results.**

Objectives: **To assess the association between air pollutants and the prevalence of bronchitic symptoms in the Taiwan Children Health Study.**

Methods: **We conducted a nationwide cross-sectional study of 5,049 Taiwanese children in 2007. Routine air pollution monitoring data were used for sulfur dioxide (SO_2), nitrogen dioxides (NO_2), ozone (O_3), carbon monoxide (CO), and particles with an aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$). The exposure parameters were calculated using the between-community 3-year average concentration. The effect estimates were presented as odds ratios (ORs) per interquartile changes for SO_2, NO_2, O_3, CO, and $PM_{2.5}$.**

Results: **In the two-stage hierarchical model adjusting for confounding, the prevalence of bronchitic symptoms with asthma was positively associated with the between-community 3-year average concentrations of NO_2 (adjusted OR, 1.81 per 8.79 ppb; 95% CI, 1.14-2.86), and CO (OR, 1.31 per 105 ppb; 95% CI, 1.04-1.64). The prevalence of phlegm with no asthma was related to O_3 (OR, 1.32 per 8.77 ppb; 95% CI, 1.06-1.63).**

Conclusions: **The results suggest that long-term exposure to outdoor air pollutants, such as NO_2, CO, and O_3, may increase the prevalence of bronchitic symptoms among children.**

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Abbreviations: CO = carbon monoxide; NO_2 = nitrogen dioxide; O_3 = ozone; OC = organic carbon; OR = odds ratio; $PM_{2.5}$ = particles with an aerodynamic diameter ≤ 2.5 μm; SO_2 = sulfur dioxide

Short-term changes in the occurrence of bronchitic symptoms are more likely to be influenced by changes in the environment, diet, or life-style risks than by changes in the genetic pool. From a preventive perspective, information on environmental, dietary, and behavioral factors is crucial.[1] In a systematic Medline search, we identified seven studies concerning exposure to ambient air pollution on development of bronchitic symptoms, but only two studies[2,3] focused on children with asthma, both of which provided suggestive but inconclusive results.

In 2007, we conducted a nationwide cross-sectional study in Taiwan, where we collected information about bronchitic symptoms during the past 12 months and also those important potential determinants of allergic disease in children. In the present study, we elaborated the associations between exposure to urban air pollution and the prevalence of bronchitic symptoms in schoolchildren, focusing on nitrogen oxides (NO_2), carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), and particles with an aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$). Further, we applied the two-stage hierarchical model to adjust for confounding, to elaborate effect modification on an

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individual level, and to assess the community-level effects of air pollution.[4,5]

Materials and Methods

Data Collection and Study Population

Taiwan Children Health Study was based on a multipurpose nationwide design that focused on outdoor air pollutants as primary interest. Communities of Taiwan were selected with the aim of maximizing the variability and minimizing the correlations in criteria outdoor pollutants based on historic routine air monitoring data. In communities with pollution patterns of interest, neighborhoods with stable, largely middle-income populations, ethnically representative of Taiwan as a whole, were identified from 2004 census data.

A total of 5,804 seventh- to eighth-grade children were recruited from public schools in 14 communities covering diverse parts of Taiwan, which was representative of Taiwanese middle-school children. Written consent was obtained from parents or guardians. The questionnaire was distributed in all communities simultaneously in September, and subjects were given the forms by project staff following their pulmonary function tests and asked to complete and return them the following day. Questionnaire responses by parents or guardians were used to categorize children's basic information, medical history, family history, personal habits, housing characteristics, and environmental conditions. The final study population was 5,052 schoolchildren (response rate, 87.0%). The study protocol was approved by the Respiratory Health Screening Steering Committee of the Taiwan Department of Health and the Institutional Review Board of National Taiwan University, and it complied with the principles outlined in the Helsinki Declaration.[6]

Health Outcomes

Questions on respiratory symptoms and illnesses were modified after those used in the Children's Health Study in Southern California.[2,7] The outcome of interest was bronchitic symptoms. The bronchitic symptoms were defined on the basis of having any one of the following: (1) one or more episodes of bronchitis (defined by the question: "How many times in the past 12 months did your child have bronchitis?"), without the following symptoms: (2) chronic cough (defined by a yes answer to the question "During the past 12 months, has this child had a cough first thing in the morning that lasted for as long as 3 months in a row?" or to the question "During the past 12 months, has this child had a cough at other times of the day that lasted for as much as 3 months in a row?"), or (3) chronic phlegm (defined by a yes answer to the question: "Other than with colds, does this child usually seem congested in the chest or bring up phlegm?"). A history of asthma for each child was assessed on the basis of the answer to the question, "Has a physician ever diagnosed your child as having asthma?"

Exposure Assessment

Complete monitoring data for the air pollutants, including SO_2, NO_2, O_3, CO, and $PM_{2.5}$, as well as daily temperature and relative humidity, are available for 14 EPA monitoring stations in Taiwan Children Health Study communities since 2005 (Fig 1). Concentrations of each pollutant are measured continuously and reported hourly—CO by nondispersive infrared absorption, NO_2 by chemiluminescence, O_3 by ultraviolet absorption, SO_2 by ultraviolet fluorescence, and $PM_{2.5}$ by β-gauge. A daily (24-h) averaged concentration was calculated when at least 13 valid hourly values were available with not more than six successive hourly values missing and an 8-h averaged concentration was calculated when at least six valid hourly values were available. We hypothesized that long-term exposure to outdoor air pollutants based on historic routine air monitoring data from 2005 through 2007 would increase the prevalence of bronchitic symptoms among children. Exposure parameters in the present study were 3-year average (2005-2007) and the yearly deviations from the 3-year average concentrations in each municipality, calculated from the 24-h NO_2, CO, SO_2, $PM_{2.5}$, and 10:00 AM to 6:00 PM 8-h O_3.

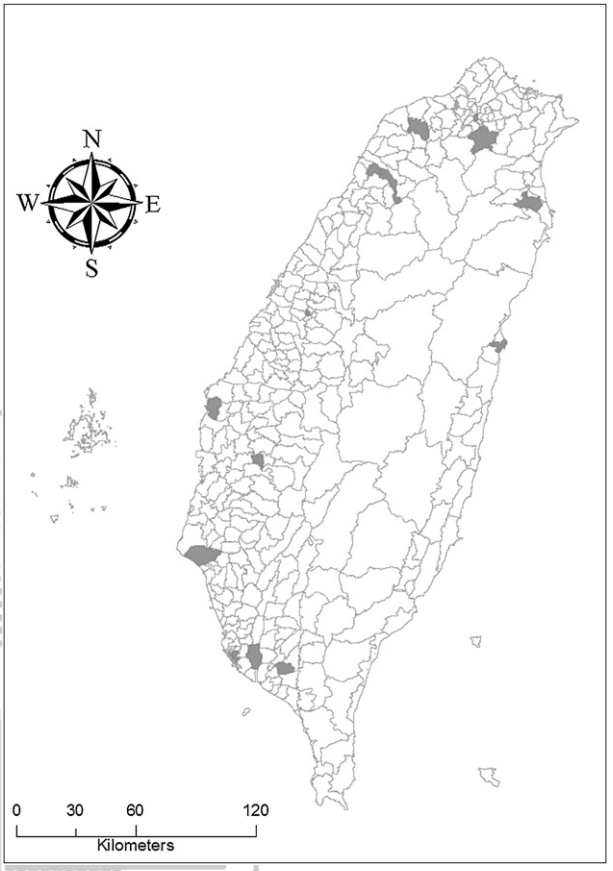

Figure 1. Locations of 14 communities in the Taiwan Children Health Study.

Covariates

Information on potential confounders was obtained from the parental-administered questionnaire. The covariates in the present analyses included age, gender, parental education, family annul income, duration of breastfeeding, maternal smoking history during pregnancy, environmental tobacco smoke, cockroaches note, carpet used, home dampness and mold, and parental atopy (Table 1). Parental atopy was a measure of genetic predisposition to asthma and it was defined as the father or mother of the index child ever having been diagnosed as having asthma, allergic rhinitis, or atopic eczema.

Statistical Methods

The association between air pollution and the prevalence of bronchitic symptoms was examined in two groups (children with

Table 1—*Distribution of Bronchitic Symptoms, Demographics, and Other Characteristics in Patients With/Without History of Asthma*

[AQ11]

[AQ10] Characteristic	Asthma (N = 376)		No Asthma (N = 4,676)		
	No.	%	No.	%	χ^2
Bronchitis	81	21.5	205	4.4	181.1 ($P < .001$)
Chronic phlegm	53	14.1	164	3.5	96.6 ($P < .001$)
Chronic cough	52	13.8	119	2.5	134.5 ($P < .001$)
Bronchitic symptoms	137	36.4	429	9.2	253.1 ($P < .001$)
Age, y					2.51 ($P = .29$)
12	255	67.8	2,971	63.5	
13	98	26.1	1,361	29.1	
14	23	6.1	344	7.4	
Sex					5.14 ($P < .05$)
Male	202	53.7	2,245	48.0	
Female	174	46.3	2,431	52.0	
Parental education, y[a]					1.92 ($P = .38$)
< 8	65	17.4	841	18.1	
8-11	244	65.4	3,111	67.1	
≥ 12	64	17.2	686	14.8	
Family annual income[a]					5.16 ($P = .08$)
Low	111	32.0	1,651	38.1	
Medium	187	53.9	2,174	50.2	
High	49	14.1	505	11.7	
Environmental tobacco smoke[a]					0.41 ($P = .52$)
Yes	188	50.4	2,267	48.8	
No	185	49.6	2,375	51.2	
Maternal smoking during pregnancy[a]					4.58 ($P = .03$)
Yes	22	5.9	174	3.7	
No	353	94.1	4,472	96.3	
Cockroaches					0.02 ($P = .88$)
Yes	331	89.5	4,137	89.4	
No	39	10.5	493	10.6	
Any home dampness and mold					5.15 ($P = .02$)
Yes	147	39.1	2,569	54.9	
No	229	60.9	2,107	45.1	
Duration of breastfeeding, mo[a]					0.67 ($P = .88$)
0	188	50.7	2,430	52.8	
1-2	143	38.5	1,714	37.3	
3-5	22	5.9	246	5.3	
≥ 6	18	4.9	209	4.5	
Carpet used[a]					1.12 ($P = .29$)
Yes	33	8.8	503	10.8	
No	340	91.2	4,151	89.2	
Pet					0.03 ($P = .86$)
Yes	222	59.0	2,743	58.7	
No	154	41.0	1,933	41.3	
Parental atopy					53.4 ($P < .001$)
Yes	160	42.6	1,170	25.0	
No	216	57.4	3,506	75.0	

[a]Number of subjects does not add up to total number because data were missing.

and without asthma) to determine whether children with asthma are more likely to develop bronchitic symptoms. We estimated adjusted odds ratios (ORs) in a two-stage hierarchical model using logistic and ecologic model analyses. The models assume two sources of variation: the variation among subjects in the first stage, part of which could be explained by the individual confounders, and the variation of air pollution between communities in the second stage, part of which could be explained by variables measured at the municipal level. In the analyses we assumed that (1) the outcome variable follows Bernoulli distribution, (2) intercept terms are random at the municipal level, and (3) all the explanatory variables are fixed effects. A logistic regression model was fitted in the first stage for the risk of bronchitic symptoms as a function of site-specific intercepts, j, where $\alpha j = 1, ..., 14$, and personal covariates. The adjusted site-specific intercepts and prevalence rates are related by $Pj = e^{\alpha j}/(1 + e^{\alpha j})$. In the second stage, these intercept terms representing the logit of the site-specific prevalence rates (Pj; j = 1, ..., 14), adjusted for personal covariates, were regressed on each site-specific ambient pollutant level by using a linear "ecologic" regression, that is, logit $\alpha j = \alpha + Uj + \beta Zj$, where Uj denotes the random departure from the general prevalence αj on the logit scale for site j and Zj denotes the ambient pollution level for site j. Thus, β can be interpreted as the log odds ratio (per interquartile changes) for each pollutant, adjusted for personal characteristics.

The results from the models are presented as ORs, along with their 95% CIs. The goodness of fit was assessed with likelihood ratio tests to determine whether a variable contributed significantly to the model. First, we fitted a full model with a complete set of covariates. To elaborate sources of confounding, we fitted models with different combinations of covariates and compared the effect from models with and without the covariate of interest. If the adjusted OR differed from the crude OR by >10%, that covariate was included in the final model.

We considered the effect of multiple pollutants on the prevalence of bronchitic symptoms. The correlation between NO_2 and CO concentrations was high (0.86), and the concentrations of $PM_{2.5}$ and SO_2 were also highly correlated (0.68). We first fitted one-pollutant models (Table 2) and then considered two-pollutant models by fitting one (NO_2 or CO) and the other (SO_2 or $PM_{2.5}$) pollutant. Finally, we fitted two-pollutant models with O_3 and another pollutant. The two-pollutant models provide estimates of the independent effects of CO, NO_2, SO_2, $PM_{2.5}$, and O_3 on the bronchitic symptoms controlling for the second pollutant in the model (Table 3). The effect of each pollutant on the risk of bronchitic symptoms was presented as ORs per interquartile changes for SO_2, NO_2, O_3, and $PM_{2.5}$.

Results

Study Population and Prevalence of Bronchitic Symptoms

The characteristics of the study population and the prevalence of bronchitic symptoms with and without asthma according to the baseline covariates are shown in Table 1. The prevalence of bronchitic symptoms with and without asthma during the past 12 months was 36.4% and 9.2%, respectively. A larger proportion of subjects with asthma than subjects without asthma were male ($\chi^2 = 5.14$, $P < .05$) and had maternal smoking during pregnancy ($\chi^2 = 4.58$, $P = .03$), parental atopy ($\chi^2 = 53.4$, $P < .001$), and less presence of any home dampness and mold ($\chi^2 = 5.15$, $P = .02$) (Table 1).

Air Pollution

The distributions of the annual mean air pollutant concentrations in the 14 monitoring stations in the years 2005 through 2007 are presented in Table 4, and the correlations between different pollutants between communities are presented in Table 5. The correlation between NO_2 and CO concentrations was high (0.86), which reflects the common source of gasoline-power vehicles or natural gas power plant combustion. The concentrations of $PM_{2.5}$ and SO_2 were also highly correlated (0.68), indicating a common source of stationary fuel combustion or diesel-power vehicles, although SO_2 concentrations were also correlated with NO_2 (0.56). The concentration of O_3 was negatively correlated with CO (0.33), but positively correlated with $PM_{2.5}$ (0.73) and SO_2 (0.37), and it was only weakly correlated with that of one (NO_2 or CO) and another ($PM_{2.5}$ or SO_2) air pollutants.

Air Pollution and Bronchitic Symptoms

In the one-pollutant model, the prevalence of bronchitic symptoms with asthma was related to NO_2 levels (adjusted OR 1.81 per 8.79 ppb change; 95% CI, 1.14-2.86). With the addition of SO_2 (adjusted OR 1.76; 95% CI, 0.99-3.14), $PM_{2.5}$ (adjusted OR, 2.01; 95% CI, 1.20-3.36), or O_3 (adjusted OR, 1.79; 95% CI, 1.12-2.85), the effect estimate for NO_2 remained significant (Table 6). The adjusted OR for 105 ppb change in CO was 1.31 (95% CI, 1.04-1.64) and the estimates changed little when a second pollutant was added. The adjusted odds ratio for 1.31 ppb change in SO_2 alone was 1.17 (95% CI, 0.97-1.40), but inclusion of O_3 increased the effect estimate substantially (adjusted OR, 1.26; 95% CI, 1.03-1.53), whereas addition of CO (adjusted OR, 1.11; 95% CI, 0.92-1.34) and NO_2 (adjusted OR, 1.02; 95% CI, 0.81-1.28) had little influence. The prevalence of bronchitic symptoms with asthma was weak or not related to $PM_{2.5}$ concentrations in any combination of air pollutants. The ~~risk~~ of bronchitic symptoms with asthma was not related to O_3 in the one-pollutant model (adjusted OR, 0.80 per 8.77 ppb change; 95% CI, 0.59-1.09), but addition of $PM_{2.5}$ reduced the effect estimate substantially (adjusted OR, 0.64; 95% CI, 0.41-1.00), and inclusion of other pollutants changes the effect estimates a little. Furthermore, the prevalence of chronic phlegm without asthma in the one-pollutant model was related to O_3 (adjusted OR, 1.32 per 8.77 ppb change; 95% CI, 1.06-1.63). With the addition of either NO_2 (adjusted OR, 1.35; 95% CI, 1.07-1.69), CO (adjusted OR, 1.37; 95% CI, 1.08-1.75), SO_2 (adjusted OR, 1.28; 95% CI, 1.03-1.59), or $PM_{2.5}$ (adjusted OR, 1.34; 95% CI, 1.00-1.78), the effect estimate for O_3 remained significant.

Discussion

The prevalence of bronchitic symptoms increased according to increased 3-year average concentrations of two pollutants, NO_2 and CO, among children with asthma. The prevalence of bronchitic symptoms with asthma was weak or not related to the levels of $PM_{2.5}$, SO_2, and O_3. Our results provide evidence that children with asthma are more likely to develop bronchitic symptoms when exposed to the air pollutants NO_2 and CO. Furthermore, the prevalence of chronic phlegm was also associated with O_3 among children without asthma.

Validity of Results

We used routine air pollution monitoring data as the basis for exposure assessment. These data reasonably represented exposures both in the school and in

Table 2—*Adjusted Odds Ratios and 95% CIs of Bronchitic Symptoms Among Children With Asthma in Two Pollutant Models*

Symptom	Two-Pollutant Model 1 ($NO_2 + SO_2$)	Two-Pollutant Model 2 ($NO_2 + PM_{2.5}$)	Two-Pollutant Model 3 ($NO_2 + O_3$)	Two-Pollutant Model 4 ($CO + SO_2$)	Two-Pollutant Model 5 ($CO + PM_{2.5}$)	Two-Pollutant Model 6 ($CO + O_3$)	Two-Pollutant Model 7 ($SO_2 + O_3$)	Two-Pollutant Model 8 ($PM_{2.5} + O_3$)
NO_2 (8.79 ppb)								
Bronchitis	1.99 (1.02-3.87)	2.04 (1.15-3.63)	1.81 (1.06-3.10)	…	…	…	…	…
Chronic phlegm	1.27 (0.59-2.74)	1.51 (0.79-2.89)	1.49 (0.81-2.73)	…	…	…	…	…
Chronic cough	1.25 (0.49-3.23)	1.26 (0.57-2.80)	1.10 (0.58-2.07)	…	…	…	…	…
Bronchitic symptoms	1.76 (0.99-3.14)	2.01 (1.20-3.36)	1.79 (1.12-2.85)	…	…	…	…	…
CO (105 ppb)								
Bronchitis	…	…	…	1.26 (0.97-1.64)	1.28 (0.99-1.65)	1.26 (0.97-1.64)	…	…
Chronic phlegm	…	…	…	1.17 (0.87-1.59)	1.22 (0.91-1.62)	1.20 (0.89-1.63)	…	…
Chronic cough	…	…	…	1.15 (0.80-1.67)	1.15 (0.81-1.65)	1.05 (0.75-1.45)	…	…
Bronchitic symptoms	…	…	…	1.27 (1.00-1.60)	1.31 (1.04-1.66)	1.27 (1.00-1.61)	…	…
SO_2 (1.31 ppb)								
Bronchitis	0.95 (0.73-1.23)	…	…	1.06 (0.85-1.32)	…	…	1.18 (0.94-1.48)	…
Chronic phlegm	1.13 (0.83-1.52)	…	…	1.15 (0.90-1.46)	…	…	1.26 (0.98-1.61)	…
Chronic cough	0.93 (0.64-1.35)	…	…	0.96 (0.71-1.29)	…	…	1.09 (0.83-1.43)	…
Bronchitic symptoms	1.02 (0.81-1.28)	…	…	1.11 (0.92-1.34)	…	…	1.26 (1.03-1.53)	…
$PM_{2.5}$ (16.84 μg/m³)								
Bronchitis	…	0.75 (0.42-1.33)	…	…	0.92 (0.54-1.56)	…	…	1.39 (0.64-2.99)
Chronic phlegm	…	1.02 (0.53-1.93)	…	…	1.12 (0.62-2.04)	…	…	1.98 (0.82-4.76)
Chronic cough	…	0.75 (0.34-1.66)	…	…	0.79 (0.39-1.62)	…	…	1.68 (0.67-4.22)
Bronchitic symptoms	…	0.75 (0.46-1.24)	…	…	0.92 (0.58-1.44)	…	…	1.61 (0.83-3.10)
O3 (8.77 ppb)								
Bronchitis	…	…	0.85 (0.59-1.23)	…	…	0.93 (0.64-1.33)	0.76 (0.52-1.12)	0.72 (0.43-1.20)
Chronic phlegm	…	…	0.87 (0.57-1.32)	…	…	0.92 (0.60-1.42)	0.75 (0.48-1.17)	0.61 (0.33-1.13)
Chronic cough	…	…	0.64 (0.42-0.99)	…	…	0.65 (0.42-1.02)	0.61 (0.38-0.98)	0.49 (0.26-0.93)
Bronchitic symptoms	…	…	0.82 (0.60-1.11)	…	…	0.88 (0.64-1.21)	0.71 (0.51-0.98)	0.64 (0.41-1.00)

Two-stage hierarchical analysis adjusting for age, sex, parental education, yearly income, during of breastfeeding, maternal smoking during pregnancy, environmental tobacco smoke, cockroaches note monthly, carpet, pets, home dampness and mold, parental atopy. ~~CO = carbon monoxide; NO_2 = nitrogen dioxide; O_3 = ozone; OR = odds ratio; $PM_{2.5}$ = particles with aerodynamic diameter 2.5 μm or less; SO_2 = sulfur dioxide.~~

Table 3—*Adjusted ORs and 95% CIs of Bronchitic Symptoms Among Children Without Asthma in Two-Pollutant Models*

Symptom	Two-Pollutant Model 1 ($NO_2 + SO_2$)	Two-Pollutant Model 2 ($NO_2 + PM_{2.5}$)	Two-Pollutant Model 3 ($NO_2 + O_3$)	Two-Pollutant Model 4 ($CO + SO_2$)	Two-Pollutant Model 5 ($CO + PM_{2.5}$)	Two-Pollutant Model 6 ($CO + O_3$)	Two-Pollutant Model 7 ($SO_2 + O_3$)	Two-Pollutant Model 8 ($PM_{2.5} + O_3$)
NO_2 (8.79 ppb)								
Bronchitis	1.11 (0.76-1.63)	1.05 (0.78-1.42)	0.98 (0.71-1.35)	…	…	…	…	…
Chronic phlegm	0.83 (0.54-1.28)	0.91 (0.62-1.32)	1.12 (0.80-1.58)	…	…	…	…	…
Chronic cough	1.49 (0.94-2.35)	1.29 (0.86-1.94)	1.27 (0.87-1.86)	…	…	…	…	…
Bronchitic symptoms	1.06 (0.88-1.10)	1.06 (0.82-1.39)	1.06 (0.83-1.34)	…	…	…	…	…
CO (105 ppb)								
Bronchitis	…	…	…	1.05 (0.90-1.22)	1.04 (0.90-1.21)	1.02 (0.87-1.20)	…	…
Chronic phlegm	…	…	…	0.93 (0.78-1.11)	0.94 (0.79-1.12)	1.06 (0.89-1.26)	…	…
Chronic cough	…	…	…	1.16 (0.97-1.39)	1.16 (0.97-1.38)	1.18 (0.98-1.42)	…	…
Bronchitic symptoms	…	…	…	1.02 (0.90-1.15)	1.02 (0.90-1.15)	1.04 (0.91-1.17)	…	…
SO_2 (1.31 ppb)								
Bronchitis	0.93 (0.80-1.07)	…	…	0.94 (0.83-1.06)	…	…	0.95 (0.83-1.09)	…
Chronic phlegm	1.14 (0.98-1.33)	…	…	1.11 (0.98-1.26)	…	…	1.04 (0.93-1.18)	…
Chronic cough	0.90 (0.76-1.07)	…	…	0.96 (0.83-1.10)	…	…	0.98 (0.84-1.14)	…
Bronchitic symptoms	0.99 (0.88-1.10)	…	…	1.00 (0.91-1.10)	…	…	0.99 (0.90-1.27)	…
$PM_{2.5}$ (16.84 µg/m³)								
Bronchitis	…	0.83 (0.63-1.10)	…	…	0.82 (0.62-1.10)	…	…	0.73 (0.49-1.10)
Chronic phlegm	…	1.35 (0.95-1.90)	…	…	1.32 (0.96-1.81)	…	…	0.97 (0.64-1.47)
Chronic cough	…	0.95 (0.64-1.39)	…	…	1.01 (0.71-1.44)	…	…	1.05 (0.63-1.76)
Bronchitic symptoms	…	0.95 (0.74-1.22)	…	…	0.97 (0.77-1.23)	…	…	0.85 (0.62-1.15)
O_3 (8.77 ppb)								
Bronchitis	…	…	0.96 (0.79-1.18)	…	…	0.97 (0.79-1.21)	0.99 (0.80-1.23)	1.13 (0.86-1.47)
Chronic phlegm	…	…	1.35 (1.07-1.69)	…	…	1.37 (1.08-1.75)	1.28 (1.03-1.59)	1.34 (1.00-1.78)
Chronic cough	…	…	1.02 (0.80-1.32)	…	…	1.07 (0.82-1.39)	1.02 (0.79-1.32)	0.98 (0.69-1.39)
Bronchitic symptoms	…	…	1.07 (0.91-1.25)	…	…	1.08 (0.91-1.28)	1.07 (0.90-1.27)	1.15 (0.93-1.43)

Two-stage hierarchical analysis adjusting for age, sex, parental education, yearly income, during of breastfeeding, maternal smoking during pregnancy, environmental tobacco smoke, cockroaches note monthly, carpet, pets, home dampness and mold, parental atopy. See Table 2 for expansion of abbreviations.

Table 4—*Mean and Distribution of 3-y Average Air Pollutant Concentrations Between Communities, Taiwan 2005-2007*

Pollutant	Mean ± SD	Minimum	Maximum	Interquartile Range
NO_2, ppb	17.68 ± 0.25	10.06	26.83	8.79
CO, 100 ppb	5.24 ± 0.06	3.04	7.78	1.05
SO_2, ppb	4.33 ± 0.10	2.16	10.09	1.31
$PM_{2.5}$, $\mu g/m^3$	33.38 ± 0.50	19.83	51.34	16.84
O_3, ppb	44.64 ± 0.39	30.34	59.12	8.77
Temperature, °C	24 ± 1.04	22.46	25.91	1.23
Relative humidity	74.0% ± 3.0%	69.0%	80.0%	4.3%

See Table 2 for expansion of abbreviations.

the home for two reasons. The schools were chosen to be in the vicinity of monitoring stations. Because the density of middle schools in Taiwan is very high, almost all children attended schools within 1 km of their homes. In addition, the two-stage hierarchical models took both individual-level and community-level information into account, which would make our results more valid.

From previous literature, we know that a high proportion of outdoor air pollutants (NO_2, CO) penetrate indoors.[8,9] Most of the Taiwanese schoolchildren spend at least 8 h/d in the school. Air conditioning is rare in Taiwanese classrooms. In addition, mechanical filtration is practically the only type of filtration in Taiwanese homes during the summer, even if the home is air conditioned. Any known or unknown factors, such as time outdoors, level of exercise, exchange, and deposition as well as penetration of air pollutants into the indoor microenvironments could be attributed to the potential problem of exposure misclassification using community-level exposure to represent personal exposure. This is also a limitation in all previous studies assessing the effects of ambient air pollution on risk of respiratory illnesses/symptoms among children.

Assessment of the independent effects of different pollutants is difficult, because urban air pollution constitutes a complex mixture of several compounds. Although all the measured pollutants have several sources, NO_2 and CO are predominantly from natural gas power plant combustion, whereas the main sources of SO_2 and $PM_{2.5}$ are stationary fossil combustion processes. In addition, busy roads typically have two types of vehicles, gasoline-powered and diesel-powered motor. NO_2, CO, and $PM_{2.5}$ are commonly from both types of emissions. In the present study, NO_2 and CO concentrations were highly correlated and SO_2 and $PM_{2.5}$ concentrations were also correlated. In the modeling, we were able to control for one pollutant (SO_2 or $PM_{2.5}$) at a time as a potential confounder when assessing the effect of the other pollutant (NO_2 or CO) and *vice versa*.

Synthesis With Previous Knowledge

In the present study, we found an 80% increase in the prevalence of bronchitic symptoms per 8.79 ppb increase in NO_2 and a 30% increased prevalence of bronchitic symptoms per 105 ppb increase in CO exposure among children with asthma. In addition, we showed a 30% increased prevalence of chronic phlegm per 8.77 ppb in O_3 among children without asthma.

Seven previous studies from southern California,[2,7] the eastern United States,[10,11] Germany,[3] Switzerland,[12] and Poland[13] have elaborated the relationships between exposure to outdoor air pollutants and the risk of bronchitic symptoms, but only two studies[2,3] focused on children with asthma. Our present study and a southern California study[2] reported an increased risk for NO_2, but the findings are inconsistent for SO_2, $PM_{2.5}$, and O_3.[2,3]

Two surveys conducted in six and 24 cities in the eastern United States showed positive associations between exposure to NO_2, SO_2, and $PM_{2.5}$ and the prevalence of chronic cough and bronchitis.[10,11] In a cross-sectional study carried out in southern California, increased bronchitic symptoms were associated

Table 5—*Correlations of Air Pollutants Across 14 Communities*

Pollutant	NO_2	CO	SO_2	$PM_{2.5}$	O_3
NO_2	1.00	0.86[a]	0.55[a]	0.37	−0.07
CO	…	1.00	0.16	0.09	−0.33
SO_2	…	…	1.00	0.68[a]	0.37
$PM_{2.5}$	…	…	…	1.00	0.73[a]
O_3	…	…	…	…	1.00

See Table 2 for expansion of abbreviations.
[a]Correlation is significant at the .05 level.

Table 6—*Adjusted ORs and 95% CIs of Bronchitic Symptoms Among Patients With and Without Asthma in Single Pollutant Models*

	Asthma		No Asthma	
Symptoms	OR	95% CI	OR	95% CI
Bronchitis	(n = 81/373)		(n = 205/4,666)	
NO_2 (8.79 ppb)	1.83	1.07-3.14	0.99	0.72-1.35
CO (105 ppb)	1.28	0.99-1.65	1.03	0.88-1.20
SO_2 (1.31 ppb)	1.11	0.90-1.38	0.95	0.84-1.07
$PM_{2.5}$ (16.84 $\mu g/m^3$)	0.96	0.57-1.62	0.83	0.62-1.11
O_3 (8.77 ppb)	0.84	0.60-1.19	0.96	0.79-1.18
Chronic phlegm	(n = 53/373)		(n = 164/4,636)	
NO_2 (8.79 ppb)	1.52	0.83-2.78	1.04	0.72-1.51
CO (105 ppb)	1.22	0.92-1.63	0.97	0.81-1.16
SO_2 (1.31 ppb)	1.20	0.95-1.51	1.10	0.97-1.24
$PM_{2.5}$ (16.84 $\mu g/m^3$)	1.17	0.65-2.11	1.30	0.94-1.79
O_3 (8.77 ppb)	0.86	0.58-1.28	1.32	1.06-1.63
Chronic cough	(n = 52/376)		(n = 119/4,676)	
NO_2 (8.79 ppb)	1.12	0.53-2.40	1.28	0.87-1.85
CO (105 ppb)	1.14	0.79-1.64	1.16	0.97-1.38
SO_2 (1.31 ppb)	0.98	0.73-1.33	0.98	0.85-1.13
$PM_{2.5}$ (16.84 $\mu g/m^3$)	0.83	0.40-1.71	1.03	0.72-1.47
O_3 (8.77 ppb)	0.65	0.42-0.99	1.01	0.79-1.28
Bronchitic symptoms	(n = 137/376)		(n = 429/4,676)	
NO_2 (8.79 ppb)	1.81	1.14-2.86	1.04	0.82-1.33
CO (105 ppb)	1.31	1.04-1.64	1.02	0.90-1.15
SO_2 (1.31 ppb)	1.17	0.97-1.40	1.00	0.91-1.10
$PM_{2.5}$ (16.84 $\mu g/m^3$)	0.99	0.63-1.57	0.98	0.78-1.23
O_3 (8.77 ppb)	0.80	0.59-1.09	1.06	0.91-1.25

Two-stage hierarchical analysis adjusting for age, sex, parental education, yearly income, during of breastfeeding, maternal smoking during pregnancy, environmental tobacco smoke, cockroaches note monthly, carpet, pets, home dampness and mold, parental atopy. See Table 2 for expansion of definitions.

with the levels of NO_2 and $PM_{2.5}$.[7] Later, a prospective southern California study found positive associations between bronchitic symptoms with asthma and NO_2, organic carbon (OC), and $PM_{2.5}$.[2] The risks of bronchitic symptoms with asthma were associated with NO_2, OC, and $PM_{2.5}$. In a cohort study conducted in Germany, the risk of bronchitic symptoms with asthma was elevated for $PM_{2.5}$.[3] In a study of Swiss schoolchildren, the risk of bronchitis was associated with NO_2, SO_2, and PM_{10} for the most-compared with the least-polluted community.[12] A survey in Poland found that outdoor air pollution level was associated with an increased risk of chronic phlegm.[13]

The possible mechanisms of NO_2 are through interaction with the immune system or impairment of respiratory response to infection, which could result in increased risk of bronchitic symptoms.[14,15] There are no plausible mechanisms through which CO exposure would influence the airways and increase the risk of bronchitic symptoms. In the present study, it was not possible to elaborate to what extent NO_2 would have direct effects on children's airways. CO is unlikely to have any direct effects on the airways. Our results did not show any association between the prevalence of bronchitic symptoms with asthma and $PM_{2.5}$. Although the risk of bronchitic symptoms with asthma was not related to the levels of $PM_{2.5}$, it was likely that there was an association with OC in PM typically present in motor vehicle exhausts and in particular in diesel exhausts. Further studies should assess these relationships.

Our findings also suggested that the prevalence of chronic phlegm without asthma was related to O_3 exposure. O_3 is a secondary pollutant in the atmosphere produced from traffic exhausts but scavenged by direct motor vehicle emissions. O_3 is a known respiratory irritant and has been shown to increase the synthesis of the allergic antibody IgE in human beings.[16] It could increase sensitization to common allergens and influence the development of phlegm.

Conclusion

The present study provides additional evidence that exposure to outdoor air pollutants increases the prevalence of bronchitic symptoms with asthma and without asthma in schoolchildren. The prevalence of bronchitic symptoms with asthma was related to NO_2 and CO exposure. The present findings also suggest that exposure to O_3 may increase the prevalence of chronic phlegm among children without asthma.

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