Short-Term Effect of Ozone on the Pulmonary Function of Children in Primary School

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The objective of this study was to evaluate the short-term effect of ambient air pollution on the pulmonary function of schoolchildren. We sampled 941 children in primary school in three communities in Taiwan (Sanchun, Taihsi, and Linyuan). The nearby stations of the Taiwan air quality monitoring network provided the hourly ambient concentrations of sulfur dioxide, carbon monoxide, ozone, particulate matter $\leq$ 10 µm in aerodynamic diameter, and nitrogen dioxide. Spirometry was performed once for each sampled child. We also obtained the status of indoor air pollution and chronic respiratory disease history by using a structured questionnaire. Multivariate linear model analysis was used to evaluate pulmonary function effects of each pollutant in addition to determinants of indoor air pollution and meteorologic conditions. We found a significantly negative association of peak O_3 concentration on the day before spirometry with individual forced vital capacity and forced expiratory volume in 1 sec. The decrease in children's lung function can occur at peak hourly O_3 concentrations < 80 ppb. The slope of lung function decrease for Taiwanese children is approximately 1 mL/ppb for peak hourly O_3 exposure. *Key words:* ozone, pulmonary function, schoolchildren, short-term effect. *Environ Health Perspect* 107:921–925 (1999). [Online 19 October 1999]
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Pulmonary function as an index of respiratory health effects of the lower airway has been documented in previous studies (*1,2*). Most major pollutants can alter pulmonary function in addition to other health effects when the exposure concentrations are high. In a relatively low-dose exposure due to common air pollution, however, each pollutant is not thought to have significant effects on pulmonary function (*3*). Ozone (O_3), a strong oxidant, is most frequently reported to produce pulmonary function impairment at low levels because it may induce lipid peroxidation and the production of cycloxygenase that triggers the neural receptors of the airway (*4,5*). Particulates $\leq$ 10 µm in aerodynamic diameter (PM_{10}) also have a negative effect on pulmonary function in many studies, but the mechanism is still unclear (*6,7*).

Although the problems of air pollution in Taiwan are relatively severe, it was not until recently that the health effects associated with air pollution were reported (*8–10*). From the preliminary analyses of the pollution-monitoring data, we know that the major pollutants in Taiwan are O_3 and particulates in most places and sulfur dioxide (SO_2) pollution in others (*11*). A cross-sectional survey of pulmonary function of children in primary school was designed to investigate the short-term effect of ambient air pollution.

Materials and Methods

Study population. A total of 941 primary school children from three communities in Taiwan (Sanchung, Taihsi, and Linyuan) were randomly sampled by class from each grade of the study population of the Study on Air Pollution and Health in Taiwan (Table 1) (*8*). There were 453 boys and 488 girls from 8 to 13 years of age. Of this group of children, 81.6% had resided in their current houses for at least 3 years. The average age of children in the study was 9.8 ± 1.6 years, standing height was 136.4 ± 11.2 cm, and body weight was 33.0 ± 9.9 kg.

Air monitoring. The hourly concentrations of five air pollutants including SO_2, carbon monoxide (CO), O_3, PM_{10}, and nitrogen dioxide (NO_2) were continuously monitored on the campus of the selected primary school in each community. The instrumentation used in the fixed-site monitoring stations were ultraviolet (UV) fluorescence for SO_2, nondisperse infrared absorption for CO, UV absorption for O_3, β-gauge for PM_{10}, and chemiluminescence for NO_2. The air quality was measured by comparing the air pollution levels with the appropriate National Ambient Air Quality Standards (NAAQS) of Taiwan (*12*) for each air pollutant. Meteorologic data such as atmospheric temperature and rainfall were also obtained from the same monitoring stations.

Pulmonary function test. We used Sensor Medics 2130 (SensorMedics Corp., Yorba Linda, CA) (*13*), a rolling-seal dry spirometry system, to test pulmonary function. One physician and one trained assistant operated each machine. All spirometry tests were conducted from May 1995 to January 1996.

The machine was calibrated before and after each day's use; no significant differences were found. Before each test, the standing height and weight of each child were measured and read off by an assistant. Another physician performed a screening physical examination for respiratory tract infections or abnormal breathing sounds.

Spirometry was performed according to the American Thoracic Society (*14*) protocol and quality verifying criteria. The test that met both the acceptability and reproducibility criteria was classified as class A, the test that met only one of these two criteria was classified as class B, and the others were classified as class C. Data in class C were not used for further analyses. Each child was tested on at least three expiratory maneuvers, and at most eight times, to attain at least three sets of valid data. The measurement of forced vital capacity (FVC), forced expiratory volume in 1 sec ($FEV_{1.0}$), forced expiratory volume in 1 sec as a percentage of the forced vital capacity ($FEV_{1.0}$/FVC), forced expiratory flow when 25–75% of FVC was exhaled ($FEF_{25–75\%}$), peak expiratory flow rate (PEF), and other pulmonary function indices were obtained. The trial with maximal value of FVC and $FEV_{1.0}$ was selected as a representative for other indices, but the FVC and $FEV_{1.0}$ could be selected from different valid trials.

Questionnaires. A respiratory health questionnaire was distributed through the schools to the children in the study period. The questionnaire was completed by either a parent or a guardian and returned to school. One nurse for each school distributed and collected the questionnaires. The questionnaire used in this study was mainly adapted and modified from the World Health Organization childhood respiratory questionnaire (*15*). We used the questionnaire data to

control the possible confounding effects of indoor air pollution and previous respiratory health status of each child. The questionnaire was divided into the following five parts: demographic data, respiratory symptoms and diseases of the children, housing conditions, children's bedrooms, and possible sources of indoor air pollution such as household smoking, pets, fowls, coal stove used, tea gas-cooker used, incense burning all day, mosquito repellent burning, indoor planting, and home dampness. Self-reported respiratory diseases such as sinusitis, wheezing or asthma,

allergic rhinitis, bronchitis, and pneumonia were included in a history of respiratory disease diagnosed by medical doctors.

Statistics. The dependent variables were all pulmonary function indices measured; the independent variables were basic determinants including sex, age, standing height, weight, body mass index (BMI), ambient and indoor air pollutants, and chronic respiratory disease history of the child. The hourly average concentrations of SO_2 (in parts per billion), CO (in parts per million), O_3 (in parts per billion), PM_{10} (in micrograms per cubic

meter), and NO_2 (in parts per billion) were taken to obtain the daytime average or peak concentrations and to be put into modeling. We used daytime average or peak concentrations from 0800 to 1800 because they were better representative of these schoolchildren's exposure.

To determine the most appropriate models for the basic determinants, we first examined the combinations of anthropometric measurements that best explained spirometric performance. Thus, we considered standing height, weight, and BMI, as well as sex interaction terms with age and height. First, bivariate plots of pulmonary function against height were constructed by sex. This was done to determine the functional form of association, then we estimated models with and without interaction terms. Finally, we included sex, standing height, and BMI only in a separate set of models.

One-pollutant models for each air pollution variable were adjusted for sex, height, BMI, community, and average atmospheric temperature and rainfall. These analyses were repeated using the air pollution values with 1-, 2-, and 7-day lags to determine separately for each air pollution variable if there was an effect on pulmonary function and which lag time showed the strongest association. For each pulmonary function measure, a multipollutant model included all of the air pollution variables that had shown significant and/or strong associations in the above analyses. We further stratified the peak O_3 concentrations into four strata: < 40, 40–59, 60–79, and ≥ 80 ppb to investigate thresholds and dose–response effects of O_3 on pulmonary function changes. All statistical analyses were performed using SPSS for Windows, release 6.1 (*16*).

Table 1. Pulmonary functions, prevalence of respiratory diseases, and meteorologic condition by study population.

Variables	Rural community (Taihsi)	Urban community (Sanchung)	Petrochemical industrial community (Linyuan)	Mean
Subjects (*n*)[a]	388	170	383	
Pulmonary function value[b]				
FVC (mL)	1,964.8 ± 493.0	2,023.7 ± 506.3	1,972.5 ± 508.1	1,979.0 ± 501.6
$FEV_{1.0}$ (mL)	1,667.0 ± 449.7	1,796.9 ± 471.1	1,752.5 ± 453.3	1,727.4 ± 457.5
$FEV_{1.0}$/FVC (%)	85.0 ± 10.8	88.6 ± 8.2	89.1 ± 5.9	87.3 ± 8.8
$FEF_{25-75\%}$ (mL/sec)	2,022.4 ± 780.0	2,353.1 ± 877.6	2,240.3 ± 731.1	2,173.4 ± 797.9
PEF (mL/sec)	3,259.4 ± 1,180.4	3,681.4 ± 1,244.2	3,679.9 ± 1,025.1	3,510.6 ± 1,149.6
Test failure[c]	27 (7.0)	3 (1.8)	16 (4.2)	46 (4.9)
Respiratory disease[c]				
Sinusitis	28 (7.2)	13 (7.6)	27 (7.0)	68 (7.2)
Wheezing or asthma	28 (7.2)	11 (6.5)	27 (7.0)	66 (7.0)
Allergic rhinitis	34 (8.8)	29 (17.1)	31 (8.1)	94 (10.0)
Bronchitis	58 (14.9)	47 (27.6)	68 (17.8)	173 (18.4)
Pneumonia	14 (3.6)	5 (2.9)	18 (4.7)	37 (3.9)
Meteorologic condition[d]				
Atmospheric temperature (°C)	26.6–29.7	13.2–22.0	21.7–29.7	13.2–29.7
Rainfall (mm)	0.0–1.0	0.0–0.4	0.0–1.2	0.0–1.2

Abbreviations: $FEF_{25-75\%}$, forced expiratory flow from 25 to 75% of FVC; $FEV_{1.0}$, forced expiratory volume in 1 sec; FVC, forced vital capacity; PEF, peak expiratory flow.
[a]Total subjects, *n* = 941. [b]Values are mean ± standard deviation. [c]Values in parentheses are percent. [d]Values are range during spirometry.

Results

Peak concentrations of air pollutants in the day before spirometry are shown in Figure 1. The ranges of peak concentrations in SO_2, CO, O_3, PM_{10}, and NO_2 were 0–72.4, 0.4–3.6, 19.7–110.3, 44.5–189.0, and 9.2–141.6 ppb, respectively. There was a high correlation between CO and NO_2 concentrations (*r* = 0.86–0.98) except at the daytime peak with a 2-day lag (*r* = 0.73). Moderately high correlations were also found among the air pollutants between SO_2 and PM_{10} (*r* = 0.68) or NO_2 (*r* = 0.71) for daytime averages with a 1-day lag. Meteorologic conditions shown in Table 1 were not very different during the study period.

Although 941 children were examined physically and performed pulmonary function tests, 46 children whose tests were classified as test failure were not used for further analyses. The reported prevalences of respiratory diseases in these schools are summarized in
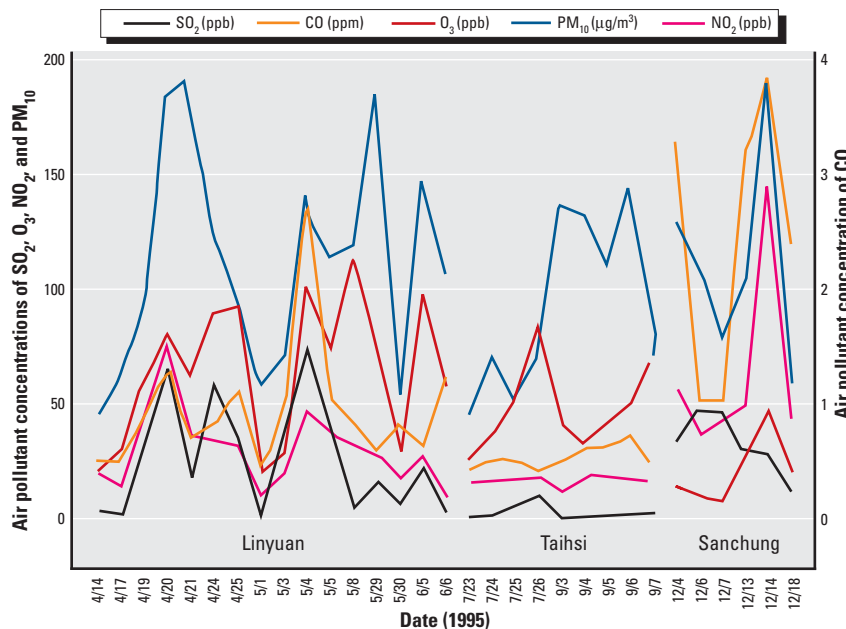

Figure 1. Daytime peak concentrations of air pollutants in the day before spirometry. Abbreviations: CO, carbon monoxide; O_3, ozone; SO_2, sulfur dioxide; NO_2, nitrogen dioxide; PM_{10}, particulate matter ≤ 10 μm in aerodynamic diameter.

Table 1. Children living in the urban area had higher rates of allergic rhinitis and bronchitis than those living in the rural and petrochemical communities. Except for FVC, the other pulmonary function values were significantly different among the three communities. Pulmonary function values except $FEV_{1.0}/FVC$ were the highest in the urban community, followed by those in the petrochemical community (Table 1).

The results of one-pollutant models for SO_2, CO, O_3, PM_{10}, and NO_2 are listed in Table 2. We found that the daytime peak O_3 concentration with a 1-day lag significantly affected both FVC and $FEV_{1.0}$; the daytime average NO_2 concentration with a 1-day lag significantly affected FVC. For the 2-day lag, daytime peak SO_2 and the daytime average CO, O_3, and NO_2 concentrations significantly affected FVC. However, no significant result was demonstrated in the models for the exposure with 7 days before spirometry.

In the multipollutant models, we found that only peak O_3 concentrations with 1-day lags showed a significant effect on both FVC and $FEV_{1.0}$. The dose–response relationship between the peak O_3 concentration with 1-day lag and lung function changes is shown in Table 3. Our models indicate that there was an approximately 1-mL decrease in both FVC and $FEV_{1.0}$ per 1 ppb O_3 exposure among schoolchildren. The average NO_2 concentration did not cause pulmonary function changes in the study. Meteorologic conditions including atmospheric temperature and rainfall also show the strongly significant effects on FVC and $FEV_{1.0}$. Besides, no indoor pollutants or chronic respiratory disease history have any significant effect in the analyses.

As shown in Figure 2, there was a gradual decline for both adjusted FVC and $FEV_{1.0}$ with the increase of peak O_3 concentration in the previous day before spirometry. There are statistically significant differences between the highest and lowest two exposed strata for FVC only.

Discussion

In this study, we reached the same conclusion about O_3 effects on pulmonary function changes as in previous studies (3,17). The peak O_3 concentration in the previous day is an important factor in lowering children's FVC and $FEV_{1.0}$. Hourly ozone concentrations in the three communities during the study period did not exceed the Taiwan air quality standard of 120 ppb, but they still showed an adverse health effect. The effect was statistically significant if the peak level exceeded 80 ppb, as compared to < 60 ppb for FVC, and there were no clear threshold values.

Epidemiologic studies have been used to investigate the acute pulmonary effects of ambient O_3 under natural conditions, such as studies conducted in summer camps, during exercise, and during everyday activity. Such studies can examine the O_3 effect under real-time measurements and patterns of O_3, other air pollutants, and various environmental conditions. In this study, the short-term health effect was estimated by using the time lag approach, i.e., the peak or average concentration of air pollutants in the days before spirometry as the exposure indices. Also, the three communities with different pollution patterns based on community monitoring were selected to enhance the variation of air pollution and to facilitate the comparison. This type of study is useful

Table 2. One-pollutant models of FVC and $FEV_{1.0}$ on daytime average and peak concentrations of air pollutants with 1-day, 2-day, and 7-day lags.

Pollutant	Time lag before spirometry	FVC (mL)		$FEV_{1.0}$ (mL)	
		Coefficient[a]	Standard error	Coefficient[a]	Standard error
SO₂ (ppb)					
Daytime average	1 day	-3.18	1.80	-1.95	1.69
	2 days	-2.70	1.49	-1.12	1.41
	7 days	0.61	2.59	-1.48	2.44
Daytime peak	1 day	-0.91	0.73	-0.57	0.68
	2 days	-1.27*	0.59	-0.64	0.56
	7 days	-1.05	1.29	-1.96	1.22
CO (ppm)					
Daytime average	1 day	-66.60	40.73	20.55	38.24
	2 days	-147.71*	64.48	-82.42	60.95
	7 days	2.20	48.13	48.23	45.58
Daytime peak	1 day	-33.25	20.74	1.20	19.48
	2 days	-16.48	19.67	-1.44	18.57
	7 days	-5.18	16.48	20.96	15.67
O₃ (ppb)					
Daytime average	1 day	-0.94	0.53	-0.68	0.50
	2 days	-1.47*	0.66	-0.87	0.62
	7 days	0.20	0.40	-0.30	0.38
Daytime peak	1 day	-0.79*	0.32	-0.64*	0.30
	2 days	-0.67	0.38	-0.40	0.36
	7 days	0.01	0.25	-0.31	0.24
PM₁₀ (μg/m³)					
Daytime average	1 day	-0.54	0.30	-0.28	0.28
	2 days	-0.37	0.39	-0.20	0.37
	7 days	-0.24	0.23	-0.40	0.22
Daytime peak	1 day	-0.34	0.19	-0.26	0.18
	2 days	-0.26	0.24	-0.17	0.23
	7 days	-0.21	0.14	-0.27	0.14
NO₂ (ppb)					
Daytime average	1 day	-2.66*	1.23	-0.46	1.16
	2 days	-3.32*	1.53	-0.93	1.45
	7 days	1.39	1.71	2.52	1.61
Daytime peak	1 day	-0.59	0.40	-0.16	0.37
	2 days	-1.33	0.72	-0.36	0.68
	7 days	-0.13	0.87	0.43	0.82

Abbreviations: CO, carbon monoxide; $FEV_{1.0}$, forced expiratory volume in 1 sec; FVC, forced vital capacity; SO_2, sulfur dioxide; NO_2, nitrogen dioxide; PM_{10}, particulate matter ≤ 10 μm in aerodynamic diameter.
[a]Values adjusted for sex, height, body mass index, community, and average atmospheric temperature and rainfall. *$p < 0.05$.

Table 3. Multi-pollutant models of FVC and $FEV_{1.0}$ on daytime peak O_3 and average NO_2 concentrations on the day before spirometry.

Variables	FVC (mL)		$FEV_{1.0}$ (mL)	
	Coefficient	Standard error	Coefficient	Standard error
Sex (female vs. male)	-148.99#	17.30	-83.90#	16.31
Height (cm)	32.24#	0.91	29.86#	0.85
Body mass index (kg/m²)	29.11#	3.11	19.24#	2.93
Sanchung versus Taihsi	-106.72	83.12	-91.53	78.33
Linyuan versus Taihsi	65.06**	23.51	132.71#	22.15
Average atmospheric temperature (°C)	-14.60**	4.59	-13.49**	4.33
Daily rainfall (mm)	-66.00**	22.89	-76.75#	21.59
Peak O_3 concentration (ppb)	-0.91*	0.37	-0.85*	0.34
Average NO_2 concentration (ppb)	0.22	1.48	1.58	1.39
Constant	-2,271.15#	206.31	-2,204.80#	194.50
Adjusted R^2	0.748		0.725	

Abbreviations: $FEV_{1.0}$, forced expiratory volume in 1 sec; FVC, forced vital capacity; NO_2, nitrogen dioxide; O_3, ozone.
*$p < 0.05$. **$p < 0.01$. #$p < 0.001$.
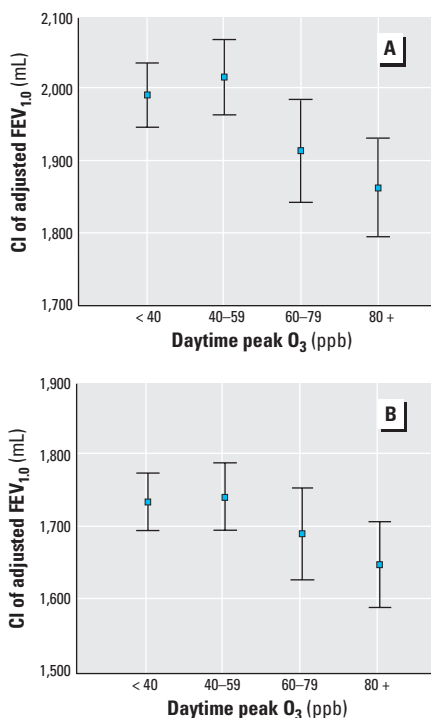
Figure 2. A gradual decline for adjusted (*A*) FVC and (*B*) $FEV_{1.0}$ with the increase of peak O_3 concentration in the previous day before spirometry. Abbreviations: CI, 95% confidence interval; $FEV_{1.0}$, forced expiratory volume in 1 sec; FVC, forced vital capacity; O_3, ozone.

to assess short-term health effects due to various air pollution levels and provides sufficient power to quantify their relationships.

There is an anticipated effect of excluding those test failure cases that were unable to meet the requirements of both the acceptability and reproducibility criteria (*18–20*). However, estimates of O_3 effect changed little in response to the inclusion of the subjects with test failure. Chronic respiratory disease history, such as bronchial asthma and allergic rhinitis, has a negative influence on pulmonary function but did not have statistical significance. All indoor air pollutants including household smoking have no significant influence on children's pulmonary function in the study. All of these factors constitute potential biases toward the null in this study.

Pulmonary function values except $FEV_{1.0}$/FVC are the highest in the urban community, even though there were higher prevalences of histories in allergic rhinitis and bronchitis. On the other hand, those are lowest in the rural community (Table 1). We first attempted to elucidate this difference due to long-term exposures to mixtures of air pollutants, but it is difficult to arrive at any conclusions under this type of study. However, the difference could come from a short-term effect of mixtures of air pollutants. We performed the spirometry in the

rural community during summer vacation (Figure 1) and, thus, it can be implied that those children had frequent outside physical activities. The difference could also be due to other possible explanations, such as exposure to indoor air pollutants, nutritional effect even after controlling for height and BMI, and children's performance of spirometry. To adequately control the potential confounding effect from the intercommunity differences, we put community variables (Sanchung vs. Taihsi and Linyuan vs. Taihsi) into the models.

Determinations of the possible adverse health effects of air pollutants can be complicated by differences in the environmental conditions of temperature and humidity. To control for these confounders, inclusion of covariates for both temperature and rainfall were used simultaneously in the models. Although Brunekreef and co-workers (*21*) found no temperature effect under ambient conditions, other studies (*22,23*) showed that ambient heating coinciding with O_3 episodes might modify the overall effect of O_3 on pulmonary function. In this study we found that both atmospheric temperature and rainfall on the day before spirometry indicated the negative relation for lung function values (Table 2).

Although we tried different numerical figures of different air pollutants during model construction, the O_3 level of the day before pulmonary function testing was the only significant pollutant that affected lung function after controlling other variables (Table 2). Because PM_{10} and O_3 were the only pollutants that exceeded the NAAQS, we concluded that SO_2, CO, and NO_2 did not have short-term effects on lung function under the low levels in Figure 1. In addition, we did not find any specific acute effect on lung function when the levels were near a daily average of 125 $\mu g/m^3$ for PM_{10}.

The study communities were located in different regions of Taiwan and therefore exhibited differences in indoor air pollution. The prevalence of most of the reported respiratory conditions was higher (day or night cough, chronic cough, shortness of breath, and bronchitis significantly so) among children whose fathers or mothers were smokers, as compared to the children of nonsmoking parents (*3*). However, we could not detect any significant effect on lung function, including passive smoking, with exposure to other combustion sources in the dwelling .

Four studies of everyday life (*24–27*) involved full spirometric measurements for the children. The Six Cities Study (*24*) also showed that pulmonary function damages occurred even when the peak ozone level was < 80 ppb, and no clear threshold level has yet been established. Larger negative coefficients

were determined for the children with a history of chronic phlegm in a study in Mexico (*25*), but our study and a Dutch study (*26*) did not reach the same conclusions. Because O_3 is highly reactive, our result suggests that it may be deeply absorbed by the lower respiratory airways and produce mild restriction and obstruction within 24 hr.

However, all of these studies (including ours) were conducted cross-sectionally or under short-term observation. Whether such an effect is reversible and/or will produce a long-term health effect should be proven by a longitudinal follow-up study in the future. Moreover, schoolchildren's individual exposure to air pollutants should be assessed in more detail to estimate the dose–response relationship more precisely. Models or field studies to characterize children's individual exposure as well as measurements of detailed time activity are strongly recommended.

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