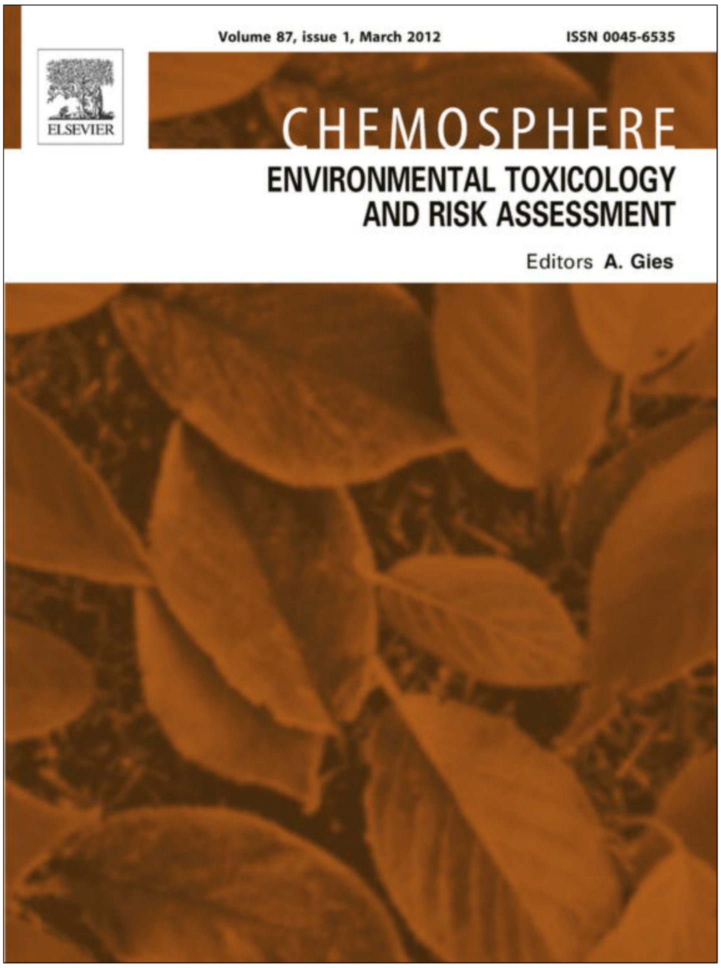
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The short-term effects of air pollution on adolescent lung function in Taiwan

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ABSTRACT

A mass screening of lung function associated with air pollutants for children is limited. This study assessed the association between air pollutants exposure and the lung function of junior high school students in a mass screening program in Taipei city, Taiwan. Among 10,396 students with completed asthma screening questionnaires and anthropometric measures, 2919 students aged 12–16 received the spirometry test. Forced vital capacity (FVC) and forced expiratory flow in 1 s (FEV_1) in association with daily ambient concentrations of particulate matter with diameter of 10 μm or less (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3) were assessed by regression models controlling for the age, gender, height, weight, student living districts, rainfall and temperature. FVC, had a significant negative association with short-term exposure to O_3 and PM_{10} measured on the day of spirometry testing. FVC values also were reversely associated with means of SO_2, O_3, NO_2, PM_{10} and CO exposed 1 d earlier. An increase of 1-ppm CO was associated with the reduction in FVC for 69.8 mL (95% CI: −115, −24.4 mL) or in FEV_1 for 73.7 mL (95% CI: −118, −29.7 mL). An increase in SO_2 for 1 ppb was associated with the reductions in FVC and FEV_1 for 12.9 mL (95% CI: −20.7, −5.09 mL) and 11.7 mL (95% CI: −19.3, −4.16 mL), respectively. In conclusion, the short-term exposure to O_3 and PM_{10} was associated with reducing FVC and FEV_1. CO and SO_2 exposure had a strong 1-d lag effect on FVC and FEV_1.

1. Introduction

Increased prevalence and hospital admissions for respiratory illnesses have been associated with air pollution, especially for children (Wardlaw, 1993; Tager, 1999; Yang et al., 2005). Several studies have found that the lung function of children is associated with air pollution. The follow-up study in Poland found poorer gain in pulmonary volume in children living in areas with higher air pollution; this association was more significant for boys (Jedrychowski et al., 1999). Langkulsen et al. (2006) found in Bangkok that the lung function of school children aged 10–15 years decreased as the level of air pollution increased in the residential area. An East Germany study analyzed data obtained from consecutive cross-sectional surveys and found that the lung function in 11–14-year-old children changed as air pollution changed over a short period (Christian et al., 2003).

The association between air pollution species and lung function may vary. Southern Californian studies had associated the reduced pulmonary function in children with particulate matter and inorganic acid vapor (Gauderman et al., 2000, 2004). Several studies had associated particulate matter and sulfur dioxide (SO_2) with decreased lung function in adolescent children (Jedrychowski et al., 1999; Christian et al., 2003; Liu and Zhang, 2009). Other studies show that nitrogen dioxide (NO_2) and ozone (O_3) are important pollutants associated with decreased lung function (Chen et al., 1999; Moshammer et al., 2006; Rojas-Martinez et al., 2007; Liu and Zhang, 2009). The variation in these study findings may be associated with study designs, lifestyles of children, ecological differences, climate variations, and more importantly, the contents of air pollutants.

Located in a basin in northwestern Taiwan, Taipei is a city with 2.6 million people in an area of 272 km^2. Over 1.5 million vehicles are major sources of air pollution in the city. Among 21 cities and counties in Taiwan, the prevalence of childhood asthma is the highest in Taipei (Department of Health, Executive Yuan, Taiwan, 1999; Lin et al. 2001). There is a significant association between childhood asthma and air pollution level in children's residential

Abbreviations: FVC, forced vital capacity; FEV_1, forced expiratory flow in 1 second; PM_{10}, particulate matter, diameter of 10 *u*m or less; SO_2, sulfur dioxide; CO, carbon monoxide; NO_2, nitrogen dioxide; O_3, ozone; 95% CI, 95% confidence interval.

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areas. This study investigated whether the lung function of children is associated with the air pollution levels in their living areas. The effects from short-term exposure to pollutants on the day (0 d) of the spirometry test, and the lag effect of exposure 1 d and 2 d earlier were also evaluated.

2. Materials and methods

2.1. Target population

With the support of Environmental Protection Administration (EPA) in Taiwan from 1995 to 1999, the childhood respiratory health study began with a mass survey for asthma among middle school children in Taiwan. A Respiratory Health Survey Steering Committee, consisting of 35 experts in pediatrics, internal medicine, family medicine, pulmonary function, environmental health, health education, biostatistics, and epidemiology approved this study. Details of this study design have been previously reported (Lin et al. 2001). Our sampling frame in the present study included 118,138 students enrolled in 87 junior high schools in Taipei city. A study team visited each school and invited students to complete the Chinese version of the International Study of Asthma and Allergies in Childhood (ISAAC) video questionnaire with parental consent. The students' parents completed the self-reported questionnaires, and school teachers assisted in collecting them. From these students, 10% (n = 10,396) were randomly selected for the lung function test. In this study, we included 2919 students who lived in 5 school districts (Songshan, Zhongshan, Zhongzheng, Wanhua, and Shilin) in Taipei. Each district was equipped with an ambient air quality monitoring system. These students completed the lung function testing from December 1996 to May 1997 with Class A or Class B results (American Thoracic Society, 1987). Each school was in the 2 km area around the ambient air quality monitor station. This study was approved by the research ethical committee at National Taiwan University College of Public Health.

2.2. Ambient air quality monitoring site and air pollution data

The 5 ambient air quality monitoring sites in Taipei city were established by the Environmental Protection Administration of Taiwan (TEPA) to monitor the general air quality mainly generated by the traffic exhaust. Each monitor system consisted of a carbon oxide analyzer (Horiba, Kyoto, Japan), an ozone analyzer (Ecotech 9810, Victory, Australia), a nitrogen oxide analyzer (Ecotech 9841, Victory, Australia) and a sulfur dioxide analyzer (Ecotech 9850, Victory, Australia), and R&P1400 (New York, American) used to measure the concentration of pollutants (PM_{10}) with particle diameters under 10 um in the air. The meteorological parameters were monitored and recorded at the ambient air quality monitoring station using Temperature/Relative Humidity Probe (Metone 083C, Oregon, USA) and Anemometer (Metone 014A, Oregon, USA) (Taiwan Air Quality Monitoring Network, 2011). The measurements were recorded hourly. The data provided by TEPA included temperature, air pressure, rainfall, wind speed, and concentrations of air pollutants.

We obtained hourly pollutant and meteorological data to analyze their association with the lung function of students. Only students attending middle schools within 2 km around the monitoring station were included in this study. In the testing day of lung function, we included the meteorological variables and air pollutants from 8:00 am to 12:00 in the data analysis because the lung function tests were taken mainly in the morning in Taipei city. For the lag effect analysis, we used the air pollutants data exposed from 8:00 am to 6:00 pm 1 d and 2 d before the spirometry testing.

2.3. Lung function tests

Seven to ten daily calibrated computerized spirometers (Model 2130, SensorMedics; Yorba Linda, CA) were normally used to measure lung function for students at the school by the same study team. The forced vital capacity (FVC) and forced expiratory flow in 1 s (FEV_1) were included in this study. These measurements were repeated up to no more than eight times for each student until the best result appeared. An experienced technician checked and classified testing data into three classes using the American Thoracic Society Standard (American Thoracic Society, 1987). Class A data was compatible with the standard, class B data was acceptable data, and class C data was unreliable data and excluded in statistical analysis. In this study, only subjects categorized to Class A and Class B were included.

2.4. Statistical analysis

In order to present the overall air pollution level in Taipei, we first combined all air pollutant records monitored for the 5 districts 6 d before the spirometry testing and reported the inter quartile levels. The mean and peak levels of air pollutants monitored on the day of spirometry testing (0-d), and 1 d and 2 d before the testing were calculated and compared among the five study districts. Data analysis then compared among these five districts the distributions of age and gender, and means of height, weight and lung function tests including FVC, FEV_1, and FEV_1/FVC.

In this study, we used multivariable regression analysis to determine FVC and FEV_1 in association with air pollutants levels of 0-d, and 1-d and 2-d lag; controlling for students living district, age, gender, height, weight, temperature and rainfall. Coefficients and 95% confidence intervals (CI) of lung function measures, FVC and FEV_1, associated with these variables were determined for all measured students in these 5 districts together. Data was analyzed using the statistical package software SAS 8.1 (SAS Institute Inc., Cary, NC, USA), and p-values <0.05 were considered as statistically significant.

3. Results

3.1. Air pollution levels

Table 1 shows the 6-d combined concentrations of measured pollutants at the 25th percentile, 50th percentile and 75th percentile levels among the 5 monitored stations. SO_2 ranged from 1.3 to 5.2 ppb and NO_2 from 19.3 to 41.7 ppb, while O_3 ranged from 5.4 to 27.4 ppb, PM_{10} from 28 to 81 μg/m^3 and CO from 0.6 to 1.4 ppm. Table 2 displays the mean and peak levels of air pollutants measured at each station on days the lung function test was performed, and 1 d and 2 d before the test. Ranges of concentrations of SO_2, CO, O_3, PM_{10} and NO_2 across these districts were 1.8–10.0 ppb, 0.60–2.10 ppm, 10.7–30.5 ppb, 35.3–98.3 μg/m^3 and 16.2–49.3 ppb, respectively.

3.2. Lung functions

Table 3 shows that 52.5% of students who received lung function test were boys and 42.8% of students were aged ⩾15 years.

Table 1
The 6-d combined quartile values of air pollutants among the five study districts.[a]

	SO_2 (ppb)	CO (ppm)	O_3 (ppb)	PM_{10} (μg/m^3)	NO_2 (ppb)
Q25th	1.3	0.6	5.4	28	19.3
Medium	2.6	0.93	15.4	51	31.8
Q75th	5.2	1.4	27.4	81	41.7

[a] Measured value of air pollutants from 6 d before the lung function test to the date of the lung function test.

Table 2
Distributions of air pollutants measured on lung function test day, and 1 d and 2 d before lung function test.

District	SO_2 (ppb)		CO (ppm)		O_3 (ppb)		PM_{10} (μg/m^3)		NO_2 (ppb)	
	Mean (SD)	Peak	Mean (SD)	Peak	Mean (SD)	Peak	Mean (SD)	Peak	Mean (SD)	Peak
Songshan										
The day of LF[a] test	5.2 (3.1)	11.4	1.4 (0.5)	2.8	15.6 (9.8)	66.8	39.8 (19.3)	108	45.1 (11.7)	88.2
1 d before LF test	1.8 (1.1)	11.4	0.8 (0.1)	2.8	20.0 (9.3)	67.0	40.9 (10.8)	83	29.2 (7.3)	88.2
2 d before LF test	2.1 (1.2)	6.7	0.8 (0.3)	3.0	20.6 (8.1)	39.0	39.0 (9.1)	87	24.0 (7.3)	61.9
Zhongshan										
The day of LF test	10.0 (8.7)	35.2	2.1 (0.8)	3.6	10.7 (6.4)	53.5	68.5 (36.4)	153	49.3 (15.8)	102.2
1 d before LF test	5.4 (3.5)	22.8	1.3 (0.5)	4.0	24.3 (8.0)	68.0	50.0 (28.6)	158	41.7 (20.1)	137.2
2 d before LF test	5.0 (2.8)	23.1	1.5 (0.2)	3.0	16.8 (10.9)	44.0	56.6 (30.1)	153	38.7 (5.8)	61.5
Zhongzheng										
The day of LF test	7.5 (2.5)	19.2	1.9 (0.6)	3.9	24.2 (8.2)	76.8	79.9 (19.3)	121	43.2 (12.7)	76.7
1 d before LF test	5.4 (2.3)	9.2	1.2 (0.3)	2.8	30.5 (11.2)	89.0	75.8 (25.7)	117	38.3 (9.2)	82.2
2 d before LF test	5.6 (1.2)	12.3	1.3 (0.2)	2.0	27.9 (12.9)	79.6	98.3 (26.5)	158	40.7 (6.0)	63.4
Wanhua										
The day of LF test	5.2 (4.2)	6.8	1.2 (0.2)	2.2	17.6 (13.5)	92.2	57.4 (53.0)	200	38.7 (8.7)	76.4
1 d before LF test	4.3 (2.6)	7.5	1.2 (0.5)	3.5	24.0 (15.7)	95.0	79.9 (50.4)	232	41.5 (21.0)	144.0
2 d before LF test	5.3 (5.7)	10.1	1.2 (0.4)	3	23.0 (9.1)	95.2	47.8 (24.1)	147	34.9 (13.3)	84.6
Shilin										
The day of LF test	4.6 (4.6)	5.9	1.2 (0.8)	3.3	18.6 (10.1)	41.4	51.6 (38.7)	154	35.5 (20.6)	87.2
1 d before LF test	2.1 (2.7)	3.8	0.7 (0.5)	2.8	22.8 (6.6)	72.0	40.9 (32.0)	169	24.5 (15.7)	101.0
2 d before LF test	1.9 (1.8)	5.7	0.6 (0.2)	3.0	25.0 (6.4)	35.2	35.3 (17.0)	125	16.2 (7.8)	46.2

[a] LF: lung function.

Table 3
Distributions of age, gender, height, weight, and lung function of students by living districts.

Variables	Songshan	Zhongshan	Zhongzheng	Wanhua	Shilin	Total
N	573	227	555	654	910	2919
Gender						
Male	54.8%	50.7%	51.5%	54.0%	51.0%	52.5%
Female	45.2%	49.3%	48.5%	46.0%	49.0%	47.5%
Age, years						
⩽13	15.0%	25.0%	27.8%	26.9%	24.4%	23.8%
14	31.7%	38.2%	31.9%	31.7%	33.5%	33.4%
⩾15	53.3%	36.8%	40.3%	41.4%	42.1%	42.8%
Height (cm)[a]	161.4 (161.1, 161.7)	160.6 (160.3, 160.9)	161.6 (161.3, 161.9)	160.4 (160.1, 160.7)	160.8 (160.5, 161.1)	161.0 (160.7, 161.3)
Weight (kg)[a]	53.6 (53.2, 54.0)	53.2 (52.8, 53.6)	55.0 (54.6, 55.4)	53.4 (53.0, 53.8)	53.7 (53.3, 54.1)	53.8 (53.4, 54.2)
Lung function[a]						
FVC (L)	3.30 (3.27, 3.33)	3.35 (3.32, 3.38)	3.33 (3.30, 3.36)	3.23 (3.20, 3.26)	3.18 (3.16, 3.20)	3.26 (3.23, 3.29)
FEV_1 (L)	3.03 (3.01, 3.05)	3.09 (3.07, 3.11)	3.05 (3.03, 3.07)	2.96 (2.94, 2.98)	2.95 (2.93, 2.97)	3.00 (2.98, 3.02)
FEV_1/FVC (%)	92.2 (92.0, 92.4)	92.3 (92.1, 92.5)	92.1 (91.9, 92.3)	91.8 (91.6, 92.0)	93.0 (92.7, 93.3)	92.3 (92.1, 92.5)

[a] Expressed by mean (95% confidence interval).

Among the five districts, students living in Zhongzheng district had the highest average height and weight. Students living in Zhongshan district had the largest mean FVC (3.35 L, 95% CI: 3.32–3.38 L) and mean FEV_1 (3.09 L, 95% CI: 3.07, 3.11 L). Students living in Shilin had the lowest mean FVC (3.18 L, 95% CI: 3.16–3.20 L) and mean FEV_1 (2.95 L, 95% CI: 2.93–2.97 L).

3.3. Association between air pollution and lung function

Table 4 shows coefficients and 95% CI of FVC and FEV_1 associated with the 1-unit change of mean and peak concentrations of each pollutant measured on 0 d of the spirometry test, and 1 d and 2 d before the spirometry test, after controlling for sex, age, height, weight, area, temperature and rainfall. Both FVC and FEV_1 were more likely to be associated with most pollutants exposed 1-d before the lung function test than to be associated with the 0-d exposure, and exposure measured 2 d before the spirometry test. The mean CO concentration exposed 1-d before the lung function test had a significant association with FVC and FEV_1; 1-ppm of CO increase was associated with the reduction in FVC for 69.8 mL (95% CI: −115, −24.4 mL) or in FEV_1 for 73.7 mL (95% CI: −118, −29.7 mL). FVC and FEV_1 were also significantly associated with the 1-d lag exposure of SO_2. FVC was associated with the O_3 exposure, stronger by daytime average levels than daytime peak levels. The association between FEV_1 and O_3 was significant only on the peak level exposed 1 d before the lung function test.

4. Discussion

The analyses of regression model showed that the reduction in lung function was significantly associated with the exposure to air pollution after controlling for personal attributes and meteorological factors. During the 0 d of lung function test; although the change of FVC was small, adolescents' FVC had significant negative association with O_3 (−2.12 mL, 95% CI: −4.07, −1.76 mL) and PM_{10} (−0.63 mL, 95% CI: −1.24, −0.13 mL). However, FEV_1 also had such an association with PM_{10} but not with O_3. Most longitudinal studies for school children had shown an adverse effect of exposure to PM_{10} or $PM_{2.5}$ on the growth of lung function (Gauderman et al., 2000; Christian et al., 2003; Gauderman et al., 2004; Rojas-Martinez

Table 4
Regression coefficients of FVC and FEV_1 associated with average and peak concentrations of air pollutants[a] on lung function test day, and 1 d and 2 d before lung function test.

Air pollutants	Day lag before lung function test	FVC (mL)		FEV_1 (mL)	
		Coefficient	(95% CI[b])	Coefficient	(95% CI[b])
SO_2 (ppb)					
Daytime average[c]	0 d	0.55	(−2.89, 3.93)	0.04	(−3.22, 3.30)
	1 d	−12.9	(−20.7, −5.09)*	−11.73	(−19.3, −4.16)*
	2 d	3.28	(−3.68, 10.2)	2.12	(−4.70, 8.94)
Daytime peak	0 d	0.63	(−1.89, 3.15)	0.36	(−2.08, 2.79)
	1 d	−8.96	(−13.5, −4.40)*	−8.48	(−12.9, −4.06)*
	2 d	2.88	(−0.52, 6.28)	2.54	(−0.79, 5.86)
CO (ppm)					
Daytime average	0 d	−11.9	(−39.9, 16.2)	−20.87	(−47.9, 6.20)
	1 d	−69.8	(−115.3, −24.4)*	−73.69	(−117.7, −29.7)*
	2 d	57.6	(−8.12, 123.4)	42.7	(−21.4, 106.8)
Daytime peak	0 d	0.47	(−18.8, 19.7)	−8.41	(−27.0, 10.2)
	1 d	−30.3	(−54.9, −5.75)*	−35.08	(−58.8, −11.3)*
	2 d	13.1	(−13.9, 40.1)	10.99	(−15.3, 37.2)
O_3 (ppb)					
Daytime average	0 d	−2.12	(−4.07, −1.76)*	−1.49	(−3.38, 0.39)
	1 d	−2.22	(−4.50, −0.06)*	−1.99	(−4.20, 0.22)
	2 d	−2.29	(−4.43, −0.15)*	−1.65	(−3.72, 0.43)
Daytime peak	0 d	−1.03	(−2.03, −0.01)*	−0.93	(−1.91, 0.05)
	1 d	−1.98	(−3.43, −0.53)*	−2.14	(−3.54, −0.73)*
	2 d	−0.76	(−2.25, 0.72)	−0.36	(−1.80, 1.07)
PM_{10} ($\mu g/m^3$)					
Daytime average	0 d	−0.63	(−1.24, −0.13)*	−0.76	(−1.35, −0.17)*
	1 d	−1.01	(−1.68, −0.34)*	−1.13	(−1.78, −0.49)*
	2 d	0.32	(−0.48, 1.13)	0.21	(−0.56, 0.98)
Daytime peak	0 d	−0.35	(−0.80, 0.09)	−0.48	(−0.90, −0.05)*
	1 d	−0.67	(−1.12, −0.23)*	−0.79	(−1.22, −0.36)*
	2 d	0.24	(−3.37, 0.84)	0.16	(−0.41, 0.74)
NO_2 (ppb)					
Daytime average	0 d	−0.33	(−1.45, 0.79)	−0.83	(−1.91, 0.25)
	1 d	−1.60	(−2.82, −0.39)*	−1.63	(−2.81, −0.46)*
	2 d	−0.3	(−2.27, 1.67)	−0.1	(−2.01, 1.81)
Daytime peak	0 d	−0.11	(−0.79, 0.57)	−0.32	(−0.98, 0.34)
	1 d	−0.96	(−1.59, −0.33)*	−0.96	(−1.57, −0.35)*
	2 d	−0.59	(−1.68, 0.50)	−0.20	(−1.26, 0.86)

[a] Values adjusted for sex, age, height, weight, area, temperature, and rainfall.
[b] 95% Confidence interval; *$p < 0.05$.
[c] Daytime on lung function test day was from 8:00 am to 12:00 pm; daytime before lung function test day was from 8:00 am to 6:00 pm.

et al., 2007). Exposure to particulate matter might need a long-term period to induce the adverse effect in lung function. In our cross-sectional study, the association between lung function performance and the short-term effect of PM_{10} is less strong. In this study, we found FVC also had significant negative association with 1-d lag and with 2-d lag exposure of O_3. Spektor et al. (1988) reported that 1 ppb increase in O_3 is associated with decreased FVC for 1.03 mL and FEV_1 for 1.42 mL among 91 summer camp children. Several studies have provided evidence that exposure to O_3 reduced FVC and FEV_1 after controlling the cofounders (Chen et al., 1999; Gauderman et al., 2000; Gauderman et al., 2004; Rojas-Martinez et al., 2007; Barraza-Villarreal et al., 2008). In our study, exposure to O_3 showed a negative relationship stronger than Spektor et al. (1988) had found.

In this study, FVC was negatively associated with more pollutants measured 1-d before the lung function test, including mean concentrations of SO_2, O_3, NO_2, PM_{10} and CO ($p < 0.05$). The association also existed between FEV_1 and these air pollutants with 1-d lag, except O_3. The major pollutants with 1-d lag association with FVC and FEV_1 were CO and SO_2. In Taipei, a heavy traffic city, CO is the most abundant content among all pollutants. In our study, increasing 1 ppm CO with 1-d lag reduced in FVC for 69.81 mL and in FEV_1 for 73.69 mL. In a previous study, Chen et al. (1999) found that the daytime average CO level had a significant 2-d lag effect on FVC for children in primary school. Exposure to CO have been associated with wheeze of children at high risk of developing asthma or atopy (Rodriguez et al., 2007). In a panel study of 19 adult asthmatics in Italy, significant negative associations were observed between morning and evening peak expiratory flow (PEF) and CO ($p = 0.01$–0.03); an increment of 1 mg/m^3 CO was associated with a PEF variation ranging −2.6, −2.8%. A similar trend was observed for FEV_1, but the associations were non-significant (Canova et al., 2010).

Besides, the increase of 1 ppb SO_2 reduced FVC for 12.9 mL (95% CI: −20.7, −5.09 mL) and in FEV_1 for −11.7 mL (95%CI: −19.3, −4.16 mL). SO_2 is an irritant to the upper airway that suppresses lung function. In a European cohort study with 3337 adults, FEV_1 decreased for 4.3% for people living in areas with high SO_2 concentrations (peaked > 380 $\mu g/m^3$) after a 12-year follow-up (van der Lende et al., 1981). Christian et al. (2003) reported that the growth rate of FVC increased 4.9% when SO_2 concentration decreased 100 $\mu g/m^3$ ($p = 0.029$). Our results showed that the short term exposure of SO_2 has a significant negative association with the lung function of adolescents, even if the exposed daily average concentration is low considering the criteria of 24-h average of 100 ppb in Taiwan. SO_2 is an important indicator of air pollution in areas with heavy traffic. SO_2 is an important indicator of air pollution in areas with heavy traffic.

The association between short-term exposure to NO_2 and the reduction in lung function in this study was similar to results of other studies. For example, FEV_1 of children had a negative effect for exposure to NO_2 (Moshammer et al., 2006); the growths of FEV_1, FVC, and $FVC_{25-75\%}$ of adolescents were significantly lowered after exposure to NO_2 (Gauderman et al., 2004). An increase of 12 ppb NO_2 might cause an annual deficit of FEV_1 for 30 mL in girls and 25 mL in boys living in Mexico City (Rojas-Martinez et al., 2007). In a critical review, Hesterberg et al. (2009) acknowledged that there are generally no adverse pulmonary effects for short-term NO_2 exposure of less than 1 ppm NO_2 for healthy individuals. However, they found adverse effects for susceptible populations exposed to 0.2–0.6 ppm NO_2. The peak NO_2 concentrations ranged from 46.2 to 144.0 ppb in our study. Brook et al. (2007) suspected that NO_2 might be a surrogate marker for adverse health effects of other components such as volatile organic compounds, aldehydes, peroxyacetyl nitrate, particle nitrate and gas, and particle phase organic nitrates, and particle-bound organics in motor vehicle exhaust. The adverse health effect of low-dose NO_2 might not be associated with the single effect of NO_2 but with mixtures of traffic-related pollution.

This population-based study used government-provided air pollution data collected from fixed air monitoring stations instead of personal exposure data. The strength of this study is we have covered a large number of study subjects and data. This makes it possible to even find very small effects. However, several other factors may also associate with lung function. Whether the small effects are clinically meaningful deserve further study. Ito et al. (2001) stated that air-monitoring data could be a reasonable surrogate measure of exposure to pollutants for the general population. Junior high schools had few air-conditioners in classrooms; indoor exposure to air pollutants was likely similar to outdoor air. In this study, we used air pollution data measured from 8:00 to 12:00 am in the lung function test day and used air pollution data measured from 8:00 am to 6:00 pm in 1-d and 2-d lag to match the time children were in schools and had their lung function tested. Schoolchildren spent about 10 h in school and they might be at home or in other places the rest of the time. Real exposure to air pollution among children might be underestimated in this study.

5. Conclusions

The lung function data measured for a large sample allowed us to evaluate changes in respiratory volumes with good statistical power. Results of this cross-sectional study had demonstrated that even below the national ambient air pollution quality criteria, 0-d short term exposure to PM_{10} and O_3 was significantly associated with reductions in lung function based on measures of FVC and FEV_1. Adolescent lung function was also negatively associated with 1-d lag effect from exposure to SO_2, O_3, NO_2, PM_{10} and CO as well and the major pollutants were CO and SO_2.

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References

American Thoracic Society, 1987. Standardization of spirometry: 1987 update. Am. Rev. Respir. Dis. vol. 136, pp. 1285–1298.

Barraza-Villarreal, A., Sunyer, J., Hernandez-Cadena, L., Escamilla-Nuñez, M.C., Sienra-Monge, J.J., Ramírez-Aguilar, M., Cortez-Lugo, M., Holguin, F., Diaz-Sánchez, D., Olin, A.C., Romieu, I., 2008. Air pollution, airway inflammation, and lung function in a cohort study of Mexico city schoolchildren. Environ. Health Perspect. 116, 832–838.

Brook, J.R., Burnett, R.T., Dann, T.F., Cakmak, S., Goldberg, M.S., Fan, X., Wheeler, A.J., 2007. Further interpretation of the acute effect of nitrogen dioxide observed in Canadian time-series studies. J. Expo. Sci. Environ. Epidemiol. 17, S36–S44.

Chen, P.C., Lai, Y.M., Chan, C.C., Hwang, J.S., Yang, C.Y., Wang, J.D., 1999. Short-term effect of ozone on the pulmonary function of children in primary school. Environ. Health Perspec. 107, 921–925.

Christian, F., Bernd, H., Josef, C., Matthias, W., Wichmann, H.E., Joachim, H., 2003. Association of lung function with decline ambient air pollution. Environ. Health Perspect. 111, 383–387.

Canova, C., Torresan, S., Simonato, L., Scapellato, M.L., Tessari, R., Visentin, A., Lotti, M., Maestrelli, P., 2010. Carbon monoxide pollution is associated with decreased lung function in asthmatic adults. Eur. Respir J. 35, 266–272.

Department of Health, Executive Yuan, Taiwan. 1999. Health Statistics. Department of Health Press, Taipei, Taiwan.

Gauderman, W.J., McConnell, R., Gilliland, F., London, S., Thomas, D., Avol, E., Vora, H., Berhane, K., Rappaport, E.B., Lurmann, F., Margolis, H.G., Peters, J., 2000. Association between air pollution and lung function growth in southern California Children. Am. J. Respir. Crit. Care Med. 162, 1383–1390.

Gauderman, W.J., Avol, E., Gilliland, F., Vora, H., Thomas, D., Berhane, K., McConnell, R., Kuenzli, N., Lurmann, F., Rappaport, E., Margolis, H., Bates, D., Peters, J., 2004. The effect of air pollution on lung development from 10 to 18 Years of age. N. Engl. J. Med. 351, 1057–1067.

Hesterberg, T.W., Bunn, W.B., McClellan, R.O., Hamade, A.K., Long, C.M., Valberg, P.A., 2009. Critical review of the human data on short-term nitrogen dioxide (NO_2) exposures: evidence for NO_2 no-effect levels. Crit. Rev. Toxicol. 39, 743–781.

Ito, K., Thurston, G.D., Nadas, A., Lippmann, M., 2001. Monitor-to-monitor temporal correlation of air pollution and weather variables in the North-Central US. J. Expo. Sci. Environ. Epidemiol 11, 21–32.

Jedrychowski, W., Flak, E., Mróz, E., 1999. The adverse effect of low levels of ambient air pollutants on lung function growth in preadolescent children. Environ. Health Perspect. 107, 669–674.

Langkulsen, U., Jinsart, W., Karita, K., Yano, E., 2006. Respiratory symptoms and lung function in Bangkok school children. Eur. J. Public Health 16, 676–681.

Lin, R.S., Sung, F.C., Huang, S.L., Gou, Y.L., Ko, Y.C., Gou, H.W., Shaw, C.K., 2001. Role of urbanization and air pollution in adolescent asthma: a mass screening in Taiwan. J. Formos. Med. Assoc. 100, 649–655.

Liu, L., Zhang, J., 2009. Ambient air pollution and children's lung function in China. Environ. Int. 35, 178–186.

Moshammer, H., Hutter, H.P., Hauck, H., Neuberger, M., 2006. Low levels of air pollution induce changes of lung function in a panel of schoolchildren. Eur. Respir. J. 27, 1138–1143.

Rodriguez, C., Tonkin, R., Heyworth, J., Kusel, M., De Klerk, N., Sly, P.D., Franklin, P., Runnion, T., Blockley, A., Landau, L., Hinwood, A.L., 2007. The relationship between outdoor air quality and respiratory symptoms in young children. Int. J. Environ. Health Res. 17, 351–360.

Rojas-Martinez, R., Perez-Padilla, R., Olaiz-Fernandez, G., Mendoza-Alvarado, L., Moreno-Macias, H., Fortoul, T., McDonnell, W., Loomis, D., Romieu, I., 2007. Lung function growth in children with long-term exposure to air pollutants in Mexico City. Am. J. Respir. Crit. Care. Med. 176, 377–384.

Spektor, D.M., Lippmann, M., Lioy, P.J., Thurston, G.D., Citak, K., James, D.J., Bock, N., Speizer, F.E., Hayes, C., 1988. Effects of ambient ozone on respiratory function in active, normal children. Am. Rev. Respir. Dis. 137, 313–320.

Tager, I.B., 1999. Air pollution and lung function growth: is it ozone? Am. Respirat. Crit. Care Med. 160, 387–389.

Taiwan Air Quality Monitoring Network, 2011. TAQMN Site. <http://taqm.epa.gov.tw/taqm/en/b0101.aspx> (26.07.11).

van der Lende, R., Kok, T.J., Reig, R.P., Quanjer, P.H., Schouten, J.P., Orie, N.G., 1981. Decreases in VC and FEV_1 with time: indicators for effects of smoking and air pollution. Bull. Eur. Physiopathol. Respir. 17, 775–792.

Wardlaw, A.J., 1993. The role of air pollution in asthma. Clin. Exp. Allergy 23, 81–96.

Yang, Q., Chen, Y., Krewski, D., Burnett, R.T., Shi, Y., McGrail, K.M., 2005. Effect of short-term exposure to low levels of gaseous pollutants on chronic obstructive pulmonary disease hospitalizations. Environ. Res. 99, 99–105.