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Effects of Heavy Industrial Pollution on Respiratory Function in the Children of Cubatao, Brazil: A Preliminary Report

by Dalia M. Spektor,* Vera A. Hofmeister,† Paulo Artaxo,‡ Jose A. P. Bragueˆ,† Francisco Echelar,‡ Diogo P. Nogueira,† Carl Hayes,§ George D. Thurston,* and Morton Lippmann*

Under a cooperative agreement between New York University and the Environmental Protection Agency, and in collaboration with the University of Sao Paulo (USP), a study is ongoing in Cubatao, Brazil, to try to establish exposure-response relationships on the impact of specific industrial effluents on respiratory function in school-age children. Cubatao, located on the coast about 44 km from the city of Sao Paulo, is surrounded by U-shaped mountains (~ 800 m) covered with subtropical forests. Its area is ~ 160 km², and it has a population of ~ 90,000. The geography is such that it causes a consistent diurnal land-sea breeze pattern and the opposite during the night, with low dispersion of the air pollutants. In a small area (~ 40 km²) against the mountains there is a concentration of over 20 large plants: oil refinery; iron and steel mill; fertilizer, cement, and gypsum production; coke kilns; and chemical, paint, and many other ancillary plants. During the 1988 school year, March through June, August through November, 600 six-year-old children, attending six different kindergarten schools, underwent monthly spirometry tests. Because the children live within a 500 m radius of their school, pollution monitors were located on each of the six schools. Particles were collected using dichotomous stacked filter units placed on 20 m towers to reduce the influence of dust from unpaved roads. The units use different pore size filters for coarse, 2 to 10 μm, and fine particles, (dp) < 2 μm, and took separate samples for day and nighttime. Three sites are in the densely populated downtown area, one is on a newly developed outskirt area, and the last two are residential areas, far from industries, up on the side of the surrounding hills (elevations, 95 and 200 m). The yearly average thoracic aerosol mass concentration (PM_{10}) is very high on all sites, ranging from 59 ± 39 μm/m³ to 240 ± 122 μm/m³, the number of days with mean PM_{10} > 100 μm/m³ range from 27 to 98% depending on neighborhood. There has not been a significant reduction of ambient PM_{10} concentrations since 1985, when previous studies by USP showed grossly abnormal lung function in kindergarten children. The initial analyses on the current study show that respiratory airflow rates are significantly associated with PM_{10} concentrations during the previous month.

Introduction

Cubatao, Brazil, has been affected for many years by very serious pollution problems due to a combination of unfavorable topography, enormous industrial emissions, lack of urban planning, etc. The area of Cubatao, 162 km², with 107,000 inhabitants, is located about 44 km from Sao Paulo on the Tropic of Capricorn. This region extends parallel to the South Atlantic coastline, and it is surrounded on three sides by hills and mountains covered by a tropical forest of the Atlantic humid type. The mountains run parallel to the coastline (SW–NE), reaching heights of 700 to 1000 m above sea level. Inside this region there are some low, isolated hills and rivers and a very irregular distribution of industrial and residential centers.

The wind patterns in the Cubatao area are strongly influenced by the local topography. The behavior of draining winds depend on the time of day, solar incidence, and angle. The draining winds start after sunset, but strong winds from the Mogi Valley merging with NE winds of about 6 km/hr from the Quilombo Valley tend to carry the emissions back to the Vila Parisi area (Fig. 1). Fertilizer plant emissions from Cubatao Centro (downtown Cubatao) have been observed deep in the Mogi Valley. In winter mornings, there are layers of thermal inversions of different depths and varied intensities. Emissions estimates, based on the industrial processes from 21 sources in the area of Cubatao (11 chemical and petrochemical industries, 7 fertilizer plants, 1 nonmetallic mineral plant, 1 paper mill, and 1 cement plant) yielded, for 1988, 25,500 tons of particulate matter, 17,800

*Institute of Environmental Medicine, New York University Medical Center, 550 First Avenue, New York, NY 10016.
†School of Public Health, University of Sao Paulo, Sao Paulo, Brazil.
‡Physics Department, University of Sao Paulo, Sao Paulo, Brazil.
§U.S. Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, NC 27711.
Address reprint requests to D. M. Spektor, Institute of Environmental Medicine, New York University Medical Center, 550 First Avenue, New York, NY 10012.

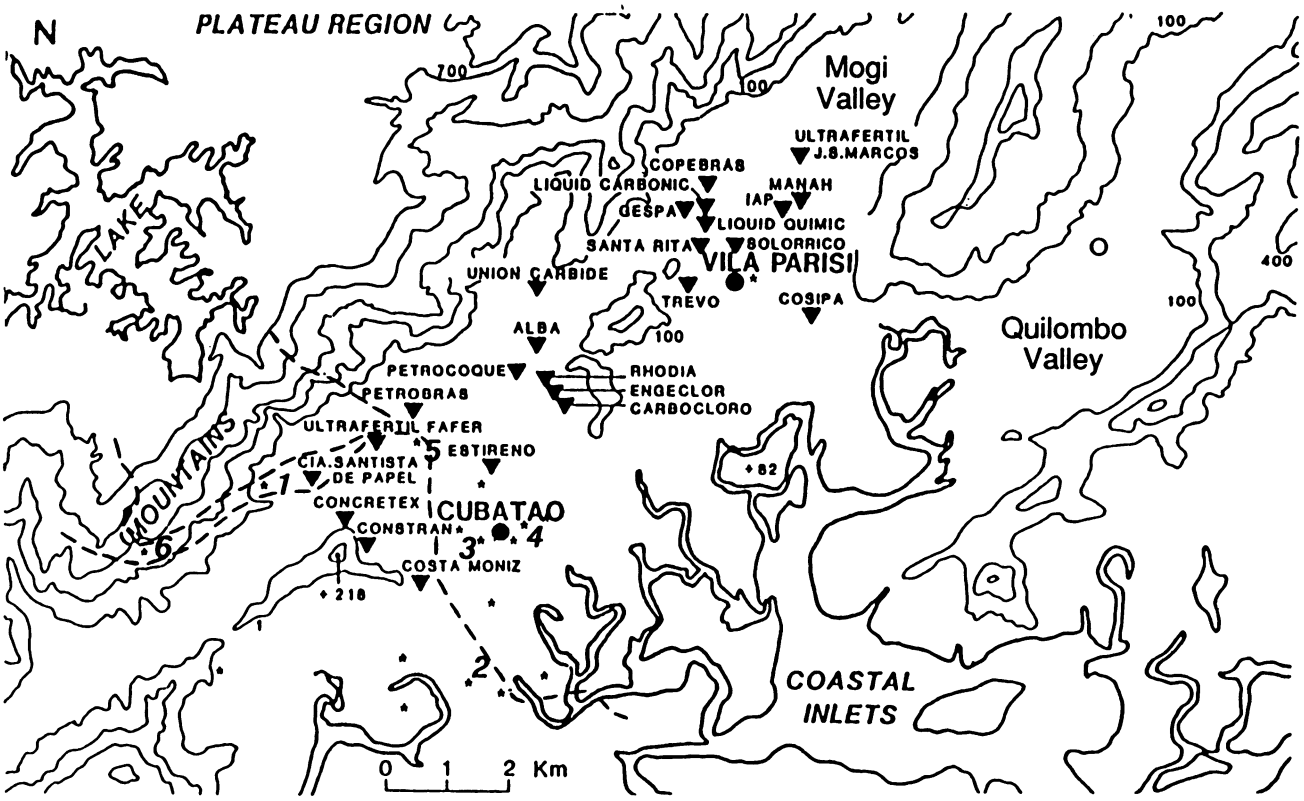

FIGURE 1. Map of Cubatao, its industries, and kindergarten schools. (1) Cota 95; (2) Nova Republica; (3) Vila Nova; (4) Jardim das Industrias; (5) Vila Elizabeth; (6) Cota 200.

tons of sulfur dioxides (SO_2), 18,800 tons of nitrogen oxides (NO_x), 70 tons of fluorides, and 7,200 tons of hydrocarbons (*1*).

The residential areas of Cubatao are intermingled with the industrial plants, commonly within 100 to 1000 m. The houses are extremely well ventilated, and cooking is done with liquified gas. While a large percentage of the adults smoke, the children's pollution exposure is essentially determined by the emissions from the nearest industrial plants. Children of 6 years of age attend kindergarten schools within a 500 m radius of their home, and in almost all cases have lived at the same address all their lives.

Hofmeister and Fischer (*2*) conducted a preliminary study in the summer of 1983 on 480 kindergarten children attending 11 schools and again in the winter of 1985 on 630 kindergarten children attending 16 schools in order to investigate the prevalence of impairment in lung function indices after living in the different neighborhoods of Cubatao for most of their lives. Each child performed standard spirometric tests, and their results were compared to Polgar's (*3*) predicted values. Air pollution levels were monitored continuously, for SO_2 and thoracic aerosol mass concentration (PM_{10}) by the state agency CETESB (Companhia de Technologia de Saneamento Ambiental) at two locations: Cubatao Centro (downtown, which is mostly residential; and Vila Parisi, surrounded by fertilizer, cement, and steel mill plants. The daily maximum and mean values of PM_{10}, SO_2, and ozone (O_3) for 1983 to 1988, as released by CETESB, are listed in Table 1. The measured forced vital capacity, forced expiratory volume in 1 sec, peak expiratory flow rate, and forced expiratory flow between 25 and 75% of FVC (FVC, FEV_1, PEFR, and FEF_{25-75}, respectively) as a percent of their predicted values showed significant differences among schools. Table 2 gives a summary of the mean PEFR values measured in 1983 and 1985 for the kindergarten children that attended the same schools as in the present study. In the 1983 study, the worst values were attained by the children of School No. 6 located near the petrochemical and styrene plants, at Cota 200. Low values were also measured in a school located near an important highway and a refinery, Vila Elizabeth, School No. 5. Other schools, based at greater distances from industries, showed less lung impairment.

As part of a broad cooperative study between New York University Medical Center's Institute of Environmental Medicine and the University of Sao Paulo's School of Public Health and Institute of Physics, a new cohort of 600 6-year-old children attending their neighborhood kindergarten school were recruited in March 1988. Simultaneously, six new air sampling stations were installed by us to gather more comprehensive air pollution data at five kindergarten schools and at a strong source area (Vila

Table 1. Annual average values of PM_{10}, SO_2, and O_3.

Location	1983 PM_{10}, $\mu m/m^3$	1983 SO_2, $\mu m/m^3$	1983 O_3	1985 PM_{10}, $\mu m/m^3$	1985 SO_2, $\mu m/m^3$	1985 O_3	1988 PM_{10}, $\mu m/m^3$	1988 SO_2, $\mu m/m^3$	1988 O_3
Centro	98	47	—	43	31	42[a]	64	11	21[a]
Vila Nova	—	—	—	69	10	10[a]	73	10	29[a]
Vila Parisi	117	47	—	140	37	—	104	14	—

[a]Number of hours above 100 ppb O_3.

Table 2. Distribution of PEFR averaged by school for 1983 and 1985.[a]

School location	School no.	1983 Normal, %	1983 Abnormal, %	1985 Normal, %	1985 Abnormal, %
Cota 95	1	—	—	49	51*
Vila Nova	3	—	—	80	20
Jardim das Industrias	4	51	49	52	48
Vila Elizabeth	5	19	81	68	32
Cota 200	6	21	79	63	37

[a]Abnormal refers to values less than 55% of Polgar's (*3*) predicted values. From Hofmeister and Fischer (*2*).

*Statistically different between schools and between year results ($p < 0.001$).

Parisi). For one school, in the Cubatao Centro region, we relied on pollution measurements made by CETESB at their Cubatao Centro site.

Methods

Schools were selected by location, some close and some far from industries, to have a range and variety of pollution levels and, at the same time having similarities in socioeconomic levels. As shown in Figure 1, Cota 95 (at 95 m) and Cota 200 (at 200 m) are residential areas located in the Atlantic forest relatively far from industries but within the thermal inversion layer. Nova Republica is a new residential area in the south, developed to house the ex-residents of the extremely polluted Vila Parisi. Jardim das Industria, Vila Elizabeth, and Vila Nova are residential areas within the industrial complex in the central area of Cubatao.

Air Sampling Measurements

Aerosols were collected at six sampling stations from May to November. Five sampling sites were located at kindergarten schools attended by the children in the new cohort. The sixth sampling site was located in the highly polluted neighborhood of Vila Parisi next one of the CETESB stations to allow for cross-comparisons of results. The Vila Parisi and Jardim das Industrias samplers were located in a tower about 20 m tall to reduce the contribution of soil dust aerosols from the unpaved roads in the area; the other sites, Vila Nova, Nova Republica, Cota 95, and Cota 200, were sampled at about 3 m height. The CETESB Cubatao Centro sampler was used to represent exposures at Vila Elizabeth. Due to wind pattern, day and night samples were collected separately; daytime samples from 7 A.M. to 7 P.M. and nighttime samples from 7 P.M. to 7 A.M. Aerosol particles were collected using stacked filter units (SFU) (*4*) at flow rates between 3 and 6 L/min, coarse particles ($2\ \mu m < dp < 10\ \mu m$; dp = particle diameter) were collected on Nucleopore 8-μm pore size, 47-mm diameter filters, and fine particles ($dp < 2\ \mu m$) were sampled on 0.4 μm Nucleopore filters. A total of 710 SFU samples were collected. The fine and coarse aerosol mass concentrations were obtained by gravimetric analysis. The filters were weighed before and after sampling with a Mettler M3 electronic microbalance with a 1-μg sensitivity. Before weighing, the filters were equilibrated for 24 hr at 20°C and 50% relative humidity. Electrostatic charges were controlled by ^{210}Po sources.

Lung Function Measurements

The children, 55% boys and 45% girls, performed standard spirometric maneuvers on a Vitalograph spirometer until they had three acceptable performances. Spirograms were read by two independent observers and the results stored in computer files. Testing was performed monthly from March to November, the standard school year in the southern hemisphere, except for the month of July, when schools close for their winter recess. Each child's height and weight was recorded every month. Each child's monthly measurement was performed between 28 and 32 days from the previous one. The children's collaboration was excellent, 456 children had at least 6 measurements, of a possible 8 yielding a compliance rate of 76%.

All children's homes were visited by an interviewer who completed a questionnaire on the medical history of the child and on the habitational characteristics and working, residence, and smoking history of the household members.

Results

Aerosol Concentrations

The average PM_{10} or thoracic aerosol mass concentration was very high for all sampling sites. Figure 2 presents the yearly average fine, coarse, and thoracic aerosol mass concentrations at the six sites. At the nonresidential Vila Parisi, the average PM_{10} was $240 \pm 122\ \mu g/m^3$. All sampling stations, even the ones relatively far from industries like Cota 95 and Cota 200, were well above the United States PM_{10} annual average standard of 50 $\mu g/m^3$; their values were 70.38 $\mu g/m^3$ and 58.96 $\mu g/m^3$, respectively.

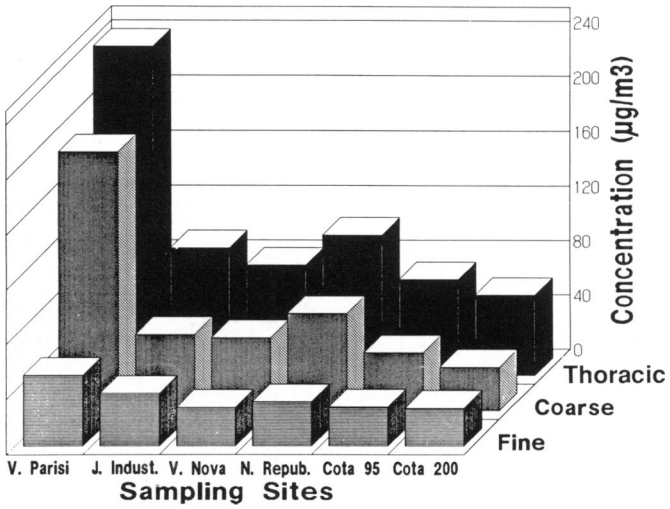

FIGURE 2. Yearly average fine, coarse, and PM_{10} aerosol mass concentrations at the six sites.

Table 3. Average regression slopes of lung function on PM_{10}.

School location	School no.	Children, n	FVC, mL/μg/m^3	FEV_1, mL/μg/m^3	PEFR, mL/sec/μg/m^3	FEF_{25-75}, mL/sec/μg/m^3
Cota 95	1	110	0.11	−0.35*	−2.04*	−1.05*
Nova Republica	2	68	−0.32	−0.62*	−2.62*	−3.14*
Vila Nova	3	85	−0.08	−0.33*	−2.53*	−1.76*
Jardim Das Industrias	4	74	−0.16	−0.55*	−1.53*	−2.44*
Vila Elizabeth	5	21	−0.25	−0.48	−2.61*	−1.32*
Cota 200	6	98	−0.23	−0.38*	−1.23*	−1.59*

*Statistically significant ($p < 0.05$).

Regressions of Spirometric Measurements on PM_{10}

The initial analysis of the lung function data was performed as individual regressions of each of the child's respiratory indices. FVC, FEV_1, PEFR, and FEF_{25-75} were regressed on the previous month's average PM_{10} concentration as measured at their school site. There were statistically significant ($p < 0.001$) group average negative slopes for the regression of FEV_1, PEFR, and FEF_{25-75} on the mean PM_{10} for the month prior to the measurement.

Table 3 displays the average slopes for the regression of FVC, FEV_1, PEFR, and FEF_{25-75} on the mean PM_{10} for the previous month grouped by school. These results show statistically significant correlation for PEFR and FEF_{25-75} at all locations. Significant FEV_1 correlations were seen at all but the Vila Elizabeth school. The mean decrement in FEV_1 associated with PM_{10} was similar at this school to those at the others, but there were only 21 students, far fewer than at the other schools.

Discussion

The preliminary results of this study suggest that cumulative monthly exposure to nonspecific thoracic mass concentration reduces lung airway flow rate. The average yearly PM_{10} concentrations ranged from 59 μg/m^3 in Cota 200 to 110 μg/m^3 in the Nova Republica neighborhood, but there was no evidence for a threshold in that the decrement per unit mass concentration was similar for the less exposed and more heavily exposed regions.

The school cohort showing the largest decrements in FEF_{25-75} is the one located in Nova Republica. This is the school attended by the children that lived in Vila Parisi before being relocated within the previous few years. These children had been exposed in Vila Parisi to PM_{10} concentrations about twice those in their present location. High exposures in the past may predispose them to greater transient changes in FEF_{25-75} as PM_{10} concentrations rise.

Additional analyses are currently in progress to examine the effects of chronic pollution exposure on lung growth rates and to determine whether specific constituents of the particulate matter have disproportionate effects on lung function.

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