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Respiratory Health and PM_{10} Pollution

A Daily Time Series Analysis[1-3]

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SUMMARY This study evaluated changes in respiratory health associated with daily changes in fine particulate pollution (PM_{10}). Participants included a relatively healthy school-based sample of fourth and fifth grade elementary students, and a sample of patients with asthma 8 to 72 yr of age. Elevated PM_{10} pollution levels of 150 $\mu g/m^3$ were associated with an approximately 3 to 6% decline in lung function as measured by peak expiratory flow (PEF). Current day and daily lagged associations between PM_{10} levels and PEF were observed. Elevated levels of PM_{10} pollution also were associated with increases in reported symptoms of respiratory disease and use of asthma medication. Associations between compromised respiratory health and elevated PM_{10} pollution were observed even when PM_{10} levels were well below the 24-h national ambient air quality standard of 150 $\mu g/m^3$. Associations between elevated PM_{10} levels, reductions in PEF, and increases in symptoms of respiratory disease and asthma medication use remained statistically significant even when the only pollution episode that exceeded the standard was excluded. Concurrent measurements indicated that little or no strong particle acidity was present. AM REV RESPIR DIS 1991; 144:668–674

Introduction

Many studies have implicated particulate air pollution as contributing to the incidence and severity of respiratory disease (1–15). Decreases in pulmonary function associated with particulate pollution levels have been observed (7, 16, 17). Fine particulate pollution is of specific concern because it contains a higher proportion of various toxic metals and acidic sulfur species (14), and, aerodynamically, it can penetrate deeper into the respiratory system (15).

In recognition of the health risks associated with fine particulate matter, national ambient air quality standards have been set for particulate matter with an aerodynamic diameter (d_a) equal to or less than a nominal 10 µm (PM_{10}). The PM_{10} standards include a 24-h standard of 150 $\mu g/m^3$, with no more than one expected exceedance per year, and an annual PM_{10} standard of an arithmetic mean of less than 50 $\mu g/m^3$ (15).

Utah Valley has experienced high PM_{10} pollution episodes during winter months. These episodes have been associated with multiple violations of the 24-h PM_{10} standard. Therefore, studies specific to Utah Valley have been conducted. Archer (18) compared age-adjusted death rates for malignant and nonmalignant respiratory disease across three Utah counties. It was estimated that 30 to 40% of respiratory cancer and nonmalignant respiratory disease deaths in Utah County may be attributable to air pollution. Recent research also has taken advantage of the intermittent operation of the local steel mill, showing large associations between respiratory hospital admissions, PM_{10} pollution, and the operation of the steel mill (19, 20).

This study investigated changes in lung function as measured by peak expiratory flow (PEF) associated with daily changes in PM_{10} pollution levels in Utah Valley. Because the effects of particulate pollution on lung function may be felt over several days, distributed lag relationships between PM_{10} pollution and PEF were evaluated. Also, possible associations between reported respiratory symptoms, asthma medication use, and PM_{10} pollution were examined.

Methods

Study Area

Utah Valley is a mountain valley situated in north central Utah. In 1990 approximately 188,000 people resided in several contiguous Utah Valley cities including and surrounding Provo and Orem (21). These cities are approximately 1,387 m above sea level and are bordered on the west by a large fresh-water lake and on the east by mountains. Most of the population is crowded into a corridor that is approximately 5 to 9 kilometers wide from the east to the west and 30 km long from the north to the south. The valley has a dry four-season climate with low level temperature inversions common during winter months. During temperature inversions, air pollutants are trapped in the valley floor, often resulting in high concentrations of PM_{10} pollution.

The principal source of PM_{10} pollution is an integrated steel mill built during World War II. The mill is located near the shore of the lake on the west side of the populated corridor, roughly in the center of the valley from north to south. When in operation, the mill emits 50 to 70% of total Utah valley PM_{10} emissions (22).

Subject Selection

Two samples of participants were selected, a school-based sample and a patient-based sample. Participants in the school-based sample were selected from fourth and fifth grade elementary students in three public elementary schools in the immediate vicinity of the PM_{10} monitors in Orem and Lindon, Utah. In November 1989, a questionnaire requesting information about respiratory illnesses and symptoms was sent home with all 701 students to be completed by a parent or guardian and then returned to school. The questionnaire was in a format similar to that recommended by the Epidemiology Standardization Project (23). The questionnaire was completed and returned by 591 children, 84% of the total.

The questionnaire identified 60 children who had a positive response to one or more of three questions: ever wheezed without a cold, wheezed for 3 days or more out of the week for a month or longer, and/or had a doctor say the "child has asthma." These children (just over 10% of the total) were selected as potential participants in the school-based sample. Potential participants in the patient-based sample consisted of 35 Utah valley residents who were receiving medical treatment for asthma and who were referred to the study by local physicians. Twenty-nine of the potential participants could not be contacted, were planning on moving out of the area, or were otherwise unable or unwilling to participate. This left 66, 41 in the school-based sample and 25 in the patient-based sample, as original participants.

Eleven of these 66 participants were not included in the final analysis for various reasons. Two moved out of town during the study period, one produced unreliable readings because of spitting into the peak flow meter, and eight completed less than 55% of days in the study period. Final analysis included a total of 55 subjects — 34 in the school-based sample and 21 in the patient-based sample. On the basis of the responses in the questionnaires, in 38% of the participants in the school-based study asthma had never been diagnosed, but they had "wheezed without a cold"; in 32% asthma had been diagnosed, but they had not been troubled by asthma in the last 12 months; 21% had been troubled by asthma in the last 12 months but did not require medication; and only 9% had asthma that required medication on a routine basis. In contrast, participants in the patient-based sample were all troubled by respiratory problems and generally required asthma medication. Summary information comparing the two samples is provided in table 1.

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TABLE 1

SUMMARY INFORMATION CONCERNING THE SCHOOL-BASED SAMPLE AND THE PATIENT-BASED SAMPLE*

	School-based Sample	Patient-based Sample
Original sample size	41	25
Final sample size	34	21
Original participants, %	83	84
Average number participating on any given study day	29 (2.6)	18 (1.6)
Mean age, yr	10.3 (0.7)	28.7 (21.3)
Youngest	9	8
Oldest	11	72
Mean PEF	260 (51)	320 (110)
Female, %	38	52
Smokers, %	0	0
Lives with parent or spouse that smokes, %	15	5
Use of asthma medication on any given day during the study period, mean %	12	67
Reported using asthma medication during study period, %	29	90

Definition of abbreviation: PEF = peak expiratory flow.

* Standard deviations are provided in parentheses when appropriate.

Materials and Methods

Research protocols were approved by the Brigham Young University institutional review board for human studies. Informed written consent was obtained and peak flow meters, health symptom diaries, and instructions were delivered to homes of participants from December 13 to 17, 1989. Each participant was provided with a mini-Wright peak flow meter (Armstrong Medical Industries Inc., Lincolnshire, IL) and daily health symptom diaries and were instructed on their proper use. Participants reported the following symptoms: trouble breathing; runny or stuffy nose; wet cough; dry cough; wheezing; fever; rash; burning, aching, or red eyes; and upset stomach. They also reported if they stayed home for the day; saw a doctor or a nurse; were hospitalized; took asthma medication on a given day; took extra asthma medication that day; or were out of town overnight.

Participants were instructed to perform the peak flow test three times in the standing position just before bedtime and record the highest reading along with the symptoms experienced that day. Parents were asked to supervise children's compliance with instructions. Participants were assisted in their homes until they demonstrated they could perform the test and record symptoms properly. Participants were instructed that if they forgot a day they should leave it blank and go on to the next day. Participants were revisited approximately 2 wk after the first visit and every month throughout the study period. During these visits participants' performances were observed, any needed retraining or encouragement was given, and the previous month's results were retrieved. Mention of air pollution levels or the steel mill was avoided.

Pollution and Weather Data

PM_{10} monitoring was conducted by the Utah State Department of Health in accordance with Environmental Protection Agency's reference method for monitoring PM_{10} (15). Samples for each 24-h period were collected commencing at midnight. PM_{10} monitoring was conducted at three sites including the Lindon site, approximately 5 km northeast of the steel mill, the Orem site, approximately 1.5 km east of the mill, and the Provo site, approximately 9 km southeast of the mill. PM_{10} levels from all three sites tracked each other very closely throughout the study period (figure 1). Mean PM_{10} levels at the Provo site were approximately 14% lower than at the other two sites. Mean PM_{10} levels at the Lindon and Orem sites were not significantly different ($p < 0.10$) and were strongly linearly correlated ($R^2 = 0.84$). PM_{10} levels from the most centrally located Orem site were used in the analysis of this study, except for 8 days during the study period for which PM_{10} data at the Orem site were not available. For these 8 days data from the Lindon site were used.

During the study period 24-h PM_{10} levels ranged from 11 to 195 $\mu g/m^3$, with an average of approximately 46 $\mu g/m^3$. The 24-h PM_{10} standard of 150 $\mu g/m^3$ was exceeded twice during the study period. Primarily because of favorable weather conditions, PM_{10} levels were lower than in recent winters. Over the past three winters when the steel mill was operating, PM_{10} levels exceeded the 24-h standard 13, 10, and 22 times per winter, and 24-h PM_{10} levels reached as high as 365 $\mu g/m^3$.

Limited monitoring of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) was conducted by the State Bureau of Air Quality. Concentrations of each of these pollutants were well below the ambient air quality standards. During the study period NO_2 levels averaged less than 0.03 ppm (compared with an annual standard of 0.05 ppm), and 24-h NO_2 levels never exceeded 0.07 ppm. No monitoring of SO_2 was conducted by the state during the study period, but monitoring conducted during the preceding winter, when weather conditions resulted in relatively higher pollution concentrations, indicated that SO_2

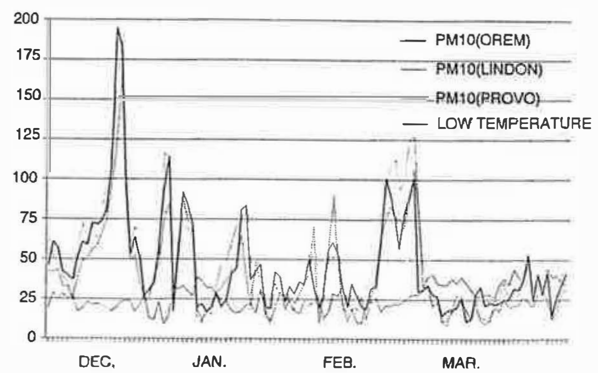

Fig. 1. Low temperature (° F) and PM_{10} levels ($\mu g/m^3$) at the Lindon, Orem, and Provo monitoring sites, December 13, 1989 through March 31, 1990.

concentrations averaged less than 0.01 ppm, and 24-h concentration levels never exceeded 0.02 ppm (compared with the 24-h standard of 0.14 ppm). Monitoring of O_3 was discontinued during winter months because conditions necessary for substantial O_3 formation do not exist during the winter period.

Supplemental 24-h integrated sampling of aerosol strong acidity was conducted daily at the Lindon site between December 28, 1989 and March 19, 1990. A Harvard impactor ($d_a < 2.5$ µm) (Harvard Apparatus, Millis, MA) equipped with an ammonia diffusion denuder to protect the acidic sampler from neutralization was used (24, 25). Strong particle acidity never exceeded the detection limit of 8 nmol/m^3, indicating that particulate acidity was very low and never exceeded the equivalence of 0.5 µg/m^3 H_2SO_4. These low hydrogen ion concentrations are typical of wintertime aerosol acidity reported for St. Louis, Missouri; Portage, Wisconsin; Topeka, Kansas; and Watertown, Massachusetts (26). These measurements do not preclude the possibility that acidic aerosols might be formed during cold winter fog conditions that did not occur during the study period but are common during some winter periods in the study area.

Daily minimum temperatures were obtained from the Brigham Young University weather station, approximately 10 km southeast of the steel mill (figure 1). The study period was unusually warm and dry compared with normal winters in the valley.

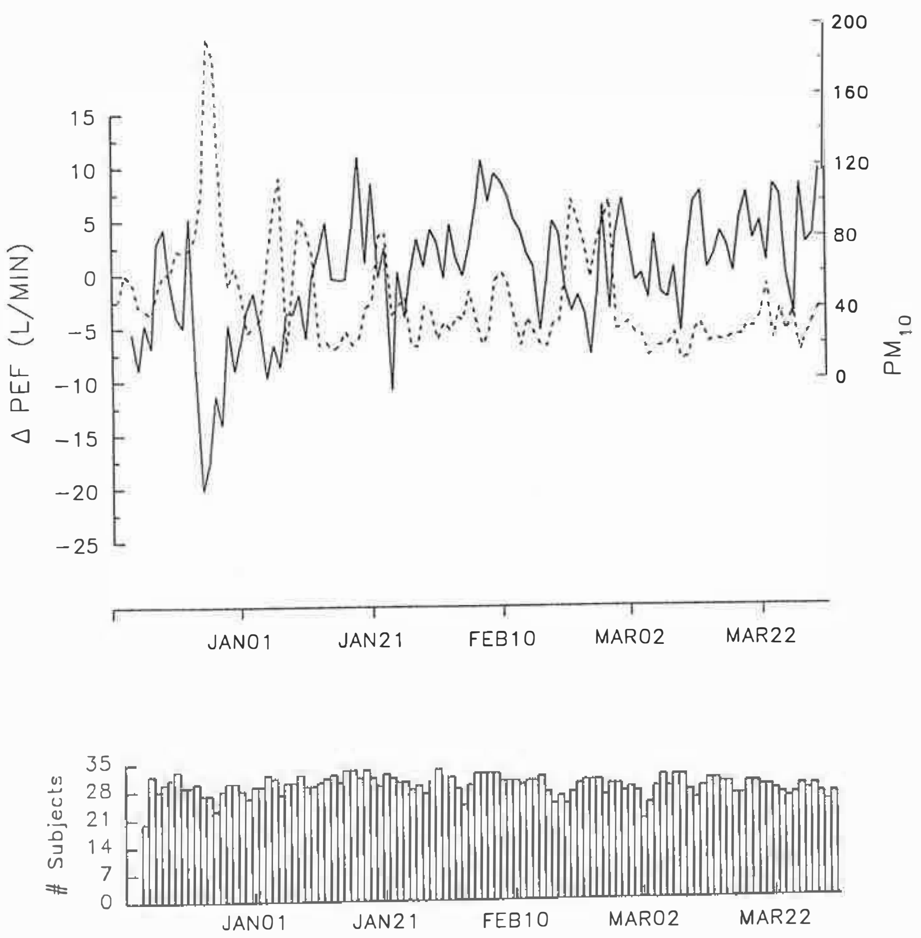

Fig. 2. PM_{10} levels (µg/m^3) *(broken line)* at the Orem monitoring site, mean peak expiratory flow deviations (ΔPEF) *(solid line)*, and daily number of participants. School-based sample, December 13, 1989 through March 31, 1990.

Statistical Methods

Statistical analysis was conducted separately for the two samples. The mean PEF (L/min) for each participant was calculated. Individual deviations of daily performance from each participant's mean PEF were calculated. These deviations were averaged across participants to obtain a daily mean deviation (ΔPEF) for each sample. On all days of the analysis, greater than 60% of the respondents provided PEF readings. ΔPEF values were plotted with PM_{10} levels, and mean values were calculated across selected ranges of PM_{10} on the same day. Single period and polynomial-distributed lag models were estimated by regressing ΔPEF on different combinations of daily low temperature, PM_{10} pollution levels, and a linear time trend variable. The time trend variable was defined as 1 to 109 and assigned in order to the 109 days in the study period.

Daily mean deviations (ΔPEF values) were computed with different sample sizes and under different environmental conditions, resulting in potential problems of heteroscedasticity, including biased standard errors of the regression coefficients. To correct for these problems, weighted least-squares regression models (27) were estimated using the inverse of the calculated standard errors of the mean (SEM) deviations (ΔPEF values) as weights. Because statistically significant ($p < 0.05$) first-order autocorrelation was observed, weighted least-squares models were estimated using the Yule-Walker estimation method (28).

Four binary response variables indicating daily symptoms of respiratory disease and asthma medication use were analyzed. The first variable indicated symptoms of upper respiratory disease and was defined as 1 when the participant reported having one or more of the following symptoms: runny or stuffy nose; wet cough; or burning, aching, or red eyes. The second variable indicated symptoms of lower respiratory disease and was defined as 1 when the participant reported having one or more of the following symptoms: trouble breathing, dry cough, or wheezing. The third and fourth variables were defined as 1 if the participant reported taking asthma medication or taking extra asthma medication, respectively.

These symptoms and medication use variables were analyzed by comparing the mean fraction of participants reporting respiratory symptoms and medication use by level of PM_{10} on the same day. These variables were also analyzed by estimating fixed effects logistic regression models. The models were fitted using the maximum-likelihood method (29). Logistic regressions were conducted for each of the four variables and were conducted separately for each sample. The regressions estimated logistic regression coefficients for PM_{10} and low temperature along with subject-specific indicator variables.

Results

Associations between PEF and PM_{10}

As can be seen in figure 2 and table 2, a negative relationship between PM_{10} pollution levels and ΔPEF for the school-based sample was observed in spite of much obvious stochastic variability. This negative relationship between PM_{10} pollution and ΔPEF was confirmed by regression analysis. Regression results for two single-period models and two polynomial-distributed lag models for the school-based sample are shown in table 3.

Several important observations were made from the regression results. First, negative correlations between ΔPEF and PM_{10} were consistently found. Second, the current-day PM_{10} levels had the largest effect on ΔPEF. Third, distributed lag models generally performed better than single-period models. Statistically significant lagged effects of PM_{10} were observed

TABLE 2

MEAN ΔPEF AND MEAN PERCENT REPORTING RESPIRATORY SYMPTOMS AND MEDICATION USE FOR DIFFERENT RANGES OF PM_{10} LEVELS

					Mean Percent Reporting			
					Respiratory Symptoms		Medication Use	
	PM_{10} Range	PM_{10} Mean	Days (*n*)	Mean ΔPEF	Upper (%)	Lower (%)	Regular (%)	Extra (%)
School-based sample	0–50	29	71	1.75	32	15	12	2
	51–100	70	30	−1.87	38	17	12	3
	101–200	134	6	−10.77	41	23	18	6
Patient-based sample	0–50	29	71	1.88	33	38	67	5
	51–100	70	30	−3.68	33	39	67	8
	101–200	134	6	−4.46	33	34	62	10

TABLE 3

REGRESSION COEFFICIENTS FOR ΔPEF (L/MIN) AND SUMMARY INFORMATIO FOR SELECTED MODELS FOR SCHOOL-BASED SAMPLE*

	Single-Period Models		Polynomial-Distributed Lag Models	
	Model I	Model II	Model III	Model IV
INTERCEPT	4.619 (1.043)†	3.481 (2.424)	7.232 (1.198)†	6.356 (2.503)‡
PM_{10} (0)	−0.066 (0.019)†	−0.064 (0.019)§	−0.040 (0.015)§	−0.039 (0.015)‡
PM_{10} (1)	—	—	−0.035 (0.007)†	−0.033 (0.007)†
PM_{10} (2)	—	—	−0.028 (0.007)†	−0.026 (0.007)†
PM_{10} (3)	—	—	−0.020 (0.008)‡	−0.018 (0.008)‡
PM_{10} (4)	—	—	−0.011 (0.006)	−0.009 (0.006)
Temperature	—	−0.099 (0.068)		−0.052 (0.066)
Time trend	—	0.063 (0.025)‡	—	−0.032 (0.026)

* The absolute values of the standard errors are provided in parentheses beneath the coefficients. The values in parentheses after PM_{10} indicate the lag values.
† Significant at $p < 0.001$ using standard *t* test.
‡ Significant at $p < 0.05$ using standard *t* test.
§ Significant at $p < 0.01$ using standard *t* test.

for 2 or 3 days. Fourth, no statistically significant correlation between low temperature and ΔPEF was observed. On the basis of the regression results of Model III reported in table 3, three consecutive days with PM_{10} levels elevated by 150 µg/m^3 would result in an estimated average reduction of PEF of 15.5 L/min, i.e., approximately 6%.

These results were not highly sensitive to two important changes in the makeup of the sample. Dropping all the participants who took any asthma medication (n = 10) during the study period produced nearly identical results to those reported in table 3. The estimated single-period effect of PM_{10} for Models I and II changed from −0.066 (SE = 0.019) and −0.064 (SE = 0.019) L/min/µg/m^3 to −0.060 (SE = 0.22) and −0.069 (SE = 0.022) L/min/µg/m^3, respectively. When the models were estimated using data from all the original participants—including those who were dropped primarily because of lack of regular or continuous PEF testing—the results were also nearly identical with the PM_{10} effects, being somewhat larger and more statistically significant.

A negative relationship between PM_{10} and ΔPEF also existed for the patient-based sample (table 2). The stochastic variability in ΔPEF (figure 3) was larger than for the school-based sample, and the negative association between ΔPEF and PM_{10} was not as readily apparent. Regression results for two single-period models and two polynomial-distributed lag models for the patient-based sample are shown in table 4.

Several important differences between the two samples existed. The current-day PM_{10} levels did not have the largest effect on ΔPEF for the patient-based sample, as was the case with the school-based sample. Distributed lag models performed better than did single-period models. Unlike the school-based sample, a positive, statistically significant correlation between low temperature and ΔPEF existed.

Models such as those reported in tables 3 and 4 were estimated individually for each participant. As with the aggregate analysis, the Yule-Walker estimation method (28) was used. Regression coefficients between PEF and PM_{10} (Model I) for participants in the school-based sample ranged from −0.416 to 0.108 with the lower quartile, median, and upper quartile equal to −0.098, −0.056, and 0.001, respectively. Because of increased stochastic variability associated with individual PEF readings, most of the coefficients were not statistically significant. However, coefficients for 25 (74%) of the participants were negative. On the basis of a modest level of statistical significance ($p < 0.10$), the correlation between PEF and PM_{10} was negative and significant for eight (26%) of the school-based participants, but it was positive and significant for only one (3%) of the participants. The mean of the regression coefficient on PM_{10} (Model I) for all participants in the school-based sample was −0.061 (SEM = 0.019) compared with −0.066 (SE = 0.019) in table 3.

Respiratory Symptoms and Asthma Medicine Use

The mean percent reporting symptoms of respiratory disease and asthma medication use increased with increased PM_{10} pollution (table 2). Logistic regression analysis confirms this association (table 5). For the school-based sample, logistic regression coefficients indicated positive, statistically significant associations between PM_{10} pollution and reported symptoms of upper respiratory disease, symptoms of lower respiratory disease, and use of asthma medication. On the basis of the logistic regression results, the estimated probabilities of reported symptoms of upper and lower respiratory disease were 1.5 and 2.1 times as high, respectively, when 24-h PM_{10} levels were at the highest level for the study period (195 µg/m^3) versus the lowest level (11 µg/m^3).

For the patient-based sample, no associations between PM_{10} pollution and

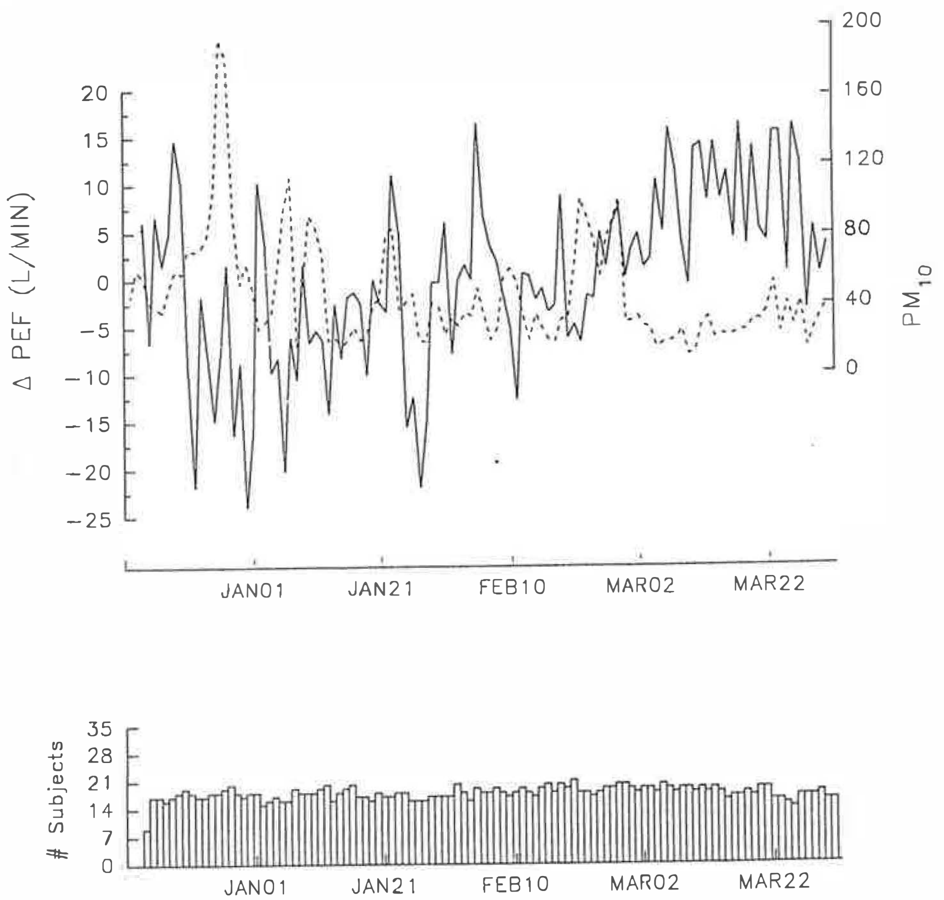

Fig. 3. PM_{10} levels ($\mu g/m^3$) (*broken line*) at the Orem monitoring site, mean peak expiratory flow deviations (ΔPEF) (*solid line*), and daily number of participants. Patient-based sample, December 13, 1989 through March 31, 1990.

TABLE 4

REGRESSION COEFFICIENTS FOR ΔPEF (L/MIN) AND SUMMARY INFORMATION FOR SELECTED MODELS FOR PATIENT-BASED SAMPLE*

	Single-Period Models		Polynomial-Distributed Lag Models	
	Model I	Model II	Model III	Model IV
INTERCEPT	3.101 (1.833)	−10.194 (3.712)§	6.749 (2.110)§	−8.338 (3.761)‡
PM_{10} (0)	−0.049 (0.030)	−0.015 (0.029)	−0.014 (0.022)	0.008 (0.019)
PM_{10} (1)	—	—	−0.026 (0.011)‡	−0.008 (0.010)
PM_{10} (2)	—	—	−0.031 (0.009)†	−0.018 (0.008)‡
PM_{10} (3)	—	—	−0.032 (0.011)§	−0.023 (0.009)‡
PM_{10} (4)	—	—	−0.027 (0.011)‡	−0.021 (0.009)‡
PM_{10} (5)	—	—	−0.016 (0.007)‡	−0.013 (0.006)‡
Temperature	—	0.173 (0.116)	—	0.186 (0.112)
Time trend	—	0.118 (0.037)§	—	0.117 (0.039)§

* The absolute values of the standard errors are provided in parentheses beneath the coefficients. The values in parentheses after PM_{10} indicate the lag values.
† Significant at $p < 0.001$ using standard *t* test.
‡ Significant at $p < 0.05$ using standard *t* test.
§ Significant at $p < 0.01$ using standard *t* test.

reported symptoms of respiratory disease were observed. A statistically significant positive association between PM_{10} pollution and reported use of extra asthma medication was observed. On the basis of the logistic regression results, the probability of the use of extra asthma medication was approximately 6.2 times as high when 24-h PM_{10} levels were at the highest level for the study period versus the lowest level.

A negative association between low temperature and reported symptoms of upper respiratory disease existed for both samples. For the school-based sample, positive associations between low temperature and both regular and extra asthma medication also existed. None of the subject-specific fixed effects coefficients was statistically significant.

Results with Violation Episode Excluded

The only pollution episode during the study period where the 24-h national ambient air quality standard for PM_{10} of 150 $\mu g/m^3$ was exceeded occurred during the latter part of December 1989 (figure 1). ΔPEF was substantially lower during those days when the standard was exceeded. Additional analysis was conducted in order to evaluate whether the statistical association between indicators of respiratory disease and PM_{10} pollution was attributed solely to this single pollution episode. The models presented in tables 3, 4, and 5 were reestimated after excluding this episode, that is, the 2 days that exceeded the PM_{10} standard and the 5 days immediately following.

After excluding this episode, the highest 24-h PM_{10} level included was 114 $\mu g/m^3$. The single-period and polynomial-distributed lag models for ΔPEF for both samples were nearly identical to those reported in tables 3 and 4, with no substantial changes in the magnitude or statistical significance of the correlation between ΔPEF and PM_{10}. The logistic regression coefficients for PM_{10} with this episode excluded were 20 to 60% larger than the coefficients reported in table 5.

Discussion

Associations observed in this study between PM_{10} pollution levels and respiratory health were mostly consistent and robust. Elevated PM_{10} levels were associated with statistically significant reductions in lung function as measured by reductions in PEF and increased reported symptoms of respiratory disease and asthma medication use. Previous studies of the acute effects of particulate pollution on lung function have suggested similar associations. Dockery and coworkers (16) reported a decrease in measurements of FVC and $FEV_{0.75}$ among 335 children in grades 3 to 5 in Steubenville, Ohio after air pollution episodes. Maximal 24-h mean particulate (TSP) concentrations were 312 $\mu g/m^3$ and SO_2 concentrations were 455 $\mu g/m^3$. The maximal FVC decline of 2.7% was observed 2 wk after the episode. Statistically significant negative associations were found with both SO_2 and TSP on the previous day. A recent reanalysis of these data has shown a stronger statistical association with 5-day mean rather than previous-day mean TSP (30). Dassen and coworkers (7) reported deficits in FVC and FEV_1 pulmonary function measurements of children in IJmond, the Netherlands. These deficits were associated with maximal TSP levels equal to 200 to 250 $\mu g/m^3$. Maximal deficits were observed 2 wk after the episode. Lebowitz and coworkers (31) reported an association between deficit of PEF in children in Tucson, Arizona, and TSP and ozone levels.

The present study supports these earlier findings, but it provides new information regarding the structure of association between particulate pollution and lung function. Daily peak flow measurements suggest that the deficit in pulmonary function in response to particulate pollution episodes can be seen immediately but continue to accumulate for several days. This was suggested by the earlier studies, but, because these studies were limited to pulmonary function measurement intervals of a week or more, was not directly testable. The deficit in lung function and the increased symptoms of respiratory disease associated with elevated levels of particulate pollution appeared to be mostly transient. The impact on the risk of developing chronic respiratory diseases in adulthood are unclear (32).

TABLE 5

LOGISTIC REGRESSION COEFFICIENTS AND SUMMARY INFORMATION FOR BOTH SAMPLES*

	Respiratory Symptoms		Medication Use	
	Upper	Lower	Regular	Extra
School-based sample				
PM_{10}	0.0036 (0.0015)‡	0.0050 (0.0020)‡	0.0090 (0.0034)§	0.0106 (0.0042)‡
Temperature	−0.0139 (0.0057)‡	−0.0046 (0.0081)	0.0291 (0.0137)‡	0.0426 (0.0179)‡
Observations	3,096	3,096	3,096	3,096
Patient-based sample				
PM_{10}	−0.0002 (0.0021)	0.0002 (0.0023)	0.0032 (0.0029)	0.0113 (0.0034)†
Temperature	−0.0186 (0.0083)‡	0.0034 (0.0093)	0.0108 (0.0113)	0.0088 (0.0151)
Observations	1,912	1,912	1,912	1,912

* The absolute value of the standard errors are provided in parentheses.
† Significant at $p < 0.001$ based on likelihood-ratio goodness-of-fit chi-square test.
‡ Significant at $p < 0.05$ based on likelihood-ratio goodness-of-fit chi-square test.
§ Significant at $p < 0.01$ based on likelihood-ratio goodness-of-fit chi-square test.

This study also provides limited guidance regarding the portion of the population that may be most responsive to the effects of particulate pollution. In the Steubenville (16) and IJmond (7) studies, general population samples were recruited. In the Tucson study (31), families of asthmatic but not necessarily symptomatic children were recruited. In this study, children with respiratory symptoms determined by questionnaire (the school-based sample) were recruited. Although the number of participants was small compared with that in the previous studies, statistically significant associations were found. In the school-based sample 74% showed a negative response to particulate pollution compared with 59% in the Steubenville study, suggesting that symptomatic children are more susceptible to the effects of particulate pollution.

On the other hand, relatively weaker associations were found with the sample of asthmatic patients (patient-based sample)—except for the use of extra asthma medication. This does not imply that asthmatics are less susceptible to PM_{10} pollution, but rather that the symptoms and pulmonary function of these diagnosed asthmatics was being managed by medication and life-style changes (e.g., staying indoors). In contrast to participants in the school-based sample who rarely used asthma medication, participants in the patient-based sample usually used asthma medication. The asthmatic patients may indeed be more susceptible to PM_{10} pollution, but their response is more readily measured as changes in medication use and not changes in PEF or daily symptom reporting.

In previous studies, high particulate pollution concentrations were accompanied by high concentrations of other pollutants. Although statistical analysis generally suggested stronger associations with particulate pollution, independent or interactive associations with ozone, SO_2, acid aerosols, or other pollutants could not be ruled out. In the present study concentrations of SO_2, NO_2, acid aerosols, and ozone were very low. PM_{10} pollution, therefore, was more explicitly implicated as the pollutant responsible for the observed associations.

Finally, this study provides no evidence that the 24-h PM_{10} standard of 150 $\mu g/m^3$ represents a threshold pollution level below which adverse respiratory health effects are negligible. In fact, these results suggest that measurable associations between respiratory health and PM_{10} pollution can be observed at PM_{10} levels well below the national ambient air quality standard.

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Exposure-related Declines in the Lung Function of Cotton Textile Workers

Relationship to Current Workplace Standards[1-3]

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SUMMARY To evaluate the effectiveness of the current workplace standards in preventing chronic health effects from cotton dust exposure, a 5-yr longitudinal study of a large multimill population of cotton textile and synthetic process workers, employed at a major U.S. textile company, was conducted. To control for and assess the effect of type of work area on annual change in lung function, we limited the analysis to those 1,817 subjects who, throughout their textile work history at the company, worked exclusively in cotton yarn manufacturing or slashing and weaving, or in synthetic textile mills. The expected effect of smoking on average annual change in lung function was demonstrated for both cotton and synthetic workers. Despite lower overall dust exposure, cotton yarn workers exhibited steeper annual declines in lung function than did workers in slashing and weaving; this difference persisted within each smoking category, indicating a dust potency effect. There were mill differences in annual change in lung function among cotton workers, potentially masking an exposure effect. A smoking-work area interaction persisted after adjusting for mill differences, with the largest annual declines observed in cotton yarn workers who smoke. A significant dose-response relationship was seen in cotton yarn manufacturing between annual declines in FEV_1, FVC, and FEF_{25-75} and average exposure by mill, and the larger declines were found in mills using the highest percentage and lowest grade of cotton. Synthetic textile workers had larger declines than did cotton textile workers, which were not explained by smoking or duration of employment. Unrecognized and unmeasured causative exposures or selection bias could explain this result. The current cotton dust standards appear to protect against the chronic effects of exposure in smokers and nonsmokers in slashing and weaving. No dose-response relationship was noted, and the observed mean annual decline in FEV_1 and FVC for these workers was 25 ml/yr or less. For yarn manufacturing workers a dose-response relationship was noted. For nonsmokers in this area, the observed mean annual decline in FEV_1 and FVC was similar to that reported for workers in slashing and weaving, indicating the absence of a significant health effect of existing exposures; at the current dust standard for yarn manufacturing, however, the dose-response model predicted slightly steeper declines for these workers compared with workers in slashing and weaving. For current smokers in yarn manufacturing, the synergistic effect of exposure and current smoking produced accelerated annual declines in FEV_1. These results suggest that, in the short term, smokers should be restricted from working in yarn manufacturing areas, and in the long term, the feasibility of lowering respirable dust levels to provide protection for all yarn manufacturing workers should be evaluated.

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Introduction

The most conspicuous respiratory health effects of cotton dust exposure are clinical symptoms of acute bronchoconstriction and a decline in expiratory flow over the work shift, typically after an absence from exposure. This acute response to cotton dust exposure, byssinosis, has been repeatedly shown to be influenced by dust concentration (1–6). In addition, the risk of byssinosis differs in relation to job in the textile process. In cohorts, attacks usually begin to appear after several years of exposure, and prevalences increase thereafter. In most studies, smoking has also been an important influencing variable on byssinosis prevalence (5, 7, 8). At times unexplained differences have been found in relation to the acute response indicator. For instance, Berry and colleagues (3, 8) found that smoking influenced byssinosis prevalence but not the across-shift decline in FEV_1. There is limited evidence that atopy, or perhaps the associated bronchial hyperresponsiveness, increases byssinosis risk (9, 10). A "mill factor" or "mill effect" has also been shown to influence byssinosis prevalence (3, 5, 11) and may be caused by one or more factors, including grade of cotton, degree of contamination with gram-negative microorganisms, and past levels of dust exposure. Byssinosis risk is influenced by length of exposure and probably by the part of the industry in which cotton dust exposure is encountered, for example, ginning, cottonseed oil mills, or textile mills. Finally, byssinosis prevalence seems to not be influenced by gender, ethnic group, or age, although gender and ethnic group may be associated with job and age with length of exposure.

Even though the term "byssinosis" refers to the acute airways response, this usage does not preclude a chronic airways response to cotton dust, which may or may not be related to byssinosis. One observed chronic effect of cotton dust exposure has been an excess of bronchitis when comparing cotton-exposed populations with community control groups (12) or to workers manufacturing synthetic textile fiber products (3). However, problems have been raised concerning the suitability of comparison groups. Pathologic evidence (13, 14) indicates that pulmonary emphysema is not a likely consequence of cotton exposure. Morphologic evidence (13) shows that bronchitis, characterized by an increase in the mucus-secreting elements of the airways, can occur in nonsmoking cotton textile workers. However, bronchial hypersecretion does not necessarily lead to functionally important airways obstruction

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