

Association of Lung Function with Declining Ambient Air Pollution

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Recent studies have found a declining prevalence of respiratory infections in East German children, along with a tremendous improvement of air pollution since 1990. The present study evaluates the effects of improved air quality on lung function. Three consecutive cross-sectional surveys of schoolchildren ages 11–14 years from three communities in East Germany were performed in 1992–1993, 1995–1996, and 1998–1999. Lung function tests were available from 2,493 children. The annual mean of total suspended particulates (TSP) declined from 79 to 25 $\mu\text{g}/\text{m}^3$, whereas levels for sulfur dioxide declined from 113 to 6 $\mu\text{g}/\text{m}^3$. Mean forced vital capacity (FVC) and forced expiratory volume in 1 sec (FEV_1) of the children increased from 1992–1993 to 1998–1999. The adjusted percent change of the geometric mean of FVC was 4.7% for a 50 $\mu\text{g}/\text{m}^3$ decrease of TSP ($p = 0.043$) and 4.9% for a decrement of 100 $\mu\text{g}/\text{m}^3$ SO_2 ($p = 0.029$). Effects on FEV_1 were smaller and not statistically significant. Our study indicates that a reduction of air pollution in a short time period may improve children's lung function. **Key words:** air pollution, children, East Germany, pulmonary function, repeated cross-sectional study. *Environ Health Perspect* 111:383–387 (2003). doi:10.1289/ehp.5355 available via <http://dx.doi.org/> [Online 25 October 2002]

Several regional cross-sectional studies in the United States and Europe have shown consistently higher rates of bronchitis and bronchitic symptoms among children with higher exposure to total suspended particulates (TSP) than in children living in less polluted areas (Avol et al. 2001; Dockery et al. 1989; Gauderman et al. 2000; Heinrich et al. 2000, 2002; Peters et al. 1999). Recently published reviews of health effects of air pollution (Committee of the Environmental and Occupational Health Assembly 1996a, 1996b; Pope and Dockery 1999) reported chronic adverse health effects even at relatively low levels of ambient particulates in urban areas.

Studies addressing the effects of higher exposure to TSP and their effect on children's lung function are more inconsistent (Dockery et al. 1989; James et al. 2000; Peters et al. 1999; Schwartz 1989; Stern et al. 1994). A Canadian cross-sectional study in the 1980s found statistically significant ($p < 0.01$) mean decrements in forced vital capacity (FVC) and forced expiratory volume in 1 sec (FEV_1) in school children from moderately elevated exposures of sulfate and ozone (Stern et al. 1994). Dockery et al. (1989) saw no indication of chronic effects of air pollution on any lung function measure in more than 5,000 children participating in the Six Cities Study of Air Pollution and Health, whereas the analyses of data from the Second National Health and Nutrition Examination Survey (NHANES II) of children and youths ages 6–24 revealed significant negative correlations of FVC and FEV_1 with annual concentrations of TSP, nitrogen dioxide, and ozone (Schwartz 1989). A recent study conducted in southern California reported a significant relationship

between air pollution level and lung function parameters (James et al. 2000; Peters et al. 1999). Particulate matter $< 10 \mu\text{m}$ in diameter (PM_{10}) and NO_2 were significantly associated with decreases in FVC and FEV_1 .

Since German reunification in 1990, ambient sulfur dioxide (SO_2) and TSP in East Germany have declined tremendously. We speculated that this reduction of air pollution might lead to an improvement of children's lung function. We therefore examined the association between declining air pollution (TSP, SO_2) and lung function parameters (FVC, FEV_1) by repeated examinations of children living in East Germany.

Methods

Design and study area. Three consecutive regional cross-sectional surveys were performed 1992–1993, 1995–1996, and 1998–1999. All 6th-grade children living in Zerst and Hettstedt and those from randomly selected schools in Bitterfeld were invited to participate. We excluded children from analysis if they had lived for less than 2 years in their current home and if their previous home was located more than 2 km from their current home. Because of the seasonal fluctuations in respiratory health, the examination period was spread over 1 year, changing the location of the examination every 2 weeks. In all surveys, the same schools were visited in the same period of the year. The University of Rostock Ethics Committee granted approval of the study design and the examination protocol. The study area and sources of air pollution are described in detail elsewhere (Heinrich et al. 1999, 2000, 2002; Pitz et al. 2001).

Ambient pollution. State authorities at all three sites from 1991 through 1998 monitored ambient pollutants. Annual means of SO_2 were available from 1991 to 1998 (in Zerst, 1993 to 1998), whereas annual means of TSP were determined from 1993 to 1998 (in Bitterfeld, 1994 to 1998). The available data suggested a roughly linear association between log-transformed pollutant concentrations and time. Therefore, we replaced the missing values of annual means at the beginning of the 1990s using linear extrapolation for the logarithmic SO_2 and TSP values. We took the average of annual means of our pollutants 2 years preceding each investigation (1991–1992, 1994–1995, 1997–1998) as exposure variables. SO_2 was measured with an Ansyco Model AF 21 M pulsed fluorescence analyzer (Environnement, Poissy, France). TSP was measured with an FH 62 IN β -ray absorption monitor (FAG Kugelfischer, Schweinfurt, Germany). The detailed methods for these measurements have been described elsewhere (Heinrich et al. 1999; Pitz et al. 2001).

Pulmonary function measurements. Methods of pulmonary function measurements are described elsewhere (Frye et al. 2001; Wjst et al. 1998). Briefly, technicians were trained thoroughly at the beginning of each survey. Subjects performed both forced and slow ventilator maneuvers while in a seated position wearing a nose clip. Forced expiratory maneuvers were repeated until three reproducible tracings were obtained that met the standards of the American Thoracic Society (American Thoracic Society 1987). The FVC and FEV_1 were recorded. Of these, the test with the maximum sum of FVC and FEV_1 was used for the analysis. All spirometers were calibrated each morning according to the manufacturer's instruction. Pulmonary function measurements were corrected to body temperature and barometric pressure-saturated.

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Within one survey, two to four investigators who changed the location of the examination every 2 weeks to account for seasonal effects performed the lung function tests. One of these technicians participated in all three surveys.

Statistical methods. Logarithmically transformed lung function parameters (FVC, FEV₁, and FVC/FEV₁) were used as response variables in linear regression analyses. As covariates we included sex, height, season of examination, lung function equipment, parental education, parental atopy, and environmental tobacco smoke (ETS).

Adjusted geometric means for all combinations of sex, area, and survey were computed. We examined the association between air pollution variables and lung function parameters, considering each pollutant separately. The models included a linear function of the air pollution variable, uncorrelated random effects for the nine combinations of area and survey, as well as all covariates listed above. The results are presented as percent change of the geometric means for a decrease of 50 µg/m³ (TSP) or 100 µg/m³ (SO₂). Statistical analyses were done using the MIXED procedure of SAS 6.12 (SAS Institute, Cary, NC, USA).

Results. The annual mean of TSP and SO₂ declined drastically during the 1990s, and differences in air pollution levels between the three areas nearly disappeared (Figure 1). The annual mean of TSP in the three areas and the years 1991–1998 fell from a high of 79 to a low of 23 µg/m³, whereas SO₂ fell from a high of 113 to a low of 6 µg/m³.

In total, parents of 3,155 of 4,005 eligible children (79%) attending 6th grade completed a questionnaire. The response rates differed slightly among study areas and surveys and ranged from 68.4% to 90.2%. Seventy-nine percent (2,493/3,155) of the children

had valid and complete lung function data. We excluded children from the analyses if they had lived for less than 2 years in their current home and if their previous home was located more than 2 km from their current home.

Table 1 shows temporal changes of crude prevalence of nonallergic respiratory diseases and symptoms in the three study areas. The prevalence of bronchitis, frequent colds, febrile infections, and shortness of breath declined within the three surveys. Possible confounding factors that potentially influence the function or the growth of the children's lungs are presented in Table 1. Housing characteristics changed tremendously over time. Bedroom sharing decreased more than 40% from 1992–1993 to 1998–1999. But also using single-oven heating, living in slab houses, and cooking with gas was more frequent in 1992–1993 than in the latter surveys.

FVC and FEV₁ increased for boys and girls from 1992–1993 to 1998–1999 (Table 2). The FEV₁/FVC ratio for boys remained stable in Zerbst and decreased only slightly in Bitterfeld and Hettstedt. There was no

change in FEV₁/FVC for girls in any region. Stratified for the area, results showed that FVC increased steadily in Bitterfeld and Zerbst for both sexes, but not in Hettstedt. In the second survey FVC and FEV₁ were lower in Hettstedt but increased in the third survey.

Results of linear regression models for annual mean concentrations of air pollutants 2 years before collection of the health data and FVC and FEV₁ are presented in Table 3. The adjusted increase of the geometric mean for a 50 µg/m³ decrease of TSP in the whole group was 4.4% (*p* = 0.052) for FVC and 4.7% for a 100 µg/m³ decrease of SO₂ (*p* = 0.025). The effects on FEV₁ were clearly smaller than the effects on FVC, and none of the effects were significant. The FEV₁/FVC ratio showed a small statistically significant increase for TSP. Although most of the observed effects are small and not statistically significant, all values for FEV₁, FVC, and FEV₁/FVC showed an improvement in the lung function of the children. In further sensitivity analyses we adjusted for additional potential confounders—low birth weight, breast-feeding, building material of house, bedroom sharing, dampness or visible molds, single-oven

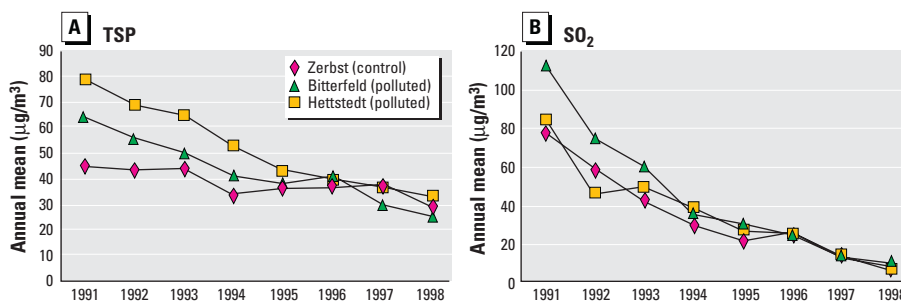


Figure 1. Annual mean of TSP and SO₂ at three ambient monitoring stations in Zerbst (control), Bitterfeld (polluted), and Hettstedt (polluted), 1991–1998. Data for SO₂ in 1991 and 1992 in Zerbst were interpolated by linear extrapolation for log (SO₂). Data for TSP in 1991 and 1992 in all three regions (Bitterfeld 1991–1993) were interpolated by linear extrapolation for log (TSP) (Pitz et al. 2001). Data for 1991–1996 from Heinrich et al. (2000); for 1997 and 1998 from Heinrich et al. (2002) and Pitz et al. (2001).

Table 1. Morbidity and characteristics of the study population ages 11–14 years in the surveys in 1992–1993, 1995–1996, and 1998–1999.

	Zerbst Survey			Bitterfeld Survey			Hettstedt Survey		
	I <i>n</i> = 288	II <i>n</i> = 231	III <i>n</i> = 194	I <i>n</i> = 211	II <i>n</i> = 375	III <i>n</i> = 320	I <i>n</i> = 238	II <i>n</i> = 202	III <i>n</i> = 236
Respiratory disorders and symptoms									
Bronchitis (lifetime)	46.7	35.9	40.7	54.0	41.8	42.8	62.4	47.0	37.8
Frequent colds (last 12 months)	30.8	25.9	21.3	32.5	24.7	26.5	35.5	26.3	23.9
Febrile infections (last 12 months)	20.2	17.0	14.7	26.7	24.7	23.2	24.4	22.6	17.7
Shortness of breath (last 12 months)	8.4	7.8	10.8	12.5	11.5	8.1	14.4	15.6	11.0
Wheezing (lifetime)	19.4	17.7	22	23.2	23.1	16.8	24.7	32.2	18.5
Possible confounders									
Boys	50.0	53.2	55.7	53.6	51.1	52.2	49.6	60.4	54.7
Height (mean in centimeters)	155.5	155.7	155.7	156.6	156.3	156.2	155.7	154.7	155.2
Higher parental education ^a	43.4	42.7	47.3	36.6	46.5	43.5	42.1	40.5	45.1
ETS	44.4	47.6	35.4	53.1	43.7	42.5	49.8	36.2	45.9
Contact with cats	45.3	45.5	46.9	17.8	28.5	25.4	40.0	39.3	39.9
Dampness and visible molds	20.6	20.8	20.2	15.3	20.3	23.8	16.5	19.8	17.2
Cooking with gas	39.8	29.5	19.4	37.7	34.3	32.5	50.2	58.7	40.3
Slab house	32.4	28.6	24.9	59.4	44.1	32.2	39.8	34.5	29.5
Sharing bedroom	39.1	26.8	21.6	46.2	40.0	26.3	38.9	33.8	22.5
Single-oven heating	52.4	34.2	40.6	34.3	29.5	30.5	50.8	52.9	41.3

^aEducation of father or mother at least 12 years. Survey I, 1992–1993; II, 1995–1996; III, 1998–1999.

heating, cooking with gas, carpeting, contact with cats, and attendance at day care center, but these adjustments changed the results only marginally (data not shown).

By adding appropriate interaction terms we computed the effect estimates separately for boys and girls, and additionally for children with different indoor exposures (dampness or visible molds, ETS exposure at home, cooking with gas, contact with cats). Stratified for sex, the increases of FVC and FEV₁ were nearly twice as high for the girls (Table 3). Children without indoor exposure tended to have slightly improved lung function values, but these improvements were small and none of them was statistically significant (data not shown).

Discussion

This study investigates the association between the strong decline of combustion-related air pollutants in selected areas of Eastern Germany and improvements in lung function of children. The adjusted percent change of the geometric means of FVC was 4.7% for a 50 µg/m³ TSP decrease (*p* = 0.043). A decrease of 100 µg/m³ SO₂ was accompanied by a 4.9% increase of FVC (*p* = 0.029). FEV₁ seemed to improve with decreasing air pollution, but the effects were smaller than with FVC and not statistically significant.

Comparison with other studies. Studies addressing the long-term exposure to TSP and SO₂ and their effect on lung function measurements are scarce. In addition, direct comparisons are limited because the measurements of ambient pollutants, sources of air pollutants, and the investigated age groups are different.

Only a few studies in children have investigated long-term effects of TSP on lung function parameters in children. A cohort of school children was analyzed in the Six Cities Study, finding no effects of air pollution on lung function (Dockery et al. 1989). Dockery et al. concluded that air pollution exposure might increase respiratory symptom rates without causing irreversible pulmonary function losses.

Schwartz (1989) analyzed the data of children and youths ages 6–24 gathered in the Second National Health and Nutrition Examination Survey (NHANES II). He reported significant negative correlations of FVC and FEV₁ with annual concentrations of TSP, NO₂, and ozone. Contrary to those of the Six Cities Study, data from NHANES II came from 44 cities with a much wider range of air pollution, thus making it more likely to detect an association.

Finally a recent study conducted in southern California reported a significant

relationship between air pollution level and FEV₁ and FVC. PM₁₀ and NO₂ were significantly associated with decreases in FVC and FEV₁, but only in girls (Peters et al. 1999). In this study the pollution differences were spatial, not temporal as in East Germany. An analysis after 4-year follow-up revealed that significant deficits in growth of lung function were associated with exposure to PM₁₀ (Gauderman et al. 2000). Avol et al. (2001) reported an increased growth in lung function in children from southern California who had moved to areas with lower PM₁₀ and a decreased growth in lung function in subjects who moved to communities with a higher PM₁₀.

Two studies of adult participants found associations for ambient particle pollution and FEV₁ and FVC. The First National Health and Nutrition Examination Survey (NHANES I) (Chestnut et al. 1991) reported that a 34 µg/m³ increase in TSP was associated with an average decrease in FVC of 2.25%. They also found a significant but smaller effect for FEV₁. A study conducted in Switzerland (SAPALDIA) (Ackermann-Lieblich et al. 1997) examined 9,651 participants in a cross-sectional population-based sample of adults (ages 18–60 years). Ackermann et al. found significant and consistent effects for PM₁₀. An increase of 10 µg/m³ PM₁₀ was associated with a 3.4% reduction of FVC and a 1.6% reduction of FEV₁.

Data on long-term effects of SO₂ are also very rare. Only three published studies investigated long-term effects of SO₂ on lung function. The Six Cities Study (Dockery et al. 1989) and the NHANES II Study (Schwartz 1989) found no association, whereas SAPALDIA (Ackermann-Lieblich et al. 1997) reported a FEV₁ decreased of 3.2% and a decrease of FEV₁ of 1.2% per 10 µg/m³ SO₂ increase.

In agreement with most of the cited articles, we found a significant association for the reduction of TSP and an increase in FVC. The effect on FEV₁ was smaller and not significant. Presumably too few children were investigated to detect significant associations. The two U.S. studies (Six Cities and NHANES) that investigated SO₂ found no effect on lung function parameters. Only the Swiss study (SAPALDIA) found an association between SO₂ and FEV₁ and FVC for adults. The effects were much bigger than the ones we found. One explanation could be that the Swiss study investigated adults that lived much longer in the polluted area, giving the pollutant more time to damage the lung. Another possible explanation relates to the study design. Because of the repeated surveys, each child had spent some time in a heavily polluted environment and

Table 2. Adjusted geometric means^a of lung function parameters for boys and girls.

	Zerbst Survey			Bitterfeld Survey			Hettstedt Survey		
	I n = 288	II n = 231	III n = 194	I n = 288	II n = 231	III n = 194	I n = 288	II n = 231	III n = 194
FVC (L)									
Boys	3.14	3.15	3.21	3.08	3.11	3.18	3.12	3.04	3.23
Girls	2.95	3.02	3.09	2.93	2.96	3.11	2.95	2.92	3.05
FEV ₁ (L/sec)									
Boys	2.74	2.70	2.80	2.71	2.69	2.77	2.73	2.65	2.79
Girls	2.68	2.72	2.80	2.69	2.71	2.81	2.70	2.66	2.75
FEV ₁ /FVC									
Boys	0.87	0.86	0.87	0.88	0.86	0.87	0.88	0.87	0.86
Girls	0.91	0.90	0.90	0.91	0.91	0.91	0.91	0.91	0.91

^aAdjusted for height, season, lung function equipment, parental education, parental atopy, and ETS. Survey I, 1992–1993; II, 1995–1996; III, 1998–1999.

Table 3. Percent change of lung function^a parameters for a decrease of annual means (2 years before the investigation) for TSP and SO₂ in Eastern Germany (*n* = 1,911).

	TSP (50 µg/m ³ decrease)		SO ₂ (100 µg/m ³ decrease)	
	Percent change	(95% CI)	Percent change	(95% CI)
FVC				
Total ^b	4.7*	(0.2–9.5)	4.9*	(0.7–9.3)
Boys	3.7	(–1.2–8.8)	3.7	(–0.8–8.4)
Girls	5.9*	(0.8–11.1)	6.2*	(1.5–11.2)
FEV ₁				
Total ^b	2.9	(–1.4–7.3)	3.0	(–1.1–7.2)
Boys	1.7	(–2.9–6.6)	1.7	(–2.8–6.3)
Girls	4.1	(–0.7–9.2)	4.5	(–0.2–9.5)
FEV ₁ /FVC				
Total ^b	–1.6*	(–3.1–0.1)	–1.5	(–3.0–0.1)
Boys	–1.7	(–3.6–0.2)	–1.7	(–3.6–0.2)
Girls	–1.4	(–3.4–0.5)	–1.2	(–3.2–0.9)

^aAdjusted for height, season, lung function equipment, parental education, parental atopy, and ETS. ^bAdditionally adjusted for gender. **p* < 0.05.

also in a much cleaner surrounding after 1990. Under the hypothesis that air pollutants damage the lung irreversibly at a young age, one would expect only minor improvements in later life. On the other hand, if the damage caused by air pollutants were reversible, the children of the first survey (1992–1993) would have recovered 2 to 3 years after reunification (1990). Both possibilities would only result in a slight improvement of lung function.

There is convincing evidence that high exposure to TSP is associated with higher rates of bronchitis and bronchitic symptoms (Avol et al. 2001; Committee of the Environmental and Occupational Health Assembly 1996a, 1996b; Dockery et al. 1989; Gauderman et al. 2000; Heinrich et al. 2000, 2002; James et al. 2000; Pope and Dockery 1999; Zemp et al. 1999). It seems plausible that frequent respiratory infections harm the lung by reducing FVC and FEV₁. Our results are well in line with several repeated cross-sectional studies done in East Germany (Heinrich et al. 2000, 2002; Kraemer et al. 1999; Von Mutius et al. 1998). All repeated cross-sectional studies of East German children showed consistently a remarkable decline of prevalence of bronchitis and bronchitic symptoms during the 1990s (Heinrich et al. 2000, 2002; Kraemer et al. 1999; Von Mutius et al. 1998). One must remember that the children were exposed to very high SO₂ and TSP levels only during their first years in life. Therefore Heinrich et al. (2000, 2002) suspect that the cumulative exposure a few years before the examination had a greater contribution to health than exposures within early infancy. We have no information about the magnitude of the lung tissue damage that was possibly caused in the first years of life. Nevertheless, our results indicate that a reduced exposure to TSP and SO₂ in a formerly heavily polluted region leads to an improvement of FVC and possibly (to a smaller degree) FEV₁.

A recently published study from southern California (Peters et al. 1999) reported a significant decrease in polluted areas in FVC and FEV₁ for girls but not for boys. An analysis of the Six Cities data addressing the effects of cigarette smoking on lung function (Gold et al. 1996) reported that adolescent girls seem to be more vulnerable than boys to the effects of smoking on the growth of lung function. Our data showed higher positive effects of better air quality on lung function for girls. However, further analyses of interactions between TSP, SO₂, and sex found no statistically significant effect. Thus it remains unclear whether the susceptibility for pollutants is different for boys and girls.

Limitations and strength. Several aspects of possible bias and confounding must be addressed. The annual mean level of TSP in

our study ranged from 25 to 65 µg/m³, a range similar to the range of community differences reported in the Harvard Six cities study (Dockery et al. 1989) (PM_{2.5}, 20–59 µg/m³), and slightly wider than the range in Switzerland (PM₁₀, 10–33 µg/m³) (Ackermann-Lieblich et al. 1997). The levels of SO₂ were substantially higher than in the Harvard Six Cities study. Unfortunately only data for TSP and SO₂ were available. Data for ozone and particles of smaller size especially would have been of interest but were not available at that time.

Other predictors of pulmonary function may confound cross-sectional comparisons. Communities could differ with respect to risk factors for lung function other than ambient pollutants, such as poverty, social class, nutrition, or smoking. Also, an unknown factor could differ by area in a manner correlated with air pollution, which would adulterate the results. This regional confounding is less likely in our repeated study than in one-time cross-sectional studies. Because of repetition of the surveys in the same area, we could show that lung function parameters improved in all areas from 1992–1993 to 1998–1999, parallel to the fast improvement of air quality. However, in 1995–1996 lung function parameters were exceptionally low in Hettstedt. Identical methods are crucial in cross-sectional studies with different areas. The flow of the examination and the equipment was the same in all three areas. The same technicians as in the Bitterfeld and Zerbst performed all lung function tests in Hettstedt. Therefore, we have no explanation for the low FEV₁ and FVC in Hettstedt during the second survey.

On the other hand, it is possible that the observed results are biased by temporal confounding. After reunification tremendous changes, particularly in the medical care system, diet, and housing conditions, took place in East Germany. A confounding factor for lung function with similar temporal changes might alter our results.

The three areas in the study are quite small. Therefore, spatial inhomogeneity should not be a problem in the study. In addition, we excluded all persons that had moved within the last 2 years and the previous home was more than 2 km distant, thus ensuring that the children were exposed to the air pollution measured by the health authorities.

So far no data are available to point out clearly which specific effects are associated with exposures to air pollutants at a particular age. It is not clear whether possible damages caused by air pollutants are irreversible or not. If reversible, the time frame of reduced exposures to air pollutants, which is necessary to improve respiratory health, would be of interest.

The lung function measurement is a complex examination that requires good effort

from the child, a well-trained investigator, and well-checked, high-quality equipment. Despite many quality checks, the improvement of FEV₁ parallel to the improvement of air quality could be caused by a systematic change in the equipment or simply by better investigators. In a study that ranges over 6 years, these flaws can never be totally excluded. We tried to cope with these problems by using the same lung-function equipment and software in all surveys. Within one survey, the lung function tests were done by 2–4 investigators who changed the location of the examination every 2 weeks to account for seasonal effects. One of these technicians participated in all three surveys. Sensitivity analyses including only lung function data measured by this technician showed similar air pollution effect estimates compared with the total data set. Therefore, investigator bias is unlikely.

Contrary to the reported studies is the investigation in the same areas at three different times, 1992–1993, 1995–1996, and 1998–1999. Within this period shortly after reunification, life in East Germany changed tremendously. Already at the time when the study was designed it could be foreseen that the air pollution in these areas would improve, although the improvement occurred at a much faster rate than expected. Today the concentration of SO₂ is close to the detection limit in the former highly polluted regions of Bitterfeld and Hettstedt (Pitz et al. 2001). TSP decreased by more than 50% from 1991 to 1998 (Figure 1). In summary, our study had the unique opportunity to investigate children's health in an area with fast improving air quality and differs in this respect to all long-term studies that investigate lung function and air pollution.

It has been shown that a reduction of air pollution is associated with a lower prevalence of bronchitis and bronchitic symptoms. Our study indicates that a reduction of air pollution in a rather short time period may lead to an improvement of children's lung function.

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