Respiratory illness in British schoolchildren and atmospheric smoke and sulphur dioxide 1973–7

II: Longitudinal findings

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SUMMARY A study was set up to investigate the effects of annual changes in the levels of atmospheric smoke and SO₂ on changes in health from 1973 to 1977 in primary schoolchildren from 28 randomly selected areas of England and Scotland. Changes in health were measured by taking the change in number of respiratory conditions reported from one annual examination to the next. The number of areas with data on pollution in each period was 5, 9, 17, and 14 respectively and within these areas the response rate varied from 65% to 74%. Altogether 857, 1436, 2702, and 2036 children respectively who were of white ethnic origin, aged 6 to 11, and had complete data on sex, social class, and changes in health were studied in each period. In 1973–4 the levels of pollution were highest and showed the greatest decline. The greatest annual mean change in smoke was a decrease from 71.9 to 50.5 µg/m³ and in SO₂ a decrease from 94.2 to 47.6 µg/m³. However, no relation was found between improvement in health and decreasing levels of pollution. In subsequent years, when the levels of pollution were lower and showed smaller changes, change in health was also unrelated to changes in pollution. Thus no evidence was found to suggest that the levels measured during the study were harmful to health.

In the past respiratory illness in primary schoolchildren has been associated with high levels of atmospheric smoke and sulphur dioxide (SO₂) in the United Kingdom.^{1,2} However, as the levels of these pollutants have been declining in recent years,³ a National Study of Air Pollution was conducted from 1973 to 1977 to investigate the effects of changes in low levels of pollution on respiratory illness in primary schoolchildren.

In cross-sectional analyses presented in the preceding paper⁴ the prevalence of respiratory illness was found to be higher in areas with high levels of smoke than in areas with low levels over the range of annual means 8.0 to 50.5 µg/m³. This range of levels was much lower than that at which effects from smoke on children's health have previously been reported. We suggested that an analysis of the effects of changes in the annual levels of pollution on changes in health might confirm whether low levels of smoke measured during the study were harmful to health.

Methods

POPULATION AND DATA COLLECTION

Details of the study population and method of data collection can be found in the accompanying paper.⁴ Briefly, children aged 6 to 11 who attended selected schools in 28 randomly selected areas of England and Scotland were studied annually by a

self-administered questionnaire completed by each child's mother or guardian from 1973 to 1977. Fieldworkers from St. Thomas's Hospital visited 18 English areas during the summer and the remainder in the autumn to organise the fieldwork. Information was collected on the presence of cough, wheeze, and colds going to the chest, and the number of attacks of asthma and bronchitis experienced during the previous 12 months. Data were also obtained on socioeconomic and environmental characteristics of the children's homes. Smoke and SO₂ were measured daily by the British Standard Smoke/SO₂ method⁵ at or near the children's schools in each area.

MEASURE OF CHANGES IN HEALTH

The longitudinal nature of the data needed to be taken into account. Korn and Whittemore⁶ have suggested that changes in health should be studied by examining changes experienced by individuals rather than the change in an average measure of health for groups. Certainly prevalence rates would have provided an insensitive measure of change in health as most children experienced no illness throughout the study.

In the cross-sectional analyses some interrelationship was found between the responses to the six respiratory questions and a simple count was made of the number of conditions reported for each child. Changes in health were studied by examining

the proportion of children who experienced a decrease, no change, or an increase in number of conditions reported for the year between two examinations. Longer periods were not studied.

In the regression analyses which require a binary response the dependent variable, the number of categories of change in health, was reduced to two. An index of improvement in health was formed, based on the hypothesis that relatively more children in areas with declining levels of pollution than in other areas would experience a decrease rather than an increase in their number of conditions. A decrease and an increase in the number of conditions were the two response categories for the dependent variable; those children showing no change were omitted from the analysis.

MEASURE OF CHANGE IN POLLUTION

The mean levels of smoke and SO₂ for the winter preceding the visit to each area were studied, because these levels of pollution tended to be higher and provided a wider separation between the areas than levels at other times of the year. In addition, winter means appeared to be associated with prevalence of respiratory illness in the cross-sectional analysis. The annual means and their changes showed high positive correlations with the winter means so the relation of the two measures of pollution to changes in health were very similar.

CHOICE OF DATA FOR ANALYSIS

Changes in health and pollution were studied over each year of the study: 1973-4, 1974-5, 1975-6, and 1976-7. Changes in health and pollution were the only changes considered in the analyses.

Although respiratory illness has been shown cross-sectionally to be associated with the younger age groups, those from the manual social classes, and from homes with gas cookers,⁷ changes in these variables were not expected to interfere with the results. The children were studied at yearly intervals so the change in age was the same for all participants. Changes in social class and cooking fuel were unrelated to change in the levels of pollution. Changes in health may nevertheless have differed between different age or social class groups so age and social class at the initial examination of each period were included in the analyses presented here. Social class at the second examination was also analysed but it did not give different results. Changes in weather conditions may have interfered with the results but they could not be studied because there were no weather stations in the study areas.

STATISTICAL METHODS

As most children experienced no respiratory conditions and few experienced a change in their number of conditions over time it would have been

inappropriate to compare the mean change in number of conditions between areas. Instead, the proportions of children who experienced a decrease, no change, or an increase were studied. Initially the χ^2 test for analysis of contingency tables,⁸ in which one classification, either rows or column, is quantitative, was used to test for a trend in proportions across the areas grouped according to their change in levels of pollution. Regression analyses were then conducted to allow for the effects of interfering variables. This analysis used a binary response as the dependent variable.⁹ Further details of this method can be found in the preceding paper.⁴

Results

RESPONSE RATES

The response rates are summarised for each period of investigation in Table 1. Most of the exclusions in each period were made because areas had data missing on winter mean levels of pollution. Further exclusions were made if information was missing on ethnic group, if the children lay outside the age range 6 to 11, or if the children belonged to a non-white ethnic group. Non-white children may have differed from white children in their experience of illness and home environment and there were too few non-whites for separate analysis. Finally, children were omitted from the analyses if they had information missing on the six respiratory conditions reported at each examination or father's social class reported at the initial examination. Among 6-11-year-olds of white ethnic origin eligible for analysis from areas with data on pollution, 857 (73.5% of 1166) were studied during 1973-4, 1436 (64.7% of 2219) during 1974-5, 2702 (66.6% of 4056) during 1975-6, and 2036 (70.3% of 2897) during 1976-7.

LEVELS OF POLLUTION

Initially we examined the levels of pollution and their

Table 1 *Summary of the response in each period of investigation*

Response	1973-4	1974-5	1975-6	1976-7
Children in 1st year	8351	8503	8335	8151
Children in 2nd year	5686	6508	6339	4281
Children with pollution data	1227	2326	4259	3059
Children excluded because:				
Ethnic group not known	18	29	59	20
Ethnic group non-white	6	20	23	36
Age outside range 6 to 11	37	58	121	106
Incomplete replies	211	534	986	617
No social class	98	249	368	244
CHILDREN ANALYSED	857	1436	2702	2036

changes in each study period. The levels of pollution were highest and showed the greatest decline in 1973-4 (Table 2). The levels continued to decline in most areas in 1974-5 but by 1975-6 the majority of areas experienced little change in their levels of smoke and SO₂. The levels remained low in 1976-7 but the levels of SO₂ increased slightly in several areas. It was possible that changes at high levels were more likely to affect health than changes at low levels, so the mean levels for the two winters over which changes were studied were examined in later analyses.

In 1973-4 there was a high negative correlation between the mean level of each pollutant and its change in level (for both pollutants $r = -0.99$, $p < 0.01$) as the decrease in levels occurred at high levels and no change took place in areas with low levels. In later periods there was no significant correlation between the mean level of each pollutant and its change in level.

CHANGES IN HEALTH AND POLLUTION

Simple contingency tables were first used to examine the relation between changes in health and levels of pollution. In 1973-4 no relation was found between

changes in health among boys and changes in the levels of smoke ($p > 0.10$) but among girls a trend was found contrary to that expected ($p < 0.10$, Table 3). Relatively more girls experienced a decrease than an increase in number of respiratory conditions in areas where there had been little change than in areas where there had been a decrease in levels of smoke. Similar results were found for areas ranked according to their change in levels of SO₂.

In subsequent years (Tables 4 to 6) no relation was found for either sex between changes in health and changes in the levels of smoke ($p > 0.10$) when the proportions who experienced a decrease, no change, or an increase in number of conditions were compared between the areas grouped according to their changes in levels of smoke. In each table the definitions of a decrease, little change, or an increase in the level of pollution were chosen so that the number of areas which fell into each group were similar. In contingency tables for 1974-5 the change in level was combined with the mean level for the two winters because it was possible that a change in health might more readily have occurred in areas with high decreasing levels of pollution than in areas with

Table 2 Summary of winter mean levels of pollution and their changes in each period of investigation

Description of data on pollution ($\mu\text{g}/\text{m}^3$)					
	No. of areas	Pollutant	Range of mean levels*	Range of change in levels	Mean change
1973-4	5	Smoke	9.1 to 113.4	-58.9 to 0.0	-29.2
		SO ₂	8.1 to 156.5	-93.5 to 0.0	-43.2
1974-5	9	Smoke	10.9 to 78.2	-25.0 to 3.6	-7.1
		SO ₂	13.4 to 123.7	-33.2 to 20.5	-5.9
1975-6	17	Smoke	7.5 to 76.3	-29.8 to 12.2	2.0
		SO ₂	28.6 to 120.9	-49.1 to 31.0	1.9
1976-7	14	Smoke	0.0 to 85.8	-8.9 to 22.5	2.8
		SO ₂	23.0 to 120.4	-12.8 to 31.6	10.0

*The mean of the two winter means in the period under investigation.

Table 3 1973-4 longitudinal analysis. Percentages of boys and girls who experienced a decrease, no change, or an increase in their number of respiratory conditions by amount of decrease in winter mean level of smoke in each area

Change in no. of respiratory conditions	Decrease in winter mean level of smoke ($\mu\text{g}/\text{m}^3$)					Probability value for χ^2 for trend
	58.9	49.8	35.9	1.4	0.0	
BOYS						
Decrease	16.6	21.2	14.3	11.2	13.5	p >0.10
No change	65.1	65.4	71.4	77.8	81.2	
Increase	18.3	14.4	14.3	11.0	5.3	
TOTAL	100 (109)*	100 (52)	100 (91)	100 (54)	100 (133)	
GIRLS						
Decrease	15.3	11.1	13.8	27.3	12.9	p <0.10
No change	67.6	73.0	63.1	67.3	76.6	
Increase	17.1	15.9	23.1	5.4	10.5	
TOTAL	100 (111)	100 (63)	100 (65)	100 (55)	100 (124)	

*Total no. of children in brackets.

medium or low decreasing levels. Changes in health in the three one-year periods between 1974 and 1977 were also unrelated to changes in the levels of SO₂ in similar analyses.

A more detailed examination of the relation between changes in health and pollution was conducted in regression analyses in which continuous measures of pollution were used. In addition to pollution, age and social class were included in the analyses because these have consistently been found to be related to respiratory illness in cross-sectional studies. Values of age and social class were taken from the examination at the beginning of each study period.

In each period age and social class showed no consistent or statistically significant relation to change in health. In 1973-4 improvement in health

after allowing for the effects of the other variables was associated with low levels of pollution which showed little change ($p < 0.05$). In 1974-5 no relation was found in boys between improvement in health and changes in the levels of smoke or SO₂ ($p > 0.10$) but in girls a relation was found between change in health and changes in the levels of smoke which depended on the levels at which the changes occurred ($p < 0.05$). Within the most polluted areas improvement in health seemed to be associated with levels of smoke which showed little change or slight increases contrary to expectation, and within the least polluted areas little association was found between improvement in health and changes in the levels. In 1975-6 and 1976-7 improvement in health in both sexes was unrelated to changes in the levels of

Table 4 1974-5 longitudinal analysis. Percentages of boys and girls who experienced a decrease, no change, or an increase in their number of respiratory conditions by areas grouped according to their changes in winter mean level of smoke

Change in no. of respiratory conditions	BOYS Change in level of smoke [†]			Probability value for χ^2_1 for trend	GIRLS Change in level of smoke [†]			Probability value for χ^2_1 for trend
	Decrease at high levels	Decrease at medium levels	Little change		Decrease at high levels	Decrease at medium levels	Little change	
Decrease	19.5	17.0	13.2	$p > 0.10$	23.3	17.1	14.3	$p > 0.10$
No change	68.8	73.9	74.2		60.6	73.0	77.1	
Increase	11.7	9.2	12.6		16.1	9.9	8.6	
TOTAL	100 (144)*	100 (88)	100 (476)		100 (155)	100 (111)	100 (462)	

[†]Decrease: $< 10 \mu\text{g}/\text{m}^3$

Little change: $> 10 < 5 \mu\text{g}/\text{m}^3$

High level: $> 40 \mu\text{g}/\text{m}^3$

Medium level: 25 to $40 \mu\text{g}/\text{m}^3$

*Total no. of children in brackets

Table 5 1975-6 longitudinal analysis. Percentages of boys and girls who experienced a decrease, no change, or an increase in their number of respiratory conditions by areas grouped according to their change in winter mean level of smoke

Change in no. of respiratory conditions	BOYS Change in level of smoke ($\mu\text{g}/\text{m}^3$)			Probability value for χ^2_1 for trend	GIRLS Change in level of smoke ($\mu\text{g}/\text{m}^3$)			Probability value for χ^2_1 for trend
	< -5	$\geq -5 < 5$	≥ 5		< -5	$\geq -5 < 5$	≥ 5	
Decrease	10.9	14.3	16.5	$p > 0.10$	11.3	10.2	13.7	$p > 0.10$
No change	79.7	76.8	75.9		80.2	81.3	78.6	
Increase	9.4	8.9	7.6		8.5	8.5	7.7	
TOTAL	100 (256)*	100 (349)	100 (726)		100 (248)	100 (342)	100 (781)	

*Total no. of children in brackets

Table 6 1976-7 longitudinal analysis. Percentages of boys and girls who experienced a decrease, no change, or an increase in their number of respiratory conditions by areas grouped according to their change in winter mean level of smoke

Change in no. of respiratory conditions	BOYS			Probability value for χ^2_1 for trends	GIRLS			Probability value for χ^2_1 for trend
	Change in level of smoke ($\mu\text{g}/\text{m}^3$)				Change in level of smoke ($\mu\text{g}/\text{m}^3$)			
	<-5	≥ -5 <10	≥ 10		<-5	≥ -5 <10	≥ 10	
Decrease	15.3	11.9	14.9	p >0.10	16.7	12.6	16.0	p >0.10
No change	71.4	78.7	76.3		70.1	80.4	76.1	
Increase	13.3	9.4	8.8		13.2	7.0	7.9	
TOTAL	100 (189)*	100 (595)	100 (215)		100 (197)	100 (602)	100 (238)	

*Total no. of children in brackets

pollution ($p > 0.10$). It was possible in each period that an association between improvement in health and decreasing levels of pollution might more readily have been found in subgroups of children who were particularly susceptible to respiratory illness, such as those from the young age groups or manual classes. However, no association was found within these groups.

The measure of improvement in health did not take into account the initial number of respiratory conditions experienced by each child and it was possible that children with severe respiratory illness might have been more susceptible than others to effects from changes in pollution. In the cross-sectional analyses greater frequency of severe illness, defined as the presence of three or more respiratory conditions, was associated with high levels of smoke. In additional longitudinal analyses, improvement and deterioration in health were studied by examining the proportions of children who changed from having severe to less severe illness and less severe to severe illness respectively. The number of children in each area who fell into these categories was very small, rarely more than 10, so the analyses were very limited. However, this measure of change in health was also unrelated to changes in the levels of pollution in the same way as the change in number of conditions which was first used.

Finally, we investigated the possibility that changes in health over more than one year might be related more closely to changes in the levels of pollution than health measured over only one year. However, between 1973 and 1975, when large decreases in levels of pollution occurred, no relation was found.

Discussion

Throughout the period of the study no consistent relation was found between change in health and changes in the levels of pollution. Over the period when the levels of pollution were highest and showed the greatest decline, relatively more children experienced a decrease than an increase in their respiratory conditions in areas with low unchanging levels of pollution than in areas with high decreasing levels, contrary to the expected trend. It could be argued that the high levels had not declined enough and children remained at greater risk from illness in the polluted than the non-polluted areas. If this were true, improvement in health should have been associated with decreasing low levels of pollution which occurred in subsequent years, but this was not the case.

Therefore the association between improvement in health and decreasing levels of pollution in 1973–4 seems more likely to have been determined by some factor other than pollution, such as weather

conditions. The polluted areas of the study were found in the north, where temperatures tend to be colder than in the south, and low temperatures have been associated with a high incidence of respiratory disease.¹⁰ Thus children living in the north may have been at greater risk from developing respiratory illness than those in the south.

Alternatively, it might be argued that no relation could be found between change in health and changes in the levels of pollution because the former was an inappropriate or imprecise measurement. However, in the cross-sectional analyses a count of the number of respiratory conditions reported each year provided a measure of illness which was found to be related to the levels of smoke in the study areas. In the longitudinal analyses the change from one group of conditions to another might have been studied but it would have been difficult to interpret.

Further evidence that changes in the levels of pollution did not affect health comes from the analysis of children who were thought to be particularly susceptible to respiratory illness. No relation was found between health and changes in the levels among the younger age groups, the manual social classes, or those with severe illness.

The effects on health from annual changes in the levels of pollution seem to have been investigated in few studies. In one study^{2,11} a cohort of children living in Sheffield were examined when they reached the age of 5 during 1963–5 and then four years later at the age of 9. In contrast to the national study, only cross-sectional analyses were performed, but as the areas were located within one city regional differences such as annual weather conditions would not have interfered with the results. It seems likely that the decline in levels of pollution which occurred from 1964 to 1968 contributed to the disappearance of a difference in prevalence rates of respiratory illness between areas. However, the rates were associated with past episodes of illness¹¹ so the decline in levels of pollution before as well as during the study may have caused improvement in health. No information on previous levels was provided but even those during 1964–8 were well above the levels in the national study.

In another study from Sheffield, changes in the health of adults with established airways obstruction appeared to be associated with the decline in levels of pollution.¹² The rate of decline of forced expiratory volume in patients followed during 1966–72 was only one-third of the rate of decline in patients of the same age studied during 1960–5. The prevalence rates of respiratory symptoms and illnesses were also lower in the former than the latter group. Improvement in the health of the patients occurred during a period when the levels of atmospheric smoke and SO₂ were

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declining markedly as described for the previous study.

Changes in the health of patients with chronic respiratory disease were studied in greater detail in London between 1954 and 1968.¹³ Daily changes in health were recorded by the patients and compared with daily measures of smoke and SO₂. Deterioration in health was associated with high peak levels of smoke and SO₂ but as the annual levels of pollution declined, the number of days with high peak levels became infrequent, and the correlation between changes in health and changes in the levels of pollution became small and statistically non-significant. Comparison of results from this study and the national study is limited because the former study was concerned with daily changes and the latter with annual changes. However, the decline in the number of days with peak levels of pollution in London which was related to deterioration in health was associated with a decline in annual means well above those in the national study. Only the levels in the last year of the study in London, 1967–8, were similar to those in the national study.

In conclusion, the evidence suggests that the levels of pollution measured during the national study were not harmful to health. Thus the cross-sectional finding of an association between respiratory illness and levels of smoke reported in the previous paper⁴ is unlikely to be causative. The results clearly throw doubt on the interpretation of many cross-sectional studies of air pollution and on air quality standards^{14 15} which have been based on cross-sectional results.

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