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Air pollution and exacerbations of bronchitis

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A simple 'diary' technique has been used in London and in other large towns to examine the relationship between daily changes in the condition of bronchitic patients and their environment. It has been shown that these changes are closely related to air pollution, as indicated by the concentrations of smoke or sulphur dioxide. There is some evidence that patients are more sensitive to the effects of pollution at the beginning than at the end of each winter. Comparative studies are now being made in London at five-year intervals to study any change in response following the definite reduction in smoke concentrations. Results indicate some decline in the response of patients to specified concentrations of sulphur dioxide, but in recent years there have been few days on which pollution has been high enough to produce any response.

In the notorious London fog of December 1952 the deaths of some 4,000 were attributed to the effects of the extraordinarily high concentrations of smoke, sulphur dioxide, and other pollutants reached at the time (Ministry of Health, 1954). Subsequently it was shown (Gore and Shaddick, 1958; Bradley, Logan, and Martin, 1958) that in other foggy periods in London changes in mortality could be related to increases in the concentrations of smoke and sulphur dioxide. More detailed studies revealed a general relationship between mortality and morbidity in Greater London and the concentrations of smoke and sulphur dioxide throughout the winter months (Martin and Bradley, 1960; Martin, 1961). Since these studies demonstrated that effects occurred in the general population, we have used a simple technique to follow the response of selected individuals to periods of high pollution. Although the data have been derived from subjective reports, the results have proved useful in assessing the relative importance of pollution and weather in producing exacerbations of bronchitis. From small beginnings in the winter of 1954–55, these studies were enlarged to involve approximately 1,000 patients both in 1959–60 and 1964–65, so as to follow the effects of changes in pollution arising out of clean air policies. Although further work is in progress, here we describe the gradual development of the technique and review the results to date.

PRELIMINARY STUDIES

In the winter of 1954–55 pocket diaries were issued to 34 patients attending the Emphysema Clinic at St. Bartholomew's Hospital. These patients were asked to record their own assessments of their state of health day by day by means of the following code:

A=condition better than usual
B=condition the same as usual
C=condition worse than usual
D=condition much worse than usual.

The method was kept as simple as possible, and the diaries used had only a small space per day, to encourage the patients to use the code rather than to write comments. The results were examined around a period of high pollution in January 1955 (Waller and Lawther, 1955) and supported the view that high concentrations of pollution, measured in terms of smoke, sulphur dioxide or other associated pollutants, were deleterious to the health of bronchitic patients, even in the absence of wet fog.

In the following winter the study was extended to include 195 patients attending four other centres in London (the Hammersmith Hospital and the Chest Clinics at East Ham, Croydon, and Edgware). All of these patients had a history of bronchitis, 80% of them were men, and the average age of the group was 56 years (range 27 to 78 years). Other groups were enrolled in Sheffield (85 patients), in Manchester (35 patients), and in the West Midlands (19 patients).

The diary code was extended so that the patients in addition could indicate:

F=fog at some time during day
X=head or chest cold that day
H=indoors all day.

When these codes applied, some patients omitted to enter A, B, C or D in their diaries, so this

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departure from simplicity impaired the completeness of reporting.

Replicated sheets were used instead of diaries for the first two months, and cheap pocket diaries were issued to all the patients on 1 January 1956. The age, occupation, and clinical diagnosis were noted for each patient. The results for this winter were assessed by means of an arbitrary scoring system:

A (better) = −1	C (worse) = 1
B (same) = 0	D (much worse) = 2

The mean score for each day was determined from the sum of the individual scores divided by the total number of entries for the day. Approximately 180 London patients filled in their diaries regularly: the results were assessed separately for each of the five centres, but finally they were pooled.

RESULTS From November to February there was a general increase in the degree of illness of the group and the several sharp peaks superimposed on this trend coincided with increases in the concentrations of smoke and sulphur dioxide as measured at the sampling site outside our own laboratory in the centre of London (Fig. 1). There was no consistent relationship with temperature or humidity measured at the Meteorological Office, close to our laboratory, although from March to May, when there was an overall decline in the degree of illness, there were a few minor peaks in the illness curve that coincided with falls in temperature (Fig. 2). The association between degree of illness and pollution could have been fortuitous if patients who expected to be worse in 'fog' merely entered C or D in their diaries when they noticed that visibility was reduced. There was some association between visibility and degree of illness (Fig. 3), but there was little response on the day of lowest visibility (19 December 1955) when wet fog was present but the concentration of smoke was not exceptionally high. Most of the minor changes in pollution produced changes in visibility that were too small to be recognized, so we thought it likely that the patients' entries indicated real changes in condition in relation to pollution (Waller and Lawther, 1957).

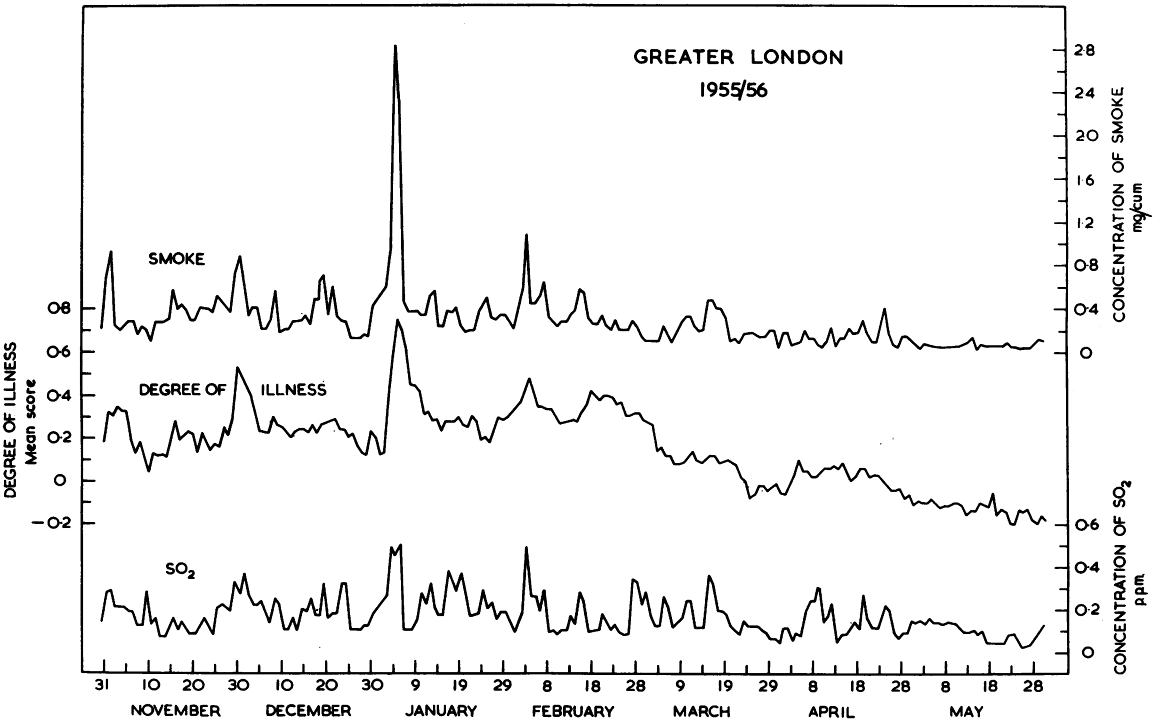

FIG. 1. *Degree of illness and pollution. London, 1955–56.*

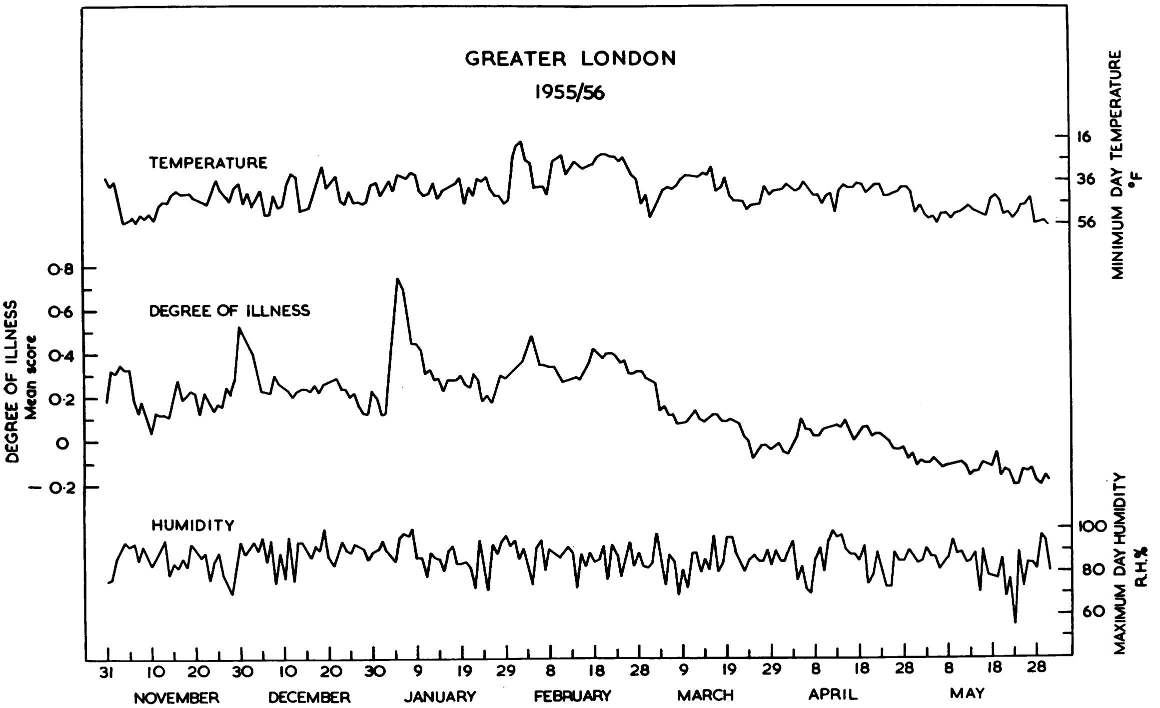

FIG. 2. *Degree of illness and weather conditions, London,* 1955–56.

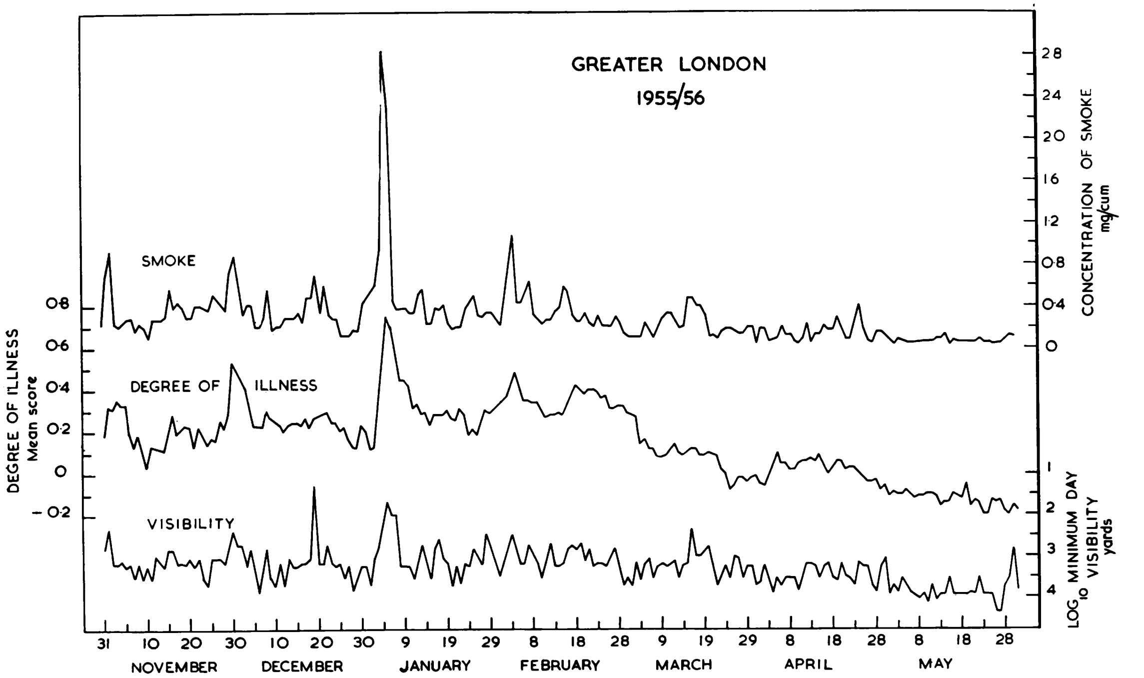

FIG. 3. *Degree of illness and visibility, London,* 1955–56.

The condition of the London patients changed uniformly, irrespective of their area of residence. Although the average concentrations of pollution differed from one area to another, increases and decreases occurred at about the same time everywhere. The situation was different in Sheffield, where with many hills and valleys it was possible for pollution to accumulate in some areas and not others. Although there was a consistent response to the major episode of high pollution in early January in all the cities in this study, the association between illness and pollution was not in general as clear cut in Sheffield as in London. Later, more detailed studies of the effects of pollution were undertaken in Sheffield (Clifton, 1967).

In Manchester (Fig. 4), the pattern of response was similar to that found in London, with a big change in the degree of illness on three occasions when pollution was high (at the end of October, in November, and in early January). There were not many patients in the West Midlands group and the random variation was large, but there was evidence of a response to high pollution on two or three occasions during the winter.

The interpretation of our results was based mainly on inspection of composite graphs which showed little or no time lag between increases in pollution and increases in the degree of illness. However, the exact time at which pollution increased in any given locality could not be established, neither could the time of day when patients began to feel worse. The pollution measurements were average concentrations over periods of 24 hours beginning and ending at noon, and the patients' diary entries referred to their overall assessment of condition each day, beginning and ending nominally at midnight. In Figs 1 to 4 the time scales have been matched as closely as possible by plotting all results at the mid-points of the periods concerned, but even then some latitude must be allowed in matching up peaks in pollution and illness. Hourly measurements made at our laboratory showed that most 'episodes' of high pollution had sharp peaks in concentrations of smoke and sulphur dioxide, lasting for a few hours (Waller and Commins, 1966), and if the patients were influenced more by maximum values than by 24-hour average concentrations, the 'stimulus' and the 'response' could appear to be out of phase by half a day either way. During periods of high pollution adverse conditions often spread slowly across London, so that patients in some areas might have been affected later than others. Despite these uncertainties about times,

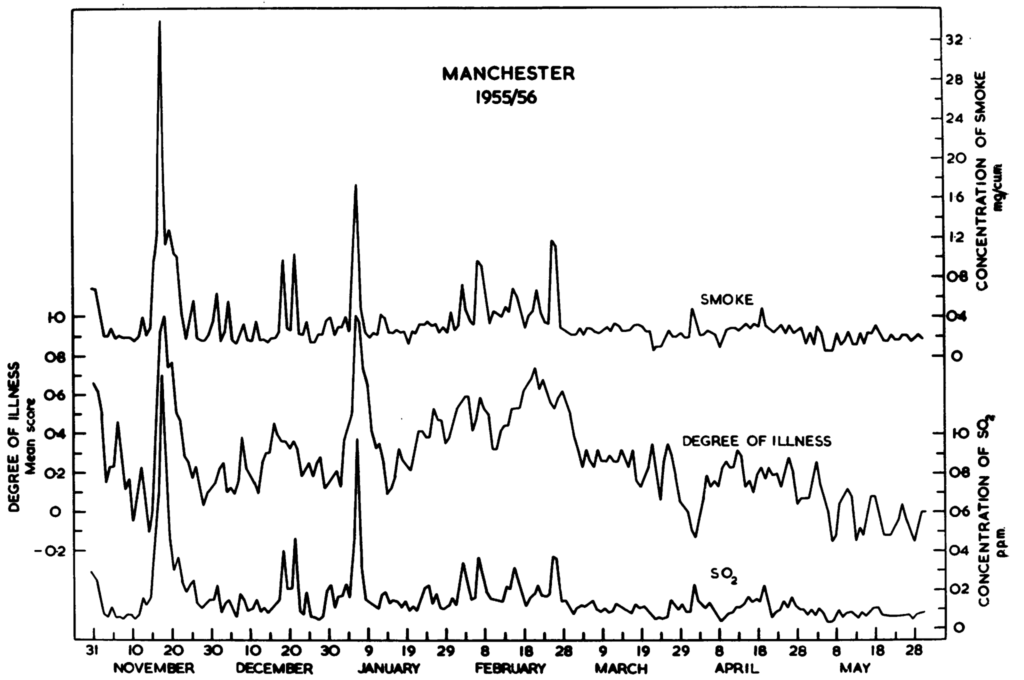

FIG. 4. *Degree of illness and pollution, Manchester, 1955–56.*

there was little doubt about the association between illness and pollution, and in general when the concentrations of smoke and sulphur dioxide increased suddenly, there was a rapid rise in the degree of illness, followed by a more gradual return to normal. This type of pattern made it difficult to assess the association adequately in terms of correlation coefficients, since pollution was often low again before the patients had recovered, and there was also the problem of allowing for the gradual change in 'baseline' in the degree of illness figures during the winter. Some idea of the relative importance of these variables was obtained by calculating correlation coefficients between each of them and the mean score, for each month separately. In London, mean score was significantly correlated with both smoke and sulphur dioxide for most of the winter, but in the other centres, where the random variation was greater, the coefficients were significant only for one or two months. In general the correlation with temperature and relative humidity was small and not significant. The results suggested that the concentrations of either smoke or sulphur dioxide could be used as indices of adverse conditions, but they gave no indication as to whether one of these pollutants was any more important than the other.

FURTHER STUDIES

Although these early studies left a number of questions unanswered, they showed that valuable information about the nature of the environmental conditions affecting bronchitic patients could be obtained by use of this simple technique, without any special care in the clinical selection of patients or location of sampling sites. Most of the patients maintained their interest and enthusiasm for filling in their diaries daily for one winter, but it began to wane once they were asked to repeat the experiment through a second winter.

No diaries were issued during the winter 1956–57, but in 1957–58 a further study was undertaken in London. Patients were again recruited from the clinics at the Hammersmith Hospital, East Ham, Croydon, Hammersmith, and Edgware, and a new centre (Enfield) was included. The aim was to recruit at least 50 patients from each centre, and in this study arrangements were made to measure pollution locally, where the subjects lived or worked, with a view to assessing the results from each area separately. At Croydon sampling apparatus was installed in the home of one of the patients; at Enfield it was installed in a factory; and at the remaining three centres it was installed in the Chest Clinic. The apparatus consisted of a standard daily smoke filter, as used at our own laboratory and at many other sites throughout the country (Warren Spring Laboratory, 1966), but sulphur dioxide was not measured. The smoke filters were changed daily by the occupants or staff at each site and sent to us once a week for assessment. Brief personal and clinical notes were obtained for each of the 246 patients originally enrolled for the 1957–58 study, and at some time during the course of the winter each was visited in his (or her) home. Nearly all the patients were within the age range 45 to 70: the mean age was 58 and 84% were male. Most were diagnosed as chronic bronchitics, with a history of cough and phlegm for more than five years. Few reported severe breathlessness, but most gave some history of wheezing. Just over half the men were in regular employment.

The type of heating in use was noted when visiting the homes: 71% had open coal fires, and a further 9% were using smokeless fuels on open fires. These proportions were typical of London homes at that time, but the situation is different now.

The results of the 1957–58 study were initially assessed on the 'scoring system', and as before there were sharp peaks in the illness curve and a gradual deterioration from the beginning to the end of the winter. The gradual change in the 'baseline' made it difficult, however, to compare the magnitude of the peaks at different times in the winter or in different winters. To overcome this difficulty, an alternative method of assessing the diary results was introduced. Each diary entry was compared with that on the preceding day, and the percentage of patients who became worse was calculated. The results are shown in Figure 5. In a period of high pollution at the beginning of December 1957, there was a large increase in the percentage worse, to 28%, and several smaller peaks in the illness curve also coincided with increases in pollution.

Temperature and humidity were also plotted but, as in the earlier study, these were not as closely related to illness as were the indices of pollution. When the 1955–56 results were recalculated on the 'percentage worse' basis, the maximum in the illness curve was 28%, in the period of high pollution in January 1956.

As a 'control' experiment, a small group of bronchitic patients living in Crawley new town and a larger group of ex-miners working in a rural area of South Wales were studied in 1957–58. In neither case was there any uniform

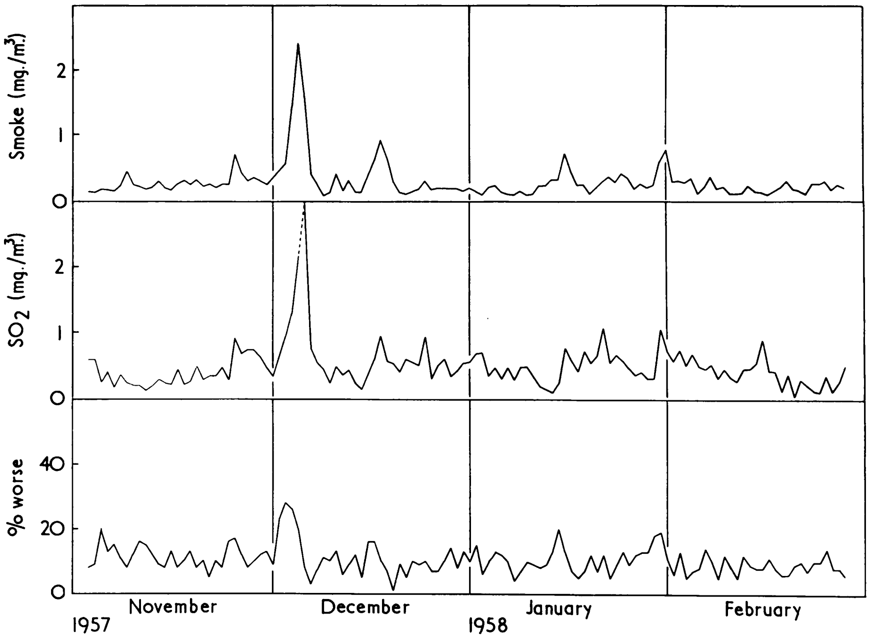

FIG. 5. *Proportion of patients 'worse than day before', London,* 1957–58.

change in condition at any time during the winter.

The use of groups of subjects with limited mobility, whose pollution exposure could be defined more precisely than that of the general population, was also explored in 1957–58. Bronchitic patients living in Salvation Army homes responded in a uniform manner to periods of high pollution, and in 1958–59 this approach was extended to men in London prisons. These too gave a uniform response, and, among a total of 36 selected patients followed in that winter, 54% became worse in the period of high pollution at the end of January 1959.

LARGE-SCALE STUDIES

The preliminary studies undertaken between 1954 and 1959 had shown that at times of high pollution changes in the condition of bronchitic patients could be demonstrated using the diary technique with small groups of about 20 carefully selected patients or with larger groups of about 200 patients selected on a more general basis. In either case there was a definite response in every episode of high pollution (when concentrations of smoke or sulphur dioxide exceeded 1,000 μg./m.^{3}), but the data were not sufficient to establish the lowest concentrations at which adverse effects occurred. A larger study was planned for the winter 1959–60, when the opportunity was taken to try a modified form of diary entry. Patients were enrolled mainly through Chest Clinics in the Greater London area, but a few were enrolled through general practitioners and prison medical officers. The criterion adopted for the selection of patients was 'those whose symptoms of chronic bronchitis, emphysema or asthma were likely to be made worse by air pollution'. Since we were anxious to include a large number of patients in this study, we did not restrict the choice in any other way, and all patients who lived or worked in Greater London were accepted. In all, 1,395 patients were enrolled in the study. Each was given a serial number; those with odd numbers received a diary with instructions to enter A, B, C or D as in earlier studies and those with even numbers received one with the following instructions:

Write BETTER if your condition has been BETTER than the day before.

Write SAME if your condition has been the SAME as the day before.

Write WORSE if your condition has been WORSE than the day before.

Although in the 'ABCD' system the patients were required to compare their current with their 'usual' condition, we proposed to assess the entries by noting whether they were better, same or worse than the day before. The new system allowed the patients to do this directly, and it was more flexible than the old since they could, where appropriate, indicate a continuous deterioration day by day without limit. We did not know, however, whether the patients would find it easier or more difficult to follow, and the results from the two systems were assessed separately in the first instance. The diaries were sent out at the end of October 1959, so that most patients had them in use by early November, and new diaries were issued to run from 1 January 1960. The study was concluded at the end of March and diaries covering the whole or part of the winter were received from 1,071 patients. There appeared to be no difference in the degree of co-operation received from patients using the two systems: 539 diaries were received from those entering 'ABCD' and 532 from those entering 'better, same, worse'. Some of the patients who failed to complete or return their diaries had died or moved out of the district since their last contact with a Chest Clinic. There was no complete follow up of non-respondents.

All the results were assessed in terms of 'per cent worse', and comparison of the daily figures obtained with the two diary systems showed close agreement throughout the range: the results were therefore combined in all subsequent analyses. Entries from all returned diaries were accepted, even if they had been filled in for only a short period. Some patients showed little or no variation in condition throughout the winter, but their inclusion only 'diluted' the results from other patients and did not affect the position of peaks. In Fig. 6 the mean concentrations of smoke and sulphur dioxide at seven sites in Inner London, maintained by the Greater London Council, have been used to provide indices of pollution. These sampling sites are in the Boroughs of Lambeth, Kensington, and Chelsea, Camden, Hackney, Greenwich, and Lewisham: they were originally chosen to represent conditions in the inner residential areas of London, and they have remained in operation continuously since 1957. Results from these sites were used also by Gore and Shaddick (1958) in their study of daily variations in mortality in the County of London, and by Martin and Bradley (1960) in similar studies in Greater London.

These results showed that there was a remarkably consistent response to pollution. On each occasion when the concentration of smoke or sulphur dioxide exceded 1,000 μg./m.[3] there was a sharp increase in the percentage of patients reporting that they were 'worse' than the day

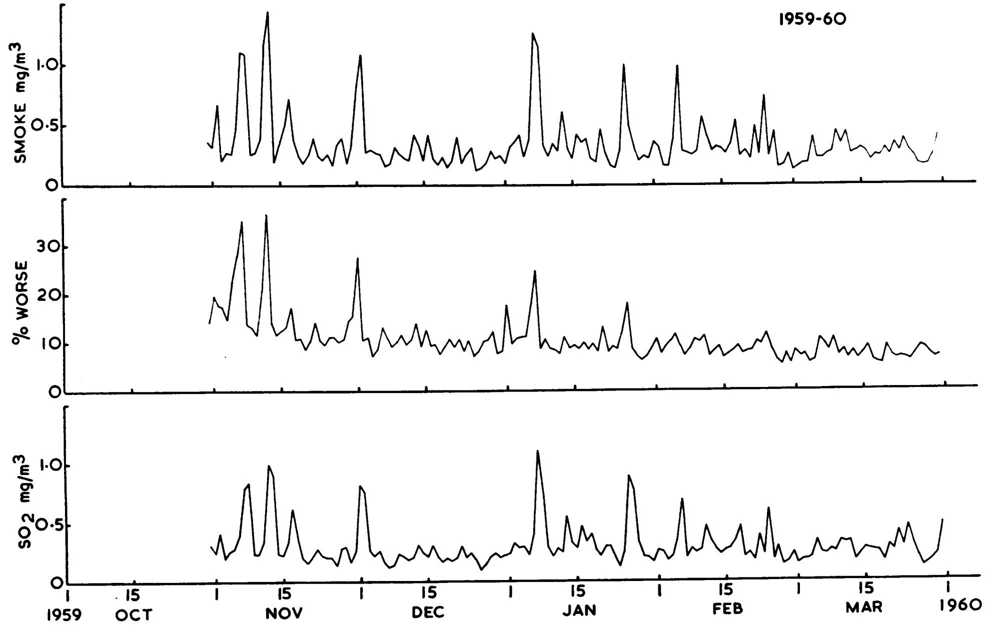

FIG. 6. *Proportion of patients 'worse than day before', London,* 1959–60.

before. The lowest concentration associated with any definite change was about 600 μg./m.³, but there was a tendency for the association to disappear towards the end of the winter. At the beginning of the study the 'baseline' was about 12·5% worse, with peaks up to 37%, and at the end the 'baseline' was only 7·5%, with no sharp peaks, even with moderate increases in pollution. As before, we could not determine whether one pollutant was more important than another in producing the observed effects. The concentrations of smoke and sulphur dioxide followed one another very closely and either could be considered as an index of pollution: they were also very similar numerically. Graphs showing daily variations in temperature and humidity were prepared, but these showed nothing like the close association demonstrated between pollution and per cent worse.

To investigate the relative importance of smoke and sulphur dioxide, a further study was made five years later, in 1964–65, by which time the operation of the Clean Air Act had led to a substantial reduction in smoke concentrations in London, but relatively little change in sulphur dioxide. Patients were enrolled through Chest Clinics as before. The diaries were of the same type, but they were specially printed to cover the whole of the winter, from October to March. All patients were asked to use the 'better, same, worse' system, as this had proved to be as satisfactory as 'A,B,C,D,' and it simplified the analysis of results. Diaries were sent to 1,395 patients (the same number as in 1959–60), and in April 1965 1,037 (74%) were returned at least partially filled in. There was no need to send out new diaries half way through the winter, but letters were written to the patients then asking them to return a postcard confirming their co-operation. Entries from the diaries were punched directly on to 80 column cards (3 cards per patient). Complete tabulations were printed from the cards and daily results were worked out by computer. The diaries were sent out a few weeks earlier than in 1959–60 so that results for a full 6-month period, beginning on 1 October 1964, could be analysed.

The mean concentrations of smoke and sulphur dioxide at the seven G.L.C. sites were used as indices of pollution, as in 1959–60. As anticipated, there was less smoke than there was in 1959–60 but the average concentrations of sulphur dioxide were similar in the two winters. The diary results for 1964–65, expressed as 'per cent worse', are shown in Figure 7.

There were fewer days of high pollution in 1964–65 than in 1959–60, owing to differences in weather conditions, so that it was difficult to make any strict comparison between the results from

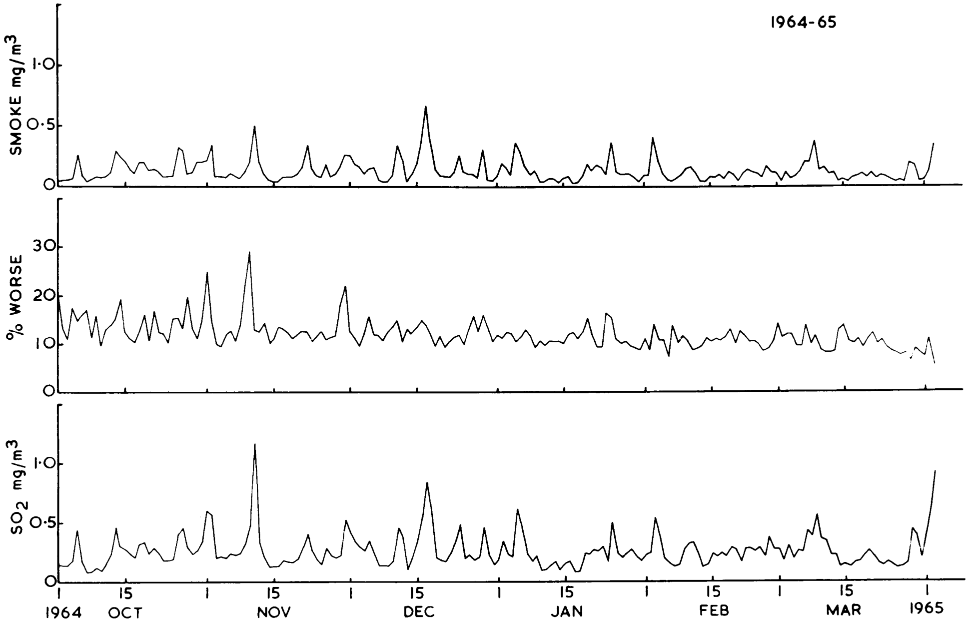

FIG. 7. *Proportion of patients 'worse than day before', London, 1964–65.*

the two studies. On the one occasion when sulphur dioxide exceeded 1,000 μg./m.³ there was a big increase (to 29%) in per cent worse. There was again a gradual decline in the 'baseline' from about 12·5% at the beginning to about 7·5% at the end of the period of observation. There was also some evidence that the association with pollution declined during the winter: in particular there was no response at all to a sudden increase in pollution on April 3. The concentration of sulphur dioxide then was 900 μg./m.³ (next to highest for the winter) and that of smoke was 300 μg./m.³. This was the last day of the study. Patients were asked to send their diaries back on April 1, but about half of them were still making entries up to April 3. On another day in the middle of the winter (17 December), when the concentration of sulphur dioxide and of smoke was within the range 600 to 1,000 μg./m.³, there was no response among the patients, but there were several other days with concentrations of sulphur dioxide close to 600 μg./m.³ when fairly well-defined peaks occurred in the 'per cent worse' curve. When the two winters were compared in terms of the association with sulphur dioxide, the general impression was of a slightly reduced and less consistent response in 1964–65 as compared with 1959–60. It was clear, however, that some association remained which had not been reduced in proportion to the reduction in smoke concentrations.

To examine the results from the two major studies on a more quantitative basis, the diary entries were reassessed on a revised scoring system. One of the problems with the original (1955–56) system, in which patients compared their daily condition with their 'usual condition', was the substantial change in baseline during the winter. The 'per cent worse' system of assessment, based on comparisons with the previous day, was devised to overcome this. It did not solve the problem completely, for the gradual increase in the illness score was replaced by a gradual decrease in 'per cent worse'. Each of these observations was of interest, for the demonstration of a deterioration in the health of bronchitic patients from November to February (Fig. 1) was in accordance with clinical impressions, and the reduction in 'per cent worse' (Figs 6 and 7) indicated that the condition of the patients tended to become more stable during the course of the winter. This was not due to any selective withdrawal of the more variable patients from the study. The percentage reported 'better' also declined gradually through each winter and it seemed likely that the patients were either losing interest or that when they reached their lowest winter level they no longer responded to changes in the environment. By

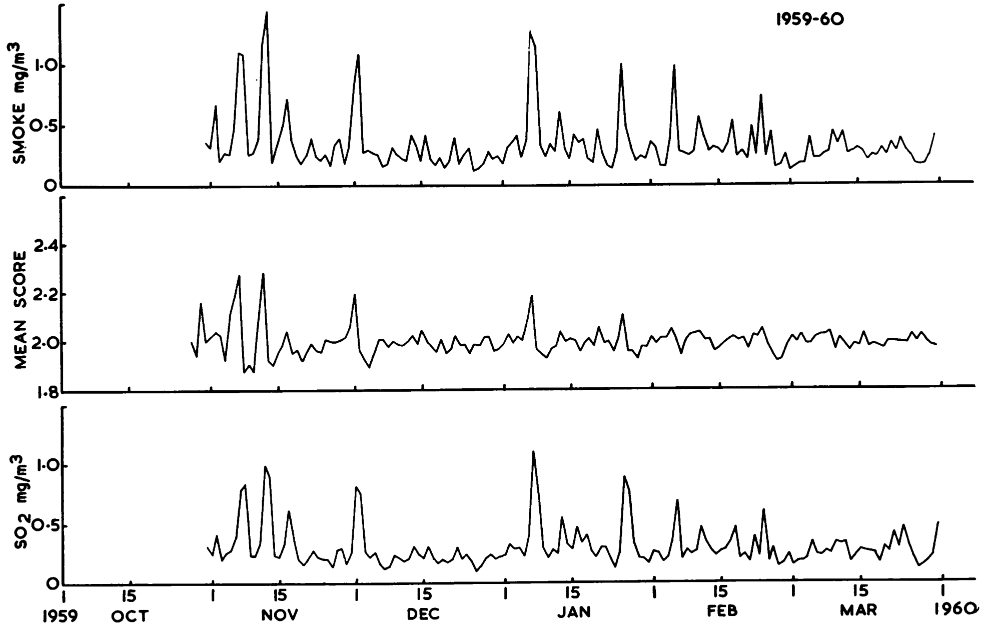

FIG. 8. *Condition of patients re-assessed on 'mean score' basis, London, 1959–60.*

assigning 'scores' to the individual entries (better = 1, same = 2, worse = 3) and calculating mean scores day by day it was found that the trends in 'per cent worse' and 'per cent better' cancelled out, yielding graphs (Figs 8 and 9) that had essentially level baselines.

The mean values of all the quantities plotted in Figs 8 and 9 are shown in Table I, together with the corresponding standard deviations, and correlation coefficients between mean score and the indices of pollution.

In each winter the overall mean score was close to 2, as expected, though there was a small decline from November to March. The standard deviation of the mean score was greatest in November, and (as shown in Table II) there were then more days

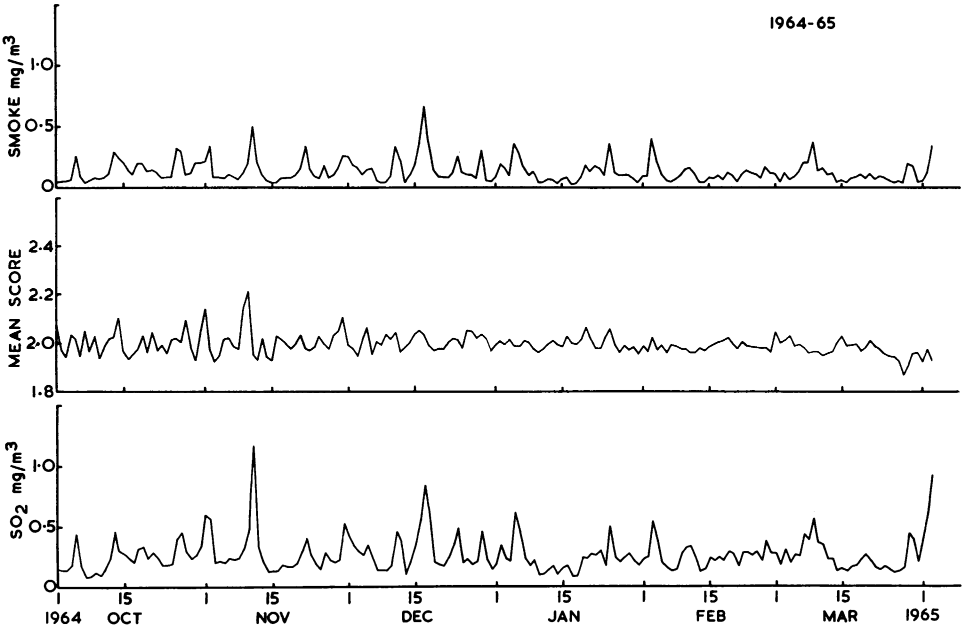

FIG. 9. *Condition of patients and concentrations of smoke and sulphur dioxide, London,* 1964–65.

TABLE I

ANALYSIS OF DIARY RESULTS, WINTERS 1959–60 AND 1964–65

	No. of Days	Mean Score		Smoke (μg./m.³)		SO₂(μg./m.³)		Corr. Coeff.	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Score/ smoke	Score/ SO_2
1959–60									
October	6	2·03	0·07	357	175	274	99	0·44	0·60
November	28	2·00	0·10	435	340	349	240	0·36	0·42[1]
December	35	1·99	0·05	294	185	248	143	0·36[1]	0·53[1]
January	28	2·00	0·06	393	284	365	235	0·61[1]	0·62[1]
February	28	1·99	0·03	340	183	285	129	0·37	0·51[1]
March	31	2·00	0·02	264	83	254	89	−0·39[1]	−0·29
Whole winter	156	2·00	0·06	342	232	296	177	0·38[1]	0·44[1]
1964–65									
October	35	2·00	0·06	144	85	262	129	0·17	0·33
November	28	2·01	0·06	131	99	275	199	0·10	0·14
December	35	2·00	0·03	158	127	292	157	0·24	0·29
January	28	1·99	0·03	117	87	228	121	0·36	0·18
February	28	1·99	0·02	109	70	252	88	0·24	0·23
March	33	1·97	0·03	110	80	272	173	−0·17	0·25
Whole winter	187	1·99	0·04	129	95	264	149	0·16[1]	0·13

The results were analysed by four or five week periods rather than calendar months.
The first period in 1959–60 and the last in each winter were incomplete.
[1] Significant at 5% level.

of high pollution than in other months. Throughout the winter of 1964–65 concentrations of smoke were well below those of 1959–60: the mean concentration during the period of the later study was only 38% of that five years earlier. There was, however, little change in the mean concentration of sulphur dioxide. Bearing in mind the earlier reservations made about the complex time relationships, the correlation coefficients between mean score and pollution were quite high, particularly in the winter of 1959–60. Those between mean score and sulphur dioxide were significant for each of the four months November 1959 to February 1960. The coefficients were much lower in 1964–65 than they were in 1959–60, and none of those for monthly periods reached the 5% level of significance.

An attempt to compare the response from month to month and from one winter to the other has been made in Table II. For this purpose days on which the mean score was more than twice the (whole winter) standard deviation above the mean were tabulated with the corresponding concentrations of smoke and sulphur dioxide. This procedure selected the main sets of coincident peaks seen in Figs 8 and 9; in general, the mean score and pollution peaks coincided exactly, but some were out of phase by one day. Peaks in October, before all the patients had been enrolled, were excluded.

Other days on which the concentration of smoke or sulphur dioxide exceeded 500 μg./m.^{3} have been included in Table II, together with corresponding 'peaks' in mean score. The response to pollution clearly declined during the course of each winter, and it would therefore be unrealistic to compare the results from an episode near the beginning of one winter with those near the end of the other. For this reason the episodes have been arranged in date order in Table II, placing those occurring at roughly the same time in each winter side by side to facilitate comparison. The deviations observed in 1964–65 were, in general, lower than those seen in 1959–60, even when the concentrations of sulphur dioxide were similar (as in the second pair). There were not enough pairs of episodes to determine an exact relationship between the 'response' of patients and the concentrations of smoke and sulphur dioxide, but the main findings can be summarized as follows:

1. Patients are most sensitive to changes in pollution at the beginning of each winter, i.e., in November.

2. The minimum pollution leading to any significant response is about 500 μg./m.^{3} of sulphur dioxide together with about 250 μg./m.^{3} of smoke (each representing the average, over 24 hours, at a group of sites in Inner London). It is important to recognize, however, that there is no evidence that either of these pollutants would, by itself, produce the same response.

3. The type of pollution found in London now, with much less smoke, and fewer days of high pollution of any kind, has led to a reduced response among the patients.

When individual diary entries were examined, it was found that many of the patients did not respond at all to episodes of high pollution, and others responded to just one or two of the episodes shown in Table II. One possible explanation was that patients were affected by the first period of high pollution that they encountered in each winter, and thereafter became relatively insensitive, due either to restriction of activities once they became ill or to protection afforded by therapy or by increased production of mucus.

TABLE II

PEAK VALUES IN DIARY STUDIES, 1959–60 AND 1964–65

1959–60				1964–65			
Date	Smoke (μg./m.^{3})	SO_2(μg./m.^{3})	Deviation	Date	Smoke (μg./m.^{3})	SO_2(μg./m.^{3})	Deviation
7 November	1,095	786	0·28*	1 November	209	599	0·14*
12 November	1,162	990	0·29*	10 November	499	1,160	0·22*
17 November	708	612	0·04				
1 December	810	809	0·20*	30 November	262	524	0·11*
				16 December	660	838	0·06
7 January	1,256	1,095	0·19*	4 January	353	614	0·02
13 January	602	546	0·04				
26 January	999	875	0·11				
5 February	977	675	0·05	3 February	402	543	0·03
24 February	736	595	0·05				
				9 March	369	554	−0·03
				2 April	345	912	−0·06

In this table, occasions on which pollution and/or mean score was high have been isolated, using the following criteria: smoke or SO_2 greater than 500 μg/m.^{3}; mean score – deviation from winter mean greater than twice the standard deviation (indicated by*). Dates refer to the pollution peaks: the dates of the mean score peaks differed from these by one day in a few cases.

Some may have escaped exposure to the earlier episodes, leaving a diminishing 'pool' of susceptibles to respond to later ones. An attempt was made to separate from the records patients who appeared to respond to several episodes of high pollution. Those who became worse on at least one-third of the occasions when the concentration of smoke or sulphur dioxide exceeded 500 μg./m.^{3} and who did not vary much at other times were identified: 307 such patients were selected in 1959–60, and 87 in 1964–65. Such combinations of results could have occurred by chance, but it was of interest to consider whether these patients were particularly sensitive to changes in pollution. There was nothing obviously different about them in respect of sex, age, or area of residence.

When the final study in the present series was planned for the winter 1967–68, these selected patients were used again to determine whether they might in fact be useful 'monitors' of the effects of pollution. Of the 87 patients selected, 50 were able and willing to participate again. To reduce the risk of patients filling in their diaries for long periods from memory (and evidence that some had done this had been seen in the earlier studies), weekly postcards were issued, drawn up for daily entries in the same way as the diaries, and stamped ready for return. The 'lapse' rate was reduced in this way, for enquiries were made immediately if postcards failed to arrive when expected. Results were graphed week by week, though it was disappointing to note that there were hardly any periods of high pollution to test responses. Pollution was measured at the same sites as before, and the results are shown in Figure 10.

The outstanding differences between these curves and earlier ones are the very low smoke concentrations and the absence of any major peaks in smoke or sulphur dioxide. There was only one day in the whole of the winter when the concentration of sulphur dioxide exceeded 500 μg./m.^{3} (9 November: SO_2 605 μg./m.^{3}, smoke 317 μg./m.^{3}). The peak in the mean score curve on that day represented a deviation that was not quite twice the standard deviation, and there were other peaks of this magnitude that did not correspond with days of high pollution. There was still some overall association with pollution, and in Table III the correlation coefficients are compared with those obtained from the same (selected) group of patients in 1964–65.

The 1964–65 coefficients had been enhanced by the selection procedure, but, as in the whole population for that year (Table I), the correlation with smoke was a little higher than that with SO_2. The relationship with several other variables was also studied; in particular, the correlation with daily

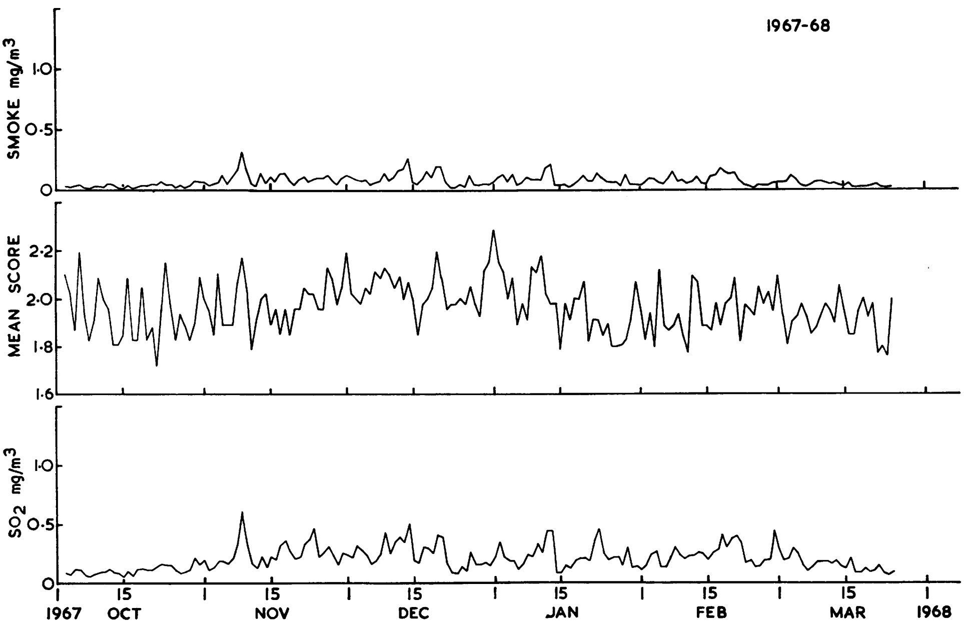

FIG. 10. *Condition of patients and concentrations of smoke and sulphur dioxide, London, 1967–68.*

TABLE III

SUMMARY OF RESULTS, SELECTED PATIENTS, 1964–65 AND 1967–68

		1964–65	1967–68
Mean score	Mean	1·98	1·96
	S.D.	0·10	0·11
Smoke (μg./m.³)	Mean	129	68
	S.D.	95	48
SO_2 (μg./m.³)	Mean	264	204
	S.D.	149	100
H_2SO_4 (μg./m.³)	Mean	7·3	6·3
	S.D.	4·8	4·0
Temp. (°C.)	Mean	6·4	6·3
	S.D.	4·1	4·3
Corr. coeff., mean score and	Smoke	0·39[1]	0·31[1]
	SO_2	0·30[1]	0·28[1]
	H_2SO_4	0·51[1]	0·26[1]
	Temp.	−0·24[1]	−0·17[1]

These results are for the whole winter period, October to March.
[1] Significant at 5% level.

measurements of particulate sulphuric acid, made at our own laboratory, was found to be relatively high. There was also a negative correlation with temperature (as measured in Central London at 9 a.m. each day). For 1967–68, all these correlation coefficients were lower but still significant. This time the correlation with sulphuric acid was lower than that with other pollutants. It seemed likely that the patients selected were particularly sensitive to pollution, for from past experience no correlation would have been expected with the very low levels of pollution encountered by such a small group.

DISCUSSION

One of the purposes of the present paper was to demonstrate the way in which a simple and inexpensive method of enquiry had led to useful indications of the effects of environment on health. This 'diary' technique is applicable only to the study of patients with diseases in which frequent changes in condition may occur. Apart from its value in studies of chronic bronchitis in relation to air pollution, it has been used to study variations of the severity of rheumatoid arthritis with changes in weather. A similar approach has also been used to assess the results of treatment among asthmatic patients (McAllen, Heaf, and McInroy, 1967; British Tuberculosis Association, 1968). As it is essential to maintain the patients' interest and co-operation, efforts have been made to find out which method of recording (on printed sheets, postcards, or pocket diaries) the patients preferred. Those who had tried more than one system favoured small pocket diaries that they could carry around with them. The use of postcards returned once a week helped us but was not popular among the patients. The diaries that were specially printed[1] to cover a whole winter season were the most convenient.

'Wandering baselines' were minimized by the use of questions relating to a change in condition compared with the day before. Only one simple question each day on general condition should be asked, since the inclusion of additional questions only tended to confuse the patient. The presence of a fairly large proportion of patients who do not respond at all to changes in the environment 'dilutes' the associations but does not cancel out the response of the others. Although we were able to select 'sensitive' patients from one study (1964–65) for use in another (1967–68), this procedure is of limited value, since their co-operation falls off if the same patients are asked to continue for more than one season; furthermore, after an interval of several years many have moved, entered hospital or died.

The results reported here demonstrate convincingly that pollution rather than adverse weather is associated with exacerbations of chronic bronchitis. So far we have not been able to show which pollutant or combination of pollutants is responsible for the associated exacerbations, and the concentrations of smoke and sulphur dioxide used can only be regarded as indices of the active agents. Attempts to assess the relative importance of smoke and sulphur dioxide have been frustrated by an absence of periods of high pollution of any kind in recent years. This improvement is in itself important; the loss of the 'blanket' of smoke over London may have reduced the tendency for temperature inversions to persist, thereby reducing the risk of high concentrations of any pollutant being reached. Comparisons between the two main studies, done five years apart, show a reduced overall response to pollution during the later winter, when there was less smoke and few periods of high pollution. The interpretation of the findings is difficult, since the susceptibility of patients to the effects of pollution may have changed as a result of improved drug therapy. Studies on mortality and hospital admissions in London also show that there is no longer a close relationship with pollution during the winter months, as there was some 10 years ago, and it is clear that the net result of the changes in pollution has been beneficial (Waller, Lawther, and Martin, 1969). The concentration of smoke in London is still declining year by year, and in future studies it may be possible

[1]These diaries were supplied by J. M. Tatler, Printer, Abbey Street Works, Derby

to observe the effects of what sulphur dioxide remains when concentrations of smoke have become very low in comparison with those of 10 to 15 years ago.

The limitations of this technique must be recognized. Some authors have used results from epidemiological studies as guides for the establishment of 'air quality criteria' in respect of sulphur dioxide (U.S. Dept. of Health, Education and Welfare, 1969). This can be misleading, for it is only possible to assess the response of patients to the general mixture of pollutants in the air. In London, even with the disappearance of much of the black smoke, there are still other pollutants present apart from sulphur dioxide. Among these, sulphuric acid may be of special interest as a respiratory irritant, and we now have daily measurements of this pollutant to link with epidemiological data. It should also be stressed that the absolute concentrations of pollutants, as measured in our surveys, serve only as a guide to the exposure of patients. In particular, all the measurements were made out of doors, whereas many of the patients would have spent much time indoors. The concentrations found indoors depend on the type of heating system, the degree of ventilation and other characteristics of the house, but in general the concentration of smoke is fairly close to that outdoors, whilst the concentration of sulphur dioxide is appreciably lower indoors. Biersteker, de Graaf, and Nass (1965) reported concentrations of sulphur dioxide in homes in Rotterdam that were on average only 20% of those out of doors, but they found one example of a house where indoor concentrations were consistently above those outside. This can happen when faulty flues or heating appliances allow fumes to escape into the room, and Biersteker *et al.* (1965) consider that this may be of some importance in episodes of high pollution, when there is little wind to induce draughts in chimneys.

One further reservation is that the measurements quoted in the present paper relate only to 24-hour average concentrations of sulphur dioxide and other pollutants. The evidence that we have from experimental work on normal subjects suggests that the effects of inhaling prepared mixtures of pollutants are of rapid onset, and peak concentrations encountered during the day may therefore be more relevant than 24-hour averages. The effects that we have reported cannot be considered as the result of 24-hour exposures to at least 500 μg./m.^{3} of sulphur dioxide together with 250 μg./m.^{3} of smoke: they are more likely to reflect the effects of brief exposures to the maximum concentrations occurring during the day, and these may be several times the 24-hour averages (Waller and Commins, 1966).

In this series we have not tried to differentiate between various respiratory symptoms, nor have we attempted to make any objective measurements of changes in lung function. Daily observations on ventilatory capacity in normal subjects and in a small number of bronchitic patients have been made in a separate study (Lawther, Brooks, and Waller, to be published), and in some individuals there is evidence of an effect of pollution. It is not, however, practicable to make daily measurements, even with the relatively simple peak flow meter, on large groups of subjects, and in a third study in our 'five-yearly' series which is now in progress (1969–70) we are again confining ourselves to the use of the simple diary technique described above.

In the course of the studies reported here we have enjoyed the enthusiastic co-operation of the physicians and staffs of more than 60 Chest Clinics and Hospitals in the London area, plus others in Sheffield, Manchester, Birmingham, and Wolverhampton. We are also indebted to general practitioners in Greater London and in Crawley who helped in the selection of patients, to Officers of the Salvation Army (London Division), members of the Prison Commission Medical Service, the Manager and staff of the Austin Junior Car Factory, Hengoed, and to members of the staff of the Ferguson Radio Corporation factory at Enfield.

Many of our colleagues in the Air Pollution Unit have assisted in the organization of the surveys, and the control study in South Wales was arranged by the M.R.C. Pneumoconiosis Unit. Access to records of pollution measurements was freely granted by the Greater London Council and the Warren Spring Laboratory, Stevenage. Mr. H. Kasap, of St. Thomas's Hospital, kindly prepared a program for the analysis of the results, and this was run on the IBM 7094 computer at Imperial College.

Finally, we are grateful to the subjects (over 3,000 in all), most of whom diligently filled in their diaries day by day, offering in addition many useful comments on their condition and on the conduct of the survey.

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