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Exposure to oxides of nitrogen: respiratory symptoms and lung function in British coalminers

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ABSTRACT Five hundred and sixty British coalminers with relatively high or relatively low exposures to oxides of nitrogen, based on measurements of concentrations of these gases at nine collieries over four years, and records of the men's places of work and colliery mining conditions over a total of eight years have been studied. Data on these men's respiratory symptoms and ventilatory capacity (FEV_1), obtained as part of an epidemiological study of British coalminers, have been used to investigate possible adverse effects of exposure to oxides of nitrogen. Exposures to oxides of nitrogen were generally well below threshold limit values, though occasional peaks after shotfiring and during diesel locomotive use did exceed short term limits. No relationship was found between exposure and respiratory symptoms or decline in FEV_1 nor was there any evidence of differences in symptoms or FEV_1 between 44 pairs of men matched for age, dust exposure, smoking habit, coal rank, and type of work, but differing in respect of exposure to oxides of nitrogen. It has not been possible to detect any adverse effects on the health of this working population of the levels of nitrogen oxides that have occurred in British mines over the past decade. With the current levels of these gases, any long term effects on respiratory health are so small as to be undetectable in the presence of smoking and dust exposure.

Nitrogen dioxide and nitric oxide are toxic gases which may be met in a variety of industries. Exposure of workers to high levels of nitrogen dioxide in particular may result in acute pulmonary oedema and bronchiolitis obliterans.[1 2] Exposure of animals to levels around twice the threshold limit value for prolonged periods has caused pulmonary overinflation associated with obstructive lesions in proximal bronchioles, an appearance resembling, though not identical with, emphysema.[3 4] Coalminers may be exposed to both nitrogen dioxide and nitric oxide either after shotfiring or from diesel engines. In the past such exposures have occasionally been high,[5 6] resulting in acute pulmonary toxicity,[7] and it has been suggested that such exposures have led to chronic lung damage characterised also by overinflation.[7] Furthermore, it has been suggested that chronic exposure to low levels of oxides of nitrogen, as in houses using gas cookers and central heating, may lead to respiratory impairment, especially in children.[8 9] Evidence, however, on the possible effects of relatively low level exposure in industry has hitherto been lacking.

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We have taken the opportunity of investigating the levels of oxides of nitrogen occurring in British coalmines and of categorising exposures of working miners to these gases between 1972 and 1979 to determine whether effects on the respiratory system can be detected.

Methods

Investigations were carried out in the remaining nine collieries from the National Coal Board's Pneumoconiosis Field Research (PFR). These collieries represent a wide range of mining conditions.[10] All working miners from these pits were considered in the study but only the respiratory health records of those miners exposed to relatively high or low levels of oxides of nitrogen were used. In each colliery over a 20 year period detailed records had been kept of the time spent by each miner in different occupational groups, these groups having previously been defined on the basis of exposures to dust for the purposes of the PFR.[10] A minimum of five shift average measurements of nitrogen dioxide and nitric oxide concentrations was made for each occupational group at each colliery, the samples being taken by randomly selected members of the group.

Measurements were made by inserting a sampling attachment containing an absorption train into the MRE type 113A gravimetric dust sampler; this method has been fully described.[11] Briefly, air is drawn through a sampling train of three tubes and any nitrogen dioxide in the air is absorbed in the first tube which contains 13X molecular sieve impregnated with triethanolamine. Nitric oxide passes through to the second tube where it is oxidised to nitrogen dioxide and, as such, it is absorbed in the third tube. The nitrogen dioxide contents of the first and third tubes are analysed subsequently using a modified Griess-Saltzman reaction, and the nitrogen dioxide and nitric oxide concentrations in the air are calculated accordingly. In addition, Ecolyser 7000 series nitrogen dioxide/nitric oxide meters were used to make continuous measurements of these gases during shotfiring and diesel locomotive operations.

In order to describe possible health effects some men who were exposed either to low or relatively high concentrations of oxides of nitrogen between 1972 and 1979 were identified as follows. For each occupational group, the following oxides of nitrogen concentration index, which was based on the ACGIH recommendations for the calculation of threshold limit values of mixtures, was calculated:

NO_x index = NO concn + NO_2 concn × 7

where the NO and NO_2 concentrations are means of the measured shift average concentrations for the group.

Occupational groups with an oxides of nitrogen index less than 0·4 were categorised as low concentration groups, those with an index between 0·4 and 0·9 as medium, and those with an index greater than 0·9 as relatively high concentration groups. Oxides of nitrogen were measured only between 1975 and 1979. Concentration categories for occupational groups in existence between 1972 and 1975 were made using these exposure measurements and comprehensive information available from the PFR on mining methods and conditions. The PFR records of attendance at work were used to identify those men who had spent more than 80% of the period 1972–9 in relatively high concentration groups and those who spent more than 80% of that period in low concentration groups with no time in high concentration groups. A total of 560 men was identified in this way, 126 with "high" exposures and 434 with "low" exposures.

The two groups of men were compared in terms of their respiratory symptoms and lung function measurements obtained in current and previous epidemiological surveys of the PFR. Respiratory symptoms and smoking histories had been obtained by the use of a standardised questionnaire whereas ventilatory function was measured by a modified Gaensler spirometer, calibrated, and operated by trained technicians under controlled conditions.[12] Forced expiratory volume in one second (FEV_1) was measured, the mean of three technically satisfactory and reproducible attempts being recorded. The results from three surveys between 1964 and 1977 were used.

In addition, for each man an estimate of cumulative exposure to respirable coalmine dust was available based on careful measurements made over many years in occupational groups.[10]

Possible health effects were investigated in two ways:

(1) Data from all identified high and low exposure men were studied by multiple linear regression to assess whether exposure to oxides of nitrogen could be shown to affect the level or rate of decline of FEV_1 after age, height, smoking habit, and exposure to respirable coalmine dust had been taken into account. Discriminant analyses were also used to investigate the effects of these gases on the prevalence of respiratory symptoms.

(2) An attempt was made to match each man with high exposure with a man with low exposure on the basis of age, dust exposure, smoking habit, colliery coal rank, and type of work. Forty four such pairs were identified and compared for prevalence of respiratory symptoms and both level and rate of decline of FEV_1.

More complete details of the methods are recorded elsewhere[13] and are available on application to the authors.

Results

LEVELS OF OXIDES OF NITROGEN

Table 1 summarises the mean shift average concentrations of nitric oxide and nitrogen dioxide observed at the nine collieries. These concentrations were well within their respective threshold limit values of 25 ppm and 3 ppm. The highest individual shift average measurements were 9·8 and 2·3 ppm for nitric oxide and nitrogen dioxide respectively. There were, however, pronounced differences between concentrations both within and between collieries. The highest exposures were observed for diesel locomotive drivers, particularly at colliery Y where the exhaust fumes were found to be drawn into the driver's cabin. Differences in shift average concentrations were observed between other occupations and these can readily be accounted for by distance travelled in diesel trains by the men concerned and the amounts of explosive used in their place of work.

The peak nitric oxide and nitrogen dioxide con-

Table 1 *Average nitric oxide and nitrogen dioxide levels in different locations at the nine PFR collieries. Figures in parentheses are number of samples*

Colliery		*Concentration (ppm)* Face	Loco	Development	Elsewhere underground	Overall
C	NO_2 NO	0·02 0·14 (161)	NA	0·02 0·15 (46)	0·02 0·10 (204)	0·02 0·12 (411)
F	NO_2 NO	0·02 0·13 (209)	NA	0·03 0·10 (2)	0·02 0·07 (80)	0·02 0·11 (291)
K	NO_2 NO	0·03 0·16 (188)	0·05 0·48 (5)	0·03 0·22 (12)	0·02 0·16 (94)	0·03 0·17 (299)
P	NO_2 NO	0·05 0·68 (271)	NA	0·10 0·79 (18)	0·03 0·24 (63)	0·05 0·61 (352)
Q	NO_2 NO	0·06 1·19 (346)	0·36 2·41 (18)	0·07 1·48 (51)	0·06 1·08 (123)	0·07 1·23 (538)
V	NO_2 NO	0·03 0·12 (243)	NA	0·02 0·14 (22)	0·03 0·11 (41)	0·03 0·12 (306)
W	NO_2 NO	0·03 0·45 (248)	0·20 1·32 (37)	0·05 0·60 (8)	0·05 0·45 (141)	0·05 0·53 (434)
X	NO_2 NO	0·03 0·18 (99)	0·12 0·55 (4)	0·03 0·90 (38)	0·03 0·11 (94)	0·03 0·27 (235)
Y	NO_2 NO	0·05 0·69 (328)	0·84 3·74 (21)	0·04 0·46 (124)	0·05 0·45 (76)	0·08 0·73 (539)

NA = Not applicable, no diesel locomotives used.

centrations summarised in table 2 were on most occasions below their recommended short term limits of 35 ppm and 5 ppm respectively. Occasional excursions above these values were observed after shotfiring and, more frequently, during diesel locomotive use. These excursions were, however, always limited to periods of less than five minutes and were mainly restricted to nitric oxide.

RESPIRATORY SYMPTOMS AND LUNG FUNCTION

Table 3 gives some characteristics of the men in low and high exposure groups. Discriminant analyses to predict the occurrence of persistent cough, of sputum production, and of breathlessness in the 560 men studied showed no association between any of these symptoms and exposure to oxides of nitrogen, though dust exposure and level of FEV_1 contributed significantly to all three fitted functions. Cigarette smoking also was associated with the occurrence of persistent coughing and sputum production but not with breathlessness. Table 4 summarises the results from multiple regression analyses of FEV_1 at the fifth PFR survey and of rate of loss of FEV_1 between successive surveys. In general agreement with previous studies, FEV_1 and loss of FEV_1 were related to age, height, smoking habit, and, in the case of FEV_1, to dust exposure but exposure to relatively high levels of nitrogen oxides was found to have no significant effect.

We were unable to find any significant differences in the mean values of FEV_1 and rate of decline of FEV_1 between the two exposure groups studied in the matched pair investigation. Odds ratio estimates (not adjusted for matching) of relative risks associated with the higher exposures to oxides of nitrogen were 1·8 and 1·3 respectively for persistent coughing

Table 2 *Summary of NO and NO_2 peak concentration measurements*

Colliery	*No of shifts sampled*	*Maximum recorded conc (ppm)* NO	NO_2	*No of occasions NO TLV-STEL exceeded**	*No of occasions NO_2 TLV-STEL exceeded**
			After shot firing		
P	10	39	1·8	3	0
Q	6	46	7	2	1
X	3	5	0·1	0	0
B'	4	94	10·5	3	1
			In diesel locomotive cabins		
K	4	100	1·3	7	0
Q	3	100	2·5	8	0
X†	2	20	1·3	0	0
Y	11	100	14	22	2
B'	3	4	0·8	0	0

*The TLV-STEL values of NO and NO_2 are 35 and 5 ppm respectively.
†Both sampling shifts were curtailed because of practical difficulties.

Table 3 *Some characteristics of the study population of 560 men*

Variable	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Lower NO_x exposure group (434 men)				
Age (y)	46·7	8·8	25	61
Height (cm)	171·1	6·0	154	187
Weight (kg)	75·9	11·2	52	108
FEV_1 (l)	3·08	0·78	0·8	5·7
Respirable dust exposure (gh/m³)	148	109	17	610
Higher NO_x exposure group (126 men)				
Age (y)	45·9	8·1	26	58
Height (cm)	173·1	6·8	157	192
Weight (kg)	74·9	10·3	54	113
FEV_1 (l)	3·29	0·75	1·4	5·0
Respirable dust exposure (gh/m³)	174	100	8	477

and for sputum production. In both cases the excess over unity is easily attributable to chance ($p > 0·25$). For breathlessness, the estimate of relative risk was 0·8.

Discussion

The acute effects of exposure to high doses of oxides of nitrogen, essentially an acute toxic pneumonitis, are well known. The condition may present as pulmonary oedema shortly after exposure, as progressive breathlessness starting a week or two after exposure and related to an obliterative bronchiolitis, or as a combination of the two. This condition is best known in farmers exposed to fumes from silage, in chemical workers exposed to spilt nitric acid, and in miners exposed to fumes from shotfiring.[14] In general, those patients who survive this acute syndrome seem to make a full recovery but there are reports of some who have apparently suffered permanent impairment of respiratory function associated with respiratory symptoms. In particular, Kennedy has described a group of coalminers who were exposed to high levels of nitrogen dioxide and who were subsequently shown to have symptoms of airways disease and evidence of raised residual volume on lung function testing, abnormalities which the author thought were due to emphysema and which he attributed to their exposure.[7] The argument is not wholly convincing[15] since a raised residual volume is known to be a feature of men exposed to coal dust[16] and is, of course, also a feature of cigarette smokers. Also the studies were uncontrolled and lacked a history of other possible causes of the abnormalities found. Nevertheless, it seems reasonable to suppose that some men exposed to high levels of such gases may well suffer permanent lung damage. What has been far from clear, however, is whether men exposed to relatively low levels of oxides of nitrogen and who have not suffered acute exposure symptoms develop chronic lung disease as a result.[17] Clearly, a study to investigate this requires to make careful estimates of exposure and to take account of other possible causes of respiratory symptoms and dysfunction such as exposure to cigarettes and coal dust.[18]

Our results are reassuring in two ways. Firstly, we have found that levels of oxides of nitrogen in the collieries we studied are in general well below accepted threshold values[19] and, secondly, we have been unable to detect any effects on health. Nevertheless, it is important to examine whether there are any reasons for considering our results invalid. In particular, are the collieries we studied representative of all British collieries and have our results been biased by studying only working miners? On the first point, the collieries concerned are spread throughout the British coalfields and the min-

Table 4 *Standardised regression coefficients (t-statistics) from multiple regression analyses of FEV_1, loss of FEV_1 between fourth and fifth surveys, and rate of loss of FEV_1 between third and fifth surveys in overall study*

Explanatory† variable	*Response variable*			
	FEV_1 at 5th survey (l)	*Loss of FEV_1 between‡ 4th and 5th surveys (l)*	*Rate of loss of FEV_1‡ between 3rd and 5th surveys (l/year)*	*Rate of loss of FEV_1 between 3rd‡ and 5th surveys—non-smokers only (l/year)*
High NO_x exposure§	1·90	0·34	−1·09	−0·33
Smoker§	− 2·81**	0·076	3·67**	NA
Age at 5th survey	−13·90***	4·23***	5·15***	1·33
Height	9·18***	2·16*	2·86**	1·26
Dust exposure	−2·77**	−1·029	1·1	1·5
Multiple corr coeff	0·68	0·20	0·32	0·26
No of men studied	560	547	547	114

NA = Not applicable
*, **, ***: significantly different from zero at 5%, 1%, and 0·1% levels respectively.
†Explanatory variables were introduced into the additive linear models in the order shown in each case.
‡A loss of FEV_1 is taken as positive.
§"Dummy" variables.

ing conditions covered reflect reasonably those in current use. Almost all the mechanised mining methods used in Britain were in use in these coalmines and those methods account for over 90% of deep mine output in the United Kingdom. The less mechanised "hand-filling" technique, which is associated with considerably more shotfiring than modern mining methods, was not covered by this study; we have, however, made some measurements of levels of oxides of nitrogen during hand filling in the course of other research.[20] Shift average concentrations of nitrogen dioxide and nitric oxide were towards the upper end of the range of individual measurements found here. The highest shift average nitrogen dioxide and nitric oxide levels observed in the other study were 0·6 and 4·9 ppm respectively. There were no measurements made of peak concentrations, but from the shift average measurements and the number of rounds of explosives fired we suspect that peaks were not much different from those shown in table 2. It is conceivable, however, that accidental high exposures could still occur in mining, and vigilance to prevent these will always be necessary.

On the second point, it could be argued that men who suffered effects from these gases became ill and left work, leaving only the fitter men for the study. While this may well be true, we were nevertheless able to show not only an effect of cigarette smoking but also the weaker effect of respirable dust exposure in this survivor population. It is therefore reasonable to believe that any effect of oxides of nitrogen at the levels we have found must be so small as to be practically undetectable in the presence of effects related to dust exposure and smoking habits. Incidentally, smoking is itself a source of exposure to oxides of nitrogen.

Two final points should be made. Firstly, an American study has detected small differences in respiratory health between workers in coalmines where diesel equipment is used and workers in coalmines without diesel equipment.[21] Although the study is inconclusive, these authors suggest that the effects may be related to diesel fume exposure. Diesel exhaust fumes are complex mixtures of gases, liquids, and particulates including other irritants such as aldehydes. Our results, therefore, should not be interpreted as implying that exposure to diesel exhaust in coalmines under normal conditions is without risk. Secondly, studies of low level environmental exposure of children to oxides of nitrogen in houses with gas fires have suggested an increased risk of respiratory symptoms.[8,9] Relatively low level exposures of rats and rabbits have also produced some chronic lung disease.[17] The lungs of men in a healthy working population are likely to be more resistant to toxic substances that those of young children. It is also well recognised that individuals within a species may react differently to the same exposure and variations between species are likely to be more pronounced. Care should be exercised in extrapolating from studies of working men to other situations and vice versa. Nevertheless, we think our results indicate that in normal working conditions underground British miners generally are at relatively little risk from oxides of nitrogen.

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