# Living near opencast coal mining sites and children's respiratory health

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**Abstract**

***Objectives*—To answer the question whether living near opencast coal mining sites affects acute and chronic respiratory health.**

***Methods*—All 4860 children aged 1–11 from five socioeconomically matched pairs of communities close to active opencast sites and control sites away from them were selected. Exposure was assessed by concentrations of particulate matter with aerodynamic diameter <10 µm ($PM_{10}$), residential proximity to active opencast sites, and particle composition. $PM_{10}$ was monitored and sampled for 6 weeks in four pairs, and for 24 weeks in one pair. A postal questionnaire collected data on health and lifestyle. Daily health information was collected by a symptom diary (concurrently with $PM_{10}$ monitoring) and general practitioner (GP) records were abstracted (concurrently with $PM_{10}$ monitoring and 52 weeks before the study). Outcomes were the cumulative and period prevalence (2 and 12 months) of wheeze, asthma, bronchitis, and other respiratory symptoms, and the prevalence and incidence of daily symptoms and GP consultations.**

***Results*—Patterns of the daily variation of $PM_{10}$ were similar in opencast and control communities, but $PM_{10}$ was higher in opencast areas (mean ratio 1.14, 95% confidence interval (95% CI) 1.13 to 1.16, geometric mean 17.0 µg/m$^3$ *v* 14.9 µg/m$^3$). Opencast sites were a measurable contributor to $PM_{10}$ in adjacent areas. Little evidence was found for associations between living near an opencast site and an increased prevalence of respiratory illnesses, asthma severity, or daily diary symptoms, but children in opencast communities 1–4 had significantly more respiratory consultations (1.5 *v* 1.1 per person-year) than children in control communities for the 6 week study periods. Associations between daily $PM_{10}$ concentrations and acute health events were similar in opencast and control communities.**

***Conclusions*—Children in opencast communities were exposed to a small but significant amount of additional $PM_{10}$ to which the opencast sites were a measurable contributor. Past and present respiratory health of children was similar, but GP consultations for respiratory conditions were higher in opencast communities during the core study period.**

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There is now a substantial body of evidence linking ambient concentrations of particulate matter of <10 µm diameter ($PM_{10}$) to respiratory symptoms, decreased lung function, hospital visits, school absences, and other health outcomes.[1–8] Previous studies have been concerned with health effects of particulate matter generated by combustion processes from point sources, by vehicle emissions, or with general urban background concentrations of $PM_{10}$. The current study was initiated in 1993 in response to concerns expressed by local community groups about a possible link between living close to opencast coal mining sites and respiratory ill health, and this concern has continued to be raised.[9–13] The study was designed to compare rural and semiurban populations exposed to a mixture of background and opencast mining $PM_{10}$—that is, overburden, soil, and diesel—with populations exposed to similar rural background concentrations of $PM_{10}$ only. The study objectives were to compare and characterise acute and chronic exposure of children living near and some distance from opencast sites; to characterise and compare their general, chronic, and acute health; and to link measures of acute and chronic exposure to measures of health.

## Methods

### STUDY AREAS

The design was based on matched pairs of rural and semiurban communities or part of them with population sizes 2000–20 000. We identified five communities close to operational opencast sites and five paired control communities some distance away (fig 1). They were matched for socioeconomic characteristics with census data, urban and rural mix, proximity to the coast, local topography, and population size. The communities near opencast sites were chosen by a predefined set of criteria.[14]

### STUDY SUBJECTS

We identified all 4860 children aged 1–11 years resident within specified geographical areas and registered with a general practitioner (GP): 2443 in opencast communities, 2417 in control communities. Young children were chosen because of their likely susceptibility to respiratory events related to pollution, absence of active smoking, and occupational exposure to pollutants, and because their movements were likely to be predominantly within the monitored community.

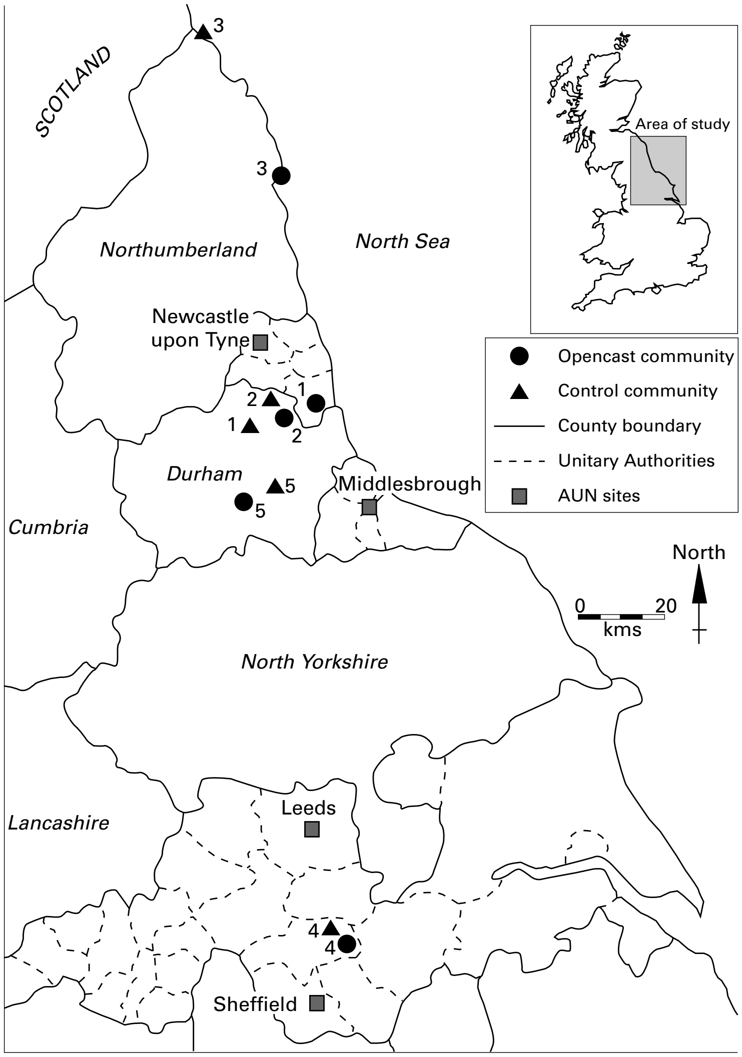


*Figure 1 Distribution of sites and communities across England.*

ASSESSMENT OF EXPOSURE

Assessment of exposure was conducted at different levels. Long term exposure was defined as living near an active opencast site, the duration of long term exposure varied with the age of the children and with the duration of activity at the opencast sites (6 months to 8 years before the monitoring periods).

The $PM_{10}$ was monitored with tapered element oscillating microbalance (TEOM) continuous real time monitors (30 minute means) placed centrally within each community to best represent the $PM_{10}$ concentrations that children were exposed to. Samples were collected by co-located samplers and near site boundaries (152 concurrent weekly samples). The $PM_{10}$ data were collected for 6 week periods in pairs 1, 3, 4, 5 and for 24 weeks in pair 2 (pair 1 November–December 1996, pair 2 February–June 1997, pair 3 June–July 1997, pair 4 Sepember–October 1997, pair 5 October–December 1997). The approximate distances between the community monitor and the first point of operational activity during the monitoring period were estimated as: opencast community 1 = 800 m, opencast community 2 = 750 m, opencast community 3 = 1300 m, opencast community 4 = 800 m, opencast community 5 = 1400 m. Wind speed and direction were also recorded at the monitoring locations in opencast and control communities.

At least 100 insoluble particles per weekly sample were characterised by scanning electron microscopy with energy dispersive analysis (SEM-EDS). The particle type was described by the categories: shale (as an indicator for opencast derived particulates),[15 16] soot, flyash, carbon, biological, quartz, and other. Particle size, number, shape, and sphericity were also recorded. Water soluble $PM_{10}$ particulates were analysed with graphite furnace atomic absorption spectrophotometry (GF-AAS) and ion chromatography.

HEALTH OUTCOMES

Health outcomes covered different levels of severity of respiratory illness. A postal questionnaire collected information on family circumstances, lifestyle factors, and on children's history of respiratory illnesses. A request for access to GP records accompanied the questionnaire; therefore, children whose questionnaires had been returned formed the basis for the collection of daily diary and GP data. The respiratory symptom diary collected information over the 6 week periods concurrently with $PM_{10}$ monitoring. The GP records were abstracted retrospectively both for the 6 week periods, when $PM_{10}$ monitoring took place, and for 1 year before this. Consultations were categorised as respiratory, skin, eye, and other. The first three categories were chosen because of the potential association with $PM_{10}$.

STATISTICAL ANALYSIS

The $PM_{10}$ concentrations were compared by differences between log ($PM_{10}$) on those occasions when paired readings were available in both communities, because of the skewed distribution: geometric means and mean ratios were therefore used as summary statistics. Comparisons of $PM_{10}$ concentrations between opencast and control communities were made with a Cochrane-Orcutt linear regression which adjusted for serial correlation.[17] Logistic regression for questionnaire data fitted models with terms for residence in an opencast community (yes or no) and pair (1, 2, 3, 4, or 5) and previously defined covariates: age, sex, housing tenure, asthma. If a significant interaction between pair and residence in an opencast community was detected, odds ratios (ORs) were estimated separately for similar groups of pairs. Two methods were used to consider the issues of variation between children and serial correlation for respiratory diary and GP data: logistic regression incorporating extrabinomial variation,[18] and logistic regression with generalised estimating equations (GEE).[19] As the health data showed little evidence of serial correlation, GEE results are not reported here.

Logistic regression models were fitted to investigate the link between daily $PM_{10}$ concentrations and daily health outcomes assuming independent errors and extra binomial variation where necessary. These included predic-

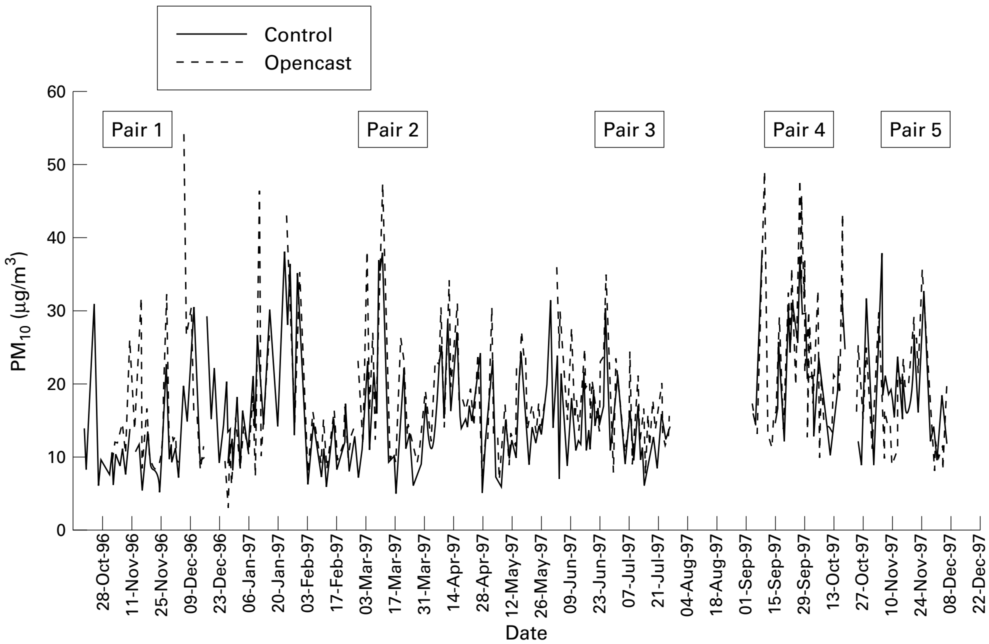


*Figure 2 Geometric means of $PM_{10}$ over 24 hours.*

tors at the community level, time varying predictors, and predictors at the level of the child. When significant interaction between residence near an opencast site and concentrations of $PM_{10}$ was found, ORs were reported for groups of similar communities.

## Results

COMPARISON OF $PM_{10}$

Figure 2 shows that despite a wide range of values (3–54 µg/m$^3$) daily $PM_{10}$ patterns were similar for much of the period. The geometric mean paired difference between simultaneous readings in opencast and control areas was 2.5 µg/m$^3$, the maximum was 35 µg/m$^3$. Most (57%) of the differences between 30 minute $PM_{10}$ were <5 µg/m$^3$ in either direction. Opencast readings were higher than control readings in 63% of paired readings, reflected in an overall geometric mean of 17.0 µg/m$^3$ in opencast (5x6 weeks) and 14.9 µg/m$^3$ in control areas.

The geometric mean ratio (table 1) was 1.14 (95% confidence interval (95% CI) 1.13 to 1.16). In pairs 1–4 opencast readings were on average higher than those in control areas, whereas in pair 5 this trend was reversed. The differences between opencast and control areas were not found to be greater under conditions when $PM_{10}$ related to the site had been expected to be higher (when the monitored wind direction was from the site to the community monitor, or during permitted site working hours).

*Table 1 Comparison of 30 minute $PM_{10}$ concentrations (TEOM) in opencast and control communities*

| *Pair* | *Duration (weeks)* | *Geometric mean (µg/m$^3$)* | | *Mean ratio (opencast/ control)* | *95% CI* | *Pairs of readings (n)* |
|---|---|---|---|---|---|---|
| | | *Opencast* | *Control* | | | |
| 1 | 6 | 14.4 | 11.4 | 1.27 | 1.20 to 1.35 | 1871 |
| 2 | 6 | 16.2 | 13.2 | 1.23 | 1.18 to 1.29 | 1975 |
| 3 | 6 | 16.1 | 13.3 | 1.21 | 1.15 to 1.27 | 1999 |
| 4 | 6 | 22.3 | 20.4 | 1.09 | 1.06 to 1.13 | 1784 |
| 5 | 6 | 17.1 | 18.1 | 0.94 | 0.89 to 1.00 | 1984 |
| 1–5 | 30 | 17.0 | 14.9 | 1.14 | 1.13 to 1.16 | 9613 |

CHARACTERISATION OF $PM_{10}$

The proportion of shale was consistently higher in samples from the boundary of the opencast sites. These particles also had the largest mean size, which reflected their closer proximity to their source. In pairs 1–4 the proportion of shale was higher in both boundary and opencast site samples compared with control area samples (fig 3). As shale is the dominant particle type associated with mineral dust emissions from opencast sites, this indicated that opencast sites were adding to the $PM_{10}$ load in the adjacent communities.

RESPONSE RATES

Parents of 1639 children in opencast communities and 1577 children in control communities returned the questionnaire (response rate 69% and 68%). Seventy seven GP practices were approached for access to their records and 2442 records were accessed (79% in opencast, 73% in control communities). Few GPs denied access to their premises, but the request by some practices to obtain individual written consent to access a record, and the subsequent lack of response from the parents, was the main reason for failure to obtain GP records. Of parents 46% who received a daily diary returned it.

COMPARABILITY AND CHARACTERISTICS OF THE STUDY SAMPLE

Questionnaire respondents in opencast and control communities were, overall, well matched for factors linked with the occurrence of respiratory illnesses (table 2). However, children in control communities were more likely to have lived at their present address for most of their lives, and live in a household with polluting cooking fuels. These imbalances

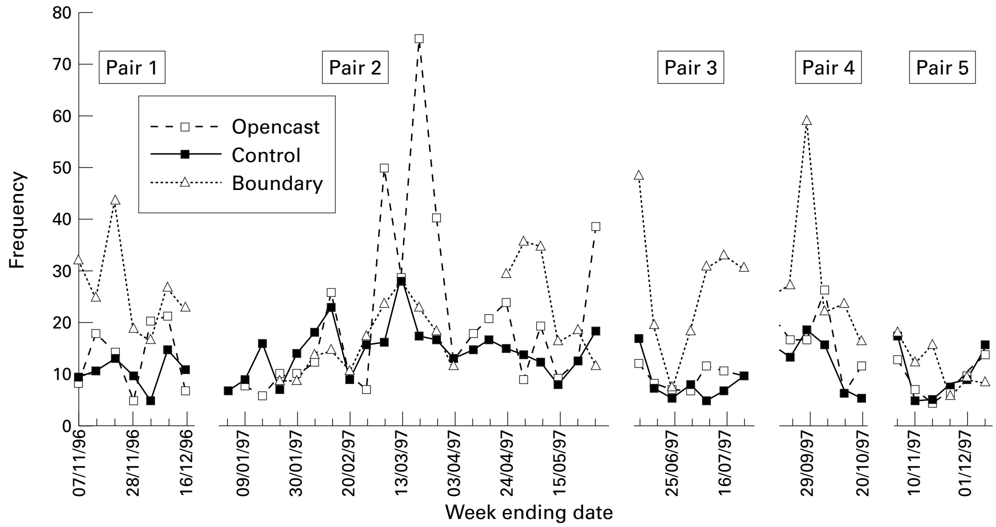


*Figure 3 Frequency of shale (%). Three high proportionate shale contents in opencast community 2 were related to local roofing work, not opencast operations.*

*Table 2 Characteristics and comparability of study samples*

| | *Communities* | |
|---|---|---|
| | *Opencast (%)* | *Control (%)* |
| Age (y): | | |
| 1–4 | 27 | 28 |
| 5–8 | 39 | 36 |
| 9–11 | 34 | 35 |
| Sex: | | |
| Male | 52 | 48 |
| Household: | | |
| Not owner occupied | 35 | 35 |
| Unemployed* | 12 | 10 |
| No car access | 18 | 20 |
| Single adult | 15 | 16 |
| ⩾1 Smokers in household | 45 | 43 |
| ⩾1 Indicators of damp | 17 | 22 |
| Polluting heating† | 66 | 63 |
| Polluting cooking‡ | 44 | 59 |
| Present address for most of life1§ | 85 | 91 |
| Long term work in dusty industry¶ | 17 | 15 |
| Respondents (n) | 1639 | 1577 |

*⩾1 Adults seeking work.
†Coal or open fire, solid fuel, coke, wood, gas fires orbottles, paraffin.
‡Solid fuel, oil, gas.
§Child at present address or within half a mile for most of life.
¶Adult in household worked in agriculture or gardening, coal industry or coal delivery (not opencast), cokeworks, opencast coal extraction, potter or ceramics, printing industry, quarrying or stonemasonry, wood or paper industry.

were considered in the statistical analysis of the health outcomes. With census variables children's households in the study population were found to be representative of their wider community population, with the exception of access to a car, which was more common in the study respondents. The subsamples for which daily diary and GP data were collected, were also similar for demographic and lifestyle characteristics.

### HEALTH OUTCOMES AND CHRONIC EXPOSURE

There was little evidence of an association between living in an opencast community and the cumulative (lifetime) prevalence of wheeze, asthma, or bronchitis or the period prevalence of asthma attacks and their severity (table 3).

### HEALTH OUTCOMES DURING THE 6 WEEK MONITORING PERIOD

Living near an opencast site was not significantly associated with the daily prevalence of wheeze, cough, or other respiratory symptoms in daily diaries (except for three outcomes in single pairs, two positive, one negative, table 4). The use of asthma relievers was not significantly associated with proximity to an opencast site in pairs 1 and 2, but there was a significant positive association in pair 3.

The GP consultation rates were overall slightly lower during the 6 week study periods compared with the year before the study (2.7 *v* 3.1 per person-year in opencast and 3.0 *v* 3.3 per person-year in control communities), and were overall slightly higher in control communities than in opencast communities. Considerable variation was again found between communities and pairs. No significant association between living in an opencast community and the rate of consultation for any reason was found, but the odds of respiratory, eye, and skin consultations, and respiratory consultations were 40% (2.1 *v* 1.5 per person-year) and 42% (1.5 *v* 1.1 per person-year) respectively higher in opencast than in control communities in pairs 1–4 but not in pair 5, for the 6 week periods. This finding was not repeated for the 52 week periods, where a more mixed picture emerged.

### SHORT TERM HEALTH ASSOCIATIONS WITH DAILY $PM_{10}$ CONCENTRATIONS

The variation between associations found in the 10 communities made it necessary to report these results in separate groups. Around half of the associations between daily concentrations of $PM_{10}$ and wheeze, cough, and other respiratory symptoms were positive and significant (table 5), and the precision of the estimates of the rest meant that they were consistent with a zero or positive association. The associations with use of an asthma reliever and GP consultations were all non-significant, but consistent in direction and of similar order to those seen for daily diary symptoms. Similar

*Table 3 Health outcomes and chronic exposure (ORs (95% CIs) for association with proximity to opencast sites)*

| | *Community* | | | | |
|---|---|---|---|---|---|
| | *Opencast* | *Control* | *OR** | *95% CI* | *Children (n)* |
| Cumulative prevalence (%): | | | | | |
| Wheeze | 36 | 37 | 1.03 | 0.8 to 1.2 | 3216 |
| Asthma | 21 | 21 | 1.03 | 0.8 to 1.2 | 3216 |
| Bronchitis | 8 | 6 | 1.3 | 0.99 to 1.8 | 3216 |
| Period prevalence in past year (%): | | | | | |
| ⩾12 Wheezing attacks | 6 | 9 | 0.5 | 0.2 to 0.93 | 588† |
| Woken child at night | 62 | 68 | 0.8 | 0.6 to 1.2 | 588 |
| Limited speech | 18 | 20 | 0.9 | 0.5 to 1.4 | 588 |
| Occurred on exercise | 60 | 61 | 1.01 | 0.7 to 1.5 | 588 |

*OR from logistic regression estimating association with community type after adjustment for pairs, child's sex, number of people in household, smoking, moulting pets, use of polluting fuel to heat or cook, damp, housing tenure, unemployment, access to transport, child's age, family history of asthma, eczema, or hayfever, propensity of parent to worry, and population stability.
†Children who have had asthma or wheezing attack in past year.

*Table 4 Health outcomes during 6 week monitoring period (ORs (95% CIs) for association with proximity to opencast sites)*

| | *Community* | | | | | |
|---|---|---|---|---|---|---|
| | *Pair** | *Opencast* | *Control* | *OR†* | *95% CI* | *Children (n)* |
| Prevalence of diary symptoms (%): | | | | | | |
| Wheeze | 1 to 5 | 4 | 4 | 0.82 | 0.36 to 1.89 | 1405 |
| Cough | 1,2,4,5 | 15 | 17 | 0.96 | 0.79 to 1.16 | 1405 |
| | 3 | 16 | 8 | 1.99 | 1.31 to 3.01 | |
| Other respiratory symptom‡ | 1,3,4,5 | 17 | 15 | 1.26 | 0.99 to 1.61 | 1405 |
| | 2 | 16 | 19 | 0.80 | 0.66 to 0.97 | |
| Asthma reliever used§ | 1,2 | 24 | 37 | 0.66 | 0.33 to 1.26 | 224¶ |
| | 3 | 31 | 13 | 4.32 | 1.12 to 16.7 | |
| GP consultations (n/person-year): | | | | | | |
| All | 1,2,3,4 | 2.7 | 2.4 | 1.10 | 0.94 to 1.29 | 2442 |
| | 5 | 2.2 | 4.6 | 0.43 | 0.24 to 0.78 | |
| Respiratory, skin, eye | 1,2,3,4 | 2.1 | 1.5 | 1.40 | 1.15 to 1.70 | 2442 |
| | 5 | 0.9 | 3.8 | 0.16 | 0.06 to 0.40 | |
| Respiratory | 1,2,3,4 | 1.5 | 1.1 | 1.42 | 1.13 to 1.79 | 2442 |
| | 5 | 0.7 | 3.2 | 0.15 | 0.06 to 0.43 | |

*Different community groupings are the result of significant interactions found in the statistical analysis.
†Association with community type having adjusted for covariates pair, sex, housing tenure, age and asthma.
‡Sore throat, ear ache, runny ear or nose.
§Numbers in pairs 4 and 5 too few to be analysed.
¶Children, who ever had asthma.

*Table 5 Short term exposure associations: change in daily health outcome per 10 µg/m³ increase in daily $PM_{10}$ (n=1405)*

| | *Communities** | | | |
|---|---|---|---|---|
| *Outcome* | *Opencast* | *Control* | *OR†* | *95% CI* |
| Daily diaries: | | | | |
| Wheeze | 1, 3, 4 | 1, 3, 4, 5 | 1.02 | 0.96 to 1.09 |
| | 2 | 2 | 1.18 | 1.05 to 1.33 |
| | 5 | | 1.59 | 1.23 to 2.06 |
| Cough | 1, 3 | 2, 4, 5 | 1.03 | 0.99 to 1.07 |
| | 2, 4, 5 | | 1.08 | 1.02 to 1.14 |
| | | 1, 3 | 1.28 | 1.16 to 1.42 |
| Other respiratory‡ | 1, 2 | 1, 2, 4, 5 | 1.01 | 0.98 to 1.05 |
| | 3, 4, 5 | 3 | 1.16 | 1.10 to 1.22 |
| Use of asthma reliever§ | 1, 2, 3 | 1, 2, 3 | 1.00 | 0.94 to 1.06 |
| Consultations with general practitioner: | | | | |
| All | 1,2, 3, 4, 5 | 1, 2, 3, 4, 5 | 1.05 | 0.96 to 1.15 |
| Respiratory, skin, eye | 1,2, 3, 4, 5 | 1, 2, 3, 4, 5 | 1.04 | 0.93 to 1.15 |
| Respiratory | 1, 2, 3, 4, 5 | 1, 2, 3, 4, 5 | 1.06 | 0.94 to 1.19 |

*Different community groupings are the result of significant interactions found in the statistical analysis.
†Association with $PM_{10}$ concentration having adjusted for covariates pair, sex, housing tenure, age and asthma.
‡Sore throat, ear ache, runny ear or nose.
§Numbers in pairs 4 and 5 too few to be analysed.

results were found when the link between respiratory events and lagged levels of $PM_{10}$ were explored. Although the OR estimates varied among the 10 communities, there were no consistent differences between those for opencast and control communities.

## Discussion

Not all findings, both on exposure and health, pointed in the same direction, and some results were apparently contradictory. An important observation affecting many analyses was the level of variation between communities and pairs, even although community pairs were well matched for lifestyle and socioeconomic factors.

Exposure to $PM_{10}$ particulate matter and health during the main 6 week data collection periods was investigated with different time scales: half hourly ($PM_{10}$ monitoring); daily ($PM_{10}$ monitoring, GP consultations, daily diary), and roughly weekly (sample characterisation). Health data were also collected for the periods before this study (cumulative and period prevalence, GP consultations in year before the study). The analysis of daily diary entries and events from GP records over the 6 week study periods allowed individual information on health outcomes to be linked with simultaneous daily measures of exposure to $PM_{10}$. When health outcomes alone were compared over the 6 week study periods or over other periods, current residence in a community near an opencast site was used as the indicator for exposure. This also applied to data on chronic health collected in the questionnaire survey, and for the 1 year period of GP data when concurrent $PM_{10}$ data were not available. Consequently, we cannot ascribe any differences in these health outcomes to variation in concentrations of $PM_{10}$ over time.

Even though the temporal pattern of concentrations of $PM_{10}$ in all 10 communities was dominated by regional patterns, the paired design of the study picked up a small but significant increase in concentrations of $PM_{10}$ in opencast communities. Shale was identified as a measurable component of $PM_{10}$ in opencast communities, indicating an opencast impact on communities. However, additional concentrations of $PM_{10}$ in opencast communities were not linked to monitored wind direction or times of permitted site activity, as had been expected from previous studies which investigated the association at distances closer to opencast sites.[15 20 21] Wind direction was monitored because it was thought to influence concentrations of $PM_{10}$ in communities, and monitors were sited to best reflect conditions experienced by children. This meant that the equipment was sited lower than if the focus of the study had been the dispersion of $PM_{10}$ created on opencast sites. Local topography might therefore have influenced readings of wind speed and direction in some communities.

Recent evidence has suggested a fairly good correlation between personal exposure to $PM_{10}$ and ambient concentrations of $PM_{10}$.[22 23] Thus the $PM_{10}$ data collected at the community monitoring sites should reflect children's exposure, although there will be some measurement error in individual exposures.

Small but significant associations were found between daily respiratory symptoms and daily concentrations of $PM_{10}$. The associations sometimes differed between communities, but they were similar in opencast communities and control communities and also similar to those in previous studies, which were mainly conducted in areas with higher concentrations of $PM_{10}$ than our study communities.

The small associations found between daily health and $PM_{10}$ data indicated that the small mean difference in concentrations of $PM_{10}$ found between opencast and control communities led to small mean effects on daily health events. Although differences in daily concentrations of $PM_{10}$ of around 2 $\mu g/m^3$ were the most common, there were days when the difference was 10 $\mu g/m^3$, or exceptionally 35 $\mu g/m^3$. However, the reported associations suggested that the prevalence of symptoms would be predicted to change very little even for the largest differences in daily concentrations of $PM_{10}$ found.

From the small positive associations found between daily concentrations of $PM_{10}$ and respiratory symptoms we might have expected to find very small differences in the analysis of health outcomes over the 6 week study periods, as the average daily difference in $PM_{10}$ was 2 $\mu g/m^3$. However, the daily analysis does not allow us to predict the effect of a change in the 6 week mean of $PM_{10}$. Very few significant associations were found between daily diary symptoms and living near opencast sites. However, there were significant associations between GP consultations for respiratory, skin, and eye conditions and living near opencast sites, in four out of five pairs over the 6 week period. These are conditions that could be expected to be exacerbated by an increase in concentrations of $PM_{10}$. It is unlikely that the positive findings on GP consultations were due to changes in behaviour of parents or GPs because they were aware of the study. There are several reasons for this: no study material sent to parents or GPs mentioned that opencast mining was the focus of the study; the effect was not found in daily diary or questionnaire data; the effect was not found for the overall consultation rate; and finally, consultation rates for the 6 week periods were lower overall than for the year before the study. This majority pattern in the GP results did not apply to pair 5, where an unusually high consultation rate occurred in the control community but not in the opencast community. Consultation with the local health authority did not suggest that a different pattern of primary healthcare delivery, or other local factors, could easily explain the excess in the recorded consultation rates in control community 5. Overall, therefore, we found an association between living near an opencast site and health outcomes over the 6 week periods for one type of health outcome but not for the other. It might be argued that this would not be too surprising given the very small size of the effect, which could have been expected on the basis of the findings from the analysis of daily $PM_{10}$ and health data.

The cumulative and period prevalence of respiratory events from the questionnaire were similar to recent national surveys[24–26] and there was little evidence for a difference between opencast and control communities. We need to be aware, however, that exposure was assessed, for this analysis, by current proximity of residence near an opencast site and these had been operational for varying periods before the survey. However, the fact that positive associations were found between residential proximity to opencast sites both with daily $PM_{10}$ and GP consultations for respiratory, skin, and eye conditions over 6 week periods does not necessarily contradict the non-significant findings of the questionnaire survey. Given the small size of the association between daily concentrations of $PM_{10}$ and health outcomes, differences in the sensitivity of exposure and health outcome measures may have contributed to these results. An extrapolation from the link between daily $PM_{10}$ and health to an estimation of an expected difference in chronic health would not be justified.

## Conclusions

We concluded that children in opencast communities were exposed to a small but significant amount of additional $PM_{10}$ to which opencast sites were a measurable contributor; past and present respiratory health of children was generally similar, but GP consultations for respiratory conditions were higher in opencast communities during the core study period. Daily concentrations of $PM_{10}$ had similar associations with daily health outcomes in all communities; despite generally low concentrations of $PM_{10}$ these associations were in line with those previously reported from other locations.

First and foremost we are indebted to the parents who completed questionnaires and daily diaries. Among the contributors to the planning and completion of the study were the following: members of the study design advisory group; staff of 20 primary schools reminded children to fill in diaries; 77 GP surgeries permitted access to their records; Environmental Health Departments and other Local Authority staff in Durham, Sunderland, Northumberland, and South Yorkshire helped in finding suitable sites and monitoring locations; landowners gave permission to locate monitoring equipment; RJB Mining (UK) and another operator provided site activity diaries; Professor Raj Bhopal gave advice at the design stage, Maxine Craven did fieldwork during the surveys; Helen Prince did part of the statistical analysis; Jacqui Tate contributed to the design and fieldwork until 1996; Susanne Young helped to co-ordinate the study and did part of the descriptive analysis; Fiona Anderson, Joyce Wotherspoon, and Sharon Ness abstracted information from GP records. Funding was received from local authorities in Northumberland, Durham, and Sunderland (May 1994 to December 1994, pilot study), Northern and Yorkshire Regional research and development grant No 94070020 (December 1994 to November 1996), DOH/DETR/MRC grant No AIR/96/9 (August 1996 to February 1999).

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