Airway responsiveness and job selection: a study in coal miners and non-mining controls

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Abstract

Background—It has been suggested that health related job selection is a major cause of the healthy worker effect, and may result in inaccurate estimates of health risks of exposures in the working environment. Improved understanding of self selection, including the role of airway hyperresponsiveness, should improve accuracy in estimating occupational risks.

Methods—We evaluated symptoms of the respiratory tract, lung function, occupational and smoking histories, and airway responsiveness from a cross sectional survey of 478 underground bituminous coal miners and non-mining controls. Workers with abnormal spirometry were excluded from methacholine testing.

Results—Methacholine responsiveness ($\geq 15\%$ decline in forced expiratory volume in one second) was associated in both miners and controls with reduced ventilatory lung function and an increased risk of respiratory symptoms. Miners with the longest duration of work at the coal face had a low prevalence of methacholine responsiveness, compared with miners who had never worked at the coal face ($12\% v 39\%$, $P < 0.01$). Throughout their mining careers, miners who responded to methacholine were consistently less likely to have worked in dusty jobs than miners who did not respond to methacholine.

Conclusions—These results provide evidence that workers who are employed in dusty jobs are less likely than their unexposed coworkers to show increased non-specific airway responsiveness, presumably as a result of health related job selection. Surveys of workers in which responsiveness data are unavailable may underestimate the effects of dust exposure on respiratory health.

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Health effects of the working environment have often been characterised through epidemiological investigations of working populations.¹⁻⁴ Complicating the interpretation of most industry based studies are selection processes that may result in the reporting of reduced specific morbidities and mortalities in certain working populations compared with

the general population.⁵ This phenomenon has been referred to as the healthy worker effect, and has been attributed primarily to health related selection in the workforce.⁶ Health related job selection leads to a differential distribution of susceptibility by exposure grouping. Unless a suitable adjustment can be made, these selection processes may obscure actual adverse health consequences of exposures, lead to an underestimation of the health effects of the work environment, or result in the paradoxical observation of improved health with increasing exposure.⁷⁻⁹

Although in the past employers have excluded workers from certain jobs based on medical screening, other mechanisms of selection and their impact on studies of workers are not well understood. Workers who are ill may be unable to meet standards of performance in certain medical tests,¹⁰ or may decline participation in health surveys.¹¹ Workers who have left an industry may show greater effects related to dust than those who remain employed.¹²⁻¹⁴ Non-specific airway hyperresponsiveness has been associated with an increased prevalence of respiratory symptoms and functional deficits in workers exposed to dust.^{15,16} Workers susceptible to the development of symptoms or other health effects, such as those with atopy or increased non-specific airway responsiveness, may choose to work in areas with lower dust or irritant exposures.^{17,18}

We evaluated airway responsiveness, occupational and smoking histories, spirometry, and respiratory tract symptoms as part of a cross sectional survey of underground bituminous coal miners and non-mining controls from central Appalachia. Our objective in this analysis was to investigate airway responsiveness as an indicator of job selection based on health, and a potential marker of susceptibility to certain lung disorders related to coal.

Methods

SUBJECTS

Volunteer miners were recruited from three large central Appalachian underground bituminous coal mines. Non-mining subjects were recruited in the same region from nine public and private employers with no recognised current adverse respiratory exposures. Recruitment began in May 1985 and was completed in July 1987. In the mining groups, people who only worked above ground were not recruited. To increase demographic comparability between miners and controls, clerical and secretarial employees were not recruited. In the mining group, supervisory

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personnel were included if they worked underground. The protocol was reviewed and approved by the institutional review board, and all volunteers gave written informed consent before participating.

QUESTIONNAIRE AND SPIROMETRY

Tests were performed at the work site before the work shift. Miners working on all three shifts were tested before entering the mine. Controls were tested in the morning before beginning their usual work activities. Initial evaluation included a self administered, standardised respiratory symptom questionnaire, modified from the British MRC (1976) questionnaire. Additional questions were related to tobacco use, allergic symptoms, and other illnesses. Incomplete or illogical response sequences were excluded from the analysis. A complete occupational history was also obtained from each worker. Miners' duration of work was calculated in two ways: years worked in underground mining jobs, and years worked in jobs at the coal cutting face. For the analysis of earlier work, jobs held by each miner on the date of the health survey, and up to 15 years before the survey, were investigated. Employment for each year before the survey was categorised as underground coal face work, underground coal mining away from the face, or surface or non-mining work, based on the job held in that year on the anniversary of the survey date.

Bronchitis was defined as production of phlegm on most days for at least three months for two years. Cough was similarly defined, with or without expectoration. Dyspnoea was considered to be present if shortness of breath occurred when walking at a normal pace on level ground. Persistent wheeze was present if the symptom occurred on most days or nights each week. Episodic wheeze was defined as three or more attacks of wheeze with dyspnoea in the three previous years, with normal breathing between attacks.

Spirometry was performed on all subjects with an 8 l survey spirometer with an attached microprocessor (Eagle II, Warren E Collins, Braintree, MA). All tests were carried out at the worksite,—for example, within a bath-house, conference room, lunch room. The standards applied were those of the American Thoracic Society 1978 Snowbird workshop.¹⁹ Forced exhalation manoeuvres were done in the standing position with a nose clip in place. A minimum of three and generally a maximum of five traces were carried out on each subject. Volunteers whose baseline forced expiratory volume in one second (FEV₁) or forced vital capacity (FVC) was less than 80% of predicted²⁰ did not receive methacholine. If a subject produced five smooth traces without excessive back extrapolated volume or premature end, he or she was not excluded from the study if the two largest FVCs or FEV₁s varied by more than 5%.

METHACHOLINE TESTS

Methacholine inhalation tests were carried out before the workshift, and generally immedi-

ately after initial spirometry. Because of time constraints, a few subjects did not perform the inhalation test at the first test session; they returned several weeks later for repeat spirometry with methacholine inhalation test. The methacholine test technique was modified from Chatham *et al.*²¹ A Devilbiss 646 nebuliser was filled with 2.5 ml of methacholine solution (JT Baker Chemicals, Phillipsburg, NJ, or Spectrum Chemicals, Gardena, CA) and was powered by a Devilbiss 571 series compressor (Devilbiss Co, Somerset, PA) delivering an air pressure of 20 pounds per square inch. The nebulisers' mean aerosol output was calculated, based on 14 measurements. The mean (SD) of measured nebuliser outputs was found to be 0.0072 (0.0016) ml/s. Methacholine solutions were prepared by the West Virginia University Hospital Pharmacy and were kept refrigerated until use and discarded after 30 days.²²

Each worker was given an initial concentration of methacholine aerosol based upon responses to certain items on the questionnaire. If there was a history of asthma or asthma like symptoms, the person first inhaled an aerosol of 5 mg/ml methacholine, otherwise 25 mg/ml was given. Each subject exhaled completely to residual volume, and nebulisation began. Subjects were then directed to inhale a single breath from the mouthpiece, slowly and continuously for a minimum of 10 seconds and until they reached their total lung capacity. Spirometry was performed after each dose of methacholine. Each subject's FEV₁ value after methacholine inhalation was compared with the largest FEV₁ obtained immediately before methacholine inhalation. If at any point a smooth trace of apparent maximal effort showed a 15% or greater decrease in FEV₁, the FEV₁ manoeuvre was immediately repeated. If the repeat effort confirmed the 15% decline, the protocol was ended and a bronchodilator given. If no decrease from baseline in the FEV₁ was found, then further inhalations of aerosol were given and spirometry repeated until the maximum dose (five breaths) of both concentrations of methacholine had been given. The test was then considered to be complete.

Subjects were categorised according to their responsiveness to methacholine aerosol inhalation. If they showed a reproducible decline in FEV₁ or 15% or more at any point in the protocol, they were classified as responders. Those who did not show a decline in FEV₁ or $\geq 15\%$ after five inhalations of the highest concentration of methacholine aerosol (25 mg/ml) were classified as non-responders.

STATISTICAL ANALYSIS

All statistical analyses were performed with the statistical analysis system (SAS Institute, Cary, NC). Analysis by χ^2 was used for comparisons of the prevalence of symptoms and methacholine responsiveness between groups. For lung function comparisons, *t* tests were used. In evaluating relations between dust exposure, smoking, airway responsiveness, and lung function, multiple regression analysis was used.

Results

A total of 478 subjects volunteered to participate in the project. Three were unable, despite repeated attempts, to perform a smooth and complete forced expiratory manoeuvre, and 27 others did not complete all aspects of the initial evaluation. Twenty subjects (10 miners) were excluded from methacholine inhalation tests because of baseline lung function (either FEV₁ or FVC) being less than 80% of the reference value,²⁰ and results from 15 female volunteers were not included in this report,

leaving 413 subjects. The miners who participated were slightly younger than controls, but were similar for race, education, and smoking (table 1).

CATEGORICAL ANALYSES

Overall, 27% of subjects responded to methacholine inhalation with a 15% or greater decline in FEV₁ from baseline. The proportion of responders was not different in miners and controls (table 2). The proportion of methacholine responders among the current cigarette smokers was not significantly higher than in the non-smokers (table 3). Responsive miners and controls both reported more respiratory symptoms than non-responders, although the differences were more notable among the non-miners (table 4). Ventilatory function in both mining and control responders was also reduced compared with non-responders. The mean age of responders was identical (39) to that of the non-responding group.

Controls, who were recruited from the same geographical region as the miners, showed a lower mean FEV₁ (tables 2 and 3). Expected differences in FEV₁ related to smoking were noted (table 3). No clear trends were noted between duration of mining and mean FEV₁, although among the coal face mining categories, the 0–5 year face mining group had the lowest mean FEV₁ (table 2).

Table 2 shows trends in methacholine responsiveness with duration of mining. As duration of mining increased, the proportion of miners who responded to methacholine declined, whether examined as years worked underground or years worked at the coal face.

The association between airway responsiveness and previous work was examined. When grouped by methacholine responses, miners' work histories showed consistent employment patterns. For the non-responsive miners, underground face work represented an average of 60% of all previous mining jobs, and in no year did face work represent less than 54% of mining jobs held (figure). In contrast, for methacholine responsive miners, underground face work averaged only 40% of their previous mine work, and this proportion was also roughly constant over all earlier years (figure). Thus, in the 15 years before the health survey, responsive miners had consistently worked in dusty jobs less often than the non-responsive miners.

LINEAR MODELS

For the miners, linear models were examined

Table 1 Characteristics of study subjects

	Miners	Non-miners
n	198	215
Age (mean, y)	37.5	40.0*
White (%)	97.9	95.3
Education (mean y)	12.6	12.8
Smokers (%)	31.3	24.2
Exsmokers (%)	24.8	29.8
Non-smokers (%)	43.9	46.0

*P < 0.05 only for age difference between miners and non-miners.

Table 2 FEV₁, Methacholine responsiveness, and duration of mining

	n	Responders (%)	Mean FEV ₁ (% predicted)
Miners	198	26	106.8
Non-miners	215	27	103.8
P value		0.54	0.01
Miners underground (y):			
0–5	18	33	107.6
5–10	117	26	106.8
>10	60	25	107.0
P value		0.76	0.96
Miners: (Time at face (y)):			
0	44	39	108.2
0–5	39	26	102.8
5–10	88	26	107.1
>10	23	12	110.3
P value		0.01	0.04

*P values for differences in means or proportions within categories.

Table 3 FEV₁ and smoking in miners and non-miners

	n	Responders (%)	Mean FEV ₁ (l)
Smokers:			
Miners	62	23	4.20
Non-miners	52	37	3.96
P value		0.10	0.06
Non-smokers:			
Miners	87	26	4.43
Non-miners	99	23	4.21
P value		0.61	0.02
Exsmokers:			
Miners	49	29	4.15
Non-miners	64	27	3.97
P value		0.81	0.12

*P values for differences in means or proportions within categories.

Table 4 Lower respiratory tract symptoms, FEV₁, and responsiveness in miners and non-miners

	n	Mean FEV ₁ (l)	Cough (%)	Bronchitis (%)	Dyspnoea (%)	Persistent wheeze (%)	Episodes of wheeze (%)
Miners:							
Responders	51	4.07	22	30	10	14	16
Non-responders	147	4.36	16	21	9	13	3
P value		< 0.01	0.38	0.20	0.85	0.92	< 0.01
Non-miners:							
Responders	59	3.86	14	29	10	11	7
Non-responders	156	4.16	12	13	1	3	5
P value		< 0.01	0.69	< 0.01	< 0.01	0.02	0.64

*P values for differences in means or proportions within categories.

Classification of jobs held for sequential years before the health survey by coal miners who (A) did not and (B) did respond to methacholine.

Table 5 Parameter estimates for models of FEV₁

	<i>Parameter estimate</i>	<i>P value</i>	<i>Residual sum of squares</i>	<i>R</i> ²
Model 1:				
Without responsiveness				
Intercept	− 3.738	0.0002	35.0	0.53
Age (y)	− 0.030	0.0001		
Height (in)	0.131	0.0001		
Pack-years	− 0.006	0.0542		
Face work	− 0.043	0.5637		
Model 2:				
With responsiveness				
Intercept	− 3.193	0.0010	36.2	0.57
Age (y)	− 0.031	0.0001		
Height (in)	0.126	0.0001		
Pack-years	− 0.006	0.0590		
Face work	− 0.093	0.2073		
Responders	− 0.279	0.0001		

to further investigate the relation between various factors and FEV₁ (table 5). Model 1 included age, height, and pack-years of smoking as continuous variables, and current underground face work as a dichotomous variable. Variables for model 2 include all those in model 1, as well as a variable for methacholine responsiveness. Model 1 investigated the FEV₁ effects without including results of airway responsiveness tests, similar to previous surveys of miners. In this analysis, current face work is associated with a 43 ml reduction in FEV₁. When responsiveness data are included in the analysis (model 2), the estimated FEV₁ reduction for current face workers increases to 93 ml. Neither face work parameter was significant.

Discussion

We evaluated duration of work, respiratory tract symptoms, smoking, and spirometry in a group of working miners and non-mining controls. Overall, the prevalence of methacholine responsiveness was similar in the miners and control workers. With increasing dust exposure (estimated by duration of work at the coal face), the proportion of miners who responded to methacholine decreased. Workers who responded to methacholine had more respiratory tract symptoms and lower lung function than those who did not respond. These results are consistent with the hypothesis that workers with hyperresponsive airways develop more symptoms related to exposure than their coworkers, and select jobs on that basis.

Other potential explanations for reduced airway responsiveness in miners with higher dust exposure seem less likely. Exposure to the mine environment might conceivably exert a

protective effect on the development or expression of increased airway responsiveness. This explanation is improbable in the light of the extensive scientific literature related to the adverse respiratory effects of mining²³ and evidence for an inflammatory response to coal mine dusts.^{24,25} A more plausible alternative explanation is that miners with increased levels of airway responsiveness and longer duration of work at the coal face remained in the workforce, but chose not to participate in the study. Such a participation bias cannot be entirely excluded, although we sought and did not identify evidence for it. There was no difference related to the duration of exposure in the proportion of responders between non-face mine workers and the control group. The study miners were similar to the entire pool of potential participants in age and duration of current employment. Also, the group of miners in the study seemed to be similar for age, sex, race, and education to the overall United States coal mining workforce, based on the results of the probability sample survey performed in 1986 by the United States Bureau of Mines.²⁶ The consistent difference in job histories between methacholine responsive and non-responsive miners is also more compatible with health related job selection than a participation bias in the survey.

Airway responsiveness as an indicator of health related job selection has been mentioned in other settings. Kongerud and colleagues reported that eight of 12 symptomatic Norwegian aluminum workers who transferred to unexposed jobs had bronchial hyperresponsiveness, compared with only one of 58 new employees.²⁷ Clearly, if such job selection is occurring, the implications for studies of occupational groups could be consequential. People responsive to methacholine have reduced FEV₁ levels and an increased risk of respiratory tract symptoms, and thus may have increased susceptibility to these dust related health effects. In this study, the least exposed group of miners, those who had never worked at the coal face, had the highest proportion of responders (39%), conversely methacholine responsive miners were less commonly identified (12%) in the high exposure category. This distribution of responders (decreasing proportion of methacholine responders with increasing exposure) tended to obscure the well known effects of mine exposure on symptoms and lung functions. The linear models also indicated that including airway responsiveness

in the model results in a larger observed effect of job exposure. In most previous occupational surveys, airway responsiveness has not been measured. If responsive workers were not symmetrically distributed within exposure groupings, the relation between exposure and respiratory health effects may have been considerably underestimated.

Cross sectional studies are acknowledged to be particularly subject to selection biases. Non-specific airway responsiveness has been implicated by several investigators as a marker of susceptibility to the progressive effects of inhaled materials.²⁸⁻³³ Thus, longitudinal occupational studies might also be affected by selection bias, and the inverse correlation between responsiveness and exposure found in this study may have implications for longitudinal study designs as well.

Other selection effects are suggested by these results. The mining group showed a significantly higher mean FEV₁, as a percentage of reference values, implying that workers who chose to enter mining may have been healthier than other workers from the region. In contrast, it was somewhat surprising that methacholine responsiveness was found in a relatively high proportion of current smokers, particularly non-miners. People who begin smoking are thought to be less susceptible to the adverse effects of mining, although it is recognised that, over time, smoking often leads to declines in lung function and increased airways responsiveness.³⁴ The percentage of responders among the non-mining smokers is likely to be explained, in part, by the significantly greater pack-years of cigarette use in this group, compared with the miners who smoked. Supporting this explanation is a significant increase in the proportion of methacholine responders with increasing cigarette pack-years (data not shown).

In conclusion, this investigation indicates that the distribution of airway hyperresponsiveness in workers exposed to dust is not random, and may introduce a bias toward the null in the investigation of exposure-effect relations. A role for airway responsiveness as a mechanism for health related job selection in dusty environments was suggested by the data. If airway responsiveness is a marker of susceptibility to the adverse lung effects of certain work environments, then stratifying workers by airway responsiveness may be important in the investigation of exposure-effect relations in occupational groups.

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