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Respiratory Protection: Associated Factors and Effectiveness of Respirator Use Among Underground Coal Miners

Hongfei Li, MD, MPH,[1] Mei-Lin Wang, MD, MPH,[1,2] Noah Seixas, PhD,[3] Alan Ducatman, MD, MSc,[1] and Edward Lee Petsonk, MD[1,2]*

Background *We investigated factors associated with the use of respiratory protection and explored the effectiveness of respirators among coal miners.*
Methods *Between 1987 and 1992, respiratory symptoms, smoking, lung function, and dust exposures were assessed longitudinally among 185 underground bituminous coal miners. Self-reported use of respiratory protection was expressed as mean percent time wearing a respirator.*
Results *Miners' respirator use increased with mean dust concentration, but decreased with tobacco consumption. Increasing age was associated with greater respirator use. Miners who had respiratory symptoms at the initial survey subsequently reported greater use of respirators. A significant protective association was found between the miners' respirator use and FEV_1 levels at both the initial and follow-up surveys.*
Conclusions *These results provide additional evidence that respirator use is protective of lung health. When respiratory protection programs are developed, factors that may affect respirator use behavior, such as age, smoking, and respiratory symptoms, should be considered. Future studies of respiratory health will need to consider workers' use of respiratory protection.* Am. J. Ind. Med. 42:55–62, 2002. *Published 2002 Wiley-Liss, Inc.*†

KEY WORDS: respiratory protection; respirator use; coal mining; respiratory symptoms; smoking; dust exposure; FEV_1

INTRODUCTION

Exposure to coal mine dust is associated with pneumoconiosis, reduced level of pulmonary function, and symptoms of chronic bronchitis [Stenton and Hendrick, 1993; Weeks, 1993; Attfield and Wagner, 1998; Fisher, 1998]. The Federal Coal Mine Health and Safety Act passed in 1969 mandated a reduction in respirable coal-mine dust to 3 mg/m^3 and a further reduction to 2 mg/m^3 in 1972 [FCMHS Act, 1969]. According to the Act, respiratory protective devices were not to be used as a primary means of controlling dust exposure, although miners were permitted to use them. Engineering controls, such as better ventilation and wet face mining, were preferred as primary measures for coal-mine dust control. Recently, it has been recommended that dust exposure levels be further reduced in order to better protect miners' lung health [NIOSH, Criteria for a Recommended Standard, 1995].

As exposure levels in underground coal miners have decreased through adoption of engineering controls, it may be assumed that the incremental health benefit to miners from use of personal protective devices will also decrease. It is unclear whether, under modern mining conditions,

[1]Department of Community Medicine, School of Medicine, West Virginia University, Morgantown, West Virginia
[2]Surveillance Branch, Division of Respiratory Disease Studies, National Institute for Occupational Safety and Health, Morgantown, West Virginia
[3]Department of Environmental Health Science, University of Washington School of Public Health, Seattle, West Virginia
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*Correspondence to: Dr. Edward Lee Petsonk, Surveillence Branch, Division of Respiratory Diseases, NIOSH, 1095 Willowdale Road, Morgantown, WV 26505. E-mail: ELP2@cdc.gov

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respirator use offers any additional health protection. It is also not known whether respirator use is uniform among miners, or whether certain miners are more likely to use respirators.

In the current study, we sought to explore the factors associated with respirator use, and also investigate evidence for the effectiveness of respirators by assessing respiratory symptoms, dust exposure levels, tobacco use, and pulmonary function in relation to reported respirator use among US underground coal miners.

MATERIALS AND METHODS

Between 1985 and 1992, a five-year prospective longitudinal study of underground U.S. coal miners was performed. Detailed study methods have been described previously [Petsonk et al., 1995; Jennison et al., 1996; Hodgins et al., 1998] and are briefly reviewed here.

Questionnaire

A standardized self-administered respiratory symptom questionnaire was administered at the initial and final surveys. This questionnaire was modified from the British Medical Research Council Instrument [1976]. 'Cough' was defined as coughing occurring on most days for at least 3 months for 2 or more years. 'Shortness of breath' was considered present if dyspnea was reported when walking at a normal pace on level ground. 'Phlegm' was defined as bringing up sputum for 4 or more days per week for at least 3 months during the year for 2 or more years. 'Wheeze' meant persistent wheeze on most days or nights each week. 'Asthma' (asthma-like symptoms) was defined as attacks of wheezing with dyspnea, with normal breathing between attacks. There were additional questions on tobacco use, medical history, family history, occupational history, and respirator use. Respirator use information and work-history were updated every 6 months. The titles and dates of all jobs held prior to enrollment in the study were recorded, as well as a listing of any known or suspected job hazards.

Spirometry

Spirometry was performed at 6-month intervals during the 5 years of follow-up. Testing was conducted using an 8L survey spirometer with an attached microprocessor (Eagle II: Warren E. Collins, Braintree, MA). All testing was performed at the worksite, using the standards of the American Thoracic Society 1978 Snowbird workshop [ATS, 1979]. Forced exhalation maneuvers were done in the standing position with a nose clip in place. A minimum of three tracings were obtained from each subject. If the two largest values for forced expiratory volume in one second (FEV_1) or forced vital capacity (FVC) varied by more than 5%, results were excluded from the study only if the subject also did not produce at least 3 smooth tracings without premature termination or excessive back extrapolated volumes. Predicted FEV_1 values were determined for each miner [Morris et al., 1971]. The mean annual decline in FEV_1 was also determined by least-square linear regression, using all the available spirometric values from the 5-year follow-up period for each subject who had at least three valid spirometry test results.

Dust Exposure Assessment

Estimates of dust exposures during the study

Dust exposure estimates were developed based on personal respirable dust samples collected for compliance purposes under the auspices of the Mine Safety and Health Administration (MSHA). Dust exposure data collected at the three study mines over the period from 1970–1990 were extracted and compared to data from the 36 mines included in the National Study of Coal Workers' Pneumoconiosis (NSCWP). These latter data had been used previously to estimate exposure for that study [Seixas et al., 1991]. Because there were insufficient data from the three study mines, and because the dust levels in the three mines appeared comparable to the NSCWP mines, estimates were derived using the data from all 39 mines. Models were developed to estimate the mean exposure by mine, occupation, and year using various levels of grouping of the three variables. The data were split into a model development and model testing subsets, and the choice of model was based on the bias, precision, and the correlation coefficient between means predicted by the model and the observed means in the validation subset. The final model selected included each mine, each year, and occupation, grouped into 10 *a priori* groups. Using estimates of mean dust concentrations obtained from the selected exposure model, and job dates from the work histories, an estimated 5-year average exposure level was determined for each study miner. Individual mean dust concentrations ranged from 0.18–1.34 mg/m^3, with an overall average of 0.81 mg/m^3. Details of the estimation procedure and results are available [Seixas, 1992 Estimation of Coal Dust Exposures for A Study of Reactive Airways in Miners, report to the National Institute for Occupational Safety and Health].

For analysis, subjects were divided into Higher and Lower dust exposure groups based on the median value (0.704 mg/m^3) of average individual dust concentrations.

Mining tenure

Duration of exposure over each subject's work history, and during the survey period, were also calculated as years

of work at the coal cutting face, years of work underground, and total years worked in any mining job.

Respirator Use Assessment

During the semiannual health survey, respirator use was assessed by asking ''What percentage of the time did you wear a respirator on the job in the past six months?'' Response categories were 0, 0–25, 25–50, 50–75, and 75–100%. The time-weighted mean of the percentage time of reported respirator use (MPTRU) during the study period was calculated as follows: for each individual miner, the midpoint of the indicated category of percent time respirator wear was multiplied by the corresponding survey interval (generally 0.5 years). These products were summed for all available surveys for the miner and the sum was divided by the total number of years the miner participated in the study. Values of MPTRU from the above calculation ranged from 0 to 87.5%, with an overall average of 17.3%. The median value for MPTRU (5%) was used to categorize subject into Lower and Higher respirator use groups.

Data Analysis

Analyses were accomplished with SAS personal computer software version 6.12, 1996 (SAS Institute, Cary, NC).

Group comparisons

Comparisons of demographic parameters, dust exposures and health outcomes were first made by grouping the miners according to category of mean percent time of respirator use (respirator use: Lower and Higher groups), the category of estimated mean dust concentration (dust exposure: Lower and Higher groups), and the combinations of these two (dust exposure respirator use: H-H, H-L, L-H, and L-L). The amount of smoking was expressed as pack-years (average packs/day multiply by total years of smoking). Individuals who reported never smoking were categorized as nonsmokers, with zero pack-years. Miners who had smoked were categorized as current or former smokers. For comparisons between groups of the prevalence and incidence of respiratory symptoms, the Chi-square test or Cochran-Mantel-Haenszel test was performed. For comparisons of mean dust concentrations, percent predicted FEV_1, and pack-years of tobacco consumption the Student's *t*-test or ANOVA was utilized.

Multiple linear and logistic regression analysis

To further investigate the factors associated with respirator use, stepwise multiple linear regression modeling was used with mean percent time of respirator use (MPTRU) as the dependent variable. The independent variables explored were age, smoking status (current smoker–yes/no), smoking pack-years during the study period, estimated mean dust concentration, the presence of any respiratory symptom at the initial survey (yes/no), and percent predicted FEV_1. The significance level for inclusion in the model was $P < 0.2$.

To assess potential protective effects of respirator use on lung function, stepwise multiple linear regression models were fitted for FEV_1 at initial or follow-up survey, and also for FEV_1 slope. The independent variables studied in fitting models for FEV_1 level were mean percent time of respirator use, age, height, smoking status (current smoker–yes/no, former smoker–yes/no), smoking pack-years at the initial or follow-up survey, estimated mean dust concentration, and mining tenure (years of mining at face, years of underground work, and years of mining at the time of initial or follow-up survey). An interaction term of dust exposure and respirator use was also included. The independent variables examined in modeling for FEV_1 slope were age, current smoker at both initial and follow-up (yes/no), pack-years during follow-up, mean percent time respirator use, mean dust concentration, dust exposure and respirator use interaction; controlling by initial FEV_1 and the length of follow-up interval. The significance level for inclusion of any of these factors in this model was also $P < 0.2$.

To evaluate the potential protective effects of respirator use in respiratory symptoms, stepwise multiple logistic regression models were developed with cumulative incidence of respiratory symptoms as the dependent variables. An incident symptom was defined as the new onset of a symptom during the study among miners in whom the specific symptom was absent at the initial survey. Independent variables examined were mean percent time of respirator use, mean dust concentration, the interaction term of these two, pack-years during study interval, current smoker at initial survey (yes/no), controlling for age and percent predicted FEV_1 at the initial survey. A P value of 0.2 was used as a threshold for adding and removing variables on successive steps to the model.

RESULTS

Demographic Characteristics

A total of 185 subjects from three coal mines was included in the study. Ninety-nine percent of the participants were white males. The average height was about 70 inches. Educational attainment averaged 12 years (Table I).

Factors Associated With Respirator Use

Miners in the Higher respirator use group had significantly more dust exposure than those in the Lower

TABLE I. Characteristics for All Subjects and by Respirator Use Category

Characteristics	All subjects, n = 185	Mean percent time respirator use during study	
		Lower (< 5%, n = 91)	Higher (≥ 5%, n = 94)
Sex, male, n (%)	184 (99.5)	90 (98.9)	94 (100.0)
Race, white, n (%)	183 (98.9)	91 (100.0)	92 (97.9)
Height, inches (SD)	70.3 (2.5)	70.3 (2.8)	70.3 (2.1)
Mean years of school, year (SD)	12.5 (1.7)	12.6 (1.9)	12.3 (1.5)
At initial survey			
Mean age, year (SD)	37.5 (7.9)	38.4 (7.6)	36.5 (8.2)
Current smokers, n (%)	57 (30.8)	29 (31.9)	28 (29.8)
Ex-smokers, n (%)	46 (24.9)	24 (26.4)	22 (23.4)
Mean pack-years (SD)	8.4 (11.1)	10.3 (12.8)	6.5 (8.8)**
Years mining at face, year (SD)	5.5 (4.7)	4.9 (5.1)	6.2 (4.2)
Years underground, year (SD)	8.8 (4.1)	9.1 (4.6)	8.4 (3.5)
Mean FEV_1, L (SD)	4.24 (0.68)	4.20 (0.66)	4.28 (0.70)
During follow-up			
Mean pack-years (SD)	2.2 (2.7)	2.6 (2.8)	1.8 (2.5)*
Mean dust concentration, mg/m^3 (SD)	0.8 (0.3)	0.6 (0.2)	1.0 (0.3)****
Mean percent time wearing respirator, % (SD)	16.8 (22.6)	0.7 (1.4)	33.3 (22.5)***
At final survey			
Mean age, year (SD)	42.4 (7.9)	43.4 (7.6)	41.5 (8.1)
Current smokers, n (%)	45 (24.3)	25 (27.5)	20 (21.3)
Ex-smokers, n (%)	54 (29.2)	27 (29.7)	27 (28.7)
Mean pack-years (SD)	10.6 (13.1)	13.0 (15.0)	8.3 (10.7)**
Mean FEV_1, L (SD)	3.89 (0.69)	3.84 (0.68)	3.95 (0.70)

*$P < 0.05$.
**$P < 0.01$.
****$P < 0.0001$.

respirator use group (mean dust concentration averaged 1.0 mg/M^3 for H vs. 0.6 mg/M^3 for L, $P < 0.001$). Tobacco consumption (mean pack-years), at both initial and final surveys and during the 5 years of the study, showed a strong inverse association with mean percent time of respirator use. Miners in the Lower respirator use group (used respirators less than 5% of the time) smoked about twice the number of cigarettes compared to the miners who used respirators more, $P < 0.05$ (Table I). Miners in the Higher respirator use group tended to have more respiratory symptoms at the initial survey, although none of the differences was statistically significant (Fig. 1). When grouped by dust exposure, the MPTRU averaged 6.9% for the Lower dust exposure group and 27.7% for the Higher dust exposure group, $P < 0.0001$, while median values for the Lower and Higher exposure groups were 0 and 19.4%, respectively. The linear regression model results indicated a significant association between mean percent time of respirator use and the explanatory variables of age, smoking, dust exposure, and the presence of initial respiratory symptoms (Table II).

Effectiveness of Respirator Use

Average respirable dust exposure during the study, and the mean percent time of respirator use were correlated (correlation coefficient 0.5597). Thus, when the miners were grouped by combination of dust exposure level and respirator use level, there were twice the number of miners in both the Higher dust-Higher respirator use (HH) and Lower dust-Lower respirator use (LL) groups than in the Higher dust-Lower respirator use (HL) and Lower dust-Higher respirator use (LH) groups (Fig. 2). The power of the analysis of respiratory symptoms was thus limited by the low numbers in the HL and LH groups. HH and LL groups had similar cumulative symptom incidence rates except for

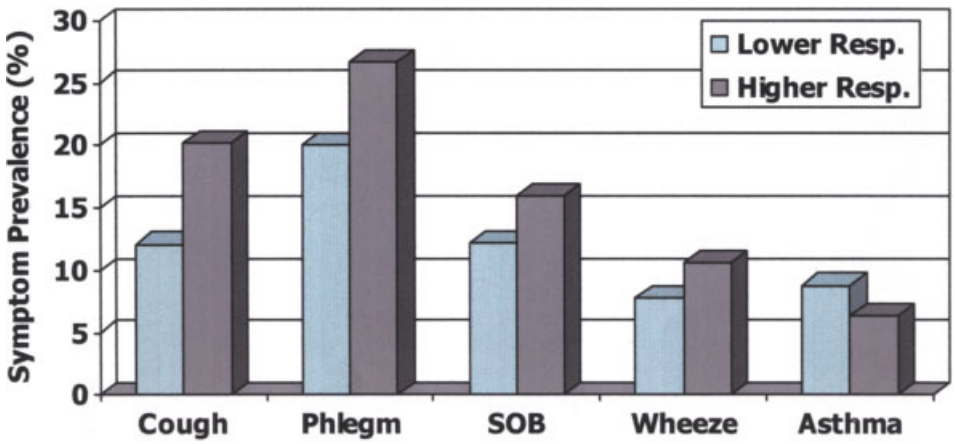

FIGURE1. Prevalence of respiratory symptoms at initial survey by respirator use status. The total number of miners in the study (185) was divided into Higher and Lower respirator use groups by the median value of mean percent time of respirator use. The prevalence rate for each symptom was calculated for these two groups.

wheezing, which was greater in the HH group ($P < 0.05$; Table III). The results from multiple logistic regression analysis did not indicate a significant protective effect on new onset of respiratory symptoms from the use of respirator. Incidence of respiratory symptoms was mostly affected by the amount of smoking during follow-up, except for wheezing (data not shown). The incidence of wheezing increased with the estimated mean dust exposure level, regardless of respirator use ($P < 0.0025$).

Table IV displays group comparisons of % predicted FEV_1 ($PPFEV_1$) and FEV_1 slopes by combined dust exposure and respirator use groups. The Higher respirator use groups tended to have greater cross-sectional $PPFEV_1$ values, although these results were not statistically significant. The average FEV_1 slopes during the 5-year study ranged from 67 ml/year in the HL group to 60 ml/year in the HH, a difference that was also not significant. Using stepwise linear regression modeling, we found that the mean percent time of respirator use was associated with a significant positive or protective effect on the FEV_1 of the miners. In the model, smoking, dust exposure, and aging had negative effects on FEV_1 (Table V).

TABLE II. Multiple Linear Regression Model for Use of Respiratory Protection*

	Mean percent time respirator use (%)		
	Partial regression coefficient	S.E.	*P*-value
Constant	−59.089	15.64	0.0002
Age (years)	0.380	0.182	0.038
Percent predicted FEV_1 at initial survey (%)	0.302	0.120	0.013
Smoking pack-years during study period	−2.161	0.522	0.0001
Respiratory symptom at initial survey (yes/no)	5.901	2.912	0.044
Estimated mean dust concentration (mg/m^3)	4.699	4.340	0.0001

*Model $R^2 = 0.4042$.

DISCUSSION

We investigated factors associated with increased use of respiratory protective devices in a group of underground US coal miners. Both smoking and dust exposure levels were strongly associated with respirator use, although in opposite directions. Thus, miners with higher use of respirators experienced higher dust exposure levels, but smoked less than those with lower respirator use. Miners who had more respiratory tract symptoms at the initial survey also reported greater use of respirators during the years of follow-up. After the effects of dust and smoking were taken into account, respirator use also increased with age.

The finding that increased respirator use was associated with higher dust exposures is not surprising. Miners clearly target their respirator use to dusty work. Jennison et al. [1996] found that respirator use was significantly associated with coal mining job categories, particularly work at the coal mining face. However, this finding has implications for interpretation of past and future studies of the health effects of coal dusts. Previous investigations of respiratory health effects from coal-mine dust exposure have not taken into account the use of protective devices. If the use of respirators was prevalent during these previous studies, our

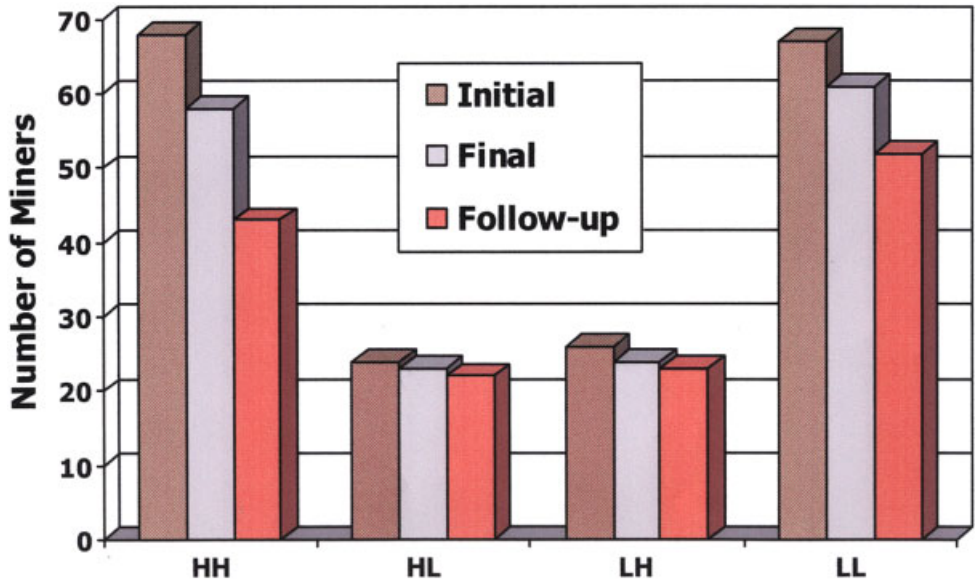

FIGURE 2. Distribution of miners by attendance at initial, final, and follow-up (both surveys), by combination of dust level and respirator use. HH: higher dust and higher respirator use group. HL: higher dust and lower respirator use group. LH: lower dust and higher respirator use group. LL: lower dust and lower respirator use group. Total 185 miners.

findings indicate that the severity of adverse health outcomes in relation to specific levels of coal-mine dust exposure may have been underestimated. To avoid misclassification of exposures, future studies among dust-exposed workers will need to take into account the effects of respiratory protection.

The initial report of respiratory symptoms was also related to subsequent increased use of respirators. Although previous studies have not investigated this issue, it is plausible that the presence of respiratory tract symptoms may motivate miners to more conscientious use of respirators. Finally, smoking and respirator use were inversely related among the study miners. Although there are a number of potential explanations for this, tobacco smoking and respirator avoidance are both risk-taking behaviors and may be associated on that basis [White et al., 1988]. Based upon these findings, respiratory protection program managers may choose to emphasize adherence issues among smoking workers.

A number of recent studies have associated coalmine dust exposures below the current exposure standard with respiratory symptoms and pulmonary function impairment [NIOSH, 1995; Henneberger and Attfield, 1997]. Carta et al. [1996] reported that even moderate exposures to mixed coal-mine dust significantly affected lung function and symptom incidence among underground miners. We evaluated symptoms and lung function among the study miners in order to detect evidence of the effectiveness of respirators under current mining conditions, taking into account smoking, and other factors. Increased respirator use during the 5-year study was in fact associated with significantly better pulmonary function at the final survey. In the regression

TABLE III. Cumulative Incidence of Respiratory Symptoms by Combinations of Dust Exposure and Respiratory Use Categories, During 5-Year Study

Symptoms	Symptom absent at initial survey N =	Cumulative incidence by combinations of dust exposure and respirator use categories, n/N (%)				*P*-value*
		H-H	H-L	L-H	L-L	
Cough	140	4/43 (9.3)	3/22 (13.6)	2/23 (8.7)	5/52 (9.6)	0.93
Phlegm	130	6/44 (13.6)	1/20 (5.0)	0/17 (0.0)	5/49 (10.2)	0.55
SOB	137	2/47 (4.3)	0/16 (0.0)	3/23 (13.0)	2/51 (3.9)	0.76
Wheeze	155	8/51 (15.7)	4/23 (17.4)	0/24 (0.0)	2/57 (3.5)	0.01
Asthma	154	3/56 (5.4)	1/21 (4.8)	1/22 (4.6)	3/55 (5.5)	0.99

**P*-values obtained by Cochran-Mantel-Haenszel test.

TABLE IV. Comparison of Lung Function among Groups by Combinations of Dust Exposure and Respirator Use Categories

	Lung function by combinations of dust exposure and respirator use categories, Mean (SD)				
Lung function index	**H-H (n = 68)**	**H-L (n = 24)**	**L-H (n = 26)**	**L-L (n = 67)**	***P*-value***
Percent predicted FEV_1 at initial survey (%)	105.1 (13.6)	101.5 (13.4)	107.2 (10.5)	106.7 (10.5)	0.28
Percent predicted FEV_1 at follow-up survey (%)	101.5 (14.2)	96.3 (15.0)	101.4 (13.5)	101.7 (12.1)	0.37
FEV_1 slope during study (L/year)	−0.060 (0.046)	−0.067 (0.049)	−0.066 (0.042)	−0.060 (0.048)	0.88

*P-values obtained by one-way ANOVA for unbalanced design.

model, higher FEV_1 values were related to more consistent use of respirators (as measured by the mean percent of time a respirator was reportedly used). A protective effect of respirators on the development of symptoms was less clearly demonstrated. Exposure to dust during the study was associated with the onset of wheezing, irrespective of respirator use. However, aside from wheezing, the cumulative incidence rates of respiratory symptoms were similar among the Higher dust-Higher respirator use (HH) group compared to the Lower dust-Lower respirator use (LL) group. Thus, for the symptoms of cough, phlegm, and shortness of breath, either respirator use was protective or the dust exposures had no effect on symptom incidence (see Table III). The absence of a protective effect of respirator use on development of wheeze could possibly be explained by the different nature of these respiratory symptoms. Wheezing may be more closely related to current exposure level, while dyspnea, cough, and phlegm production result from chronic inflammatory processes. These latter symptoms may be better correlated with measures of lifetime cumulative exposure, which were unavailable in the current study. An additional factor in our study may be that younger miners had higher levels of current dust exposure (data not shown); older miners had lower current exposure levels but may have experienced higher cumulative exposure due to historically higher mine dust exposures.

The effectiveness of respiratory protection is an issue that has not been well studied. Wang et al. [1999] found that use of respiratory protection appeared to reduce the risk of decline in FEV_1 in a study in which lung function had been followed up for an average of 11 years among underground coal miners. We observed a similarly protective relationship between reported respirator use and FEV_1 at the final health survey. In our study, the group of miners who were exposed to higher dust exposure levels but used respirators did not experience an increased incidence rate for most respiratory symptoms, aside from wheezing, which appeared to be related to dust and independent of the use of a protective device.

There are several limitations and weaknesses in this study that may have diminished our ability to detect protective effects of respirators. First, misclassification of exposures may have occurred, and any error in estimates of exposure may obscure the effects of exposure [Heederik and Attfield, 2000; Werner and Attfield, 2000]. Secondly, the strong correlation between dust level and respirator use in this study made it more difficult to observe the effect of respirator use itself. Third, the relatively small sample size and short study period may also have diminished our ability to see effects of respiratory protection on symptoms. Most miners work for 30–40 years underground, while miners in this study were only followed for 5 years. Miners in the

TABLE V. Multiple Linear Regression Models for FEV_1 at Initial and Follow-Up Surveys, and the Longitudinal Decline During 5-Year Study Period

	FEV_1 at initial survey (L)	**FEV_1 at follow-up survey (L)**	**FEV_1 slope during study (L/year)**
R^2	0.5365	0.4989	0.0608
Constant	−3.5313, 1.0855 (0.0014)*	−3.1164, 1.1595 (0.0079)	−0.0628, 0.0306 (0.04)
Age (years)	−0.0375, 0.0047 (0.0001)	−0.0377, 0.0050 (0.0001)	$P > 0.2$, not entered
Height (inches)	0.1327, 0.0145 (0.0001)	0.1247, 0.0153 (0.0001)	N/A
Percent time of respirator use	0.0042, 0.0018 (0.0227)	0.0048, 0.0020 (0.0142)	$P > 0.2$, not entered
Current smoker (yes/no)	−0.1363, 0.0758 (0.0736)	−0.1597, 0.0866 (0.0669)	−0.0136, 0.0082 (0.10)
Estimated mean dust concentration (mg/m^3)	−0.2270, 0.1361 (0.0970)	−0.2470, 0.1441 (0.0883)	$P > 0.2$, not entered
Baseline FEV_1 (L)	N/A	N/A	−0.0117, 0.0050 (0.02)
Follow-up interval (year)	N/A	N/A	0.0107, 0.0046 (0.02)

*Values are coefficient, standard error (*P*-value).

Higher dust exposure group reported using respirators on average less than 28% of the time. The benefit of this degree of respirator use on the processes of developing respiratory symptoms and reduction of pulmonary function may be difficult to detect during this time frame. A relatively short study period may also explain why we were able to detect a statistically significant protective effect of respirator use on cross-sectional FEV_1 results, but did not find a significant effect on FEV_1 slopes.

The FEV_1 slopes that were observed in this study were somewhat greater than would be expected among an otherwise healthy population [Kerstjens et al., 1997]. However, all study participants were working as underground miners, and over 56% were current or former smokers. Thus, the lung function declines appear reasonable, and similar to those observed among other occupationally exposed populations [Humerfelt et al., 1993].

Respiratory protection is a complex field involving industrial hygiene, physics, physiology, toxicology, medicine, anthropology, engineering, law, and worksite administration [White et al., 1988]. Although the use of respirators is widespread, it is generally considered the least effective and often the most costly method of protecting workers. Socio-economic status, age, and other factors related to work organization may influence the effectiveness of respirator use [Aucoin, 1975; Jaraiedi et al., 1994]. Preferred methods of reducing hazards include substitution of less toxic alternative agents, and installation and maintenance of engineering controls, to eliminate potential exposure at the source. Our results nevertheless support an ongoing role of respirator use in the coal-mining environment. In work places where alternative products and engineering methods are not available, a well-designed and well-monitored respiratory protection program can still provide a protective environment for workers. Our results also imply that future studies of dust exposure must account for differential respirator use. Further exploration is needed to characterize respirator use behavior, and the efficacy of respirator programs among miners and other exposed workers.

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