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# Self-Reported Use of Respiratory Protection Among a Cohort of Underground Bituminous Coal Miners

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To investigate the extent to which respiratory protection is used in current underground coal mines, patterns of self-reported respirator use were analyzed in a cohort of 193 underground bituminous coal miners who were followed for five years. At six-month intervals, miners were asked what percentage of time they used a respirator at work. Based on 1370 responses, the mean percentage of time that a respirator was worn was 18.9% for all subjects, with 39.8% reporting no respirator use at all observation points. Coal mining job category was significantly associated with respirator use. Face workers reported wearing respirators a mean of 28.1% of the time compared with 9.8% for nonface workers and 3.0% for supervisors. Higher tenure was associated with lower respirator use. Respirator use was not related to smoking, mine, age, or years of education. Further study is needed relating patterns of respirator use to temporal changes in coal mine dust exposure. Failure to account for respirator use may result in overestimation of miners' cumulative exposures to respirable coal mine dust.

**Keywords: dust exposure, respirators, respiratory protective devices, underground coal mines**



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Investigations of underground coal miners in the United States have demonstrated that cumulative coal mine dust exposure is associated with the development of coal workers' pneumoconiosis (CWP), as well as with reductions in ventilatory lung function, even in the absence of radiographically detected pneumoconiosis.[1–3] To reduce the risk of pneumoconiosis, in 1969 the Federal Coal Mine Health and Safety Act was passed, mandating a reduction in respirable coal mine dust to 3 mg/m$^3$, with further reduction to 2 mg/m$^3$ in 1972. The act also requires coal mine operators to furnish approved respirators to all miners who request them, but stipulates that their use shall not be substituted for environmental control measures that keep respirable dust levels within acceptable limits.[4] Based on health and environmental data from the United States, over a 40-year working life between 2 and 12% of miners exposed to 2 mg/m$^3$ dust in U.S. bituminous coal mines are expected to develop Category 2 or greater CWP; between 1.3% and 6.7% are predicted to develop the more severe form, progressive massive fibrosis.[3]

However, studies relating coal mine dust exposure to respiratory health[1–3] have not addressed the possibility that miners may be using respiratory protective devices, which might alter the relationship between measured personal or area dust samples and health outcomes. The Federal Coal Mine Health and Safety regulations require coal mine operators to furnish approved respirators to all miners who request them.[4] Respirator fit testing and training are at the discretion of mine operators, although training in the use of self-rescuers is mandatory.

Recent work suggests that errors in the estimation of individuals' exposures may result in underestimation of the health effects of occupational exposures.[5] Only one previous study has assessed the extent to which respirators are used by underground coal miners in the United States, and that was conducted in 1970–71.[6] To investigate the extent to which respiratory protection is used under the current coal mine dust

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standard, the authors analyzed patterns of reported respirator use in a cohort of underground coal miners.

## METHODS

Between May 1985 and July 1987 underground bituminous coal miners from three large mines in the northern Appalachian region were recruited to participate in a longitudinal study of respiratory health. The mines chosen were located in the same coalfield, used longwall technology for at least part of their production, and were large, employing at least 100 miners. All miners on all shifts were offered a brief presentation about the project and were invited to participate in the study. An occupational history was administered at the beginning of the five-year study period. During each of the semiannual follow-up surveys, miners were asked about interim job changes and use of respiratory protection. Respirator use was assessed by asking, "In the past six months, what percentage of the time did you wear a respirator on the job?" and was reported categorically as 0%, 0–25%, 25–50%, 50–75%, or 75–100%. For statistical purposes the categorical responses were assigned the midpoint of the reported range (0 = 0, 0–25 = 12.5, 25–50 = 37.5, 50–75 = 62.5, 75–100 = 87.5). Jobs were categorized using the Mine Safety and Health Administration classification scheme for collection of respirable dust samples. Classification codes <100 refer to "Underground Section (Face)" workers, and encompass operators of longwall and continuous mining equipment, coal loading, and roof support activities. Job codes from 100–199 ("General Underground Nonface") include electricians, mechanics, and conveyor work, and hereafter will be referred to as "nonface" jobs. Codes between 200–299, "Underground Transportation (Nonface)" jobs, involve operation of tracked and rubber-tired vehicles and will be referred to as "transportation" jobs. Job codes 300–399 refer to surface activities, such as coal cleaning and preparation, and those in the range 400–499 are supervisory and staff positions, which may involve surface and underground work.

For each miner a respirator use variable was calculated, representing the mean of the reported percentage of time of respirator use at all surveys from the date of study enrollment until a change in job category occurred that resulted in a job code change. Changes in respirator use associated with job changes were analyzed separately. Group means of the respirator use variable were calculated for the entire cohort, for all miners who indicated any respirator use, and by job code, by taking the mean of the values assigned to individual miners. The group standard deviation represents the variability of individual miners' means around the group mean. Smoking status was determined at the initial survey. Individuals who reported never smoking were categorized as nonsmokers. Miners who had smoked were analyzed in two ways: First, only current smokers were classified as smokers. The analyses were also done with current and former smokers grouped as smokers.

Statistical analyses were performed using the Statistical Analysis System (SAS Institute, Inc., Cary, N.C.). T-tests were used to assess significance of differences between continuous variables, and Fisher's exact test was used for differences in proportions. A Bonferroni correction was applied for tests involving multiple comparisons. The respirator use variable is positively skewed and associated with a significant degree of between-groups variance inhomogeneity ($p=.0005$), so a log transformation was performed to bring the data toward a normal distribution. Because many miners had values of the respirator use variable equal to zero, the transformation was performed using log (mean+1). The resulting transformation had a nonsignificant level of variance inhomogeneity as measured by Levene's F ($p=.3040$). A general linear model was generated to examine the significance of age, tenure in underground mining, years of education, smoking status, job category, and mine in predicting the transformed respirator use variable. A p-value of $<.05$ was required for statistical significance.

## RESULTS

Of the 1202 miners who were invited to participate, 223 (18.6%) volunteered for the study, and 201 (90%) completed the respirator use question at least once. Eight were surface workers and were excluded from further analysis, leaving 193 underground miners for whom respirator use was analyzed. To estimate how representative the study group was of the working population, information was collected concerning the age and tenure of all eligible employees at the three mines during the recruitment period. The age and tenure of the study group was not significantly different from that of the eligible working population of the three mines (data not shown). A demographic summary of the study cohort is shown in Table I. Supervisors had more years of education (13.4 years versus 12.3 years, $p=.01$) and tenure in underground mining (12.6 years versus 9.9 years, $p=.005$) than face workers. The demographic characteristics of the nonface and transportation groups were not significantly different from those of the face workers.

The number of times a miner answered the respirator use question ranged from 1 to 10, and the total number of responses was 1370. Overall the mean reported percentage of time a respirator was worn was 18.9%, with a mean standard deviation of 7.9% for individual miners' responses. The distribution of self-reported respirator use is shown in Table II. Of the 193 subjects (36.8%) 71 reported no use of respiratory protection during all surveys. Miners who indicated at least some respirator use reported wearing them a mean of 29.9% of the time, with a mean standard deviation of 12.5% for individual miners' responses.

Face workers reported wearing respirators for a mean of 28.1% of their time on the job, significantly higher than nonface workers or supervisors (Table III). Transportation workers reported wearing respirators for a mean of 23.2% of the time, similar to face workers. Fewer face workers than nonface workers or supervisors reported never wearing respirators. Face workers were also more likely to indicate higher levels of respirator use than were nonface workers (Table IV). Fifty percent of face workers reported wearing a respirator for more than 25% of their time on the job, compared with 8.6% for nonface workers. No supervisors reported wearing a respirator for more than 25% of the time. Wearing a respirator for more than 50% of the time on the job was reported by 25.5% of face workers and 3.5% of nonface workers. Less than 10% of all miners reported using a respirator more than 75% of the time; this was similar among face, nonface, and transportation workers.

The number of miners who reported job changes that involved a change in job classification code was small. Only changes from

**TABLE I. Demographics of Study Participants**

| Miner Characteristics (N = 193) | |
|---|---|
| Mean age (years) | 38.6 |
| % Male | 99.0% |
| Mean education (years) | 12.5 |
| Mean underground tenure (years) | 11.0 |
| % Current smokers | 32.2% |
| % Never smokers | 43.5% |



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**TABLE II. Percentage of Time on the Job That a Respirator Was Worn, by Job Classification**

| | Job Classification Percentage of Miners in Job Class (Cumulative Percentage) | | | | |
|---|---|---|---|---|---|
| % of Shift | Face n = 98 | Nonface N = 58 | Transport N = 11 | Supervisors N = 26 | All Miners N = 193 |
| 0% | 23.5 | 43.1 | 45.5 | 69.2 | 36.8 |
| 1–25% | 26.5 | 48.3 | 18.2 | 30.8 | 33.2 |
| | (50.0) | (91.4) | (63.6) | (100) | (70) |
| 26–50% | 24.5 | 5.2 | 18.2 | | 15 |
| | (74.5) | (96.6) | (81.8) | | (85) |
| 51–75% | 18.4 | 3.4 | 9.1 | | 10.9 |
| | (92.9) | (100) | (90.9) | | (95.9) |
| >75% | 7.1 | | 9.1 | | 4.1 |
| | (100) | | (100) | | (100) |

face to nonface jobs occurred with sufficient frequency to permit meaningful analysis. The 20 miners who moved from face to nonface jobs reported using respirators a mean of 28.7% of their work time while they worked at the face and a mean of 8.2% of the time after their move to nonface work. This was statistically significant ($p=.0.01$). The survey instrument did not collect information about the reasons for job changes.

A linear model was generated, predicting the log transformation of the respirator use variable based on age, underground tenure, education, smoking, job category, and mine. Job category and tenure were found to be significantly associated with respirator use (Table V). Within job categories, higher tenure was significantly associated with lower respirator use for face workers, transportation workers, and supervisors. Smoking status was not significantly associated with respirator use, whether or not former smokers were included in the smoking group.

## DISCUSSION

Little information is available regarding patterns of respirator use among coal miners or workers in other dusty trades. Harris[6] reported a survey of 511 miners from 47 coal mines, performed shortly after the passage of the Federal Coal Mine Health and Safety Act. He indicated that 40–90% of the underground work force possessed a respirator, and between 20% and 60% of underground workers reported wearing a respirator at some time during their shift. Of miners who used respirators, more than half (57%) reported respirator use for 3 hours or less each shift, or less than 50% of the shift. When wearing habits were observed by the investigators, it was felt that reported wearing times were generally overestimated. Measured wearing times ranged from 10–90%

**TABLE III. Mean Respirator Use as a Percentage of Work Time, by Job Classification**

| Job Class (N) | Mean Respirator Use (Group SD, Miner SD) | p |
|---|---|---|
| Face (98) | 28.1 (27.2, 11.5) | reference |
| Nonface (58) | 9.8 (17.8, 4.0) | 0.0001 |
| Transportation (11) | 23.2 (28.5, 7.8) | 0.3422 |
| Supervisors (26) | 3.0 ( 5.9, 2.8) | 0.0001 |

**TABLE IV. Percentage of Workers Reporting Higher Levels of Respirator Use, by Job Class**

| | Percentage of Time Respirator Used | | | |
|---|---|---|---|---|
| Job Class | Never % (p) | >25% % (p) | >50% % (p) | >75% % (p) |
| Face | 23.5 | 50.0 | 25.5 | 7.1 |
| | (ref.) | (ref.) | (ref.) | (ref.) |
| Nonface | 43.1 | 8.6 | 3.5 | 3.4 |
| | (.01) | (<.0001) | (.0003) | (.49) |
| Transportation | 45.5 | 36.7 | 18.2 | 9.1 |
| | (.146) | (.53) | (.73) | (.59) |
| Supervisor | 69.2 | 0 | 0 | 0 |
| | (.03) | (<.0001) | (.002) | (.34) |

(mean 46%) of the work period observed.[6] In comparison the present study found over 60% of miners reported some use of respiratory protection. As a group, this cohort reported using respirators a mean of 18.9% of the time. Excluding the 39.8% of subjects who consistently reported not using respirators, mean respirator use was 29.9% of the working time.

The methods and survey population for this study are not entirely comparable to the Harris[6] study. Both involved underground bituminous coal miners at large mines; the current study involved three mines in the northern Appalachian coal fields, while the previous work studied 47 Appalachian and midcontinent mines. Face workers represented slightly over 50% of study participants in both surveys. Harris obtained a single estimate of respirator use, self-reported in an interview. The current study reports averages derived from multiple estimates of respirator use obtained by questionnaire over a five-year period. While Harris also assessed appropriateness of the respirators being used, and reasons that miners did not use respirators, neither of these parameters was assessed in the present survey. A major difference between the studies is that almost all of Harris's subjects would have begun their mining careers prior to implementation of the Federal Coal Mine Health and Safety Act. As the present study population had worked a mean of 11.0 years in underground coal mining, a substantial percentage of this group has been employed in mining only since the act was passed.

**TABLE V. Linear Model Predicting Log (Respirator Use + 1)**

| Parameter | Estimate | T value | P value | Std Error of Estimate |
|---|---|---|---|---|
| Intercept | 3.829 | 3.53 | 0.0005 | 1.083 |
| Mine 2 vs Mine 1 | 0.417 | 1.29 | 0.1999 | 0.324 |
| Mine 3 vs Mine 1 | 0.222 | 0.68 | 0.4996 | 0.328 |
| Current vs nonsmoker | −0.206 | −0.85 | 0.3986 | 0.244 |
| Former vs nonsmoker | −0.270 | −0.96 | 0.3359 | 0.279 |
| Nonface job[A] | −1.074 | −4.43 | 0.0001 | 0.242 |
| Transportation job[A] | −0.435 | −0.95 | 0.3422 | 0.457 |
| Supervisory job[A] | −1.526 | −4.60 | 0.0001 | 0.331 |
| Tenure (yrs) | −0.064 | −2.34 | 0.0202 | 0.027 |
| Age (yrs) | −0.010 | −0.70 | 0.4819 | 0.015 |
| Education (yrs) | −0.025 | −0.44 | 0.6584 | 0.058 |

[A]Respirator use for miners in indicated jobs compared with those in coal face jobs



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Harris[6] suggested that visible dust levels seemed to be the most important criterion on which miners based their decision regarding respirator use. Historically jobs at the face have been associated with the highest dust levels among underground mining jobs. Reports on respirable dust exposures in U.S. underground bituminous mines suggest that dust levels on continuous mining and longwall sections averaged about 1.0 mg/m$^3$ and 2.0 mg/m$^3$, respectively, during the study, with 12% and 38% of the respective samples being above the 2.0 mg/m$^3$ U.S. federal dust exposure standard.[7] Underground nonface jobs (including transportation) have been associated with intermediate exposures, while supervisory positions generally have the lowest exposures.[8] In the present study face workers reported greater individual respirator use than did nonface workers, while supervisory personnel reported the least respirator use. This suggests that respirator use may be associated with either visible dust levels or miners' perceptions of their risk of dust exposure.

In Harris's work[6] 37% of nonusers cited "breathing difficulties" and 55% referred to other physical discomfort as a reason for not wearing a respirator. However, that study was performed in 1970–71, and recent research reveals that performance decrements associated with wearing a respirator generally are due to respirator weight rather than breathing resistance.[9] In a study of painters, White et al.[10] observed that an individual's decision to wear a respirator was more closely related to his or her beliefs about discomfort or inconvenience than to beliefs about potential health benefits.

There are few studies that evaluate the extent to which respirators are used in any industry. A recent study of granite workers in Singapore found that use of respirators increased with increasing age and years of exposure, but the author did not assess whether age was related to exposure in some way.[11] No significant relationship between age or years of education and reported respirator use was observed in this study. Lower tenure was associated with increased respirator use regardless of job category. The authors speculate that newer workers may be more acutely aware of potential adverse health effects, while those who have worked underground for a period of years without suffering adverse consequences may not perceive benefit in continued use of respirators. Previous studies have not investigated the relationship between education and use of respiratory protection.

The present study involved a relatively small group of miners, and it is not clear that the respirator use patterns observed are representative of the mining industry. Only 18.6% of the eligible miners volunteered for this study, although the age and work tenure of study participants was not significantly different from that of the overall eligible workforce. The study group was also demographically similar to that identified in a 1986 U.S. Bureau of Mines (BOM) survey that used a probability sample to characterize the 151,737 members of the entire U.S. coal mining work force.[12] Underground miners in the BOM survey were 98% male and 96% white, with a mean age of 38 years. They had a mean tenure of 11 years in mining, with 9 years at the current mine. Most (78%) had at least a high school diploma. Large mines (greater than 100 employees) employed 75% of the underground miners in the BOM survey. Thus, the participants in this study do not appear to be different for these characteristics from either the eligible work force at the study mines or the entire U.S. coal mining work force. However, miners who chose to participate in these health studies may have had a different pattern of respirator usage than their co-workers, perhaps related to increased awareness of health issues.

What are the implications of the use of respirators among miners reported in this study? Performance of respirators is frequently described in terms of a protection factor (PF), defined as the ratio of the concentration of a contaminant outside the facepiece of the respirator to its concentration inside the facepiece.[13,14] Since respirator use is almost always intermittent, it has been suggested that it is more accurate to look at the effective protection factor (EPF). This is the ratio of the amount of respirable dust to which an individual is exposed to the amount actually inhaled. The EPF includes dust inhaled with and without respiratory protection. If intermittent respirator use occurs during periods of greatest dust exposure, the EPF may be high even if total duration of respirator use is relatively short. In contrast, if dust levels are essentially constant, the EPF depends on the length of time for which the respirator is worn. For example, a respirator with a protection factor of 12 has an EPF of only 1.85 if it is worn 50% of the time, assuming constant dust levels.[15] Although the study questionnaire did not evaluate the type of respirator used, most miners in this study were observed to use filtering dust masks, with assigned protection factors (APF) of 5–10. Some of the employees also wore powered air-purifying respirators (APF 25–50).[16]

Respirator effectiveness also depends on proper selection, fit, and maintenance. While the Federal Coal Mine Health and Safety Act covers selection of appropriate respiratory equipment, it does not mandate training, fit testing, or medical clearance, which are all parts of comprehensive respiratory protection programs required by OSHA for general industry. Hewson and Ralph have called EPF the "program protection factor" (PPF), realizing that it is a function of workplace exposure conditions, worker activities, respirator maintenance, and patterns of respirator use. In their study population self-reported respirator use was high (50–95% of the shift, median 65%), and the PPF generally varied by less than an order of magnitude over a six-month period. In that population intermittent respirator use provided a reasonably consistent degree of respiratory protection.[17]

Without information relating temporal changes in dust exposure to respirator use, it is difficult to assess the EPF for the 60% of the miners who used respirators in this study. If dust levels are fairly constant, the effective protection afforded by using a respirator 29.9% of the time (the mean for those who reported at least some respirator use) would be only 1.41 for a respirator with a protection factor of 50 (Appendix). However, if miners can accurately judge environments with high dust exposure and wear their respirators accordingly, they may achieve substantial respiratory protection despite apparent low overall use. Consistent with this is the finding that miners who worked at the coal face, and thus were likely to be exposed to the highest dust concentrations,[7] reported using respirators more than other miners. If miners' decisions on respirator use are in part based on their potential dust exposures, then respirator use may confound the relationships observed between environmental measurements and health outcomes. Further study is necessary to determine whether the observed exposure-response relationships for coal mine dust would be modified if actual patterns of respirator use were taken into account.

## CONCLUSIONS

Overall, the reported percentage of time that respirators were worn by miners in this study was less than 20%, and a substantial minority of the workers (39.8%) reported never using a respirator during up to five years of follow-up. Face workers, who historically have been exposed to the highest dust concentrations, reported significantly greater use of respiratory protection than miners in other jobs. This suggests that decisions regarding respirator wear may be related to perceived dust exposure. It is unclear

whether current patterns of respirator use result in effective protection factors of public health importance. To answer this question, future studies will need to associate patterns of intermittent respirator wear with environmental sampling data that reflect temporal changes in dust exposure rather than just time-weighted averages.

If patterns of respirator use are found to result in meaningful EPFs, then further study will be necessary to determine if current recommendations for dust control need to be modified to take into account respirator use among study populations.

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## APPENDIX

$$EPF^{(15)} = \frac{t_0}{\frac{t_1}{PF} + (t_0 - t_1)}$$

$t_0$ = total sampling time

$t_1$ = time the respirator is worn

Assuming a 6 hour ($t_0$ = 360 minutes) underground work shift, and that a respirator is worn for 29.9% of the shift ($t_1$ = 107.6 minutes):

Protection Factor (PF) = 10 yields EPF = 1.37

Protection Factor (PF) = 25 yields EPF = 1.40

Protection Factor (PF) = 50 yields EPF = 1.41



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