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EFFECTS OF EXPOSURE TO DIESEL EMISSIONS AMONG COAL MINERS: A PROSPECTIVE EVALUATION

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Abstract—This paper reports results from a prospective design employed to test the hypothesis that exposure to diesel emissions leads to chronic respiratory effects amongst underground coal miners. Changes in respiratory function and development of chronic respiratory symptoms were measured over a 5-year study period in diesel exposed and control miners from Eastern and Western U.S. underground coal mines. Spirometric measures of respiratory function included Forced Expiratory Volume in one second (FEV_1). Forced Vital Capacity (FVC), and Forced Expiratory Flow Rate at 50 per cent of FVC (FEF_{50}). Chronic respiratory symptoms, which included persistent cough, persistent phlegm, and breathlessness, were obtained by questionnaire as were smoking status and occupational history. The pattern of evidence does not support the tested hypothesis when comparing the data on diesel vs. non-diesel exposed miners.

INTRODUCTION

PREVIOUS NIOSH studies of the effects of diesel emissions on the respiratory health of underground coal miners have failed to document adverse reactions associated with diesel emissions. These studies include estimates of acute respiratory effects over the 8-hour work shift (REGER *et al.*, 1982; AMES *et al.*, 1982), and chronic respiratory effects over a 5-year study period (AMES *et al.*, 1984). Yet it is known that diesel emissions contain gases of known toxicity, notably NO_2, NO_X, CO, and aldehydes, as well as particulate (WEISENBERGER, 1981). Measurements of these contaminants taken in the mine atmosphere have been recorded at levels high enough to add legitimacy to concern whether the negative findings should be interpreted to indicate 'no effect', or whether the findings represent simply an inability to document effects with the research designs and exposure measurements used. To date, these NIOSH epidemiological studies of exposure to underground diesel exhaust emissions have used solely 'work status', and 'work tenure' in underground mines as indices of presumptive exposure to diesel contaminants. Actual levels of diesel contaminants have not been used in these studies. This paper is a continuation of NIOSH efforts to explore the relationship between diesel emissions and respiratory symptoms and impairment in underground coal mines by using actual estimates per worker of exposure to diesel emissions obtained through industrial hygiene characterisation of the mine environment. Measurements in the mine and on the miners were taken at two time periods, thus allowing a prospective design. This paper tests the general hypothesis that underground exposure to diesel emissions among coal miners represents a risk for chronic respiratory disease.

DATA AND METHODS

Respiratory symptom and function measurements and personal and occupational histories were determined for 337 white male miners who worked in underground coal mines employing diesel-powered equipment underground. These mines were located in Kentucky, Colorado, Utah, and Wyoming. Respiratory measurements were taken in 1977 and again in 1982, thus allowing 5-year change in functions to be computed. Five-year changes were computed for measures of:

1) respiratory function, including Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second ($FEV_{1.0}$),and Forced Expiratory Flow rate at 50% of FVC (FEF_{50}); and,

2) incidence of respiratory symptoms, including chronic cough, chronic phlegm, and breathlessness. These measurements are described in greater detail in another paper (AMES, *et al.*, 1984).

Age, weight, height, and smoking status in 1977 are included in the analysis as adjustment factors. Least-squares means are used to analyze 5-year changes to respiratory function (SAS, 1979). Logistic regression analysis, using the same adjustment factors, is employed to analyse the incidence of chronic respiratory symptoms (COX, 1970). Each index of exposure to diesel contaminants was divided into thirds for ease in demonstrating a dose-response function. These cutpoints are: for NO_2 0 ppm, $\leq$ 0.2 ppm, and $\geq$ 0.3ppm; for CO_2 0 ppm, $\leq$ 790 ppm, and $>$ 791 ppm; for CO 0 ppm, $\leq$ 3 ppm, and $<$ 3 ppm; and for respirable particulate 0 mg/M^3, $\leq$ 0.6 mg/m^3 and $\geq$ 0.7 mg/M^3.

Area samples of diesel contaminants were taken both in 1977 and in 1982 with the expectation that change functions would be derived. However, only the 1982 data are used owing to problems in comparability between the two measurement time periods. The use of 1982 diesel contaminant levels should provide conservative estimates of the 5-year exposures. These samples were taken in work areas that could be related to the occupational history collected for the miners during the 5-year study period.

Four contaminants were measured as indices of diesel exhaust emissions: NO_2, CO_2, CO, and respirable particulate. Measurements were taken using standard NIOSH protocols. NO_2 should be considered a key diesel emission as it has known toxic effects on the respiratory system. CO_2 is a generalized indicator of exposure to fossil fuel combustion. The industrial hygiene characterization procedures and values are presented separately (PIACITELLI, 1985). Area samples were taken in seven work site exposure zones: intake, shuttlecar cab, roofbolter, return, continuous miner cab, main haulageway, and feederbreaker/dumppoint. Then for each job (using the NIOSH-developed Lainhart occupational codes for underground coal mining), an eight-hour shift weighted average was computed using average lengths of time occupied by each job in each exposure zone. A separate matrix was made for each of the four diesel contaminants. In this way, exposure indexes could be constructed for each miner of each of the four diesel contaminants by summing the product of years at each job by the exposure levels for that job (as a weighted average of time spent in each of the seven exposure zone sample areas).

Five-year changes were computed for FVC, FEV$_{1.0}$, and FEF$_{50}$ as well as the 5-year incidence of the chronic respiratory symptoms of cough, phlegm, and breathlessness. These symptoms were considered chronic if they persisted for three months or more per year. Forced vital capacity is an index of restrictive airways disease; FEV$_{1.0}$ an index of obstructive airways disease, and FEF$_{50}$ an index of small airways disease. The symptoms indicate chronic bronchitis.

The data for the 126 Western miners are presented separately from that of the 211 Eastern miners. The reason for this separation is that there were major differences in average age, education level, and other factors requiring control. Separate analysis of the Eastern and Western mines has the added advantage of allowing a replication of the test of the hypothesis under different conditions.

RESULTS

Respiratory function changes. Looking at the results for diesel contaminant and respiratory function, no significant cumulative NO$_2$ effect is seen in the 5-year changes of FEV$_{1.0}$ or FVC for either Western or Eastern miners in least-squares means models which adjust for the effects of age, height, weight, and cigarette smoking status, (Table 1, panels 1 and 2). There is no evidence of a dose-response gradient for either measure of respiratory function change. A statistically significant contrast, but opposite in direction to that hypothesised, in cumulative NO$_2$ exposure is revealed in Eastern

TABLE 1. PANEL 1. LEAST-SQUARES MEANS FOR RESPIRATORY FUNCTION CHANGES BY INDICES OF CUMULATIVE EXPOSURE

Respiratory function 5-year changes by thirds of cumulative exposure	Least-squares means of 5-year changes under simultaneous adjustment for age, height, weight, and cigarette smoking status	
	West	East
FEV$_{1.0}$ (ML) 5-Year CH		
Cum NO$_2$		
1st third	−0.09	−0.16
2nd third	−0.10	−0.10
3rd third	−0.08	−0.10
Prob H_0: $D_I - D_J = 0$	All $D_I - D_J$ NS	All $D_I - D_J$ NS
Cum CO$_2$		
1st Third	−0.08	−0.14
2nd Third	−0.09	−0.12
3rd Third	−0.10	−0.13
Prob H_0: $D_I - D_J = 0$	All $D_I - D_J$ NS	All $D_I - D_J$ NS
Cum CO		
1st Third	−0.09	−0.15
2nd Third	−0.11	−0.09
3rd Third	−0.08	−0.13
Prob H_0: $D_I - D_J = 0$	All $D_I - D_J$ NS	All $D_I - D_J$ NS
Cum Resp dust		
1st Third	−0.09	−0.14
2nd Third	−0.11	−0.09
3rd Third	−0.09	−0.16
Prob H_0: $D_I - D_J = 0$	All $D_I - D_J$ NS	All $\mathrm{D_I - D_J}$ NS

TABLE 1. PANEL 2. LEAST-SQUARES MEANS FOR RESPIRATORY FUNCTION CHANGES BY INDICES OF CUMULATIVE EXPOSURE

Respiratory function 5-year changes by thirds of cumulative exposure	Least-squares means of 5-year changes under simultaneous adjustment for age, height, weight, and cigarette smoking status	
	West	East
FVC (ML) 5-Year change		
Cum NO_2		
1st third	0.01	−0.09
2nd third	−0.01	−0.12
3rd third	0.07	0.12
Prob H_0: $D_I - D_J = 0$	All $D_I - D_J$ NS	All $D_I - D_J$ NS
Cum CO_2		
1st third	0.09	−0.08
2nd third	0	−0.12
3rd third	−0.01	−0.09
Prob H_0: $D_I - D_J = 0$	All $D_I - D_J$ NS	All $D_I - D_J$ NS
Cum CO		
1st third	0.08	−0.09
2nd third	−0.08	−0.12
3rd third	0.07	−0.09
Prob H_0: $D_I - D_J = 0$	$D_1 - D_2 < 0.01$; $D_2 - D_3 < 0.01$	All $D_I - D_J$ NS
Cum Resp dust		
1st third	0.08	−0.08
2nd third	−0.06	−0.08
3rd third	0.05	−0.15
Prob H_0: $D_I - D_J = 0$	$D_1 - D_2 < 0.01$; $D_2 - D_3 < 0.05$	All $D_I - D_J$ NS

miners, but not Western miners, for FEF_{50} between the first third and the second third of cumulative exposure (Table 1, panel 3).

This same pattern of relationship holds true for CO_2. No significant cumulative CO_2 effect is seen in the 5-year changes of $FEV_{1.0}$ or FVC, either in Eastern or Western miners (Table 1, panels 1 and 2). Among Eastern miners, a statistically significant contrast exists for FEF_{50} between the first and second third of cumulative CO_2 exposures. Again, the significant contrast is in the opposite direction to that hypothesised.

No consistent pattern of evidence supports a dose-response relationship of CO exposure and 5-year respiratory function change. Significant contrasts exist in Western miners for FVC (Table 1, panel 2) and for both Western and Eastern miners for FEF_{50} (Table 1, panel 3), but not in a dose-response pattern.

Finally, no consistent pattern of evidence supports a dose-response relationship between cumulative respirable dust particulate and 5-year respiratory function changes (Table 1, panels 1, 2 and 3). While statistically significant contrasts exist, they are not patterned in a consistent manner.

Respiratory symptom incidence. Looking at the incidence of chronic respiratory symptoms by diesel contaminant, we see that cumulative NO_2 is related to the incidence of chronic cough and chronic phlegm in Eastern miners only (Table 2, panel 1). Cumulative CO_2 is related to the incidence of chronic phlegm in both Eastern and

TABLE 1. PANEL 3. LEAST-SQUARES MEANS FOR RESPIRATORY FUNCTION CHANGES BY INDICES OF CUMULATIVE EXPOSURE

Respiratory function 5-year changes by thirds of cumulative exposure	Least-squares means of 5-year changes under simultaneous adjustment for age, height, weight, and cigarette smoking status	
	West	East
FEF_{50} (ML/Sec) 5-Year change		
Cum NO_2		
1st third	−0.35	−0.38
2nd third	−0.36	−0.02
3rd third	−0.61	−0.46
Prob H_0: $D_i - D_j = 0$	All $D_i - D_j$ NS	$D_1 - D_2 < 0.01$
Cum CO_2		
1st third	−0.46	−0.35
2nd third	−0.42	−0.05
3rd third	−0.34	−0.26
Prob H_0: $D_i - D_j = 0$	All $D_i - D_j$ NS	$D_1 - D_2 < 0.05$
Cum CO		
1st third	−0.48	−0.39
2nd third	−0.15	−0.11
3rd third	−0.61	−0.23
Prob H_0: $D_i - D_j = 0$	$D_1 - D_2 < 0.05$; $D_2 - D_3 < 0.01$	$D_1 - D_2 < 0.01$
Cum Resp dust		
1st third	−0.48	−0.35
2nd third	−0.18	−0.06
3rd third	−0.58	−0.20
Prob H_0: $D_i - D_j = 0$	$D_2 - D_3 < 0.01$	All $D_i - D_j$ NS

Western mines (Table 2, panel 2). Cumulative CO is related to cough in Eastern mines (Table 2, panel 3). Finally, cumulative respirable particulate is related to chronic cough and chronic phlegm, but in Eastern miners only (Table 2, panel 4).

INTERPRETATION

We find no support for the hypothesis that exposure to diesel exhaust in underground coal mines is related to decrements in pulmonary function. It is noted that the time span under investigation, 5 years, may be too short for the development of chronic respiratory function impairment.

We find limited support for the hypothesis that exposure to underground diesel contaminants in coal mines is related to the incidence of chronic respiratory symptoms, notably cough and phlegm. The strongest case for the relationship to chronic cough and chronic phlegm was seen in relation to CO_2 exposure. CO_2 is an inevitable outcome of the combustion of fossil fuels, but as it may also be formed as 'black damp' it must not be regarded as a unique marker of diesel exhaust emissions.

The incidence of chronic respiratory symptoms in relation to exposure to diesel exhaust contaminants in underground coal mines is important for several reasons. First, chronic cough and chronic phlegm are bronchitic symptoms. Second, our previous research has shown chronic phlegm to be related to early retirement with

TABLE 2. PANEL 1. LOGISTIC ANALYSIS OF RESPIRATORY SYMPTOM INCIDENCE BY INDICES OF CUMULATIVE EXPOSURE

Full model: symptom incidence by cumulative exposure	Restricted model	Variables tested for additional explanation
Age	Age	
Height	Height	
Weight	Weight	
Smoking status	Smoking status	
Cum NO_2 Exp1*		Cum NO_2 Exp1
Cum NO_2 Exp2		Cum NO_2 Exp2
Y-Intercept	Y-Intercept	

	Log likelihoods by symptom and region		
	Full model	Restricted model	Additional EXPL
Cough			
Western	−62.767	−63.948	X^2 = 2.36, NS
Eastern	−26.297	−31.591	X^2 = 10.59, <0.01
Phlegm			
Western	−78.247	−78.349	X^2 = 0.20, NS
Eastern	−32.308	−38.478	X^2 = 12.34, $<.01$
Breathlessness			
Western	−40.614	−40.857	X^2 = 0.49, NS
Eastern	−24.797	−26.656	X^2 = 3.72, NS

TABLE 2. PANEL 2. LOGISTIC ANALYSIS OF RESPIRATORY SYMPTOM INCIDENCE BY INDICES OF CUMULATIVE EXPOSURE

Full model: symptom incidence by cumulative exposure	Restricted model	Variables tested for additional explanation
Age	Age	
Height	Height	
Weight	Weight	
Smoking status	Smoking status	
Cum CO_2 Exp1*		Cum CO_2 Exp1
Cum CO_2 Exp2		Cum CO_2 Exp2
Y-Intercept	Y-Intercept	

	Log likelihoods by symptom and region		
	Full model	Restricted model	Additional EXPL
Cough			
Western	−60.655	−63.948	X^2 = 6.59, <0.05
Eastern	−29.023	−31.591	X^2 = 5.14, NS
Phlegm			
Western	−71.038	−78.349	X^2 = 14.62, <0.001
Eastern	−33.894	−38.478	X^2 = 9.17, <0.05
Breathlessness			
Western	−38.953	−40.857	X^2 = 3.81, NS
Eastern	−24.197	−26.656	X^2 = 4.92, NS

*Cumulative exposure is entered in the logistic analysis using 2 binary-coded variables to code the three exposure level categories.
NS = Not significant, alpha 0.05. All tests use 2 DF.

TABLE 2. PANEL 3. LOGISTIC ANALYSIS OF RESPIRATORY SYMPTOM INCIDENCE BY INDICES OF CUMULATIVE EXPOSURE

Full model: symptom incidence by cumulative exposure	Restricted model	Variables tested for additional explanation
Age	Age	
Height	Height	
Weight	Weight	
Smoking status	Smoking status	
Cum CO Exp1		Cum CO Exp1
Cum CO Exp2		Cum CO Exp2
Y-Intercept	Y-Intercept	

Log likelihoods by symptom and region

	Full model	Restricted model	Additional EXPL
Cough			
Western	−61.520	−63.948	X^2 = 4.86, NS
Eastern	−27.227	−31.591	X^2 = 8.73, $<.05$
Phlegm			
Western	−78.186	−78.349	X^2 = 0.33, NS
Eastern	−33.721	−35.478	X^2 = 3.51, NS
Breathlessness			
Western	−40.303	−40.857	X^2 = 1.11, NS
Eastern	−25.660	−26.655	X^2 = 1.99, NS

TABLE 2. PANEL 4. LOGISTIC ANALYSIS OF RESPIRATORY SYMPTOM INCIDENCE BY INDICES OF CUMULATIVE EXPOSURE

Full model: symptom incidence by cumulative exposure	Restricted model	Variables tested for additional explanation
Age	Age	
Height	Height	
Weight	Weight	
Smoking status	Smoking status	
Cum Resp Dust Exp1*		Cum Resp Dust Exp1
Cum Resp Dust Exp2		Cum Resp Dust Exp2*
Y-Intercept	Y-Intercept	

Log likelihoods by symptom and region

	Full model	Restricted model	Additional EXPL
Cough			
Western	−61.719	−63.948	X^2 = 4.46, NS
Eastern	−28.572	−31.591	X^2 = 6.04, <0.05
Phlegm			
Western	−77.644	−78.349	X^2 = 1.41, NS
Eastern	−34.046	−38.478	X^2 = 8.86, <0.05
Breathlessness			
Western	−38.602	−40.857	X^2 = 4.51, NS
Eastern	−25.746	−26.655	X^2 = 1.82, NS

*Cumulative exposure is entered in the logistic analysis using 2 binary-coded variables to code the three exposure level categories. NS = Not significant, alpha 0.05. All tests use 2 DF.

disability in coal miners (AMES and TRENT, 1984). Clearly, further research appears warranted.

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DISCUSSION

P. ELMES: How sensitive do you think your study was for a change in FEV, and the other indices of airways disease, bearing in mind that these people are probably losing 30 or 40 cc a year on this sort of index; how much greater would the fall have to have been for you to have demonstrated a relationship?

R.G. AMES: I think perhaps the most critical thing is simply the short five-year time period.

P. ELMES: You would have to get something like a thirty or forty percent increase in the rate of fall before it would show up, so that it is a relatively insensitive test at only five years.

R.G. AMES: I am aware of that.

YUNG SUNG CHENG: Our experiences with diesel particulate measurement in underground mines, and with diesel exhaust, show that particulate sizes are generally less than 0.3 μm in diameter. Therefore the respirable dust measurement does not really reflect the true diesel particle concentration in the coalmine where a higher coal dust concentration prevails.

R.G. AMES: I call that a partial index. Some studies have been made on the relative contribution that the diesel makes to the total particulate underground, and it is quite small. For one thing the diesels are all water-scrubbed.

M. LIPPMAN: The miners are subjected to both coal dust and diesel exhaust. Where there are differences, as in the Eastern mines using NO_2 as an exposure index, how well can the effects of the coal dust and the diesel exhaust be separated?

R.G. AMES: I don't know. The differences between the Eastern mines and the Western mines is also the difference between Eastern miners and Western miners. The mining situations are different; the Eastern miners are older, have more underground experience, the mines are less high; the Western mines typically much larger, the miners are frequently younger and many of the miners are college-educated people.

M. LIPPMANN: With all of these factors being constant, comparing coalmines in the East with all of them with and without diesel, could you correct for the coal effect and see a residual diesel effect? In fact, any effect that was there might have been due to a synergism between NO_2 and the dust.

R.G. AMES: I'm not sure, but we put the total particulate in the model and analysed both separately, so we should be adjusting for the effects of dust within each separate model.

R.I. MCCALLUM: How did you administer the questionnaires? Secondly, were aldehydes taken into account, and what effect is there likely to be from the efficiency of the diesel motor, as this will make some difference in the carbon monoxide and carbon dioxide output?

R.G. AMES: The questionnaires were administered by trained NIOSH technicians when the rest of the data were obtained.

G.M. PIACITELLI: Since the majority of measurements were below the limit of detection (0.01 ppm), no correlations with epidemiologic data were attempted.

M. MCCAWLEY: In response to the earlier question concerning the use of respirable dust measurements in the model, we have monitored the submicron particulate mass, which seems to be almost entirely ($>80\%$) diesel particulate, in the mines used in these studies for prospective epidemiology. We found that the average submicron particulate mass was approximately 0.5 mg/m^3. This did not vary by more than about 0.2 mg/m^3 among the mines. While there was some correlation of this particulate with respirable dust, it was not very high.