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Epidemiological–Environmental Study of Diesel Bus Garage Workers: Acute Effects of NO_2 and Respirable Particulate on the Respiratory System

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Personal samples of nitrogen dioxide (NO_2) and respirable particulate (RP) were collected over the shift on 232 workers in four diesel bus garages. Response was assessed by an acute respiratory questionnaire and before and after shift spirometry. Measures of exposure to NO_2 and RP were associated with work-related symptoms of cough; itching, burning, or watering eyes; difficult or labored breathing; chest tightness; and wheeze. The prevalence of burning eyes, headaches, difficult or labored breathing, nausea, and wheeze experienced at work were higher in the diesel bus garage workers than in a comparison population of battery workers, while the prevalence of headaches was reduced. Mean reductions in forced vital capacity (FVC), forced expiratory volume in 1 sec (FEV_1), peak flow, and flows at 50 and 75% of FVC were not obviously different from zero. There was no detectable association of exposure to NO_2 or respirable particulate and acute reductions in pulmonary function. Workers who often had respiratory work-related symptoms generally had a slightly greater mean acute reduction in FEV_1 and FEF_{50} than did those who did not have these symptoms, but these differences were not statistically significant.

INTRODUCTION

Despite the extensive use of diesel engines in mines, locomotives, buses, and trucks, and the increased use of diesel cars, there are few studies of the acute effects of diesel exhaust on animal or human subjects. There are only five short-term experimental studies reported in the literature. Two animal studies were of such high concentrations as to cause death (Pattle *et al.*, 1957; Pattle and Collumbine, 1956). Battigelli *et al.* (1966) exposed rats to diesel exhaust and measured mucociliary clearance at the end of the exposure. Animals exposed for 40 hr to 2.7 ppm nitrogen dioxide (NO_2) and 9 mg/m^3 particulate had a 22% mean reduction in clearance, and an occasional complete inhibition of clearance. Animals exposed to higher NO_2 levels (4–5 ppm) but lower particulate (0.9 mg/m^3) for 41 and 100 hr had less inhibition of clearance than in comparable exposures with more particulate. Half of the animals exposed for 4 hr to 11 ppm NO_2 (and high but not measured particulate) showed inhibition of clearance, with complete recovery in 72 hr. Sheep exposed to about 1/2 mg/m^3 diesel particulate from which gases were removed showed no change in tracheal mucus velocity, pulmonary resistance, static lung compliance, and airway reactivity to aerosolized carbachol (Abraham *et al.*, 1980).

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The only experimental study of humans was reported by Battigelli in 1965. Breathing diluted diesel exhaust through a mouthpiece for 1 hr resulted in no significant changes in airways resistance with mean NO_2 levels of 4.2 ppm (1.5–7) and mean sulfurdioxide (SO_2) levels of 1 ppm (0.5–2.8). By contrast, these same high concentrations resulted in eye irritation (for over 50% of the subjects) that was intolerable within 10 min. Exposure to diesel exhaust with a mean level of 2.0 ppm NO_2 and 0.5 ppm SO_2 was occasionally intolerable. The average irritation score was 1.5, where 1 was some irritation and 2 was conspicuous but tolerable irritation. A more diluted exhaust mixture containing 1.3 ppm NO_2 and 0.2 ppm SO_2 caused an eye irritation score of 0.9 (0 = no irritation); the most sensitive subjects experienced conspicuous but tolerable irritation (Battigelli, 1965). Commins *et al.* (1957) commented on the considerable eye irritation and lachrymation they experienced in the two diesel bus garages they sampled. Irritation was particularly noticeable when the buses were started from cold.

There are only three epidemiological studies of acute effects of diesel exposure and two of them involved exposure to diesel exhaust plus other particulate, namely coal dust (Ames *et al.*, 1982) and salt (Gamble *et al.*, 1978). Coal miners who were smokers and working in diesel coal mines with less than 1 ppm NO_2 had significant over the shift reductions in FEV_1 and FEF_{50}; the reductions were similar to those of coal miners who were smokers and worked in nondieselized mines. Nonsmokers and ex-smokers showed no significant acute reduction in pulmonary function. Salt (NaCl) miners exposed to mean NO_2 levels of 1.5 ppm and mean respirable particulate levels of 0.7 mg/m^3 had small reductions in pulmonary function over the shift that were associated with NO_2 exposure but not associated with exposure to respirable particulate.

The third epidemiological study was a survey of diesel bus garage workers in Egypt (El Batawi and Noweir, 1966). Concentrations of NO_2 in the two garages were below 1 ppm (mean values were 0.4–0.7 ppm). The most common symptoms were eye irritation (42%), headache (37%), dizziness (30%), gastric troubles (24%), rheumatic pains and psychological conditions (21%), and throat irritation (19%).

There are few controlled studies of the acute effects of exposure to respirable particulate alone. Humans were exposed for 5 hr to plastic impregnated with carbon black ("inert dirt"). Of the particles, 77% were less than 5.3 μm and so particle size was larger than diesel particulate. Exposure on subsequent days to 2, 10, and 25 mg/m^3 resulted in a slight decrease in FEV_1, but no significant changes in FVC, FEF_{25-75}, nasal resistance, or nasal mucociliary clearance (Anderson *et al.*, 1979).

There are several experimental studies of the effect of NO_2 on pulmonary function (for example, Hackney *et al.*, 1978; Folinsbee *et al.*, 1978; Kerr *et al.*, 1978; von Nieding *et al.*, 1973). No effects on the airways were observed after 2 hr exposure to concentrations as high as 1.5 ppm. However, exposure to NO_2 as low as 0.1 ppm for 1 hr in some asthmatics increased the airway reactivity to bronchoconstrictors (Orehek *et al.*, 1976).

The questions addressed in this paper relate to changes in pulmonary function

and work-related symptoms that occur over a shift, and the association of these changes with exposure to diesel exhaust.

METHODS

Measurements of respirable particulate and NO_2 were made on each worker and collected on the same day as the pulmonary function tests and questionnaires. NO_2 was measured using a passive sampler (Palmes, 1976) and respirable particulate was determined gravimetrically. These time-weighted average exposure measures are used to estimate dose–response relations, and are also used as surrogate measures of the total diesel exhaust exposure.

Area samples for the irritants SO_2, formic acid, formaldehyde, sulfate, phenol, and acrolein were well below existing federal standards, even when we use the highest value obtained in the additive formula recommended by ACGIH for irritants as a group. We have not analyzed for dose–response relations for these compounds due to the low levels and unavailability of personal environmental samples for them. Thus, in the context of this paper, references to exposure to diesel exhaust indicate exposure to NO_2 and respirable particulate.

Each worker was administered a respiratory questionnaire which included questions on symptoms occurring at work and thought by the worker to be work-related. Associations between diesel exhaust exposure and work-related symptoms were analyzed using a logistic model. Age and exposure were retained as continuous variables; garage and smoking category were the other independent variables. Comparisons with a population of battery workers were made without adjustments for age and smoking. These comparison workers were administered a similar questionnaire and did not show a statistically significant association of acute symptoms with acid exposure (Gamble *et al.*, 1984).

For each worker a minimum of five forced expirations were recorded on magnetic tape using an Ohio 800 rolling seal spirometer[1] before beginning work and then again at the end of the shift (6–7 hr). Maximum forced expiratory volume in 1 sec (FEV_1), forced vital capacity (FVC), peak flow rate (PFR), and flows at 50 and 75% of expired FVC (FEF_{50}, FEF_{75}) were obtained by lining up the after-shift maximum envelope at total lung capacity of the before-shift maximum envelope and measuring flows at before-shift percentages of FVC. Changes in pulmonary function (ΔPFT) were calculated as (after-shift pulmonary function) minus (before-shift pulmonary function). The effects of diesel exhaust on pulmonary function were estimated in two ways. First, it was determined whether mean changes were significantly different from zero, assuming there should be no change in the absence of an environmental exposure. Second, dose–response relationships were analyzed by multiple linear regression techniques.

Characteristics of study population. Table 1 summarizes demographic characteristics of the study population of 115 white males, 96 black males, 8 white females, and 8 black females. Age was bimodally distributed, with 59% of the workers between the ages of 18 and 38 and 27% between the ages of 46 and 59.

[1] Mention of company does not constitute endorsement by NIOSH.

TABLE 1
CHARACTERISTICS OF DIESEL BUS GARAGE STUDY POPULATION, MEANS (SD)

	n	Age	Years worked	Respirable particulate (mg/m^3)	NO_2 (ppm)	Pack years	Cigarettes/ day
Nonsmokers	66	39.6	11.5	0.20	0.20	—	—
		(13.5)	(12.0)	(0.24)	(0.22)		
Ex-smokers	50	40.9	12.4	0.26	0.25	14.1	19.7
		(12.3)	(11.5)	(0.29)	(0.27)	(17.7)	(13.7)
Smokers	116	37.2	7.0	0.25	0.23	19.6	19.8
		(12.7)	(9.0)	(0.26)	(0.25)	(18.1)	(11.5)
Garage A	17	42.0	14.7	0.35	0.56		
		(13.4)	(13.7)	(0.15)	(0.38)		
Garage B	39	36.9	8.0	0.61	0.50		
		(11.7)	(11.1)	(0.38)	(0.32)		
Garage C	73	42.2	10.5	0.12	0.13		
		(14.6)	(11.2)	(0.08)	(0.11)		
Garage D	103	36.3	8.4	0.16	0.13		
		(11.3)	(9.5)	(0.14)	(0.06)		
Shift 1 (Day)	177	40.5	11.0	0.23	0.22		
		(13.1)	(11.1)	(0.25)	(0.06)		
Shift 2 (Afternoon)	43	31.8	4.5	0.31	0.25		
		(31.1)	(4.5)	(0.31)	(0.25)		
Shift 3 (Night)	12	36.0	4.2	0.12	0.15		
		(10.0)	(4.7)	(0.07)	(0.07)		
All	232	38.7	9.5	0.24	0.23		
		(12.9)	(10.7)	(0.26)	(0.24)		

The distribution by years worked was highly skewed with a mean of 9.5 years and median of 5.2 years. Workers on the afternoon and night shifts were generally younger and had worked about 6 years less than the day shift workers, and measures of respirable particulate (RP) and NO_2 on the night shift were about one-half those of the day and evening shifts, respectively. Before-shift baseline pulmonary functions were approximately normally distributed with the following mean values (with SD): FVC = 4.64 liters (1.06); FEV_1 = 3.61 liters (0.95); PFR = 9.02 liters/sec (2.37); FEF_{50} = 4.57 liters/sec (1.81); and FEF_{75} = 1.54 liters/sec (0.81).

RESULTS

Symptoms

The prevalence of acute symptoms ranged from 15 to 54%, but were elevated above expected only in the high-exposure group and in garages A and B. The strongest associations of exposure and prevalences were with the symptoms of eye irritation, labored breathing, chest tightness, and wheeze. Age was commonly associated with a symptom but, except for wheeze, the younger the age, the higher the prevalence of the symptom. Smoking was associated only with

cough and wheeze, and was elevated above expected among only the current smokers (Table 2).

The prevalence of acute symptoms in the study population was also compared with the prevalence among workers in a lead acid battery plant. (Gamble *et al.*, 1984). The two populations were similar in age (38.7 with an SD of 12.9 compared with 36.1 with an SD of 12.6) and in smoking composition (7% more smokers, 1% more ex-smokers, and 8% fewer nonsmokers in the battery population).

The majority of workers in the garage and battery populations thought their symptoms were work-related. Except for chest tightness and eye irritation, the proportion often reporting the symptoms was similar in the two populations. The prevalences of eye symptoms, headaches, difficult or labored breathing, nausea, and wheeze were higher among the garage workers, while the prevalence of sneeze was higher among the battery workers (Table 3).

The acute symptom questions were asked such that past exposures or jobs could affect the response; acute symptoms and exposure on the day of the study could be unrelated, or only indirectly related to exposure levels that day. In garage D, workers were also asked at the end of the shift whether they experienced certain symptoms that day. The agreement between symptoms that day, and past work-related symptoms occurring on that job, was as follows: Cough = 73% agreement; eyes itch, burn, or water = 62%; headache = 71%; wheeze = 97%; and chest tightness = 91%.

Pulmonary Function

Changes in pulmonary function over the shift were normally distributed around zero, and no pulmonary function parameter had a mean value that was significantly different from zero (Table 4).

Even the most complex multiple regression model explained less than 10% of the variation in ΔPFT. The only consistently significant explanatory variable was work shift. The least-square means for ΔPFT during the day shift were consistently positive, whereas the averages of the afternoon and night shifts were negative.

Symptoms and Pulmonary Function

The mean decrement in ΔPFT for all workers with acute symptoms was usually greater than the decrement in those without symptoms. However, the variability was quite large and the differences were generally small (Table 5).

DISCUSSION

This study of diesel bus garage workers shows that acute symptoms are more sensitive indicators of diesel exhaust exposure than are acute changes in ventilatory function over the shift (ΔPFT). Eye irritation was the most sensitive of the symptoms about which we asked. There were no apparent decrements in pulmonary function associated with this symptom, and no reductions in pulmonary function associated with exposure.

While irritation and acute discomfort are recognized as valid for the establishment of threshold limit values, prevalences of acute symptoms among working

TABLE 2

PREVALENCE OF ACUTE SYMPTOMS BY AGE,[a] SMOKING, GARAGE, AND EXPOSURE (LOGISTIC ANALYSIS USED TO CALCULATE EXPECTED VALUES[b])

		Cough		Nose tickled or irritated		Sneeze		Eyes itch, burn, or water		Headache		Difficult or labored breathing		Tight or constricted feeling in chest		Nausea		Itching skin		Wheeze	
	n	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E	OBS	% O/E
Prevalence	232	48.7		39.7		34.9		53.9		31.9		16.8		15.1		15.5		32.3		17.7	
Age			*c*		*e*		*f*		*e*		*f*		*g*		*g*		*e*		*c*		*c*
≤40	142	55	112	44	120	40	114	64	119	37	118	16	96	15	97	21	135	38	117	13	71
>40	90	39	81	27	68	27	77	38	70	23	72	18	107	16	105	7	44	23	73	26	150
Smoking status			*c*		*g*		*g*		*g*		*g*		*g*		*g*		*g*		*g*		*d*
Nonsmokers	66	38	79	39	101	32	92	52	97	35	110	11	63	9	61	11	71	32	100	11	59
Exsmokers	50	40	85	36	96	30	89	54	105	40	129	16	94	12	81	14	103	24	77	8	43
Smokers	116	59	118	41	101	39	109	55	99	27	82	21	124	20	130	19	114	36	109	26	151
Garage			*e*		*d*		*g*		*e*		*g*		*e*		*f*		*c*		*f*		*c*
A	17	59	120	47	129	35	104	65	128	41	134	18	104	24	160	18	124	24	77	35	163
B	39	77	154	59	144	46	129	92	165	44	134	39	231	28	184	33	201	46	140	31	184
C	73	51	108	43	115	34	101	38	77	29	94	14	80	14	93	14	101	37	118	19	96
D	103	35	71	29	70	31	87	49	86	28	86	11	64	10	63	10	58	25	76	9	54

NO_2 exposure			*f*			*g*			*g*			*e*			*f*			*c*			*c*			*f*			*g*			*d*	
≤0.14 ppm	134	45		94	37		97	33		96	43		82	30		95	13		80	10		70	13		92	28		87	12		65
0.14–0.3 ppm	54	48		96	41		98	35		98	57		103	32		98	17		101	19		120	15		87	41		121	20		121
>0.3	44	61		124	46		112	41		115	82		147	39		117	27		160	25		162	23		135	36		112	32		190
RP exposure			*d*			*g*			*g*			*e*			*c*			*c*			*c*			*f*			*g*			*c*	
≤0.17	135	39		83	38		95	34		99	45		84	30		91	13		83	11		77	12		77	30		94	13		81
0.17–0.31	46	54		105	33		83	30		85	53		98	24		81	11		59	13		77	15		97	37		112	13		59
≥0.31	51	69		139	51		128	41		118	78		144	45		139	31		182	28		179	26		161	33		104	33		192
NO_2 and RP			*c*			*g*			*g*			*e*			*f*			*d*			*c*			*g*			*g*			*d*	
NO_2, T, RP, NO_2*RP			*g*			*g*			*g*			*g*			*g*			*g*			*g*			*g*			*g*			*g*	

[a] Frequency of symptoms: sometimes, fairly often, and very often. The question was asked using the following format: "We are interested in knowing if you have any of the following symptoms that you think might be caused or made worse by your work. Indicate how often you have these symptoms at work or shortly after work. If you do have the symptoms, indicate whether you think it had nothing to do with your present job, was caused, or was made worse by your present job."

[b] Expected values by age are adjusted for smoking; expected values by smoking status are adjusted for age. All other expected values are adjusted for both age and smoking.

[c] $p < 0.05$.

[d] $p < 0.005$.

[e] $p < 0.0005$.

[f] $p > 0.05$.

[g] $p > 0.10$.

TABLE 3
COMPARISON OF ACUTE SYMPTOMS PREVALENCE IN DIESEL BUS GARAGE WORKERS AND BATTERY WORKERS

	Bus garage (n = 232)			Battery (n = 248)		
Symptom	Sometimes	Often	Total % (95% CI)	Sometimes	Often	Total % (95% CI)
Cough						
Work related	25.4	10.3	35.7 (27–47)	23.5	7.7	31.2 (25–37)
Not work related	10.8	2.2	13.0 (8–17)	8.5	3.2	11.7 (8–16)
Nose tickled or irritated						
Work related	21.1	13.8	34.9 (29–41)	17.1	8.5	25.6 (20–31)
Not work related	3.0	1.7	4.7 (2–7)	5.3	1.6	6.9 (4–10)
Sneeze						
Work related	19.4	5.6	25.0 (19–31)	30.1	11.0	41.1 (35–47)[a]
Not work related	8.6	1.3	9.9 (6–14)	10.6	1.2	11.8 (8–16)
Eyes itch, burn, or water						
Work related	25.4	24.1	49.5 (43–56)[a]	17.4	6.1	23.5 (18–29)
Not work related	3.4	0.9	4.3 (2–7)	3.2	1.6	4.9 (2–8)
Headaches						
Work related	15.1	9.1	24.2 (19–30)[a]	7.3	4.9	12.1 (8–16)
Not work related	6.0	1.7	7.7 (4–11)	6.9	3.2	10.1 (6–14)
Difficult or labored breathing						
Work related	10.0	3.5	13.5 (9–18)[a]	2.8	0.8	3.6 (1–6)
Not work related	2.6	0.9	3.5 (1–6)	1.6	0.4	2.0 (0–4)
Tight or constricted feeling in chest						
Work related	8.3	3.0	11.3 (7–15)	2.4	5.7	8.1 (5–12)
Not work related	2.2	0.9	3.1 (1–5)	3.7	5.7	9.3 (6–13)
Nausea						
Work related	8.7	4.8	13.5 (9–18)[a]	2.5	2.0	4.5 (2–7)
Not work related	1.3	0.9	2.2 (0–4)	2.9	0.4	3.3 (1–6)
Itching skin						
Work related	15.7	11.8	27.5 (22–33)	19.1	12.2	31.3 (26–37)
Not work related	3.1	1.3	4.4 (2–7)	4.1	1.2	5.3 (2–8)
Wheeze						
Work related	10.3	3.4	13.7 (9–18)[a]	3.3	1.2	4.5 (2–7)
Not work related	3.0	0.9	3.9 (1–6)	4.5	0.4	4.9 (2–8)

[a] $P < 0.05$ that the prevalence is higher.

populations are reported only rarely. Gamble *et al.* (1976) asked rubber workers about work-related symptoms in a similar fashion to the questions in this study. Baelum *et al.* (1982) asked printers exposed to solvents and nonexposed controls about a variety of acute symptoms at work, after work, and on weekends and holidays. Garabrant *et al.* (1984) reported a lower prevalence of eye irritation among workers exposed to about 4 mg/m^3 boron oxide. The results from these and previously mentioned studies are summarized in Table 6.

Only the results from the study of battery workers are directly comparable with

TABLE 4
CHANGES IN PULMONARY FUNCTION OVER THE SHIFT IN WORKERS EXPOSED TO DIESEL EXHAUST
(MODEL: $\Delta PFT = \alpha + \beta_1$ (SHIFT) $+ \beta_2$ (SMOKING) $+ \beta_3$ (RP) $+ \beta_4$ (NO_2) $+ \beta_5$ (RP $*$ NP_2))

	ΔFVC[a] (ml)	ΔFEV_1 (ml)	ΔPKF (ml/sec)	ΔFEF_{50} (ml/sec)	ΔFEF_{75} (ml/sec)
Overall mean (SD)	−12 (20)	−19 (18)	+179 (1095)	−102 (701)	−45 (396)
Significant independent Variables ($P < 0.05$)	Model N.S.	Shift	NO_2 RP 8 NO_2	Shift	Shift
Least-square means (SE); mean values adjusted for variables in the model					
Shift					
Day	—	+11 (14)	+298 (86)	+20 (55)	+12 (31)
Afternoon	—	−111 (28)	−76 (172)	−440 (110)	−235 (62)
Night	—	−20 (55)	−96 (335)	−130 (215)	+58 (121)
Smoking					
Nonsmokers	—	−42 (29)	+161 (177)	−164 (113)	−16 (64)
Ex-smokers	—	−18 (31)	+61 (189)	−94 (121)	−37 (68)
Smokers	—	−61 (23)	−96 (142)	−292 (91)	−113 (51)
RP coefficient (β_3)	—	+124 (98)	+168 (601)	+158 (385)	+371 (218)
NO_2 coefficient (β_4)	—	+12 (94)	+2013 (580)	+47 (371)	−236 (210)
r^2	0.05	0.08	0.09	0.08	0.08

[a] The overall model for ΔFVC was not significant and so only the overall mean is presented.

those of this study. However, it is interesting that about one-half of the printers and bus garage workers experience eye irritation, a higher prevalence than that of the other groups. The strong dose–response relationship, experimental reports, anecdotal notes, and personal experience provide consistent support that eye irritation is a sensitive indicator of diesel exhaust exposure. Cough and labored breathing may also be indicators of diesel exposure, but appear less sensitive than eye irritation.

There are several possible reasons for the higher symptom rates among the diesel-exposed population. Several irritants are present in diesel exhaust, primarily aldehydes such as formaldehyde and acrolein (Pattle *et al.*, 1957; Linnell and Scott, 1962; Fassett, 1963). Residents in California report eye irritation as the most common symptom during an air pollution episode; aldehydes, including acrolein and formaldehyde, are among the suspect candidates causing the irritation (Goldsmith, 1968; Jaffe, 1968). At 10–20 ppm, NO_2 is a mild irritant to the eyes, nose, and upper respiratory mucosa (Patty, 1963). Seven of 13 asthmatics exposed for 2 hr to 0.5 ppm NO_2 experienced chest tightness, headache, or slight burning of the eyes (Kerr *et al.*, 1978). It is possible that some of these symptoms could be related to air pollution, as all of the bus garages were in large cities while the battery plants were in smaller towns, and the low-exposure groups of bus workers had a slightly higher prevalence of symptoms than did the battery workers. If the exposures on the day of the study reflect the exposure on the day the symptoms actually occurred in the study population, the threshold for the acute symptoms is around 0.3 ppm NO_2 and 0.3 mg/m^3 RP.

What is the importance of the acute symptoms? The agreement between acute symptoms reported on the day of the study and the general occurrence of acute

TABLE 5
MEAN CHANGES IN PULMONARY FUNCTION OF THOSE WITH AND WITHOUT WORK-RELATED SYMPTOMS

	Frequency of symptoms		
	None	Sometimes	Often
Cough			
n	95	59	24
ΔFEV_1 (SD)	−10 (183)	−8 (173)	−69 (264)
ΔFEF_{50} (SD)	−67 (644)	−61 (789)	−250 (981)
Nose tickled or irritated			
n	128	49	32
ΔFEV_1 (SD)	−11 (181)	−1 (176)	−45 (212)
ΔFEF_{50} (SD)	−88 (703)	−87 (751)	−73 (814)
Sneeze			
n	120	45	13
ΔFEV_1 (SD)	+2 (182)	−50 (178)	−121 (285)
ΔFEF_{50} (SD)	−4 (708)	−232 (816)	−515 (891)
Eyes Itch, Burn, or Water			
n	98	59	55
ΔFEV_1 (SD)	−0.6 (175)	−43 (184)	−12 (208)
ΔFEF_{50} (SD)	−22 (633)	−206 (765)	−86 (857)
Headache			
n	134	35	21
ΔFEV_1 (SD)	−4 (191)	−30 (140)	−34 (255)
ΔFEF_{50} (SD)	−33 (702)	−150 (827)	−30 (822)
Difficult or labored breathing			
n	182	23	8
ΔFEV_1 (SD)	−7 (177)	−43 (164)	−156 (326)
ΔFEF_{50} (SD)	−57 (716)	−162 (777)	−436 (1075)
Tight or constricted feeling in chest			
n	186	21	7
ΔFEV_1 (SD)	−6 (171)	−44 (180)	−159 (337)
ΔFEF_{50} (SD)	−63 (658)	+8 (824)	−43 (1118)
Nausea			
n	191	20	11
ΔFEV_1 (SD)	−13 (171)	−46 (225)	−126 (314)
ΔFEF_{50} (SD)	−79 (665)	−246 (1084)	−410 (1028)
Itching skin			
n	152	38	27
ΔFEV_1 (SD)	−16 (177)	−20 (211)	−10 (192)
ΔFEF_{50} (SD)	−82 (684)	−112 (918)	−63 (726)
Wheeze			
n	185	24	8
ΔFEV_1 (SD)	−11 (162)	−58 (205)	−144 (335)
ΔFEF_{50} (SD)	−75 (392)	−210 (1099)	−414 (990)

TABLE 6
PREVALENCE OF ACUTE WORK-RELATED RESPIRATORY SYMPTOMS

	Rubber workers	Printers	Controls	Battery acid	Egyptian diesel bus garage	U.S. diesel bus garage
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
Cough	20 (13–27)			43 (37–49)		49 (42–55)
Nose		63 (56–70)	15 (5–25)	33 (27–38)		40 (33–46)
Sneeze				53 (47–59)		35 (29–41)
Eye	33 (25–41)	49 (35–63)	17 (7–27)	28 (23–34)	42 (34–52)	54 (47–60)
Headaches		54 (40–68)	38 (25–51)	22 (17–28)	37 (29–46)	32 (26–38)
Labored breathing				5 (2–7)		17 (12–22)
Chest tightness	19 (13–26)			17 (13–22)		14 (10–19)
Nausea				8 (4–11)		16 (11–20)
Itch	26 (19–33)			37 (31–43)		32 (26–38)
Wheeze	12 (7–19)			9 (3–15)		18 (13–23)
Reference	Gamble *et al.* (1976)	Baelum *et al.* (1982)		Gamble *et al.* (1984)	El Batawi and Noweir (1966)	This study

symptoms was very good for some symptoms (wheeze, chest tightness), but not as good for others (cough, headache, burning eyes). The lack of association between decrements in pulmonary function and acute symptoms does not allow for a more objective confirmation of symptoms. All studies on the effect of diesel exhaust suggest that symptoms are more sensitive than changes in pulmonary function.

There were no associations between our measures of diesel exposure (NO_2 and respirable particulate) and acute reductions in pulmonary function. NO_2 exposure in this study was below 1.5 ppm, the level at which statistically significant increases in airway resistance have been observed in human exposure studies (von Nieding *et al.*, 1973). Reductions in pulmonary function have been observed at lower exposure levels (0.5–1 ppm NO_2 for 2 hr); the reductions were not statistically significant although the number of subjects was small (n = 15, 10, and 16, respectively) (Folinsbee *et al.*, 1978; Kerr *et al.*, 1978; Hackney *et al.*, 1978).

Although smokers consistently had the largest reduction in pulmonary function over the shift, the change was not statistically greater than that of ex-smokers and nonsmokers. The lack of a statistically significant smoking effect is not an uncommon finding in acute studies (McKerrow *et al.*, 1965; Bouhuys *et al.*, 1969; Gandevia and Milne, 1965; Gamble *et al.*, 1978).

Shift was a variable associated consistently with acute changes in pulmonary function. The changes tend to follow the pattern of diurnal changes in pulmonary function observed in nonexposed workers; i.e., rise during the morning shift, and reduction during the afternoon and night shifts. Further, the mean changes in diesel bus workers are of the same order of magnitude as those observed in nonexposed workers (see Table 7).

Airway reactivity and depression of tracheal mucus velocity appear to be more

TABLE 7
EFFECT OF SHIFT ON CHANGES IN PULMONARY FUNCTION IN UNEXPOSED WORKERS, COMPARED WITH DIESEL BUS WORKERS (+ = INCREASE, − = DECREASE)

	Morning shift			Afternoon shift			Night shift		
	n	Change	(SD)	*n*	Change	(SD)	*n*	Change	(SD)
ΔFEV_1 (ml)									
Guberan *et al.* (1969)	19	+150		19	−70		19	−20	
	19	+150		19	−40		19	−0	
Walford *et al.* (1966) ($=\Delta FEV_{0.75}$)	79	+90		72	−140		47	−90	
Lapp *et al.* (1972)	42	+110	(220)	—			—		
McKerrow *et al.* (1965)	14	+100		—			—		
Merchant *et al.* (1974)	12	+60	(220)	—			—		
This study	177	+4	(164)	43	−113	(235)	12	−68	(154)
ΔFVC (ml)									
Guberan *et al.* (1969)	19	+60		19	−40		19	−50	
	19	+60		19	−70		19	−10	
Lapp *et al.* (1972)	42	+70	(180)	—			—		
McKerrow *et al.* (1965)	14	+60		—			—		
This study	177	+10	(201)	42	−88	(217)	12	−84	(135)
ΔPeak Flow (ml/sec)									
Lapp *et al.* (1972)	42	−30	(930)	—			—		
This study	177	+274	(1042)	43	−123	(1457)	12	−286	(782)
ΔFEF_{50} (ml/sec)									
Lapp *et al.* (1972)	42	+160	(650)	—			—		
Merchant *et al.* (1974)	12	−10	(570)	—			—		
This study	177	−8	(633)	43	−463	(74)	12	−313	(541)
ΔFEF_{75} (ml/sec)									
Lapp *et al.* (1972)	42	−0	(360)	—			—		
This study	177	−2	(380)	43	−239	(466)	12	−13	(403)

sensitive than pulmonary mechanics, at least to the effects of gaseous exposures such as SO_2, NO_2, and ozone (O_3) (Abraham *et al.*, 1980). Tracheal mucus velocity in rats is reduced at particulate concentrations that produce in humans no increase in pulmonary resistance (Battigelli *et al.*, 1966; Battigelli, 1965). Particle size may affect response, however, as exposure of human volunteers for 5 hr to up to 25 mg/m^3 of an inert dust of larger particle size than diesel particulate decreases FEV_1, but not nasal mucociliary clearance, FVC, or FEF_{25-75} (Anderson *et al.*, 1979). Tracheal mucus velocity was not measured. Acute exposures may increase rather than decrease clearance rate. Camner *et al.* (1973) found that the clearance was increased when persons took 10 deep inhalations of carbon dust (50 mg/ml and 10 μg deposited in the lung). Short-term exposure to 5 ppm SO_2 momentarily increased mucociliary transport, while maximal midexpiratory flow decreased (Wolff *et al.*, 1975).

The results of the study reported here suggest that NO_2 and particulate phases of diesel exhaust were below the threshold for producing a measurable reduction in lung function.

The current OSHA standard for NO_2 is 5 ppm. NIOSH recommends a 15-min ceiling level of 1 ppm. Strip chart recordings of NO_2 taken at the garages show that levels above 1 ppm were not uncommon (with the exception of garage C). There were in fact several TWA values above 1 ppm. Since the levels of NO_2 were high relative to the other irritants we suggest that maintaining NO_2 below the NIOSH recommendation may be an effective way to reduce the prevalence of symptoms.

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