Changes in Forced Expiratory Volume in One Second and Peak Expiratory Flow Rate across a Work Shift among Unexposed Blue Collar Workers[1-3]

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SUMMARY Pre- and postshift spirometry was obtained on 1,113 blue collar workers employed at 35 work sites judged to have no hazardous occupational respiratory exposures on the basis of inspection visits and environmental sampling. In addition to spirometry, a standardized questionnaire was administered by trained personnel. A study population of 944 remained after exclusion of workers for incomplete demographic data and/or spirometry with poor within-session reproducibility, i.e., ≥ 10% variability in the two largest values of either FVC and/or FEV_1. Overall mean values of changes across the work shift in FEV_1 and peak expiratory flow rate (PEFR) were −0.8% (−0.04 L) and +2.1% (+0.13 L/s), respectively. Standard deviations for these across-shift changes were 5.8% (0.19 L) and 13.2% (1.19 L/s) for FEV_1 and PEFR, respectively. In univariate analyses, mean values of across-shift changes were not statistically related to age, race, sex, smoking status, work shift, or FEV_1/FVC ratio. However, variability (i.e., standard deviation) of across-shift changes were significantly related to some of these factors. These observations provide a basis for interpreting results of occupational respiratory morbidity surveys involving measurement of changes in FEV_1 and/or PEFR across a work shift.

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Introduction

The rationale for testing pulmonary function before and after a work shift is that decline across the shift may serve as evidence of an adverse physiologic response to a workplace exposure. An acute effect of inhaled cotton dust was demonstrated in the first published study of across-shift changes in pulmonary function (1). This technique has subsequently been used to investigate the acute respiratory effects of a wide variety of occupational exposures (2–12). FEV_1 has been the pulmonary function index used most frequently to assess change across a work shift, as spirometry has proved to be feasible and reliable in large field surveys and FEV_1 is sensitive to acute bronchoconstriction induced by inhaled agents. In fact, federal regulations require that medical monitoring of cotton textile mill workers include pre- and postshift measurements of FEV_1 (13). Peak expiratory flow rate (PEFR), although more variable in its measurement than FEV_1, has also been used to detect acute changes in airway function across a work shift.

The purposes of this report are to describe across-shift changes in FEV_1 and PEFR observed in a large population of unexposed blue collar workers and to evaluate these changes with respect to various host factors. The results offer a better understanding of a research and surveillance tool that is already widely used for assessing acute effects of a variety of occupational respiratory hazards.

Methods

Between February 1979 and June 1981, 1,113 workers at 35 work sites underwent medical evaluation. The work sites, selected to obtain control subjects for a National Institute for Occupational Safety and Health (NIOSH) survey of workers exposed to dust in the cotton industry, were located throughout the southern half of the United States. These included beverage bottling plants, food preparation and packaging plants, assembly plants, parks, and nurseries. Prior to inclusion in the study, each work site was visited by a NIOSH industrial hygienist to verify absence of hazardous respiratory exposure. Environmental monitoring to quantitate exposures included area and personal airborne dust sampling using direct-reading instruments and pump-cassette-filter assemblies, organic solvent sampling using charcoal tubes, and gas sampling using detector tubes. All monitoring indicated minimal vapor, gas, and particulate exposures or no exposure at all.

Trained interviewers administerd a standardized questionnaire based on the British Medical Research Council Questionnaire (14). Information was obtained regarding demographic characteristics, respiratory symptoms, smoking history, and occupational history.

Immediately before and after an 8-h work shift, each worker performed spirometry using standard techniques (15). At each session, a minimum of five FVC maneuvers was performed by each subject on a dry rolling-seal spirometer (Model 840; Ohio Medical Products, Madison, WI). Flow and volume signals, displayed on an oscilloscope during each test session, were recorded on analog tape for later computer processing in the laboratory. Only "acceptable" flow-volume curves (e.g., free of cough, hesitation, early termination, etc.) were used. For each session, the subject's largest values of FEV_1 and PEFR were reported, even if these occurred on different acceptable curves. Data from 169 participants were excluded from the study. Demographic data were missing for 21; 52 were missing preshift or postshift session spirometry data; and 96 others were excluded on the basis of poor within-session reproducibility of spirometry, defined here as ≥ 10% difference between either the two largest FEV_1 values or the two largest FVC values at either the preshift or the postshift session. Data from the remaining 944 workers were analyzed.

For each individual worker, across-shift FEV_1 and PEFR changes were calculated in terms of percent of preshift value. Separate univariate analyses were performed to assess the statistical relationship of several host factors to shift changes in FEV_1 and PEFR. These host factors included: age (years analyzed as a continuous variable as well as dichotomized at age 30); sex (male or female); race (black, white, or other); smoking status

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TABLE 1

BASELINE DEMOGRAPHIC AND PULMONARY FUNCTION CHARACTERISTICS

	n	%	Mean	SD
Sex				
Male	845	89.5	—	—
Female	99	10.5	—	—
Race				
Black	424	44.9	—	—
White	281	29.8	—	—
Other	239	25.3	—	—
Smoking status				
Ex-smoker	125	13.2	—	—
Never-smoker	385	40.8	—	—
Smoker	434	46.0	—	—
Work shift				
Day	718	76.1	—	—
Evening	192	20.3	—	—
Night	26	2.8	—	—
Age, yr	944	—	33.30	11.90
Preshift FEV_1, L	944	—	3.69	0.78
Preshift FVC, L	944	—	4.55	0.91
Preshift FEV_1/FVC	944	—	0.81	0.08
Preshift PEFR, L/s	944	—	9.56	2.22

(never, ex-, or current); work shift (day or evening), and the mean of each worker's preshift and postshift FEV_1/FVC ratios (analyzed as a continuous variable as well as dichotomized at the clinically relevant value of 0.70). (Because of a limited number of observations available on night shift workers, night shift was not included in the univariate analysis of work shift.)

Differences in standard deviations were tested for significance using the F test to compare two variances or Bartlett's test to assess homogeneity of more than two variances (16). Statistical tests included independent sample *t* tests (to evaluate host factors of sex, shift, dichotomized age, and dichotomized FEV_1/FVC); analysis of variance (to evaluate race and smoking status); and analysis for correlation (to evaluate age and FEV_1/FVC as continuous variables) (16).

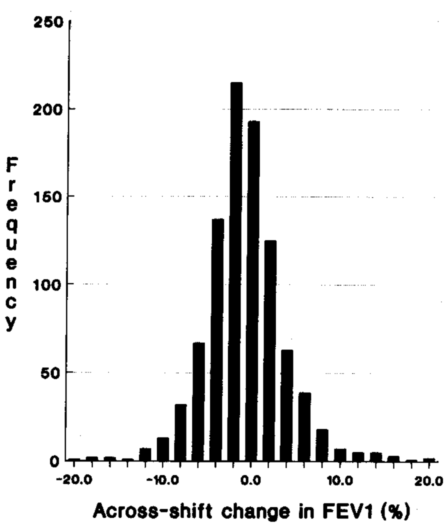

Fig. 1. Frequency distribution of across-shift change in FEV_1.

Results

Baseline demographic and pulmonary function characteristics of the study group (n = 944) are displayed in table 1. Ages of the analyzed subjects ranged from 14 to 77 yr, with a mean of 33 yr. The overwhelming majority, nearly 90%, were male. Approximately 30% were white and 45% black. The other 25% were predominantly Hispanics. Slightly more than 40% were never-smokers, whereas 46% were current smokers. About 75% were studied on the day shift, and 20% on the evening shift. Mean preshift values of FEV_1 and PEFR were 3.69 L and 9.56 L/s, respectively.

Frequency distributions of across-shift changes for both FEV_1 and PEFR approximated the normal distribution (figures 1 and 2). As shown in table 2, the overall mean across-shift change in FEV_1 was 0.8% (−0.04 L), with a standard deviation of 5.8% (0.19 L). The mean across-shift change in PEFR was +2.1% (+0.13 L/s) with a standard deviation of 13.2% (1.19 L/s). Also shown in table 2, across-shift changes in FEV_1 and PEFR observed among the 96 workers excluded from the overall analyses as a result of poor quality spirometry were not significantly different from changes observed among the 944 workers included in the analysis. Of note is that 83 of the 96 workers excluded from the overall analyses performed reproducible spirometry either pre- or postshift. The mean FEV_1/FVC ratio of these 83 workers was not statistically different from that observed in the study group (0.80 and 0.81, respectively).

As shown in tables 3 and 4, mean values of across-shift changes in FEV_1 and PEFR were not found to be signifi-

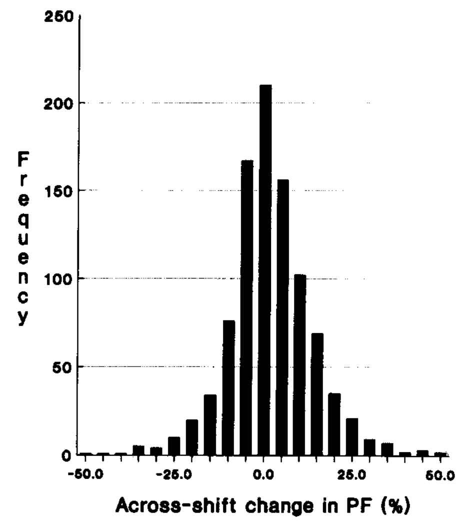

Fig. 2. Frequency distribution of across-shift change in peak expiratory flow rate (PF).

TABLE 2

OVERALL MEAN ACROSS-SHIFT CHANGE IN FEV_1 AND PEFR AMONG WORKERS INCLUDED IN THE ANALYSIS COMPARED WITH WORKERS EXCLUDED FROM THE ANALYSIS BECAUSE OF POOR WITHIN-SESSION REPRODUCIBILITY

	Included Workers (*n* = 944)		Excluded Workers (*n* = 96)		
	Mean	SD	Mean	SD	p Value
FEV_1 change					
Percent	−0.8	5.8	−0.2	11.6	0.66
Absolute, L	−0.04	0.19	−0.03	0.30	0.91
PEFR change					
Percent	+2.1	13.2	+3.0	29.0	0.75
Absolute, L/S	+0.13	1.19	+0.02	1.87	0.57

TABLE 3

MEANS AND STANDARD DEVIATIONS OF ACROSS-SHIFT PERCENT CHANGE IN FEV_1 BY HOST FACTORS

Factor	n	Mean (%)	p Value (%)	SD	p Value
Age			0.706*		
< 30 yr	460	−0.7		5.3	
⩾ 30 yr	484	−0.8	0.745	6.2	0.001
Sex					
Male	845	−0.7		5.7	
Female	99	−1.0	0.657	6.1	0.367
Race					
Black	424	−0.5		6.7	
White	281	−0.8	0.483	4.2	< 0.0001
Other	239	−1.1		5.5	
Smoking status					
Ex-smoker	125	−1.1		6.2	
Never-smoker	385	−0.5	0.475	5.3	0.013
Smoker	434	−0.9		6.0	
Work shift					
Day	718	−0.8		5.5	
Evening	192	−0.8	0.933	6.8	0.0003
FEV_1/FVC			0.498†		
< 0.70	76	−0.9		7.8	
⩾ 0.70	868	−0.8	0.863	5.6	< 0.0001

* p value from correlation analysis; r = 0.012.
† p value from correlation analysis; r = 0.022.

TABLE 4

MEANS AND STANDARD DEVIATIONS OF ACROSS-SHIFT PERCENT CHANGE IN PEFR BY HOST FACTORS

Factor	n	Mean (%)	p Value	SD (%)	p Value
Age			0.703*		
< 30 yr	460	+1.7		12.4	
⩾ 30 yr	484	+2.5	0.364	13.9	0.013
Sex					
Male	845	+2.0		12.8	
Female	99	+2.5	0.790	16.2	0.001
Race					
Black	424	+2.5		15.1	
White	281	+1.8	0.636	10.5	< 0.0001
Other	239	+1.6		12.5	
Smoking status					
Ex-smoker	125	+1.0		13.6	
Never-smoker	385	+2.7	0.396	13.4	0.654
Smoker	434	+1.9		12.9	
Work shift					
Day	718	+2.3		13.6	
Evening	192	+1.6	0.509	12.7	0.255
FEV_1/FVC			0.045†		
< 0.70	76	−0.6		16.2	
⩾ 0.70	868	+2.3	0.132	12.9	0.004

* p value from correlation analysis; r = 0.012.
† p value from correlation analysis; r = 0.065.

cantly related to age, sex, race, smoking status, work shift, or FEV_1/FVC. However, the variability of measured shift changes differed significantly in some of the univariate analyses. Standard deviations of shift-related changes in FEV_1 were smaller for younger workers, for white workers, for never-smokers, for day shift workers, and for workers with a more normal FEV_1/FVC ratio. Standard deviations of the shift change in PEFR were smaller for younger workers, for male workers, for white workers, and for workers with a more normal FEV_1/FVC ratio.

Discussion

Age, race, and sex have not been previously evaluated as potential risk factors for mean across-shift FEV_1 and/or PEFR change in an unexposed population. However, our findings of no significant relationship between these three major demographic variables and mean across-shift pulmonary function change is not surprising, given that age (5, 7, 9, 10, 12, 17), race (17), and sex (5, 12, 17) have not been significantly related to change in FEV_1 across a work shift among occupationally exposed workers. Similarly, age was not a significant determinant of across-shift PEFR change in studies of occupationally exposed workers (7, 12). Enarson and Yeung (18) reported a statistically significant correlation of age with across-shift change in FEV_1, but this significant correlation was limited to the nonsmoking group and was no longer evident when only those subjects with a normal FEV_1 were considered. In partial contrast, results of experimental cotton dust exposure studies suggest that only among smokers is age a significant predictor of across-shift FEV_1 change (17). The greater declines observed among older smokers exposed to cotton dust are therefore likely an effect of smoking rather than of age.

Among exposed workers, smoking has sometimes been associated with larger mean across-shift FEV_1 decrement (9, 18), but many investigators have failed to demonstrate any effect of smoking on across-shift change in FEV_1 (2–8, 10–12, 19, 20). Curiously, among a group of 42 research laboratory workers used as a control group, Lapp and coworkers (4) observed that smokers had a significantly larger increase in FEV_1 over a work shift. In the much larger study of unexposed workers reported here, smoking status was not related to across-shift change in pulmonary function. However, our findings do not preclude a possible smoking-age interaction leading to greater pulmonary function declines among exposed workers who smoke, an effect suggested by results of an experimental study (17).

The existence of a diurnal cycle in ventilatory function might be expected to translate into a work-shift effect on across-shift change in pulmonary function. In fact, although work-shift schedule has sometimes not been found to be a statistically significant determinant of mean change in FEV_1 of exposed workers (19, 21, 22), work shift has often either shown a trend (22) or has been clearly associated with a statistically significant effect (19, 20, 23, 24). Our results fail to provide evidence that the time of day over which the work shift is scheduled is a significant determinant of mean change in either FEV_1 or PEFR, but our survey involved few workers on the night shift and was not specifically designed to investigate diurnal cycling of pulmonary function.

Our finding of no significant association between FEV_1/FVC ratio and across-shift change in FEV_1 among unexposed workers is not surprising in that several investigators have failed to find a significant association between baseline pulmonary function and across-shift change in FEV_1 among exposed workers (2, 4, 5). Enarson and Yeung (18) reported a statistically significant correlation between baseline percent-predicted FEV_1 and absolute volume change in FEV_1 across a work shift among nonsmokers, but not among smokers (18). On the other hand, we have previously reported results of experimental cotton dust exposures demonstrating that those with lower FEV_1/FVC ratios have significantly larger across-shift decrements among the current smokers subgroup and overall, but not among the never-smoker subgroup (17).

Our results regarding significant differences in variability of across-shift changes analyzed by FEV_1/FVC ratio are consistent with the phenomenon, widely recognized by clinicians, that workers with impaired function tend toward greater variability of pulmonary function (25). Age and smoking status are both likely to be related to impaired functional status, and these indirect relationships may help to explain the significant associations these two factors have with variability of across-shift changes. Other variability differences are less easily explained. One source of variation, which should be consistent over all our observations, is the larger variation associated with data collection in field situations as compared with laboratory conditions (26).

Considering that only declines in pulmonary function are of clinical interest (a one-tailed statistical approach), and allowing for a conventional false positive (type I error) rate of 5%, criteria for defining significant across-shift changes can be calculated: (mean across-shift change) − (1.65) (SD). This approach yields overall criteria for defining a statistically significant shift change in FEV_1 of −10.4% (−0.35 L) and for defining a statistically significant shift change in PEFR of −19.7% (−1.83 L/s). Notably, these values are essentially equivalent to the 10% and 20% criteria often used to define significant individual across-shift changes in FEV_1 and PEFR, respectively (27, 28). Given the standard deviation differences of across-shift changes observed between subgroups of our study population, consideration might be given to deriving separate criterion values on the basis of specific host factors. Using means and standard deviations from tables 3 and 4, derived criteria range from −7.7 to −13.8% (−0.26 to −0.48 L) for significant change in FEV_1 and −15.5 to −27.3% (−1.43 to −2.29 L/s) for significant shift change in PEFR. Thus, a sensitive program for medical monitoring of individual workers might employ criteria for across-shift changes of approximately 8% for FEV_1 and 16% for PEFR.

This conventional approach to setting criteria, which is based entirely upon data obtained from unexposed subjects, might be criticized for not considering false negative rates. A more sophisticated method for deriving criteria considers factors such as benefit of early diagnosis and cost of overdiagnosis (29), and could incorporate the means and variabilities of across-shift changes in pulmonary function reported here. Another alternative approach for interpreting across-shift changes in pulmonary function, not practical in most situations, involves derivation of individual criteria for each worker on the basis of data from multiple across-shift spirometry tests under conditions of no exposure (30).

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