An Industrial Study of the Biological Effects of Cotton Dust and Cigarette Smoke Exposure

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Until recently, little awareness had been expressed in the U.S. medical literature about respiratory disease acquired from working in the cotton textile industry. Independent studies of individual American cotton textile mills conducted since 1967[1-4] indicate that byssinosis is common and particularly prevalent in preparation areas. The extent of the disease in some yarn processing and weaving areas has not been well documented nor has a control population unexposed to cotton dust been included in previous studies. The study described in part in this paper provided the opportunity to measure several parameters of respiratory disease in all processing areas in primary textile mills over a wide gradient of cotton dust exposure and compare these results with those found in a large control population of synthetic and wool workers.

Evidence has accumulated that total dust samples, the basis for the current ACGIH standard for cotton dust,[5] are frequently inappropriate indicators of byssinosis risk.[4,6-8] The vertical elutriator cotton dust sampler designed by Lynch and Lumsden[9] to sample lint-free dust with a mass median aerodynamic diameter of 15μ was used extensively in this study to provide more appropriate levels of dust exposure. Dose-response curves developed from these data are described in a separate paper presented to this conference.[10]

The vast majority of epidemiological literature dealing with vegetable dust exposure consists of cross-sectional, descriptive studies of individual textile plants. Four studies, three cross-sectional[11-13] and one prospective,[8] have been more comprehensive and included many different manufacturing plants and processes. With the several hundred workers involved in each study, and a wider gradient of dust exposure, these investigations have been able to study risk factors associated with pulmonary dysfunction in these populations. Nevertheless, the role smoking might play in influencing susceptibility to the effects of vegetable dusts has not been studied thoroughly, often because the number of workers in the population would not support such analyses. No incidence data is available on the effects of smoking in a population exposed to vegetable dusts. Available information from cross-sectional studies has, however, shown that the prevalence of byssinosis is generally greater among those who smoke cigarettes.[1,4,10,14,15] There is some evidence that cigarette smoking may potentiate the effects of cotton dust.[4,16] Our study of nearly 3000 textile workers including over 900 control subjects was designed to consider estimates of risk while taking into account factors of exposure gradient, smoking habits, age, and sex. It is the purpose of this paper to describe and quantitate individual and combined effects of cotton dust and cigarette exposure as associated with byssinosis prevalence and four parameters of ventilatory capacity. Because of the constraint of time, only white males employed in preparation and yarn processing areas will be considered for statistical analyses.

Methods

Selection of the Population: Initially, a total of 22 North Carolina textile manufacturing plants were visited to determine the grade and count of yarn manufactured, plant layout, ventilation systems, machine exhaust systems and distribution of workers by sex, race, age and work area. Twelve plants processed primarily cotton, five cotton-synthetic blends and five either synthetic or wool material. Based on information gained through these visits and from a previous survey[4] which provided estimates on the distribution of smoking habits, three strata of exposure (cotton = high risk, cotton-synthetic blend = moderate risk, synthetic-wool = low risk) were selected for a three factor factorial design to fill adequately four categories of age (15-29, 30-39, 40-49, 50-70), sex and three categories of smoking habit (never smoked, current smoker, former smoker). Initially two plants at extremes of exposure were picked for the first two surveys. From these surveys better estimates of demographic characteristics and disease prevalence were sought to help select other plants to fill categories of the factorial design. Other selection criteria were age of the plant, whether it was associated with a mill village and proximity to other mills under consideration. At least thirty miles were allowed between plants.

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Three cotton mills, all processing strict low middling cottons, were selected. Mill A processed cotton with a mean count of 6, Mill B with a mean count of 31, and Mill C with a mean count of 33 plus 25% synthetic material. Two cotton-synthetic blend mills processing primarily strict middling cottons were selected. Mill D processed 50% synthetic material and 50% middling cotton with a mean count of 29, and Mill E processed 49% synthetic and both strict low middling and middling cottons with a mean count of 32. The grade, count and mix of materials had been relatively constant in the few years preceding the study in all five cotton mills. Two synthetic processing mills, Mill G and Mill H, processed only synthetic material and one mill, Mill F, processed 100% wool. All had previously been cotton mills but none had processed cotton for more than 20 years. All mills selected had once been associated with a mill village.

Within each mill up to four primary work areas were defined. The preparation area included opening, blending, picking, carding, drawing, combing and roving. The yarn processing area included spinning, winding, twisting, spooling and warping. Slashing and weaving operations were combined to form a third primary work area. Other employees studied were those employed in the warehouse, shops, labs, supply areas, inspecting area, the yard and administrative personnel. None of these employees could be assigned a dust level since their dust exposure was intermittent and variable.

Survey Methods and Definitions. — Plant surveys consisted of four components: a questionnaire, pulmonary function tests, chest x-rays and environmental dust sampling. The British Medical Research Council Questionnaire for Respiratory Symptoms as modified for byssinosis to which were added questions regarding smoking history, allergy history, and occupational exposures* was administered by three interviewers (V.G., J.U., J.M.). Based on answers the following definitions, to be considered in this paper, were adopted. Byssinosis was defined by Schilling's[17] criteria:

Grade 0. — No evidence of Monday cough, tightness or breathing difficulty.

Grade 1/2. — Occasional chest tightness or breathing difficulty on Monday or a Monday cough.

Grade 1. — Chest tightness or breathing difficulty every Monday.

Grade 2. — Chest tightness or breathing difficulty on Monday and other days.

Smoking habit was defined as:

Never Smoked: Subject never smoked as much as one cigarette a day, or one ounce of tobacco a month, for as long as one year.

Moderate Smoker: Currently smoking at least one but less than 20 cigarettes per day and had been doing so up to one month before the interview.

Heavy Smoker: Currently smoking at least 20 cigarettes per day and had been doing so up to one month before the interview.

Cigar & Pipe Smokers: Currently smoking one ounce of tobacco per month or had been doing so up to one month before the interview.

Mixed Cigarette, Pipe or Cigar Smokers: Categorized as current cigarette smokers.

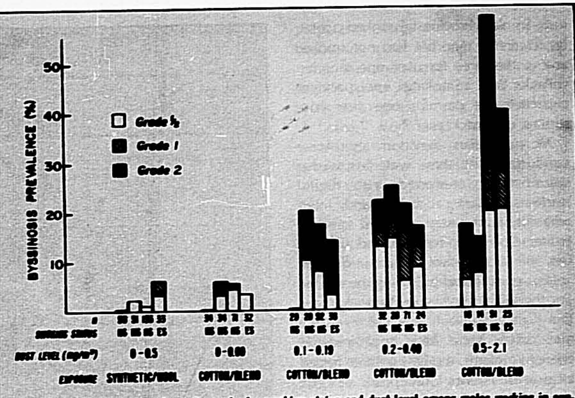

Fig 1. — Byssinosis prevalence by grade, by smoking status and dust level among males working in synthetic/wool mills and cotton/blend mills. North Carolina, 1970-71.

Table 1. — Distribution of Population of Textile Workers by Sex, Mill Type, Work Area and Smoking History. — North Carolina, 1970-71

Mill Type	Preparation		Yarn		Slash/Weave		Other		Total	
Sex	M	F	M	F	M	F	M	F	M	F
Cotton (Mills A,B,C)										
Number	208	6	231	280	225	140	123	47	787	473
Mean Age	39.9	39.3	36.7	41.4	43.3	41.3	42.0	44.2	40.2	41.6
Current Smokers (%)	59.6	16.7	63.6	31.1	64.0	39.3	62.6	36.2	62.5	33.9
Ex-smokers (%)	19.2	—	14.3	8.2	15.1	2.9	17.9	4.3	16.4	6.1
Mean No. pack years	20.0	20.0	20.5	11.5	24.5	12.6	22.1	12.9	22.0	12.0
Blend (Mills D,E)										
Number	143	21	184	245	87	65	49	9	463	300
Mean Age	40.4	38.7	39.2	41.7	41.0	39.8	45.4	41.0	40.6	41.1
Current Smokers (%)	60.8	52.4	59.2	38.0	56.4	47.7	71.4	44.4	60.5	40.9
Ex-smokers (%)	20.3	4.8	17.4	7.8	14.9	10.8	18.4	—	17.9	7.9
Mean No. pack years	22.0	8.4	21.1	11.1	20.1	11.1	22.3	13.2	21.4	11.0
Synthetic/Wool (Mills F,G,H)										
Number	209	1	224	360	—	—	91	19	524	380
Mean Age	34.6	31.0	35.0	38.3	—	—	38.1	36.6	35.4	38.2
Current Smokers (%)	70.3	—	63.4	43.1	—	—	48.4	5.3	63.5	41.1
Ex-smokers (%)	8.6	—	9.8	5.0	—	—	28.6	21.1	12.6	5.8
Mean No. pack years	15.2	—	18.3	10.7	—	—	20.6	18.6	17.4	11.0

Ex-Smoker: Previously smoked cigarettes, cigars or pipe but had not smoked any of the three for over one month.

Pack Year: Smoking one pack of cigarettes per day for one year constitutes one pack year.

All pulmonary function tests were conducted with three waterless wedge spirometers† equipped with digital readouts.‡ Their accuracy and inter-reliability were tested against a standard 9 liter Collins Spirometer and through use of a constant volume delivery system prior to and following the survey. For the initial surveys in Plants A and F the digital read-out was not available and curves were hand measured. At these two plants, the best of three forced expirations was accepted as the measured value for the $FEV_{1.0}$ and the FVC. In all other plants the mean of the two highest $FEV_{1.0}$ readings and the highest FVC reading of four or more forced expirations were used. The FVC was uniformly measured at six seconds of expiration. If the spirograms were not uniform and the two highest $FEV_{1.0}$ not within 200 cc of each other, additional expirations were requested in an effort to obtain the two highest $FEV_{1.0}$ values within 200 cc of each other.

All workers were tested on Monday following two days away from work in the hour preceding the beginning of their work shift. Each employee returned to the same spirometer to repeat the sequence of forced expirations following six hours of exposure to workroom air. Changes in $FEV_{1.0}$ ($\Delta FEV_{1.0}$) and in FVC (ΔFVC) over six hours of exposure were calculated by taking the difference between the two measured values. Excepting Plant A, where the tests were spread over three Mondays, all pulmonary function testing was done on a single Monday in each plant.

All subjects were asked to have 4" x 5" posteroanterior and lateral chest films taken at the plant during working shifts on the mobile x-ray unit of the Occupational Health Section, North Carolina State Board of Health. All films were reviewed for evidence of pathology and workers with abnormal films were advised to obtain 14" x 17" films and consult their physicians.

Dust sampling was done with 25 vertical elutriator cotton dust samplers following the recommended methods set forth by Lynch.[9] Flow rates were established prior to the investigation and

[illegible]

[illegible]								
	[illegible]		[illegible]		[illegible]		[illegible]	
[illegible]	M	F	M	F	M	F	M	F
[illegible]	n=[illegible]	n=6	n=[illegible]	n=[illegible]	n=[illegible]	n=[illegible]	n=119	n=47
0-4 µm (%)	[illegible]	[illegible]	41.6	32.1	11.3	20.1	31.9	31.9
5-14 µm (%)	[illegible]	20.1	18.6	16.1	19.9	20.1	16.0	17.0
15-25 µm (%)	14.6	—	[illegible]	15.4	23.1	16.5	21.0	10.9
25+ µm (%)	28.5	20.3	30.2	35.4	45.7	43.2	31.1	36.2
[illegible]	n=[illegible]	n=[illegible]	n=[illegible]	n=204	n=[illegible]	n=64	n=47	n=9
0-4 µm (%)	25.9	18.1	27.3	25.8	26.4	23.6	10.6	11.1
5-14 µm (%)	21.6	[illegible]	18.8	17.6	17.4	28.1	27.7	44.4
15-25 µm (%)	15.1	9.5	18.6	18.4	20.9	28.1	17.0	22.2
25+ µm (%)	37.6	[illegible]	38.5	40.2	37.2	20.3	44.7	22.2
[illegible]	n=[illegible]	n=1	n=[illegible]	n=[illegible]	—	—	n=27	n=1
0-4 µm (No.)	[illegible]	0	[illegible]	[illegible]	—	—	12	0
5-14 µm (No.)	12	1	29	53	—	—	9	1
15-25 µm (No.)	5	0	11	17	—	—	2	0
25+ µm (No.)	0	0	1	6	—	—	4	0

checked midway through the survey. Samplers were distributed at approximately 50 foot intervals by attaching them to support columns with inlets placed in the breathing zone. Sampling began in each plant on a Monday and continued through Wednesday. A greater number of samples was collected in the preparation area of all plants. Dessicated 37 mm vinyl metricel filters were used in sampling; each was redessicated prior to weighing on a Cahn Electrobalance.

Sequency of Medical and Environmental Surveys. — The initial survey of Plant A, conducted in April, 1970, included the questionnaire, pulmonary function tests and chest films. The vertical elutriator cotton dust sampler was under development and not available for use. Fractionated dust samples from a cyclone sampler, high volume samples and some personal and vertical elutriator samples were collected.[9] Plant F was surveyed in June of 1970; cyclone fractionated samples were collected. Beginning November, 1970, Plants D, B, E, C, G, and H were surveyed in sequence with two weeks allowed for each plant. Dust sampling using vertical elutriators began in December, 1970 and was completed within four weeks of the plant medical survey in these six plants. Vertical elutriator sampling was completed in Plant F in March, 1971 and Plant A in April, 1971. There was no major change in use of raw products nor in plant ventilation in any plant between the medical and environmental surveys.

Analysis of Data:

All data were punched on IBM cards, then transferred to magnetic tape for computer processing. Individual median, mean, and geometric mean dust levels were calculated by taking the median, mean, and geometric mean dust levels from all samples collected in a given workroom and assigning each subject in the workroom that dust level. Subjects were then categorized by dust level.

To evaluate the effects of dust exposure and cigarette smoking on byssinosis grade, we used a three factor factorial design and a population of 846 white males employed in preparation and yarn processing areas. Five levels of respirable dust were defined: level one contained all white male synthetic/wool workers regardless of median dust exposure; level two through five contained white male cotton/blend workers—level two those with median dust levels between 0 and 0.09 mg/m³; level three those between 0.1 and 0.19 mg/m³; level four those between 0.2 and 0.49 mg/m³; and level five those between 0.5 and 2.1 mg/m³ of cotton dust. Four smoking levels, those who had never smoked, moderate smokers, heavy smokers and former smokers (pipe and cigar smokers were excluded), and four age categories (15-29, 30-39, 40-49, 50-70) were defined. Byssinosis grade by cell was then tallied (Table 4), reduced by a severity function within each smoking-age-dust exposure category and analyzed.[4] Hypotheses concerning the three main effects of dust exposure, smoking and age and their first-order interactions (smoking x age, smoking x dust exposure and age x dust exposure) could then be tested.[18] Although shown in Table 4, former smokers were not included in statistical tests of hypotheses concerning byssinosis prevalence.

Data for evaluation of effects of dust exposure and smoking on four measures of ventilatory capacity ($FEV_{1.0}$, $\Delta FEV_{1.0}$, FVC and ΔFVC) for 722 workers (85.3% of those with questionnaire data) are shown in Figs 2, 3, 4, and 5 and Table 5, in terms of adjusted means for each dependent variable within each smoking and dust category. The arrangement of subjects in these categories suggests a two factor factorial design with four response variables for which multivariate analysis of variance is appropriate. Covariates of age and height were used to provide adjusted mean values.

Twelve hypotheses concerning effects of dust level and smoking habit were tested by multivariate tests, combining all four response variables and univariate tests of individual response variables. The hypotheses, likelihood ratios, test statistic values with degrees of freedom and significance levels are summarized in Table 6. A $p \leq 0.05$ was accepted as the level of significance.

Results

Table 1 summarizes the distribution of the population by mill type, primary work area, sex and smoking. 1260 cotton mill workers, 803 blend mill workers and 904 synthetic-wool mill workers were studied—a total of 2967, over 94% of those listed on payrolls of the eight plants selected. Preparation areas were staffed almost exclusively by men while women predominated in yarn processing areas. In slashing, weaving, and "other" work areas men predominated. Mean ages of men and women in all primary work areas of cotton and blend mills were similar, but both men and women were somewhat younger in the synthetic/wool mills. The prevalence of current cigarette smoking was similar in all primary work a.eas of cotton mills but lowest among men in preparation areas and women in yarn processing areas. Among men in blend mills, the prevalence of smoking was slightly lower in slashing and weaving areas and highest among those working in "other" work areas. Among women working in blend mills, smoking prevalence was lowest among those working in yarn processing areas. In synthetic and wool mills greater numbers of current smokers were found in the preparation and yarn production areas than "other" areas among both men and women. Few differences in smoking prevalence were apparent when comparing males and females between mill types. Cotton and blend mills were found to have more former cigarette smokers than control synthetic and wool mills. The highest rate of former smokers, a fifth of those in the work area, was found among males working in preparation areas of cotton and blend mills. Taking into account age differences, little difference existed between major mill types in the number of packs of cigarettes consumed.

Table 2 summarizes duration of cotton

Table 3. — Age Adjusted Byssinosis Prevalence (All Grades) and Prevalence Ratios (P.R.) Relative to Never Smoked Blend Prevalence = 100, by Smoking History, Sex, Work Area and Mill Type. North Carolina, 1970-71.

	Preparation			Yarn			Slash/Weave			Total		
	No.	Prev.	P.R.	No.	Prev.	P.R.	No.	Prev.	P.R.	No.	Prev.	P.R.
Cotton Mills												
Men												
Never Smoked	44	24.3	657	51	10.1	273	47	10.3	278	142	17.5	473
Current Smokers	124	47.1	1273	147	15.2	411	144	16.7	451	415	25.3	684
All Men	208	38.4	1038	231	12.9	349	224	15.4	416	663	22.2	600
Women												
Never Smoked	5	0	—	170	17.2	382	81	8.2	182	256	14.6	324
Current Smokers	1	0	—	87	19.4	431	55	11.6	258	143	18.7	416
All Women	6	0	—	280	15.9	353	140	11.1	247	426	14.6	324
Blend Mills												
Men												
Never Smoked	27	4.2	114	43	0	—	25	7.2	195	95	3.7	100
Current Smokers	87	24.9	673	109	2.0	54	49	6.6	178	245	11.5	311
All Men	142	21.9	592	183	2.1	57	87	6.7	181	412	9.8	265
Women												
Never Smoked	9	0	—	133	4.9	109	27	3.1	69	169	4.5	100
Current Smokers	11	17.5	389	93	8.4	187	31	5.5	122	135	8.4	187
All Women	21	16.8	373	246	6.5	144	65	4.5	100	332	6.2	138
Synthetic-Wool Mills												
Men												
Never Smoked	44	1.1	30	60	0.6	16	—			104	1.2	32
Current Smokers	147	1.0	27	142	0.5	14	—			289	1.0	27
All Men	209	0.8	22	224	0.6	16	—			433	1.1	30
Women												
Never Smoked	1	0	—	187	0	—	—			188	0	—
Current Smokers	0	0	—	155	0	—	—			155	0	—
All Women	1	0	—	360	0	—	—			361	0	—

dust exposure by mill type, primary work area and sex. Although mean ages were similar, a far greater number of men working in preparation and yarn processing areas and women working in yarn processing areas of blend mills compared with cotton mills had been exposed to cotton dust for more than 15 years. In slashing and weaving areas, the percentage exposed longer than 15 years was similar among men but reversed among women. Of those working in synthetic-wool mills nearly a third (five percent for 15 or more years) had been occupationally exposed to cotton dust previously.

Age adjusted byssinosis prevalences (all grades) by mill type, for three primary work areas, sex, and smoking habits are shown in Table 3. Prevalence ratios have been calculated relative to males and females who never smoked and worked in blend mills. Men working in preparation areas of cotton mills clearly have the highest byssinosis prevalence, nearly double that of men working in the same areas in blend mills. Both men and women had similar byssinosis prevalences in yarn processing and slashing and weaving areas of cotton mills, with a somewhat lower prevalence for women in the latter area. In blend mills, byssinosis prevalence was low, similar in yarn processing and slashing and weaving areas, but lower among men in yarn processing areas. Six former cotton textile workers working in synthetic/wool mills gave histories consistent with byssinosis by questionnaire; two consisted of a history of symptoms when working in cotton. Prevalence ratios indicate a nearly thirteen fold increase in byssinosis prevalence among smoking males working in preparation areas over that of non-smoking males working in blend mills. Within primary work areas, a 50 to 100% increase in byssinosis prevalence was generally observed among smokers over non-smokers, except for men working in preparation areas of blend mills for whom the increase in prevalence was nearly 600%, and men working in slashing and weaving areas of blend mills among whom nonsmokers had slightly higher prevalences.

To test for effects of dust exposure, levels smoking habits, and age on byssinosis prevalence, all white males working in preparation and yarn areas were categorized by these three factors by byssinosis grade as shown in Fig 1 and Table 4. Inspection of these data reveals a clear increase in prevalence and severity with increasing levels of cotton dust, least apparent among those who never smoked among whom no case of byssinosis occurred below 0.2 mg/m^3 of cotton/blend dust. Among moderate smokers a gradient of increasing prevalence occurred through four dust levels and then decreased at the highest dust level. However, among heavy smokers and to a lesser degree among former smokers, prevalence increased with each increase in dust level and was markedly increased at the highest dust level at which 58.8% of heavy smokers had some grade of byssinosis and nearly 30% were grade two byssinotics. When prevalence within age categories was considered, no convincing trend was apparent through any dust or smoking category.

Statistical analysis revealed an adequate fit of the model to test six hypotheses summarized at the bottom of Table 4. Highly significant ($p < .0001$) differences in prevalence and severity were found between dust levels and between smoking categories. As suggested by the marked increases in prevalence at the highest dust levels among heavy smokers and former smokers, strong evidence ($p < .0001$) of interaction between dust levels and smoking was found. Although the test for differences between age groups approached significance ($p = .0593$), neither interaction involving age differences approached significance.

Four measures of ventilatory capacity were used to test for objective evidence of effects of dust exposure and cigarette smoking. Height and age adjusted dust level-smoking category $FEV_{1.0}$ means are shown in Table 5 and Figure 2, and statistics in Table 6. Uniformly the highest values were found among those working with synthetic and wool, among whom $FEV_{1.0}$ levels for current and former smokers were lower than for those who never smoked, but no significant difference was detected (H_8: $p = .749$). Among those exposed to the lowest level of cotton dust, those who had never smoked clearly had the highest $FEV_{1.0}$ values while moderate, then heavy smokers had the lowest values. Analysis of variance for differences in means at this dust level revealed a significant difference between smoking categories (H_9: $p < .005$). No other differences between smoking categories were detected at higher dust levels. No detectable changes in $FEV_{1.0}$ across dust levels among nonsmokers nor former smokers were found. When effect of dust level among current smokers was tested, both moderate and heavy smokers had lower values than nonsmokers. These were of borderline significance (H_5: $p < .076$ and H_6: $p < .039$). Within all five dust levels, a trend toward lower $FEV_{1.0}$ values at higher dust levels was apparent (H_1: $p < .027$). Differences in mean $FEV_{1.0}$ between all smoking categories over all dust levels at which smokers were lower than those who never smoked, were also found (H_2: $p < .023$). No evidence of interaction over all smoking and all dust levels was detected for $FEV_{1.0}$ (H_3: $p = .594$).

Evaluation of change in $FEV_{1.0}$ is shown in Figure 3, Table 5 and Table 6. No evidence of significant smoking effects were found in any of five dust levels (H_8-H_{12}: N.S.) nor was there any difference in mean change in $FEV_{1.0}$ in nonsmokers over the five dust levels (H_4: N.S.). Among moderate and heavy smokers, strong evidence of dust effects were found (H_5: $p < .002$, H_6: $p < .005$) and a significant dust effect was also detected among former smokers (H_7: $p < .033$). The effect of dust over all smoking categories was clear (H_1: $p < .0001$) but no smoking effect (H_2: $p = .597$) nor dust x smoking interaction (H_3: $p < .122$) was detected.

Because of the strong correlation of $r = 0.83$. between $FEV_{1.0}$ and FVC, results of univariate tests for FVC (Figure 4, Tables 5 and 6) were expected to be similar to those for $FEV_{1.0}$. This was generally true, except for loss of a significant smoking effect over all dust levels (H_2: $p = .601$). The significant smoking effect among those working in 0.0 to 0.09 mg/m^3 of cotton/blend dust was also lost (H_9: $p = .102$), but the marginally significant dust effect among moderate and heavy smokers retained, although reversed (H_5: $p = .037$ and H_6: $p = .067$).

A similar but weaker correlation of $r = 0.64$ was found between $\Delta FEV_{1.0}$ and ΔFVC (Fig 5, Tables 5 and 6) but results of all univariate tests were the same for both variables. The effect of dust level within moderate, heavy and former

Table 4. — Byssinosis Prevalence by Grade, Age, Smoking Status and Exposure Dust Level Among White Males Working in Preparation and Yarn Processing Areas of Cotton/Blend and Synthetic/Wool Mills. — North Carolina, 1970-71

Exposure & Dust Level	Age (yrs)	Never Smoked 15-29	Never Smoked 30-39	Never Smoked 40-49	Never Smoked 50-70	Never Smoked Total	Moderate Smokers 15-29	Moderate Smokers 30-39	Moderate Smokers 40-49	Moderate Smokers 50-70	Moderate Smokers Total	Heavy Smokers 15-29	Heavy Smokers 30-39	Heavy Smokers 40-49	Heavy Smokers 50-70	Heavy Smokers Total	Ex-Smokers 15-29	Ex-Smokers 30-39	Ex-Smokers 40-49	Ex-Smokers 50-70	Ex-Smokers Total	Total
Synthetic/Wool 0 -0.5 mg/m³	n	(26)	(8)	(11)	(11)	(56)	(17)	(9)	(15)	(10)	(51)	(43)	(40)	(39)	(23)	(135)	(5)	(8)	(10)	(10)	(33)	(279)
	Grade 0 (%)	100	100	100	100	100	100	100	100	90	98.0	97.7	100	100	100	99.3	80.0	100	90.0	100	94.0	98.6
	Grade 1/2 (%)	0	0	0	0	0	0	0	0	10	2.0	2.3	0	0	0	0.7	20.0	0	0.0	0	3.0	1.0
	Grade 1 (%)	0	0	0	0	0	0	0	0	0	0.0	0.0	0	0	0	0.0	0.0	0	10.0	0	3.0	0.4
	Grade 2 (%)	0	0	0	0	0	0	0	0	0	0.0	0.0	0	0	0	0.0	0.0	0	0.0	0	0.0	0.0
Cotton/Blend 0 -0.09 mg/m³	n	(15)	(7)	(4)	(8)	(34)	(16)	(5)	(6)	(7)	(34)	(24)	(14)	(16)	(17)	(71)	(2)	(7)	(5)	(18)	(32)	(171)
	Grade 0 (%)	100	100	100	100	100	93.7	100	83.3	100	94.2	95.8	85.7	100	94.1	94.4	100	100	80.0	100	96.9	95.9
	Grade 1/2 (%)	0	0	0	0	0	6.3	0	0.0	0	2.9	4.2	7.1	0	5.9	4.2	0	0	20.0	0	3.1	2.9
	Grade 1 (%)	0	0	0	0	0	0.0	0	0.0	0	0.0	0.0	0.0	0	0.0	0.0	0	0	0.0	0	0.0	0.0
	Grade 2 (%)	0	0	0	0	0	0.0	0	16.7	0	2.9	0.0	7.1	0	0.0	1.4	0	0	0.0	0	0.0	1.2
Cotton/Blend 0.1-0.19 mg/m³	n	(7)	(3)	(5)	(14)	(29)	(7)	(3)	(3)	(7)	(20)	(8)	(16)	(17)	(11)	(52)	(4)	(4)	(6)	(22)	(36)	(137)
	Grade 0 (%)	100	100	100	100	100	85.7	100	100	57.1	80.0	100	81.3	88.2	63.6	82.7	100	75.0	83.3	86.4	86.1	86.9
	Grade 1/2 (%)	0	0	0	0	0	14.3	0	0	14.3	10.0	0	18.8	5.9	0.0	7.7	0	25.0	0.0	0.0	2.8	5.1
	Grade 1 (%)	0	0	0	0	0	0.0	0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
	Grade 2 (%)	0	0	0	0	0	0.0	0	0	28.6	10.0	0	0.0	5.9	36.4	9.6	0	0.0	16.7	13.6	11.1	8.0
Cotton/Blend 0.2-0.49 mg/m³	n	(14)	(7)	(5)	(6)	(32)	(13)	(3)	(7)	(5)	(28)	(18)	(13)	(25)	(15)	(71)	(5)	(3)	(3)	(13)	(24)	(155)
	Grade 0 (%)	78.6	85.7	60.0	83.3	78.1	84.6	100	57.1	60.0	75.0	61.1	84.6	84.0	86.7	78.9	100	100	66.7	76.9	83.3	78.8
	Grade 1/2 (%)	14.3	14.3	20.0	0.0	12.5	7.7	0	28.6	20.0	14.3	11.1	0.0	4.0	6.7	5.6	0	0	0.0	15.4	8.3	9.0
	Grade 1 (%)	0.0	0.0	20.0	0.0	3.1	0.0	0	0.0	20.0	3.6	16.7	15.4	8.0	0.0	9.9	0	0	33.3	0.0	4.2	6.5
	Grade 2 (%)	7.1	0.0	0.0	16.7	6.3	7.7	0	14.3	0.0	7.1	11.1	0.0	4.0	6.7	5.6	0	0	0.0	7.7	4.2	5.8
Cotton/Blend 0.5-2.1 mg/m³	n	(6)	(1)	(6)	(5)	(18)	(5)	(3)	(4)	(2)	(14)	(7)	(11)	(16)	(17)	(51)	(3)	(3)	(13)	(6)	(25)	(108)
	Grade 0 (%)	100	100	83.3	60.0	83.3	80.0	100	75.0	100	85.7	42.9	63.6	18.8	47.1	41.2	66.7	66.7	53.8	66.7	60.0	58.3
	Grade 1/2 (%)	0	0	0.0	20.0	5.6	20.0	0	0.0	0	7.1	14.3	9.1	31.3	17.6	19.6	0.0	0.0	30.8	16.7	20.0	15.7
	Grade 1 (%)	0	0	16.7	0.0	5.6	0.0	0	0.0	0	0.0	14.3	18.2	12.5	0.0	9.8	0.0	0.0	7.7	16.7	8.0	7.4
	Grade 2 (%)	0	0	0.0	20.0	5.6	0.0	0	25.0	0	7.1	28.6	9.1	37.5	35.3	29.4	33.3	33.3	7.7	0.0	12.0	18.5

H1: Dust Effect (p < .0001)
H2: Smoking Effect (p < .0001)
H3: Age Effect (p = 0.0593)
H4: Dust and Smoking Interaction (p = .0001)
H5: Dust and Age Interaction (p = 0.3528)
H6: Age and Smoking Interaction (p = 0.9986)

smokers was again significant (H_5: p=.042, H_6: p=.002, H_7: p=.029) as was dust effect over all smoking categories (H_1: p=.0004).

Multivariate tests (Table 6), taking all response variables together indicate that the difference in means between smoking categories is significant in only one dust category, the lowest level of cotton/blend dust (0-0.09 mg/m^3). Differences in means between dust levels reveals no effect of dust level among nonsmokers (H_4: p=.778) and the effect of dust level among former smokers only approaches significance (H_7: p=.093). However, the difference in means for all response variables between dust levels for moderate and heavy smokers is highly significant for both (H_5: p = .0025, H_6: p =.0007). Clearly, current smokers are largely responsible for the highly significant difference in mean values between dust levels over all smoking categories (H_1: p<.0001). However, only a marginal and insignificant difference was found between means of smoking categories over all dust levels (H_2: p=.076), and no interaction between all dust levels and all smoking levels (H_3: p=.549) was apparent.

Comment

Accurate accessment of two powerful risk factors in an industrial setting is frustrated by a background of selective migration of workers away from exposure to these factors, cotton dust and cigarette smoke. This is especially true in cross-sectional studies where it is difficult, if not impossible, to trace the movement of subjects within categories of risk or out of the population altogether. Even with a prospective approach, underestimates of risk imposed by occupational exposure occur because of changing employment and retirement. Effects of duration of exposure to environmental agents therefore, must be judged from a survivor population.

Numerous references to selection away from dust exposure[12, 19] and cigarette smoking exposure[4, 20] appear in the literature dealing with vegetable dusts. Indirect evidence of selection away from smoking cigarettes is decreased consumption of tobacco among currently smoking workers occupationally exposed to these agents.[21, 22] An increase in the number of former cigarette smokers among those heavily exposed to dust suggests a selection process away from a recognized harmful inhalant.[4, 20] Although there was no evidence of decreased cigarette consumption among those studied in this survey, there was a uniform trend toward higher rates of former smokers among workers exposed to cotton dust, particularly in dustier preparation areas where a fifth of the men were ex-smokers. There is some evidence that migration occurs within textile mills from higher to lower areas of exposure[4] and that some, particularly those with pulmonary impairment, leave the mill.[23] Self-selection has been cited as the probable explanation for observed lack of increased loss in ventilatory capacity with increased cigarette consumption.[24, 25] Bouhuys and colleagues reported that flow rates for active hemp workers 50 to 69 years of age were significantly higher among smokers than those who were nonsmokers or light smokers, a phenomenon they attributed to a process of self-selection.[20] From this evidence, it is probable that selective migration is an important but unaccounted for factor in this population. Taken over the exposed population as a whole, however, underestimates of risk of exposure to cotton dust and cigarette

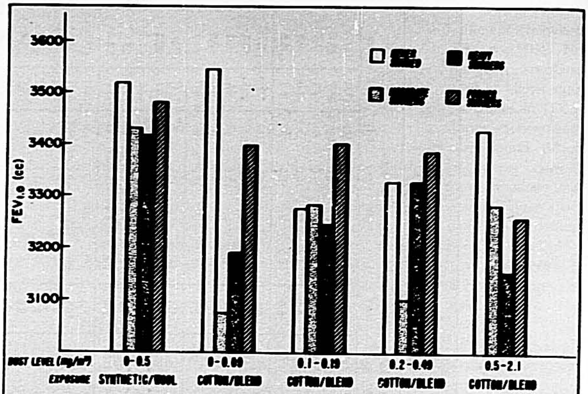

Fig 2. — Age and height adjusted $FEV_{1.0}$ by smoking status and dust level among white males in synthetic/wool mills and cotton/blend mills. North Carolina, 1970-71.

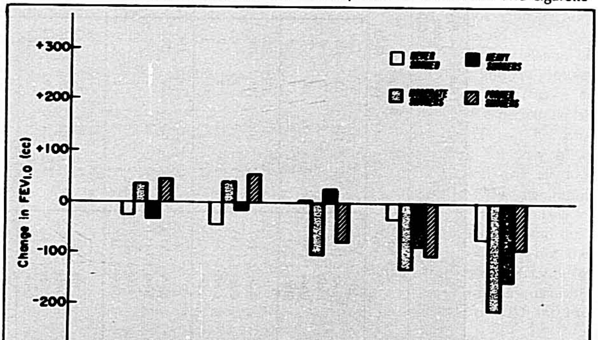

Fig 3. — Age and height adjusted change in $FEV_{1.0}$ by smoking status and dust level among white males working in synthetic/wool mills and cotton/blend mills. North Carolina, 1970-71.

smoke are likely. This is especially important when studying indicators associated with pulmonary insufficiency, such as dyspnea and measures of ventilatory capacity. Indicators of acute symptoms, such as those of byssinosis which, without associated pulmonary insufficiency are often not severe enough to alter the worker's job or smoking habit, are not expected to be as affected by selective migration.

Despite evidence that we were dealing with a survivor population, when considering byssinosis symptoms, the effects of both cotton dust and cigarette smoke exposure were pronounced. The finding that byssinosis prevalence increases with cotton dust level is well established and needs no further discussion.[10,12,26] The finding of a significant association between cigarette smoking and byssinosis symptoms is consistent with the few studies that consider the factor of smoking. In the comprehensive study of Northern Ireland flax operatives, a significant smoking effect was found among men and women.[15] Schilling, on reviewing Lancashire data for effects of tobacco smoking, found a significant association between byssinosis prevalence and smoking among women; inadequate numbers of nonsmokers precluded analysis among men.[14] In a study of male cardroom and spinning room workers, Bouhuys reported a significant increase in all grades of byssinosis among smokers.[1] In a previous study,[4] we reported a significant cigarette smoking effect and evidence of a positive interaction between increased exposure to cotton dust and cigarette smoke on byssinosis symptoms among men. In that study, with a relatively narrow, crudely defined gradient of exposure to cotton dust, no significant dust exposure effect on byssinosis index was found. With the wider and more objectively defined levels of exposure to cotton dust available in this study, the expected strong association between byssinosis prevalence and dust level was confirmed. Further evidence is presented that a positive interaction exists between cotton dust exposure and cigarette smoking. This potentiation effect appears to occur primarily among former and heavy smokers exposed to high levels of lint-free cotton dust.

The effects of these two inhalants on ventilatory capacity are more difficult to

Table 5. — Age and Height Adjusted Forced Expiratory Flow Rates and Volumes by Smoking Status, and Exposure Dust Level Among White Males Working in Preparation and Yarn Processing Areas of Cotton/Blend and Synthetic/Wool Mills. — North Carolina, 1970-71

Smoking Status	Never Smoked	Moderate Smokers	Heavy Smokers	Former Smokers
Exposure				
Synthetic/Wool (0-0.5 mg/m³)				
n	(52)	(43)	(117)	(28)
FEV1.0	3.519	3.432	3.417	3.483
Δ FEV1.0	-.026	.036	-.033	.044
FVC	4.474	4.604	4.452	4.513
Δ FVC	-.016	-.010	-.006	-.001
Cotton/Blend (0-0.09 mg/m³)				
n	(33)	(29)	(61)	(28)
FEV1.0	3.546	3.075	3.190	3.402
Δ FEV1.0	-.046	.042	-.016	.054
FVC	4.608	4.296	4.309	4.466
Δ FVC	-.047	.023	.013	.113
Cotton/Blend (0.1-0.19 mg/m³)				
n	(24)	(17)	(45)	(31)
FEV1.0	3.277	3.285	3.246	3.404
Δ FEV1.0	.006	-.104	.026	-.078
FVC	4.370	4.403	4.442	4.526
Δ FVC	.013	-.075	.038	-.039
Cotton/Blend (0.2-0.49 mg/m³)				
n	(25)	(23)	(56)	(19)
FEV1.0	3.330	3.103	3.330	3.350
Δ FEV1.0	-.033	-.132	-.007	-.111
FVC	4.284	4.148	4.445	4.277
Δ FVC	-.026	-.073	-.002	-.061
Cotton/Blend (0.5-2.1 mg/m³)				
n	(17)	(11)	(43)	(20)
FEV1.0	3.431	3.286	3.156	3.259
Δ FEV1.0	-.070	-.212	-.156	-.093
FVC	4.327	4.214	4.162	4.356
Δ FVC	-.046	-.248	-.156	-.118

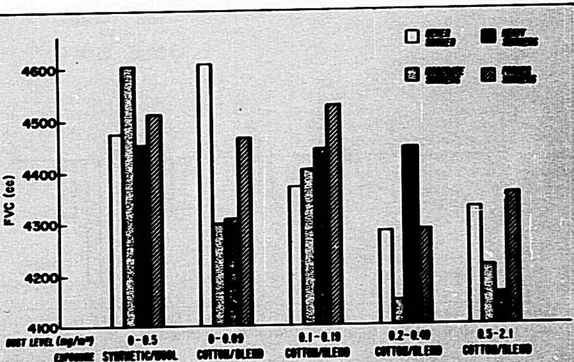

Fig 4. — Age and height adjusted FVC by smoking status and dust level among white males working in synthetic/wool mills and cotton/blend mills. North Carolina, 1970-71.

Table 6. — Multivariate Analysis of Variance of Pulmonary Function Data For Smoking and Dust Effects Among White Males Working in Preparation and Yarn Areas of Cotton Blend and Synthetic Wool Mills. North Carolina, 1970-71.

	Hypotheses	Multivariate Tests: Likelihood Ratio	x^2	D.F.	p	Univariate Tests: D.F.	FEV1.0 F	FEV1.0 p	FEV1.0 F	FEV1.0 p	FVC F	FVC p	FVC F	FVC p
	Main Effects													
H1	No Dust Effect	0.9148	62.325	16	.0001	4/700	2.739	.027	6.467	.0001	3.267	.012	5.611	.0004
H2	No Smoking Effect	0.9723	19.626	12	.076	3/700	3.193	.023	0.634	.507	0.628	.601	1.006	.391
H3	No Dust, Smoking Interation	0.9365	46.147	48	.549	12/700	0.855	.594	1.490	.122	1.106	.352	1.006	.386
	Main Effects Within Levels													
H4	No Dust Effect Among Non-Smokers	0.9837	11.492	16	.778	4/700	1.191	.313	0.279	.891	1.254	.286	0.225	.923
H5	No Dust Effect Among Moderate Smokers	0.9481	37.250	16	.0025	4/700	2.115	.076	4.258	.002	2.560	.037	2.486	.042
H6	No Dust Effect Among Heavy Smokers	0.9418	41.928	16	.0007	4/700	2.531	.039	3.829	.005	2.198	.067	4.513	.002
H7	No Dust Effect Among Former Smokers	0.9663	23.950	16	.093	4/700	0.464	.765	2.620	.003	0.683	.607	2.699	.029
H8	No Smoking Effect Among Synthetic/Wool Workers (0-0.5 mg/m³)	0.9777	15.747	12	.205	3/700	0.411	.749	1.397	.241	0.659	.581	0.027	.994
H9	No Smoking Effect Among Cotton/Blend Workers (0.0-0.09 mg/m³)	0.9697	21.484	12	.045	3/700	4.383	.005	1.207	.306	2.065	.102	1.890	.128
H10	No Smoking Effect Among Cotton/Blend Workers (0.1-0.19 mg/m³)	0.9879	8.517	12	.744	3/700	0.471	.707	1.837	.137	0.319	.814	1.037	.376
H11	No Smoking Effect Among Cotton/Blend Workers (0.2-0.49 mg/m³)	0.9828	12.130	12	.437	3/700	0.999	.606	0.719	.544	1.409	.238	0.271	.848
H12	No Smoking Effect Among Cotton/Blend Workers (0.5-2.1 mg/m³)	0.9843	11.059	12	.525	3/700	0.935	.575	1.059	.368	0.581	.623	1.474	.219

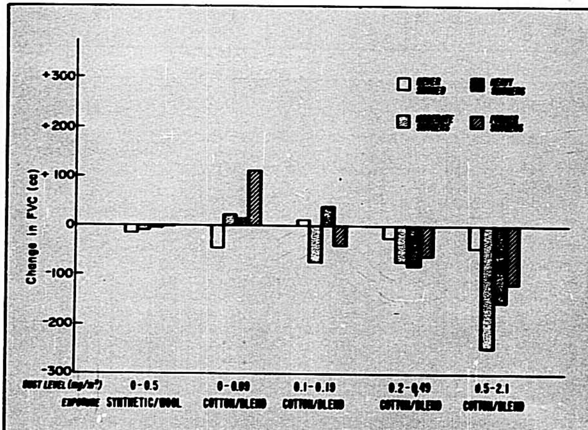

Fig 5. — Age and height adjusted change in FVC by smoking status and dust level among white males working in synthetic/wool mills and cotton/blend mills. North Carolina, 1970-71.

interpret, possibly because selective migration is more pronounced. In this population, as categorized and tested, exposure to cotton dust, judged by the overall multivariate test, very strongly ($p < .0001$) influences ventilatory capacity, clearly over-riding the effect of smoking($p = .076$). However, when tests within smoking categories are considered, no dust effect on any of the four measures of ventilatory capacity exists among those who never smoked cigarettes. Highly significant dust effects are found over all four response variables among moderate and heavy smokers and significant decrements in $FEV_{1.0}$ and FVC among former smokers with increased exposure. Exposure to cigarette smoke appears to be an important determinant of both level of ventilatory capacity ($FEV_{1.0}$ and FVC) and acute response to cotton dust ($\Delta FEV_{1.0}$ and Δ FVC). A potentiating effect on decrement in ventilatory capacity among heavy smokers exposed to relatively high levels of cotton dust was suspected by

McKerrow and Schilling.[16] Our results show no trend toward greater drops with heavier smoking, nor differences between current and former smokers. However, the real relationship between ventilatory capacity and smoking to risk may be obscured by self-selection between categories of cigarette smokers and out of the population.

The question of the influence of cigarette smoking on biological response to cotton dust gains importance when one considers that no case of byssinosis occurred among nonsmokers below 0.2 mg/m^3 and that no cotton dust effect was detected on any parameter of ventilatory capacity among those who never smoked. Smoking appears to lower the population threshold of susceptibility to the more pronounced effects of cotton dust exposure. Because of the high prevalence of cigarette smoking in this population, a lower threshold limit value is necessary, primarily to protect the smoker. It is apparent that assignment of cigarette smokers, particularly heavy smokers, to high risk work areas should be avoided.[4] Those conducting studies into the mechanism of lung damage by vegetable dusts should be aware of this relationship and consider effects of cigarette smoke in their experimental models. We suspect with this dose dependent agent(s), one mechanism by which cigarette smoke may potentiate the effects of cotton dust is through interference with bronchial clearance.[4] A reliable animal model would contribute greatly to evaluation of such mechanisms of lung damage and testing of other epidemiological observations.

Summary

Evaluation of 846 white male textile workers from a cross-sectional study, showed that cigarette smoking interacts with exposure to lint-free cotton dust to increase byssinosis prevalence and severity and appears to increase the over-riding deleterious effect of cotton dust on four measures of ventilatory capacity. Both the experimental scientist and those responsible for maintaining the health of the cotton textile worker should be aware of this relationship.

*For questionnaire, obtain document from ASIS, National Auxiliary Publications Service, care of CCM Information Corporation, 866 Third Avenue, New York, 10022.

†Jones Pulmonor II, Jones Medical Instrument Corp., Oakbrook, Ill.

‡Cardio-Pulmonary Instruments, Houston, Texas.

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