

DAILY CHANGES IN VENTILATORY CAPACITY IN SMOKERS AND IN NON-SMOKERS

BY

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The long-term effects of cigarette smoking on the respiratory tract have been studied by many authors by making a comparison between the incidence of clinical symptoms and signs of respiratory disease in smokers and that in non-smokers. The extensive literature on this subject was reviewed in the Report of the Royal College of Physicians on "Smoking and Health" (1962).

Physiological evidence of the short-term effects of cigarette smoking shows that airway resistance, as judged by body plethysmograph records, is increased after the inhalation of cigarette smoke (Nadel and Comroe, 1961; Zamel, Youssef, and Prime, 1963). Physiological evidence of longer-term ventilatory defect attributable to cigarette smoking has been obtained by a comparison of ventilatory capacity in groups of smokers and non-smokers. Thus, Higgins (1959) found that indirect maximum breathing capacity, based on measurements of three-quarter second forced expiratory volume, was significantly lower in smokers than in non-smokers in random samples of men in England and Wales. Carey, Merrett, Elwood, Pemberton, and McAulay (1965) derived regression equations for the prediction of one-second forced expiratory volume, FEV(1), and forced vital capacity, FVC, on age and stem height in non-byssinotic non-preparers in the flax-spinning industry; their findings were compatible with the hypothesis that, for a given age, sex, and stem height, and under similar conditions of exposure to occupational dust and similar residential exposure to air pollution, average values of FEV(1) are lower in smokers than in non-smokers.

In what follows, an attempt has been made to compare daily changes in ventilatory capacity in a group of smokers with those in a group of non-smokers, matched as closely as possible for relevant physical attributes as well as for occupation.

METHODS

The subjects for the survey were selected from the staff of Public Health Inspectors employed by the Belfast County Borough Health Committee. Out of a possible total of 52 men, 47 were seen at a preliminary interview when the age, stem height, and smoking habits of each man were recorded. As ventilatory capacity is known to be affected by age and by stem height (*e.g.* Carey and others, 1965), each smoker* was matched as closely as possible with a non-smoker with respect to age (± 2 years) and stem height† (± 2 cm.).

Seven smokers and seven non-smokers met these criteria for matching (Table I). The amounts smoked by the smokers had not varied greatly for at least the previous year, and no control had ever smoked in his life.

A Poulton spirometer (McKerrow, McDermott, and Gilson, 1960) was used for the measurement in litres of forced expiratory volume—1 second, FEV(1), and forced vital capacity, FVC. The timing mechanism of the instrument was calibrated, and the water temperature of the spirometer was taken before each series of tests. On each of the five days of the experiment, the water temperature of the spirometer was found to be within the range 15°-25° C., at which the accuracy of the instrument is better than ± 2 per cent., so that no further corrections were made to FEV(1) or FVC measurements for temperature or barometric pressure changes.

Each public health inspector participating in the study was instructed in the correct method of doing spirometry tests before the first day of the

* A smoker is defined as an individual who has smoked on average at least one cigarette per day for at least a year; a non-smoker is defined as an individual who has never smoked in his life.

† Stem height is defined as the vertical distance (in cm.) from the vertex of the head to the surface of a wooden chair on which the individual is seated erect.

TABLE I

MORNING AND AFTERNOON MEASUREMENTS OF FEV(1) AND FVC (LITRES) IN SEVEN MALE SMOKERS (S) AND SEVEN MATCHED CONTROLS (N.S.)

Subject	Tobacco (g. per day)	Age (yrs)	Stem Height (cm.)	FEV(1)										FVC									
				Monday		Tuesday		Wednesday		Thursday		Friday		Monday		Tuesday		Wednesday		Thursday		Friday	
				a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
S.1	15	19	96	4.5	4.6	4.3	4.4	4.2	4.3	4.4	4.5	4.1	(4.4)	5.2	5.3	5.2	5.3	5.3	5.3	5.2	5.2	5.3	(5.3)
NS.1	0	17	97	4.3	4.3	4.5	4.3	4.4	4.4	4.5	4.7	(4.5)	4.7	4.5	4.8	4.8	4.9	4.7	4.8	5.1	(4.9)	5.1	4.9
S.2	15	55	92	(3.8)	3.8	3.8	3.7	3.9	3.7	3.7	3.8	3.7	3.6	(4.7)	4.7	4.8	4.7	4.9	4.7	4.6	4.7	4.6	4.6
NS.2	0	57	94	3.2	3.1	3.1	3.2	3.1	3.0	3.0	3.0	3.0	3.1	4.5	4.5	4.5	4.5	4.4	4.3	4.4	4.7	4.3	4.4
S.3	30	60	94	3.1	2.9	3.1	3.1	3.2	3.2	3.2	3.0	3.3	3.2	4.2	3.8	4.0	4.0	4.1	4.0	4.0	4.0	4.0	4.1
NS.3	0	61	93	3.1	3.2	3.1	3.1	3.2	3.1	3.2	3.2	3.2	3.2	4.2	4.3	4.2	4.4	4.5	4.4	4.4	4.4	4.2	4.4
S.4	20	33	100	4.8	4.7	4.7	4.4	4.7	4.4	4.5	4.5	4.6	4.6	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
NS.4	0	31	98	5.3	5.3	5.6	5.4	5.6	5.4	5.5	5.4	5.5	5.5	5.9	6.2	6.5	6.4	6.5	6.5	6.5	6.5	6.4	6.4
S.5	20	27	97	(4.7)	4.5	5.1	4.9	5.0	4.7	4.5	4.4	4.7	4.6	(5.4)	5.3	5.6	5.5	5.5	5.5	5.3	5.2	5.4	5.3
NS.5	0	27	95	3.9	3.8	3.9	3.7	3.7	3.6	3.7	3.8	3.7	3.5	4.6	4.5	4.6	4.5	4.5	4.3	4.4	4.3	4.4	4.2
S.6	20	31	95	3.4	3.1	3.1	3.0	3.0	3.0	3.2	3.0	3.0	3.0	4.4	4.3	4.5	4.2	4.4	4.4	4.4	4.3	4.3	4.4
NS.6	0	33	94	4.8	4.8	4.8	4.6	4.6	4.4	4.5	4.5	4.5	4.5	5.7	6.0	5.8	5.6	5.8	5.7	5.7	5.8	5.6	5.7
S.7	15	32	97	3.5	3.3	3.5	3.2	3.4	3.5	3.3	3.5	3.3	3.3	5.1	5.1	5.3	5.0	5.0	5.3	5.0	5.3	5.4	5.2
NS.7	0	31	99	4.6	4.8	4.5	4.5	4.6	4.8	4.7	4.7	4.6	4.7	6.1	6.2	6.0	5.9	6.2	6.1	5.9	6.2	6.0	6.1

Measurements in parentheses () indicate mean value substituted due to absence of subject.

test. Measurements of FEV(1) and FVC were obtained for each of these fourteen men before starting work (9.00-10.00 a.m.) and at the end of the day (4.00-5.00 p.m.) on each of the five days of the experiment. The mean of the last three of five technically satisfactory blowings was taken as the appropriate measurement for analysis. It was not possible to test the men in a predetermined order for administrative reasons. On three occasions one or more of the men was unable to attend for the tests, and estimates of these missing plots were used in the analysis (see foot-note to Table I).

RESULTS

Table I shows the age, stem height, and smoking habits, and the morning and afternoon values of

FEV(1) and FVC for each day of the experiment, for each smoker (S) and his control (NS). No smoker smoked less than fifteen cigarettes daily, three smoked twenty, and one smoked thirty cigarettes. These smoking habits had persisted for at least one year.

The analyses of variance of the data on FEV(1) are given in Table II which shows for smokers, but not for non-smokers, that there were significant* falls from morning to afternoon. This Table further shows that observed differences between subjects were not consistent for either smokers or non-smokers on each day of the experiment. In this and all subsequent analyses, non-significant interactions

* The level of significance used throughout is P < 0.05.

TABLE II
ANALYSIS OF VARIANCE ON FEV(1) READINGS (LITRES) IN TABLE I

Group	Source of Variation	Sums of Squares (litres ²)	Degrees of Freedom	Mean Squares (litres ²)	Variance Ratio
Smokers	Subjects (S) ..	28.9929	6	4.8322	F = 162.36; n ₁ = 6, n ₂ = 24; P < 0.001 F = 0.74; n ₁ = 4, n ₂ = 24; P > 0.05 F = 6.82; n ₁ = 1, n ₂ = 31; 0.025 > P > 0.01 F = 2.27; n ₁ = 24, n ₂ = 31; 0.025 > P > 0.01
	Days (D) ..	0.0877	4	0.0219	
	Times (T) ..	0.0893	1	0.0893	
	S x D ..	0.7143	24	0.0298	
	Residual ..	0.4051	31	0.0131	
	Total ..	30.2893	66		
Non-Smokers	Subjects (S) ..	45.7098	6	7.6183	F = 336.61; n ₁ = 6, n ₂ = 24; P < 0.001 F = 0.14; n ₁ = 4, n ₂ = 24; P > 0.05 F = 4.04; n ₁ = 1, n ₂ = 33; P > 0.05 F = 2.80; n ₁ = 24, n ₂ = 33; 0.01 > P > 0.001
	Days (D) ..	0.0129	4	0.0032	
	Times (T) ..	0.0322	1	0.0322	
	S x D ..	0.5431	24	0.0226	
	Residual ..	0.2628	33	0.0080	
	Total ..	46.5608	68		

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have been pooled with the corresponding residual to give the residuals shown in Tables II and III.

Table III shows the analyses of variance of the data on FVC. The analyses suggest that differences in mean FVC between subjects who are non-smokers are not consistent on each day of the experiment. No significant difference in mean FVC between time of day was found for either smokers or non-smokers.

Table IV shows mean morning and mean afternoon values of FEV(1), and of FVC for smokers and for non-smokers for each day of the experiment. The following comparisons are of interest:

- (1) The mean FEV(1) of smokers was significantly less than that of non-smokers on all mornings and on all afternoons.
- (2) The mean FVC of smokers was always less than that of non-smokers on all mornings and on all afternoons. These differences were

significant on all afternoons except one (Friday) but were significant on only two mornings (Wednesday and Thursday).

- (3) The mean morning values of FEV(1) for smokers were always greater than the corresponding afternoon values (except on Friday when the difference was zero), but these differences were significant only on Monday and Tuesday. In non-smokers, mean FEV(1) declined from morning to afternoon on all days except Monday (when there was a slight increase), but the difference was significant only on the Tuesday.
- (4) The differences between mean morning and mean afternoon values of FVC show a less consistent pattern. In smokers, FVC declined on three days only and none of these differences was significant. In non-smokers, FVC increased on three days of the week and

TABLE III
ANALYSIS OF VARIANCE ON FVC READINGS (LITRES) IN TABLE I

Group	Source of Variation	Sums of Squares (litres ²)	Degrees of Freedom	Mean Square (litres ²)	Variance Ratio
Smokers	Subjects (S) ..	39.1374	6	6.5229	F = 691.13; $n_1 = 6, n_2 = 55; P < 0.001$
	Days (D) ..	0.0743	4	0.0186	F = 1.96; $n_1 = 4, n_2 = 55; P > 0.05$
	Times (T) ..	0.0206	1	0.0206	F = 2.07; $n_1 = 1, n_2 = 55; P > 0.05$
	Residual ..	0.5191	55	0.0094	
	Total	39.7514	66		
Non-Smokers	Subjects (S) ..	44.1398	6	7.3566	F = 285.97; $n_1 = 6, n_2 = 24; P < 0.001$
	Days (D) ..	0.0606	4	0.0152	F = 0.59; $n_1 = 4, n_2 = 24; P > 0.05$
	Times (T) ..	0.0002	1	0.0002	F = 0.02; $n_1 = 1, n_2 = 33; P > 0.05$
	S × D ..	0.6174	24	0.0257	F = 2.16; $n_1 = 24, n_2 = 33; 0.025 > P > 0.01$
	Residual ..	0.3948	33	0.0119	
Total	45.2128	68			

COMPARISON OF MEAN MORNING AND MEAN AFTERNOON VALUES OF FEV(1) AND FVC (LITRES)

Ventilatory Capacity (litres)	Group	Monday			Tuesday		
		a.m.	p.m.	Difference (a.m.-p.m.)	a.m.	p.m.	Difference (a.m.-p.m.)
FEV(1)	Smokers (a)	3.9714	3.8429	0.1285*	3.9429	3.8142	0.1285*
	Non-Smokers (b)	4.1714	4.1857	-0.0143	4.2143	4.1142	0.1001*
	Difference (b)-(a)	0.2000*	0.3428*		0.2714*	0.3000*	
FVC	Smokers (a)	5.0714	5.0000	0.0714	5.1286	5.0286	0.1000*
	Non-Smokers (b)	5.1142	5.2142	-0.1000*	5.2142	5.1429	0.0713*
	Difference (b)-(a)	0.0428	0.2142*		0.0856	0.1143*	

*Difference significant at P < 0.05

decreased on the remaining two days, the mean increase on Monday being significant.

CONCLUSIONS

- (1) The average morning and average afternoon values of FEV(1) of smokers were always significantly less than those of non-smokers. The mean FVC of smokers was less than that of non-smokers and here significant differences were found more often in the morning rather than in the afternoon series of tests. These data suggest that FEV(1) may be a more valuable index than FVC for detecting changes in ventilatory function due to cigarette smoking. Further, the ratio of average FEV(1) to average FVC of smokers on each day of the experiment was slightly less than that of non-smokers, suggesting that cigarette smoke produces obstructive rather than restrictive pulmonary effects.
- (2) The decline in average FEV(1) in smokers was, more often than not, greater than that in non-smokers. These differences in morning and afternoon average FEV(1) of smokers may not reflect the true fall in FEV(1) of smokers during the day, because it was ascertained later that six of the seven smokers had smoked at least one cigarette before carrying out the morning tests.
- (3) The largest significant difference between the mean FEV(1) of smokers and of non-smokers was 0.37 litres and the largest significant difference between the morning and afternoon means of FEV(1) in smokers was 0.13 litres. Such changes are unlikely to be of clinical

importance except in patients with low respiratory reserves, for example, advanced cases of chronic bronchitis.

SUMMARY

The daily changes in ventilatory capacity in a group of smokers were compared with those in a group of non-smokers, matched as closely as possible for age, sex, stem height, and occupation.

The average morning and afternoon values of 1-second forced expiratory volume of smokers were always significantly less than those of non-smokers. The average forced vital capacity of smokers was less than that of non-smokers. The decline during the day in average 1-second forced expiratory volume tended to be greater in smokers than in non-smokers, and this decline may be an underestimate of the true fall.

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EN MALE SMOKERS AND IN SEVEN MATCHED CONTROLS FOR EACH DAY OF THE EXPERIMENT

Wednesday			Thursday			Friday		
a.m.	p.m.	Difference (a.m.-p.m.)	a.m.	p.m.	Difference (a.m.-p.m.)	a.m.	p.m.	Difference (a.m.-p.m.)
3.9143	3.8286	0.0857	3.8286	3.8142	0.0144	3.8142	3.8142	0.0000
4.1714	4.1142	0.0572	4.2000	4.1571	0.0429	4.1714	4.1428	0.0285
0.2571*	0.2856*		0.3714*	0.3429*		0.3572*	0.3286*	
5.1000	5.1000	0.0000	5.0000	5.0142	-0.0142	5.0714	5.0571	0.0143
5.2571	5.2142	0.0429	5.1857	5.2000	-0.0143	5.1429	5.1571	-0.0142
0.1571*	0.1142*		0.1857*	0.1858*		0.0715	0.1000	

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