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BRONCHITIS IN TWO INTEGRATED STEEL WORKS

I. VENTILATORY CAPACITY, AGE, AND PHYSIQUE OF NON-BRONCHITIC MEN

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A study of the aetiology, prevalence, and progression of respiratory disability among the men employed in two large integrated steel works in South Wales is being undertaken from the Department of Social and Occupational Medicine, Welsh National School of Medicine, with the financial support of the Nuffield Foundation.

Epidemiological studies have repeatedly underlined the importance of three environmental factors in the aetiology of chronic bronchitis—urban atmospheric pollution, atmospheric pollution at place of work, and cigarette smoking—all of which are in a real sense controllable. It is not possible, of course, to determine in any particular patient with chronic bronchitis precisely how much of his illness is attributable to a particular environmental factor (M.R.C., 1966), and this lies at the root of the controversy whether persons with chronic bronchitis should become eligible for benefit under the National Insurance (Industrial Injuries) Act. It is possible, however, to estimate the proportionate contributions of occupation, place of domicile, and smoking habits to the prevalence of chronic bronchitis in defined populations, and this is the main purpose of the study in South Wales—to assess the relative importance of the three major environmental influences in the aetiology of chronic bronchitis among the men employed in the two steel works. An integrated steelworks is particularly suitable for a study of this type because the greater part of its very large working population is distributed between a number of clearly-defined departments with widely differing working environments. The two works we have studied are the Ebbw Vale works of Richard Thomas and Baldwins Limited (population about 9,500), and the Margam and Abbey works of the Steel Company of Wales Limited at Port Talbot (population about 16,500).

The departments include coke ovens, blast furnaces, steelmaking by the open hearth and converter processes, hot mills, cold mills, tinplate, galvanizing, limestone quarries, traffic, electrical and mechanical maintenance, laboratories, and offices.

In this first paper we describe how we collected information about the respiratory symptoms, ventilatory capacity, physique, smoking habits, and occupational and social histories of all types of male employees (production, maintenance, managerial, and office workers), and we present data on the distribution of ventilatory capacity, age, and physique among the non-bronchitic men (*i.e.* men without persistent cough and phlegm). A full account of how we organized the field surveys is a necessary prelude to the presentation of our results. Because the surveys were exceptionally large and difficult to administer, this account may also be of general interest. The data we present on the distributions of ventilatory capacity among non-bronchitics will be used as one of the yard-sticks against which, in subsequent publications, we shall attempt to measure the effect upon lung function of occupation, smoking habits, and domestic environment. Since the distributions are based on an unusually large number of observations they will, we hope, also provide acceptable standards of lung function for more general use.

METHODS AND MATERIAL

To minimize the bias inherent in a survey of volunteers, it was important to interview and examine as many as possible of the 26,000 men employed at the two works. It was also important to carry out the main part of the investigation over as short a period as possible and at the same time of year in the two works, for lung function (Morgan, Pasqual, and Ashford, 1964), respiratory symptomatology, and sickness absenteeism are known to vary with season. Such an ambitious project called for careful planning of its organization and administration, the full co-operation of management, trades unions, and employees, a well-designed, short, and largely precoded questionnaire, the taking of only such measurements of physique and lung function as could be recorded quickly and with reasonable accuracy under the difficult conditions of a large-scale survey in a heavy industry, and the training of a large team of field workers.

Co-operation of Management, Trades Unions, and Employees.—Crucial to the success of our approach to management, trades unions, and employees was the advice and support of the chief medical officers of the two works. Without it, and without the help of their staff, we should not have been able to launch the surveys, or having launched them, to have seen them through to a satisfactory conclusion. Under their guidance meetings were held with management and trades union representatives to explain the scope and purpose of the investigation and to discuss its practicability and possible effects upon production and industrial relations. In particular, the trades union representatives needed to be assured that the information obtained from employees would be regarded as confidential and would not be disclosed to anyone without the consent of the person concerned. When this was confirmed, they gave the investigation every support, explaining its aims to their members before it began and enlisting their co-operation while it was in progress. When management and unions had both agreed to support the project, it was widely publicized by press conferences, radio and television interviews, posters, and works newspapers.

Design of the Questionnaire.—Observer variation in recording the respiratory symptoms upon which a diagnosis of chronic bronchitis must be based has been the source of much confusion (Cochrane, Chapman, and Oldham, 1951; Fairbairn, Wood, and Fletcher, 1959). The standardized questionnaires developed by the M.R.C. committee on the Aetiology of Chronic Bronchitis have to some extent resolved the confusion. They permit the pooling of the findings of different observers within a survey and have made it possible to compare the results of different surveys. In our investigation we used the M.R.C. short questionnaire on respiratory symptoms (1960). In addition to the standard questions on respiratory symptoms, chest illnesses, and smoking habits, we included a series of questions to provide a summary of each man's occupational history. Our questionnaire was designed so that almost all the answers could be coded at the time of the interview in a form suitable for direct transfer to Hollerith punch cards.

Measurements.—Weight, standing height, sitting height, and ventilatory capacity were recorded for each man interviewed. Before weights and heights were taken, the men were asked to remove headgear, overcoats, and footwear.

Weights were measured on portable bathroom scales which were checked at the end of each day of the survey against a standard weight.

Heights were measured on inch-tapes fixed to a vertical wall. The men were asked first to stand fully erect with heels and back of the head against the wall and then to sit with the base of the spine against the wall. Heights were recorded to the half-inch below the actual height, as indicated by a set-square placed vertically on top of the head and against the measuring tape.

The Garthur Vitalograph was used to record forced ventilatory output. This is a portable, dry-spirometer with a chart carrier moved by a 50-cycle, 230 volt synchronous motor linked to its pneumatic system. Forced ventilatory output is recorded by the vertical excursion of a stylus arm across the surface of a waxed chart as it moves horizontally from left to right at uniform speed. The horizontal axis of the chart reads for six seconds in 0·1 second subdivisions and its vertical axis for six litres in 0·05 litre subdivisions. Each vitalograph was calibrated at our occupational hygiene laboratory before the survey began, on two random dates during the exercise, and after the survey had finished. Litre increments of air were passed by water displacement into the instrument under test up to a maximum of six litres, at which level it was left for 3 minutes. We found the instruments consistent and reliable in their performance. The maximum mean difference from the true volume for the four readings at 6 litres on any one instrument was 0·5 per cent. and no appreciable leak was detected at any of the tests. The ambient temperature was recorded for each set of tracings taken during the survey.

Choice and Training of Field Workers.—Because such large populations were to be interviewed and examined, it was impossible to conduct our investigation at the two works simultaneously. We decided, therefore, to survey the population at Ebbw Vale at a set time in the first year and then to move to Port Talbot at the same time of the year, 12 months later. This demanded a large team of interviewers who would be accessible for training and available for a period of intensive field-work at the same time in two successive years. Pre-clinical and other science students in the University were canvassed, with excellent results. The employment of university students for epidemiological investigations has much to commend it. They are used to handling scientific instruments, soon grasp the implications of observer and instrumental variation and the importance of randomization, quickly acquire the basic techniques of standardized questioning, are available for training during term-time, have time to spare for field-work during vacations, and, above all, are energetic and enthusiastic and tolerate well the considerable stresses that build up while a large-scale survey is in progress. The students were issued with printed instructions on the use of the vitalograph and the questionnaire, and in the Spring terms of 1964 and 1965 acquired, under supervision and in small sub-groups, experience in the handling of the instruments and the coding of answers to the questionnaire. They also took part in pilot surveys of small industrial populations in other steel works. These served both to give them experience in the field before the main surveys were launched and to uncover ambiguities in the questionnaire during its draft stages. We should emphasize that, apart from having their accommodation, meals, and travelling expenses found for them, our students were not paid for their valuable contribution to the investigation and that the standard of their work was very high indeed. Fifty students helped us during the intensive phase of our survey at Ebbw Vale, which occupied 13 days of the Easter vacation, 1964. For the Port Talbot survey we had the help of 75 students for 20 days during the corresponding vacation, 1965.

ORGANIZATION.—The students worked in teams of three: two to interview and one to take measurements of height, weight, and ventilatory capacity. Interviewing stations were established in strategically placed offices around the works (15 at Ebbw Vale and 21 at Port Talbot). With the help of certain members of the works staff who acted as liaison officers, the doctors and non-medical scientists on the staff of the Department of Social and Occupational Medicine were each made responsible for defined sectors of the works with two or more interviewing stations in them. They supervised and supported the student teams in their sectors and helped to maintain the flow of volunteers to the stations. A central office, connected by telephone to all the interviewing stations, was used as survey headquarters. From that office the statistical staff co-ordinated the randomized distribution around the works of student teams and their equipment each morning, and the collection, checking, and filing of completed questionnaires. From it the staff of the occupational hygiene laboratory also serviced and calibrated the vitalographs and other measuring instruments.

POPULATION AND SAMPLE.—At Ebbw Vale our intention was to include all the men employed in the works. In 13 days the student teams interviewed 6,562 men and over the next 3 months a follow-up team interviewed a further 1,519 men who for one reason or another were not seen at the time of the main survey. Altogether 8,081 men were therefore interviewed. This represents 85 per cent. of the 9,535 men employed at Ebbw Vale at the time of the survey.

Because the population at the Port Talbot Steel Works was so very much larger (16,726 at the time of the survey), we decided to mark on the works nominal roll before the survey began a 20 per cent. random sample of men over 25 years old, to pay particular attention to these men during the main part of the survey, and, after it had finished, to make every effort to persuade those not yet seen to co-operate. The random sample contained the names of 3,079 men. In 20 days the student teams interviewed 10,335 men, of whom 2,438 were in the sample. After the main survey a further 528 men from the sample were traced and persuaded to co-operate so that 96 per cent. of the sample (2,966 men) were interviewed. Including both sample and non-sample, 10,863 men were seen (65 per cent. of the total works population).

RESULTS

The analysis which follows deals with ventilatory capacity of men without persistent cough and phlegm in the populations of the two works. That is to say, we have excluded all the men who answered "yes" to Questions 6 and 10 in the questionnaire on respiratory symptoms approved by the Medical Research Council's (1965) Committee on the Aetiology of Chronic Bronchitis (6. Do you usually bring up any phlegm from your chest first thing in the morning in the winter? 10. Do you bring up phlegm like this on most days for as much as three months each year?).

In Table I the numbers and proportions of men with persistent cough and phlegm are shown for the two works separately. In this and subsequent Tables we have included only men for whom all numerical measurements were recorded, so the numbers do not quite correspond with those mentioned in the introduction. (We were short of one or more measurements for 297 men at Ebbw Vale and for 122 men at Port Talbot.) As would be expected, the percentage of men with persistent symptoms increases with increasing age. Unexpectedly, however, at ages over 25, the proportion is consistently higher for Ebbw Vale than for Port Talbot. The question immediately arises whether this is due to an under-representation of men with bronchitis among the men interviewed at Port Talbot, since only 65 per cent. of that works population was seen, compared with 85 per cent. of the population at Ebbw Vale. We explore this possibility in Table II in which the 20 per cent. random sample of the works population at Port Talbot (of whom 96 per cent. were interviewed) is compared with the other men seen there (all of whom were, of course, volunteers). There is no consistent difference between the random sample and the non-sample in respect of respiratory function ($FEV_{1\cdot 0}$ and FVC), height, or the proportion with persistent symptoms. For the purpose of establishing norms and distributions of respiratory function, we have decided, therefore, to use all the data collected at Port Talbot, rather than to limit ourselves to the smaller number of observations available from the random sample.

For the determination of forced expiratory volume (FEV) the Medical Research Council's Committee on Chronic Bronchitis recommends that the mean of three measurements after two practice blows should be recorded for each subject. On the other hand, in the United States, the Committee on Rating of Mental and Physical Impairment (1965) has categorically stated that the test should be administered three times and the highest value accepted as the most representative of the subject's ability. In a large-scale survey of a works population, it is of the first importance that the men should be away from their work for as short a time as possible. For this reason we decided to adopt a modification of the American procedure. Each subject was allowed one practice blow, repeated if his technique was obviously faulty, and then two definitive tracings were made. Forced expiratory volumes at one second ($FEV_{1\cdot 0}$) and forced ventilatory capacity (FVC) were read from

TABLE I

NUMBER OF MEN INTERVIEWED AND PERCENTAGE WITH PERSISTENT COUGH AND PHLEGM

Age (yrs)	Ebbw Vale				Port Talbot			
	Persistent Cough and Phlegm			Percentage with Persistent Cough and Phlegm	Persistent Cough and Phlegm			Percentage with Persistent Cough and Phlegm
	Yes	No	Total		Yes	No	Total	
<20	42	441	483	8·7	21	127	148	14·2
20–24	133	786	919	14·5	81	428	509	15·9
25–29	162	667	829	19·5	137	662	799	17·1
30–34	179	631	810	22·1	271	1102	1373	19·7
35–39	240	642	882	27·2	391	1251	1642	23·8
40–44	240	668	908	26·4	442	1358	1800	24·6
45–49	220	562	782	28·1	414	1075	1489	27·8
50–54	257	576	833	30·9	376	963	1339	28·1
55–59	293	491	784	37·4	298	632	930	32·0
60–64	213	329	542	39·3	224	379	603	37·1
65–69	8	4	12	(66·7)	55	129	184	29·9
Total	1,987	5,797	7,784	25·6	2,710	8,106	10,816	25·1

TABLE II

COMPARISON OF RANDOM SAMPLE WITH NON-SAMPLE VOLUNTEERS AT PORT TALBOT

Age (yrs)	Percentage with Persistent Cough and Phlegm		Mean $FEV_{1\cdot 0}$ (litres)		Mean FVC (litres)		Standing Height (in.)	
	Sample	Others	Sample	Others	Sample	Others	Sample	Others
<20	—	14·2	—	4·5	—	5·2	—	68·6
20–24	—	15·9	—	4·4	—	5·3	—	68·7
25–29	14·7	18·2	4·2	4·2	5·1	5·2	68·5	68·5
30–34	21·2	19·2	4·0	4·0	5·0	4·9	68·6	68·5
35–39	19·6	25·3	3·7	3·7	4·7	4·7	68·1	68·1
40–44	23·1	25·1	3·4	3·5	4·4	4·5	67·7	67·7
45–49	24·9	28·9	3·2	3·2	4·2	4·2	67·4	67·5
50–54	28·1	27·8	3·0	3·0	4·0	3·9	67·1	67·1
55–59	35·0	31·6	2·6	2·7	3·6	3·7	66·7	67·0
60–64	38·9	36·5	2·4	2·4	3·4	3·4	66·7	66·5
65–69	27·2	31·3	2·2	2·3	3·1	3·2	65·4	65·9

these two spirograms after the field work had been completed and corrected at 37°C. saturated with water vapour (BTPS) from the ambient temperature recorded on the charts. In Table III we compare the higher with the mean of the two readings for the Ebbw Vale population. At each 5-yearly age group the higher of the two readings is of course greater than the mean of the same two readings (the difference is about 0·1 litres for $FEV_{1\cdot0}$ and 0·05 litres for FVC). The standard deviation of the higher readings, however, is consistently smaller than that of the mean of the two readings. Table IV shows the correlation of $FEV_{1\cdot0}$ with standing height, an important variable influencing ventilatory capacity. The correlation coefficients are consistently greater for the higher than for the mean of the two measurements. The smaller standard deviations and the greater correlations suggest that for epidemiological purposes the higher readings have some small advantage, so in the analysis which follows we have used the higher of the two recorded values of $FEV_{1\cdot0}$ and its related FVC.

TABLE III

COMPARISON OF HIGHER READING WITH MEAN READING OF TWO OBSERVATIONS OF $FEV_{1\cdot0}$ AT EBBW VALE (NON-BRONCHITICS ONLY)

Reading	Age (yrs)	$FEV_{1\cdot0}$ (litres)		FVC (litres)	
		Mean	High	Mean	High
Mean Values for Each Age Group	<20	4·14	4·24	4·93	4·99
	20–24	4·11	4·20	5·06	5·11
	25–29	3·94	4·05	4·99	5·05
	30–34	3·75	3·84	4·78	4·85
	35–39	3·47	3·57	4·52	4·58
	40–44	3·21	3·30	4·31	4·36
	45–49	2·96	3·05	4·03	4·09
	50–54	2·75	2·83	3·80	3·86
	55–59	2·55	2·63	3·63	3·69
	60–64	2·40	2·47	3·39	3·44
Standard Deviations for Each Age Group	<20	0·74	0·72	0·76	0·76
	20–24	0·75	0·73	0·75	0·74
	25–29	0·76	0·74	0·77	0·76
	30–34	0·76	0·74	0·75	0·73
	35–39	0·72	0·70	0·73	0·71
	40–44	0·73	0·71	0·75	0·75
	45–49	0·72	0·70	0·76	0·76
	50–54	0·70	0·69	0·77	0·76
	55–59	0·65	0·65	0·74	0·74
	60–64	0·62	0·62	0·71	0·71

TABLE IV

CORRELATION BETWEEN STANDING HEIGHT AND $FEV_{1\cdot0}$ FOR HIGHER AND MEAN OF TWO READINGS AT EBBW VALE (NON-BRONCHITICS) ONLY

Age Group (yrs)	Correlation (r) between Height and $FEV_{1\cdot0}$	
	Mean	High
<20	0·287	0·307
20–24	0·328	0·336
25–29	0·327	0·333
30–34	0·290	0·295
35–39	0·236	0·242
40–44	0·295	0·308
45–49	0·278	0·289
50–54	0·279	0·288
55–59	0·246	0·254
60–64	0·287	0·292

Forced expiratory volume at one second is one of the more commonly used measures of ventilatory capacity. Mean values of the higher readings and their standard deviations by 5-yearly age groups are given for the non-bronchitics (as defined) in the two works populations in Table V. Although from early adult life onwards the mean declines steeply with age (at the end of working life it is reduced by about 40 per cent.) the standard deviation remains constant (for the Port Talbot population, at 20–24 years the mean $FEV_{1\cdot0}$ was $4\cdot43 \pm 0\cdot64$ litres; at 60–64 years it was $2\cdot58 \pm 0\cdot65$ litres).

Forced vital capacity also declines with age (again with constant standard deviation) but less steeply than $FEV_{1\cdot0}$ (Table V). Between early adult life and retirement the mean value is reduced by about 33 per cent. (at Port Talbot from $5\cdot31 \pm 0\cdot75$ litres at 20–24 years to $3\cdot54 \pm 0\cdot73$ litres at 60–64 years).

$FEV_{1\cdot0}$ expressed as a percentage of FVC provides a useful measurement of airways obstruction. Mean values for this index (FEV per cent.) are presented in Table V. It declines less steeply with age than either $FEV_{1\cdot0}$ or FVC. Between early adult life and retirement it falls by about 13 per cent. (at Port Talbot from a level of $83\cdot7 \pm 7\cdot2$ at 20–24 years to $72\cdot9 \pm 10\cdot8$ at

TABLE V

VENTILATORY CAPACITY ($FEV_{1\cdot0}$, FVC, AND $FEV_{1\cdot0}$ PER CENT.) OF NON-BRONCHITICS AT EBBW VALE AND PORT TALBOT

Age (yrs)	$FEV_{1\cdot0}$ (litres)				FVC (litres)				$FEV_{1\cdot0}$ per cent.			
	E.V.		P.T.		E.V.		P.T.		E.V.		P.T.	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
<20	4·24	0·72	4·52	0·65	4·99	0·76	5·28	0·66	85·3	9·4	85·7	7·7
20–24	4·20	0·73	4·43	0·64	5·11	0·74	5·31	0·75	82·4	9·8	83·7	7·2
25–29	4·05	0·74	4·22	0·68	5·05	0·76	5·14	0·77	80·3	9·9	82·2	7·6
30–34	3·84	0·74	4·05	0·69	4·85	0·73	4·96	0·78	79·2	10·2	81·7	7·3
35–39	3·57	0·70	3·80	0·62	4·58	0·71	4·78	0·71	77·9	10·2	79·7	7·7
40–44	3·30	0·71	3·53	0·65	4·36	0·75	4·50	0·72	75·7	10·5	78·6	8·1
45–49	3·05	0·70	3·30	0·63	4·09	0·76	4·30	0·68	74·8	12·4	76·8	9·4
50–54	2·83	0·69	3·04	0·64	3·86	0·76	4·00	0·69	73·4	11·8	75·9	9·6
55–59	2·63	0·65	2·79	0·62	3·69	0·74	3·72	0·70	71·1	13·5	75·0	10·1
60–64	2·47	0·62	2·58	0·65	3·44	0·71	3·54	0·73	71·9	12·1	72·9	10·8

65–69 years). However, for FEV per cent. (unlike for $FEV_{1\cdot0}$ and FVC) the standard deviation increases substantially with age (Table V) and for each age group the distribution is negatively skewed (see Figure).

To obtain the best estimate of the ventilatory capacity of non-bronchitic men both for our study of bronchitis and also for more general use, we had originally intended to pool the measurements taken from the two steel works. Table V shows why this idea had to be abandoned. From adolescence to age of retirement the measurements of ventilatory capacity were substantially and consistently higher for the men at Port Talbot than for the men at Ebbw Vale: at each age the mean values for $FEV_{1\cdot0}$ and FVC were about 5 per cent. (0·2 litres) higher at Port Talbot. We reviewed our survey techniques but were unable to find in them any explanation for the difference: the Garthur vitalographs were calibrated before and during both surveys and all readings corrected from ambient temperature to body temperature and pressure saturated with water vapour (BTPS); although different university students were recruited for the second survey (Port Talbot), they were of the same age, had the same academic background, were given the same preliminary instruction and training, and were subject to the same supervision as those used for the first survey; and the

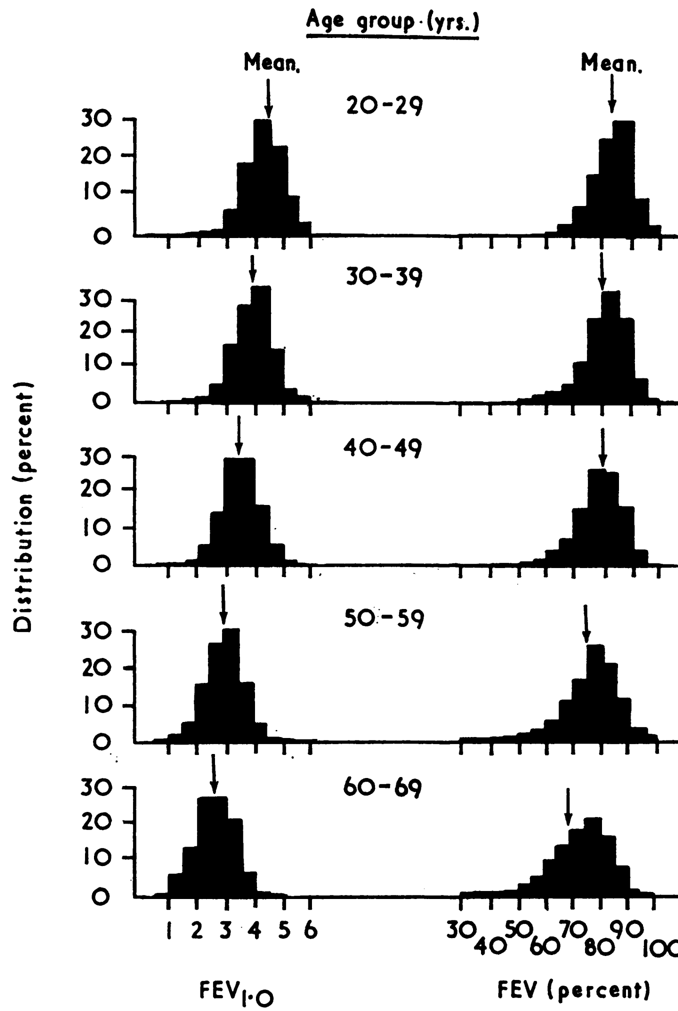

FIGURE.—Percentage distributions of $FEV_{1\cdot0}$ and $FEV_{1\cdot0} \times 100/FVC$.

data from the two surveys were checked, coded, and analysed in the same way and by the same scientific staff.

We can only conclude that the men in the two populations, although working in the same occupations and living no more than about 35 miles apart, are themselves intrinsically different. The medical histories they gave at interview were not greatly different; in fact there was an unusual degree of concordance between the two populations in repect of the proportions giving a history of asthma, pneumonia, tuberculosis, and heart disease (Table VI). However, as already pointed out, there were proportionately more men with persistent cough and phlegm at Ebbw Vale than at Port Talbot (Table I). Such men have been excluded from our analysis of the distribution of ventilatory capacity in the two populations, but it seems reasonable to assume that there were also proportionately more men at Ebbw Vale with a degree of respiratory disability falling short of that defined by the presence of persistent cough and phlegm. Whatever the truth of this, the proportion of non-bronchitics who had never smoked was certainly lower at Ebbw Vale (Table VI) and the men in the two populations were also noticeably different in physique (Table VII). Age for age the men at Port Talbot were about half an inch taller than the men at Ebbw Vale. They were also about 5 lb. heavier, and the obesity index W/H^2 (Khosla and Lowe, 1967) indicates that this is more than would be expected from their greater height.

To explore the interrelation of $FEV_{1\cdot 0}$, FVC, and FEV per cent. and the relation of each to sitting height, standing height, weight, and obesity as measured by the index W/H^2, we computed zero order correlations between all possible pairs of those seven variables for each of the nine 5-yearly age groups from 20–24 to 60–64 years. The correlations were very similar for the two works populations and consistent from age group to age group.

Table VIII (overleaf) shows the results for the 1,358 men in the 40 to 44-year age group at Port Talbot. We have chosen the age group 40 to 44 because it lies at the middle of the age range and the Port Talbot population because the numbers were so much larger. The other age groups at both Port Talbot and Ebbw Vale show almost identical patterns. The Table is complex, but four main points emerge:

(*i*) $FEV_{1\cdot 0}$ is highly correlated with FVC ($r=0\cdot 845$) and quite highly with FEV per cent. ($r=0\cdot 512$), but there is no correlation between FVC and FEV per cent. This suggests that for epidemio-

TABLE VI

MEDICAL AND SMOKING HISTORIES OF NON-BRONCHITICS AT EBBW VALE AND PORT TALBOT

Age (yrs)	Asthma (per cent.)		Pneumonia (per cent.)		Tuberculosis (per cent.)		Heart Disease (per cent.)		Never Smoked (per cent.)	
	E.V.	P.T.	E.V.	P.T.	E.V.	P.T.	E.V.	P.T.	E.V.	P.T.
<20	3·2	3·1	11·1	7·9	0·7	—	0·7	1·6	36·7	43·3
20–24	4·2	4·4	10·7	10·7	0·8	0·9	1·3	2·1	28·9	35·7
25–29	4·8	3·6	13·8	12·1	2·7	2·7	1·4	2·3	25·4	30·7
30–34	2·8	3·0	10·3	13·5	2·2	2·3	2·3	2·3	20·6	29·7
35–39	1·4	1·6	14·9	13·6	1·7	1·8	2·8	2·4	14·3	20·1
40–44	1·5	1·8	15·3	12·9	2·7	1·8	2·5	2·8	12·9	15·8
45–49	1·1	1·7	12·8	13·7	1·8	1·0	3·9	2·2	9·6	14·3
50–54	1·9	1·5	15·8	12·8	2·4	1·5	5·4	4·0	12·1	18·0
55–59	2·0	1·1	12·6	14·7	1·6	1·1	7·4	5·2	11·4	14·9
60–64	1·5	0·8	16·7	14·2	0·9	1·8	11·7	6·3	7·6	13·7

TABLE VII

STANDING HEIGHT, BODY WEIGHT, AND OBESITY INDEX OF NON-BRONCHITICS AT EBBW VALE AND PORT TALBOT

Age (yrs)	Standing Height (in.)				Body Weight (lb.)				Obesity Index ($W/H^2 \times 1000$)			
	E.V.		P.T.		E.V.		P.T.		E.V.		P.T.	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
<20	67·7	2·4	68·7	2·2	148	20·9	155	20·8	32·3	4·3	32·8	3·9
20–24	68·1	2·5	68·8	2·7	158	23·2	163	24·2	34·1	4·7	34·6	4·5
25–29	68·1	2·5	68·5	2·5	167	26·0	169	25·7	36·0	5·5	36·0	4·9
30–34	67·8	2·2	68·5	2·5	169	25·8	174	25·7	36·8	5·0	37·1	4·8
35–39	67·7	2·5	68·1	2·4	169	25·0	173	24·5	36·9	5·2	37·3	4·7
40–44	67·2	2·3	67·8	2·4	169	29·5	174	24·7	37·4	5·1	37·9	4·8
45–49	66·9	2·4	67·5	2·3	167	27·0	172	24·9	37·3	5·8	37·8	4·9
50–54	67·0	2·4	67·1	2·5	167	25·9	172	26·4	37·2	5·5	38·1	5·1
55–59	66·6	2·4	66·9	2·6	163	26·5	169	26·2	36·7	5·5	37·7	5·0
60–64	66·4	2·5	66·7	2·4	160	25·5	169	26·2	36·3	5·4	38·1	5·4

TABLE VIII

ZERO ORDER CORRELATIONS* BETWEEN PAIRS OF NUMERICAL VARIABLES FOR 1,358 NON-BRONCHITICS AGED 40–44 YEARS AT PORT TALBOT

	$FEV_{1\cdot0}$	FVC	$FEV_{1\cdot0}$ per cent.	Sitting Height	Standing Height	Weight
FVC	0·845					
FEV per cent.	0·512	(−0·010)				
Sitting Height	0·344	0·423	(0·042)			
Standing Height	0·376	0·460	(−0·053)	0·704		
Weight	0·201	0·161	0·112	0·486	0·461	
Obesity Index	(0·014)	0·076	0·154	0·152	(−0·053)	0·859

* Correlations which are not significant at the 1 per cent. level are given in brackets.

logical purposes, if only one of the three indices is to be used, $FEV_{1\cdot0}$ is probably the most informative.

(*ii*) There is very little difference between sitting height and standing height in respect of their relation to either $FEV_{1\cdot0}$ or FVC. If anything, standing height has the higher correlation, and since it is easier to measure and can be measured more reliably than sitting height, it is clearly the measurement of choice.

(*iii*) $FEV_{1\cdot0}$ and FVC are both correlated with weight ($r=0\cdot201$ and $0\cdot161$ respectively). But the fact that there is little or no association between these two measures of ventilatory capacity and the obesity index suggests that their relationship with weight is an indirect one attributable to the quite high correlation between weight and height ($r=0\cdot461$). For $FEV_{1\cdot0}$ and FVC, therefore, if standing height is taken into account, weight can be ignored.

(*iv*) FEV per cent. is unrelated to either standing or sitting height and has only low correlations with weight ($r=0\cdot112$) and the obesity index ($r=0\cdot154$). For epidemiological purposes FEV per cent. can therefore be used without reference to height or weight.

From these correlations it is clear that in the estimation of the mean ventilatory performance expected of groups of healthy men of different ages, body weight is of little significance, height is of importance for $FEV_{1\cdot0}$ and FVC but makes no contribution to FEV per cent., and sitting height can be ignored if standing height is taken into account. Table IX gives therefore the regressions of $FEV_{1\cdot0}$ and FVC on age and standing height and of FEV per cent. on age alone for our two industrial populations and compares them with data published by Cotes, Rossiter, Higgins, and Gilson (1966) for men selected from surveys carried out by the M.R.C. Pneumoconiosis Research Unit at various times and in different parts of the United Kingdom between 1958 and 1965. (The number of subjects examined and the mean values of the more important variables in the three studies are given in Table X, opposite.) For $FEV_{1\cdot0}$ and FVC, the constant terms and the regression coefficients on age and height are very similar in the three studies. For FEV per cent. the regression coefficient on age and the constant term are in close agreement in our two studies, but are somewhat higher than the values given by Cotes and others (1966). In view of the small numbers upon which the Pneumoconiosis Research Unit's regression equations are based, we consider that the equations derived from our observations on 8,106 subjects at Port Talbot now provide the best data available for the calculation of expected values of $FEV_{1\cdot0}$, FVC, and FEV per cent. for non-bronchitic males in the United Kingdom.

The equations given in Table IX for the relation between FEV or FVC and the two variables age and

TABLE IX

REGRESSION OF VENTILATORY CAPACITY ON HEIGHT AND AGE DATA FOR EBBW VALE, PORT TALBOT, AND COTES AND OTHERS (1966) COMPARED

Index of Ventilatory Capacity	Regression on Height (in.) and Age (yrs)	S.D.	R
$FEV_{1\cdot0}$ (litres) (E.V.) =	0·085 Ht—0·041 Age—0·667	0·68	0·68
(P.T.) =	0·108 Ht—0·042 Age—2·037	0·59	0·72
(Cotes) =	0·088 Ht—0·033 Age—1·12	0·45	0·83
FVC (litres) (E.V.) =	0·122 Ht—0·035 Age—2·429	0·69	0·67
(P.T.) =	0·150 Ht—0·037 Age—4·106	0·63	0·71
(Cotes) =	0·129 Ht—0·032 Age—3·02	0·52	0·82
$FEV_{1\cdot0}\times100$/FVC/(E.V.) =	89·19—0·304 Age	10·9	0·35
(P.T.) =	90·08—0·275 Age	8·6	0·34
(Cotes) =	85·35—0·169 Age	8·3	0·31

TABLE X

DATA USED FOR REGRESSION RELATIONSHIPS IN TABLE IX

Subjects	Number of Subjects	Age Range (yrs)	Mean Values of Variables				
			Age (yrs)	Height (in.)	$FEV_{1\cdot0}$ (litres)	FVC (litres)	$FEV_{1\cdot0}$ (per cent.)
Non-bronchitic Steel Workers, Ebbw Vale	5,797	16–69	38·0	67·4	3·49	4·48	77·6
Non-bronchitic Steel Workers, Port Talbot	8,106	16–69	41·6	67·8	3·55	4·50	78·7
Non-bronchitic Workers in Non-dusty Occupations, (Cotes and others, 1966)	275	20–64	45·3	67·7	3·34	4·29	77·9

height necessarily assume that the regressions of $FEV_{1\cdot0}$ and FVC on height are the same at all ages. But this is not strictly true. Table XI shows that in fact the regression of $FEV_{1\cdot0}$ on height decreases substantially with age. The regression of FVC on height decreases less with age, but the decline is nevertheless obvious. In the calculation of the values of $FEV_{1\cdot0}$ and FVC to be expected in non-bronchitic men at different ages and heights which are presented in Tables XII and XIII, we have therefore used age-specific regression equations.

TABLE XI

COEFFICIENT FOR THE REGRESSION OF $FEV_{1\cdot0}$ AND FVC ON STANDING HEIGHT BY AGE FOR NON-BRONCHITICS AT PORT TALBOT

Age (yrs)	$FEV_{1\cdot0}$ (litres per inch)	FVC (litres per inch)
<20	0·15	0·15
20–24	0·13	0·19
25–29	0·13	0·19
30–34	0·14	0·18
35–39	0·11	0·16
41–44	0·10	0·14
45–49	0·10	0·14
50–54	0·09	0·14
55–59	0·08	0·11
60–64	0·09	0·13
65–69	0·07	0·11

TABLE XII

EXPECTED VALUES* FOR $FEV_{1\cdot0}$ (LITRES) BY AGE AND HEIGHT AT B.T.P.S.†

Age (yrs)	Height (in.)						
	61	63	65	67	69	71	73
20–24	3·38	3·65	3·92	4·19	4·46	4·73	5·00
25–29	3·21	3·48	3·75	4·02	4·29	4·56	4·82
30–34	3·04	3·31	3·58	3·85	4·12	4·39	4·65
35–39	3·08	3·28	3·48	3·68	3·88	4·08	4·29
40–44	2·85	3·05	3·25	3·45	3·65	3·85	4·06
45–49	2·64	2·84	3·05	3·25	3·45	3·65	3·85
51–54	2·42	2·63	2·83	3·03	3·23	3·43	3·63
55–59	2·31	2·47	2·63	2·79	2·95	3·11	3·28
60–64	2·12	2·28	2·44	2·60	2·76	2·92	3·09
65–69	1·93	2·10	2·26	2·42	2·58	2·74	2·90

* The standard deviation of these expected values is about 0·59 litres.
† Body temperature and pressure saturated with water vapour.

TABLE XIII

EXPECTED VALUES* FOR FVC (LITRES) BY AGE AND HEIGHT AT B.T.P.S.†

Age (yrs)	Height (in.)						
	61	63	65	67	69	71	73
20–24	3·94	4·29	4·65	5·00	5·35	5·70	6·05
25–29	3·82	4·17	4·52	4·87	5·22	5·57	5·93
30–34	3·64	3·99	4·34	4·69	5·04	5·39	5·75
35–39	3·75	4·04	4·33	4·62	4·90	5·19	5·48
40–44	3·53	3·81	4·10	4·39	4·68	4·97	5·26
45–49	3·36	3·65	3·94	4·23	4·51	4·80	5·09
50–54	3·12	3·41	3·70	3·99	4·27	4·56	4·85
55–59	3·03	3·26	3·49	3·73	3·96	4·19	4·43
60–64	2·88	3·11	3·35	3·58	3·81	4·04	4·28
65–69	2·70	2·93	3·16	3·40	3·63	3·86	4·09

* The standard deviation of these expected values is about 0·63 litres.
† Body temperature and pressure saturated with water vapour.

Conclusions

In medicine the problem of delineating the boundaries of the normal is one of the more difficult aspects of the study of the abnormal. The general purpose of our survey of respiratory symptomatology and lung function among steelworkers is to investigate the prevalence of respiratory disability among them and to determine the relative importance of the environmental influences which determine it. In this first paper we have examined the distribution of lung function among the men without persistent cough and phlegm, according to their age and physique.

Our data on the relation of ventilatory capacity to age agree closely with most of the studies quoted by Cotes (1965). Because of the large numbers in our survey we can therefore state with confidence that, for adult white males, $FEV_{1\cdot0}$ decreases in a linear model by about 0·04 litres and FVC by about 0·035 litres for each year of life, that this rate of decrease does not alter with advancing years, and that the standard deviation about the mean of the two measures of ventilatory capacity is also unrelated to age.

With regard to physique, we have confirmed that for $FEV_{1\cdot0}$ and FVC weight *per se* (*i.e.* obesity) is of no significance. (This is fortunate, because the relation between weight and age is not linear: Khosla and Lowe, 1967.) Stature, on the other hand, is of considerable significance. Unexpectedly, we have found that standing height is a little more highly correlated with ventilatory capacity than stem height. This suggests that for epidemiological purposes standing height is the measurement of choice; it is certainly a great deal easier to measure. It has generally been assumed that the relation between ventilatory capacity and height is independent of age, at least in adult life. We have found that this is not so. As age increases, both $FEV_{1\cdot0}$ and FVC increase less steeply with increasing height. The change is far from trivial: age-specific coefficients for the regression of $FEV_{1\cdot0}$ on standing height give a difference between the expected values for men 62 in. tall and men 72 in. tall of 1·4 litres at 30–34 years, but of only 0·7 litres at 65–69 years.

The accuracy of measurements of $FEV_{1\cdot0}$ and FVC is dependent upon the ability and willingness of the subjects to co-operate. If for any reason a subject does not make an all-out effort to expel the air from his lungs, the tests will underestimate his ventilatory capacity. Lack of understanding and, in bronchitis, fear of coughing are particularly liable to interfere with the measurement of FVC and for these reasons it is probably not so reliable a measure as $FEV_{1\cdot0}$, with which it is highly correlated ($r = 0\cdot85$). From the point of view of population studies, FVC also has the disadvantage that it is rather more highly correlated with height ($r = 0\cdot46$ at age 40–44) than is $FEV_{1\cdot0}$ ($r = 0\cdot38$). Clinically, $FEV_{1\cdot0}$ as a percentage of FVC is a useful index of airways obstruction. Epidemiologically, it has the great advantage that, although it declines with age, it is unrelated either to height or, unexpectedly, to FVC. Unfortunately, however, the statistical use of $FEV_{1\cdot0}$ per cent. is complicated by the fact that for each age group its distribution is negatively skewed and that from about age 35 the standard deviation of the mean value becomes progressively greater with increasing age.

We have concluded the presentation of our material with Tables of the mean values of $FEV_{1\cdot0}$ (Table XII) and FVC (Table XIII) to be expected in groups of healthy men of different ages and heights. Because they are based on an exceptionally large number of non-bronchitic men (8,106) distributed over a wide age range (from 16 to 69 years), and because they are corrected for the change with age in the relation between ventilatory capacity and height, we consider that they are the most representative Standard Tables now available. It has to be admitted, however, that the value of standard tables to clinicians or to epidemiologists is limited. Ventilatory capacity varies so greatly even among healthy subjects that an individual's performance may be very considerably reduced by pulmonary disease and still be above the lower limit of what a standard table might suggest as "normal" for his height and age. For epidemiological purposes "expected" values of ventilatory capacity provide sensitive measures of differences between groups of subjects, but in every study local norms need to be defined. In our own study we have shown that two populations of men living and working no more than about 35 miles apart and engaged in strictly comparable occupations can differ significantly both in physique and in ventilatory capacity.

Summary

The organization of a survey of respiratory disability among the men employed in two large steel works in South Wales is described. Data on the respiratory symptomatology, ventilatory capacity, standing height, sitting height, weight, and social and occupational histories of 8,081 men in the works at Ebbw Vale and of 10,863 men in the works at Port Talbot have been collected. In this paper the distribution of ventilatory capacity among the men without persistent cough and phlegm in the two populations is described.

(1) Age for age the mean values of $FEV_{1\cdot0}$ and FVC are about 5 per cent. (0·2 litres) higher at

Port Talbot. Height for height the men at Port Talbot are also heavier.

(2) $FEV_{1\cdot 0}$ is highly correlated with FVC ($r=0\cdot 8$) and quite highly with FEV per cent. ($r=0\cdot 5$), but there is no correlation between FVC and FEV per cent.

(3) There is very little difference between standing height and sitting height in respect of their relation to $FEV_{1\cdot 0}$ or FVC.

(4) $FEV_{1\cdot 0}$ and FVC are unrelated to weight, except in so far as weight and height are fairly highly correlated.

(5) FEV per cent. ($FEV_{1\cdot 0} \times 100/FVC$) is unrelated to height or weight.

(6) Although the mean values of $FEV_{1\cdot 0}$ and FVC decline steeply with age, their standard deviations remain constant. For FEV per cent., however, the standard deviation about the mean increases substantially with age.

(7) The regression on height of $FEV_{1\cdot 0}$ and of FVC decreases with age.

The implications of these findings are discussed and regression equations and tables of expected values of $FEV_{1\cdot 0}$ and FVC by age and height for non-bronchitic males in the United Kingdom are presented.

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