RESPIRATORY MEASUREMENTS OF 3,556 SHEFFIELD SCHOOLCHILDREN

BY

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In the epidemiological study of respiratory disease increasing use has been made of simple tests of ventilatory capacity such as the forced vital capacity (FVC), forced expiratory volume in a specified period, usually one second ($FEV_{1.0}$), and the peak expiratory flow rate (PFR). Most of these studies have been carried out in adults, for whom there are numerous series of data indicating ranges of performance in health and disease. There is relatively little information relating to children. Strang (1959) presented normal values for FVC and $FEV_{1.0}$ in 418 boys and girls aged 7 to 18 years, coming from "a good residential area of Newcastle-upon-Tyne". Lyons, Tanner, and Picco (1960) presented normal values for FVC and $FEV_{1.0}$ in 1,163 boys and girls aged 6 to 14 years coming from a "predominantly middle class" background in New York.

Neither of these studies provided sufficient standards for use in an investigation started in Sheffield concerning the relationship between the respiratory disease pattern of schoolchildren and their environment. The present investigation is intended to fill this gap and is based on an examination of 3,556 children aged 4 to 11 years, providing over 250 boys and 250 girls in each of the years 6 to 10. The results are presented in a form which, it is hoped, will be convenient for both epidemiological and clinical use.

METHODS

All the available children, irrespective of their history of past illnesses, in eighteen infant and junior schools in the city were examined between January and September, 1964. Twelve of the schools serve pre-war or post-war local authority housing estates, and six serve areas where the children, for the most part, live in rented or owner-occupied 19th century

sub-standard terrace houses. The social class distribution by fathers' occupation of a sample of 498 children taken from these schools in 1963 was as follows:

	<i>Social Class</i>		<i>Percentage</i>
I	Professional, etc.	.. ..	0.0
II	Intermediate	.. ..	4.2
III	Skilled	.. ..	66.0
IV	Partly Skilled	.. ..	15.4
V	Unskilled	.. ..	14.4

Each child was weighed and measured in ordinary indoor clothing without shoes and jackets, the heights being recorded to the nearest 0.25 cm. and the weights to the nearest 0.05 kg.

The tests of ventilatory capacity were obtained with a Poulton spirometer fitted with a battery-operated transistorized timer and a Wright peak flow meter. Both these pieces of equipment are light and easily portable. The direct reading Poulton spirometer was selected in preference to one giving a trace because this eliminates any error in interpretation of the record and because the instrument is very simply calibrated. The ability to make such a check on uniformity of behaviour is an important attribute when collecting data from different schools on separate occasions. The McKesson Vitalor, which gives traces, was used in a pilot study designed to select the most appropriate interval for the FEV. Most investigators, including Strang and Lyons, have preferred 1.0 sec., although some have used shorter intervals, such as 0.75 sec. In many of the younger school children it was found that by 1.0 sec. the trace was reaching its asymptote, and the FEV reading was therefore very near to the FVC. As a result of the pilot investigation an interval of 0.75 sec. was chosen. Despite this the mean FEV percentage, the ratio of the $FEV_{0.75}$ to the FVC, was 86.0 per cent. in boys of height 100–115 cm.,

falling to 80.6 per cent. in those over 140 cm. The equivalent percentages for girls were 87.5 and 84.5 respectively. Strang (1959), using an interval of 1.0 sec. for FEV, obtained figures of 84.6 per cent. for boys and 88.6 per cent. for girls, while Lyons and others (1960), using the same interval, gave a minimum of 86.4 per cent. in their series of 1,163 children. It is possible that both investigators were measuring something approaching a vital capacity in their smaller children, and that even in the Sheffield group a still shorter interval, such as 0.5 sec., might have been used.

When recording ventilatory measurements, Strang (1959) used the mean of the best three readings following a number of practice attempts, while Lyons and others (1960) used the best of two readings providing that these varied by no more than 150 cc. Both these workers traced their readings on revolving drums. For the Sheffield children the best of five readings was used throughout. The reason for adopting this procedure was that the younger children often required explanations and practice. Once they achieved a good reading they frequently lost interest and failed to repeat it. Alternatively these young children, having stood in a queue and watched other children perform, sometimes gave their best reading first and failed to equal it in subsequent attempts. In children aged 6 years or over it was usual to get three or four good readings out of five, but in the youngest groups one or two

good readings out of five were the rule. Forced vital capacities and forced expiratory volumes are corrected to body temperature.

The repeatability of results obtained with the Poulton spirometer and Wright peak flow meter, working with a fairly rapid turnover of children on school premises, was tested by repeated examination of 83 boys and 90 girls in the age range 9 yrs 6 mths to 11 yrs 3 mths for twelve weekly occasions throughout one term. In spite of absences it proved possible to get eight or more readings for over 90 per cent. of the children. The mean coefficients of variation for FVC, FEV_{0.75}, and PFR were 3.5, 3.9, and 7.4 per cent. respectively for boys and 4.0, 4.6, and 8.0 per cent. for girls. No attempt was made to correct for the growth of the children during the 12 weeks of the term, and children presenting with respiratory infections were not excluded from the series. Because of these factors the figures give a relatively pessimistic measure of the repeatability of results.

RESULTS

AGES, HEIGHTS, AND WEIGHTS

Table I gives the distributions of height to age for boys and girls together with means, standard deviations, and percentiles. The class intervals of height and age permit direct comparisons with the London County Report figures (Scott, 1961). Generally speaking, the Sheffield children average

TABLE I
DISTRIBUTION OF HEIGHT TO AGE WITH MEANS, PERCENTILES,

Sex		Boys								
Age (yrs)		4-	5-	6-	7-	8-	9-	10-	11-	Total
Height (cm.)	<100	6	2							3
	100-	8	31							39
	105-	6	48	29	2	1				86
	110-	2	77	78	26	1				188
	115-		25	91	73	12	3	1		207
	120-		7	40	84	69	24	5		228
	125-		1	11	56	120	74	24	1	287
	130-			2	15	62	107	63	15	264
	135-				2	29	69	85	30	215
	140-					1	30	60	52	143
	145-						5	28	41	74
	150-							10	19	29
	155 and Over						1	1	2	4
Total		22	191	251	258	295	313	277	160	1,767
Mean Height		108.3	110.4	116.0	121.6	127.8	132.7	137.7	143.1	
SD		4.65	5.40	5.27	5.59	5.27	6.02	6.69	6.01	
Percentiles	5th		101.1	107.0	112.0	120.0	122.5	126.5	132.2	
	10th		102.6	109.2	114.5	121.0	125.2	129.4	134.9	
	25th		106.4	112.0	117.4	124.2	128.3	133.0	138.9	
	50th		110.8	115.9	121.5	127.6	132.5	137.6	143.1	
	75th		113.9	119.3	125.6	131.4	136.8	142.4	147.6	
	90th		117.7	123.4	129.1	135.0	140.7	146.9	151.2	
	95th		119.6	125.1	131.2	137.5	143.3	149.4	153.3	

Boys Overall mean height ($\bar{y}$) = 126.9 cm.
Overall mean age ($\bar{x}$) = 8.46 yrs.

Correlation coefficient +0.87
Regression coefficient b_{yx} = +5.40

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from 1 to 2 cm. less in height, but within each age group the height variation is similar to that in the London series. Table II gives information comparing the two series of children. The correlation between height and age is high, and for practical purposes within the age range studied the regression is linear. Correlation coefficients and regression coefficients are given in Table I.

The relationships between height and weight were similar in Sheffield and London children after correction for weight of clothing as detailed in the London County Report (Scott, 1961).

RESPIRATORY MEASUREMENTS

It would be possible to present the ventilatory capacity data in terms of each of the single variables age, height, and weight. Alternatively, any of the three possible pairs or all three variables together

could be used. In practice it is clearly simpler to use one fixed variable if this is appropriate. Strang (1959) discusses the advantage of height over age, weight, and surface area. In conformity with his work, the Sheffield data is presented in terms of height only; Table III (overleaf) shows the corresponding correlation coefficients, regression coefficients, and regression equations for FVC, FEV_{0.75}, and PFR. Within the range of children studied here a high positive correlation is present with each measure, although it is slightly less marked with the PFR. The trends are essentially linear except at the extremes of height where the numbers of children examined were small. On the basis of these figures, therefore, there appeared to be little benefit in relating ventilatory capacity to height cubed, although Strang (1959) favours this procedure for his own series which covers an age range including the growth period associated with puberty.

TABLE II
COMPARISON OF SHEFFIELD AND LONDON CHILDREN, HEIGHT FOR AGE

Age (yrs)						6		10	
Height (cm.)						Mean	Interquartile Range	Mean	Interquartile Range
Sex	Boys	Sheffield	..	..	..	116.0	112.0-119.3	137.7	133.0-142.4
		London	..	..	..	117.0	112.7-121.1	139.1	134.8-143.6
	Girls	Sheffield	..	..	..	115.2	111.7-118.6	136.9	132.1-141.7
		London	..	..	..	116.5	112.5-121.0	139.1	134.3-143.9

I

STANDARD DEVIATIONS, REGRESSION AND CORRELATION COEFFICIENTS

Girls								
4-	5-	6-	7-	8-	9-	10-	11-	Total
1	2	8						3
9	27	25						44
8	84	83	5					122
6	61	99	32	5				187
1	20	31	84	25	2	3		234
	1	6	83	70	27	7	2	221
	1	1	39	104	101	30	7	288
			10	55	81	83	22	252
			1	23	67	83	35	209
				4	18	62	41	125
					4	27	28	59
					3	7	21	31
						3	11	14
25	196	253	254	286	303	305	167	1,789
106.8	109.3	115.2	120.4	127.0	131.8	136.9	142.2	
4.76	4.67	5.17	5.48	5.89	6.07	6.97	8.01	
	101.3	105.8	111.1	116.7	122.3	125.8	129.4	
	103.1	108.3	113.1	119.6	124.9	128.3	131.6	
	106.1	111.7	116.5	122.8	127.2	132.1	136.4	
	109.0	115.4	120.2	126.9	131.2	136.7	142.0	
	112.7	118.6	124.1	130.8	136.1	141.7	148.1	
	115.5	121.9	128.0	134.7	139.5	146.1	153.5	
	117.9	124.0	129.7	137.6	142.6	148.9	156.1	

Girls Overall mean height ($\bar{y}$) = 126.1 cm.
Overall mean age ($\bar{x}$) = 8.48 yrs.

Correlation coefficient $+0.86$
Regression coefficient $b_{yx} = +5.45$

TABLE III
CORRELATION COEFFICIENTS, REGRESSION COEFFICIENTS, AND REGRESSION EQUATIONS FOR FVC, FEV_{0.75}, AND PFR AGAINST STANDING HEIGHT

Sex	Measurement (y)	Mean and SD (litres)	Correlation with Standing Height in cm. (x)		
			r	byx	Regression Equation
Boys	FVC	1.85 ± 0.511	+0.90	+0.040	y = 0.040x - 3.226
	FEV _{0.75}	1.51 ± 0.401	+0.87	+0.030	y = 0.030x - 2.297
	PFR	226.3 ± 62.9	+0.73	+3.92	y = 3.92x - 271.15
Girls	FVC	1.69 ± 0.490	+0.91	+0.037	y = 0.037x - 2.976
	FEV _{0.75}	1.42 ± 0.406	+0.88	+0.030	y = 0.030x - 2.363
	PFR	217.1 ± 66.3	+0.77	+4.25	y = 4.25x - 318.83

Table IV (below) and Tables V and VI (opposite) relate the measures of FVC, FEV_{0.75}, and PFR respectively to height. The mean values of FVC are similar to those recorded by Strang (1956) and rather higher than the means recorded by Lyons and others (1960). This is shown in Fig. 1.

Examination of the data in Tables IV, V, and VI showed that the variance of each measure increased with height. For practical simplicity, therefore, and because it makes no assumptions about the form of the distribution, the ventilatory capacity data has been arranged in these Tables to show the 5th, 10th,

TABLE IV
FORCED VITAL CAPACITY (litres)

Sex			Height (cm.)											
			<100	100-	105-	110-	115-	120-	125-	130-	135-	140-	145-	150-
Boys	Mean	.. .. .	0.78	1.00	1.14	1.27	1.42	1.63	1.85	2.04	2.28	2.50	2.73	2.89
	SD	.. .. .	±0.05	±0.18	±0.15	±0.16	±0.18	±0.21	±0.22	±0.24	±0.27	±0.28	±0.29	±0.31
	Median	.. .. .			1.14	1.27	1.42	1.62	1.85	2.05	2.28	2.51	2.75	
	Observed	.. .. .			77	80	79	80	80	80	81	83	81	
	10th	.. .. .			82	86	84	86	84	84	85	87	84	
	25th	.. .. .			92	92	90	92	92	93	92	91	91	
	Median	.. .. .			100	100	100	100	100	100	100	100	100	
Girls	Observed	.. .. .			75	75	77	81	81	82	83	82	84	
	10th	.. .. .			80	81	82	85	85	86	87	86	87	
	25th	.. .. .			89	89	90	93	93	93	93	93	92	
	Median	.. .. .			100	100	100	100	100	100	100	100	100	
	75th	.. .. .			110	109	108	109	108	108	108	107	109	
	90th	.. .. .			119	115	116	117	115	115	114	115	114	
	95th	.. .. .			125	120	119	121	119	122	118	119	116

FIG. 1.—Height and Mean Vital Capacity. Comparison of Sheffield figures with those of Strang (1959) and Lyons and others (1960).

TABLE V
FORCED EXPIRATORY VOLUME₀₋₇₅ (litres)

Sex			Height (cm.)												
			<100	100–	105–	110–	115–	120–	125–	130–	135–	140–	145–	150–	155 and Over
Boys	Mean		0.68	0.86	0.97	1.09	1.18	1.35	1.52	1.66	1.82	2.01	2.17	2.27	2.28
	SD		±0.05	±0.17	±0.13	±0.14	±0.17	±0.19	±0.19	±0.19	±0.24	±0.23	±0.22	±0.28	±0.26
	Median				0.97	1.09	1.19	1.34	1.52	1.66	1.81	2.01	2.18		
	$\frac{\text{Observed Median}}{\text{Median}} \times 100$ at various percentiles	5th			77	77	75	78	79	80	78	82	84		
		10th			82	83	80	83	84	84	83	85	87		
		25th			92	92	89	93	91	93	92	94	91		
		50th			100	100	100	100	100	100	100	100	100		
75th				108	108	109	110	108	107	108	107	107			
90th				116	117	118	121	116	116	118	114	113			
95th			120	122	123	124	122	119	123	118	117				
Girls	Mean		0.69	0.81	0.92	1.01	1.13	1.30	1.45	1.60	1.75	1.90	2.16	2.29	2.51
	SD		±0.17	±0.12	±0.16	±0.15	±0.17	±0.16	±0.19	±0.20	±0.21	±0.23	±0.28	±0.22	±0.37
	Median				0.93	1.02	1.13	1.29	1.44	1.60	1.74	1.91	2.09		
	$\frac{\text{Observed Median}}{\text{Median}} \times 100$ at various percentiles	5th			71	75	74	80	80	80	80	79	85		
		10th			76	79	81	84	84	84	85	83	89		
		25th			87	89	90	92	92	92	92	93	92		
		50th			100	100	100	100	100	100	100	100	100		
75th				111	111	111	109	108	108	109	107	112			
90th				122	120	119	117	116	116	117	115	124			
95th			128	124	125	121	122	121	120	118	127				

TABLE VI
PEAK FLOW RATE (litres per minute)

Sex			Height (cm.)												
			<100	100–	105–	110–	115–	120–	125–	130–	135–	140–	145–	150–	155 and Over
Boys	Mean		118	139	155	168	183	207	231	248	267	292	306	323	285
	SD		±5	±37	±29	±34	±37	±40	±45	±44	±53	±49	±47	±50	±60
	Median				152	169	183	205	229	243	263	293	305		
	$\frac{\text{Observed}}{\text{Median}} \times 100$ at various percentiles	5th			74	70	67	73	72	74	71	71	76		
		10th			78	75	74	78	78	80	77	79	79		
		25th			88	85	85	88	87	88	88	88	87		
		50th			100	100	100	100	100	100	100	100	100		
75th				115	113	113	112	112	115	116	112	113			
90th				130	123	128	129	129	125	128	122	123			
	95th			139	129	135	136	137	134	135	127	126			
Girls	Mean		109	126	140	156	180	202	222	243	262	287	318	331	359
	SD		±31	±31	±33	±33	±36	±40	±41	±46	±48	±53	±55	±49	±56
	Median				137	152	178	201	222	241	260	284	321		
	$\frac{\text{Observed}}{\text{Median}} \times 100$ at various percentiles	5th			67	70	69	70	72	72	72	70	75		
		10th			73	77	75	74	77	77	78	77	78		
		25th			84	87	88	88	86	86	86	88	85		
		50th			100	100	100	100	100	100	100	100	100		
75th				115	118	114	112	112	114	115	116	110			
90th				137	132	128	126	123	126	126	125	120			
	95th			148	137	137	135	130	134	132	129	130			

25th, 50th, 75th, 90th, and 95th percentiles within each 5 cm. class interval containing sufficient children to justify such treatment. The measures at each percentile are expressed as ratios of the median. This form of presentation is similar to that adopted by Kemsley, Billewicz, and Thomson (1962) in their new weight for height standard based on British anthropometric data. The pattern of the data is similar to that of Kemsley and others in that the

values for each percentile bear a nearly constant relationship to the median throughout the range of height. It is therefore justifiable to assess any individual's performance in terms of the median for his height class.

It is extremely simple in practice to use the median score for children of the same height as a reference standard. For example, a boy of height 117.5 cm. with an actual FVC of 1.15 litres would have an

expected FVC of 1.42 litres (Table V). His ratio of actual FVC to expected FVC is

$$\frac{1.15}{1.42} \times 100 = 81.$$

This would place him amongst the bottom 10 per cent. of children for this measure (Table IV). On the other hand, had his FVC reading been 1.60 litres, his ratio would be

$$\frac{1.60}{1.42} \times 100 = 113,$$

and he would be amongst the top 25 per cent. (Table IV). Should the same boy be seen some considerable time later, his new height and respiratory measurements could be handled in the same way and the new ratio compared directly with the old one. For the purpose of an epidemiological study on groups, the distribution of ratios or percentile rankings of a study group can be compared with the equivalent distribution for a control group. In this context data can be used from both cross-sectional and longitudinal studies.

The percentile distributions of Tables IV, V, and VI are shown diagrammatically in Figs 2 to 4. These Figures are intended to make the data more readily usable where interpolation is required between the mid-points of the height classes used in the tabulations. Alternatively, mean heights can be calculated from the regression equations in Table III, since the differences occurring between the means and medians

are of no practical importance when calculating ratios to the median within the range covered by the series.

SUMMARY

1,767 boys and 1,789 girls from eighteen Sheffield Infant and Junior schools were examined for age, height, weight, and respiratory measurements.

Mean heights averaged 1.2 cm. less than the figures for schoolchildren of the 1959 London County Report, but there was little difference in terms of weight for height.

Tables and Figures for FVC, $FEV_{0.75}$, and PFR are given, permitting the prediction of mean values from standing height and permitting children to be given a ratio of actual respiratory performance to expected performance and a percentile ranking. Procedures are suggested for applying these techniques to clinical practice and epidemiological research.

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FIG. 2.—Height and Forced Vital Capacity (5th to 95th percentile).

FIG. 3.—Height and Forced Expiratory Volume₀₋₇₅ (5th to 95th percentile).

FIG. 4.—Height and Peak Expiratory Flow Rate (5th to 95th percentile).

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