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Lung function and the response to exercise in New Guineans: role of genetic and environmental factors

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1. Information on respiratory symptoms and, in most instances, the ventilatory capacity (forced expiratory volume and forced vital capacity) were obtained on 2026 men, women and children comprising the total population of 12 villages situated at 2000 m in the Eastern Highlands and 1735 coastal people on Karkar Island. On selected healthy adults measurements were made of the total lung capacity and its subdivisions, the transfer factor for the lungs for carbon monoxide (151 subjects aged 20–63 years) and the ventilation and the cardiac frequency during submaximal exercise (132 subjects aged 17–34 years). The transfer factor was standardized to a haemoglobin concentration of 14.6 g/100 ml and alveolar capillary oxygen tension of 14.7 kPa (110 Torr).

2. The ventilatory capacity was reduced by the presence of respiratory symptoms or a loose cough but not by smoking local tobacco (Brus). For subjects with apparently healthy lungs and after allowing for the effects of age and of stature, the ventilatory capacity of the highland men, women and children was similar to that of representative Europeans. The coastal people had lower values including lower partial regression coefficients on age. The total lung capacity, its subdivisions and the transfer factor for the adult highlanders were larger than for the coastal people; the values were similar to or larger than for Europeans. The values for the coastal people resembled those for people of Indian, African and Chinese descent living in the tropics. The partial regression coefficient of transfer factor on age in the New Guineans was more negative than in the Europeans.

3. For the healthy young adults, analysis of the lung function data in relation to those for exercise point to the differences between the groups being due to the combined effects of an ethnic factor plus differences in the level of physical activity. The lung volumes, ventilatory capacity and ventilation during exercise are the resultant of both effects. The exercise tidal volume is a function of the ethnic factor but not the level of activity, while the reverse is true of the lung transfer factor for carbon monoxide.

Studies in mammalian physiology suggest that the size and effectiveness of the lung as an organ of gas exchange reflect the requirements for external respiration of the whole organism (see, for example, Weibel 1973). Data for man are more numerous than for animals but they contribute proportionately less to understanding the causes of biological variation. This is due mainly to the majority of measurements relating to people living in industrialized communities, where the range of habitual activities is both relatively narrow and poorly documented. In addition, when a difference does occur – for example, in relation to athletics – difficulty arises in separating the direct effect of the athletes' high level of habitual activity from the possible genetic precursors. The joint Australian and U.K. study in New Guinea, as part of the International Biological Programme, provided the opportunity to relate the lung function to measurements of the nutritional status, the habitual activity and the physiological response to exercise in people living at sea level and at 2000 m. By combining the information from these different sources and comparing them with those for other ethnic groups, the components due to the different ethnic and environmental factors might be isolated. Woolcock, Sinnett and their respective colleagues (e.g. Woolcock, Colman & Blackburn 1972; Sinnett & Soloman 1968) have already gone some way to doing this; the present study confirms and extends their findings.

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Subjects and methods

The subjects for study were coastal dwellers on Karkar Island, and highlanders who were mostly living at 2000 m in the Eastern Highlands. Additional highland subjects included residents at Goroka (altitude 1700 m) and labourers on coastal plantations. On Karkar Island during the studies of exercise and detailed lung function in young adults the ambient temperature was 20 °C obtained by air conditioning; for the remaining studies it was on average 26 °C. In the highlands the mean laboratory temperature was 22 °C.

The measurements of lung function comprised the forced expiratory volume (f.e.v.$_{1.0}$) and vital capacity (f.v.c.), which were measured using a McDermott dry spirometer, and the lung volumes and transfer factor including its subdivisions, the diffusing capacity of the alveolar capillary membrane and the volume of blood in the lung capillaries; these indices were obtained respectively using the closed-circuit helium-dilution method and the single-breath carbon monoxide method based on a resparameter. The transfer factor ($T_{l'}$) was calculated using a single breath rather than a multibreath estimate of the lung volume during the test; the reason for this was discussed in a previous publication (Cotes *et al.* 1973*c*). The methods of measurement are described in detail elsewhere (Cotes 1968). Respiratory symptoms were obtained using a modified version of the M.R.C.'s questionnaire on respiratory symptoms. The loose cough sign of Gandevia was elicited (Gandevia 1969) and a clinical examination was carried out. The ages of the subjects were, in most instances, those obtained during the previous demographic survey (Hornabrook, this volume, p. 229); for the children and for some of the adults on Karkar Island, these were based on birth records. In other cases they were estimated using all the available information.

The physiological response to exercise comprised the measurement of ventilation minute volume, including respiratory frequency and tidal volume, the cardiac frequency and the consumption of oxygen during each minute of a progressive submaximal exercise test on a bicycle ergometer (Monark). After a short practice the rate of work was initially 30 W and was increased every alternate min by 30 W (Cotes 1972).

The stature was measured using a Harpenden stadiometer, and mass using a spring balance. The skinfold thickness at four sites (over the biceps and triceps muscles, below the angle of the scapular and above the anterior superior iliac spine) were obtained using Harpenden skinfold calipers (Weiner & Lourie 1969). The sum of the four skinfold measurements was used to estimate the proportion of body weight which is fat and hence the lean body mass. The method (Durnin & Rahaman 1967) has been shown to also hold for New Guineans (Durnin, Ferro-Luzzi & Norgan 1972). The measurements of the lung function were related to stature and age. In the case of the transfer factor and the K_{CO} (transfer factor per unit of lung volume) they were adjusted to the haemoglobin concentration of 14.6 g % and the alveolar oxygen tension of 14.7 kPa (110 Torr) (Cotes *et al.* 1972). In a preliminary analysis the body masses of the subjects were also included. However, in the case of the ventilatory capacity (f.e.v. and f.v.c.), where data for large numbers of subjects were available for analysis, the mass was found not to reduce the scatter about the regression relationship on age and height; as this has also been the finding in most other studies, the mass has not been considered further. The lung-function data for the present New Guinea subjects have been compared with those reported by Woolcock and her colleagues which are referred to above, also with data for other ethnic groups including men, women and some children, of European, African, Indian and Chinese descent (Cotes *et al.*

1973*b*, *c*; Miller, Ashcroft, Swan & Beadnell 1970; Miller *et al.* 1972; Edwards, Miller, Hearn & Cotes 1972; Da Costa 1971).

The data for the physiological response to submaximal exercise were analysed in terms of the tidal volume at the minute volume of 30 l min^{-1} ($V_{t,30}$) and the ventilation minute volume and the cardiac frequency at the consumptions of oxygen of 45 mmol min^{-1} (1.0 l min^{-1}) and 67 mmol min^{-1} (1.5 l min^{-1}). The indices are designated $\dot{V}_e$ and f_c with the subscripts 1.0 and 1.5 respectively. For each group of subjects the regression of the $V_{t,30}$ on the vital capacity was used to obtain a standardized tidal volume ($V_{t,30,st}$) at the vital capacity of for men 4.0 l and for women 3.5 l. The indices for cardiac frequency ($f_{c,1.0}$ and $f_{c,1.5}$) were similarly related to the lean body mass using the procedure of Cotes *et al.* (1973*a*); in this way standardized frequencies ($f_{c,st}$) were obtained at the values for lean body mass in men of 55 kg and in women 40 kg. The findings were compared with those for other ethnic groups including European factory workers (Cotes *et al.* 1969), European amateur racing cyclists (Cotes *et al.* 1971), men of Indian and African descent living in Trinidad (Edwards *et al.* 1972) and men and women of African descent in Jamaica (Miller *et al.* 1972).

Table 1. Relation of lung function to smoking category in highland New Guineans

Data standardized to age 40 years, height 1.55 m.

	number	f.e.v.$_{st}$	f.v.c.$_{st}$	f.e.v. %$_{st}$
males				
never smoked	40	2.58	3.44	74.4
Brus > 1 leaf	74	2.70	3.58	74.8
Brus + European tobacco	65	2.67	3.50	76.4
females				
never smoked	122	2.36	3.06	76.5
Brus ⩽ 1 leaf	131	2.45	3.19	76.8
Brus + European tobacco	22	2.45	3.08	78.8

Results

(*a*) *Ventilatory capacity*

Measurements of f.e.v. and f.v.c. were carried out on the entire population of 11 villages in the highlands and on a comparable number of villagers living on Karkar Island, except that it was not possible to obtain values from the very young children and some of the older adults. The proportion of subjects with multiple respiratory symptoms or with physical signs in the chest did not differ significantly as between the highland and coastal populations. The subjects with these features, after standardizing for age and height, were found to have lower ventilatory capacities than subjects with apparently normal chests. A similar analysis for the data with respect to smoking classified by the type and amount of tobacco smoked per day (table 1) did not show any significant difference compared with non-smokers. Accordingly, the definitive analysis was confined to subjects who were free from chest symptoms or signs, including both smokers and non-smokers. The subdivisions of the populations by age and by symptom groups are given in table 2. The findings in the children including the regression equations of vital capacity on height and the f.e.v.$_{1.0}$ as a percentage of the vital capacity (f.e.v. %) are given in figure 1. The regressions of f.e.v.$_{1.0}$ and f.v.c. on age and height for the adults are given in figures 2 (*a*) and (*b*).

For all subjects relative to their height and, in the case of adults, their age, the ventilatory capacity (f.e.v. and f.v.c.) were less in the females than in the males. The values for the highlanders, both adults and children, were very similar to those of the Europeans. The present results for the children were almost identical with, and those in the adults were on average slightly higher than, those reported by Woolcock and her colleagues for comparable subjects living at an altitude of 1100–1500 m. The ventilatory capacity of the coastal people was significantly less than that of the highlanders and similar to that found by Woolcock *et al.* for the

Table 2. Subjects in selected age-groups seen during the epidemiological survey

	highland villages				Karkar Island			
	5–14 year		25 year +		5–14 year		25 year +	
	m	f	m	f	m	f	m	f
total no.	254	240	426	478	273	269	286	318
without f.e.v.	104	81	43	89	85	107	11	36
with f.e.v. and symptoms	50	53	217	199	73	55	157	142
f.e.v. and no symptoms	109	106	166	190	115	107	118	140
mean age/years	10.8	10.6	37.9	36.7	10.7	10.7	38.1	37.1
mean ht/m	1.27	1.27	1.58	1.48	1.25	1.28	1.60	1.52

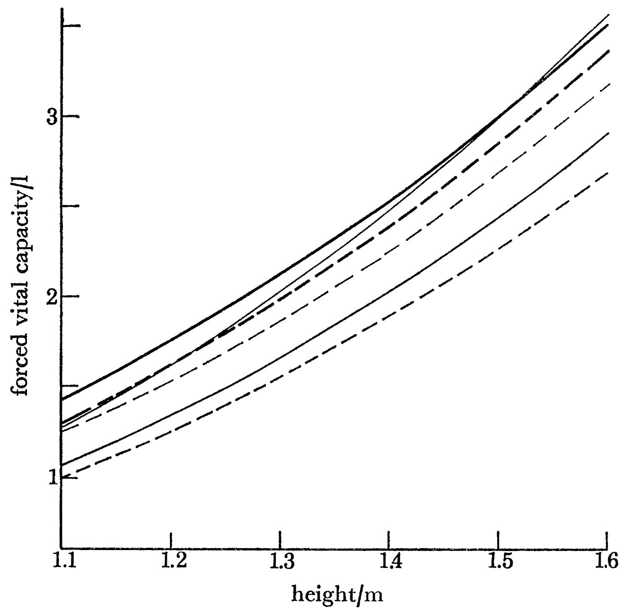

Figure 1. Ventilatory capacity relative to height in children in New Guinea; comparison with Europeans. The coefficients of variation about the regression lines are on average 12 % (range 10 % to 15 %).

		f.e.v. %	equations
highlanders			
———	boys	84.8	f.v.c. = $1.128\ \mathrm{ht}^{2.414}$
— — —	girls	85.2	f.v.c. = $1.005\ \mathrm{ht}^{2.561}$
coastal			
———	boys	86.4	f.v.c. = $0.819\ \mathrm{ht}^{2.694}$
— — —	girls	85.6	f.v.c. = $0.766\ \mathrm{ht}^{2.668}$
Europeans			
———	boys	84.0	
— — —	girls	86.9	

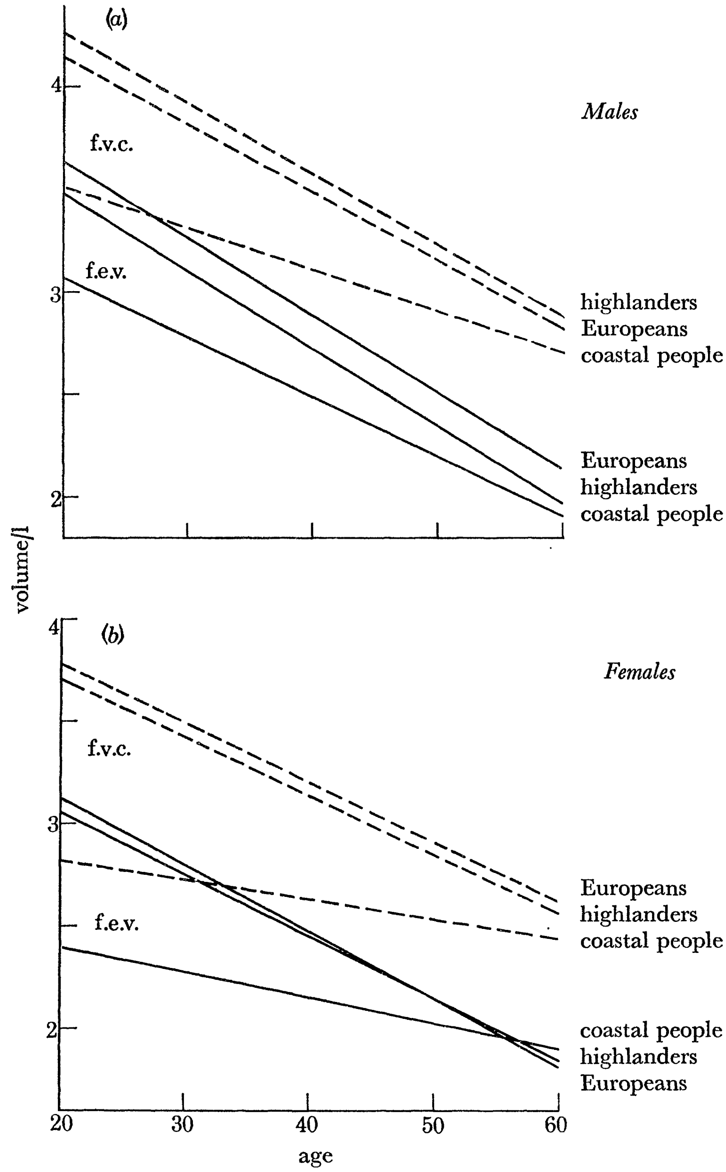

FIGURE 2. Relationship of ventilatory capacity at height 1.55 m to age in New Guineans; comparison with Europeans. The standard deviation about the regression lines is on average for males 0.4 l (range 0.38–0.45) and for females 0.3 l (range 0.28–0.35).

Equations (*a*) males

Highlanders:

f.e.v. = 4.32 ht − 0.038 age − 2.46
f.v.c. = 5.21 ht − 0.035 age − 3.12

Coastal people:

f.e.v. = 4.19 ht − 0.029 age − 2.84
f.v.c. = 4.74 ht − 0.020 age − 3.45

Equations (*b*) females

Highlanders:

f.e.v. = 3.98 ht − 0.032 age − 2.45
f.v.c. = 5.17 ht − 0.029 age − 3.72

Coastal people:

f.e.v. = 2.82 ht − 0.015 age − 1.65
f.v.c. = 3.68 ht — 0.010 age − 2.67

TABLE 3. LUNG FUNCTION IN NEW GUINEANS; MEAN VALUES AND RANGES

	unit	coastal men	coastal women	Highland men	Highland women
number of subjects …	—	45 (43)	35 (32)	45 (41)	26 (23)
age	year	34.5 (21–63)	37.0 (20–56)	34.2 (20–56)	30.5 (20–50)
height	m	1.62 (1.46–1.72)	1.51 (1.41–1.64)	1.60 (1.45–1.70)	1.52 (1.35–1.61)
haemoglobin concentration	g dl^{-1}	11.2 (6.7–13.6)	10.8 (5.1–14.6)	14.4 (6.3–17.6)	13.1 (10.0–15.3)
forced expiratory volume (f.e.v.$_{1.0}$)	l	2.79 (1.52–4.00)	2.02 (1.41–2.80)	3.21 (1.68–4.26)	2.45 (1.48–3.16)
forced vital capacity (f.v.c.)	l	3.53 (2.06–5.30)	2.53 (1.79–3.20)	3.99 (2.46–5.19)	3.12 (2.17–4.0)
100 × f.e.v./f.v.c. (f.e.v. %)	%	78.8 (59.3–88.8)	80.2 (66.5–90.2)	80.5 (68.2–91.4)	78.6 (68.2–90.7)
vital capacity (v.c.)	l	3.68 (2.31–5.36)	2.64 (2.07–3.22)	4.19 (2.34–5.30)	3.22 (2.14–4.09)
total lung capacity (t.l.c.)	l	5.09 (3.32–6.96)	3.72 (3.05–4.69)	5.89 (4.03–7.91)	4.45 (3.42–5.44)
functional residual capacity (f.r.c.)	l	2.73 (1.71–4.30)	2.03 (1.48–3.23)	3.25 (2.29–4.21)	2.40 (1.62–3.86)
residual volume (r.v.)	l	1.40 (0.80–3.01)	1.08 (0.59–1.94)	1.68 (0.85–2.83)	1.23 (0.7–1.99)
100 × r.v./t.l.c. (r.v. %)	%	27.3 (16.6–51.2)	28.9 (17.3–41.4)	27.78 (15.7–41.9)	27.4 (20.5–42.5)
transfer factor ($T_{l',s}$)	ml min^{-1} Torr^{-1}	28.3 (15.2–55.2)	20.9 (9.2–40.7)	34.5 (11.7–51.5)	31.6 (22.2–44.2)
$T_{l',s}/V_A$ ($K_{CO,s}$)	min^{-1} Torr^{-1}	5.84 (3.29–11.7)	5.90 (2.9–10.4)	6.12 (1.85–9.76)	7.6 (4.97–11.1)

V_A is alveolar volume. The numbers of subjects for the measurement of transfer factor are in parentheses.

inhabitants of the Trobriand Islands. They were also similar to those reported by others for the Chinese living in Singapore, people of African descent in the Caribbean, and people of Indian descent in the United Kingdom. The regression coefficients on height for the adult subjects were similar as between the highlanders and coastal dwellers and comparable to those for the other ethnic groups. The regression coefficients on age were significantly less negative in the coastal dwellers, indicating an apparently less rapid deterioration with increasing age compared with the highlanders and Europeans. In this respect the data for the coastal people resembled those for people of Indian and African descent living in Guyana.

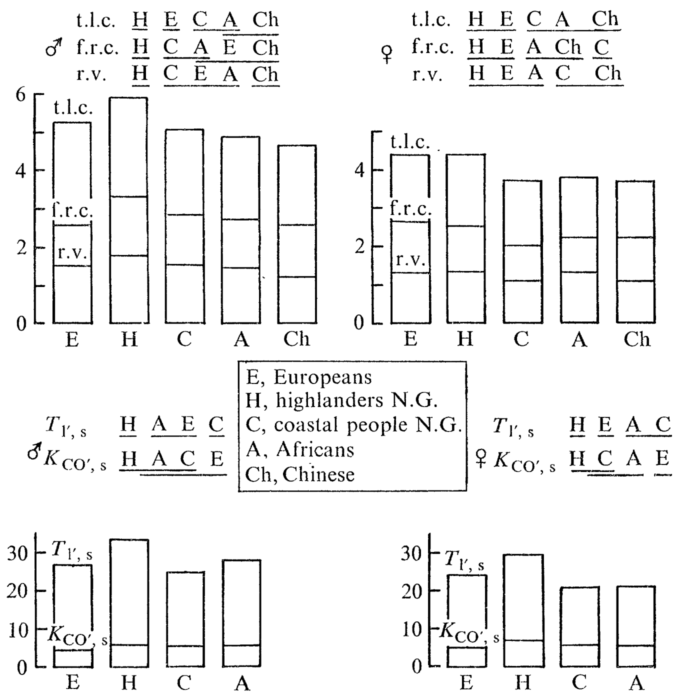

FIGURE 3. Standardized lung function for adults by ethnic group (♂ age 40 a, height 1.6 m, ♀ age 37 a, height 1.51 m). Significant differences between the groups are indicated by a break in the lines beneath the symbols.

(*b*) *Lung volumes and transfer factor*

Measurements of the total lung capacity and the transfer factor in young adults were made in conjunction with the studies on exercise and have been reported previously (Cotes *et al.* 1973*c*). Measurements on older subjects were made subsequently. The present data related to those subjects in both studies who were aged 20 years or above and were free from any stigmata of chest illness. The mean data are given in table 3. Linear regression analyses yielded coefficients on age and height similar in most instances to those expected from studies of other ethnic groups: however, the coefficients on height for the total lung capacity in the coastal women and for the residual volume in the highland men were only significant at the 10% level. The regression coefficients on age for the transfer factor ($T_{l',s}$) in the highland and coastal men and women (respectively for men −0.47 and −0.42 units and for women −0.57 and −0.46 units) appear to be more negative than in other populations.

The results of a comparison of the absolute magnitude of the indices of lung function for the present subjects with those for other ethnic groups are given in figure 3. The sources for the latter data are given above.

For both sexes and for all subdivisions of the total lung capacity after standardizing for age and height, the volumes in the highlanders were significantly higher than in the coastal dwellers. In addition, for both sexes in the case of expiratory reserve volume, and for men in the case of residual volume, the values in the highlanders were also greater than in the Europeans. The lung volumes in the highland men were larger than those found by Woolcock and her colleagues; for women the two sets of data were similar. The volumes in the coastal dwellers were similar to those reported for the Chinese in Singapore and for people of African and Indian descent in the Caribbean.

The transfer factor of the highlanders after standardizing for age and height and haemoglobin concentration was significantly higher than that of the coastal dwellers and of the other groups including the Europeans and the people of African and of Indian descent whose results were similar. The transfer factor of the coastal dwellers resembled that of the latter groups but was rather lower than for the Europeans. The values for the K_{CO} (transfer factor per litre of lung volume) were similar for all groups except the Europeans whose values were on average lower.

TABLE 4. DATA FOR LUNG FUNCTION AND THE RESPONSE TO SUBMAXIMAL EXERCISE IN YOUNG MEN OF DIFFERENT ETHNIC GROUP STANDARDIZED FOR BODY SIZE AND COMPOSITION (AGE 25 year, HEIGHT 1.7 m, LEAN BODY MASS 55 kg, HAEMOGLOBIN CONCENTRATION 14.6 g dl^{-1}, O_2 UPTAKE 1.5 l min^{-1} AND FOR $V_{t,30}$ A VITAL CAPACITY OF 4 l)

Significant differences are indicated by different letters beneath the data ($P < 0.05$)

	New Guineans		Europeans (U.K.)		Caribbeans	
	coastal subsistence	highland farmers	factory workers	amateur cyclists	African and Indian clerks, etc.	hill farmers
lung function						
forced expiratory volume	3.26	3.74	4.06	4.39	3.31	3.45
(f.e.v.$_{st}$/l)	d	c	b	a	d	d
total lung capacity	5.61	6.74	6.27	6.77	5.69	
(t.l.c.$_{st}$/l)	c	a	b	a	c	
transfer factor	35.0	41.7	35.0	38.3	31.2	
($T_{l',s,st}$/ml min^{-1} Torr^{-1})	c	a	c	b	d	
submaximal excercise						
ventilation	42.7	38.7	36.5	35.1	47.6	38.9
($\dot{V}_{e,1.5,st}$/l min^{-1})	c	b	ab	a	d	b
tidal volume	1.06	1.05	1.33	1.30	1.11	1.18
($V_{t,30,st}$/l)	a	a	b	b	a	a
cardiac frequency	119	113	132	114	139	124
($f_{c,1.5,st}$/min^{-1})	b	a	c	a	d	b

Physiological response to submaximal exercise

The ventilation, tidal volume and cardiac frequency during progressive submaximal exercise were obtained for young adult men and women in the highlands and on Karkar Island. Measurements were also made on male labourers from the highlands who were working on the Island. The data for the latter subjects were very similar to those for the men in the highlands despite the migrants having the lower haemoglobin concentrations (mean values respectively 11.8 and 14.4 g dl^{-1}); the two sets of data have accordingly been combined. The lung function of these subjects has already been reported (Cotes *et al.* 1973*c*) and a detailed account of the exercise data will be presented elsewhere (Patrick, Kay, Saunders & Cotes, in preparation). The interrelations between the lung function and the exercise data for these subjects, also for others on whom similar data have been obtained are analysed in tables 4 and 5 and in the discussion below.

Table 5. Data for lung function and the response to submaximal exercise in young women of different ethnic group standardized for body size and composition (age 25 year, height 1.58 m, lean body mass 40 kg, haemoglobin concentration 14.6 g dl^{-1}, O_2 uptake 1.0 l min^{-1} and for $V_{t,30}$ a vital capacity of 3.5 l)

Significant differences ($P < 0.05$) are indicated by different letters beneath the data.

	New Guineans			
	coastal	highland	Europeans	Jamaican housewives
lung function				
forced expiratory volume	2.41	2.77	3.11	2.38
(f.e.v.$_{st}$/l)	c	b	a	c
total lung capacity	4.12	4.82	4.97	4.22
(t.l.c.$_{st}$/l)	b	a	a	b
transfer factor	28.7	32.8	28.2	23.0
($T_{l',s,st}$/ml min^{-1} torr^{-1})	b	a	b	c
submaximal excercise				
ventilation	27.6	24.6	26.9	29.5
($\dot{V}_{e,1.0}$/l min^{-1})	bc	a	b	c
tidal volume	1.01	1.07	1.34	1.11
($V_{t,30,st}$/l)	a	a	b	a
cardiac frequency	135	122	134	145
($f_{c,1.0,st}$/min^{-1})	b	a	b	c

Discussion

The present results were obtained using relatively sophisticated equipment which was checked during use by repeated calibrations. Thus their technical reliability is probably of a high order. The subjects inevitably had some difficulty in comprehending what was required for the performance of the tests but most responded to patient instruction and very few results were lost on account of failure of cooperation. The long-term reproducibility was not assessed so it is not known if the results were truly representative of the subjects; the limited evidence which is available suggests that this was so. For the studies on ventilatory capacity, the results were also representative of the communities since the subjects comprised whole populations: this was also the case for the epidemiological studies of Vines (1970) but not for other physiological studies reported for the Territory. In the present instance the numbers in the different villages differed slightly from those of the demographic surveys but this was due mostly to migration and the number of lapses was small. However, on account of exclusions due to respiratory symptoms the data for healthy subjects relate to those whose lungs have proved resistant to the prevailing lung disorders. Whether or not the lung function of these subjects is inherently 'superior' to that of the remainder cannot be determined from the data at present available.

For the studies of detailed lung function and of exercise the young adult highlanders were a sample of their age-groups but the remaining subjects were selected partly on the grounds of their availability and may not be representative. However, in their selection they are probably reasonably comparable to those of the other studies cited.

The present data for ventilatory capacity provide the first accurate indication of the effect upon lung function of the high prevalence of respiratory symptoms amongst villagers in New Guinea. This aspect is discussed elsewhere (Anderson 1973). For the coastal dwellers without symptoms the data for ventilatory capacity are similar to those of Woolcock and her colleagues. For the highland women in the case of the f.e.v. and the f.v.c. and for the highland men in the case of the f.v.c. and the t.l.c. the present results are higher. The criteria for exclusion of subjects on account of symptoms were apparently similar in the two studies but they differed in that in the earlier one the subjects were those prepared to walk to the mission hospital and the measurements of ventilatory capacity were derived from the larger of two reproducible curves. Both these aspects might be expected to yield higher values than for the present study where the subjects composed the whole population and the measurement was the mean of three technically satisfactory results after two practice attempts. That the present results are higher may reflect environmental factors, including those discussed below; but in this case a similar difference in ventilatory capacity should have obtained for the children. This was not observed.

Compared with other ethnic groups the ventilatory capacities of the New Guinea highlanders are similar to the average reported for Europeans. The ventilatory capacity and the lung volumes of the coastal people are smaller than for highlanders and Europeans but are very similar to the average reported for people of Indian, African and Chinese descent in various parts of the world. These observations are evidence for an ethnic difference in lung size with the Europeans having in general the larger lungs. It is uncertain whether or not there is also an ethnic difference in the transfer factor but the majority of the evidence suggests that there is not. Superimposed on the genetic variation is an additional variation of environmental origin. This may be due partly to the effects of altitude *per se* but is also due to differences in physical activity which are reflected in the physiological response to exercise. Data on the relation of the lung function to the response in exercise are contained in tables 4 and 5 and are discussed below. Meanwhile the apparently greater decline with age of the ventilatory capacity in the highlanders than in the coastal people, while not related to the prevalence of respiratory symptoms in the two communities, may reflect other environmental factors including differences in domestic atmospheric pollution from wood fires (Cleary & Blackburn 1968). The more negative regression coefficient on age of the transfer factor ($T_{l',s}$) in the New Guineans than in Europeans may be due partly to this cause. However, the decline may also be related to that in the amount of body muscle which is a striking feature of the anthropometric survey (Harvey, this volume, p. 279). A more detailed examination of these aspects must await the outcome of longitudinal studies.

The environmental determinants of the overall lung function include the nutrition, the incidence of infection and the atmospheric pollution; in the present study these have been allowed for, the first by regression analysis on height and the others by exclusion of subjects with symptoms referable to the chest. In these circumstances the effect of activity may be investigated by relating the lung function standardized for age and body size to indices of exercise performance similarly standardized. Of these the exercise cardiac frequency standardized for both the consumption of oxygen and the quantity of body muscle provides an indication of the effectiveness of use of the circulation during exercise and hence of the current level of physical training (Cotes *et al.* 1973*a*). In relation to the development of the lung the relevant level of activity is that during childhood but the activity during early adult life is probably related to it. For the men of the present study (table 4) the cardiac frequency of the New Guinea highlanders is significantly lower than that of the coastal dwellers and both are lower than for the European factory workers. The cardiac frequency of the highlanders resembles that of amateur racing cyclists in the U.K.: the cardiac frequency of the coastal dwellers resembles that of hill farmers in the Caribbean. The latter, in turn, have lower frequencies than sedentary workers in the Caribbean where values are higher than in any other group. For the women (table 5) the pattern is similar, with the lowest frequencies in the New Guinea highlanders and the highest in the Jamaican housewives. Thus for both the men and the women there are clear cut differences in cardiac frequency ($f_{c,st}$) between subjects who differ in their probable levels of physical training but none in relation to ethnic group. This is also the conclusion of other workers who have used as an index the physical working capacity (e.g. Davies *et al.* 1972). Thus the present data provide a score for physical activity against which the indices of lung function can be assessed. The relation of the score to the average daily and peak levels of energy expenditure for the present subjects has still to be established.

The data for lung function (figure 3) provide clear-cut evidence for an ethnic difference in lung size, but leave unexplained the large lungs of the New Guinea highlanders relative to those of the coastal dwellers. The data for cardiac frequency suggest that the difference in the vital capacity can be explained mainly on the basis of the different levels of physical activity of the two groups of subjects. This is also the case for the difference in lung size between the European amateur racing cyclists and the factory workers. However, the explanation does not extend to the residual volume which, while it is larger in the New Guinea highlanders than in the coastal dwellers, is smaller in the European cyclists than in the factory workers; thus the difference in the New Guineans may be an effect of altitude but the evidence is inconclusive. On this view, for the men in the Caribbean the absence of a difference in lung size between the hill farmers and the sedentary subjects may be due to the habitual activity of these men diverging mainly during adult life.

In the case of the transfer factor ($T_{l', s, st}$) there is a significant negative correlation between the mean transfer factor in the different groups of subjects and the exercise cardiac frequency (figure 4). This finding provides support for the view, for which there is so far limited evidence (see, for example, Cotes & Hall 1970), that the transfer factor is influenced by habitual activity but is independent of ethnic group. By contrast, for the exercise tidal volume ($V_{t,30,st}$) there is a significant ethnic difference but no difference attributable to activity except to the extent that this also influences the vital capacity. The exercise ventilation ($\dot{V}_{e,1.0}$ or $_{1.5}$) within ethnic groups (tables 4 and 5) is apparently slightly lower both for the active than for the less active subjects and for the subjects of European descent compared with other ethnic groups. Thus the ventilation minute volume during exercise resembles the overall size of the lung in being influenced by both genetic and environmental factors.

In conclusion the present data support the view that the lung function and the ventilatory response to exercise of young adults with healthy lungs may be described in terms of the age, the sex, the body size, the ethnic group and an index of physical activity. The possible role of altitude, independent of its effect upon activity, has still to be established as has the relevance of these and other factors to the decline in lung function with age. In the latter respect the changes with time in the lung function of the New Guineans who were the subjects for the present study may be particularly informative.

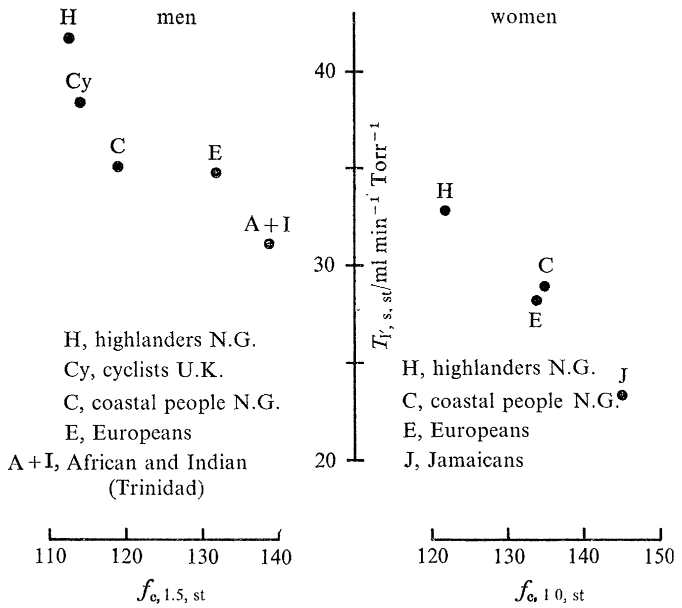

FIGURE 4. Relation of transfer factor ($T_{l', s, st}$) to exercise cardiac frequency ($f_{C, st}$) for groups of young adults (Hb 14.6 g dl^{-1}; for men height 1.7 m, $\dot{V}_{O_2}$ 1.5 l min^{-1}, l.b.m. 55 kg; for women height 1.58 m, $\dot{V}_{O_2}$ 1.0 l min^{-1}, l.b.m. 40 kg).

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REFERENCES (Cotes *et al.*)

Anderson, H. R. 1973 Chronic lung disease in New Guinea highlanders. *Thorax* (in the Press).

Cleary, G. J. & Blackburn, C. R. B. 1968 Air pollution in native huts in the highlands of New Guinea. *Archs environm. Hlth* **17**, 785–794.

Cotes, J. E. 1968 *Lung function: assessment and application in medicine*, 2nd ed. Oxford: Blackwells.

Cotes, J. E. 1972 Response to progressive exercise: a three-index test. *Br. J. Dis. Chest* **66**, 169–184.

Cotes, J. E., Berry, G., Burkinshaw, L., Davies, C. T. M., Hall, A. M., Jones, P. R. M. & Knibbs, A. V. 1973*a* Cardiac frequency during submaximal exercise in young adults; relation to lean body mass, total body potassium and a mount of leg muscle. *Q. Jl exp. Physiol.* 239–250.

Cotes, J. E., Dabbs, J. M., Daley, C., Hall, A. M., Johnson, G. R., Reed, J. W. & Saunders, M. J. 1971 Above-average exercise capacity in competition cyclists; relationship to body muscle. *J. Physiol., Lond.* **218**, 63–64*P*.

Cotes, J. E., Dabbs, J. M., Elwood, P. C., Hall, A. M., McDonald, A. & Saunders, M. J. 1972 Iron deficiency anaemia: its effect on transfer factor for the lung (diffusing capacity) and ventilation and cardiac frequency during submaximal exercise. *Clin. Sci.* **42**, 325–335.

Cotes, J. E., Dabbs, J. M., Hall, A. M., Axford, A. T. & Laurence, K. M. 1973*b* Lung volumes, ventilatory capacity and transfer factor in healthy British boy and girl twins. *Thorax* 709–715.

Cotes, J. E., Davies, C. T. M., Edholm, O. G., Healy, M. J. R. & Tanner, J. M. 1969 Factors relating to the aerobic capacity of 46 healthy British males and females, ages 18–28 years. *Proc. R. Soc. Lond.* B **174**, 91–114.

Cotes, J. E. & Hall, A. M. 1970 The transfer factor for the lung; normal values in adults. In *Normal values for respiratory function in man* (ed. P. Arcangeli), pp. 327–343. Torino: Panminerva Medica.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Cotes, J. E., Saunders, M. J., Adam, J. E. R., Anderson, H. R. & Hall, A. M. 1973c Lung function in coastal and highland New Guineans: comparison with Europeans. *Thorax* **28**, 320–330.

Da Costa, J. L. 1971 Pulmonary function studies in healthy Chinese adults in Singapore. *Am. Rev. resp. Dis.* **104**, 128–131.

Davies, C. T. M., Barnes, C., Fox, R. H., Ojikutu, R. O. & Samueloff, A. S. 1972 Ethnic differences in physical working capacity. *J. appl. Physiol.* **33**, 726–731.

Durnin, J. V. G. A., Ferro-Luzzi, A. & Norgan, N. G. 1972 An investigation of a nutritional enigma – studies on coastal and highland populations in New Guinea. *Hum. Biol. Oceania* **1**, 318.

Durnin, J. V. G. A. & Rahaman, M. M. 1967 The assessment of the amount of fat in the human body from measurements of skinfold thickness. *Br. J. Nutr.* **21**, 681–689.

Edwards, R. H. T., Miller, G. J., Hearn, C. E. D. & Cotes, J. E. 1972 Pulmonary function and exercise responses in relation to body composition and ethnic origin in Trinidadian males. *Proc. R. Soc. Lond.* B **181**, 407–420.

Gandevia, B. 1969 A productive cough upon request as an index of chronic bronchitis: the effects of age, sex, smoking habit and environment upon prevalence in Australian general practice. *Med. J. Aust.* **1**, 16–20.

Miller, G. J., Ashcroft, M. T., Swan, A. V. & Beadnell, H. M. S. G. 1970 Ethnic variation in forced expiratory volume and forced vital capacity of African and Indian adults in Guyana. *Am. Rev. resp. Dis.* **102**, 979–981.

Miller, G. J., Cotes, J. E., Hall, A. M., Salvosa, C. B. & Ashworth, A. 1972 Lung function and exercise performance in healthy Caribbean men and women of African ethnic origin. *Q. Jl exp. Physiol.* **57**, 325–341.

Sinnett, P. F. & Solomon, A. 1968 Physical fitness in a New Guinea highland population. *Papua N. Guinea med. J.* **2**, 56–60.

Vines, A. P. 1970 *An epidemiological sample survey of the Highlands, Mainland and Island regions of the Territory of Papua and New Guinea.* Port Moresby: Department of Public Health.

Weibel, E. R. 1973 Morphological basis of alveolar-capillary gas exchange. *Physiol. Rev.* **53**, 419–495.

Weiner, J. S. & Lourie, J. A. 1969 *Human biology: a guide to field methods.* Oxford: Blackwell.

Woolcock, A. J., Colman, M. H. & Blackburn, C. R. B. 1972 Factors affecting normal values for ventilatory lung function. *Am. Rev. resp. Dis.* **106**, 692–709