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Lung function in coastal and highland New Guineans —comparison with Europeans

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The lung volumes, ventilatory capacity, and transfer factor of young adult male and female New Guineans living at sea level, after standardization for age, height, and, in the case of transfer factor, the haemoglobin concentration, resemble those of people of Indian and West African descent. The inspiratory capacity and expiratory reserve volume are smaller than for comparable Europeans. The highland New Guineans have a larger total lung capacity and transfer factor than the coastal dwellers due mainly to a larger inspiratory capacity. Compared with representative Europeans, the highlanders have a similar total lung capacity but larger transfer factor. The exceptional lung function of the New Guinea highlanders is not closely related to altitude and is probably determined at least in part by their present mode of life entailing a high level of habitual activity. This factor needs to be taken into account when considering ' normal values '.

The total lung capacity and transfer factor (diffusing capacity) for the lung vary with stature but, whereas the transfer factor is apparently independent of ethnic group (Cotes and Hall, 1970), this is not true of the total lung capacity. Europeans in general have the largest lungs, and smaller values for total lung capacity in relation to stature are reported for both the Chinese (Chuan and Chia, 1969) and the inhabitants of the Indian subcontinent (e.g., Cotes and Malhotra, 1965); comparable values might also be expected for New Guineans. However, the lung volumes of New Guinea highlanders living at the relatively low altitude of 1,200 m after allowance for differences in stature resemble those of Europeans (Woolcock *et al.*, 1970). No comparable data have yet been reported for New Guineans at sea level and while the peak flow rate of inhabitants of islands off the mainland is in general less than that of the highlanders no differences related to altitude have been found within each of these groups (Vines, 1970). In the present study the lung function of young adult coastal dwellers and highlanders have been compared directly using identical methods. The data form part of a joint Australian and United Kingdom investigation into the biological status of New Guineans, including the factors which underlie the capacity for exercise. A summary of the findings, including those on exercise, has been given to the 12th Pacific Congress (Cotes *et al.*, 1972a).

SUBJECTS

The subjects were young adult men and women of whom most were drawn from two populations selected for detailed study; first, coastal dwellers from Kaul Village on KarKar Island approximately 10 miles off the mainland of New Guinea and 40 miles north of Madang. The island is tropical with a mean maximum and minimum daily temperature of 30°C and 23°C and an annual rainfall of 300 cm; the village is at 150 m and subsists by horticulture with most of the men cultivating gardens to provide their own needs. In addition, some do casual work on neighbouring plantations or for the local Rural Council. The diet is mainly carbohydrate including taro, paw paw, fruit, and nuts but while the protein intake is low there is no overt malnutrition. Anaemia is common on account of malaria and worm infestations. The villagers who took part in the study were young adults of both sexes who were identified during a preceding demographic and epidemiological survey which also included a clinical examination (R. W. Hornabrook, R. Harvey, and others, in preparation). They were selected on account of apparent good health and willingness to undergo the present and other investigations, including studies of diet, customary activity, environmental heat exposure, and physiological adaptation to heat. Other subjects studied on the coast included European residents and highland labourers working on nearby coconut plantations. These plantation workers, who had been on the coast for up to two years, came from the Minj and adjoining districts in the New Guinea central highlands near to Lufa which was the home of the subjects for the second phase of the study.

The highland dwellers who were assessed constituted a random sample from the 17 or 18 to 30 years age group in the Lufa population. Lufa is at 2,000 m; the terrain is rugged, the mean maximum and minimum daily temperatures are 25·5°C and 14·5°C, and the annual rainfall is 165 cm. Like the Kauls the Lufa are horticulturists but the women do most of the cultivation; they also differ in having a higher level of habitual activity and calorie intake (Durnin, Ferro-Luzzi, and Norgan, 1972). In addition, on account of having wood fires alight in their homes at night, they are exposed to considerable domestic atmospheric pollution (Cleary and Blackburn, 1968).

METHODS

Subjects in groups of three attended by appointment at the laboratory. On KarKar Island, this was at the island's Administration Centre and subjects were brought in by motor vehicle on the morning of the test. In the highlands, the laboratory was at Goroka (altitude 1,700 m) and subjects were brought down from Lufa the previous day. The laboratory temperature on the coast was maintained by air conditioning at 20°C; in the highlands it was on average 22°C, range 19–25°C. Measurements started at 8.0 a.m. and continued into the afternoon; subjects received light refreshment in mid-morning.

Weight was measured to the nearest kilogramme and height and stem height to the nearest centimetre, the latter using a portable Harpenden stadiometer. A respiratory symptom questionnaire modified from that developed by the Medical Research Council[1] was applied, with a view to establishing the presence or absence of persistent cough, wheeze or production of phlegm, undue breathlessness on exertion, and consumption of tobacco in terms of leaves (brus), sticks (muruk) or cigarettes. Subjects were also asked to cough and the presence of a loose cough or sputum production was noted. Haemoglobin-concentration was determined using an EEL spectrophotometer on blood taken from a finger. Forced expiratory volume ($FEV_{1 \cdot 0}$) and forced vital capacity (FVC) were measured using a bellows spirometer fitted with an electronic timer (McDermott, McDermott, and Collins, 1968); the spirometer was calibrated daily using the weight and orifice supplied with the equipment. The observer demonstrated the procedure to the subject who then repeated it as often as was necessary to acquire the technique. Five test breaths were then recorded and the mean was obtained for the last three. Volumes were reported at BTPS. Total lung capacity (TLC) and its subdivisions, including the inspiratory capacity (IC), expiratory reserve volume (ERV), and residual volume (RV), were then measured by closed circuit spirometry using helium as the indicator gas. The transfer factor (TF) and its sub-divisions, the diffusing capacity of the alveolar membrane and volume of blood in the lung capillaries (Dm and Vc respectively), were measured by the single breath carbon monoxide method with a 10-second breath-holding time using the same apparatus (Resparameter) (Meade *et al.*, 1965). A catherometer (Cambridge) was used for helium analysis, a paramagnetic analyser (Servomex OA150) for oxygen, an infrared gas analyser (Grubb Parsons) for carbon monoxide. The calibration of the analysers was confirmed at regular intervals during the study by serial dilution of the test gases. Measurement of lung volumes preceded that for the transfer factor which was itself prefaced by practice attempts using air. Once the technique had been acquired the subject made the measurement in duplicate, using first the test gas mixture with oxygen and secondly that with 'air'. In preliminary studies the initial back tension of carbon monoxide in the subject's blood was estimated by the oxygen rebreathing method and found to be too low materially to influence the result. The transfer factor is the product of alveolar volume during the test breath and transfer coefficient (KCO, i.e., transfer factor per litre of alveolar volume). The alveolar volume was obtained in two ways—first from the residual volume by closed-circuit spirometry plus the volume inspired (designated VA), which yielded TF, and, secondly, from the dilution in the lung of the single breath of test gas (designated VA′) which yielded TF′. For the present subjects the latter yielded the more representative results on account of the subjects not always starting the test inspiration from residual volume. The details of the procedures and calculations are available elsewhere (Cotes, 1968).

One subject was unable to perform the test procedures and 26 were recalled for repeat measurements. Subsequently the data were scrutinized for gross inconsistencies between related indices. This led to the data for 14 subjects being excluded from the analysis on technical grounds. There were also six exclusions on account

[1] Obtainable from W. J. Holman Ltd., Dawlish, Devon, England

of other data being incomplete. Following scrutiny the data were transferred to punch cards for computer analysis, including construction of a cross-correlation matrix and derivation of linear regression equations for indices of lung function on age, height, and weight. These were applied to the basic indices (for example, forced expiratory volume), the derived indices (for example, forced expiratory volume as a percentage of forced vital capacity), and the adjusted indices (in particular, the transfer factor corrected to a haemoglobin concentration of 14·6 g% and alveolar oxygen tension of 110 torr (designated TF,s)). This was done by substituting a value of unity for $\frac{1}{\theta}$ in the equation of Roughton and Forster (1957):

$$\frac{1}{TF,s} = \frac{1}{Dm} + \frac{1}{\theta\ Vc}$$

The need for doing this is discussed elsewhere (Cotes *et al.*, 1972b). A similar adjustment was also made to the Kco (transfer factor per unit alveolar volume, designated Kco,s). In addition, the data for the diffusing capacity of the alveolar membrane and the volume of blood in the lung capillaries were analysed separately using in both cases the reciprocal terms $\frac{1}{Dm}$ and $\frac{1}{Vc}$ which is the form in which these indices are derived.

For comparison of results both within the present study and with those for other subjects including representative Europeans the data were adjusted to the arbitary heights of 1·7 m for men and 1·58 m for women; also, where appropriate, to age 25 years using regression coefficients obtained for Europeans. The validity of using this procedure is considered in the discussion. But it should be noted that, on account of each index being adjusted separately, the standardized values for composite lung volume indices (i.e., TLC,std) differ slightly from the sum of the standardized components (i.e., RV,std+VC,std or its standardized subdivisions). The European data with which comparison was made were, for men, subjects with minimal dust exposure studied during a recent occupational survey (Becklake *et al.*, 1970) and for women a sample drawn from the population of the Vale of Glamorgan (Cotes and Hall, in preparation). In both studies the methods were the same as or very similar to those used in New Guinea. These data were preferred to those for the European men and women studied on KarKar Island because the latter were few in number. In the interpretation of results the 5% level of probability was accepted as significant.

RESULTS

PRIMARY DATA Complete data were obtained for 27 male and 26 female coastal dwellers from Kaul, 27 highlanders working on coastal plantations, and 26 each of highland men and women from Lufa: mean values and ranges are given in Tables I and II. Data were also obtained for 10 European men and seven women living on KarKar Island but these are not reported in detail for the reason given above. The New Guineans were shorter and lighter in weight than is usual for Europeans of the same age. There were only small differences in size between the coastal dwellers and both groups of highlanders. The haemoglobin concentrations of the Lufa highlanders resembled those normally associated with life at sea level despite their living

TABLE I

MEAN VALUES AND RANGES FOR LUNG FUNCTION AND RELATED INDICES FOR YOUNG MEN STUDIED IN NEW GUINEA

		Coastal People	Highlanders on Coastal Plantations	Highlanders
Number		27	27	26
Age	a	24·5 (17–32)	24·6 (19·0–32·0)	24·8 (18–30)
Height	m	1·65 (1·53–1·72)	1·59 (1·48–1·75)	1·62 (1·53–1·70)
Weight	kg	58·3 (50–68·5)	63·3 (51·0–78·0)	59·7 (52·5–70·5)
Haemoglobin concentration	g%	11·0 (7·2–13·5)	11·9 (8·8–14·2)	14·4 (12·6–15·9)
Forced expiratory volume ($FEV_{1.0}$)	l.	3·07 (2·2–4·0)	3·10 (1·8–4·3)	3·44 (2·66–4·26)
Forced vital capacity (FVC)	l.	3·83 (2·9–5·3)	4·01 (2·3–5·0)	4·22 (3·06–4·90)
FEV% (i.e., $FEV_{1.0}\times 100 \div FVC$)	%	80·1 (68·9–88·8)	76·9 (66·8–86·6)	81·5 (69·6–91·4)
Total lung capacity (TLC)	l.	5·15 (4·28–6·90)	5·31 (3·40–6·51)	6·00 (3·73–6·98)
Vital capacity (VC)	l.	3·87 (3·0–5·4)	4·08 (2·19–5·18)	4·45 (2·81–5·30)
Functional residual capacity (FRC)	l.	2·61 (1·87–4·30)	2·59 (1·72–3·79)	3·15 (1·56–4·21)
Residual volume (RV)	l.	1·27 (0·80–1·84)	1·24 (0·82–1·89)	1·54 (0·85–2·19)
RV% (i.e., RV×100÷TLC)	%	24·5 (16·6–31·9)	23·5 (14·5–35·5)	25·7 (15·7–35·1)
RV′/RV	—	1·13 (0·75–1·89)	1·28 (0·87–1·90)	1·27 (0·73–1·80)
VA′/VA	—	0·99 (0·90–1·14)	1·03 (0·91–1·14)	1·04 (0·90–1·16)
Transfer factor (TF)	ml min^{-1} $torr^{-1}$	26·7 (15·1–40·9)	32·2 (17·9–52·1)	36·8 (26·8–44·8)
Transfer coefficient (Kco)	min^{-1} $torr^{-1}$	5·39 (3·1–8·6)	6·47 (3·9–8·9)	6·51 (4·5–8·4)
Diffusing capacity of alveolar membrane (Dm)	ml min^{-1} $torr^{-1}$	55·2 (32·5–109·9)	73·5 (34·2–178·9)	88·5 (32·1–270·3)
Vol. of blood in alveolar capillaries (Vc)	ml	77·5 (35·6–188·7)	78·1 (35·6–185·2)	55·6 (15·2–104·2)
Dm/Vc	ml min^{-1} $torr^{-1}$	0·82 (0·23–1·83)	1·16 (0·33–4·23)	2·08 (0·60–7·98)

VA is alveolar volume; VA′ and RV′ are volumes obtained from the dilution in the lung of a single breath containing helium.

TABLE II

MEAN VALUES AND RANGES FOR LUNG FUNCTION AND RELATED INDICES FOR YOUNG WOMEN STUDIED IN NEW GUINEA

		Coastal People	Highlanders
Number		26	26
Age	a	22·0 (17·0–31·0)	21·7 (17·0–30·0)
Height	m	1·56 (1·45–1·67)	1·52 (1·35–1·60)
Weight	kg	52·4 (45·5–62·5)	52·4 (42·0–62·0)
Haemoglobin concentration	g%	9·9 (8·5–11·8)	13·2 (10·0–14·3)
Forced expiratory volume ($FEV_{1.0}$)	l.	2·33 (1·70–2·93)	2·55 (2·03–3·16)
Forced vital capacity (FVC)	l.	2·86 (2·00–3·70)	3·12 (2·43–4·00)
FEV% (i.e., $FEV_{1.0} \times 100 \div FVC$)	%	81·8 (48·6–90·4)	82·1 (69·4–92·3)
Total lung capacity (TLC)	l.	3·91 (3·05–4·48)	4·27 (3·42–5·44)
Vital capacity (VC)	l.	2·88 (2·29–3·49)	3·25 (2·63–4·09)
Functional residual capacity (FRC)	l.	2·11 (1·52–2·85)	2·15 (1·42–3·86)
Residual volume (RV)	l.	1·04 (0·59–1·57)	1·02 (0·63–1·78)
RV% (i.e., $RV \times 100 \div TLC$)	%	26·3 (16·5–38·0)	23·6 (15·6–32·7)
RV′/RV	—	1·13 (0·56–1·82)	1·44 (0·82–2·29)
VA′/VA	—	0·98 (0·80–1·17)	1·07 (0·92–1·26)
Transfer factor (TF)	ml min^{-1} $torr^{-1}$	22·8 (14·6–30·0)	27·8 (22·4–35·3)
Transfer coefficient (Kco)	min^{-1} $torr^{-1}$	6·04 (4·4–8·0)	6·94 (5·1–8·8)
Diffusing capacity of alveolar membrane (Dm)	ml min^{-1} $torr^{-1}$	42·4 (24·8–90·1)	61·7 (39·2–263·2)
Vol. of blood in alveolar capillaries (Vc)	ml	83·3 (39·7–370·4)	54·6 (27·7–89·3)
Dm/Vc	ml min^{-1} $torr^{-1}$	0·60 (0·07–1·58)	1·58 (0·55–6·93)

VA is alveolar volume; VA′ and RV′ are volumes obtained from the dilution in the lung of a single breath containing helium.

at medium altitude but were higher than those obtained for the coastal men and women and the plantation workers. In the absence of any allowance for differences in body size the lung volumes of the New Guineans were smaller than is usual for Europeans of this age but no differences were observed for effectiveness of use of the lung volumes as assessed by the ratio indices FEV% (of vital capacity) and RV% (of total lung capacity). The data for the transfer factor did not show consistent differences between the groups but the transfer factor per unit lung volume (Kco) and the ratio of the diffusing capacity of the alveolar membrane to the volume of blood in the lung capillaries (Dm/Vc) were apparently greater in highlanders and highland plantation workers than in the other subjects.

Respiratory symptoms including cough, phlegm or wheeze were absent among the coastal people, while one or more symptoms were present in seven men and 11 women from Lufa and in three of the plantation workers. The symptoms tended to occur together and, in the highlanders, after allowing for differences in height between the groups, were associated with slightly lower values for the vital capacity and forced expiratory volume; however, the average difference of 4·7% was not significantly different from zero. For the other indices the mean values obtained in subjects with and without symptoms were virtually identical. In the New Guineans, unlike the small group of Europeans studied on KarKar Island, no association was observed between a history of smoking and either the occurrence of cough and phlegm or any impairment of lung function. Few of the New Guinea subjects smoked western style tobacco.

The effect of age on the indices of lung function after allowing for differences in body size was insignificant except for the transfer factor in the coastal women and residual volume in the highland men and women, among whom weak negative correlations were observed ($r \triangleq -0{\cdot}40$).

DATA STANDARDIZED FOR STATURE AND HAEMOGLOBIN CONCENTRATION Stature was positively correlated with vital capacity and/or related indices of lung size in all groups except the highland men among whom lung size was positively correlated with body weight. Transfer factor was positively correlated with height in the coastal men and the plantation workers but not in the other groups. Mean data for the groups of New Guineans adjusted to both a common height and in the case of indices of gas transfer a standard haemoglobin concentration (see METHODS) are given in Tables III and IV. The Tables also contain values for the representative European subjects referred to above. The results of comparisons between the groups are shown in Figs. 1 to 6 by histograms and tables[1] in which for each index the groups are placed in their rank order and significant differences are indicated by a break in the lines beneath the symbols.

For the coastal dwellers, both men and women, the total lung capacity and the forced expiratory volume after standardizing for height were smaller than in the highlanders and the Europeans. The difference was mainly due to the

[1] The histograms for subdivisions of total lung capacity (Figs. 1 and 2) have been constructed using the standardized values for RV, IC, and TLC. On account of the method used for standardizing to a common height (see Methods), the expiratory reserve volume is indicated only approximately.

TABLE III

MEAN VALUES AND STANDARD DEVIATIONS FOR INDICES OF LUNG FUNCTION STANDARDIZED TO HEIGHT 1·70 M IN YOUNG MEN STUDIED IN NEW GUINEA AND ALSO REPRESENTATIVE VALUES FOR EUROPEAN MEN OF THE SAME HEIGHT AND AGE[1]

		Coastal People		Highlanders on Coastal Plantations		Highlanders		Europeans	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Forced expiratory volume ($FEV_{1\cdot 0}$)	l.	3·26	0·44	3·48	0·42	3·74	0·34	4·06	0·50
Forced vital capacity (FVC)	l.	4·10	0·49	4·57	0·43	4·66	0·49	4·83	0·54
FEV% (i.e., $FEV_{1\cdot 0} \times 100 \div FVC$)	%	80·1	5·64	76·9	4·94	81·5	5·06	83·8	7·3
Total lung capacity (TLC)	l.	5·61	0·62	6·23	0·57	6·74	0·77	6·27	0·75
Vital capacity (VC)	l.	4·16	0·47	4·63	0·47	4·89	0·52	4·83	0·54
Inspiratory capacity (IC)	l.	2·78	0·39	2·99	0·39	3·14	0·39	3·20	0·47
Functional residual capacity (FRC)	l.	2·65	0·54	3·14	0·48	3·43	0·68	2·98	0·56
Expiratory reserve volume (ERV)	l.	1·41	0·41	1·70	0·34	1·81	0·44	1·64	0·38
Residual volume (RV)	l.	1·41	0·27	1·53	0·34	1·77	0·40	1·46	0·47
RV% (i.e., $RV \times 100 \div TLC$)	%	24·5	3·85	23·5	5·01	25·7	4·43	23·3	5·4
Transfer factor (TF, s)[2]	ml min^{-1} $torr^{-1}$	35·6	6·50	44·4	10·6	39·5	5·65	35·0	5·9
(TF′, s)[2]	ml min^{-1} $torr^{-1}$	35·0	7·13	43·1	8·61	41·7	5·08		
Transfer coefficient (Kco, s)[2]	min^{-1} $torr^{-1}$	6·86	1·41	8·17	1·79	6·67	1·49	6·23	0·91

[1] For details see Methods. The results of the statistical analysis of these data are given in the text and in Figs 1, 3, and 5.
[2] Data adjusted to a haemoglobin concentration of 14·6 g%.

TABLE IV

MEAN VALUES AND STANDARD DEVIATIONS FOR INDICES OF LUNG FUNCTION STANDARDIZED FOR HEIGHT 1·58 M IN YOUNG WOMEN STUDIED IN NEW GUINEA AND ALSO REPRESENTATIVE VALUES FOR EUROPEAN WOMEN OF THE SAME AGE AND HEIGHT[1]

		Coastal People		Highlanders		Europeans	
		Mean	SD	Mean	SD	Mean	SD
Forced expiratory volume ($FEV_{1\cdot 0}$)	l.	2·41	0·37	2·77	0·29	3·11	0·35
Forced vital capacity (FVC)	l.	2·99	0·35	3·45	0·37	3·75	0·46
FEV% (i.e., $FEV_{1\cdot 0} \times 100 \div FVC$)	%	81·8	8·74	82·1	6·03	83·2	5·00
Total lung capacity (TLC)	l.	4·12	0·55	4·82	0·57	4·97	0·53
Vital capacity (VC)	l.	3·00	0·31	3·58	0·35	4·01	0·49
Inspiratory capacity (IC)	l.	1·88	0·26	2·34	0·44	2·25	0·43
Functional residual capacity (FRC)	l.	2·14	0·47	2·42	0·52	2·82	0·35
Expiratory reserve volume (ERV)	l.	1·13	0·28	1·29	0·38	1·56	0·31
Residual volume (RV)	l.	1·10	0·33	1·19	0·27	1·24	0·24
RV% (i.e., $RV \times 100 \div TLC$)	%	26·3	5·72	23·6	3·79	23·4	5·20
Transfer factor (TF, s)[2]	ml min^{-1} $torr^{-1}$	29·4	5·14	31·0	5·18	28·9	4·93
(TF′, s)[2]	ml min^{-1} $torr^{-1}$	28·7	5·42	32·8	5·07	28·2	4·90
Transfer coefficient (Kco, s)[2]	min^{-1} $torr^{-1}$	7·63	1·16	7·43	1·12	5·99	0·72

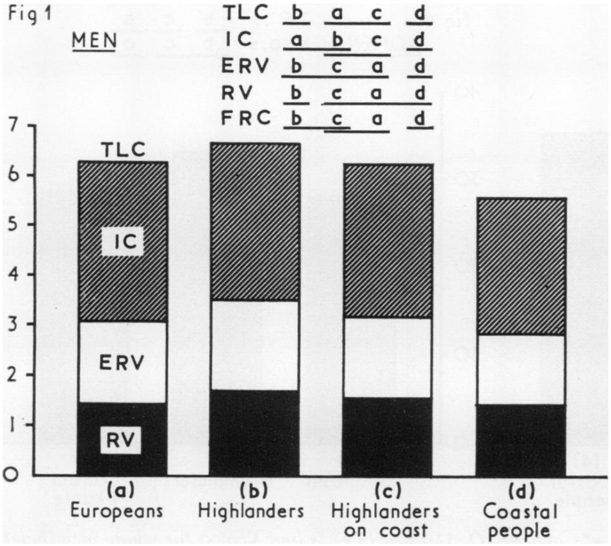
[1] For details see Methods. The results of the statistical analysis of these data are given in the text and in Figs 2, 4, and 6.
[2] Data adjusted to a haemoglobin concentration of 14·6 g%.

coastal dwellers having a smaller inspiratory capacity; the expiratory reserve volume was also smaller in the coastal dwellers than in most other groups of subjects. For the highland women and male plantation workers compared with the Europeans the total lung capacity and its subdivisions were in general similar. For the highland men compared with the Europeans the total lung capacity was increased mainly on account of the residual volume being larger. The ratio of the residual volume to the total lung capacity was similar for all groups of subjects. The forced expiratory volume of the highlanders was less than that of the Europeans but the ratio of the forced expiratory volume to the forced vital capacity was similar in all groups.

The transfer factor (TF′s, std) of both men and women was larger in the highlanders than in the coastal dwellers whose values were similar to those of the Europeans (Figs. 5 and 6). The transfer coefficient standardized for haemoglobin concentration (Kco,s) was higher in the New Guineans than in the Europeans.

Concerning the subdivisions of the transfer factor, the diffusing capacity of the alveolar membrane both in absolute units (**Dm′, std**) and as a ratio to the volume of blood in the alveolar capillaries (Dm′/Vc′) was significantly higher in the highlanders than in the other subject groups. The volume of blood in the lung capillaries (Vc′, std) among the men was larger for the plantation workers than for the other groups. Among the women, the coastal dwellers had larger capillary blood volumes than the Europeans and highlanders.

As between men and women, after allowing for differences in height and, in the case of the trans-



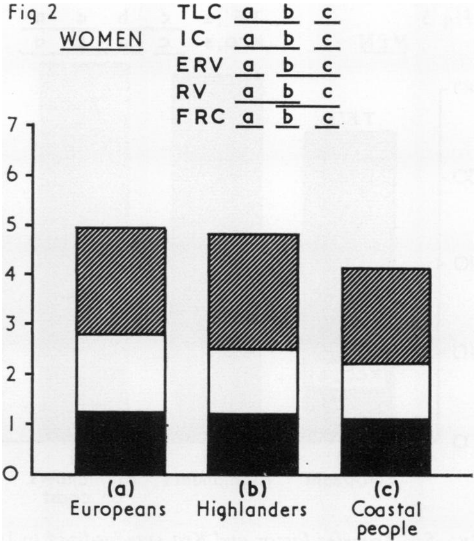
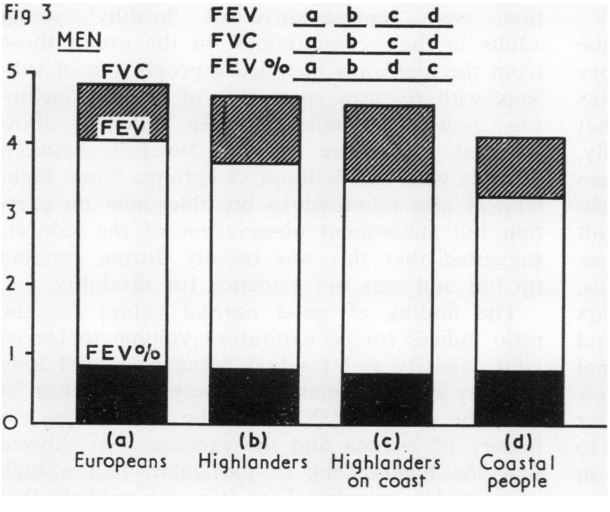


FIG. 1. *Total lung capacity and subdivisions for young men (height 1·7 m) in New Guinea, also representative Europeans.*
FIG. 2. *Total lung capacity and subdivisions for young women (age 25 a, height 1·58 m) in New Guinea and UK.*



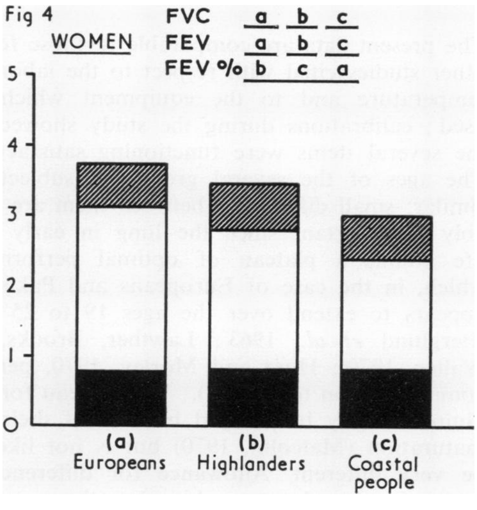
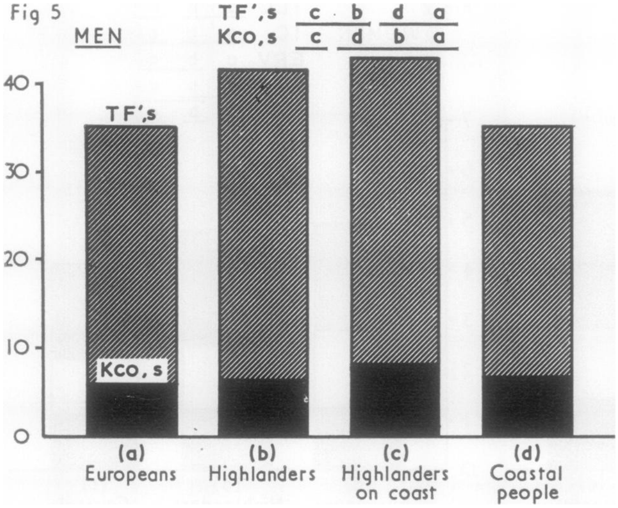


FIG. 3. *Forced expiratory volume ($FEV_{1\cdot0}$), forced vital capacity (FVC), and FEV × 100 ÷ FVC (FEV%) for young men (height 1·7 m) in New Guinea, also representative Europeans.*
FIG. 4. *Forced expiratory volume ($FEV_{1\cdot0}$), forced vital capacity (FVC), and FEV × 100 ÷ (FEV%) for young women (age 25 a, height 1·58 m) in New Guinea and UK.*

fer factor, the haemoglobin concentration (TF's), the men of all subject groups had a larger total lung capacity, vital capacity, inspiratory capacity, and transfer factor than their women folk. By contrast, the Kco,s was larger in the women than in the men, while similar values across the sexes obtained for functional residual capacity and expiratory reserve volume in all groups and for residual volume in the Europeans and the coastal dwellers.



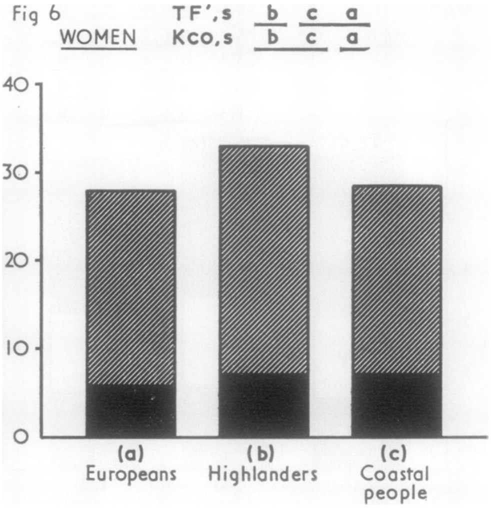


FIG. 5. *Transfer factor and Kco standardized to* 14·6 *g% and* $P\bar{c}$, O_2 110 *torr* (*TF′, s and Kco, s*) *for young men* (*height* 1·7 *m*) *in New Guinea, also representative Europeans.*

FIG. 6. *Transfer factor and Kco, standardized to Hb* 14·6 *g% and* $P\bar{c}$, O_2 110 *torr* (*TF′, s and Kco, s*) *for young women* (*age* 25 *a, height* 1·58 *m*) *in New Guinea and UK.*

DISCUSSION

The present data are comparable to those for the other studies cited with respect to the laboratory temperature and to the equipment which was used ; calibrations during the study showed that the several items were functioning satisfactorily. The ages of the several groups of subjects are similar; small differences between them are probably unimportant since the lung in early adult life attains a plateau of optimal performance which, in the case of Europeans and Pakistanis, appears to extend over the ages 19 to 25 years (Berglund *et al.*, 1963 ; Lawther, Brooks, and Waller, 1970 ; Hunt and Morley, 1970, personal communication to J. E. C.). The plateau for New Guineans may be delayed because of their later maturation (Malcolm, 1970) but is not likely to be very different. Allowance for differences in body size has been made using the regression coefficients on height obtained for Europeans. These have been established with greater reliability than for New Guineans but in the case of the forced expiratory volume and vital capacity the two are very similar as they also are for Malaysian aboriginals (Anderson *et al.*, in preparation ; Dugdale, Bolton, and Ganendran, 1971) ; by analogy with data for subjects of African and East Indian origin (Miller *et al.*, 1972) the similarity is also likely to apply to the other indices.

The subjects, because of the method of selection, were representative of 'healthy' young adults in their communities. In the event, those from the highlands included a proportion of subjects with features suggestive of mild bronchiolitis; however, detailed analysis failed to show material differences in lung function between subjects with and without symptoms. Some highlanders also admitted to breathlessness on exertion but subsequent observation of the subjects suggested that this was usually during running up hill and was not evidence for disability.

The finding of good normal values for the ratio indices forced expiratory volume to forced vital capacity and residual volume to total lung capacity excluded material airways obstruction at the time of study. None of the subjects gave a history of asthma and the exercise tests showed that the highlanders, in particular, had a high capacity for exercise. Thus it seems unlikely that the results were influenced by the presence of lung disease. The presence of iron deficiency anaemia was allowed for in calculating the standardized value for the transfer factor and the Kco. In other respects anaemia is unlikely to have influenced the result.

The results for the coastal dwellers compared with Europeans of the same age and height show a similar transfer factor but a smaller total lung capacity. The latter is due to the coastal New Guineans having smaller inspiratory capacities and expiratory reserve volumes. This picture is similar to that observed for people of Indian and African descent, who also have a similar transfer factor to Europeans but smaller total lung capacity (e.g., Miller *et al.*, 1972). Thus the difference in lung function between the coastal dwellers and Europeans is probably ethnic in origin.

The New Guinea highlanders have larger total lung capacities and larger transfer factors compared with the coastal dwellers. They also have a somewhat different genetic contribution (e.g. Beaven, Hornabrook, Fox, and Huehns, 1972). However, the genetic differences are probably in the direction of variation in the proportions of genes from other population groups within the eastern hemisphere among whom the lung size is in general less than in Europeans. In addition, the occurrence of a large transfer factor cannot readily be explained on ethnic grounds since this index has not exhibited ethnic variation in other population studies. Thus while the differences in lung size and in transfer factor between the coastal and highland New Guineans may be of genetic origin this seems unlikely.

The difference in lung size between the New Guineans is due less to the variation in the residual volume and in the expiratory reserve volume than in the inspiratory capacity which, compared with other subdivisions of the total lung capacity, is more susceptible to variations in the strength of the respiratory muscles including the accessory muscles. The muscle strength was not measured in the present study but it might be expected to be greater in the highlanders than in the coastal dwellers since the former live at medium altitude and also have a greater capacity for exercise. Thus the exceptional lung function of the New Guinea highlanders compared with others in the eastern hemisphere may well be of environmental origin.

Life at high altitude entails exposure to hypoxia, which probably increases the strength of the respiratory muscles through increasing the proportion of the maximal breathing capacity which is used on exercise. In fact, the lung volume of populations at high altitude is usually increased compared with those at sea level (e.g., DeGraff *et al.*, 1970; Harrison *et al.*, 1969; Cotes and Ward, 1966); however, an increase is not invariable. The increase in lung size of the New Guinea highlanders obtains for both the present subjects living at 2,000 m and those of Woolcock and Blackburn at 1,200 m (Woolcock, Colman, and Blackburn, 1972). These altitudes are at or below those at which in other parts of the world the lung volumes of resident Europeans are at sea level values (e.g., Goldman and Becklake, 1959). Thus the stimulus to lung expansion may not be altitude *per se* but rather altitude, habitual activity, and possibly other factors acting together to increase the stimulus to ventilation. The experimental studies of Weibel and his co-workers point to a similar conclusion (Weibel, 1972).

The New Guinea highlanders compared with the coastal people have a higher level of habitual activity (Durnin *et al.*, 1972). In this respect, their physiological response to exercise resembles that of athletes in western countries (Sinnett and Solomon, 1968; Cotes *et al.*, 1972c), while the coastal people resemble non-athletic members of the UK population (Patrick, Kay, Saunders, and Cotes, in preparation). The main factor contributing to these differences in lung size is probably the respective levels of habitual activity which is obtained during childhood and adolescence. If this is so, the VC,std should correlate with habitual activity which, in turn, should reflect the extent to which the exercise cardiac frequency (after allowance for body muscle) deviates from the expected value (Cotes *et al.*, 1973). This proves to be the case for the female New Guineans among whom a significant relationship for the coastal dwellers also applies to the mean data for the highlanders (Fig. 7). There is no similar relationship for the men (Patrick *et al.*, in preparation). In addition, the hypothesis suggests that lung volume should be diminished in those members of the next generation of the highlanders

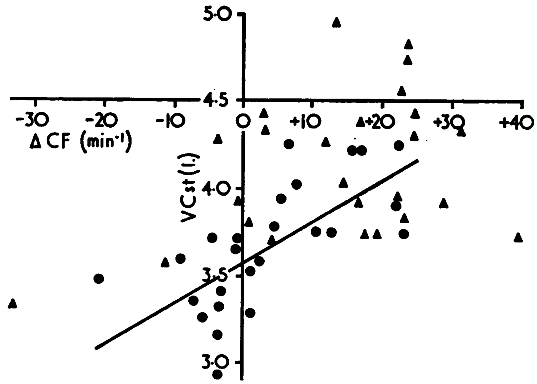


FIG. 7. *Data for vital capacity at height 1·58 m (Vc, st) and an index of physical activity (exercise cardiac frequency predicted from body muscle minus frequency observed, △ CF) in coastal and highland women (● and ▲ respectively); the regression line for the coastal women also describes the data for the highlanders.*

who adopt a western style of living; this aspect is now being investigated. Meanwhile the picture which emerges is of a basic similarity in lung size between the highlanders and the coastal people on which is superimposed an acquired difference due to the environment. On this basis the New Guineans resemble in their lung size the Indians, African Negroes, Malayans, and Chinese rather than the Europeans, compared with whom the apparent similarity of the New Guinea highlanders is an acquired phenomenon due to environmental factors.

In the present study the ventilatory capacity was assessed in terms of the forced expiratory volume ($FEV_{1\cdot 0}$) which is mainly dependent on vital capacity. Physical training increases the vital capacity but it exerts a less direct effect upon the ventilatory capacity which is mainly determined by intrapulmonary factors (Stuart and Collings, 1959; Shapiro and Patterson, 1962). Thus our finding that the ventilatory capacity of the highlanders is intermediate between that of the coastal people and the Europeans is consistent with the hypothesis that the respective levels of habitual activity contribute to the differences between the groups. In this our results differ in detail from those of Woolcock and her colleagues (Woolcock and Blackburn, 1967; Woolcock *et al.*, 1970) who observed that the peak expiratory flow rates and forced expiratory volumes of New Guinea highlanders were similar to those of Europeans. For the forced expiratory volume this difference may reflect the selection of subjects for the respective studies. In the case of the peak expiratory flow rate, the difference may be due to the fact that this index in healthy subjects is determined mainly by factors related to inspiratory capacity, which is similar for the highlanders and the Europeans, whereas the FEV is influenced also by the expiratory reserve volume. Among New Guineans the absence of any significant effect upon the FEV of smoking native tobacco is not unexpected since this is also a feature of other studies (Vines, 1970; Anderson *et al.*, in preparation).

The finding of higher values for the transfer factor (TF's, std) among highlanders than among coastal people (who have values similar to those of Europeans) is consistent for both sexes. This difference is due to the highlanders having larger lungs; the transfer coefficients (Kco, s) for the two groups were similar. By contrast, the identity between coastal people and Europeans is due to the smaller lungs of the former being compensated for by higher values for Kco, s. In this they resemble subjects of average habitual activity of Indian and West African origin among whom the transfer factor (after adjustment for age, height, and haemoglobin concentration) is in most instances similar to that usually found for Europeans and the other ethnic groups for whom results are available (Cotes and Malhotra, 1965; Miller *et al.*, 1972; Hunt, 1968). Direct comparison of the data for coastal New Guineans and Jamaicans of African descent showed similar transfer factors (TF's, std) for men but among the women the New Guineans had the higher values. However, the Jamaican women had a higher cardiac frequency relative to body muscle during submaximal exercise so it seems likely that their lower transfer factor was associated with taking less exercise.

These findings show that compared with the New Guinea coastal dwellers the men and women in the highlands as well as having a large lung volume also have a large transfer factor. The differences are of similar magnitude to those observed in other parts of the world for subjects living at altitudes of 3,000 m compared with sea level (DeGraff *et al.*, 1970; Guleria, Pande, Sethi, and Roy, 1971; Remmers and Mithoefer, 1969) but in the present instance for the reasons cited above altitude *per se* does not seem to be a sufficient explanation. The larger transfer factor of the New Guinea highlanders compared with the coastal dwellers, like the larger lung volume, may alternatively be due to greater habitual activity which by itself can produce changes of similar magnitude (e.g., Cotes *et al.*, 1971). The effect is more marked when the exercise is taken during childhood (Andrew, Becklake, Guleria, and Bates, 1972) than during adult life (Reuschlein *et al.*, 1968).

The high transfer factor in the highlanders is associated with a 'normal' volume of blood in the lung capillaries but a significantly increased diffusing capacity of the alveolar membrane. The latter may be due to attenuation and increase in area of the lung membrane consequent upon the increase in total lung capacity. This is the converse of the finding for men from India who, compared with Europeans, have a lower value for Dm, std in association with a smaller TLC, std (Cotes and Malhotra, 1965). In the Indian study the transfer factor resembled that of representative Europeans because the low Dm, std was compensated for by an increase in Vc, std. Similar features might therefore have been expected for the New Guinea coastal dwellers but while for both men and women the average Dm, std was lower than in the other groups the difference was not significant. Vc, std in the coastal people compared with the other groups is significantly increased for women but not men. Thus the changes are in the expected direction but they are rather variable. This may reflect variation in blood volume from other causes including interaction between habitual activity and ambient temperature which is high on KarKar Island; the high Vc, std of the plantation workers may be explained on this basis.

In conclusion our results suggest that the lung volumes and gas transfer capability of the coastal New Guineans is similar to that of other ethnic groups, who, compared with Europeans, have smaller lungs but similar transfer factors. The enhanced lung volumes and transfer factor of the New Guinea highlanders compared with coastal people may be of genetic origin but it is more probably determined by environmental factors. We suggest that the most important determinant is the high level of habitual activity which is made possible by the climate at high altitude and is also dictated by the requirements for subsistence farming in a mountainous terrain. These conditions are now changing rapidly and the lung function of future generations is likely to be affected in consequence. Meanwhile the findings may have application in other communities where the level of habitual activity is different from that in the western culture to which most of our present measurements apply.

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