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A study of temperature regulation in New Guinea people

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Body-temperature regulation has been studied in two communities in New Guinea. On Karkar Island in the hotter coastal region, 40 young adult males and the same number of young female villagers, together with 39 plantation workers and 14 Europeans, were examined. At Lufa, near Goroka, in the cooler and drier highlands, 30 male and 25 female adult villagers, together with 36 older people, were investigated. Temperature regulation was studied using an air-conditioned bed in which the subjects received standardized exposures to cool and warm environments and the sweating response was measured during controlled hyperthermia at 38 °C.

The results did not reveal any important difference in response between the coastal villagers and the highland people. The Europeans living on Karkar Island had the high sweating capacity which is characteristic of the acclimatized European, whereas the sweat rates of the New Guinea people were closely comparable to the level for an unacclimatized European. Comparison of the two sexes showed the lower sweat rates and the pattern of deep body and skin temperature changes found in women in previous studies using this technique. The changes in deep body temperature, skin temperature, blood flow and heart rate during the successive periods of exposure to a thermally neutral climate, with cooling and during rewarming, do not indicate that the indigenes of New Guinea utilize the vasomotor control mechanism more efficiently than Europeans.

Introduction

A study of the physiology of temperature regulation and the degree of exposure to heat stress in New Guinea people following their traditional pattern of life formed one aspect of the joint United Kingdom/Australian multidisciplinary study in the Human Adaptability Section of the International Biological Programme. Although there have been several investigations of heat and cold tolerance in the Australian Aborigine and in other primitive societies living in hot climates, the New Guinea people had not been previously studied.

Because of the apparently substantial differences in the mode of life and environment of people living in the highlands as compared with the coastal areas, it was considered desirable to study groups representative of these two areas. The final choice of locations also reflected a compromise between the desire to investigate people following the traditional pattern of life, as untouched as possible by western influence, with the need for reasonable accessibility. The two sites chosen were Kaul village on Karkar Island, as representing the hotter and more humid coastal region, and Lufa village near Goroka, in the cooler and drier highlands.

The thermal physiology programme was in two parts: (*a*) field studies to assess the degree of thermal stress the villagers are exposed to during the course of their normal daily pattern of work and leisure, (*b*) laboratory studies designed to measure the response of the thermoregulatory system to a standardized test involving exposure to both cold and heat stress.

In the present paper we are concerned with the results of the laboratory tests which took place on Karkar Island late in 1969 and at Goroka in the highlands in 1970.

The principal aims were: (1) to compare thermoregulatory function in representative samples of young adult male and female villagers in the two communities; (2) to study the differences in temperature regulation between the two sexes in New Guinea; and (3) to compare the results with those obtained using the same test procedures on Europeans.

Table 1. The physical characteristics of the groups of villagers, plantation workers and Europeans tested on Karkar Island, the villagers tested at Goroka, and control groups of male and female unacclimatized Europeans

Mean values and standard deviations are given for each group.

	no.	age / years	height / cm	mass / kg	duBois s.a. / m^2	subscap. skinfold thickness / mm
			male groups			
Kaul	39	25.0 ± 4.8	162.7 ± 5.7	56.9 ± 5.0	1.60 ± 0.09	8.46 ± 1.54
Lufa	30	25.1 ± 3.9	162.3 ± 4.2	59.4 ± 4.2	1.63 ± 0.06	9.02 ± 1.27
high plantation	20	25·5 ± 1.7	160.0 ± 4.2	62.1 ± 4.8	1.64 ± 0.08	8.90 ± 3.92
low plantation	14	26.3 ± 4.8	161.0 ± 3.3	55·4 ± 4.9	1.57 ± 0.08	9.76 ± 1.35
old Lufa	11	49.5 ± 4.3	156.4 ± 4.1	52.8 ± 5.4	1.51 ± 0.09	9.92 ± 2.27
European Karkar	14	30.7 ± 6.7	178.0 ± 5.6	68.9 ± 8.3	1.86 ± 0.13	9.92 ± 2.29
European controls	14	24.2 ± 2.8	173.0 ± 5.9	69.2 ± 7.8	1.82 ± 0.12	—
			female groups			
Kaul	34	22.4 ± 4.7	154.7 ± 5.5	50.8 ± 5.3	1.47 ± 0.09	13.54 ± 3.43
Lufa	25	22.1 ± 4.3	152.6 ± 5.9	52.4 ± 5.0	1.48 ± 0.09	14.84 ± 6.05
old Lufa	8	44.7 ± 3.4	153.4 ± 5.2	47.2 ± 4.8	1.43 ± 0.09	9.11 ± 1.55
European controls	17	25.8 ± 6.8	165.1 ± 8.3	61.9 ± 6.8	1.68 ± 0.11	—

Methods

Subjects

The physical characteristics of the subjects in the various groups studied on Karkar Island and at Goroka in the highlands are set out in table 1.

In the Karkar study, 40 males and an equal number of young adult females from Kaul village took part in the tests, and in addition there were two smaller groups of subjects drawn from the plantation workers, some of whom had been recruited from lowland areas of New Guinea (low plantation workers) and others who had come from the highlands (high plantation workers). A group of Europeans living on the Island were also tested.

In the highland study, 30 male and 25 female young adult villagers took part and in addition there were groups of older men and women.

The physical characteristics of the villagers from Karkar and Lufa were closely comparable, but the Europeans were somewhat taller and heavier.

Tests on the plantation workers were included because it was considered of interest to determine whether there was any physiological evidence that acting as hired labour in the plantation involved adapting to a greater degree of thermal stress than the normal pattern of village life. For similar reasons, it was decided to test groups of the less active older people at Lufa.

For comparison with the subjects tested in New Guinea, measurements on unacclimatized European males and females are also included.

Thermoregulatory function test

The equipment and the basic thermoregulatory function test procedure are described in detail in I.B.P. Handbook No. 9 (Weiner & Lourie 1969). Briefly, the equipment consists of a specially designed air-conditioned bed in which the air flow from a blower can be partitioned between hot and cold heat-exchangers so as to maintain any required temperature between 15 and 55 °C. The air flow is distributed over the whole of the subject's body, except the head, by wrapping a double layered plastic sheet, formed into ducts with holes on the inner surface, around the subject lying on the bed. Deep body temperature is monitored from both ears using thermistor thermometers with the ears and head will insulated from the external air temperature. Mean skin temperature from eight body sites is measured with thermistor thermometers attached to the sweat collecting suit. To measure the rate of sweating, the subject is dressed in a thin plastic suit which seals at the neck and from which the sweat is withdrawn under negative pressure, measured, and samples taken for subsequent biochemical analysis. Peripheral blood flow is recorded from one hand using a venous occlusion plethysmograph with the water maintained at 32 °C. Automatic venous occlusion at the wrist was provided by a cuff inflating unit cycling once every 15 s, with 5 s on and 10 s off to give four inflow records each minute. A photoelectric pulsimeter was attached to the thumb of the opposite hand to record heart rate and also to indicate bursts of vasoconstrictor activity which can affect the blood-flow measurements.

Experimental procedures

For the physiological studies on Karkar Island, a temporary laboratory was constructed at the Island's Government Station at Miak Village. It consisted of three intercommunicating rooms and was equipped with air-conditioners. A portable generator was installed to provide electric power. The subjects were transported between Kaul Village and the laboratory at Miak by car. With the equipment available, two subjects could be tested simultaneously and initially a pair of subjects were tested in the morning (a.m.) and another pair in the afternoon (p.m.). Once the routine had become well established, it frequently proved possible to test two pairs of subjects in the afternoon. It had been anticipated that there might be a serious problem in getting a sufficient number of villagers to volunteer for the tests. However, by spending much time and care explaining how the equipment worked and exactly what the experiment involved, it proved possible to persuade volunteers to come forward. The presentation to each subject of a specially designed I.B.P. badge, and a polaroid picture of the individual dressed in the suit, also helped to attract volunteers.

Following the thorough briefing and explanation of the test procedures, the subjects' heights, weights and hand volumes were recorded. Skinfold thicknesses were measured at two sites (subscapular and mid-lateral surface upper arm) using Harpenden skinfold calipers. They then voided urine, were fitted with the ear-thermistors, dressed in the plastic suits and took their places on the beds.

Thermoregulatory function test routine

The function test is designed to measure the superficial and deep body temperatures, heart rate and blood flow, on exposure to a thermally neutral environment, and the changes produced by a 30 min exposure to cooling conditions, with the air temperature to the bed at 15 °C. The bed air temperature is then raised to 45 °C to warm the subject to sweat onset, which is detected by starch iodine papers applied to the forehead for 30 s in every 2 min. Finally, the body temperature is rapidly raised to 38 °C and then held at this level for 30 min while the sweat rate is measured. The experimental routine is illustrated in figure 1.

Results

The results are set out in tables giving the means and standard errors for seven of the nine main groups with the comparison of old and young adults in Lufa treated separately. Subjects with a deep body temperature of 37.5 °C or more at the end of the neutral stage or showing other evidence of a fever were excluded (table 1).

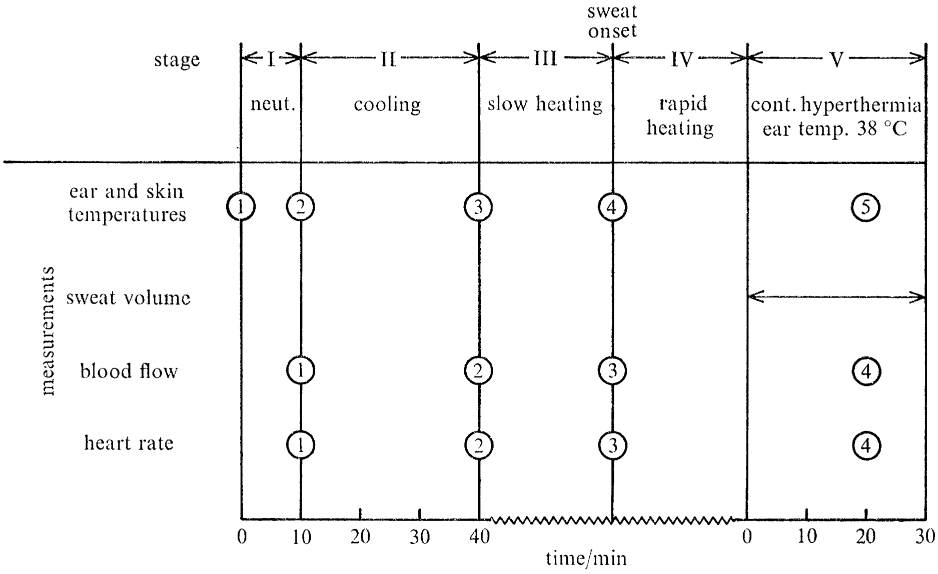

Figure 1. The thermoregulatory function test experimental routine.

Body temperatures

Comparison of deep body temperatures between ethnic groups

The mean results with standard errors for deep body temperatures of the nine groups measured at the end of the neutral and cooling stages and at sweat onset are given in table 2. Because of the effect of diurnal rhythm, the morning and afternoon experiments were analysed separately. There were no significant differences between the male adult villagers, the plantation workers or Europeans, except at the end of the neutral stage in the afternoon experiments, where the Kaul villagers, and to a lesser extent the low plantation workers, had the higher body temperatures.

There were no significant differences between the Kaul and Lufa female villagers in the morning experiments, although the Kaul females tended to have the higher temperatures (see table 2) and this difference was significant ($P < 0.05$) for the first two stages of the afternoon tests. Compared with the unacclimatized European controls tested in the afternoon, the New Guinea villagers had a significantly lower ($P < 0.05$) sweat onset threshold.

Comparison of skin temperatures between ethnic groups

Skin temperatures were analysed in the same way as deep body temperatures and the means with their standard errors for the four stages of the test are set out for males and females separately in table 3. There were no significant differences between the groups of male New

Table 2. The mean deep body temperatures (°C) ± s.e. for the various young adult groups recorded at the end of the neutral stage, end of cooling and at sweat onset, shown separately for morning and afternoon tests

	female			male					
	European unacclimatized control	Kaul	Lufa	European unacclimatized control	European Karkar	Kaul	Lufa	high plantation	low plantation
morning									
number of subjects	—	18	12	6	—	22	14	2	6
end of neutral stage	—	37.07 ± 0.05	36.99 ± 0.04	36.69 ± 0.06	—	36.92 ± 0.06	36.75 ± 0.05	36.55 ± 0.35	36.94 ± 0.12
end of cooling	—	37.06 ± 0.05	36.97 ± 0.04	36.69 ± 0.06	—	36.87 ± 0.06	36.73 ± 0.04	36.51 ± 0.32	36.99 ± 0.13
sweat onset	—	37.02 ± 0.03	36.95 ± 0.03	36.60 ± 0.02	—	36.70 ± 0.07	36.77 ± 0.06	36.47 ± 0.23	36.80 ± 0.12
afternoon									
number of subjects	17	16	13	8	14	17	16	18	8
end of neutral stage	37.16 ± 0.05	37.26 ± 0.03	37.05 ± 0.08	36.97 ± 0.06	36.87 ± 0.07	37.16 ± 0.06	36.96 ± 0.04	36.89 ± 0.07	37.09 ± 0.08
end of cooling	37.26 ± 0.06	37.31 ± 0.03	37.01 ± 0.07	36.91 ± 0.07	36.85 ± 0.07	37.05 ± 0.06	36.93 ± 0.04	36.91 ± 0.06	37.08 ± 0.09
sweat onset	37.26 ± 0.08	37.09 ± 0.04	37.01 ± 0.04	36.91 ± 0.06	36.85 ± 0.08	36.85 ± 0.06	36.95 ± 0.04	36.73 ± 0.06	36.91 ± 0.07

Table 3. The mean skin temperatures (°C) ± s.e. for the various young adult groups recorded at the end of the neutral stage, end of cooling, at sweat onset, and during controlled hyperthermia

Morning and afternoon experiments are shown separately.

	female			male					
	European unacclimatized control	Kaul	Lufa	European unacclimatized control	European Karkar	Kaul	Lufa	high plantation	low plantation
				morning					
number of subjects	—	18	12	6	—	22	14	2	6
end of neutral stage	—	33.36 ± 0.19	32.48 ± 0.27	34.10 ± 0.22	—	33.20 ± 0.17	32.83 ± 0.25	33.24 ± 0.14	32.71 ± 0.22
end of cooling	—	29.38 ± 0.18	29.57 ± 0.45	32.69 ± 0.43	—	30.43 ± 0.20	30.83 ± 0.30	31.03 ± 1.53	29.74 ± 0.34
sweat onset	—	37.49 ± 0.10	37.18 ± 0.12	36.35 ± 0.08	—	36.94 ± 0.12	36.85 ± 0.12	36.68 ± 0.18	37.16 ± 0.10
controlled hyperthermia	—	37.36 ± 0.05	37.29 ± 0.04	37.54 ± 0.08	—	37.38 ± 0.04	37.32 ± 0.03	37.38 ± 0.18	37.35 ± 0.03
				afternoon					
number of subjects	17	16	13	8	14	17	16	18	8
end of neutral stage	33.34 ± 0.18	34.02 ± 0.10	34.81 ± 0.20	34.49 ± 0.23	34.25 ± 0.12	34.33 ± 0.13	34.55 ± 0.14	34.18 ± 0.14	33.86 ± 0.26
end of cooling	31.12 ± 0.19	30.02 ± 0.14	31.79 ± 0.39	33.41 ± 0.32	31.31 ± 0.22	31.29 ± 0.21	32.17 ± 0.25	31.26 ± 0.23	30.79 ± 0.29
sweat onset	37.04 ± 0.12	37.45 ± 0.08	37.13 ± 0.11	36.51 ± 0.14	36.85 ± 0.13	36.86 ± 0.08	37.05 ± 0.08	36.67 ± 0.17	36.92 ± 0.19
controlled hyperthermia	37.46 ± 0.04	37.39 ± 0.04	37.37 ± 0.04	37.46 ± 0.07	37.41 ± 0.04	37.34 ± 0.03	37.33 ± 0.44	37.38 ± 0.04	37.38 ± 0.04

Guineans in the morning. In the afternoon, the groups differed significantly ($P < 0.01$) at the end of cooling, with the Lufa villagers showing the highest and the low plantation workers the lowest skin temperatures. The responses of the Europeans tested on Karkar Island agreed closely with the New Guineans at all stages. The unacclimatized European males had significantly higher ($P < 0.001$) skin temperatures at the end of cooling both in the morning and afternoon experiments, whereas at the neutral stage this difference was only present in the morning tests. At sweat onset, and during controlled hyperthermia, there were no significant differences between any of the groups. There were significant differences ($P < 0.01$) between the two female groups of villagers at the neutral stage, both in the morning and afternoon, but whereas the Kaul villagers had the higher temperature in the morning the difference was reversed in the afternoon. Compared with the Lufa villagers, the Kaul villagers had lower temperatures at the end of cooling and higher temperatures at sweat onset, although the differences were only significant ($P < 0.05$) in the afternoon experiments. The temperatures of the European unacclimatized controls were comparable with the villagers at the end of the neutral stage, between those of the other groups at the end of cooling and were significantly lower than the Kaul villagers, but not the Lufa villagers at sweat onset. There were no significant differences between any of the groups during controlled hyperthermia.

Comparison of body temperatures between the sexes

Deep body temperature was generally higher for the female groups compared with their respective male groups throughout the test up to sweat onset, although the differences were not always significant, especially for the Lufa villagers in the afternoon tests. The principal differences in skin temperatures occurred at the end of cooling and sweat onset. At the end of cooling, the males had higher skin temperatures whereas at sweat onset they were lower. There were no clear-cut differences between the sexes in the neutral stage and during controlled hyperthermia.

Comparison of body temperatures between the old and young adult villagers in Lufa

The mean deep body and skin temperatures with the standard errors for the old and young adult villagers are set out in table 4. The only significant differences ($P < 0.05$) were lower temperatures for the old people at the end of cooling (deep body temperatures for males) and at sweat onset (skin temperatures for females).

Heart rates

Comparison of heart rates between ethnic groups

The mean heart rates (beats/min) with standard errors combining morning and afternoon experiments for each group at the end of the neutral stage and during controlled hyperthermia, together with their differences, are set out in table 5. At the neutral stage, the male Kaul villagers had the lowest and the low plantation workers the highest heart rates of the four groups of indigenes studied. The Europeans in Karkar had higher heart rates than any other group. During controlled hyperthermia, the New Guineans were comparable, but markedly lower than both the European groups. Although there was a tendency for the Europeans to have the largest increase in rate between the two stages, the differences were not significant. The females showed a similar pattern of differences between groups compared to the males, but there were no significant differences.

Table 4. A comparison of the deep body and skin temperatures (°C) of the young adults with the older subjects studied at Lufa

	ear				skin			
	female		male		female		male	
	young	old	young	old	young	old	young	old
	afternoon		morning		afternoon		morning	
number of subjects	13	8	14	10	13	8	14	10
end of neutral stage	37.05 ± 0.08	37.17 ± 0.08	36.75 ± 0.05	36.58 ± 0.09	34.81 ± 0.20	34.56 ± 0.11	32.83 ± 0.25	33.13 ± 0.35
end of cooling	37.01 ± 0.07	37.12 ± 0.07	36.73 ± 0.04 *	36.58 ± 0.06	31.79 ± 0.39	32.03 ± 0.36	30.83 ± 0.30	31.32 ± 0.33
sweat onset	37.01 ± 0.04	36.99 ± 0.07	36.77 ± 0.06	36.85 ± 0.06	37.13 ± 0.11 *	36.56 ± 0.26	36.85 ± 0.12	36.91 ± 0.11
controlled hyperthermia	—	—	—	—	37.37 ± 0.04	37.40 ± 0.03	37.32 ± 0.03	37.33 ± 0.04

* Significantly different at 5 % level.

Table 5. The mean heart rates (beats/min) ± s.e. for the various young adult groups at the end of the neutral stage and during controlled hyperthermia (the change in heart rate produced by heating is also shown)

	female			male					
	European unacclimatized control	Kaul	Lufa	European unacclimatized control	European Karkar	Kaul	Lufa	high plantation	low plantation
number of subjects	17	34	25	14	14	38	29	20	14
end of neutral stage	78.2 ± 2.6	69.9 ± 2.1	73.2 ± 2.3	66.1 ± 2.1	68.3 ± 3.4	58.5 ± 1.2	61.0 ± 1.5	63.6 ± 2.6	66.4 ± 1.8
controlled hyperthermia	105.7 ± 2.13	102.2 ± 1.4	101.4 ± 1.9	99.0 ± 2.2	101.1 ± 2.6	89.8 ± 1.4	89.0 ± 1.3	95.7 ± 2.0	91.0 ± 2.8
change from neutral stage to controlled hyperthermia	29.0 ± 2.2	32.4 ± 1.8	28.2 ± 2.3	32.9 ± 2.7	32.9 ± 3.4	31.3 ± 1.3	28.0 ± 1.6	31.8 ± 1.9	25.2 ± 2.4

Comparison of heart rates between the sexes

The females had the higher heart rates at both stages of the test, but the increase in rate between the stages showed no sex difference.

Comparison of heart rates between the old and young adults in Lufa

The heart rates of the old and young adults in Lufa are compared in table 6. For both men and women at the two stages, the heart rates were closely comparable with no evidence of an age effect.

TABLE 6. A COMPARISON OF THE HEART RATES (BEATS/MIN) ± S.E. OF THE YOUNG ADULTS WITH THE OLDER SUBJECTS STUDIED AT LUFA AT THE END OF THE NEUTRAL STAGE AND DURING CONTROLLED HYPERTHERMIA (THE CHANGE IN HEART RATES PRODUCED BY HEATING IS ALSO SHOWN)

	female		male	
	young	old	young	old
no. of subjects	25	8	29	11
end of neutral stage	73.2 ± 2.3	72.3 ± 3.1	61.0 ± 1.5	60.8 ± 2.8
controlled hyperthermia	101.4 ± 1.9	98.1 ± 3.1	89.0 ± 1.3	89.1 ± 2.5
change from neutral stage and controlled hyperthermia	28.2 ± 2.3	25.9 ± 3.2	28.0 ± 1.6	28.3 ± 2.6

Hand blood flow

Comparison of blood flow between the ethnic groups

The mean hand blood flows (ml per 100 ml tissue per minute) with standard errors, are set out in table 7. There were significant differences ($P < 0.05$) between the four male New Guinea groups at the end of the neutral stage, largely due to the lower value found in the low plantation workers, and also at sweat onset ($P < 0.001$) and during controlled hyperthermia ($P < 0.05$), where the Lufa villagers had higher flows than the other groups. The male Europeans on Karkar had blood flows which were similar to the other groups, except for a tendency to be lower than the Lufa villagers at sweat onset and higher than the Kaul villagers during controlled hyperthermia. By contrast, the unacclimatized European controls had higher blood flows than all the other groups throughout the test. The female villagers were significantly different ($P < 0.05$) in the first three stages, with the Kaul villagers having the lower flows, and the same trend was present during controlled hyperthermia. The unacclimatized female European controls had lower blood flows than the New Guinea villagers at the end of the neutral stage. By the end of cooling, they were between the two groups of New Guinea villagers, but in the last two stages of the test they were higher, especially during controlled hyperthermia.

Comparison of blood flows between the sexes

Comparison of blood flows for the men and women in the two villages revealed a very close agreement throughout, except that the Kaul females had lower values at the end of cooling. The unacclimatized European female controls had lower blood flows in the neutral stage and at the end of cooling, but thereafter were comparable.

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TABLE 7. THE MEAN HAND BLOOD FLOWS (ml per 100 ml tissue per min) ± S.E. FOR THE VARIOUS YOUNG ADULT GROUPS AT THE FOUR STAGES OF THE TEST

	female			male					
	European unacclimatized control	Kaul	Lufa	European unacclimatized control	European Karkar	Kaul	Lufa	high plantation	low plantation
number of subjects	17	36	26	14	14	38	30	19	16
end of neutral stage	7.4 ± 1.2	10.0 ± 0.8	14.2 ± 1.8	21.1 ± 1.8	10.0 ± 1.6	10.7 ± 1.0	12.6 ± 1.4	9.7 ± 1.4	6.7 ± 1.4
end of cooling	1.9 ± 0.2	1.4 ± 0.1	2.3 ± 0.3	6.4 ± 1.3	1.4 ± 0.4	1.9 ± 0.2	2.4 ± 0.3	2.3 ± 0.2	1.7 ± 0.3
sweat onset	24.8 ± 1.6	15.7 ± 0.9	21.8 ± 1.8	29.3 ± 3.2	15.7 ± 2.1	12.9 ± 1.0	21.8 ± 1.3	16.0 ± 2.1	14.4 ± 1.7
controlled hyperthermia	40.0 ± 4.7	25.5 ± 1.2	29.5 ± 2.2	46.1 ± 4.1	31.8 ± 3.4	24.3 ± 1.4	29.8 ± 1.6	25.6 ± 2.4	24.3 ± 1.6

Comparison of blood flows between the young and old in Lufa

The comparison of hand blood flows in the old and young adults at Lufa (table 8) indicates a tendency for the old subjects to have the lower blood flows at all stages, but the differences are not significant.

TABLE 8. A COMPARISON OF THE HAND BLOOD FLOWS (ml per 100 ml tissue per min) ± S.E. OF THE YOUNG ADULTS WITH THE OLDER SUBJECTS STUDIED AT LUFA

	female		male	
	young	old	young	old
no. of subjects	26	10	30	11
end of neutral stage	14.2 ± 1.8	10.8 ± 1.8	12.6 ± 1.4	7.8 ± 1.5
end of cooling	2.3 ± 0.3	1.9 ± 0.4	2.4 ± 0.3	1.8 ± 0.2
sweat onset	21.8 ± 1.8	17.0 ± 1.7	21.8 ± 1.3	18.1 ± 2.1
controlled hyperthermia	29.5 ± 2.2	27.6 ± 2.8	29.8 ± 1.6	29.4 ± 2.2

Sweat rates

The means and confidence limits for the initial sweat rates (ml/min) during the period of controlled hyperthermia are set out in table 9 for males and females separately. Previous studies have shown little or no effect of time of day so that morning and afternoon experiments are combined. In agreement with previous studies using the controlled hyperthermia test, there was found to be no correlation between body size and sweat rate of individuals within the various groups. Accordingly, the results have not been expressed in terms of body mass or surface area. Although the Europeans were larger and heavier than the indigenes, the difference in sweat losses are so large that correction for body size does not materially alter the results.

TABLE 9. THE MEAN INITIAL SWEAT LOSSES (ml/min) WITH 95% CONFIDENCE LIMITS DURING CONTROLLED HYPERTHERMIA FOR THE VARIOUS GROUPS STUDIED

	no. of subjects	mean	95% confidence limits
females			
European unacclimatized control	15**	1.69	0.92–3.12
Kaul	32*	3.32	2.60–4.23
Lufa	24	3.64	2.62–5.07
males			
European unacclimatized control	12	5.62	4.27–7.41
European Karkar	13	13.42	11.30–15.95
Kaul	36	4.75	3.98–5.67
Lufa	30	5.53	4.60–6.64
high plantation	18	6.05	4.26–8.59
low plantation	14	4.60	3.63–5.81
the old			
Lufa female	8	2.69	1.60–4.51
Lufa male	11	3.84	2.32–6.37

** and *: sweat not measurable in two subjects and one subject respectively.

Comparison of sweat rates between ethnic groups

There were no differences between the sweat losses of the male Kaul and Lufa adult villagers or between the villagers and plantation workers. The Europeans on Karkar had much higher sweat losses ($P < 0.001$) than any of the New Guinea people. The unacclimatized Europeans

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TABLE 10. THE MEAN CONCENTRATIONS (mmol/l) OF SODIUM, POTASSIUM AND CHLORIDE IONS IN THE SWEAT AND URINE SAMPLES OF EACH OF THE GROUPS TESTED IN NEW GUINEA WITH 95 % CONFIDENCE LIMITS (THE RATES OF EXCRETION OF THE IONS (μmol/min) ARE ALSO SHOWN)

group		Karkar European male	Kaul male	Lufa male	low plantation male	high plantation male	old Lufa male	Kaul female	Lufa female	old Lufa female
no. of subjects		14	34	29	12	19	11	34	22	44
					sweat					
Na^+	mmol/l	64.0	30.5	32.9	30.3	23.1	33.7	21.7	25.0	17.7
		(53.3 77.0)	(26.1 35.6)	(28.9 37.3)	(21.7 42.1)	(17.7 30.2)	(23.9 47.5)	(16.1 29.2)	(17.3 36.2)	(7.9 39.7)
	μmol/min	736.0	115.0	139.4	111.3	108.4	142.8	89.8	85.1	57.7
K^+	mmol/l	5.0	9.4	9.4	8.9	8.8	8.8	8.3	12.4	14.1
		(4.4 5.8)	(7.9 11.2)	(8.3 10.6)	(7.4 10.6)	(6.9 11.3)	(7.0 11.1)	(7.3 9.4)	(10.3 15.0)	(7.0 28.5)
	μmol/min	57.9	35.6	39.8	32.7	41.4	37.3	34.4	42.3	46.1
Cl^-	mmol/l	62.5	31.2	28.7	33.3	25.4	31.4	24.4	21.5	16.5
		(52.4 74.5)	(26.9 36.2)	(24.9 32.9)	(25.3 43.7)	(20.2 32.0)	(22.0 44.8)	(19.1 31.1)	(15.8 29.2)	(7.5 36.2)
	μmol/min	718.6	117.8	121.4	122.3	119.1	133.0	101.1	73.0	53.8
Na^+/K^+ ratio		13.6 ± 1.4	3.7 ± 0.3	3.9 ± 0.3	3.9 ± 0.6	3.1 ± 0.4	4.7 ± 1.1	3.0 ± 0.4	2.7 ± 0.7	1.6 ± 0.6
					urine					
Na^+	mmol/l	159.8	45.7	36.4	27.8	7.2	60.2	34.5	51.7	15.8
		(119.2 214.4)	(35.0 59.8)	(23.1 57.6)	(11.5 67.2)	(3.5 15.0)	(22.8 159.0)	(26.3 45.3)	(28.8 92.8)	(4.7 52.5)
	μmol/min	117.0	45.3	29.9	26.0	5.5	38.5	30.5	24.7	9.0
K^+	mmol/l	59.7	72.0	76.5	102.1	59.9	90.4	60.0	115.9	192.2
		(44.5 80.3)	(53.9 96.3)	(48.8 119.9)	(67.9 153.5)	(41.9 85.4)	(72.9 112.2)	(45.3 79.4)	(78.5 171.1)	(45.9 804.4)
	μmol/min	43.0	67.5	62.7	95.6	56.4	57.8	53.8	55.2	110.2
Cl^-	mmol/l	146.4	71.3	30.6	62.0	46.3	55.2	56.9	37.8	24.6
		(107.7 198.9)	(58.2 87.3)	(20.6 45.6)	(40.5 95.0)	(33.7 63.6)	(23.6 129.0)	(44.1 73.4)	(22.8 62.7)	(13.0 46.4)
	μmol/min	106.8	68.7	25.1	58.0	45.8	35.3	51.9	18.0	14.1
Na^+/K^+ ratio		3.0 ± 0.5	0.9 ± 0.1	0.8 ± 0.2	0.5 ± 0.1	0.5 ± 0.2	1.0 ± 0.2	0.7 ± 0.1	0.9 ± 0.2	0.2 ± 0.2

on the other hand had sweat losses closely comparable with the New Guineans. There was also no difference between the two groups of female villagers, but the unacclimatized European female controls had a lower sweat loss.

Comparison of sweat rates between the sexes

In all cases, the females had lower sweat rates than the comparable groups of males; the difference being most marked for the European control groups.

Comparison of sweat rates between the young and old adult villagers

There were no significant differences between the old and young adults studied at Lufa, and indeed the results were closely comparable a shown by table 9.

Sweat and urine electrolyte analysis

Samples of the sweat and urine collected during the bed tests were frozen and subsequently analysed for sodium, potassium and chloride ions. The results are set out in table 10, giving the mean concentration in millimoles per litre with 95% confidence limits; the excretion rate is shown as micromoles per minute.

The concentrations of sodium and chloride in the sweat of the New Guineans was approximately half that of the Europeans, whereas potassium was almost double, so that the sodium/potassium ratios were markedly lower in the New Guineans.

A similar picture of differences in the excretion of these ions was present in the urine.

Chloride excretion tended to be lower in the Lufa villagers than for the Kaul people and the high plantation workers excreted remarkably little sodium.

Discussion

The physiological responses to the function test of the villagers from Kaul on Karkar Island and from Lufa in the highlands were closely comparable. The Kaul villagers tended to have the higher deep body temperatures, but this may only reflect a greater prevalence of low-grade fevers, possibly of malarial origin, in the coastal people. Sweat rates were indistinguishable in the two groups, suggesting a similar level of habitual exposure to heat stress. Originally, it had seemed probable that the Lufa villagers would be less heat acclimatized because of the cooler climate. However, the field study (Budd, Fox, Hendrie & Hicks 1974) has shown that the lower air temperature in the highlands is at least partly offset by higher radiant heat levels and lower windspeeds and the hilly nature of the countryside may result in higher peaks of metabolic heat production when walking and working.

The plantation workers on Karkar Island and the old people at Lufa both gave responses to the function test which were very similar to those of the young adult villagers. Working as paid labour in developing countries with a hot climate can require a considerable increase in heat acclimatization (Wyndham 1965; Ojikutu, Fox, Davies & Davies 1972). However, it would appear from the sweating capacity that the plantation workers were not expected to work appreciably harder or become more exposed to heat than the villagers. Although the ability to adapt to heat is apparently unimpaired by age (Robinson *et al.* 1965), the absence of any significant difference in the response of the older subjects in this study is somewhat surprising since in general they appeared to be less active than the younger adults. The finding is, however, useful in helping to exclude any possible effects of the small differences in age between the populations compared.

The comparisons between the two sexes in both villages show a number of differences in response which are similar to the pattern found in other ethnic groups using the present technique (Fox *et al.* 1969; Fox, Even-Paz, Woodward & Jack 1973; Ojikutu *et al.* 1972). The sweating capacities of the two sexes in these studies are compared in figure 2. The lower sweating capacity of the European or Caucasian female has been well documented (McCance 1938; Hardy & DuBois 1940; Hardy, Milhorat & DuBois 1941; Kawahata 1960; Wyndham, Morrison & Williams 1965; Löfstedt 1966; Morimoto, Slabochova, Naman & Sargent 1967; Fox *et al.* 1969).

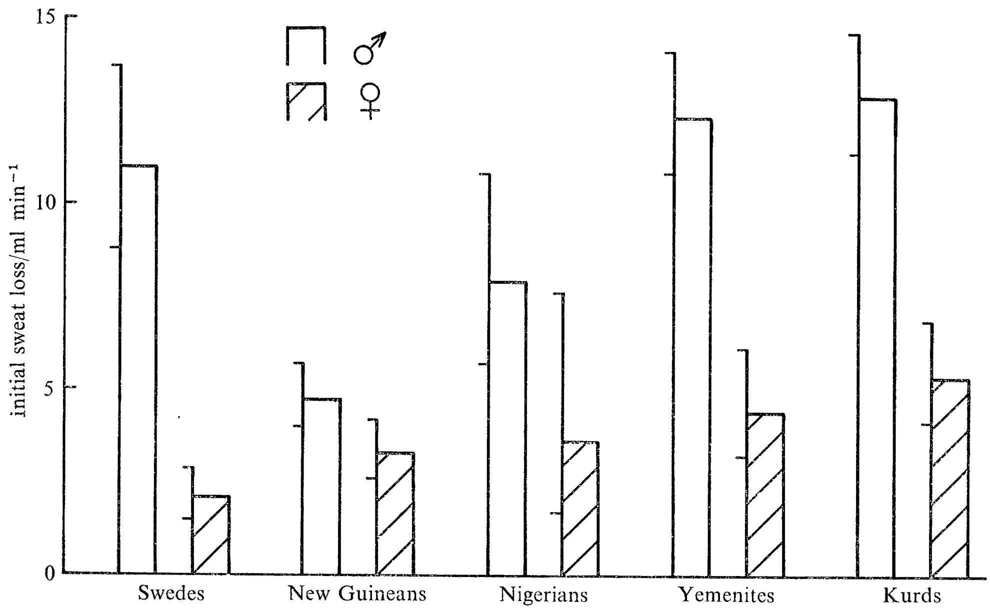

FIGURE 2. A comparison of the maximum sweating capacity measured in the New Guineans with those found in previous studies on Swedes, Nigerians, Yemenites and Kurds.

Other ethnic groups have received comparatively little attention, except by McCance and his colleagues using the response to injected pilocarpine as an index of sweating on Bantu, Indians and Sudanese (McCance & Purohit 1969; McCance 1969; McCance, Rutishauser & Knight 1969). In general, both the present and McCance's studies agree in showing smaller differences between the sexes in the non-Caucasian groups. The pattern of sex differences in body temperatures were also similar to those found previously. In particular, the higher deep body and skin temperatures of the females at sweat onset and lower skin temperatures earlier in the test, are similar to the findings in the Israel (Fox *et al.* 1973) and Swedish (Fox *et al.* 1969) studies. This gives further support to the hypothesis that one of the factors contributing to the female's lower sweat rate is a greater capacity to store body heat before sweating is initiated.

The sweat rates of the Europeans on Karkar Island were much higher than those of the New Guinea indigenes and closely comparable with the level for artificially heat-acclimatized Europeans. The male New Guineans had sweat rates similar to the unacclimatized European, whereas the females in New Guinea were somewhat higher than their European counterparts. The low sweating capacity of the New Guinea people is in agreement with studies using the same function test on the indigenes of other hot countries such as Israel (Fox *et al.* 1973) and

Nigeria (Ojikutu *et al.* 1972), illustrated in figure 2. It also agrees with the results of studies using the work-in-the-heat technique to compare Europeans and African people living in the same hot climate. These studies include the comparison by Robinson *et al.* (1941) of white and Negro share croppers in a hot region of the United States; a study of white and Negro recruits to the U.S. Army by Baker (1958); a comparison of Europeans and Nigerians by Ladell (1950, 1957); several studies on the South African Bantu (Weiner 1950; Wyndham, Bouwer, Devine & Patterson 1952; Strydom & Wyndham 1963) and a comparison of Chaamba Arabs with French servicemen living in the hot, dry climate of the Sahara Desert (Wyndham, Metz & Munro 1964*b*). The relatively few studies on other races have generally given similar findings, thus the Australian Aborigine was found to sweat less than the white Australian by Wyndham, Macpherson & Munro (1964*a*), although the converse has been reported by McFarlane (1969).

Tests on indigenes in Singapore using the P4SR Index (McArdle *et al.* 1947) showed a lower sweat loss than that predicted for acclimatized Europeans (Macpherson 1960). Naturally acclimatized Indians tested immediately after being flown from India have been found to have the same sweat rate as the unacclimatized European and when tested again after becoming de-acclimatized by living 3 months in England without exposure to heat, the Indians sweated significantly less than the Europeans (Edholm *et al.* 1965).

In spite of these intensive studies, there is as yet no satisfactory explanation for the marked differences in the sweating response of the Caucasian compared with the indigenes of hot countries (Strydom & Wyndham 1963; Wyndham 1966). It is obviously of advantage to be able to thermoregulate in hot conditions with less recourse to sweating, but the ability to do so clearly implies the presence of other differences which have not, as yet, been identified. It had been hoped that measurement of hand blood-flow would reveal any important difference in thermoregulatory efficiency arising from a more efficient heat transport by the circulation. Hand blood flows were comparable for all the groups studied in New Guinea, except that the Europeans had higher flows during controlled hyperthermia, but the unacclimatized European levels were higher throughout the test. At first sight, this result seems surprising and appears to imply a reduced capacity to dissipate body heat by vasomotor regulation. However, there is an alternative explanation. The blood flow through the body extremities including the hands is controlled by the vasoconstrictor vasomotor nerves, whereas over the rest of the body surface an active vasodilator mechanism predominates (Fox & Edholm 1963). Variations in the blood flow through the extremities play a major role in the fine control of body temperature when man is living in a temperate or cool climate, but the mechanism is an inefficient method of promoting heat loss in warm conditions, because above a moderate level of flow even a very large further increase in hand blood flow only produces a small increase in heat loss. It seems quite possible that a reduced blood flow in the extremities may be one of the concomitants of prolonged heat exposure. Blood flow through skin regions controlled by the active vasodilator mechanism was not measured in this study, but any substantial differences would have been reflected in skin temperature changes and these were not found.

Intensive studies on Caucasians have shown that the sweating capacity of an individual or group of individuals reflects the amount of use made of the sweating mechanism over a period of time. During artificial heat acclimatization by controlled hyperthermia, a high correlation has been demonstrated between the amount of sweat secreted during the period of heat treatments and the resultant increase in sweating capacity (Fox, Goldsmith, Kidd & Lewis 1963) and the increased sweating capacity is considered to represent a local training response of the sweat gland to repeated use (Fox, Goldsmith, Hampton & Lewis 1964). Similarly, when exposed to the same hot conditions as Caucasians during artificial heat acclimatization, the indigenes of hot countries, like the Bantu in South Africa (Wyndham *et al.* 1964*c*) and Indians (Edholm *et al.* 1965) are also capable of responding with an increase in sweating capacity.

The question as to whether 'artificial' acclimatization in the laboratory produces the same physiological changes as 'natural' acclimatization through residence in a hot climate was examined by Hellon, Jones, Macpherson & Weiner (1965). They concluded that 'The phenomenon of natural acclimatization to tropical climates if not identical with, at least has the same physiological basis as the artificial acclimatization produced experimentally in the laboratory'. It has also been suggested that part of the increase in sweating capacity observed in short-term 'artificial' or 'natural' acclimatization may only be a temporary phenomenon which in the longer term is replaced by other adaptations reducing the need for sweating. The explanation for the much lower sweating capacity found in the indigenes of hot countries compared with people of white European or Caucasian origins could have a similar basis.

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