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The Response of Normal Men and Women to Changes in Their Environmental Temperatures and Ways of Life

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THE RESPONSE OF NORMAL MEN AND WOMEN TO CHANGES IN THEIR ENVIRONMENTAL TEMPERATURES AND WAYS OF LIFE

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CONTENTS

Sudanese men and women were flown to Cambridge in the winter of 1966/67 and at once began to take part in an experiment there lasting for 8 days with a corresponding number of British subjects. The Sudanese conformed to the British way of life. Time was provided for relaxation and exercise and the intakes and expenditures of water, salt and energy were measured.

The British party were flown to Khartoum in the spring of 1968—not, for political reasons, as was originally planned in June 1967. They matched up again with the Sudanese subjects and adopted the daily routine of the latter while a similar programme of relaxation exercise and measurements was being carried out.

The dry-bulb temperatures out of doors in England ranged from −5.6 to 12.5 °C but the rooms were warmed. The dry-bulb temperatures ranged from 14.8 to 38.7 °C in Khartoum and none of the rooms were cooled.

The food in Khartoum provided more protein and less salt than in Cambridge.

The subjects ate more and expended more energy in Cambridge than in Khartoum and they also tended to gain weight, particularly the Sudanese. The British food intakes were considerably lower in Khartoum and, in spite of expending less energy, the subjects lost weight.

To live the lives they did the British males had an obligatory water expenditure of around 2223 ml/day in Cambridge and 2920 ml. in Khartoum; the figures for the Sudanese were 2278 and 3381. All the subjects would have required about 7 to 8 g of sodium chloride/day in Khartoum to make their food palatable and to provide for the obligatory losses.

The women ate less, expended less energy and had considerably lower obligatory losses of water and salt than the men.

Neither the British nor the Sudanese showed impaired ability to perform arithmetic or prolonged vigilence tests in their unaccustomed environment. The Sudanese were less cautious than the British in that they made more false reports of signals in the vigilance task.

Introduction

People are now moving more and more freely from one climatic extreme to the other and the change is often made in a matter of hours. It is well known that after a few days people become habituated to the new climate and it has been established that a prolonged residence at high environmental temperatures enables men to perform physical tasks with greater efficiency and less danger to themselves than newcomers. 'Know-how' comes into this to some extent (Hellon, Jones, Macpherson & Weiner 1956; Ladell 1964) and the whole process has come to be known as acclimatization. It is characterized by earlier and more profuse sweating, a lower percentage of salt in the sweat and lower body temperatures at work. Considerable acclimatization, however, can be achieved beforehand in temperate climates by the daily performance of strenuous physical tasks in a hot room, and to a more moderate extent by hard work in lower temperatures (Strydom *et al.* 1966*b*). This is a matter of great importance to the armed forces and to industry, and the circulatory adjustments of acclimatized and unacclimatized men and many other facets of the process have been studied from many angles and with various objectives.

Nearly all the work on artificial acclimatization and on its rate of decay has been carried out on men between the ages of 20 and 40 engaged on severe physical tasks, as shown by the publications of Ladell (1955) from West Africa, of Malhotra, Sharma & Sivaraman (1959) and Malhotra (1958, 1960) from India, of Edholm *et al.* (1962, 1964*a*) from Aden and of Wyndham *et al.* (1963), Wyndham (1965, 1966), Strydom *et al.* (1966*a*, *b*) from Johannesburg.

Women of European extraction have been known for some time to produce less sweat than men when exposed to similar high temperatures (McCance 1936, 1938*a*; Hardy & Milhorat 1939; Hardy & DuBois 1940; Hardy, Milhorat & DuBois 1941). More recently the physical response and limitations of women to gross changes in their environmental temperatures have been more fully investigated (Kawahata 1960; Morimoto, Slabochova, Naman & Sargent 1967; Weinman, *et al.* 1967; Fox & Lofstedt 1968), and their capacity to acclimatize to severe physical performances has been studied (Hertig *et al.* 1963; Haslag & Hertzman 1965; Wyndham, Morrison &

Williams 1965). It is not known why women do not respond so well as men. On the basis of a rather limited number of experiments Kawahata (1960) concluded that the sexual hormones were alone responsible while Fox *et al.* (1969) considered that the differences were mainly due to the fact that women had more subcutaneous fat and that they were naturally less well acclimatized.

There are indications of ethnic differences as well as sexual differences in the way people respond to high environmental temperatures and in their capacity to work in them. Thus Ladell (1950, 1951) found that Nigerian males produced less sweat than Europeans on exposure for several hours and Wyndham, Bouwer, Devine & Paterson (1952) obtained a similar result on the South African Bantu. The Saharan Arabs and the Bushmen in the Kalahari desert have also been found to sweat less than Europeans (Wyndham & Morrison 1956; Wyndham, Metz & Munro (1964). It is not easy to eliminate the effects of acclimatization from these comparisons, but Edholm *et al.* (1964*b*) did their best to do so.

Studies of the sweat glands in cystic fibrosis (Kessler & Anderson 1951; di Sant'Agnese, Darling, Perera & Shea 1953*a*, *b*) led to tests for the response of these glands in localized areas of the body to acetylcholine or pilocarpine (Gibson & Cooke 1959; Anderson & Freeman 1960). The application of this relatively simple technique to large numbers of persons has shown that European and North American males living in the same environment produce more sweat than females (Kahn & Rothman 1942; Gibson & Shelley 1948; Herrmann, Prose & Sulzberger, 1952; Lobeck & Huebner, 1962; McCance, Rutishauser & Knight 1968; McCance & Purohit 1969) and that they respond to a lower dose of the drug (Janowitz & Grossman 1950). Indians and Bantu speaking groups south of the Sahara do not react so well to pilocarpine as Europeans living in the same surroundings (McCance & Purohit 1969).

These results (see also Collins & Weiner 1964) are in line with those described on the exposure of the two sexes and the several ethnic groups to high temperatures and acclimatization. There is evidence that Sudanese males respond equally well and Sudanese women rather better to pilocarpine than their European counterparts residing at similar ambient temperatures (McCance 1969).

The present investigation was designed to study how normal men and women of various ages and races respond to changes in their environmental temperatures and way of life. They had not been acclimatized artificially beforehand nor was any attempt made to hasten the process after their arrival in the new climate. They were, however, closely observed, particularly their expenditure of energy, their intakes of the unaccustomed food and their salt and water requirements. Both males and females in two ethnic groups participated. No previous experiments of the same kind have been found in the literature.

Plan of the experiment

The original plan was to bring seven students and doctors from Khartoum to Cambridge just before Christmas 1966, and another group very early in January 1967. These were to be paired with a corresponding number of British subjects and the following determinations made upon them: energy intakes and energy expenditures, the intake of water from all sources and its excretion in the urine, the intake of sodium chloride and its excretion in the urine. With this information and certain assumptions it was proposed to calculate their salt and water requirements, and experiments were also to be made to test their performance at simple arithmetic and vigilance. All the subjects were to be kept out of doors as much as possible to subject them to such weather as there might be.

It was planned to transport the British personnel to Khartoum in June 1967, in two groups, and to repeat there everything that had been done in Cambridge. Unfortunately, owing to the political situation the authorities did not consider it wise to carry out the Khartoum stage of the experiment in June 1967, and it was not possible to take the British subjects to Khartoum till the end of March 1968. The weather then was not nearly so hot as it would have been in June, although it was considerably hotter than it had been in the Cambridge winter, nor was it possible to assemble all the subjects at that time. The experiment, however, was completed according to the original plan although on fewer numbers. It has, therefore, been possible to compare the energy intakes and expenditures, the salt and water requirements and the subjects' vigilance and performance at arithmetic at two very different environmental temperatures.

The subjects

Table 1 gives the age, height, weight—in Cambridge and Khartoum—and sex of the subjects who participated fully in the experiment. Three of the British and one of the Sudanese subjects

Table 1. The ages, heights, weights and sexes of the subjects

British					Sudanese				
			weight/kg					weight/kg	
	age years	height cm	at Cambridge	at Khartoum		age years	height cm	at Cambridge	at Khartoum
Males					*Males*				
John H.	23	168	64.8	65.0	F. Abdeen	24	184	69.4	70.7
Alec M.	68	175	49.5	50.5	S. Ahmed	22	175	56.1	59.2
David MacL.	21	173	58.1	59.4	H. Ahmed	27	167	58.5	—
David M.	29	179	75.8	73.3	A. Asha	24	179	66.8	69.4
Charles P.	21	175	65.6	66.0	T. Gaafer	22	175	90.2	96.5
Andrew P.	20	184	81.8	86.0	S. Ibrahim	22	175	72.4	72.7
Malcolm, P.	32	179	62.9	64.9	A. Latif	25	170	58.1	57.8
Peter S.	22	178	70.1	69.4	A. Magoub	23	173	67.9	69.4
Ian S.	22	168	65.6	64.7	A. Tambal	24	173	64.1	72.6
Tony T.	22	174	61.5	63.0					
David W.	24	175	71.9	—					
Females					*females*				
Felicity M.	26	163	47.3	—	A. Ziada	23	161	52.2	58.0
Hilary O.	31	166	51.7	53.4	L. Abdalla	22	158	37.0	42.5
Caroline P.	28	168	68.5	—	T. Lewis	20	161	58.6	58.0
Dorothy S.	39	163	52.4	47.9					

could not for one reason or another take part in the second half of the experiment in Khartoum. The weights of the British subjects changed little in the interval between the two halves of the experiment except for those of Andrew P., and Dorothy S. The former had gained about 4 kg by the time he got to Khartoum and the latter had lost about the same amount. A number of the Sudanese subjects gained weight after the first part of the experiment in Cambridge, notably S. Ahmed, A. Asha, T. Gaaffer, A. Tambal, A. Ziada and L. Abdalla. A. Tambal had put on 8.5 kg in the 15 months.

The environment

Temperature

Tables 2 and 3 give the meteorological records from the R.A.F. station at Oakington 5 km from Cambridge in December 1966 and January 1967. Table 4 gives the records provided by the meteorological office in Khartoum.

Table 2. Meteorological records: Cambridge, December 1966
08h 00 readings

date ...	12	13	14	15	16	17	18	19	20
barometric pressure/mbar†	980	980.1	1010	1017.3	1014.6	1027.8	1013	1023	1015.3
temperature/°C	+5.9	4.3	0.6	3.0	9.1	4.6	7.0	5.8	6.3
vapour pressure/mbar†	9.3	7.9	5.8	6.7	11.7	8.4	6.9	8.6	8.6
relative humidity (%)	100	95	90	88	99	99	88	93	90
max. temp./°C	8.4	6.2	3.4	8.7	10.5	9.1	12.5	11.7	6.7
min. temp./°C	2.1	−0.4	−1.3	1.2	1.9	4.0	5.3	5.2	0.3
wind direction (°)	210	350	270	140	190	230	240	200	340
wind speed knots	8	15	5	7	12	14	20	8	14
wind speed m/s	4	8	2.5	3.5	6	7	10	4	7
rainfall/mm	0.1	nil	0.2	nil	0.6	1.4	nil	0.4	nil

† 1 mbar = 100 Pa.

Table 3. Meteorological records: Cambridge, January 1967
08h 00 readings

date ...	2	3	4	5	6	7	8	9	10
barometric pressure/mbar†	1021.3	1025.2	1023.9	1018.1	1024.7	1015.4	1020	1028	1017.1
temperature/°C	0.4	−0.3	−1.4	−0.5	−0.2	−0.8	−3.1	−4.9	−0.4
vapour pressure/mbar†	6.0	4.8	5.0	5.5	5.9	6.3	7.9	4.1	5.9
relative humidity (%)	95	79	90	99	95	97	98.2	96	93
max temp./°C	4.3	3.0	3.1	3.2	2.1	2.3	1.7	1.0	+4.6
min. temp./°C	−1.5	−2.6	−1.5	−1.0	−1.3	−2.3	−5.4	−3.9	+0.5
wind direction (°)	270	300	280	330	320	140	280	300	240
wind speed knots	10	10	12	15	10	8	6	8	14
wind speed m/s	5	5	6	8	5	4	3	4	7
rainfall/mm	trace	0.12	nil	1.0	3.0	0.4	nil	0.2	1.1

† 1 mbar = 100 Pa.

Table 4. Meteorological records: Khartoum, March to April 1968
08h 00 readings

	March				April				
date ...	28	29	30	31	1	2	3	4	5
barometric pressure/mbar†	1011	1012	1014	1020	1016	1017	1015	1013	1012
temperature/°C	22.7	19.0	20.0	20.7	20.7	18.3	19.5	21.6	23.0
vapour pressure/mbar†	9.0	8.7	9.3	9.8	9.9	8.5	10.1	5.9	6.7
relative humidity (%)	25	40	40	42	41	40	44	23	24
max. temp./°C	36.7	34.3	31.3	32.5	32.2	30.7	30.3	32.4	35.0
min. temp./°C	20.1	16.4	16.4	17.9	16.6	18.7	14.8	18.1	19.0
wind direction (°)	45	0	45	0	0	0	45	0	0
wind speed knots	12	9	11	9	11	11	7	8	2
wind speed m/s	6	4.5	5.5	4.5	5.5	5.5	3.5	4	1
rainfall/mm	nil	nil	nil	nil	nil	nil	nil	nil	nil

† 1 mbar = 100 Pa.

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The temperatures were lower in January 1967 than they were in December 1966; the relative humidities were very high nearly all the time. The temperature at 08h 00 was usually between 3 and 7 °C in December and 0 °C or a little below in January. There was a fall of snow during the experimental week in January. The highest external temperature was 12.5 °C in December and 8.1 °C in January. The wind was slight most of the time and varied from 2.5 to 10 m/s (5 to 20 knots) in December and 3 to 8 m/s (6 to 15 knots) after Christmas. The rooms in which the subjects worked and ate were warmed, but there was little heat in the bedrooms.

The temperatures at Khartoum were around 20 °C at 08h 00 with maximum day temperatures of 34 to 35 °C. The relative humidity never exceeded 42 %. Readings were taken on the roof of the hostel at Khartoum and the dry-bulb temperatures ranged from 20 to 32 °C nearly every day. Temperatures taken with a globe thermometer on the roof were usually 23 °C at 8 a.m. and 48 to 49 °C in the afternoon. In a shady room in the hostel these temperatures were naturally more constant and varied from 21.5 to 32 °C. In the middle of the day they were usually in the neighbourhood of 30 °C. There was no artificial cooling in any of the rooms.

Daily routine

In Cambridge the participants who were strangers to the town lodged in Sidney Sussex College, and had all their meals in the Department of Experimental Medicine—10 to 20 min away on foot. Tests and laboratory exercises were carried out in the Department of Anatomy, which was close by the rooms in Experimental Medicine which were acting as the refectory and metabolic base.

The day began at 08h 00 and the subjects were expected to have reached the refectory, delivered their previous 24 h collections of urine, weighed themselves under supervision and be ready for breakfast at 09h 00. On the first and last mornings pulse rates and body temperatures were measured while the subjects were still recumbent and 10 ml of blood were taken from an anticubital vein. The mornings were devoted mainly to the study of energy expenditures. These involved out of door activities—often in small groups—respiratory tests during them and also in the laboratory. To some extent the weather determined the exercise chosen. Learning to play golf, walks, timed and otherwise, snowballing, swimming and a little football all had their turn. The basal rates on most subjects were determined before they got up but in a few after lying recumbent for a standard time at the laboratory. Lunch was at 13h 00 and from 14h 00 to 16h 00 expeditions were made; one was to Ely Cathedral and one to Pye's factory. Sometimes the subjects played football and once they went to skate. Tea was at 16h 00. The psychological tests on the control subjects, who were outside the rest of the experiment, were carried out during the afternoon and on the experimental subjects after tea between 17h 00 and 19h 00. Supper was at 19h 00 and, after it, the subjects returned to Sidney Sussex College where squash rackets, table tennis and refreshments of known weight and composition were available. This programme was not always followed strictly by three of the men, David M., Malcolm P. and Alec M., and two of the women Dorothy S. and Felicity M. who lived in Cambridge and had work to do there.

Whatever the advantages in experimental design might have been, it was not feasible to adhere to this circadian rhythm in Khartoum where the practice of the country called for a much earlier start and a rest period in the early afternoon. Much more work, moreover, had to be done every day in Khartoum by those in charge of the experiment, because there was not enough

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time available at that season of the year to have the subjects in two groups one after the other as had been done in Cambridge. This almost doubled the number of subjects and the number of observations that had to be made on them every day, and this meant some further reorganization of the timetable. The male subjects and most of the observers lived in the male students hostel and all the subjects and observers fed in the refectory there. The 'mores' of the country made it necessary to lodge the female subjects in their own hostel some distance away, to and from which they had to be transported by a small bus or Landrover. In Khartoum, therefore, the day usually began for the male participants with an early cup of tea and the study of energy expenditures from 06h 30 to 09h 00. The women joined them later or at breakfast which was at 09h 00.

Some expeditions were made on most days between 10h 00 and 13h 00. One was to the hospital, for example, one to the junction of the two Niles and another to Omdurman. On two of the days longer expeditions were made, one to the Omdurman battle ground and one to a village on the White Nile and then on to the Jebel Awlia dam. On these expeditions breakfast was taken on the bank of the Nile and at the village respectively. While the participants were on these expeditions the subjects who were acting as the local controls did their psychological tests from 11h 00 till 13h 00, when everyone collected for lunch at the refectory. Between 14h 00 and 16h 00 half the subjects did their psychological tests and the others had their records checked and rested. The second half did their vigilance and arithmetic tests between 16h 00 and 18h 00 and the first half had their records checked and sometimes went swimming. Tea was available between 15h 30 and 16h 30 and the evening meal was served between 18h 30 and 20h 00. After it most of the subjects went to swim or take exercise at the University ground. The women often went back to their hostel.

The diets

Most of the Sudanese were Muslims and both in Cambridge and Khartoum the diets contained no pig meat or offals. Table 5 gives a list of the foods served in Cambridge at breakfast, lunch and supper in December 1966 and January 1967. White bread, sugar, salt-free butter, jam or marmalade, salt, and milk for coffee were available at all the meals. Tea, milk and cake were provided every day at 16h00, and biscuits, lemon squash and beer as an evening snack, but these have not been included in the table. Some of these foods were very strange to the Sudanese. Table 6 gives a list of the foods provided in Khartoum. As in Cambridge, white bread, sugar, butter, marmalade, milk and salt and soft drinks were always at hand, and limited amounts of beer. The table does not include the tea, milk and biscuits provided every day at 06h 00 and 16h 00. The differences between the two diets were considerable. The fish in Khartoum did not come from Grimsby, but from the Nile, and consisted as a rule of excellent filleted talapia. The basis of the molokhia stew was a vegetable containing so much pectin that it presented itself almost as a jelly. Its composition in terms of nutrients varied according to the day from 2 to 2.4 % protein, 7 to 14 % of fat, and 3.4 to 4.8 % of carbohydrate. Kisra was a folded, loose textured, millet preparation containing 3.4 % protein, 2 % fat, and 32 % carbohydrate. The baglawa contained 4.34 % protein, 13 % fat and nearly 50 % carbohydrate and, therefore, provided, gram for gram, more than twice as many joules as the others. The salads were based upon an assortment of fresh green vegetables of the lettuce type, and there was always an abundance of raw sliced tomatoes, sometimes with and sometimes apart from the green salads.

Table 5. Menus in Cambridge

12 to 19 December and 2 to 9 January (both inclusive)

Breakfast	nflakes lk led egg . or coffee	'Rice Krispies' milk scrambled egg toast tea or coffee	cornflakes milk haddock tea or coffee	'Rice Krispies' milk fried egg fried bread tea or coffee	cornflakes milk baked beans fried bread tea or coffee	'Rice Krispies' milk boiled egg tea or coffee	cornflakes milk fried egg fried bread tea or coffee	'Rice Krispies' milk boiled egg tea or coffee
Lunch	caroni- ieese natoes inned) aches inned) stard	soup corned beef pickles stewed apples custard coffee	sausages baked beans apple (raw) banana (raw) coffee	tomato soup kedgeree jam tart coffee	mixed vegetable soup cheese flan tomatoes blackberries apples (stewed) custard coffee	soup tongue rice pickles lettuce celery apples (raw) banana (raw) coffee	sausages baked beans tinned fruit mousse coffee	tomato soup tongue cold beef pickles celery apple banana coffee
Supper	nce tatoes nashed) ussels-sprouts ncemeat irt fee	liver potatoes peas sponge- pudding jam sauce coffee	stew potatoes butter beans apple pie custard coffee	roast lamb roast potatoes peas gravy apricots (tinned) mousse coffee	steak & kidney pudding potatoes swede butter beans treacle pudding treacle coffee	roast beef roast potatoes celery cabbage butter beans mincemeat pie coffee	steak pie potatoes (mashed) peas swede trifle coffee	turkey potatoes stuffing cabbage Christmas pudding brandy sauce coffee
Breakfast	nflakes lk iled egg or coffee	'Rice Krispies' milk fried egg fried bread tea or coffee	cornflakes milk haddock tea or coffee	'Rice Krispies' milk fried egg fried bread tea or coffee	cornflakes milk boiled egg tea or coffee	'Rice Krispies' milk fried egg fried bread tea or coffee	cornflakes milk baked beans fried bread tea or coffee	'Rice Krispies' milk boiled egg tea or coffee
Lunch	nato soup rned beef ery ricots stard	spaghetti- cheese tomatoes custard (tinned) blackberry	sausages baked beans apple (raw) banana (raw) coffee	cheese flan tomatoes (tinned) Eves pudding coffee	oxtail soup kedgeree tomato sauce apple (raw) banana (raw) coffee	sausages baked beans mincemeat tart coffee	soup cheese flan tomatoes (tinned) banana (raw) coffee	oxtail soup tongue rice (savoury) jam tart coffee
Supper	nce tatoes as ncemeat tart ffee	liver potatoes cabbage sponge- pudding jam sauce coffee	roast lamb roast potatoes leeks swede apple tart custard coffee	beef stew potatoes (mashed) butter beans peaches (tinned) coffee	roast beef roast potatoes peas treacle- sponge custard coffee	meat pie potatoes cabbage trifle coffee	meat pies potatoes butter beans fruit salad mousse coffee	turkey potatoes sprouts stuffing Christmas pudding brandy sauce coffee

TABLE 6. MENUS IN KHARTOUM

27 March to 30 April inclusive

BREAKFAST							
entil soup ried fish ea or coffee	Egyptian beans liver cheese tea or coffee	boiled eggs cheese tea or coffee	lentil soup fried fish tea or coffee	boiled eggs cheese tea or coffee	sausages eggs tea or coffee	lentil soup fried fish tea or coffee	Egyptian beans liver fried egg tea or coffee
LUNCH							
chra stew ice alad resh fruit (apple, banana)	molokhia stew rice salad kisra cherries cream caramel	potato stew macaroni salad pineapple (tinned) custard	bean stew rice macaroni cherries jelly	aubergine pie salad macaroni baglawa	lentil soup roast mutton salad chips cauliflower trifle	ochra stew rice salad cherries cream caramel	molokhia stew pigeon (roast) rice salad melon
SUPPER							
ongue hips alad heese	fried fish potato salad rice pudding cheese	sausages egg chips apples (fresh)	cutlet potatoes salad melon jelly cheese	chicken salad peas and carrots melon cheese	veal rice potato salad mango cheese	tongue potato salad banana fritters banana (fresh) guava (fresh) cheese	cutlets chips salad marrow bananas oranges cheese

Clothing

All dressed to suit themselves. The Sudanese had been provided with overcoats before they arrived in Cambridge and rarely went out without them. They also as a rule wore gloves and some bought warm hats. The men wore a thick shirt or a shirt and vest, pants, substantial trousers and socks, a woollen 'pullover' and a jacket. The British men wore their normal winter garments. Some of both ethnic groups had particoloured close-fitting woollen headgear which always generated a certain amount of good humoured banter. The women wore a skirt and 'sweater' or a thick dress with some variety of slip, a girdle and woollen pants underneath, woollen stockings and shoes or lined boots. They also put something warm over their heads out of doors.

In Khartoum the men wore a thin cotton shirt, sometimes with short sleeves, and sometimes with a vest of some kind under it. A few wore a light woollen 'pullover' in the early morning. A number liked sandals or gymshoes with or without socks, made of cotton or one of the synthetic fibres. The women wore a light frock or a skirt and a half sleeved blouse, some form of brassière with or without a slip, brief little pants underneath, and usually sandals without socks or stockings. They tended to put on light hats if they were to be out for some time in the middle of the day. Some of the men and also the women changed into shorts both in Cambridge and Khartoum for squash or other vigorous exercise. The Muslims of both sexes tended to wear their national dress in Khartoum, particularly in the later parts of the day, and one of the women did so all the time both in Cambridge and Khartoum, but over the same sort of garments the others had on.

METHODS

Energy expenditure

This was carried out by recording 'activities' and indirect calorimetry, as described by Durnin & Passmore (1967). The results for all the determinations of energy have been expressed as kilocalories (kcal) and mega-joules (MJ). Each subject kept a diary in which he recorded what he was doing minute by minute. The time spent on these various activities was added up daily and difficulties in the classification of any of them were discussed.

The basal metabolic rate of all subjects was determined in Cambridge using a Kipp and Zonen diapherometer and again in Khartoum using a Benedict–Roth spirometer. All values fell within the normal range. No evidence was found that the resting metabolic rates of the two groups were different, or that the resting oxygen consumptions of either group were lower in Khartoum than they were in Cambridge (Collins & Weiner 1968). This is not surprising. The methods used in the two places were not the same, which would have been a pre-requisite for a comparison between the resting rates in the two places, nor had the subjects had previous training in how to use the machines—as, for instance, Martin (1930) had had. It took some days to determine the resting metabolic rates of all the new arrivals and there were cultural difficulties, moreover, in getting at the basal metabolic rates of any of the females in Khartoum before they got up in the morning. A study of the previous work shows that, apart from the fact that individuals vary greatly among themselves, no real change in the mean of either group was to be expected in a few days (Osiba 1957), possibly not for about 6 months (MacGregor & Loh 1941; Roberts 1952), even if then (Malhotra, Ramaswamy & Ray 1960).

The minute volume of the expired air was measured with Max Planck respirometers during representative 'activities' of each subject on some 20 to 30 occasions both in Cambridge and Khartoum. Unfortunately facilities were not available for analysing expired air on a scale sufficient to cope with the numbers of samples. It was therefore necessary to assume that 5 % of the oxygen was extracted from the inspired air. Five subjects were tested in Cambridge when working on a stationary bicycle, and four subjects were subsequently tested in Edinburgh when walking on a treadmill, and the extraction rates observed did not differ widely from this figure. It was accordingly used to calculate the rates of oxygen consumption. Where no measurements of the energy cost of an activity had been made, figures given by Durnin & Passmore (1967) were used.

Although the indirect calorimetry was thus limited, each subject had been trained in making scientific observations, and the activities were recorded carefully. The records are therefore likely to have been more reliable than usual in surveys of energy expenditure. In calculating daily rates of energy expenditure serious errors are far more likely to arise from inaccurate records of activities than from inaccurate figures for the energy being expended on them. There is nothing to suggest that a common error may have biased all the calculated daily expenditures and for any one subject the calculated figure is unlikely to be in error by more than 10 %.

Dietary intakes

The amounts of each item of food on the menu served to the subjects were recorded, and the weight of any uneaten material deducted from the weight served. The subjects were able to choose how much of each dish they wanted and there was usually enough to provide an additional serving for those with larger appetites. Each subject had his or her own container of butter, sugar, jam or marmalade, and salt. These were weighed daily before breakfast and replenished as required. Drinks were measured into calibrated plastic mugs or taken from proprietary bottles or cans of known volume. The subjects were individually responsible for keeping a record of the number and type of drinks they had in the day. This record was collected daily and checked with the subject.

The meals were arranged so that, broadly speaking, the menus repeated on alternate days.

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Samples of each food were taken for analysis on at least two occasions, and on every occasion if it was, or seemed likely to be, variable in composition.

The foods were stored in the refrigerator during the day in Cambridge and then at −20 °C until analysed. In Khartoum the samples were frozen immediately, packed while still frozen, and transported to London by air in an insulated box, and then immediately by road to Cambridge where they were at once unpacked and stored at −20 °C until analysed. They were still in a frozen state on their arrival in Cambridge.

The samples were allowed to thaw out and then mixed very thoroughly in the container in which they had been stored. Portions were then taken for the determination of moisture and ash. The ash was extracted with hydrochloric acid as described by McCance, Widdowson & Shackleton (1936) and sodium determined by flame photometry. Foods of unknown composition or of variable composition were analysed for fat and total nitrogen; carbohydrate was estimated by difference. In the foods eaten in this study little or no error was introduced by this approximation.

A few foods were not analysed for nitrogen, fat and carbohydrate if their composition had been well established. The figures for them were taken from McCance & Widdowson (1960) or Watt & Merrill (1964), making allowance for any difference between the amount of water in the samples analysed and the food as given in these tables.

Urine and blood

Urine was collected over 24 h periods under toluene. The volume was measured and a portion retained for determination of freezing-point, sodium and total nitrogen. The measurements of total nitrogen were made on pooled samples, representative of the entire 8 days; the other measurements were made on the individual daily samples.

Blood was withdrawn without stasis before breakfast into disposable syringes. Clotting was prevented with heparin. Some of the blood was used for the determination of haemoglobin and packed cell volumes and the remainder separated and used for the determination of sodium.

Vigilance and arithmetic tests

The first of these was a 1 h vigilance test and the second a 30 min adding test. Both have been shown to respond to a rise in body temperature (Wilkinson *et al.* 1964). Both tests have also been shown recently to be able to detect a reduction of sleep—to 2 h on one night, for example, or 5 h on two (Wilkinson 1969). Tests of the vigilance type, moreover, have been found to be impaired by heat (Mackworth 1950; Pepler 1958) and cold (Poulton, Hitchings & Brooke 1965).

In the vigilance trial the experimental party were subjected to four 1 h tests on 4 alternating days, first in Cambridge and then in Khartoum. Controls for the British subjects did not travel to Khartoum, but carried out the same two sets of tests with the same interval of time between them in Cambridge. It was planned to control the Sudanese subjects in a similar way, but unfortunately it was not possible to complete the second set of tests in Khartoum.

In the test itself the subjects were required to listen for 1 h to a series of $\frac{1}{2}$s bleeps occurring every 2s over a background of 'white' noise at a sound pressure level of about 85 dB above threshold. Forty of the 1800 bleeps heard during the hour lasted only for three-eighths of a second and these were irregularly placed among the others. The subject's task was to report the short bleeps by pressing a key. Each subject's correct and incorrect reports were subsequently added up and recorded.

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In the adding test each subject was given a book containing 215 little 'sums' on each page. Each consisted of five 2-digit numbers and a space for the answer to be written underneath them. The subjects' task on each occasion was to complete correctly as many sums as possible in half an hour. The performances of each subject were 'scored' according to the number of sums completed and the percentage incorrect. The experimental party carried out one half-hour test on each of the 8 experimental days in England and again, later, in Khartoum. Controls for the British subjects carried out the same routine at the same intervals of time in Cambridge and those for the Sudanese subjects did this in Khartoum.

After the first vigilance test half of the subjects were given their scores immediately it was over, and, after the first adding tests, just before the second one on the following day. The other subjects were not given their scores. After the second of each of these tests the results were given to those subjects who had not received them after the first one and withheld from those who had been told them on the previous occasion, and this alternating routine was maintained throughout the series.

Results and comments

Energy expenditure

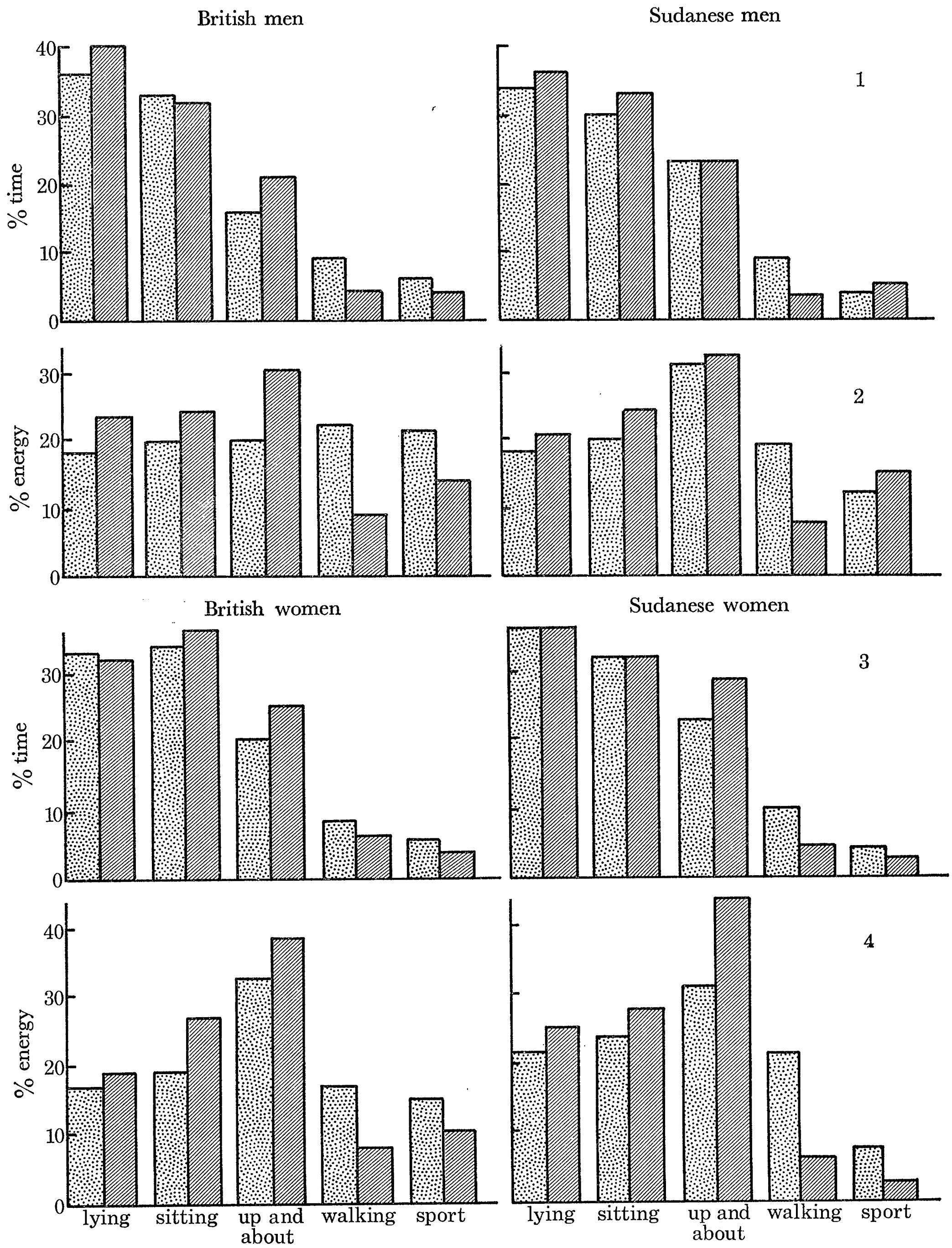
Table 7 shows the mean amounts of energy expended by the different subjects in Cambridge and Khartoum. All but one of the subjects expended less energy in Khartoum and the results for the one exception were close enough together to be within the range of the method's experimental error. The differences between the expenditures of the British males in Cambridge and Khartoum, and between those of the Sudanese males also, were both highly significant ($P < 0.001$ in each case). There were similar differences at a lower level between the women's

Table 7. Mean daily expenditure of energy in Cambridge and Khartoum

	British subjects					Sudanese subjects			
	Cambridge		Khartoum			Cambridge		Khartoum	
males	MJ	kcal	MJ	kcal	*males*	MJ	kcal	MJ	kcal
John H.	15.5	3705	11.8	2820	F. Abdeen	13.3	3170	11.3	2690
Alec M.	10.8	2690	8.7	2090	S. Ahmed	11.8	2820	10.0	2380
David McL.	15.4	3670	11.6	2760	H. Ahmed	11.7	2797	—	—
David M.	14.7	3500	10.9	2600	A. Asha	13.1	3130	12.0	2860
Charles P.	13.2	3150	11.9	2830	T. Gaafer	14.3	3420	13.8	3300
Andrew P.	14.3	3420	13.2	3140	S. Ibrahim	14.9	3560	13.2	3150
Malcolm P.	12.0	2860	10.3	2460	A. Latif	11.5	2750	11.1	2180
Peter S.	13.4	3200	11.4	2710	A. Maghoub	12.4	2970	11.1	2640
Ian S.	14.8	3530	10.9	2610	A. Tambal	11.6	2760	10.3	2460
Tony T.	13.6	3250	11.6	2770					
David W.	15.0	3580	—	—					
mean, excluding D.W.	13.8	3298	11.2	2679	mean, excluding H.A.	12.9	3074	11.3	2704
females					*females*				
Felicity M.	8.9	2130	—	—	A. Ziada	8.4	2000	8.6	2060
Hilary O.	11.6	2770	9.8	2340	L. Abdalla	8.7	2070	7.3	1730
Caroline P.	11.3	2693	—	—	T. Lewis	10.5	2510	8.2	1950
Dorothy S.	11.4	2720	10.0	2390					
mean, excluding F.M. and C.P.	11.5	2745	9.9	2370	mean	9.2	2193	8.0	1913

expenditures of energy in Cambridge and Khartoum, but there were not enough of them to treat the results statistically.

Figure 1 shows the mean percentages of their total time spent by the male subjects lying, sitting, up and about, walking and at sport in Cambridge and Khartoum, and figure 2 the mean percentages of their total energy expended on these occupations. Figures 3 and 4 give similar information about the women.



FIGURES 1 TO 4. The percentage of the men's and women's total time spent and total energy expenditure at various occupations. ▦, Cambridge; ▨, Khartoum.

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The British and the Sudanese spent the greater part of their time together and the general pattern of their activity was, therefore, much the same. Figures 1 to 4 show this, but they also bring out some of the reasons behind the general results in table 7. Both the British and the Sudanese spent more of their total time walking in Cambridge than they did in Khartoum. This was partly because they were expected to walk from Sidney Sussex College to the laboratories and canteen once or twice a day and several of their minor tasks and exercises involved walking. The weather was cold, moreover, and both sexes tended to walk vigorously at speeds not far from 6.5 km/h unless they were out to look at the shops. In Khartoum the distance from the canteen and men's hostel to the laboratory was about the same as the distance from the College to the working centre in Cambridge, but there was very nearly always transport available. The streets were dusty, moreover, and very hot at midday and people would hang about for the transport rather than walk, and when they did walk their speeds were not more than 5 km/h. Consequently, both sexes expended more of their total energy walking in Cambridge than they did in Khartoum. When the actual figures for the time and the expenditure of energy were subjected to analysis, the differences for both groups of males were highly significant ($P < 0.001$).

The British spent more time and energy playing games in Cambridge than they did in Khartoum ($P < 0.1$ and 0.025 respectively), but the Sudanese did not. In compensation for this the British spent less of their time and expended less of their energy on their backs and pottering about in an inactive way in Cambridge than they did in Khartoum ($P < 0.005$). Such considerations help to show why there was a greater difference between the mean energy expenditures of the British in the two environments than there was between those of the Sudanese (see table 7).

Energy intakes

Table 8 gives the mean individual intakes of energy per day of the subjects in Cambridge and Khartoum. As was to be expected the intakes and expenditures of the males in Cambridge were at a lower level than those of the recruits studied by Edholm *et al.* (1970). The mean intake of the British males amounted to 13.8 MJ/day (3283 kcal/day) as against 10.1 MJ/day (2416 kcal/day) in Khartoum and the difference was significant ($P < 0.005$). The two British women also had higher mean energy intakes in Cambridge than they had in Khartoum. The mean intake of the Sudanese male subjects was 13.6 MJ/day (3238 kcal/day) in Cambridge as against 12.4 MJ/day (2972 kcal/day) in Khartoum ($P < 0.05$) and all three Sudanese women had higher intakes in Cambridge than they did in Khartoum. The means for the three were 8.3 and 6.8 MJ/day (1970 and 1632 kcal/day). There was no internal evidence whether these reduced intakes in Khartoum were the direct result of the action of the environment on the centre for regulating appetite or whether they were secondary to the reduced expenditures (see table 7). The former is the more probable, however, since Edholm *et al.* (1964) obtained energy intakes in his soldiers 25% less in Aden than in Britain, although their energy expenditures were about the same in each place.

Energy balances and changes of weight

Tables 9 and 10 show each person's total energy balance and his or her change of weight over the 8 experimental days in Cambridge and in Khartoum. The means for the British and the Sudanese men and women as groups are also given and finally the means for all the British and all the Sudanese together. In Cambridge both ethnic groups gained weight, particularly the Sudanese. The correlation coefficient between the energy balances and change of weight in British males was $+0.581$ ($P < 0.05$), but when the sexes were combined the correlation

TABLE 8. MEAN DAILY INTAKE OF ENERGY IN CAMBRIDGE AND KHARTOUM

	British subjects					Sudanese subjects			
	Cambridge		Khartoum			Cambridge		Khartoum	
males	MJ	kcal	MJ	kcal	*males*	MJ	kcal	MJ	kcal
John H.	16.5	3937	12.1	2890	F. Abdeen	12.3	2931	13.4	3195
Alec M.	7.4	1761	9.4	2240	S. Ahmed	14.2	3396	14.1	3362
David McL.	14.6	3476	10.0	2380	H. Ahmed	13.8	3289	—	—
David M.	11.1	2658	12.4	2960	A. Asha	14.5	3472	12.3	2945
Charles P.	15.2	3614	9.9	2360	T. Gaafer	14.9	3554	13.1	3118
Andrew P.	15.0	3580	9.4	2250	S. Ibrahim	14.8	3525	12.0	2873
Malcolm P.	13.7	3279	8.6	2060	A. Latif	14.3	3420	13.0	3092
Peter S.	14.3	3418	11.2	2680	A. Maghoub	11.8	2816	10.7	2547
Ian S.	14.7	3496	8.5	2030	R. Tambal	11.7	2786	11.1	2644
Tony T.	15.1	3609	9.7	2310					
David W.	14.5	3454	—	—					
mean, excluding D.W.	13.8	3283	10.1	2416	mean, excluding H.A.	13.6	3238	12.4	2972
females					*females*				
Felicity M.	7.2	1718	—	—	A. Ziada	7.9	1880	5.9	1411
Hilary O.	11.3	2697	10.7	2550	L. Abdalla	8.8	2104	7.7	1830
Caroline P.	14.0	3343	—	—	T. Lewis	8.1	1927	6.9	1654
Dorothy S.	11.5	2734	8.5	2030					
mean excluding F.M. and C.P.	11.4	2716	9.6	2290	mean	8.3	1970	6.8	1632

TABLE 9. THE EFFECTS OF THE ENERGY BALANCE ON THE BODY WEIGHT (CAMBRIDGE)

	British subjects				Sudanese subjects		
	total energy balance				total energy balance		
males	MJ	kcal	change of weight/kg	*males*	MJ	kcal	change of weight/kg
John H.	+7.7	+1840	+2.10	F. Abdeen	−8.0	−1920	+1.26
Alec M.	−31.1	−7420	−0.20	S. Ahmed	+19.4	+4620	+0.70
David McL.	−6.5	−1550	+0.95	H. Ahmed	+16.5	+3936	+1.25
David M.	−28.2	−6730	−1.15	A. Asha	+11.4	+2720	+0.80
Charles P.	+15.5	+3700	+0.43	T. Gaafer	+4.5	+1070	+0.60
Andrew P.	+5.3	+1275	+0.14	S. Ibrahim	+21.9	+5220	+1.49
Malcolm, P.	+13.9	+3322	+0.20	A. Latif	+11.0	+2620	+1.64
Peter S.	+7.3	+1740	+0.55	A. Maghoub	+9.0	+2152	+0.50
Ian S.	−1.1	−272	+1.30	R. Tambal	+4.8	+1136	+0.69
Tony T.	+12.0	+2860	+1.08				
David W.	−4.2	−1008	+0.85				
mean	−0.9	−204	+0.57	mean	+10.0	+2395	+0.99
females				*females*			
Felicity M.	−13.8	−3290	+0.20	A. Ziada	−4.0	−960	+0.80
Hilary O.	−2.4	−584	+0.99	L. Abdalla	+1.1	+272	+1.30
Caroline P.	+22.2	+5280	+0.475	T. Lewis	−19.5	−4660	−0.01
Dorothy S.	−0.4	−88	+0.05				
mean	+1.4	+330	+0.43	mean	−7.5	−1793	+0.70
mean males + females	−0.3	−66	+0.53	mean males + females	+0.6	+136	+0.92

coefficient was +0.492 and this was just not significant ($P > 0{\cdot}05$). The correlation coefficient between the energy balances and the changes of weight in the Sudanese males was 0.149 and when the women were included the correlation coefficient rose to +0.391 which was still not significant.

In Khartoum the British men lost weight as a group and so did the women. The correlation coefficient between the energy balances and the change of weight was +0.454 for the men ($P > 0.05$) and for the two sexes together +0.512 (again $P > 0.05$). The Sudanese men had a mean average gain in weight as in Cambridge and their mean energy balance was positive

Table 10. The effect of the energy balances on the body weight (Khartoum)

British subjects	total energy balance			Sudanese subjects	total energy balance		
males	MJ	kcal	change of weight/kg	*males*	MJ	kcal	change of weight/kg
John H.	+2.3	+560	0	F. Abdeen	+16.9	+4040	+1.70
Alec M.	+5.0	+1200	0	S. Ahmed	+32.9	+7856	+1.82
David McL.	−12.7	−3040	−0.23	H. Ahmed	—	—	—
David M.	+12.1	+2880	−0.23	A. Asha	+2.9	+680	−0.68
Charles P.	−15.8	−3760	−0.91	T. Gaafer	−6.1	−1456	+2.49
Andrew P.	−29.8	−7120	−1.82	S. Ibrahim	−9.3	−2216	+0.57
Malcolm P.	−6.7	−1600	−0.68	A. Latif	+30.6	+7296	+2.49
Peter S.	−1.0	−240	−1.59	A. Maghoub	−3.1	−744	−1.14
Ian S.	−19.4	−4640	−1.36	R. Tambal	+4.9	+1172	−0.23
Tony T.	−15.4	−3680	−0.45				
David W.	—	—	—				
mean	−8.1	−1944	−0.73		+8.7	+2079	+0.88
females				*females*			
Felicity M.	—	—	—	A. Ziada	−21.8	−5192	+0.68
Hilary O.	+7.0	+1680	−0.20	L. Abdalla	−3.4	−800	−0.90
Caroline P.	—	—	—	T. Lewis	+10.0	+2368	−0.27
Dorothy S.	−12.1	−2880	−0.50				
mean	−2.5	−600	−0.35		−5.1	−1208	−0.16
mean males + females	−7.6	−1803	−0.70		+5.0	+1182	+0.60

and the correlation coefficient was +0.581. This fell to +0.44 when the women were included and neither of these coefficients was significant.

All these correlations would probably have been higher: (1) if the groups had been more homogeneous, (2) if the measurements of the energy expenditures had been more exact, and (3) if the percentage of water in the lean body mass could have been stabilized or accurately measured.

Organic constituents of the diets

Table 11 gives the mean chemical composition of the diets eaten by the British subjects in Cambridge and in Khartoum, and Table 12 the corresponding information about the Sudanese subjects. The small energy intakes in Khartoum *vis-à-vis* Cambridge, which have already been discussed, and shown in table 8, were caused by the intakes of most of the organic food constituents also being smaller as tables 11 and 12 show. Only the mean protein intake of the Sudanese men was an exception to this and it was mainly brought about thus. (1)

The Sudanese men and women had energy intakes in Khartoum nearer their energy intakes in Cambridge than the British had. (2) As table 13 shows, moreover, the Sudanese elected to make up their intakes of energy with more of the high protein foods available in Khartoum

Table 11. Mean chemical composition of the diets eaten by the British subjects

	Cambridge			Khartoum		
	protein (as N)	fat	carbohydrate	protein (as N)	fat	carbohydrate
males	g/day	g/day	g/day	g/day	g/day	g/day
John H.	18.3	144	454	17.3	104	361
Alec M.	12.7	32	314	15.9	61	308
David McL.	17.0	141	434	11.1	81	313
David M.	17.2	113	327	14.2	109	335
Charles P.	18.1	140	492	10.6	59	362
Andrew P.	18.3	130	491	11.4	75	325
Malcolm P.	17.3	120	458	11.8	73	284
Peter S.	17.2	122	481	12.0	89	360
Ian S.	20.3	142	432	11.5	65	265
Tony T.	15.7	153	472	11.7	72	353
David W.	17.7	126	471	—	—	—
mean excluding D.W.	17.2	124	436	12.8	79	327
females						
Felicity M.	10.0	74	218	—	—	—
Hilary O.	13.9	107	330	11.4	87	322
Caroline P.	15.3	134	440	—	—	—
Dorothy S.	14.2	113	353	12.5	67	322
mean excluding F.M. and C.P.	14.1	110	342	12.0	77	322

Table 12. Mean chemical composition of the diets eaten by the Sudanese subjects

	Cambridge			Khartoum		
	protein (as N)	fat	carbohydrate	protein (as N)	fat	carbohydrate
males	g/day	g/day	g/day	g/day	g/day	g/day
F. Abdeen	14.4	116	404	19.6	109	444
S. Ahmed	15.8	127	487	18.9	101	508
H. Ahmed	18.4	102	493	—	—	—
A. Asha	16.6	109	503	14.5	78	488
T. Gaafer	14.7	131	459	20.3	107	411
S. Ibrahim	14.1	144	482	16.5	90	418
A. Latif	16.8	106	538	16.8	93	473
A. Maghoub	16.2	90	417	15.0	79	370
A. Tambal	13.7	94	418	17.0	81	378
mean excluding H.A.	15.3	115	464	17.3	92	436
females						
A. Ziada	11.8	73	237	10.6	52	172
L. Abdalla	10.7	78	272	11.2	56	262
T. Lewis	11.0	79	245	11.6	62	201
mean	11.2	76.7	251	11.1	57	212

than the British did. Consequently the Sudanese men and women had absolute intakes of protein in Khartoum above, or little below, those in Cambridge, whereas those of the British were well below.

TABLE 13. THE MEAN PERCENTAGES OF THE DIETARY ENERGY DERIVED FROM PROTEIN

	Cambridge	Khartoum
British men	13.0	13.8
British women	13.0	13.2
Sudanese men	11.7	14.4
Sudanese women	14.2	16.5

Diurnal dietary variations

There were, as always on such freely chosen dietaries, considerable personal variations of an apparently random nature, and the ranges of these have not been included in tables 8 to 12. There was, however, one almost consistent finding. Both the British and the Sudanese men, and the British women, ate less on their first than on their second or on their 'average' day. The Sudanese women were not so consistent. The results are most easily summarized as energy intakes and are given in table 14. The differences were all significant. Since the differences were

TABLE 14. VARIATIONS IN THE MEAN FOOD INTAKES OF THE SUBJECTS WITH THE PROGRESS OF THE EXPERIMENT

	Cambridge						Khartoum					
	1st day		2nd day		8-day mean		1st day		2nd day		8-day mean	
subjects and significances	MJ	kcal	MJ	kcal	MJ	kcal	MJ	kcal	MJ	kcal	MJ	kcal
British subjects *males*	12.0	2873	14.4	3441	13.6	3255	8.2	1952	11.8	2818	10.3	2458
between days 1 and 2			$P < 0.001$						$P < 0.01$			
between day 1 and the 8-day mean					$P < 0.01$						$P < 0.001$	
females	8.6	2046	10.0	2390	11.0	2623	7.6	1812	10.8	2570	9.7	2317
Sudanese subjects *males*	10.9	2597	12.8	3067	13.6	3243	10.9	2614	13.5	3223	12.4	2972
between days 1 and 2			$P < 0.01$						$P < 0.01$			
between day 1 and the 8-day mean					$P < 0.001$						$P < 0.01$	
females	8.4	1997	7.4	1772	8.2	1970	6.4	1519	6.6	1574	6.8	1634

shown equally whether the subjects were playing the part of hosts or guests, travelling and major changes in the environment overnight can be excluded as being the important reasons. The main one was probably the procedure (tiresome at first) of measuring one's food and drink. The results show clearly how deceptive the results of a one-day food-weighing project might be, however carefully it was done.

The exchanges of water

Table 15 shows the mean daily intakes, functional expenditures and excretions of water and solutes by the British subjects and table 16 the corresponding information about the Sudanese party. The intake of water includes the water taken as drinks, as part of the solid food, and the water of metabolism. These were measured by weight. The first two shaded so imperceptibly into each other owing to the milk, sweetened soft drinks, sauces and gravies that all consumed, that it was not considered justifiable to try to separate them. The water of metabolism was calculated in the conventional way on the assumption that 100 g of protein gave rise to 40 g of

TABLE 15. THE MEAN DAILY INTAKE, FUNCTIONAL EXPENDITURE AND EXCRETION OF WATER; AND OF OSMOLAR MATERIAL IN THE URINE. BRITISH SUBJECTS

	Cambridge				Khartoum			
	total intake ml	undetermined loss/ml	urine vol./ml	urine mmol/day	total intake ml	undetermined loss/ml	urine vol./ml	urine mmol/day
males								
John H.	3720	1822	1898	1059	4314	2801	1513	765
Alec M.	3054	774	2280	1068	3646	1313	2333	871
David McL.	2882	1667	1215	867	3061	2495	566	625
David M.	3309	1360	1949	1057	3523	2272	1251	761
Charles P.	3382	1521	1861	1297	3295	2479	816	700
Andrew P.	3113	1469	1644	965	3705	2950	855	565
Malcolm P.	3521	1062	2459	1004	3833	1662	2171	661
Peter S.	3440	1181	2259	1112	4749	2554	2195	734
Ian S.	4885	1129	2756	1205	4323	2119	2204	684
Tony T.	2705	1311	1394	919	3391	2655	737	566
David W.	3731	1926	1805	1143	—	—	—	—
mean excluding D.W.	3401	1330	1972	1055	3784	2330	1464	693
females								
Felicity M.	1831	675	1156	726	—	—	—	—
Hilary O.	2322	919	1403	909	2605	1635	970	787
Caroline P.	3419	985	2434	1165	—	—	—	—
Dorothy S.	2440	829	1611	759	2790	1476	1314	658
mean excluding F.M. and C.P.	2381	874	1507	834	2698	1556	1142	723

TABLE 16. THE MEAN DAILY INTAKES, FUNCTIONAL EXPENDITURES AND EXCRETIONS OF WATER; AND OF OSMOLAR MATERIAL IN THE URINE. SUDANESE SUBJECTS

	Cambridge				Khartoum			
	total intake ml	undetermined loss/ml	urine vol./ml	urine mmol/day	total intake ml	undetermined loss/ml	urine vol./ml	urine mmol/day
males								
F. Abdeen	2813	1578	1335	778	3713	2463	1250	805
S. Ahmed	3102	1398	1704	822	4032	2764	1268	802
H. Ahmed	3390	1217	2173	992	—	—	—	—
A. Asha	3486	1509	1977	979	4188	3336	850	674
T. Gaafer	2889	1401	1488	974	3858	2889	969	1106
S. Ibrahim	3021	1545	1476	851	3633	2738	895	649
A. Latif	3516	1006	2510	908	3873	2263	1610	708
A. Maghoub	2915	1363	1552	957	3539	2785	754	790
A. Tambal	2254	1046	1208	944	3249	2548	701	645
mean excluding H.A.	3000	1508	1656	902	3761	2723	1037	772
females								
A. Ziada	2250	897	1353	636	2397	1456	941	480
L. Abdalla	1870	921	949	647	1914	1119	795	491
T. Lewis	2111	1043	1068	633	2469	1266	1103	566
mean	2077	954	1123	639	2260	1280	946	512

water, 100 g of fat to 107 g of water and 100 g of carbohydrate to 55 g of water. The volume of urine was measured and assumed to be the volume of water excreted by the kidney, because the correction involved in converting urine volume to urine weight is of the same order as the weight of solutes in the urine, and thus for practical purposes urinary volume may be regarded as urinary water.

The intake of water by the British men and women, taken together, was on the whole higher in Khartoum than Cambridge ($P < 0.025$). Four of the subjects (John H., Malcolm P., Peter S. and Ian S.) drank large amounts of water with their meals, and their intakes in both environments tended to be high. Alec M. drank all his liquid apart from his meals. Some of the Cambridge party, who happened to be medical students, were aware of the potential risks of dehydration in a hot climate, and this may have influenced the amount they drank in Khartoum. The mean daily 'undetermined' loss of the men and the women was about 1000 ml higher in Khartoum than in Cambridge, and the difference was highly significant ($P < 0.001$). This loss included the water evaporated from the lungs and skin and water excreted with the faeces. Three of the subjects reported that they had loose stools on 1 day in Khartoum, and another on 2 days but none of them had serious diarrhoea and the water lost in this way was probably not much higher in Khartoum than in Cambridge. The difference was due to the evaporation. The urine volumes were nearly all lower in Khartoum and this difference was significant ($P < 0.001$). The osmolal concentrations in the urine were not, however, high. Only one, which amounted to 1104 mmol/kg, exceeded the 1000 mmol/kg mark. This was partly due to the fact that in Khartoum, where high osmolalities might have been expected, the osmolar output in the urine was low, and, in fact, the difference between the outputs in Cambridge and Khartoum was highly significant ($P < 0.001$).

In the pattern of their water exchanges the Sudanese men and women resembled the British. Their intake of water from all sources was higher in Khartoum ($P < 0.001$) and their functional expenditure of water also ($P < 0.001$). Their urine volumes were smaller and again the difference was highly significant and less osmolar material was excreted in the urine, but this difference was only significant when men and women were dealt with as a single group ($P < 0.01$). Two of the mean daily urines in Khartoum had osmolalities exceeding 1000 mmol/kg. T. Gaafer's was 1131 and A. Magoub's 1061 mmol/kg but most of the others were quite dilute, one of them, A. Latif's, only 437 mmol/kg. One of the women's urines contained 511 mmol/kg. There was a considerable similarity between the water exchanges of the British women and the Sudanese women. Their response to the change of environment was similar to that of their menfolk, but their intakes and urine volumes were characteristically lower as were their functional losses and osmolar outputs.

The intake and output of sodium

In table 17 are set out the mean daily intakes and excretions of sodium by the British subjects, and similar information about the Sudanese subjects is given in table 18. Both tables show that the food, which had been prepared intentionally according to local custom, provided considerably more salt in Cambridge than it did in Khartoum. All the intakes were affected by this and the differences were highly significant ($P < 0.001$). In terms of sodium chloride, which is the usual way of expressing salt intakes, the British men were getting from their food about 13 g/day in Cambridge and 6 g/day in Khartoum. The mean for the Sudanese men was rather less than this in Cambridge and rather more in Khartoum, but the difference was there just

TABLE 17. THE MEAN DAILY INTAKE AND EXCRETIONS OF SODIUM (mmol) BY THE BRITISH SUBJECTS

	Cambridge					Khartoum				
	intakes					intakes				
	food	added at table	total	urine	difference	food	added at table	total	urine	difference
males										
John H.	248	7	255	247	−8	127	21	148	119	−29
Alec M.	232	0	232	279	+45	125	21	146	120	−26
David McL.	205	14	219	198	−21	79	40	119	67	−52
David M.	183	24	207	228	+21	133	40	173	126	−47
Charles P.	256	46	302	250	−52	78	48	126	95	−31
Andrew P.	264	3	267	212	−55	85	6	91	37	−44
Malcolm P.	204	7	211	249	+38	93	15	108	83	−25
Peter S.	209	18	227	262	+35	107	21	128	80	−48
Ian S.	230	35	265	307	+42	97	23	120	75	−45
Tony T.	222	16	238	183	−55	82	17	99	40	−59
David W.	212	41	253	271	+18	—	—	—	—	—
mean excluding D.W.	225	17	242	241	−1	101	25	126	84	−41
females										
Felicity M.	127	10	137	145	+8	—	—	—	—	—
Hilary O.	175	42	217	227	+10	113	57	170	112	−58
Caroline P.	166	60	226	293	+67	—	—	—	—	—
Dorothy S.	187	26	213	184	−29	94	53	147	139	−8
mean excluding F.M. and C.P.	181	34	214	206	−9	104	55	159	126	−33

TABLE 18. THE MEAN DAILY INTAKES AND EXCRETIONS OF SODIUM (mmol) BY THE SUDANESE SUBJECTS

	Cambridge					Khartoum				
	intake					intake				
	food	added at table	total	urine	difference	food	added at table	total	urine	difference
males										
F. Abdeen	201	11	212	197	−15	157	32	189	140	−49
S. Ahmed	217	8	225	208	−17	146	23	169	135	−34
H. Ahmed	203	32	235	259	+24	—	—	—	—	—
A. Asha	196	2	198	226	+28	120	23	143	107	−36
T. Gaafer	201	67	268	217	−51	156	74	230	211	−19
S. Ibrahim	204	44	248	199	−49	131	15	146	105	−41
A. Latif	214	42	256	273	+17	125	38	163	129	−34
A. Maghoub	164	22	186	189	+3	129	40	169	113	−56
A. Tambal	166	22	188	199	+11	123	21	144	111	−33
mean excluding H.A.	195	27	223	214	−9	136	33	169	131	−38
females										
A. Ziada	127	10	137	154	+17	74	34	108	68	−40
L. Abdalla	151	3	154	124	−30	78	17	95	73	−22
T. Lewis	138	37	175	151	−24	98	42	140	104	−36
mean	139	17	155	143	−12	83	31	114	82	−33

the same, and equally significant. Both the British and the Sudanese tended to add less salt to their food in Cambridge than they did in Khartoum, but the additions were small compared to the amounts provided by the food and the differences were not significant. This was partly because the amounts of salt added by the individuals in both ethnic groups—see tables 17 and 18—varied so extensively—0 to 46 mmol/day in Cambridge for the British men and 2 to 67 mmol/day for the Sudanese. In spite of the additions at table tending to compensate for the amounts in the food, the total intakes of the British and the Sudanese in Cambridge were both significantly higher than they were in Khartoum ($P < 0.001$ and $P < 0.005$ respectively). Both the British and the Sudanese excreted significantly more sodium in their urine in Cambridge than they did in Khartoum ($P < 0.001$ and $P < 0.005$ for the two groups respectively) but there was always some present. The smallest mean daily excretion was that of Tony T. and his urine contained 40 mmol (2.32 g NaCl)/day. The small amounts of sodium in the urine in Khartoum helped to account for the small amounts of solutes to which reference has already been made.

The figures in the fifth and tenth columns of each table are the differences between the intakes of sodium and the amounts found in the urine. When the former exceeded the latter a negative sign has been placed before the figure and a positive sign if the amount in the urine was the greater of the two. The mean of the British men in Cambridge was −1 and for the women −9. In Khartoum the figures were −41 and −33. The corresponding figures for the Sudanese men were −9 and −12 in Cambridge and −38 and −33 in Khartoum. The subjects were probably losing very little salt through the skin in Cambridge, and the amounts in the faeces were certainly small. The overall means, therefore, in Cambridge were of exactly the order to be expected and the variations between the individuals may be regarded as random errors due to technical difficulties, magnified by the fact that the amounts in question were small and were obtained as the differences between two large numbers.

In Khartoum the same random errors must have been made but the sodium in the urines was consistently less than that in the food and the greater part of the missing sodium was undoubtedly lost through the skin.

The osmolar loads and their disposal

Table 19 gives the mean daily osmolar loads provided by the diets in Cambridge and Khartoum. These were derived from the minerals, organic materials in the food and their products of metabolism. Of the last urea was the most important. The table also shows the routes by which these loads were excreted. The amounts in the urine were measured directly (see table 15 and 16). The amounts in the sweat were obtained by adding 10 % to the amount of sodium found there (tables 17 and 18) to account for the potassium invariably present and in approximately these proportions (Hancock, Whitehouse & Haldane 1929; McCance 1938*b*, 1969): this figure was then doubled since both these electrolytes are fully ionized in the body and accompanied by chloride or organic ions in both the sweat and the faeces. The urea found in the sweat was neglected, since all the most recent work has gone to show that the total dermal losses of nitrogen are small, even in hot climates, and most of these will be abraded cells (Darke 1960; Ashworth & Harrower 1967; *Recommended intakes* 1969). The fallacies inherent in all balance experiments (Wallace, Weil & Taylor 1958) probably lie behind the higher estimates of, for example, Isaksson, Lindholm & Sjogren (1966).

The figures show that there was a very considerable difference in the osmolar loads provided by the two diets. This was in great measure due to the larger amount of salt eaten in Cambridge. The British also ate more protein there and consequently excreted more urea but the Sudanese did not (tables 11 and 12). It is also clear from the table that 10 to 13 % of the osmolar material was disposed of by the skin and to a very limited extent by the faeces in Khartoum whereas these routes of disposal were negligible in Cambridge.

Table 19. Mean daily osmolar loads (mmol) and their routes of disposal in Cambridge and Khartoum

		Cambridge			Khartoum		
			route of disposal			route of disposal	
		total for disposal	urine	sweat and faeces	total for disposal	urine	sweat and faeces
British	men	1057	1055	2.2	783	693	90
	women	854	834	20	795	723	72
Sudanese	men	922	902	20	806	722	84
	women	655	639	26	584	512	72

The obligatory water expenditures in the two environments

Table 20 sets out the mean daily obligatory losses of water by the British and the Sudanese in Cambridge and Khartoum. The losses by the skin and lungs are those which have already been summarized in tables 15 and 16: the losses in the urine are those which would have been required to excrete the solute load in the urine assuming it had contained 1175 mmol/kg. This

Table 20. The mean daily water requirements of the British and the Sudanese in Cambridge and Khartoum

		Cambridge			Khartoum		
		obligatory losses			obligatory losses		
		lungs and skin/ml	urine ml	requirements ml	lungs and skin/ml	urine ml	requirements ml
British	men	1330	893	2223	2330	590	2920
	women	874	710	1584	1556	616	2172
Sudanese	men	1508	770	2278	2723	658	3381
	women	942	590	1532	1280	436	1716

is a modest figure for the concentrating capacity of the normal kidney (McCance *et al.* 1969). The minimum obligatory expenditures are the sum of the two and represent the requirements of the subjects in the experimental environments. The differences between Cambridge and Khartoum and between the men and the women are characteristic and both these differences might have been forecast qualitatively from a knowledge of the environments and the diets. Thus (1) the losses by the skin were always higher in Khartoum because the environmental temperatures were higher and were, in fact, about 900 ml/day higher for the men and 500 ml for the women. (2) The obligatory losses in the urine were always higher in Cambridge than in Khartoum because the solute load was higher in the former, and less of the sodium chloride in it was excreted by the skin. (3) The women's figures were always below those for the men because (*a*) they took less exercise and probably produced less sweat per unit energy expended on it (McCance 1938*a*, 1969; Wyndham *et al.* 1965; Fox & Löfstedt 1968; McCance *et al.* 1968;

Fox *et al.* 1969; McCance & Purohit 1969) and (*b*) they ate less and, therefore, the solute loads on their kidneys were not so great, but their power of renal concentration equally good.

Table 21 sets out the amount of water that these men and women would have had to drink to maintain osmolar balance if they had been given this food in dry packs, and forced to lead the lives they did in fact lead. About one-fifth of the obligatory expenditure came from the water of metabolism. The former could of course have been materially reduced by cutting down the insolation, the amount of exercise taken and the solute load (Hervey & McCance 1952, 1954).

Table 21. The minimum amounts of water needed in that form per person per day to meet the obligatory expenditures in the two environments

	Cambridge			Khartoum		
	obligatory expenditure of water/ml	water derived from dry food by metabolism (ml)	minimum required (ml)	obligatory expenditure of water/ml	water derived from dry food by metabolism (ml)	minimum required (ml)
British men	2223	416	1807	2920	298	2622
women	1584	346	1238	2172	289	1883
Sudanese men	2278	416	1862	3381	381	3000
women	1032	244	788	1716	216	1500

The salt requirements

It may be deduced from tables 17 and 18 that the mean daily obligatory losses of sodium (as NaCl) were about 0.60 g for each of the subjects in Cambridge, and about 2.4 and 2.0 g for the men and women respectively in Khartoum. Had the food contained no more than this it would have been unpalatable to most of the subjects. No salt would theoretically have been excreted in the urine and there would, in all probability, have been a reduction in the volume of extracellular fluid, and a possible loss of physiological efficiency. Hence, to provide for palatability and to supply a safety margin, the practical provision of sodium chloride in Khartoum should have been around 7 to 8 g per person per day. This is in fact about the amounts ingested by the British men and the Sudanese women. The British women and the Sudanese men ate rather more (between 9 and 10 g per person per day).

Although it is probable that Indians from the subcontinent may not lose so much water or salt through the skin as the British or the Sudanese would when subjected to an equal heat load (McCance & Purohit 1969; McCance 1969) the present findings may be compared with those of Malhotra *et al.* (1959). The Indian soldiers, then investigated, walked for 2 h/day in environmental dry-bulb temperatures of 37 to 40 °C and their obligatory water losses were about 5000 ml/day. 3.1 g/day was not enough sodium chloride to meet their requirements for palatability and physiological loss. 6.2 g was just about enough but some would have preferred a little more.

Vigilance and arithmetic tests

Table 22 sets out the mean results of the British and the Sudanese subjects, and of their controls, in the vigilance test, and table 23 gives the same information about the adding tests. For the British subjects the series of tests in the Sudan was the one expected to be done under 'stress'; for the Sudanese subjects signs of 'stress' were thought more likely to be shown in

TABLE 22. THE MEAN NUMBER OF TIMES THE $\frac{3}{8}$ SECOND BLEEPS WERE DETECTED CORRECTLY AND INCORRECTLY IN THE VIGILANCE TEST

		British				Sudanese			
		subjects		controls		subjects		controls	
	test	correct	incorrect	correct	incorrect	correct	incorrect	correct	incorrect
Cambridge	1	16.0	27.6	16.7	20.7	18.1	50.9	16.5	29.2
	2	20.0	14.7	19.6	29.2	23.2	53.1	20.7	31.4
	3	20.0	19.0	2.00	30.2	22.5	36.4	24.0	66.2
	4	26.0	14.7	22.0	17.6	21.5	34.6	24.4	26.8
mean		20.5	19.0	19.8	24.4	21.3	43.7	21.4	38.4
Khartoum	1	22.0	11.8	16.2	22.5	21.4	35.6	—	—
	2	24.0	14.9	16.0	17.3	25.6	22.7	—	—
	3	26.0	12.9	16.5	17.3	26.2	20.4	—	—
	4	25.0	12.4	16.8	13.5	24.3	19.1	—	—
mean		24.2	13.0	16.4	17.6	24.4	24.4	—	—

TABLE 23. THE MEAN NUMBER OF SUMS FOUND TO HAVE BEEN DONE CORRECTLY AND INCORRECTLY IN THE ADDING TEST

		British				Sudanese			
		subjects		controls		subjects		controls	
	test	correct	incorrect	correct	incorrect	correct	incorrect	correct	incorrect
Cambridge	1	142	4.89	137	4.34	116	8.58	147	9.32
	2	158	4.59	153	3.15	121	5.46	161	8.11
	3	160	4.72	162	3.76	123	5.82	162	7.54
	4	170	4.00	172	2.60	123	7.27	172	7.08
	5	182	4.03	184	3.26	133	5.25	183	6.25
	6	191	3.95	186	3.01	141	6.06	196	7.53
	7	199	4.17	192	3.60	149	4.49	204	6.24
	8	205	3.57	201	2.83	153	4.14	205	6.99
mean		176	4.24	173	3.32	132	5.88	179	7.38
Khartoum	1	163	6.96	170	6.07	127	7.47	173	8.53
	2	184	6.15	188	3.90	133	6.09	188	8.19
	3	190	4.88	204	3.93	132	7.87	192	8.57
	4	197	5.59	210	4.74	137	4.70	206	9.61
	5	205	4.84	205	4.60	143	4.52	202	8.73
	6	215	4.78	212	4.34	150	5.04	211	7.79
	7	219	5.12	217	4.46	146	4.48	218	7.22
	8	216	5.18	221	3.10	159	5.35	219	6.19
mean		199	5.43	203	4.39	141	5.69	201	8.10

TABLE 24. THE WATER EXCHANGES OF FIVE SUDANESE STUDENTS IN JUNE

males	total fluid intake/ml	water vol. / ml	undetermined losses/ml
A. Asha	5340	817	4523
F.	4561	930	3631
A.	4196	632	3564
mean	4699	793	3906
females			
L. Abdalla	3153	402	2751
T. Lewis	2620	902	1718
mean	2887	702	2235

Cambridge. In fact, neither of the two environments created enough 'stress' to affect the performance of the subjects. Indeed, in the vigilance test the British subjects did relatively better in Khartoum than their controls who had never left Cambridge. The Sudanese, moreover, did relatively better in Cambridge than would have been expected from the performance of their controls at the same stage of practice in the Sudan, and in the adding test this difference was significant ($P < 0.05$).

The performance of the subjects was not affected by telling them the results of their previous tests. If they had been, the better performances in the unusual environment might have been attributed to some extent to 'motivation'—but it was not so.

In short, no evidence was obtained that the heat in the Sudan was great enough to upset the performance of the British subjects; nor was there any evidence that the Sudanese subjects were put off by the cold of the Cambridge winter to an extent which made them do their tests worse than they did them later at home.

In spite of these rather negative findings one interesting difference between the two ethnic groups did emerge from the vigilance test. The Sudanese, while reporting about the same number of signals correctly as the British did, made many more false reports. Among the experimental subjects this effect was highly significant ($P < 0.001$); among the controls the effect was almost as pronounced but did not quite reach significance, probably because the Sudanese completed only one series of tests. This apparent lack of caution on the part of the Sudanese may reflect ethnic differences of a psychological nature which would repay further study.

Discussion

This investigation was originally planned as a contribution to our knowledge of human ecology and adaptation rather than to that of acclimatization to heat, and it was mainly for this reason that women were included among the subjects. The arrangements allowed the participants many degrees of freedom, and in everything they did of their own volition—in the clothing they wore, the exercise they took, and when they took it—each participant tended to choose the alternatives he preferred and to behave generally in a way which helped him to remain within his particular zone of thermal comfort (Benzinger 1969).

Special attention was given all the same to salt and water requirements because of their importance in hot climates. Many more such experiments will have to be made, however, before concrete, quantitative, advice can be given to those organizing civilian or military operations in places where the temperatures will be high. The advice can never be really precise, moreover, because both salt and water requirements vary according to (*a*) the individual or individuals concerned, (*b*) their sex, (*c*) the degree of acclimatization, (*d*) the work to be done, (*e*) the climatic environment or 'heat load' to be expected. Among civilians the last is perhaps the most difficult to define because they can find so many ways of escaping from an unpleasant 'heat load'—by varying, for example, their clothing and behaviour—and this has come out over and over again in this experiment.

Nevertheless, had the British party gone to Khartoum at the end of June, as it was originally hoped they would do, their salt and water requirements would certainly have been higher. El Neil investigated the water exchanges of five Sudanese medical students in June 1966 as a pilot experiment. The studies have not yet been published although some preliminary results were reported to a private meeting at the end of July. The environmental temperatures ranged at the time from 28 to 40 °C but the subjects were largely indoors. Three of the subjects in the pilot experiment (A. Asha, L. Abdala and T. Lewis) also took parti n the main experiment later on, and the figures obtained in 1966 are given in table 24. The intakes of A. Asha and L. Abdala and their losses by the lungs and skin were over 1 l higher in the summer. T. Lewis's intake and undetermined losses were also raised, but not so much. All their urine volumes were lower in June 1966 than in the main experiment. One might hazard a guess from these very limited and not strictly comparable results that the water requirements of the men would have been at least 1 l more in June and those of the women 800 ml more.

Although the experiments were not planned to study 'acclimatization' to heat, the process is well known to accelerate the commencement of sweating and to increase its amount. The Sudanese males were presumably more acclimatized than the British were and it is interesting, therefore, that the Sudanese men lost significantly more water by the lungs and skin in Khartoum (tables 15 and 16 and text) although their energy expenditure was the same (table 7).

In spite of its apparent simplicity this experiment has involved a considerable number of persons and techniques, and a team of about 10 people may be said to have been required to manage it. This may be compared with the team of 22 which was required for the Edholm *et al.* (1964) 'Aden' experiment. Nevertheless, the results obtained in Cambridge and Khartoum have been quantitative. Differences, many of them statistically significant, have been found between the way people ordered their day, the exercise they took, the quantities of food they ate and the amounts of salt and water they required. Differences have also been found between the sexes in many of these respects. The results have, therefore, a number of facets which might be discussed but, in a sense, there is little to discuss. The facts are there for future reference as a contribution to the International Biological Programme.

The originators of this experiment are immensely grateful to all those who made it possible. Thanks must go first to the Government of the Sudan for their hospitality and support and to the Medical Research Council for their financial backing, but many others come to mind—the Professors who put their departments at our disposal were equally important in their own way, the cooks also who prepared the meals and the highly trained staff who weighed them. The subjects too must not be forgotten, but for many of them it was an adventure and most of them enjoyed it.

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