SOME MEDICAL ASPECTS OF HUMAN CLIMATOLOGY
IN THE EQUATORIAL TROPICS*

BY

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Early in 1944 the Board of Admiralty invited the Medical Research Council's Royal Naval Personnel Research Committee to examine the effects imposed on ships' companies by the climatic conditions which were prevalent in warships operating in warm climates. At that time it appeared inevitable that the defeat of Japan would be accomplished only by a series of amphibious and air operations which would keep an enormous fleet supported by a train of supply and repair ships constantly at sea for many months, or even years, in tropical or subtropical waters. The impact of the warm climate on these operations could not be forecast, and it was clearly of the utmost importance to know more about it. The essence of the problem and the early activities of a subcommittee appointed to deal with it have been described by Critchley (1945, 1947), Bedford (1946), Ellis (1947, 1948, 1950), and Mackworth (1950). During the last five years this work has been continued at the Royal Naval Tropical Research Unit, Singapore. Some of the conclusions, which go a long way to provide a solution to the purely medical side of the wartime operational problem, have been referred to elsewhere (Ellis, 1953a).

I shall discuss three medical aspects of the warm-climate problem, with which the Singapore experiments were not primarily concerned but from which they could at no time be divorced—namely, skin diseases, fatigue, and heat incapacitation—and consider some of the general principles which underlie their prevention. In developing this theme I shall draw on the work of the Medical Research Council's team at Singapore and on numerous discussions with my colleagues Dr. R. K. Macpherson, Dr. J. S. Weiner, Mr. R. D. Pepler, Dr. J. O. Irwin, Dr. R. H. Fox, Miss H. M. Ferres, Mr. P. S. B. Newling, Mr. A. R. Lind, Dr. M. L. Thomson, Dr. P. J. Hare, Surgeon Lieutenant-Commander R. T. John, R.N., and Major J. M. Adam, R.A.M.C.

Skin Diseases

During the war about 10% of ships' companies in the Eastern and British Pacific Fleets and 6% of those on shore were treated every month for some form of skin disease. When the Tropical Research Unit advance party arrived at Singapore in 1948 an Army team, led by Major P. H. Sanderson, R.A.M.C., were just completing a dermatological survey of British troops in Malaya and Hong Kong. They found fungus infections on the bodies of one man in three, on the feet of one man in two, prickly heat affecting one in four, and 8% with bullous impetigo (Sanderson and Sloper, 1953). Prickly heat

(miliaria rubra) and pyogenic and mycotic dermatoses were thus prominent in the initial appraisal of the difficulties to be surmounted in experiments which were to involve repeated daily work in warm atmospheres.

The precautions adopted were simple. No man with an infectious condition of the skin was allowed at first to work in the climatic chambers. Candidates with moderate or severe infections which were not easy to cure were rejected at their initial medical examination. Each subject wore freshly laundered shorts or overalls or worked in the nude each time he was exposed to high temperatures and was given two freshly laundered towels—one for use during an experiment and one for use afterwards. They used hot- and cold-water showers after each exposure. The bathrooms and climatic chambers (including personal furniture such as chairs and stepping-stools) were scrubbed out with disinfectant each Sunday morning. Each man wore his own plimsolls, a new pair being issued to him on arrival, except in experiments which involved heavy sweating on successive days, when they sometimes preferred to work in bare feet and were allowed to do so. The plimsolls were rinsed in fresh water and dried in a drying cupboard each night between experiments, so that the men always put on dry shoes.

On arrival at the unit approximately 35% of the subjects had mild mycotic infections, usually of the toe clefts, and were given the appropriate treatment. About 25% had mild acne vulgaris or boils or pimples. The latter were the only skin disorders which increased in incidence subsequently (to about 35%), and several men found that working in the heat made their acne worse also. Only 4% showed any evidence of prickly heat, and even then the diagnosis was sometimes doubtful. The rarity of this condition during the experiments illustrated that repeated exposure to very warm conditions for a few hours each day for as long as five months will not cause it, provided those exposed can spend some of the time between exposures in an atmosphere where their skin is not moistened with perspiration.

When the combined requirements of the Korean and Malayan campaigns threatened to curtail the supply of subjects during 1951 and 1952, confidence in these simple precautions was such that men were allowed occasionally to participate in experiments with quite severe dermatoses of fungal origin which were treated. No cross-infections were observed to occur, and the conditions were cured or improved during the experiments. During four years 320 men from the Royal Navy and the Army acted as subjects for periods varying from 2 to 201 days and were available at the unit for over 15,000 man-days. With one exception, which is described later, it was never

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necessary to remove a man from an experiment for skin disease. This justified a heavy laundry bill and the expenditure on installing adequate showers and a drying cupboard.

Clean bodies, clean clothes, clean and efficient bathrooms, routine inspections, and frequent and early treatment where necessary will do much to reduce the wastage of man-hours in areas where skin disease is rife. Under campaigning conditions all these ideals are often impossible to achieve, but they should be the aim of those responsible for the administration of ships, barracks, and permanent camps. The responsibility for maintaining acceptable standards of personal and barrack hygiene lies with the executive officers and non-commissioned officers, who are in intimate and continuous contact with the men, rather than with the medical branches, as anti-malarial discipline did during the war; but unit medical officers can do much to inculcate the right ideas in these quarters. In ships, the best personal hygiene in the world cannot be expected to keep the skin healthy when the thermal environment is so warm that continuous sweating is unavoidable and the water, even from the "cold" showers, is so hot that a man can hardly stand under it. These evils can be avoided only by sound design and construction and by sending to the Tropics ships which have been built to operate in warm climates. This is now axiomatic following the dramatic reduction in skin diseases and other heat illnesses after the introduction of air-conditioning to submarines operating in the Tropics in wartime and more recently to frigates patrolling the Persian Gulf during the warm months of the year.

When the preventable skin diseases have been dealt with there will remain a small nucleus of conditions which cannot be cured and which get better only when the sufferer returns to a cooler climate, and for these invaliding is often the only solution.

Fatigue

Tropical neurasthenia (Eijkman, 1924; Carthew, 1927; Stannus, 1927; Castellani, 1929; Lamprell, 1948) and the syndrome to which the terms tropical fatigue or hot-climate fatigue have been applied more recently (Lee and Macpherson, 1948; Macpherson, 1949; Ellis, 1952a, 1953b) belong essentially to the same group of climatic disorders, but differ in degree and chronicity with the proportions of the climatic or neurotic components and the different circumstances under which they are encountered. When healthy men live for a long time in an unduly warm climate, some of them suffer from hot-climate fatigue, typified by lethargy, mental retardation, reduced powers of concentration and sense of responsibility, irritability, mild changes in personality, and forgetfulness. These are associated often with excessive sweating, unsatisfactory sleep, skin diseases, loss of weight and appetite, and ill-defined digestive disorders. This syndrome develops particularly when men live and work at levels of warmth which result in the presence of unevaporated sweat on the skin and in the clothing or bedding. The majority will suffer in one way or another after a time, but in a healthy community serious breakdown will not be encountered very often, and there may be little reference to the condition in routine sickness returns. Most of these effects can be surmounted temporarily when it is necessary to make a special effort, and are relieved by resumption of life in a cooler climate.

Factors other than climate, inertia, monotony, isolation, domestic stress, excessive social activity, adverse conditions of service, overwork, inadequate cultural influences, unsuitable clothing, insect pests, and ill-health may all colour the picture according to the local situation; but some of the features of "hot-climate fatigue" are nearly always present

(Ellis, 1953b). The causes can be represented in various ways:

- Hot climate alone (a warship's company in the Tropics).
- Hot climate+inertia+domestic stress (housewife's fatigue).
- Hot climate+monotony, perhaps+alcohol (as a result of long-term residence).
- Hot climate+isolation+operational fatigue+domestic worries+insects+lowered morale (troops engaged in tropical warfare).
- Hot climate+overwork+social stress, perhaps+alcohol (Government or Service officials in large centre).
- Hot climate+monotony+domestic stress+isolation, perhaps+alcohol (a warship's company on detached service).
- Hot climate+monotony+domestic stress+isolation+insects+cultural deficiencies (isolated tropical communities).

And the clinical picture can be as varied as the causes.

Some of the psychological characteristics have been investigated in the laboratory. At Cambridge, Mackworth (1950) used tests simulating various tasks which are carried out in warships, tanks, or aircraft to show that, even during exposures lasting only two to three hours, the performance of naval ratings and of men from the Royal Air Force deteriorates when the average effective temperature lies between 81 and 86° F. (27.2 and 30° C.).* At Singapore, Pepler observed a similar though more variable effect when the subjects were naval ratings who were acclimatized to the Tropics. This zone of warmth is only slightly above that—78–85° F. (25.6–29.4° C.)—within which the majority of sedentary lightly clad persons become uncomfortably warm in that part of the world (Ellis, 1952b, 1953c).

The complex, and only partially elucidated, physiological basis of fatigue in temperate climates may be complicated in warm climates by profuse sweating, with associated losses of water and electrolytes and the secondary effects on the skin and the circulatory systems, by the impact of a raised body temperature on cellular metabolism, the central nervous system, and neuromuscular conduction, and by the response to stress, when stress is present, of the endocrine system. A great deal has been learnt of the factors which give rise to fatigue in the Tropics, but we know very little of the physiological sequence which intervenes between the cause and the effect; although some pieces of this jigsaw puzzle are now beginning to fall into place.

Hot-climate Fatigue

We repeatedly saw acute fatigue developing at Singapore when 12 men were carrying out standardized work, stepping up on to and down from 12 in. (30 cm.) stools in time to a metronome, in a climate which was near to the limit they could tolerate. "Step-climbing" was always easy at the start of an experiment. They stepped uniformly in good time, and were fairly silent and circumspect. Perhaps 8 out of 12 would be reading magazines. As their exposure continued they started to sweat and some of them would stop reading. Then the step-climbing became "tired," although the time-keeping was still quite good. Next, some of the subjects would start stepping out of time, and this might consist either in stepping too quickly or stepping too slowly or stepping too quickly at one time and stepping too slowly at another. Their actions became badly co-ordinated; some staggered occasionally; some moved their arms very much more than they had done previously; some moved them less; a few looked as though they had the "weight of the world on their shoulders"; and one man would hyperventilate and grit his teeth. Euphoric cheerfulness and a smiling acceptance of the conditions would fluctuate with grumbling irritability and morose attitudes. Eventually, at times, some of them could not go on with their work. They did not collapse, but they simply could not continue to step on and off their stepping-stools and said that they felt so tired that they could fall asleep on the spot.

*Wet- and dry-bulb temperatures of 90 and 80, and 95 and 85° F. (32.2 and 26.7, and 35 and 29.4° C.) when the average air speed was 100 feet (30.5 metres) per minute and the subjects were stripped to the waist.

This excessive tiredness was accompanied sometimes by nausea, headache, light-headedness, or aches in the legs or trunk, but it also occurred alone. Slowness in answering questions, mistakes in reading a clock or in naming a colleague or messmate, a false appreciation of the passage of time, over-confidence in their ability to survive, and afterwards a poor memory for events at the time simulated the symptoms of anoxia. These latter features may occur a considerable time before an individual finds the atmosphere intolerable. They are insidious, often unrecognized by the person affected, and, if he should be an operator who needs to think and act quickly, may have disastrous effects on the efficiency with which he does his job. The identical work which the men were doing was tolerated easily under slightly cooler conditions, and "acute hot-climate fatigue" seemed as useful a term for describing this condition as any other.

Neither hot-climate fatigue nor tropical fatigue is an entirely satisfactory descriptive term for the more chronic effects of warm climates, and both are likely to be abused. A phrase indicating a general slowing down and inefficiency, but not implying that the condition is due to either fatigue or neurosis, such as "hot-climate decrement," might be more acceptable; but it is wise to pause before coining any more new names for this diffuse group of conditions. It certainly does not help the recovery of a man with a good personality who is suffering from severe environmental stress to label him a neurasthenic; nor does it help, at times, to send him to a psychiatrist when all he wants is a rest in cooler surroundings. "Tropical neurasthenia" should be reserved as a diagnosis for the more serious and much rarer cases with well-developed neuroses or psychoses, which tropical environmental stress may precipitate in persons who are already unstable or who have been ill before.

Heat Incapacitation

Probably the most important wartime sidelights on the aetiology of heat incapacitation were the recognition that widespread dermal anhidrosis following prickly heat might aggravate fatigue (Wolkin, Goodman, and Kelley, 1944; O'Brien, 1947) or precipitate acute heat incapacitation (Ladell, Waterlow, and Hudson, 1944), and the frequent observation that salt deficiency might give rise to fatigue as well as cause heat cramps or collapse.

The incidence of heat incapacitation is not easy to gauge. Many cases never come under medical care, or the symptoms are so transient that even if they do they are not included in the official sickness returns or are attributed to some other cause. Reports from ships' medical officers when the Eastern Fleet was congregating in 1944 revealed that the actual cases diagnosed as heat exhaustion amounted to about 5% of the total strength per year (0.4 per 100 man-months; Ellis, 1948). The true incidence must have been very much greater than this. In an excellent review of 120 naval patients with diagnosed salt-deficiency states, observed during two and a half years afloat in the Tropics, Stenning (1945) commented, "It is doubtful whether any single member of the ship's company who served at sea in the Tropics for more than six months was not affected to a greater or lesser extent by the effects of uncompensated salt loss." He divided his cases into subclinical salt deficiency, heat shock, heat exhaustion with abdominal pain, heat cramp, the "dyspeptic type," the "vomiting type," the "vomiting-diarrhoea-pyrexial type," salt deficiency with low-grade pyrexia, and hyperpyrexia. Loss of salt from the body, an abnormally low concentration of salt in the urine, and a satisfactory therapeutic response to salt administration were always diagnostic features.

Further evidence was provided by Thomson (1946), who described 66 cases which occurred in a battleship in the Eastern Fleet between January, 1944, and March, 1945: 89% were due to primary salt deficiency. Similar accounts are to be found in other naval medical officers' journals and leave no doubt that in wartime these problems were of major importance to the Navy. Notable features were the rarity of true hyperpyrexia—that is, temperatures exceeding

104° F. (40° C.)—and that newcomers to the Tropics were affected more frequently than acclimatized personnel.

In peacetime, ships are not usually manned with their war complements, nor are they closed down for action for long periods or "darkened" at night. Fuel economies limit the amount of sea time and high-speed steaming which is possible. These factors all help to alleviate the thermal environment between-decks. A request from the Commander-in-Chief of the Far East Station for all cases of heat exhaustion to be reported between June, 1952, and February, 1953, drew no replies. Minor heat incapacitation is not quite so uncommon as this suggests, particularly in troopers and other ships passing through the Tropics; but it is usually recognized promptly, and those afflicted recover rapidly and are often well again by the time they are seen by a medical officer.

The incidence of heat exhaustion was said to be as low in Army units as it was in Naval units in Malaya. However, my colleague, Captain R. H. Fox, R.A.M.C., kept this possibility in mind when he went on a three-day anti-bandit patrol in a fresh-water swamp during the rainy season whilst he was on leave in 1952. Although they were shaded from the sun by the jungle, the relative humidity of the atmosphere was high, and this, together with the heavy work of ploughing through swampy undergrowth whilst carrying heavy equipment, caused excessive sweating. It was considered that under these conditions casualties due to water and salt deficiency might occur, especially since drinking unpurified swamp water was discouraged, all fresh water had to be carried, and the men did not appreciate fully the necessity to drink adequately at frequent intervals. There were no casualties in his platoon, although the strain was severe, but four men in another platoon were incapacitated during the same operation and dropped out at various times, thus hazarding themselves and the rest of the party. Salt-deficiency dehydration was by far the most likely cause of their failure.

After discussions with Captain Fox, Lieutenant-Colonel W. M. Stewart, R.A.M.C., inquired concerning the incidence of similar cases amongst other units in the area. He concluded from the replies that in general the medical officers to the operational groups were not willing to diagnose heat exhaustion unless there was some severe disability without any other obvious diagnosis; but 31 cases of heat incapacitation were reported by the medical officer of one battalion within three months. These were all confirmed to be due to salt deficiency by the absence of chlorides in the urine and a favourable response to treatment with salt tablets. It is highly probable that the true incidence of heat incapacitation in the Army and in the Navy was, and still is, masked by the transient nature of this condition when it occurs in healthy men.

Physiological Features of Heat Incapacitation

Now, the subjects of the Singapore experiments were acclimatized to work in a warm climate, supplied plentifully with palatable drinking-water, and encouraged to take salt either in accordance with their personal wishes or as a fairly accurate replacement of the salt they had lost by sweating. Under these circumstances very few developed heat cramps. It was a rare occurrence for a man to collapse so completely that he lost consciousness while working in the climatic chambers, although they had to be supported frequently when they retired and afterwards were amnesic, either partially or completely, for the events at the time. True hyperpyrexia was never seen. Why, then, were they incapacitated?

First, there were the thermogenic factors, the heat absorbed from the air by conduction and convection and by the electro-magnetic waves of radiant warmth from the surroundings, and the heat generated internally by their metabolic processes. Together, these raised their temperatures beyond the limits at which their bodies could function efficiently.

Second, there were the processes which permitted evaporative cooling of the skin surface to take place under favourable circumstances but led to deficits in the body water and salt. These deficits occurred even when water was freely available and the men were trying their best to drink it, for many men cannot absorb water from the alimentary tract rapidly enough to maintain their body water at a constant level when they are sweating profusely. If they try to drink more than their body is willing to accept the water distends their stomachs, causing nausea, distaste for water, and, not infrequently, vomiting, when 1 to 2 pints (570 to 1,140 ml.) of fluid are projected forcibly. This distension of the stomach alone appeared to precipitate syncopal symptoms sometimes, presumably by pressure on the great veins, for the symptoms were relieved in some measure after vomiting. The loss of water in pure water deficiency is usually borne by the total fluids of the body, but when deficiency of sodium chloride is associated with it, as it is when sweating is the main cause, the strain will tend to fall more on the small extracellular fluid compartment, which includes the important plasma water. A relatively small deficit under these circumstances may give rise to symptoms of circulatory failure if the rate of sweating is high.

Third, vasovagal faintness, probably due to a sudden lowering of blood pressure in the great veins returning blood to the heart caused by a reduced circulating blood volume, the gravitational effects of sudden changes in posture, sudden peripheral vasodilatation or acute gastric distension, or due to emotional apprehension of the heat, was a not uncommon cause of temporary heat incapacitation. This was seen when subjects who had been sweating freely rose from a sitting to a standing position after they had been resting, or even when they sat upright after lying back in a canvas chair; and at times it would suddenly precipitate incapacitating symptoms in a man who had been symptom-free. Slowing of the heart rate was a characteristic feature, despite the climatic stress, as it is in the syncope of blood donors. Emotional factors may have contributed to the sudden exit of some subjects from experiments where climates of great severity were used; but they were more clearly demonstrated by occasional visitors who thought they were going to faint within a few minutes of entering the climatic chambers before any other effect could be incriminated, rather like medical students seeing their first operation.

Fourth, as I have described already, even though the thermogenic influences did not appear to be in themselves overpowering, although the intake of salt and water seemed ample and they did not faint, there were occasions when men simply could not continue with work which they could do with ease in a cooler climate. This accentuation, under very warm climatic conditions, of the normal fatiguing effect of a given work situation may of course be secondary to the combined effects of minor degrees of dehydration, pyrexia, or circulatory insufficiency, or to metabolic or endocrinological changes which have not yet been identified in relation to fatigue, or it may be a primary effect of the climate on the mechanism of fatigue itself.

This sequence of events can be related to the more severe clinical conditions which occur when quick relief from a warm environment is not possible, when the thermogenic load is greatly increased by powerful external factors such as the heat of the desert sun, heavy work, or impermeable clothing, when the normal compensatory mechanisms are interfered with by reduced sweating from acquired or congenital defects of the sweat glands, or when salt deficiency and dehydration are unrecognized or cannot be corrected. It provides a useful basis for classifying the mechanisms responsible for heat incapacitation when considering prevention and treatment.

Physiological Features of Heat Incapacitation in Healthy Young Men

- I. *Water and salt deficiency* (cramps, headache, circulatory failure, alimentary tract disorders, syncope, and fatigue)
- II. *Thermoregulatory failure* (rapidly rising body temperature, perhaps with headache, vomiting and clouding mentality, with either a dry or moist skin)

- (a) Thermogenic (due to excessive warmth, hard work, too much clothing, etc.)
- (b) Anhidrotic: acquired (following miliary rubra or sunburn); congenital (congenital sweat-gland defects)
- (c) Toxic-infective (for example, malaria and infectious fevers)
- III. *Circulatory failure* (rapid pulse, falling B.P. and dizziness, or "black-out" with bradycardia)
 - (a) Intense peripheral vascular dilatation
 - (b) Pooling of blood in dependent extremities
 - (c) Reduced circulating blood volume
 - (d) Acute distension of the stomach
 - (e) Vasovagal syncope due to reduced pressure in great veins, or, sometimes, emotional factors
- IV. *Acute fatigue* (inability to work efficiently in the relative absence of I, II, and III)

Heat incapacitation is a clumsy diagnosis; but a better alternative, for describing a condition in which fatigue, collapse, cramps, vasovagal fainting, abdominal upsets, or pyrexia may all be presenting symptoms of similar underlying physiological changes which prevent a man doing his work in a warm atmosphere, does not come easily to mind.

A review in retrospect of 110 case histories of acclimatized fit young men who were unable to complete their experimental tasks at Singapore revealed that fluid and electrolyte loss, pyrexia, and frequently circulatory failure too, often occurred together. One of the most common early complaints was abdominal discomfort with nausea, and another was headache. Cramps were a prominent feature only four times, and rectal temperatures rose above 104° F. (40° C.) on only three occasions. Postural fainting, probably vasovagal and associated with transient bradycardia, was a relatively common terminal incident, and severe progressive fatigue was another. One man sweated so profusely that his rectal temperature rarely reached 101° F. (38.3° C.), but he succumbed to circulatory failure unless he maintained a steady fluid intake. Another who sweated less profusely than most of the others, and was often unable to drink enough to replace the amount he did sweat, would depart before the others with a rapidly rising rectal temperature (103° F. (39.4° C.) or higher); but there was nothing to suggest that we were dealing with more than one clinical entity despite the diverse physiological effects and symptomatology.

None of the men exhibited dermal anhidrosis; but one of them, who became suddenly less heat-tolerant than he had been previously, developed diffuse and generalized miliary profunda, "rice-grain" distensions of the sweat glands, when he worked in a hot atmosphere. These became more prominent as he approached the limit of his endurance and faded within 10 minutes when he recovered afterwards in a cooler place. They were associated with marked acne vulgaris of the face, but not elsewhere. No obvious histological abnormalities of the sweat glands were detectable in biopsy material recovered from miliary-bearing areas. It was thought to be a constitutional defect related possibly to androgen-oestrogen imbalance.

The less acute states which do not lead to complete incapacitation and account for more chronic climatic illness may be classified in the same way. But there can be no strict demarcation between acute and subacute heat illness, nor between heat incapacitation which is due purely and simply to failure to adjust physiologically to a strenuous environment and failure which is aggravated by concomitant somatic or psychological defects. The scheme shown is not fully comprehensive, but it is adequate to cover the more common warm-climate effects which are encountered in healthy young adults. The prophylaxis of these conditions includes the prevention of skin diseases, which has already been discussed, the provision and use of adequate amounts of drinking-water and salt, and the control of the thermal environment.

Salt and Water Requirements

In the United Kingdom most adults who are not employed in hot industries have a total daily water intake or output of about 2.5 litres, and their salt requirements are met by the salt in their food or taken on the plate. Sweat contains between 0.1 and 0.6% sodium chloride, and the

amount a man sweats is related to the stress imposed by the thermal environment and the average energy cost of the work he is doing. Thus in one Singapore experiment, when a man (weighing 72 kg.) sat at rest for only three and a half hours wearing a pair of shorts in a saturated atmosphere at the temperature of the body—99.4° F. (37.4° C.), relative humidity 97%—he sweated 6.2 litres of sweat, an amount approximately equal to his total circulating blood volume or his normal water output for two and a half days in England. If the average salt concentration of his sweat had been 0.3%, he would thus have lost 18.6 g. in this short period of time.

When we began work in Singapore we accepted the advice that provided a man was allowed to drink as much water as he wished and advised to take plenty of salt with his food he would not become dehydrated. But when this advice was followed in an experiment involving continuous daily exposure (for four hours) for several months there was clinical and physiological evidence that some subjects became dehydrated and less heat-tolerant. When the salt losses were replaced systematically on a later occasion by giving each man 1 g. of salt for each litre of sweat he secreted during an experiment as well as by encouraging the practice of taking salt with the food, the men were able to withstand repeated daily exposure to much higher temperatures with equanimity.

Individuals vary enormously. Under the same working conditions one man may lose twice as much sweat or three times as much salt per unit of body weight as another man, and the day-to-day losses of the same individual over a period of several months may vary nearly as much. Furthermore, identical environmental conditions rarely recur outside the laboratory.

From the evidence available, salt appears to be the only substance which leaks away during heavy sweating in amounts which the body cannot afford to lose. Other electrolytes and most of the water-soluble vitamins are present, but in amounts which are unlikely to cause deficiencies in normally nourished people in the Tropics (Lugg and Ellis, 1954). Limitations of technique have left our knowledge of this aspect incomplete, however, and the sweat should not be overlooked as a possible pathway by which tropical deficiencies may occur until these gaps have been filled.

In practice the usual finding is that those who cannot avoid sweating freely day after day regulate their salt and water requirements without supervision, provided salt and palatable drinking-water are available and they understand the nature of salt deficiency. Many men who cannot take free salt can take sugar- and enteric-coated salt tablets. They learn that if they have diarrhoea, a poor appetite, vague indigestion, and develop a blotchy skin after taking a liberal supply of salt, then they have probably taken too much; and, alternatively, if they lose their appetite and energy and experience headaches, cramp-like aches and pains, occasional dizziness, "black-outs," and perhaps some loss of weight, when they have been sweating profusely and neglecting their salt intake, they recognize that this is probably the reason. The prompt therapeutic response in either case will show if they are correct in their assumptions.

Many men who cannot, or will not, drink tepid water will welcome cooled water. The way in which a fixed water ration is used may also influence the benefit to be derived from it. Recent observations by Kenney (1954) on male West Africans working in a warm atmosphere showed that when they drank more than 100 ml. of water in one dose a significant diuresis offset rehydration, so that when a man drank the same water ration in frequent small doses instead of occasional larger doses he saved as much as 300–400 ml. in 90 minutes.

General measures, such as increasing the salt content of food or drinking-water, need to be handled cautiously in view of the wide variation in individual requirements and likes and dislikes. In warships salting the main water supply is not practicable because of the adverse effect on the ships'

water-pipes. But the salt content of bread has recently been increased successfully on the Far East Station. The daily intake of the average man was increased by approximately 5 g.* in this way without impairing the palatability of the bread.

General directives concerning salt and water requirements in tropical theatres should be available and be kept up to date with current opinion on these matters; but their recommendations should be interpreted with due regard to the wide range of human variability and to the fact that too much salt, as well as too little, gives rise to unpleasant symptoms. The requirements under different operational circumstances can be assessed satisfactorily only by those on the spot. Further accurate studies of the salt and water requirements of men serving under different campaigning and climatic conditions would be of great practical value.

The Control of the Thermal Environment

It is not the duty of a health service to recommend measures for the control of the thermal environment, but it is a medical responsibility to advise on the limiting conditions above which adverse effects on efficiency, health, or comfort are likely to occur. A provisional recommendation made by the Royal Naval Personnel Research Committee to the Admiralty 10 years ago, that, wherever practicable, in spaces where men live or work in ships the effective temperature (or corrected effective temperature) should be kept below 80° F. (26.7° C.) and should not exceed 86° F. (30° C.) (Bedford, 1946), is supported by the results of the Singapore experiments as well as any such general recommendation could be expected to be. But I would prefer to see 78° F. (25.6° C.) as the upper desirable limit rather than 80° F. (26.7° C.). If the ventilation and air-cooling arrangements of ships, armoured fighting vehicles, or aircraft built for warm climates impose warmer conditions than 86° F. (30° C.) effective temperature on Service personnel for more than short periods the efficiency of the machine will be offset by the inefficiency of the crews, and the more this limit is exceeded the more serious the human failure is likely to be. There is no reason to believe that similar considerations do not apply to commercial enterprises and shipping.

The Singapore studies emphasize that when men are working in warm environments which are near to the limits they can tolerate, very small additions to climatic stress may turn a tolerable situation into one which few can withstand. One cannot add to the vigour of their work, expect them to wear extra clothing or equipment, introduce additional heat-producing machines into the compartments in which they work, increase the numbers of sweating and heat-producing occupants, or reduce the supply of ventilating air and air movement with impunity, or this narrow margin may be exceeded. A rise in wet-bulb temperature of only about 2° F. (1.1° C.) or a relatively small decrease in air movement, from a pleasantly perceptible (150 ft./min.) to a "still" or stagnant condition (20 ft./min., a normal indoor condition in England, or less) are sufficient to change otherwise identical and acceptable conditions of climate, work, and clothing into conditions which none can tolerate. Conditions which can be tolerated for two hours cannot be endured for a third hour. A man who sits at rest for three to four hours can withstand a wet-bulb temperature 4 to 5° F. (2.2 to 2.8° C.) higher than if he engages in constant light activity or intermittent work which is rather more strenuous.

When men who have been stripped to the waist wear drill overall suits over their shorts in very warm climates the additional stress is similar to that imposed by increasing the mean radiant temperature of their surroundings by about 40° F. (22.2° C.). Under these conditions the suit does not help them to withstand long-wavelength heat radiations such as men may have to endure in ships' machinery spaces. The waves of radiant warmth are impeded by the suit, but evaporative cooling is reduced so considerably that this gain

*The salt content of bread baked to the revised naval recipe is 10 g. per lb. (22 g. per kg.), compared with 5 g. per lb. (11 g. per kg.) with the normal recipe.

is discounted, and the overalls absorb approximately their own weight of sweat. The very real protection which overalls provide against steam leaks, burns from very hot metal parts, dirt or oil, and flash burns in wartime cannot be denied; but they should be made of the lightest and most ventile and durable fabrics which will meet these other requirements.

Since Bedford (1946) proposed that the effective temperature scales should be used in the Navy for describing warm environments, no better alternative has appeared. The ventilated dry- and wet-bulb thermometers, of either the "sling" or Assmann design, still provide the medical observer with the most accurate and convenient method for measuring the air temperature and humidity. The silvered katathermometer has not been replaced by any more simple and equally accurate alternative for measuring turbulent air currents of low velocity. The globe thermometer has emerged successfully from a series of comparisons, with other available methods for determining the mean radiant temperature, made by Newling in a "radiant-heat tunnel" at Singapore. The "corrected effective temperature" also gained support from physiological investigations by Macpherson and others of the team in the same radiant-heat tunnel (Macpherson, 1952). But it is wise to remember that the effective temperature scales were constructed primarily to deal with the thermal environment to which persons engaged in light work are exposed indoors during the summer in homes and offices in North America. They are most useful when used for this type of environment, and are beset with pitfalls when used for situations which they were not designed to meet.

Conclusions

Apart from information about the various factors which limit work at high temperatures, probably the most useful facts which have been derived from these studies so far are, first, that the effects on men in the Tropics are very similar to the effects observed on men doing the same kind of work in temperate climates, provided the workers are trained to work in the heat and are able to recuperate between exposures in an atmosphere which is not so warm that it induces perceptible sweating; secondly, that the upper tolerable levels of warmth for men in a similar state of training for work in warm atmospheres are much the same whether they are living in the Tropics or in England; and, thirdly, that the variations between individuals, and even in the same individual from day to day, are very great at times. Observations made on small numbers, or on only a few occasions, may be misleading if they are used as a basis for general conclusions. Finally, with regard to men who are not specially trained to work at high temperatures, Weiner and Macpherson (1953) have produced evidence, from experiments carried out under otherwise identical conditions in Singapore and at Oxford, which indicates that untrained men in England are less heat-tolerant than untrained men in Singapore.

I have referred to only a few aspects of the many problems which arise from the impact of warm climates on man, and no attempt has been made to review contemporary opinion on these controversial topics. There is still much to be learnt. Special situations, such as those which result when men have to work hard and wear impermeable protective clothing in warm atmospheres, may need to be investigated as separate problems when they arise, and the effects of repeated and prolonged exposure to warm atmospheres require much more study. But, within the limitations of the techniques available at the present time, many of the principles which are relevant to the practical problem of maintaining the efficiency and health of men engaged in military or naval operations in warm humid climates

are now established as firmly as they are likely to be by a purely experimental approach, and should be tested thoroughly in practice. In this way the shortcomings of the results of research will be revealed and new problems will be uncovered.

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REFERENCES

- Bedford, T. (1946). *Med. Res. Coun. Lond. War Memo. No. 17.*
 Carthew, M. (1927). *J. trop. Med. Hyg.*, **30**, 113.
 Castellani, A. (1929). *Ibid.*, **32**, 173.
 Critchley, M. (1945). *British Medical Journal*, **2**, 145, 208.
 — (1947). *Brit. J. industr. Med.*, **4**, 164.
 Eijkman, C. (1924). *Lancet*, **1**, 887.
 Ellis, F. P. (1947). *Brit. med. Bull.*, **5**, 1015.
 — (1948). *British Medical Journal*, **1**, 587.
 — (1950). *Med. J. Malaya*, **4**, 175.
 — (1952a). *Lancet*, **2**, 527.
 — (1952b). *J. Hyg., Lond.*, **50**, 415.
 — (1953a). *Ann. roy. Coll. Surg. Engl.*, **13**, 369.
 — (1953b). *Symposium on Fatigue*. Ergonomics Research Society. Lewis, London.
 — (1953c). *J. Hyg., Lond.*, **51**, 386.
 Kenney, R. A. (1954). *Brit. J. industr. Med.*, **11**, 38.
 Ladell, W. S. S., Waterlow, J. C., and Hudson, M. F. (1944). *Lancet*, **2**, 491, 527.
 Lamprell, B. A. (1948). *Med. J. Malaya*, **3**, 34.
 Lee, D. H. K., and Macpherson, R. K. (1948). *J. appl. Physiol.*, **1**, 60.
 Lugg, J. W. H., and Ellis, F. P. (1954). *Brit. J. Nutr.*, **8**, 71.
 Mackworth, N. H. (1950). *Spec. Rep. Ser. med. Res. Coun. Lond.*, No. 268.
 Macpherson, R. K. (1949). *Pap. Dep. Physiol. Univ. Qd.*, **1**, No. 10.
 — (1952). *Abstr. XIX int. Physiol. Congr.*, p. 583.
 O'Brien, J. P. (1947). *Brit. J. Derm. Syph.*, **59**, 125.
 Royal Naval Tropical Research Unit. Unpublished reports to the Medical Research Council's Royal Naval Personnel Research Committee.
 Sanderson, P. H., and Sloper, J. C. (1953). *Brit. J. Derm.*, **65**, 252.
 Stannus, H. S. (1927). *Trans. roy. Soc. trop. Med. Hyg.*, **20**, 327.
 Stenning, J. C. (1945). *J. roy. nav. med. Serv.*, **31**, 129, 195.
 Thomson, M. L. (1946). *Rep. R.N.P. 46/345 Royal Naval Personnel Research Committee. Med. Res. Coun. Lond.*
 Weiner, J. S., and Macpherson, R. K. (1953). *Abstr. XIX int. Physiol. Congr.*, p. 874.
 Wolkin, J., Goodman, J. I., and Kelley, W. E. (1944). *J. Amer. med. Ass.*, **124**, 478.

COMA AND ALLIED DISTURBANCES OF CONSCIOUSNESS IN HYPOPITUITARISM

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In an early account of hypopituitarism Simmonds (1914) described a woman who was subject to attacks of unconsciousness, one of which ended in death. Later it came to be recognized that these patients were prone to loss of consciousness and often died in coma, a phenomenon which was usually attributed to hypoglycaemia. Further experience has shown, however, that hypoglycaemia is only one of many factors which may affect their state of consciousness. Allott and Simmons (1951) and Summers and Sheehan (1951) have discussed "hypopituitary coma" in post-partum necrosis of the pituitary gland, while Caughey *et al.* (1952) and Ingraham *et al.* (1952) have reported on coma with tumours in and around the pituitary fossa. In other papers Caughey (1953, 1954) has described a variety of factors causing disturbances of consciousness in hypopituitarism. These changes of consciousness included hypersomnia, fainting, hypoglycaemic attacks, and "hypopituitary coma." From these and other reports it is clear that these patients are unduly vulnerable to factors affecting the level of consciousness, and that the diagnosis and