THE COMPOSITION OF HUMAN SWEAT

WITH SPECIAL REFERENCE TO VARIATION DUE TO ETHNIC ORIGIN, ACCLIMATIZATION STATUS AND OTHER FACTORS

A Thesis submitted for the Degree of

Doctor of Philosophy

at

The University of London

by

IAN CLARK MACDONALD

June, 1974

ABSTRACT

Recent research indicates that active transport of sodium in the secretory segment of the sweat gland, followed by the diffusion of water and other solutes into the lumen, forms a sweat precursor fluid. This precursor is modified as it passes through the duct by the reabsorption of sodium producing a more dilute solution. The sweat which is finally expelled at the skin surface however, can vary widely in composition from person to person. Previous work has shown that concentrations can be affected by dietary intake, skin temperature, sweat rate, duration of sweating and methods of sweat collection. Limited information, based on comparable techniques, is available on sweat composition of different ethnic groups.

For this study, standard methods for obtaining total body (excluding the head) sweat samples have been used. Results from tests in England, Sharjha, Israel, Nigeria, New Guinea and India have been presented. The ethnic groups studied included both sexes, different age groups and people at various levels of acclimatization.

Distinct ethnic differences were found in sweat electrolyte composition. The Indian army groups had the highest sodium/potassium ratios, but most tropical indigenes had much lower values than the British groups. Examination of urine electrolyte excretion rates indicated that many of the differences were due to dietary intake.

Females were found to have lower sweat sodium/potassium ratios than males. This difference was found to be independent of sweat rates and urine sodium/potassium ratios.

Changes in sweat composition during sweating episodes were examined before and after acclimatization. Increasing sodium concentrations and decreasing sweat rates have been attributed to hydration of the skin. Flatter regression slopes for sweat sodium/potassium ratio on time and on cumulative sweat volume after acclimatization suggest that fatigue of the metabolic process for sweat production may also be involved.

CONTENTS

INTRODUCTION

Many studies have been made on the chemical composition of human sweat. The results of these studies have been well documented but when one reads about the subject, the problem of describing the nature of sweat becomes evident. Reported sweat rates and composition vary from one study to the next and often it cannot be said whether this variation is due to differences in the people secreting the sweat, the method of stimulating sweating activity, collection techniques or other factors which may affect the process of sweat production.

The purpose of this study has been to determine whether or not differences in sweat electrolyte concentrations exist between groups of people from differing ethnic origins and environmental backgrounds and to examine why these differences should occur. By using the results obtained from a standardized thermoregulatory function test, the dependence of these concentrations upon acclimatization, sex, diet, skin temperature, sweat rates and the duration of sweating have been investigated.

Thermoregulation

Like other mammals, man must maintain his deep body temperature within narrow limits to continue functioning. To prevent overheating, he must dissipate the heat produced by metabolism or gained from the environment. In ambient temperatures several degrees lower than that of the body this is not a problem and the core temperature is usually maintained by controlling the convective and radiant heat losses from the body surface. These losses are dependent upon the difference between the body surface temperature and the environmental temperature. If metabolic heat production or the ambient temperature is increased, the required heat loss is adjusted by raising the temperature of the exposed surface and increasing the heat flow to the environment. This is done by increasing

the cutaneous blood flow to warm the skin, or removing insulation in the form of clothing. Increased air movement over the body also facilitates the removal of heat by convection.

These means of temperature regulation are effective, however, only as long as the environmental temperature is adequately lower than the body temperature (Collins & Weiner, 1962). As ambient temperature increases, the rate of convective and radiant heat losses decrease, so metabolic heat production must be reduced to prevent body temperature from rising to unacceptable levels. Under these conditions, heat can still be taken up by the evaporation of water on the skin surface. Although some evaporative heat dissipation always occurs from water lost by respiration or diffusion through the skin, this represents only about 12 W/m^2, or one fifth of the metabolic heat production in a resting man. By utilizing sweat glands to produce a watery secretion on the skin, man can increase evaporative heat dissipation to 420 W/m^2 in a hot dry environment (Robinson, 1962). Provided that an adequate drinking supply is available to maintain body water content, activity in hot conditions is limited by the amount of sweat that can be provided and evaporated on the body surface.

Sweat Glands

Eccrine sweat glands, numbering 2 - 3 million on the human body according to Kuno (1956), cover almost all parts of the body and are mainly concerned with thermoregulation. They are described as tubular invaginations of the epithelium with a single layer of cells forming the deeper secretory segment and a double layered excretory duct leading to the surface. The secretory cells rest upon a network of flat myoepithelial cells and an underlying hyalin basement membrane which surrounds the entire gland. The cells of the duct are generally cuboidal, becoming somewhat flattened closer to the skin surface (Montagna, 1956).

Although the total volume of the eccrine glands is calculated to be no more than 40 cc, they are capable of secreting as much as 2 litres per hour, or up to 10 litres each day (Kuno, 1956).

Histologically, the eccrine gland is simple and much the same diameter throughout its length. The secretory segment is closely coiled with the basal or proximal part of the duct. The distal section of the duct then leads more or less straight to the surface, forming a tight helix as it passes through the epithelium before opening directly onto the skin (Montagna, 1956), through a keratin ring (O'Brien, 1950).

When stained with toluidine blue, the single layered secretory segment has two distinguishable cell types, usually referred to as large clear cells and small dark cells, both resting on the myoepithelial layer and basement membrane (Montagna, 1956). The large clear cells, which in the resting state are laden with glycogen, are probably the major source of sodium in sweat. With profuse sweating in salt depleted subjects, these cells become atrophied and vacuolated and glycogen is depleted (Dobson, 1962). In the freshly dissected coil, the ductal section can be easily distinguished from the secretory segment by the cuticular luminal wall of the duct (Sato & Dobson, 1970).

Development of Sweat Glands

In the human fetus, sweat glands begin to appear on the palm and sole during the fourth month. This is followed by development in the axilla, the forehead and scalp and finally the rest of the body by the end of the fifth month. At birth all sweat glands have been developed and during the following 10 months they gradually become active (Montagna, 1956). By $2\frac{1}{2}$ years, no more glands become active and about half of them, although they appear anatomically perfect, never secrete (Kuno, 1956).

Distribution of Sweat Glands

Szabo (1962) showed that the density of skin appendages (sweat

glands and hair follicles) is inversely related to the rate of body surface growth during post natal development. Assuming an even density of sweat glands on the body surface at birth, he calculated the relative density resulting from the spreading out of these appendages as the body surfaces grow at different rates. This hypothetical distribution of the sweat glands agrees closely with data obtained from actual counts of ducts in split skin specimens from an adult body. From his tables, of the total of about 3 million sweat ducts in the adult man, 12% are found on the head, 20% on the upper extremity, 30% on the lower extremity and 38% on the trunk.

Regional Sweating Activity

The distribution of thermal sweating activity has been measured by Weiner (1945) giving values of about 10% each from the head and upper extremity, 25% from the lower extremity and 55% from the trunk. These values are seen to be variable however, and estimates for the head can vary from 6% to 11% for one subject measured on different occasions. The contribution to thermal sweating from each hand is generally less than 1% of the body total sweat production.

The regional distribution of the thermal sweat output per active gland as calculated by Thomson (1954) shows high values for the trunk and leg (0.007 - 0.016 mg/min), moderate values for the forearm (0.006 mg/min) and forehead (0.005 mg/min) and low rates for the hands and feet (0.001 - 0.002 mg/min). When he compared the regional distribution of functional sweat glands in groups of Europeans and Africans (who worked in the same conditions) there was considerable variability within each group but the two groups were not significantly different.

It has been reported that the relative magnitude of sweating activity on different regions of the body surface is not proportional to overall sweat rates. Ferguson, Hertzman, Rampone and Christenson (1956)

found that as the sudomotor drive is strengthened by elevating the ambient temperature, there is an increase in the relative contribution of the upper extremity and trunk. They concluded that the sweating activity on one part of the body surface cannot be used to predict sweat rates from any other region. The results obtained by their method (15 minute samples using the dessicating capsule technique) indicated that regional sweating is never proportional to total sweat rates. Custance (1965) however, using a ventilated capsule which could continuously record the sweat rate on a 14 cm^2 area of skin, found a high correlation between regional sweating and total body sweating (weight loss) despite a wide range of ambient temperature, clothing and sweating activity. He concluded that provided each subject is considered separately and the same capsule site is used every time, sweat rates from a single area of skin can be used to represent whole body sweating.

Thermal and Emotional Sweating

Eccrine sweating is evoked by both thermal and emotional stimuli, each producing different regional sweating patterns. In comfortable ambient temperatures, the general body surface is dry. A certain degree of palmar and plantar sweating usually occurs however, with a large variability due to individual differences. Kuno (1956) has shown that a thermal stimulus such as a rise in environmental temperature has the effect of initiating sweating on the general body surface, with more sweat being produced as the temperature is increased. Palmar sweating however, shows no concurrent increases. He also shows that in neutral conditions an emotional stimulus such as performing difficult mental arithmetic will immediately increase sweating on the palm and the sole of the foot. Rebell and Kirk (1962) have noted the dependence of the emotional sweating response in the axilla on age. In prepuberty, a mild axillary sweating response can be evoked by a thermal stimulus but not by an emotional

stimulus. After puberty, a strong response is produced by both thermal and emotional stimuli. Kuno (1956) described the combined effects of thermal and emotional stimuli. At very low temperatures (less than 10^{o}C), emotional sweating is suppressed and in warm environments, where thermal sweating is already occuring, an emotional stimulus augments both general body and palmar sweat rates. He also reported that at very high temperature and sweat rates, an emotional stimulus has been found to suppress both types of sweating.

In a recent paper by Allen, Armstrong and Roddie (1973), regional distribution of emotional sweating is reported. Stimuli at air temperatures of 26^{o}C produced significant sweating increases on all parts of the body but no significant difference was found between increases on the hands and feet when compared with increases on the other regions of the body (the arms and legs, the head and neck and the trunk). From their calculations, it can be seen that weight losses due to emotional sweating at 26^{o}C are in the region of 20 g/m^{2}/hr.

Innervation of the Sweat Gland

Both thermal and emotional sweating are under the control of the central nervous system (Chalmers & Keele, 1952). Anatomically, innervation of the sweat glands appears to be part of the sympathetic system. From the temperature regulating and emotional centres in the brain, descending pathways in the central nervous system link with connector cells in the lateral horn of grey matter in the spinal cord. These give rise to preganglionic fibres in the sympathetic chain. After relaying in sympathetic ganglions, the post ganglionic fibres pass to the sweat glands. The chemical transmitter from the nerve endings to the sweat glands however, is not adrenaline or noradrenaline as is normally found in the sympathetic system but acetylcholine which is found at all post ganglionic parasympathetic nerve terminals (Dale & Feldburg, 1934).

Innervation to sweat glands, therefore, is cholinergic and a strong sweating response can be produced by the direct effect upon the glands of acetylcholine injected intradermally (Chalmers & Keele, 1952). Although injections of adrenaline normally inhibits eccrine sweating in man, very small quantities have been shown to enhance it (Kuno, 1965).

Sweating is also elicited by the axon reflex mechanism which can be stimulated by the injection of agents with a nicotine like action. The method of action of injected sudorific agents and the site of action of blocking agents can be determined by the band methods described by Wada, Arai, Takagaki & Nakagawa (1952). This is done by preventing the diffusion of the injected agent beyond a rubber band stretched around the forearm. They showed that the sweating response elicited by an effective dose of pilocarpine, mecholyl or adrenaline was localized in the area on one side of a band to which the injected agent could diffuse. Axon reflex sweating however, appeared equally quickly on both sides of the band in response to effective doses of nicotine, acetylcholine or hypertonic sodium chloride.

Secretion of Salt and Water

In the secretory segment and duct of the eccrine sweat gland, sodium and potassium activated adenosine triphosphatase ($Na^+ + K^+$ + ATP-ase) has been demonstrated (Adachi & Yamasawa, 1966). In the presence of sodium and potassium, this enzyme stimulates the excretion of sodium from within the gland cells into the intercellular spaces. This excretion against a concentration gradient utilizes the energy liberated by the conversion of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and inorganic phosphate (Pi) (Dobson & Sato, 1972).

When secretory cells are exposed to cholinergic drugs, the permeability of the cell membranes is increased and there is a sodium influx. This increases the intracellular sodium concentrations and the

resulting $Na^+ + K^+$ + ATP-ase activity catalyses the release of energy for the excretion of sodium (Sato & Dobson, 1971). Sodium is secreted into intercellular canaliculi between the clear cells, followed by the passage of water, chloride, urea and other solutes to form an isotonic secretory fluid. This then passes from the intercellular canaliculi which open into the lumen but are closed distally by a tight junction. The mechanism can produce pressures as high as 500 mm Hg (Schulz, 1969) and the fluid passes from the secretory segment toward the surface by way of the duct.

In the duct, there is also evidence of active sodium transport (Sato & Dobson, 1970; Sato, Dobson & Mali, 1971). The two-step reabsorption hypothesis as described by Slegers (1967) suggests the active removal of sodium from the secretory fluid as it passes through the coiled proximal portion of the duct. This reabsorption is accompanied by the passage of chloride and water. The fact that the sweat to plasma urea concentration ratio remains constant over a wide range of plasma concentrations and sweat secretion rates, suggests that reabsorption in the proximal duct includes a constant fraction of the water from the secretory fluid but no urea. The second reabsorption step, in the distal (straight) duct, involves the reabsorption of sodium in partial exchange with potassium, ammonia and lactate but with no movement of water or urea across the luminal boundary of the duct. The resulting sweat appearing at the skin surface is hypotonic to plasma but with relatively higher concentrations of urea, potassium, lactate and ammonia.

Energy Requirements for Sweating

Because sweating involves the production of a hypotonic solution, osmotic work must be performed. The high energy phosphate, which fuels the sodium pump, is from ATP (Dobson & Sato, 1972). The metabolic source of ATP comes from aerobic glycolysis (1 mole of glucose producing 6 moles of CO_2 and 38 moles of ATP) or anaerobic glycolysis (1 mole of glucose

producing 2 moles of lactate and 2 moles of ATP). The studies of Dobson and Sato (1972) show that aerobic glycolysis which is much more efficient as an energy producing mechanism, is the major contributor to sweat gland requirement. Under conditions of arterial occlusion however, when aerobic glycolysis is hampered, Van Heyningen and Weiner (1952) found that sweat production is decreased and lactate concentrations increase with the severity of ischaemia. For the active transfer of sodium, Dobson and Sato (1972) have shown that 1 mole of ATP will transport 3 moles of sodium which will be accompanied by the passive diffusion of approximately 1,055 moles of water.

Enzyme studies by Sato, Dobson and Mali (1971) have shown that approximately 15 nanomoles of ATP can be generated per sweat gland per hour. Assuming three million active sweat glands on the whole body and 100% efficiency, this would mean the transport of about 140 m moles of sodium per hour. Since the precursor fluid is found to contain about 140 mEq of sodium/l, this would mean a fluid production of about 1 litre per hour (Dobson & Sato, 1972). Aerobic glycolysis produces 38 moles of ATP from each mole of glucose, so a whole body sweat gland production of 4.5×10^{-3} moles of ATP per hour would require 0.216 gm of glucose per hour or the expenditure of about 1 watt. Since much of the glycolysis is anaerobic however (Dobson & Sato, 1972), the efficiency would be much lower.

Composition of Sweat

Sweat has been shown to contain sodium and chloride at about half the blood plasma concentration, potassium, lactate and urea relatively more concentrated and traces of other components (Robinson & Robinson, 1954). Unlike the well regulated concentrations in blood or the expected compensatory excretion rates in urine, it is found that the electrolytes in sweat fluctuate widely in concentration and excretion rate. Sweat

losses affect, but are not immediately affected by, the electrolyte balance of the body as a whole.

Sodium, potassium and chloride have been of primary interest due to the necessity of dietary replacement. Other major constituents such as lactate and the non-electrolyte urea can be regarded as metabolic by-products and are of secondary importance in the consideration of short term losses.

Studies to date have shown that under normal circumstances, the main factors which are independently and immediately able to influence electrolyte concentrations in the whole body sweat are sweat rate and skin temperature (Weiner & Van Heyningen, 1952a). Acclimatization to heat (Dill, Hall & Edwards,1938; Johnson, Pitts & Consolazio, 1944) and dietary intake (Conn, 1949a; McCance, 1938; Robinson, Kincaid & Rhamy, 1950), are often associated with the regulation of sweat solutes. Reports have also been made of changes in concentration during the time course of sweating (Johnson, Pitts & Consolazio, 1944).

Sweat Electrolyte Concentration and Sweat Rate

Most investigators have reported that in general, as sweat rate increases the concentration of sodium or chloride in general body sweat also increases but always remains below the levels found in the blood plasma (Hancock, Whitehouse & Haldane, 1929; Ladell, 1945b; Robinson & Robinson, 1954). Although large individual variation is usually found, with sodium or chloride as low as 10 mEq/l ranging up to over 100 mEq/l, sweat concentrations within an individual can change by a factor of at least two by altering the sweat rate.

The use of controlled experiments, designed to eliminate other factors which could affect salt concentrations have established the positive correlation of sodium chloride concentration and sweat rate (Schwartz & Thaysen, 1956; Cage & Dobson, 1965). Bulmer and Forwell (1956)

consider sweat rate to be the main factor immediately affecting sodium concentration in the sweat. Palmar sweating appears to exhibit behaviour differing from that on the general body surface. It has been reported that with profuse palmar sweating, secretion hypotonic to blood plasma has been observed, but with intermittent or low rate sweating hypertonic (180 mM sodium chloride on average) solutions have been measured (Lobitz & Osterberg, 1947). More recent studies, however, have shown that palmar sweat produced by indirect heating or intradermal injections of methacholine (Acetyl-1-B-Methylcholine) contains sodium and chloride concentrations comparable to forearm sweat and varying directly with the rate of secretion (Collins, 1962).

Sweat Electrolyte Concentration and Skin Temperature

Investigations into the effect of skin temperature upon sweat solute levels show that local warming of the arm produces concentrated sweat and cooling produces dilute sweat (Cramer, 1890; Kittsteiner, 1911 and 1917). This finding is supported by the fact that sweat chloride concentration and skin temperature remain correlated when they fluctuate independently of other factors (Johnson, Pitts & Consolazio, 1944). Simultaneous armbag collections have shown that the warmer limb secretes higher chloride concentration (Robinson, Gerking, Turrell & Kincaid, 1950). Chloride concentration in whole body sweat washed off into collecting baths have a closer relationship to skin temperature than to sweat rates according to Weiner and Van Heyningen (1952a), but some outdoor experiments of Dill, Hall & Van Beaumont (1966) have not supported this finding. At high sweat rates and concentration, sodium levels appear to be unaffected by skin temperature (Bulmer & Forwell, 1956) and it has been suggested that previous observations may have been due to greater sweat gland "fatigue" in the limb of armbag experiments. Collins and Weiner (1960) showed that by enclosing the arm in an impermeable envelope, the rate of sweating

elicited by a standardized stimulus falls off more quickly with time when compared with sweating on the exposed body surface. They suggest that more rapid hydration and swelling of the skin in the armbag may obstruct the sweat ducts.

Sweat Electrolyte Concentration and Acclimatization

Perhaps more has been written about acclimatization than any other factor affecting sweat rates and concentrations. Acclimatization is generally, but not always, associated with a decrease in sweat sodium and chloride concentrations. Some confusion may arise due to increased sweat rates which also usually accompany acclimatization. At similar sweat rates, decreases in chloride concentration have been shown during acclimatization in outdoor desert conditions (Dill, Hall & Edwards, 1938). With some indoor experiments however (where higher chloride concentrations are often found when compared with similar outdoor experiments) no evident differences have been found in sweat chlorides produced at the same skin and rectal temperature before and after acclimatization (Johnson, Pitts & Consolazio, 1944). Differences have also been observed between rapid acclimatization (short periods of profuse sweating daily) and living in the heat continuously with long bouts of sweating. With rapid acclimatization, sweat chloride concentrations rise during a period of sweating to higher levels than with acclimatization due to living in the heat (Ladell, 1945a).

When the diet remains unaltered during acclimatization, decreases in sodium and chloride concentrations are found in the sweat and urine. Upon first exposure to heat, there is little change in sweat electrolyte levels, but urine losses are quickly reduced to maintain total excretion rates. After a few days of heat stress, sweat sodium and chloride concentrations gradually drop while the overall excretion rates are maintained by compensatory increases in urine concentrations (Conn, Johnston & Louis, 1946a).

This salt conservation is effected by desoxycorticosterone acetate (DCA) or aldosterone from increased activity of the adrenal cortex. Injections of DCA in acclimatized subjects reduce the need for functional activity of the adrenal cortex, while sweat electrolyte concentrations are maintained at a low level. When the application of exogenous DCA is terminated after a few days, the ability to produce dilute sweat is impaired until the adrenal cortex regains a high level of functional activity. Sweat gland training by several days of intense muscular activity, even at very low temperatures, also produces a reduction in sodium and chloride levels (Ahlman, Eranko, Karvonen & Leppanen, 1952).

Fluctuations in levels of natural acclimatization due to seasonal environmental temperature changes also affect sweat electrolyte concentrations. Sodium and chloride levels are found to be lower in the summer despite higher sweat rates(Berenson & Burch, 1953; Ohara, 1966).

During a routine of experimental heat exposure, the improvement in salt conservation in sweat usually starts on the second day. For a given thermal stress, the sweat chloride concentration will reach a minimum in about five days (Robinson & Robinson, 1954).

Potassium Concentration in Sweat

While sodium and chloride in sweat are nearly always reported to be hypotonic to plasma, potassium on the other hand is usually found in sweat at concentrations relatively higher than in plasma.

Little or no effect is found in sweat potassium levels due to excessive or restricted intakes of potassium chloride (Hancock, Whitehouse & Haldane, 1929), hard muscular activity (Ahlman, Eranko, Karvonen & Leppanen, 1952), alterations in the volume, tonicity or acid base balance of body fluids (Amatruda & Welt, 1953), or change in sweat rate (Schwartz, Thaysen & Dole, 1954). Potassium concentrations appear to be higher from skin enclosed in an impermeable envelope (Robinson & Robinson, 1954) but

the rate of secretion has been found to be reduced (Bass, Mager & Barrueto, 1959).

Armbag sweat which contains palmar sweat may not be representative of general body sweat, since palmar sweat has been shown to contain significantly higher concentrations of potassium, whether stimulated by methacholine or heat (Collins, 1962). Variation in potassium concentrations has been reported to be inversely related to those of sodium and chloride. With DCA injections, potassium concentration increases have been observed (Conn, Louis, Johnston & Johnson, 1948).

At moderate to high sweat rates, potassium excretion becomes a linear function of sweat rate, indicating little further reduction in concentration but at very high sweat rates, potassium concentrations have been reported to increase again (Gordon & Cage, 1966). High levels have been found in subjects after strenuous exercise (Ahlman, Eranko, Karvonen & Leppanen, 1952).

Effects of Diet and Salt Depletion on Sweat Electrolyte Concentration

Since the association was first made between salt losses in the sweat and heat illness, studies have been carried out to examine the interrelationships of salt balance, diet and sweat losses (Weiner & Van Heyningen, 1952b). With repeated exposures to high temperatures, salt deficiency has an effect upon composition of thermal sweat (McCance, 1938). With a generous salt intake, little if any change occurs in sodium, potassium or chloride concentrations. With progressive salt deficiency however, sodium and chloride concentrations are reduced by as much as one half and potassium concentration may have doubled. Johnson, Pitts and Consolazio (1944) found that the administration of single large doses of sodium chloride immediately before heat stress (outdoor marching) has no effect on sweat chloride concentration. Sweat chloride concentrations may be increased with a reduction in water intake (Hancock, Whitehouse & Haldane, 1929).

Conn and Johnston (1944) have reported the effects of abrupt changes in daily intake of sodium chloride on sweat electrolyte levels. A change from high to low salt intake results in an immediate fall in urinary output, but sweat concentrations are not reduced significantly until one or two days later. With the fall in sweat chloride, the urine concentration increases to maintain overall salt balance. Even at very low salt intakes (2 - 3 g/day), remarkable ability to maintain salt balance is found (Conn, Johnston & Louis, 1946b). Upon resumption of a high sodium chloride intake, urine excretion rates rise immediately, followed in a few days by moderate increases in sweat concentrations (Robinson, Kincaid & Rhamy, 1950). When high sweat rate and low sodium chloride intakes are used to produce controlled salt depletion of the body, reductions in renal output are observed within one or two hours and complete adaptation occurs within five to fourteen hours. Initial decreases in sweat concentration however, do not occur for at least eight hours and if the heat stress situation is continuous, the reduction may not be observed for up to a day (Robinson, Nicholas, Smith, Daly & Pearcy, 1955). The effect of the salt conserving mechanisms on both the kidneys and the sweat glands is less marked when dehydration accompanies salt depletion than when water losses are replaced (Robinson, Maletich, Robinson, Rohrer & Kunz, 1956).

Dietary control of salt intake has little effect on sweat rate, but at any given sweat rate for an individual, a low salt intake will produce lower sweat concentrations. At higher sweat rates, the effects of dietary control is more apparent (Sigal & Dobson, 1968). Even on diets where salt depletion is not apparent from analysis of blood sodium and chloride levels, sweat concentration tends to fluctuate with intake (Costa, Calloway & Margen, 1969).

Adrenal cortical function plays a large part in the salt conserving

mechanisms which respond to salt depletion or dietary control (Conn, 1949b). The main feature of this mechanism is the ability of electrolyte active hormones of the adrenal cortex such as aldosterone or deoxycorticosterone acetate to increase the reabsorption of sodium (and chloride) from the urine and sweat, producing more dilute secretions. With salt depletion of the body, such hormones act naturally to lower salt concentrations in the urine and sweat, but even when abundant salt is provided in the diet, the salt conservation process can be activated artificially. Administration of DCA or ACTH (adrenocorticotrophic hormone which stimulates the adrenal cortex) will reduce sweat salt concentrations to very low levels comparable to those found with high degrees of heat acclimatization and salt depletion.

Pathological conditions such as adrenal carcinoma, Addison's disease, or cystic fibrosis, which affect the corticosteroids or salt conservation mechanisms, have provided evidence useful in the investigation of the mechanism for regulating sodium and chloride excretion in sweat.

Sweat Phosphate Concentration

Relatively little has been written about the phosphate content of sweat. Except for traces attributed to the nuclei of desquamated cells, negligible phosphate (inorganic, acid hydrolysable or bound) is found in sweat (Bischoff, Maxwell & Hill, 1931; Morimoto & Johnson, 1967). Levels ranging from 40ug/100 ml (Robinson & Robinson, 1954) to 3.5 mg/100 ml (Kuno, 1956) have been reported however. Kuno (1956) has suggested that phosphate concentrations in sweat may be related to dietary intake.

Active transport of sodium in the sweat gland is powered by high energy phosphate from ATP. In determing $Na^+ + K^+$ + ATP-ase activity in sweat gland homogenates, Sato, Dobson and Mali (1971) have reported inorganic phosphate production rates of about 5 moles/Kg protein/hr in the palmar eccrine glands of Rhesus monkeys. This phosphate would presumably

be retained for recombination with ADP by glycolysis (Dobson & Sato, 1972) since concentrations in sweat are very low. No information is available on the relationship between $Na^+ + K^+$ + ATP-ase activity and phosphate in sweat.

Changes in Sweat Composition with Duration of Sweating

When sweating is gentle, or restricted to levels which can be maintained indefinitely in normal day to day living, little change in sweat composition is observed with time except over long periods when acclimatization effects may appear. With more intense stimulation of the sweat glands by heat stress or drugs however, distinct changes occur within minutes or hours which cannot be attributed to acclimatization effects and which in fact exhibit characteristics quite different from those of acclimatization (Bulmer & Forwell, 1956). Apart from a transient change at the onset of sweating described as "first sample phenomenon" (Schwartz, 1968), these changes with duration of sweating are usually characterized by a reduction in sweat rate and an increase in sodium and chloride concentration. This behaviour is usually referred to as hidromeiosis (Sargent, 1962).

Increases in sodium and chloride concentrations have been observed in outdoor marching experiments when sweat chloride levels have been increased despite increases or decreases in plasma concentration and whether water, saline or no fluid was injested (Johnson, Pitts & Consolazio, 1944). When heavy sweating produces this change in sweat electrolyte concentrations, a break in the heat stress situation of an hour or so provides an opportunity for the sweat glands to recover. When sweating recommences, the electrolytes are excreted at a lower concentration but the increase is once again observed (Ladell, 1945b). These concentration changes are much less apparent in subjects who have been 'naturally' acclimatized, that is, those who have been exposed to

elevated ambient temperatures for long periods during several days. Ladell (1945a) also showed that although subjects who have been 'artificially' acclimatized, that is exposed to short daily periods of intense sweating activity, can initially produce low sweat chloride levels at high sweat rates, the concentration soon increases, a characteristic he ascribed to fatigue of the sweat gland's power to do osmotic work.

Despite the large concentration changes which are observed, the sodium and chloride levels remain below plasma concentration. Potassium concentration, which is usually reported to vary inversely with that of sodium, shows an expected decline during sweating. For this reason, the ratio of sodium to potassium is an even more sensitive indication of the reabsorptive activity of the sweat gland and changes in this ratio with duration of sweating have been used as an index of acclimatization by Furman and Beer (1963). They found that with unacclimatized subjects, the sodium/potassium ratio increased several times during a two hour period of heavy sweating but that with naturally acclimatized subjects (people who are used to working outdoors in hot environments) this change was much smaller. Although absolute concentrations of sodium or potassium were different from subject to subject, while each was being acclimatized by daily exposures to heat stress, the increase observed in sodium/potassium ratio was less marked on successive days. The experiments of Furman and Beer (1963) also showed that the administration of aldacetone (an aldosterone inhibitor) removed this acclimatization effect, suggesting that it was due to adrenal cortical activity. These observations indicate that the changes in sodium/potassium ratio during sweating can be used as an index of acclimatization, or the ability of the sweat glands to maintain sodium reabsorption. Furman and Beer (1963) used this ratio even when samples were not adequate to obtain the absolute concentrations of sodium or potassium.

With acclimatized subjects, temporal effects appear to be due mainly to concurrent changes in skin temperature or sweat rate, as sodium or chloride increases due to fatigue are less evident (Robinson, Gerking, Turrell & Kincaid, 1950; Weiner & Van Heyningen, 1952a). Gordon and Cage (1966) suggested that if glucose, as the source of energy for sweat secretion, is the limiting factor for rapid and continuing sweating, then reductions in sweat rate will occur when the demand for glucose exceeds the available supply and glycolytic rate must decrease.

Although a decline in sweat rates can occur in subjects resting in conditions where humidity is low and ventilation is adequate to remove water from the skin when it appears as sweat, it is more common in humid conditions or when the skin is allowed to soak in sweat or water (Sargent, 1962). This phenomenon is usually referred to as 'sweat suppression due to hydration of the skin'. The sweat rate from the skin enclosed in an impermeable barrier falls off much more rapidly with time than that from well ventilated skin. When sweating occurs in very humid conditions such as are found in an armbag, droplets adhering to the skin are probably absorbed by it (Collins & Weiner, 1960). This argument is supported by the maceration of the skin which is apparent at the end of a period of such exposure. Higher overall osmotic concentration of the sweat supports the theory that water is absorbed by the skin but does not account for the reduced potassium levels which may occur. Collins and Weiner (1960) suggest that the swelling of the skin by hydration however, may obstruct the sweat ducts and thus play a role in the apparent failure of the sweat glands and alterations of sweat composition with time.

Changes in sweat rate due to hydration of the skin have been observed both in whole body sweat (Hertig, Riedesel & Belding, 1961; Brebner & Kerslake, 1964) and in palmar sweat (Peiss & Randall, 1957; Randall & Peiss, 1957). The suppression of palmar sweating appears not to

be due to the duration of sweat production but to the length of time the skin is exposed to water or high humidities. In palmar sweating, suppression can be total within an hour when the hand is immersed in water at 35 - 40°C. Randall and Peiss (1957) found that at lower temperatures this suppression is less marked and fingers soaked in water at 5°C for an hour show sweating responses to deep breathing or emotional disturbance comparable to those of control fingers.

Soaking the finger in saturated sodium chloride solution however, has no suppression effect on palmar sweating. Iontophoresis of methacholine (10^{-4}) in water does not stimulate palmar sweating, whereas the same concentration in saturated sodium chloride does, suggesting that hydration of the palmar epithelium during the administration suppresses the sweating before it can be observed (Peiss & Randall, 1957).

The amount of water absorbed by the skin has been measured on the palm and forearm by Peiss, Randall and Hertzman (1956). Water absorbed over about half an hour on palmar surface appears to be at least twice as great as on the forearm skin, where they observed mean rates of 0.18 mg/cm^2/min. Inhibition of sweating on the palm and sole appears to be directly related to the amount of hydration of the stratum corneum. The recovery from this suppression of sweating occurs as water diffuses to the surface and is lost 'insensibly' from the skin.

The time course of sweating when the whole body is immersed in water is again a function of the duration of soaking. Decline in sweat rates follow a similar time course for a given stimulus when referred to commencement of soaking, rather than the start of the stimulus (Hertig, Riedesel & Belding, 1961). Presoaking in 15% saline does not produce this effect and interrupting a water soak with a period in saline has the effect of interrupting the decline until the water soak is resumed (Brebner & Kerslake, 1964).

Rapid changes in concentration have been observed during the first few minutes of sweating, with the first samples containing more sodium in relation to sweat rate than subsequent samples (Schwarz, 1968). This 'first sample phenomenon' may be due to a delay in sodium reabsorption in the duct after the onset of fluid production but has little effect on overall sweat losses, because the phenomenon is of short duration in normal individuals. Pretreatment of the sweat glands by iontophoresis of cyclic AMP or bradykinin abolishes this initial high concentration. These drugs may be naturally involved in the efficient reabsorption of sodium in the duct (Gordon & Schwarz, 1971).

The problem of isolating temporal effect in thermal sweat electrolyte concentration from other factors is difficult, due to the fact that sweating must commence from zero sweat rate and rise to a steady level before changes due to temporal effects alone can be observed. Greatest sodium and chloride concentration changes happen during the period when the sweat rate is still rising. Berenson and Birch (1953) showed that continued sweating at a steady rate then results in less marked concentration changes. They also showed that by using concentration, time and maximum concentration, it is possible to produce a linear relationship for both sodium and chloride in sweat. The resulting slopes of these relationships for the two electrolytes were found to be similar within subjects

Kerslake (1972) has pointed out the difference between hidromeiosis (suppression of sweating due to hydration of the skin) and sweat gland fatigue (a decline in the ability of the glands to perform osmotic work). He states that hidromeiosis is the restriction of sweating activity due to hydration and swelling of the epithelium and in particular the keratin ring or tube surrounding the duct where it opens onto the skin. Brebner & Kerslake (1964) describe this decrease as exponential and tending toward

zero sweat rate at infinite time. Kerslake (1972) suggests that this time course could be explained by random blockage of the sweat ducts due to sudden obstruction by cellular debris in the sweat as the keratin rings become swollen. He also points out that although some fatigue of the sweat gland may occur, many of the observed changes in sweat rate formerly ascribed to fatigue can also be explained in terms of hidromeiosis.

Ethnic Difference

Although many works have been published on different ethnic groups, little experimental work has been done comparing the sweat electrolytes of these groups using similar techniques.

Robinson, Dill, Wilson and Neilsen (1941) compared white men and negroes working in the heat. Most of the differences between white and negro share croppers they attributed to a difference in area to weight ratios. Although the white share croppers had higher sweat rates, the negroes had higher sweat chlorides.

Most information shows lower sodium concentrations with acclimatization. Indian troops, artificially acclimatized in Britain, however, showed significant increases compared with naturally acclimatized and unacclimatized states. Sweat rates were also significantly higher with artificial acclimatization and potassium concentrations were higher when compared with the unacclimatized state. No change in sodium potassium ratio occured, however, with changes in the state of acclimatization. A comparative study of the sweat gland response in unacclimatized Indians and Europeans showed no significant differences in the forearm response to methacholine nor in sodium or potassium concentration of the sweat (Collins & Weiner, 1965).

In the study on the Bantu of Uganda, McCance, Rutishauser and Knight (1968) reported that the sweat of Caucasian adults had a higher sodium concentration than the Africans. Using iontophoresis of pilocarpine to

stimulate sweating, they found that African males and females and Caucasian females had similar sweat rates which were significantly lower ($p \leq 0.001$) than those of the Caucasian males. The Caucasian adults of both sexes in their study had significantly higher ($p \leq 0.01$) sodium concentrations than the Bantu.

McCance and Purohit (1969) later increased the number of Bantu and European adult subjects and also included a group of Indians living in Africa. Again the Europeans had higher sweat rates than any other group, but the Africans had lower ($p \leq 0.001$) sodium concentrations than the Indians and Europeans, who were similar in this respect. There was no evidence to suggest that the Africans were sodium deficient. Similar studies in the Sudan (McCance, 1969) showed Sudanese males to have similar sweat rates and sodium concentrations to European males. Sudanese females however, although having lower sweat rates than the males ($p \leq 0.05$) produced significantly more sweat than European, Indian or Bantu females. Sudanese sodium concentrations were similar to those of Europeans and Indians.

Comparisons of the physiological reactions to heat stress in Caucasians and Bantu have been made by Wyndham (1966). In the unacclimatized state, at fixed energy expenditures and environmental conditions, Caucasians had higher rectal temperatures and heart rates at the end of four hours work, despite the fact that their capacity for evaporative heat dissipation (their sweat rate) was greater than the Bantu's. In the acclimatized state, both groups had closely similar rectal temperatures and heart rates (which were lower than for the unacclimatized state) but the Bantu still had lower sweat rates. It has been suggested that although the Bantu do not appear to have an advantage in the ability to regulate body temperatures by increasing heart rates or sweat rates, they are nevertheless more able to cope with work in the heat

(Wyndham, Strydom, Morrison, Williams, Bredell, Van Rahden, Holdsworth, Van Graan, Van Rensburg & Munro, 1964).

From the point of view of examining distinct ethnic groups, India has been shown to be a favourable field for comparative studies. Some Indian groups have undergone environmental and occupational specialization for hundreds of generations and well documented history and high level of inbreeding over two thousand years provides unique and interesting groups (Sanghvi, 1966). Groups of people from the south, central and north eastern zones of India, and the Himalayas are not only genetically isolated but are also from environmentally distinct backgrounds (Malhotra, 1966).

Less is known however, about the backgrounds of the African tribes. Rather than using knowledge of their ancestry to supplement heat stress studies, physiological responses to heat have been used to speculate on the length of time the Bushmen have inhabited their present territory (Wyndham, Strydom, Ward, Morrison, Williams, Bredell, Van Rahden, Holdsworth, Van Graan, Van Rensburg & Munro, 1964).

Sweating in Women

It is generally accepted that women have lower sweat rates and sodium chloride levels than those which are found in men 'Ohara, 1966; Brown & Dobson, 1967; Dobson, 1967; Kuno, 1956). Individual variability is high however, and considerable overlap does occur between sexes.

Morimoto, Slabochova, Naman & Sargent (1967) observed that men had higher sweat rates per unit surface area than women, this difference being significant in humid conditions but not when the subjects were exposed to a hot dry environment. With increasing thermal stress and sweat rate, they found that sweat chloride concentration also tended to increase but that there was no significant difference between men and women. Forris, Fox and Woodward (1968) suggested that sweating in women was lower than in men because sweating is a training response and women do not call upon

their sweating mechanism as frequently as men. Women can also rely more on vasomotor thermoregulatory control because they have a lower basal metabolic rate, a relatively larger peripheral heat sink and a greater insulation against transient heat exposures. It has been shown however, (Fox and Ferris, 1968) that females can produce large sweat volumes if they have been exposed to prolonged periods of intense physical exercise.

Following the heat reactions of the sexes, Wyndham, Morrison and Williams (1965) found that males and females showed parallel changes in rectal temperature, heart rate and sweat rate during the time course of several hours of heat stress. In the unacclimatized state, women had significantly higher recal temperatures and heart rates than the men but lower sweat rates. After acclimatization to heat, only the sweat rates differed significantly between the sexes.

McCance and Purohit (1969) found significant differences in sweat rate between the sexes in Europeans ($p < 0.001$) and Indians living in East Africa ($p < 0.05$). Although Bantu males had higher sweat rates than the females, the difference was not significant. Sudanese men also had higher sweat rates than their women ($p < 0.05$) (McCance, 1969). Differences in sweat sodium concentration occur between the ethnic groups but no significant differences could be shown between the sexes within any one group of the Europeans, Bantu, Indians or Sudanese (McCance & Purohit, 1969; McCance, 1969).

A notable factor intrinsic to women is the fluctuation of electrolyte levels during the menstrual cycle. Sweat electrolyte levels may double during the cycle exhibiting a premenstrual peak, ovulatory peak or both (Lieberman, 1966). Because sweat rates affect electrolyte concentrations, the amount of sodium which can be reabsorbed by the ducts (or sodium free water cleared by the ducts) has been measured by Taylor, Sato, Morris and Dobson (1969). They found that this ductal free

clearance (which should be inversely related to concentration at the same rate) has also shown ovulatory and premenstrual peaks in some women. The phenomenon was found to be variable however, and some women showed no changes at all.

Sampling Techniques

Upon reading the literature on sweat and its constituents it becomes evident that the estimates of losses of sweat in natural environments, if based on losses recorded under experimental conditions, can vary widely. Care must be taken when comparing experimental and natural situations. Many experimental techniques such as intradermal injection of sudorific agents make no attempt to mimic natural conditions, whereas others do to a greater or less extent. The method of stimulating sweating and collecting the secretion for analysis can have a definite effect on the final product. Studies have been made to compare the results obtained by simultaneous application of different techniques. Samples of sweat can be collected from the whole body or from small representative areas. The use of various types of capsules for enclosing small areas of skin can produce large differences in sweat rates (Ohara, 1966). Differences have been observed between indoor and outdoor experiments (Johnson, Pitts & Consolazio, 1944). Sweat rates may (Custance, 1965) or may not (Ferguson, Hertzman, Rampone & Christensen, 1956) be proportional from one part of the body to another when sampling from small areas. Allowing the skin to become wetted during sweat collection affects sweat rates and composition (Brebner & Kerslake, 1963, 1964; Folk & Peary, 1953; Randall and Peiss, 1957; Collins & Weiner, 1960, 1962). Differences in sweating behaviour have also been attributed to the effects of heat, exercise, drugs and circadian variation (Herrman & Mandol, 1955; Crockford, Davies & Weiner, 1970). Much of the variability in recorded concentrations in sweat have been explained by sampling methods and the advantages and disadvantages of

various techniques have been investigated (Robinson & Robinson, 1954). These studies have been valuable in assessing how representative sampling techniques are and in developing reliable simplified methods for determining losses during sweating. They have shown differences which must be considered when comparing results by different techniques.

Because sweat is a biological product, it is an extremely variable substance, which makes it a rich field for study. What changes occur in the sweating behaviour within a subject when various parameters are manipulated? These parameters may include the condition of the individual (hydration, electrolyte balance, body and skin temperature, levels, acclimatization, fatigue, biochemistry, illness) or the applied stimulus (sudorific drugs, metabolic activity, heat, humidity).

Conversely, under standardized applied stimuli and collection techniques, what can the sweat from an individual tell us about his condition and what can differences in sweating tell us about groups of people?

Standardized tests have been developed to assess the response of individuals or groups to thermal stress (Henschel, 1967). Although there is a large individual variability, one would expect people exposed to various levels of heat stress to exhibit corresponding levels of acclimatization.

The problem of coping with environmental conditions in tropical areas may be different for the indigenous population. In the treatment of the ill effects of heat stress, this could be an important factor. Calculated losses of nitrogen in tropical conditions, based on observations made in temperate climates indicate that negative balance will occur, unless daily protein intake is increased by 13 - 14% (Consolazio, Matoush, Nelson, Isaac & Canham, 1966). But since the indigenous people do maintain nitrogen balance despite sweat losses and

lower intake (Ashworth & Harrower, 1967) this assumption must be wrong and under the tropical conditions, not so much is lost. Weiner, Wilson, Wheeler and El Neil (1972) have shown that in hot climates, sweat nitrogen losses are reduced when the diet is low in protein.

When looking for differences between individuals or groups, standardized testing techniques must be used to make the results comparable. The techniques need not mimic real life situations, as long as they are used consistently and the results reflect some desired aspect of the response to heat stress. Any results should always be qualified by the methods used.

There has been little evidence available with which to make comparative studies of sweat electrolytes in groups of subjects of differing ethnic origin. During the International Biological Programme ("acclimatization to heat" section) the opportunity was presented to study the sweat from groups of people from various parts of the world. The results from a standardized thermoregulatory function test (Fox, Crockford & Loftstedt, 1968; Fox, Crockford, Hampton & MacGibbon, 1967) served to assess the degree of acclimatization in these groups and their physiological responses to heat stress.

In this thesis, I have looked at the electrolyte composition of thermally induced sweat which was collected as part of the standardized test procedure. Unacclimatized and acclimatized British volunteers of both sexes have been used as control subjects. Comparisons have been made between them or with other groups to evaluate the effects of sex, diet, sweat rates or ethnic differences on sweat electrolyte concentrations.

In addition, for some subjects, the changes in sweat electrolyte composition within the set heat stress period have been compared with changes in skin temperature, sweat rate and duration of sweating.

The different groups of subjects which have been studied, together with their physical characteristics are shown in Table 1.

Table 1

Table of Subjects

Group (British)	Sex	No. of Subs	Physical Characteristics Height (cm)	Weight (Kg)	Age (yr)	Dubois Area m^2	Tests	Test Routine [1]	Sweat Collection Type [2]	Sample Collection Time (min)
Army Group I	male	25	174.1 ±8.1	69.3 ±8.1	25.0 ±5.1	1.83 ±0.14	1. Unacclimatized 2. Naturally Acclimatized	A	I	0 - 15
Army Group II	male	8	169.3 ±5.6	67.2 ±8.1	22.5 ±2.7	1.77 ±0.11	1. Unacclimatized	A	I	0 - 15
Army Group III	male	12	168.7 ±4.5	62.0 ±5.6	22.5 ±1.1	1.71 ±0.08	1. Unacclimatized 2. Unacclimatized repeat	C	III	0.- 30
Army Group IV	male	14	173.0 ±5.8	69.2 ±7.8	24.2 ±2.8	1.82 ±0.12	1. Unacclimatized 2. Artificially Acclimatized	C	III	0 - 30
Hampstead	female	15	165.1 ±8.3	61.9 ±6.8	25.8 ±6.8	1.68 ±0.11	1. Unacclimatized	C	III	0 - 30
Cyclists	female	14	167.4 ±8.4	63.1 ±7.1	25.6 ±7.2	1.71 ±0.13	1. Athletes (Acclimatized)	A	I	0 - 15
Cyclists	male	13	179.6 ±7.7	70.9 ±5.8	25.7 ±6.3	1.89 ±0.12	1. Athletes	A	I	0.- 15
Runners	male	11	173.8 ±6.6	62.0 ±6.5	26.0 ±4.7	1.75 ±0.12	1. Athletes	A	I	0.- 15
Swimmers	male	13	176.5 ±4.6	74.1 ±7.4	18.0 ±2.5	1.90 ±0.11	1. Athletes	A	I	0 - 15

Cyclists	male	13	175.6 ±7.7	70.5 ±5.8	23.1 ±6.3	1.85 ±0.12	1. Athletes	A	I	0.- 15
Runners	male	11	173.8 ±6.6	62.0 ±6.5	26.0 ±4.7	1.75 ±0.12	1. Athletes	A	I	0.- 15
Swimmers	male	13	176.5 ±4.6	74.1 ±7.4	18.0 ±2.5	1.90 ±0.11	1. Athletes	A	I	0 - 15

Table 1 continued

Group (Israel)	Sex	No. of Subs	Physical Characteristics Height (cm)	Weight (Kg)	Age (yr)	Dubois Area m^2	Tests	Test Routine[1]	Sweat Collection Type[2]	Sweat Collection Sample Collection Time (min)
Yemenite	male	22	162.4 ±5.2	61.5 ±10.0	25.7 ±4.2	1.65 ±0.13	1. Summer	A	I	0 - 15
Yemenite	female	15	153.0 ±6.4	50.3 ±10.1	24.6 ±4.0	1.45 ±0.14	1. Summer	A	I	0 - 15
Kurd	male	20	169.1 ±6.6	64.3 ±6.1	26.1 ±3.7	1.73 ±0.10	1. Summer	A	I	0 - 15
Kurd	female	13	153.2 ±4.5	57.2 ±11.7	25.2 ±3.2	1.53 ±0.17	1. Summer	A	I	0 - 15
Yemenite	male	16	Taken from summer population				1. Winter	B	I	0 - 10
Yemenite	female	6	Taken from summer population				1. Winter	B	I	0 - 10
Kurd	male	16	Taken from summer population				1. Winter	B	I	0 - 10
Kurd	female	4	Taken from summer population				1. Winter	B	I	0 - 10

Kurd	female	4	Taken from summer population

1. Winter	B	I	0 - 10

Table 1 continued

Group (Nigeria)	Sex	No. of Subs	Physical Characteristics				Tests	Test Routine[1]	Sweat Collection	
			Height (cm)	Weight (Kg)	Age (yr)	Dubois Area m^2			Type[2]	Sample Collection Time (min)
Students	female	8	160.5 ±4.9	53.3 ±7.8	21.5 ±1.9	1.54 ±0.11		B	I	0 - 10
Students	male	17	172.8 ±5.5	69.3 ±6.1	26.5 ±3.6	1.81 ±0.10		B	I	0 - 10
Heavy Industry workers	male	24	169.9 ±5.4	61.8 ±5.4	25.2 ±2.0	1.72 ±0.10		B	I	0 - 10
Light Industry workers	male	15	166.4 ±4.6	54.2 ±4.1	25.2 ±2.8	1.60 ±0.07		B	I	0 - 10
Villagers	male	7	169.2 ±4.6	61.6 ±4.6	25.3 ±3.2	1.70 ±0.08		B	I	0 - 10

Table 1 continued

Group (New Guinea)	Sex	No. of Subs	Physical Characteristics Height (cm)	Weight (Kg)	Age (yr)	Dubois Area m^2	Tests	Test Routine[1]	Sweat Collection Type[2]	Sample Collection Time (min)
Low Plantation workers	male	19	161.0 ±3.3	55.4 ±4.9	26.3 ±4.8	1.57 ±0.08		C	II	0 - 30
High Plantation workers	male	20	160.0 ±4.2	62.1 ±4.8	25.5 ±1.7	1.64 ±0.08		C	II	0 - 30
Kaul	male	41	162.7 ±5.7	56.9 ±5.0	25.0 ±4.8	1.60 ±0.09		C	II	0 - 30
Kaul	female	40	154.7 ±5.5	50.8 ±5.3	22.4 ±4.7	1.47 ±0.09		C	II	0 - 30
Lufa	male	30	162.3 ±4.2	59.4 ±4.2	25.1 ±3.9	1.63 ±0.06		C	II	0 - 30
Lufa	female	30	152.6 ±5.9	52.4 ±5.0	22.1 ±4.3	1.48 ±0.09		C	II	0 - 30
Lufa Old	male	11	156.4 ±4.1	52.8 ±5.4	49.5 ±4.3	1.51 ±0.09	1. Effect of age	C	II	0 - 30
Lufa Old	female	10	153.4 ±5.2	47.2 ±4.8	44.7 ±3.4	1.43 ±0.09	1. Effect of age	C	II	0 - 30
Lufa Boys	male	10	131.0 ±5.4	31.3 ±2.5	11.3 ±1.3	1.06 ±0.07	1. Effect of age	C	II	0 - 30
Europeans	male	14	178.0 ±5.6	68.9 ±8.3	30.7 ±6.7	1.86 ±0.13		C	II	0 - 30

			±5.2	±4.8	±3.4	±0.09	1. Effect of age	C	II	0 - 30
Lufa Boys	male	10	131.0 ±5.4	31.3 ±2.5	11.3 ±1.3	1.06 ±0.07	1. Effect of age	C	II	0 - 30
Europeans	male	14	178.0 ±5.6	68.9 ±8.3	30.7 ±6.7	1.86 ±0.13		C	II	0 - 30

Table 1 continued

Group (India)	Sex	No. of Subs	Physical Characteristics Height (cm)	Weight (Kg)	Age (yr)	Dubois Area m^2	Tests	Test Routine[1]	Sweat Collection Type[2]	Sweat Collection Sample Collection Time (min)
Laboratory Workers	male	10	168.1 ±5.0	55.6 ±6.4	22.6 ±2.8	1.63 ±0.11	1. Some repeat tests	C	II,III	0 - 30
Villagers	male	13	163.4 ±3.2	47.7 ±2.1	20.1 ±1.8	1.49 ±0.04	1. Some repeat tests	C	II,III	0 - 30
North Indian Army	male	29	172.0 ±5.5	59.8 ±7.1	26.3 ±3.7	1.71 ±0.11	1. Some repeat tests	C	II,III	0 - 30
South Indian Army	male	28	167.8 ±3.4	56.8 ±5.7	28.1 ±3.0	1.64 ±0.08	1. Some repeat tests	C	II,III	0 - 30
Gurkhas	male	33	161.2 ±4.5	55.9 ±4.0	25.7 ±3.7	1.58 ±0.07	1. Some repeat tests	C	II,III	0 - 30

1 see Figure 1 (Methods)

2 see Figures 6,7,8 (Methods)

METHODS

Subjects

As can be seen from Table 1, a large variety of groups of people have been studied. They are described in greater detail below.

British Army

These subjects were chosen by the army from soldiers stationed in England and Scotland. Group I was picked from a regiment which was to be posted in the Middle East. It was first tested at Hampstead in England in early September 1968 and then posted. About a year later the men were retested in Sharjha where they had been living and had become naturally acclimatized to heat. These subjects have been used as the naturally acclimatized control group and as unacclimatized subjects.

Army group II was tested in late September 1968. The men were used as unacclimatized control subjects.

Each subject in Army group III was tested twice in mid November 1970. Two to four days were left free between the first and second test for each subject. The results of the first test served as unacclimatized levels and the two tests were used to examine the reproducability of results.

Army group IV was first tested in mid February 1971, giving unacclimatized levels. The men were retested about three weeks later after being acclimatized to heat by a daily routine of 2 hours of controlled hyperthermia (38^{o}C) on eleven of the intervening days. These men have been used as the artificially acclimatized control subjects and as unacclimatized control subjects.

All British army subjects, when in an unacclimatized state, have been used to represent the background level of acclimatization normally found in a temperate climate. This combined group will be refered to as unacclimatized male controls.

See figures 6, 7, 8 (methods)

British Females

A group of females working at Hampstead Laboratories were tested in the autumn of 1970. Although some were more active than others, none were trained athletes. These subjects have been used as the unacclimatized female controls.

British Athletes

Four groups of British athletes, all of national or international standing have been included for comparisons. These groups consist of male runners (middle distance), swimmers and cyclists and female cyclists. As no other heat acclimatized British females were available, the cyclists have been used as the acclimatized female control group.

Israel

These groups were volunteers from Kurd and Yemenite communities living and working in the Negev desert. They were tested in the summer of 1968 and then as many as possible were retested in the following winter.

Nigeria

Five Nigerian groups were tested in the spring of 1969. These were villagers, male and female students and workers in heavy and light industry. These groups have previously been classified (Ojikuto, Fox, Davies & Davies, 1972). The subjects of these groups were mainly from the Yoruba tribe and lived in the vicinity of Lagos.

New Guinea

The groups studied in New Guinea were tested either in Kaul, a village on the island of Karkar just off the mainland or in Lufa, a village in the highlands of the mainland. The Lufa groups had always lived in the highlands and were tested there. All other groups were tested on Karkar where they lived or worked. The Kaul villagers and the

'Low Plantation' workers had always lived on the island.. The 'High Plantation' workers, indigenous to the highlands of the mainland, were employed in the plantation fields on the island. The Europeans had lived in New Guinea for many years and were acclimatized to the conditions there. The tests on Karkar were carried out in the autumn of 1969 and the highland experiments took place in the summer of 1970.

India

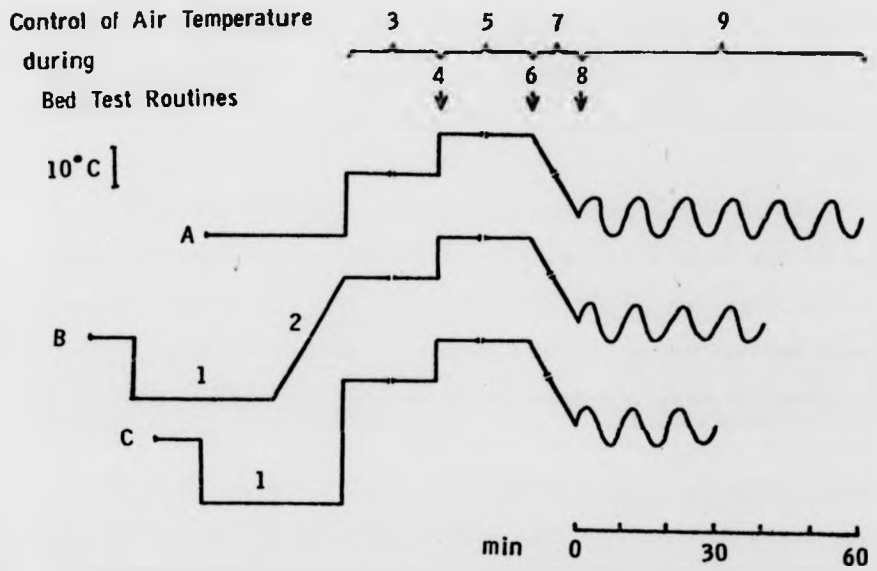
There were three groups of army subjects all temporarily stationed in New Delhi but originally coming from Nepal,(Gurkhas),,South India (Madras Engineers) and North West India (Raj Rif). These subjects were tested between September and December of 1972 (late summer to early winter). Some subjects, who were tested early in the program were retested at a later date when the weather was cooler. In addition, two civilian groups were tested early in December. One group consisted of casual labourers living in a village just outside New Delhi and the other consisted of laboratory attendants, who spent most of their time doing sedentary work and lived in the outskirts of New Delhi.

Comparisons between Subject Groups

Four groups of British army subjects have been used as control subjects. They have also been used to study the effects of natural and artificial acclimatizion and the individual reproduceability of test results. The athletes show the effect of intense physical activity upon acclimatization. The British females serve as an unacclimatized control group and the female cyclists as an acclimatized group.

The other ethnic groups have been used for comparisons with the control groups and for variation in the subgroups within them. Sexual differences are available from the control groups, Israel, Nigeria,and New Guinea studies, seasonal differences from Israel and Indian studies and age differences from the New Guinea indigenes, Army group I and the swimmers. The effect of the ethnic background is available from the subgroups

Figure 1 Control of Air Temperature during Bed Test Routines



Key:- A, B & C - start of routines.
Air temperature 30°C.
Routine A 30 min., routines B and C 10 min.

1 Cooling stage. Air temperature 15°C.
Routine B and C only for 30 min.

2 Air temperature increased 2°C/min from 15°C to 45°C.
Routine B only.

3 Slow warming. Air temperature 45°C.

4 Sweat onset.

5 Rapid warming. Air temperature 55°C.

6 Aural temperature 37.5°C.

7 Air temperature 30 - 40°C.

8 Target. Aural temperature 37.9 - 38.0°C.

9 Controlled hyperthermia. Air temperature continously adjusted to maintain aural temperature at 38.0°C.

——·—— timing variable, dependant on subject's response.

of all four field studies.

All the subjects were volunteers and were given medical examinations before the test. Volunteers were not accepted as subjects if they had complaints such as infected ears or perforated tympanic membranes which might give a poor indication of deep body temperature (see Temperature Measurements). Pregnant women were not accepted as subjects.

Test Routine

The sweat samples used in this study were obtained using equipment based on a thermoregulatory function test (bed test) developed at Hampstead (Fox, Crockford & Lofstedt, 1968) with equipment belonging to the Medical Research Council.

Although some modifications were made to the test routine from one study to the next, the procedure remained unchanged after the commencement of sweating (see Figure 1). All subjects were studied in the temperature controlled bed while wearing the standard vapour barrier suit (see Basic Equipment). The basic routine consisted of a neutral period at 30°C, a slow warming period at 45°C which ended at onset of sweating, a rapid warming period at 55°C until the deep body temperature reached 38°C (target) and then a period of controlled hyperthermia during which the deep body temperature was maintained at 38°C. In later tests, a cooling period was introduced after the neutral stage.

Test Routine A

1. At the beginning of this routine, the air temperature was at 30°C and held there for half an hour (neutral stage).

2. The air temperature was then raised to 45°C (slow warming) and held there until sweating started. The subject's forehead was periodically tested for sweating activity by applying starch iodide paper for 20 seconds.

3. At sweat onset, the air temperature was raised to 55°C

(rapid warming) to bring the deep body temperature (aural temperature) to 38°C quickly. When the aural temperature reached 37.5°C, the air temperature was lowered so that the deep body temperature would rise more slowly and become stable at the controlled hyperthermia temperature of 38°C.

4. The air temperature was adjusted during the controlled hyperthermia period of one hour to maintain the aural temperature at 38°C.

Test Routine B

This routine started with a 10 minute neutral stage (air temperature 30°C) followed by a 30 minute cooling period at 15°C. The air temperature was then gradually raised (2°C per minute) to the slow warming temperature of 45°C and held there until sweat onset. The test then continued as for Routine A, but with a controlled hyperthermia period of 40 minutes only.

Test Routine C

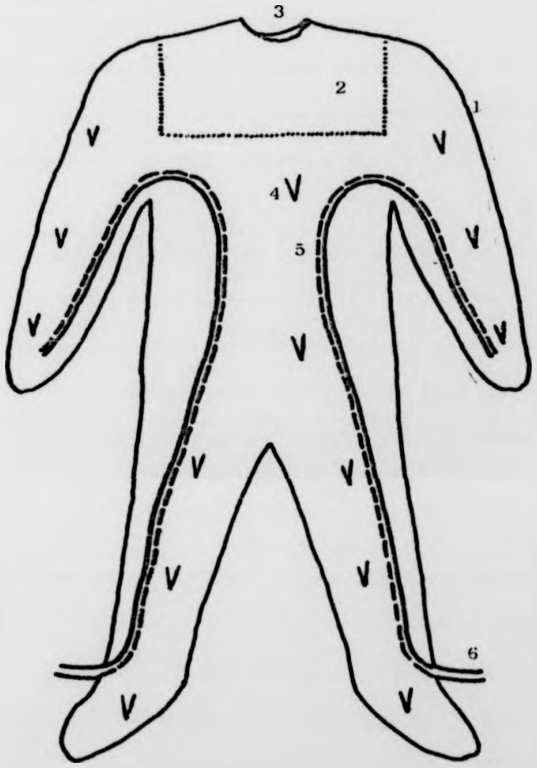
This routine was the same as Routine B except that the air temperature was raised immediately to 45°C at the end of the cooling period and controlled hyperthermia lasted for 30 minutes.

Principle of the Standard Thermoregulatory Function Test Equipment

The equipment was designed to provide a standardized thermal stress situation to which individuals could be subjected. At the same time, the physiological responses of the subject (changes in deep body temperature, skin temperature, heart rate, peripheral circulation and sweating behaviour)were monitored. The equipment was designed to be reasonably portable and self-contained. It could be assembled for use in a few days, requiring only cold water and electricity supplies and an indoor area of about 2 x 3 metres.

The equipment was based around an air conditioned bed upon which the subject could lie in a vapour barrier suit which completely covered him except for the head. The ambient temperature supplied by the bed provided

Figure 2 Vapour Barrier Suit



1 Welded sheet P.V.C. suit
2 Neckpiece of latex rubber sheeting
3 Neck hole
4 P.V.C. thermistor pockets welded into suit
5 Perforated tubing inside suit
6 Sweat extraction tubing

the heat stress situation and was controlled by the operator/observer. Physiological responses during the bed test were always recorded manually and sometimes automatically by peripheral equipment as well.

The Basic Equipment

Vapour Barrier Suit

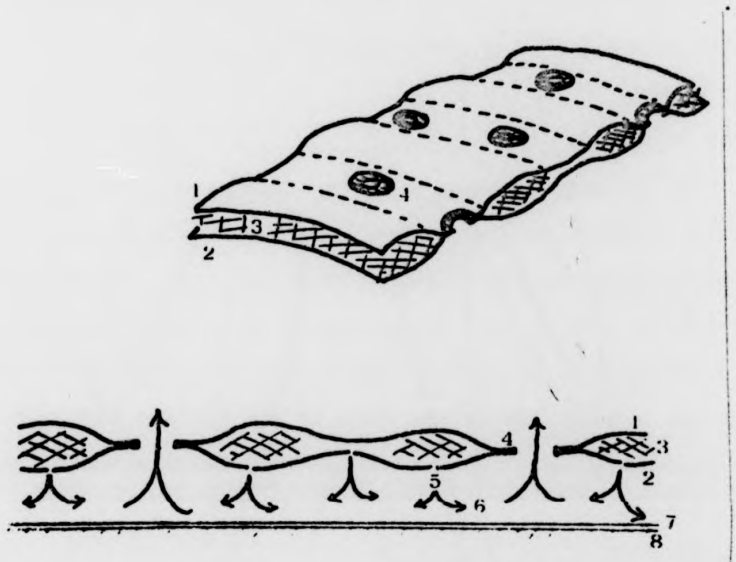
An airtight PVC suit with a double layered neck piece of latex sheeting enclosed the entire body except for the head (see Figure 2). Sweat produced inside the suit could be extracted under suction by way of a tube provided at each ankle. The passage of sweat to the extraction tubes was facilitated by perforated tubing which extended inside the suit from the ankles up each side of the trunk of the suit and down each arm. On the outside of the suit V-shaped PVC pockets were provided for the location of thermistors used in assessing skin temperature at eight points on the body.

Under slight suction (2 cm Hg) the suit would adhere closely to the body to maintain the positioning and contact of the thermistors with the skin. A dead space of 100 - 200 cc remained between the skin and the suit mostly between the fingers and toes, at the axilla and along the perforated tubing in the suit. For comfort, the suit suction was kept at this low level until after sweat onset. Then when accurate sweat rate measurements were required, the dead space was reduced to a minimum of about 10 cc by increasing the suction to 12 cm Hg, and any sweat could be steadily drawn off the skin as it was produced. If any garments were worn under the vapour barrier suit, they were made from materials which were non-absorbant and non-contaminating.

Mattress and Ventilated Layer

A bed with a PVC covered foam plastic mattress was provided for the subject to lie on. On top of this mattress was a ventilated layer which could be wrapped around the subject. The ventilated layer was made

Figure 3 Ventilated Layer (oblique and cross section)

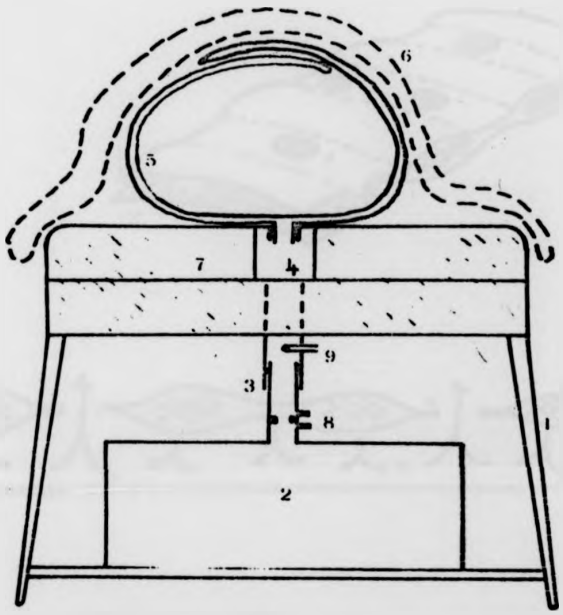


1 Outer P.V.C. sheet
2 Inner P.V.C. sheet
3 Plastic mesh
4 Weld joining sheets
5 Small perforations through inner sheet
6 Airflow represented by arrows
7 Vapour barrier suit
8 Skin

section)

t

Figure 4 Temperature Controlled Bed (cross section)



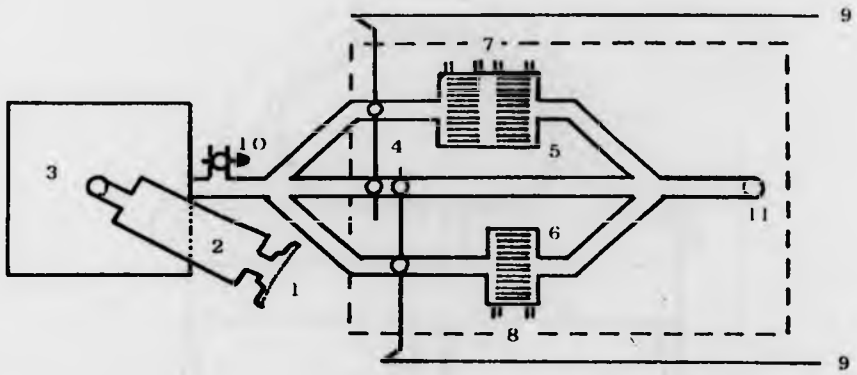
1 Bed framework
2 Temperature controlled air supply
3 Duct to mattress
4 Central channel and ports to ventilated layer
5 Ventilated layer (as wrapped around subject)
6 Blanket over subject
7 Foam filled P.V.C. covered mattress
8 Calibrated restriction and tubing to airflow manometer
9 Air temperature thermistor thermometer

ection)

l layer
bject)

rflow manometer

Figure 5 Temperature Controlled Air Supply for Beds (plan view)



1 Air intake filter
2 Silencer
3 Blower box
4 Air temperature butterfly control valves
5 Cooling heat exchangers
6 Warming heat exchanger
7 Cold water connections
8 Hot water connections
9 Air temperature control rods
10 Bleed for airflow control
11 Vertical duct to mattress

from two sheets of PVC which were sealed around the edges and spot welded at intervals over the surface to hold them together (see Figure 3). The upper sheet (inner when wrapped about the subject) was finely perforated. Between the two sheets was a loosely woven plastic mesh which could not be tightly compressed. This mesh kept the two sheets apart even when the weight of the subject was upon them. The lower (outer) sheet was provided with a row of ports which attached to the bed along a large central channel in the mattress (see Figure 4). This duct acted as a manifold through which temperature controlled air could be supplied by way of the ports into the ventilated layer, through the loosely woven plastic mesh, to the fine perforations where it was expelled onto the subject in his vapour barrier suit.

Temperature Controlled Air Supply

The air for the temperature controlled bed was provided by an electric blower, situated under the bed, which could supply a minimum of 300 cu ft/min. To reduce motor noise which could be upsetting to the subject, air was drawn in through an 8" circular filter and then to the blower by way of a car exhaust silencer. Noise was further reduced by placing the blower itself within a double walled box, the cavity of which was filled with sand. This insulation reduced the sound to a monotonous background noise which was not unpleasent. From the blower the airflow was regulated by a bleed and then passed to a three branch manifold incorporating compound butterfly valves designed to maintain a constant airflow from the blower. This manifold and valve system allowed the airflow to be proportioned and directed through a warming heat exchanger, a two stage cooling exchanger or a byepass duct to a second manifold where the three airstreams rejoined (see Figure 5). Final air temperature was regulated by directing an appropriate portion of the airflow through either the warming or cooling heat exchangers by operating the butterfly

valves remotely with control rods. Airflow was measured by tapping a differential manometer across a calibrated restriction in the ducting to the mattress (see Figure 4). Just before entering the mattress, the air temperature was monitored with a thermistor thermometer. The temperature controlled air was ducted to the central channel in the mattress through a port centrally located on the under side.

The warming heat exchanger was supplied by pump driven recirculating water which was electrically heated and automatically thermostatted at 85°C. The first stage cooling heat exchanger was supplied with cold tap water. This removed the heat put into the air by the blower motor reducing the air temperature from about 45°C to about 30°C, depending upon the initial temperature of the cold water supply. The second stage of the cooling was supplied by water recirculating from a ¾ HP refrigerator unit with a 10 gallon reservoir, thermostatted at 4°C. This supply was usually adequate to reduce the air temperature to 15°C within two minutes and hold it at that temperature for half an hour.

The blower, heat exchangers and hot water supplies were compact enough to be positioned under the bed and were mounted on the framework.

Temperature Measurements

All temperature measurements were made with thermistors. The meters which were used had torsionally suspended movements and conductive glass faces to avoid any hysteresis or sticking and ensure accurate measurements. They were driven by constant voltage mercury batteries and were provided with a battery check and voltage supply adjusting potentiometer to maintain accuracy throughout the experiment. Thermistors and meters were regularily calibrated against an NPL thermomoter in a high stability water bath.

Deep body temperature was measured aurally with thermistors (which were mounted in hearing aid earpieces) located in both ears and positioned

5 mm from the tympanum. The ears were covered with wads of cotton wool and foam plastic ear muffs. A soft thermally insulated PVC helmet then covered the whole head except for the face.

Both ear temperatures were read on the same meter ($35^{\circ}C$ - $40^{\circ}C$, ± 0.005) using a selector switch to choose left or right.

Average skin temperatures were measured using an eight point skin harness. The thermistors were located in V-shaped PVC pockets welded to the outside of the vapour barrier suit. The sites used for the skin temperatures were palm, anterior mid forearm, lateral mid upper arm, sternum at the level of the nipples, abdomen between the iliac crest and the umbilicus, anterior mid thigh, lateral mid calf and the planter surface of the foot.

Two meters were used for recording skin temperatures, one with a range from $20^{\circ}C$ to $30^{\circ}C$ and the other $30^{\circ}C$ to $40^{\circ}C$, (± 0.01).

Air temperature was measured on two meters. One of these meters had a dual air temperature range ($25^{\circ}C$ - $45^{\circ}C$ or $40^{\circ}C$ - $60^{\circ}C$ (± 0.02)) and a range selector switch. The other meter had a lower range ($5^{\circ}C$ - $25^{\circ}C$, ± 0.02)).

For air temperatures, separate thermistors were used on each meter, but if skin temperature range had been changed, the thermistor harness lead was replugged into the other meter.

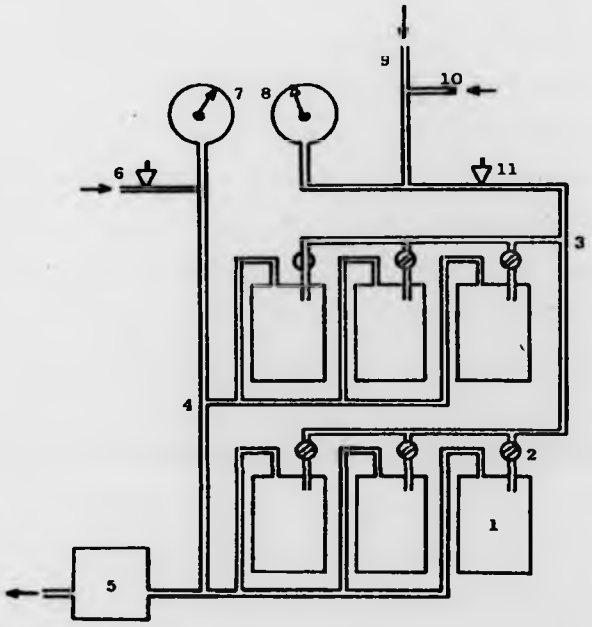
Sweat Collection

To minimize the effect of solutes left on the skin, the subjects were asked to take a shower before the test and encouraged to rinse thoroughly to remove any traces of soap if it was used.

The PVC suit worn by the subjects was designed to be airtight and water-proof and enabled the collection of sweat produced by all parts of the body except the head.

The sweat extraction tubes from the ankles joined a common line to

Figure 6 Type I Sweat Collection Apparatus



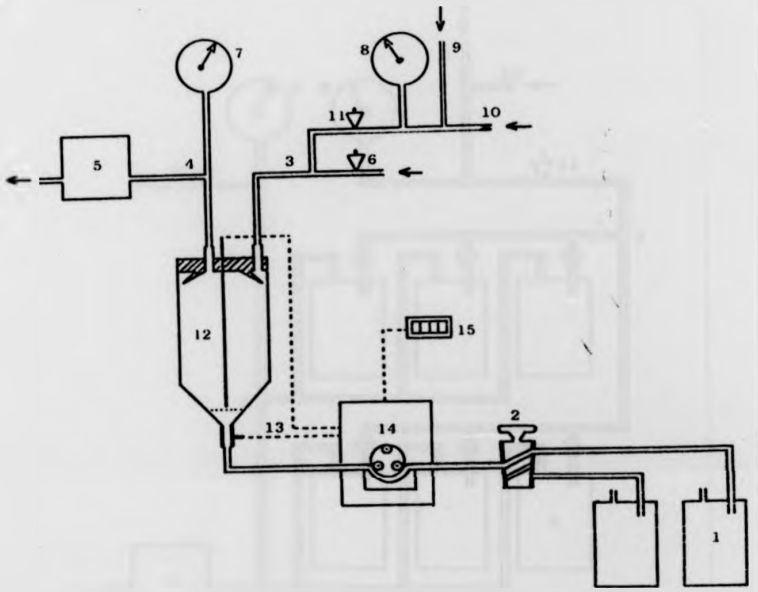
1 Sweat collection jar
2 Stopcock
3 Sweat collection line
4 Suction line
5 Suction pump
6 Pump suction control valve and air bleed
7 Pump suction gauge
8 Suit suction gauge
9 Sweat line from vapour barrier suit
10 Pinhole air bleed
11 Suit suction control valve

3

ir bleed

uit

Figure 7 Type II Sweat Collection Apparatus



1 Sweat collection jar
2 2 - way tap
3 Sweat collection line
4 Suction line
5 Suction pump
6 Pump suction control valve and air bleed
7 Pump suction gauge
8 Suit suction gauge
9 Sweat line from vapour barrier suit
10 Pinhole air bleed
11 Suit suction control valve
12 Electrode chamber for peristaltic pump control
13 Electrode leads to peristaltic pump
14 Peristaltic pump
15 Pump revolution counter

the collection apparatus. This was provided with an air bleed which helped to maintain the pressure level in the suit and kept the sweat moving quickly to the collection apparatus. Thus the time lag due to the dead space in the line was removed.

The sweat collection apparatus was of three different designs, all using suction from a vacuum pump to draw the sweat from the suit.

Type I. Tap and Jar

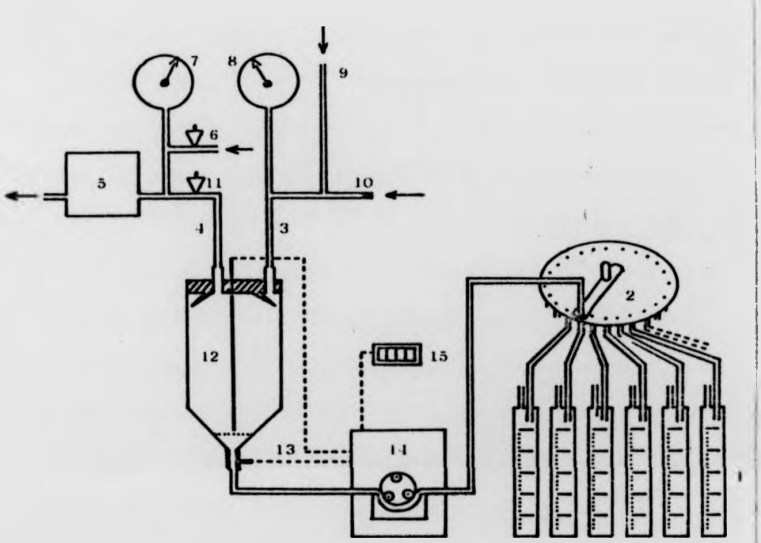
Six jars (1 pint Kilner) were connected in parallel to a vacuum pump, each by way of an opening in the sealed lid (see Figure 6). A second opening allowed each to be connected, in parallel, to the sweat collection line by way of a stop cock. Two needle valves were used to control the negative pressure in the suit, one by adjusting the suction from the pump (by allowing air to bleed into the vacuum line) and the other by restricting the line to the suit.

There were five separate collection periods made during the test, one from sweat onset to target (see Routine A) and four during controlled hyperthermia, which lasted for 40 or 60 minutes. The sixth jar was used as a spare, or to collect extra sweat produced after the end of the experiment. Suit pressure was maintained at 5 cm Hg except during the last five minutes at the end of each collection period when it was increased to 25 cm Hg. The separate collections could each provide sweat rate and concentration information.

Type II. Peristaltic Pump and Jar

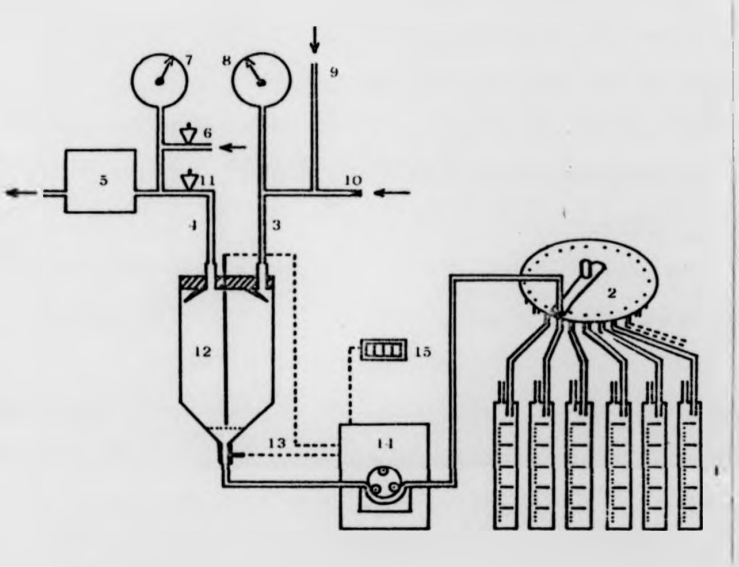
Suit pressure was controlled as above by two needle valves which interrupted the line to the suit and regulated the pump pressure by means of a bleed. Instead of passing straight into the collection jar, the sweat was collected in a chamber with a pendent electrode (see Figure 7). When the level of the sweat in the chamber rose to the electrode, a peristaltic pump was activated, which removed the sweat from

Figure 8 Type III Sweat Collection Apparatus



1 Sweat collection cylinders
2 24 - way tap
3 Sweat collection line
4 Suction line
5 Suction pump
6 Pump suction control valve and air bleed
7 Pump suction gauge
8 Suit suction gauge
9 Sweat line from vapour barrier suit
10 Pinhole air bleed
11 Suit suction control valve
12 Electrode chamber for peristaltic pump control
13 Electrode leads to peristaltic pump
14 Peristaltic pump
15 Pump revolution counter

Figure 8 Type III Sweat Collection Apparatus



1 Sweat collection cylinders
2 24 - way tap
3 Sweat collection line
4 Suction line
5 Suction pump
6 Pump suction control valve and air bleed
7 Pump suction gauge
8 Suit suction gauge
9 Sweat line from vapour barrier suit
10 Pinhole air bleed
11 Suit suction control valve
12 Electrode chamber for peristaltic pump control
13 Electrode leads to peristaltic pump
14 Peristaltic pump
15 Pump revolution counter

the electrode chamber and ran it to a collecting jar at atomospheric pressure. A counter was incorporated to record the number of revolutions of the pump which was proportional to the volume of sweat collected.

Only two jars were used, one for collecting the sweat produced from sweat onset to target and the other for the sweat produced during controlled hyperthermia. The suit pressure was maintained at 2 cm Hg until a few minutes before target (or when the deep body temperature reached about 37.7°C - see Routine A) when it was raised to 12 cm Hg. At that time the suit was 'sucked down' to a greater extent and more sweat was extracted from it as the dead space was taken up. It was necessary to allow the pump to catch up with this extra volume of sweat before the test period of controlled hyperthermia could begin. With the suit suction maintained at 12 cm Hg, the rate of sweating during controlled hyperthermia was determined by recording the revolutions of the peristaltic pump every two minutes. The total revolutions during controlled hyperthermia were then calibrated against the volume collected and the sweat rate for each two minutes could then be calculated.

Type III. Peristaltic Pump and Serial Collection

Modifications to the Type II collection system were made to provide serial samples of the sweat as it was collected. A 24 way tap enabled collections as short as one or two minutes to be made throughout the test, so that changes in sweat composition during the test could be determined accurately (see Figure 8). The system was also modified to reduce dead space, possible contamination due to valves and evaporation due to low pressures and passage of air over the sample while being collected. The samples were collected in either preweighed universal containers or graduated measuring cylinders. A double check on sweat rate could be made by comparing the peristaltic pump revcounter readings and the measured volumes over the timed periods. The suit pressure was

raised to 12 cm Hg at sweat onset and maintained there to enable serial collections to proceed before target. Once the dead space of about 10 cc in the pumping system had been filled, the volumes collected would represent the sweat production over the same period but the actual sweat collected would have been produced some minutes before, depending upon the sweat rate. To enable comparisons to be made with other types of collection method, the controlled hyperthermia period always started and ended with a collection change. Since the volume of 5 ml was the minimum desirable size for a sample, collection times varied from one to ten minutes depending on the sweat rate.

Table 1 shows the method of collection and sampling periods used for each group of subjects.

Urine Collection

The subjects were asked to empty their bladders, if possible, before the experiment and again after the experiment, the time and volume being noted on each occasion. Thus an indication of the urine excretion rates of the electrolytes could be measured from samples taken from the post experimental collection.

Sample Storage

Originally, all samples were stored in glass universal containers or stoppered pyrex tubes at 4°C without preservation. It was found however, that large numbers of samples packaged together (as for shipping or being returned to storage after a portion of the analysis) would not be cooled to bacteriostatic temperature sufficiently quickly to prevent the growth of organisms in the specimens. For this reason, all subsequent samples were kept frozen except during brief periods for analysis. Samples from abroad were always frozen hard and packed in insulated containers to ensure they remained as cool as possible during shipment.

It became evident that any leakage which occurred while the samples

Figure 9 Sweat and Urine Samples packed for Storage

Storage

were in a semi-frozen state could affect the concentrations. Loss of higher concentration liquid phase resulted in dilute samples. Glass universal containers and bijoux bottles proved to be particularly bad for leakage, especially if they were overfilled. The aluminium caps and rubber dams tended to loosen in storage, and during transport, when it could not be ensured that the samples remained upright, the possibility of leakage could not be neglected. When leakage was suspected, the higher value of duplicate samples was considered to be more reliable.

A more satisfactory method of storing sweat and urine was developed for the experiments conducted in India. A maximum of 5 ml of sample was put into stoppered 10 ml hard plastic tubes and frozen upright. These were then forced sideways into tight fitting envelopes made from heavy gauge polythene sleeving so they could be stored upright in rows of six to ten tubes (see Figure 9). This method provided samples which were easy to label, light and convenient to transport, clean and simple to handle and relatively free from errors due to contamination or loss of solution.

If at any time a portion was to be removed from a sample, it was first completely thawed and thoroughly mixed before division.

For analysis, samples were unpacked, put into racks and quickly brought to room temperature by immersing the lower part of each tube or bottle in warm water. After each analysis, the samples were quickly refrozen loosely spaced and upright in racks before being repacked and sealed in polythene envelopes.

Chemical Analysis of the Sweat and Urine Samples

Volumes

All the sweat and urine samples were measured in graduated cylinders at the time of collection. The only exception to this was for the small volumes collected from the unacclimatized female controls which were determined gravimetrically in pre-weighed sample containers.

Sodium and Potassium Determinations

Sodium and potassium were determined using an EEL model 150 direct reading clinical flame photometer running on town gas. (After the laboratories at Hampstead were converted to North Sea gas, bottled butane gas was used). A stock standard containing 200 mEq/l sodium and 100 mEq/l potassium was stored at 4°C. From this, a working standard was produced by 1 in 200 dilution in a volumetric flask. For dilutions and for setting the zero on the photometer, deionized distilled water was always used. All glassware for use with the flame photometer was kept free of soaps or detergent and was triple rinsed in deionized distilled water before use.

Samples were diluted in 20 ml volumetric flasks; 0.1 ml of urine or 0.2 ml of sweat was used to produce 1/200 and 1/100 dilutions respectively. Urine samples were read directly and sweat readings were divided by 2 to produce the correct concentrations. With exceptionally concentrated or dilute samples more appropriate dilutions were employed and the true concentrations obtained by using corresponding correction factors. Dilutions were made using 0.1 and 0.2 ml blowout pipettes.

Occasional dilution of stock standard along with samples showed the pipetting technique to be accurate and reproducible to within the resolution of the photometer (± 2% of the reading).

The photometer was left running for an hour before use to stabilize and the calibration was checked after every 5 or 6 samples, or more often if instability occurred. As deionized water was supplied to the machine between samples, the zero was constantly checked.

Chloride Determination

I. Titration with N/10 Silver Nitrate and Silver Electrode Chloride Potentiometer

This method of analysis was used for the earlier samples. For this method, 1 ml of urine or 2 ml of sweat was added to about 5 ml of

buffer (50% glacial acetic acid (analytical grade) in deionized distilled water) in 20 ml glass beakers. The burette for dispensing the silver nitrate was provided with a platinum electrode in contact with the solution in the tip below the stop cock. A silver electrode and an air bubbler for stirring were attached to the outside of the burette tip. When the burette tip and the silver electrode were immersed in the buffered solution, the voltage between the silver and platinum electrodes was measured on a potentiometer. The bubbler ensured adequate mixing as the silver nitrate was measured out. When the chloride in the solution became completely precipitated as silver nitrate and free silver ions remained in solution, a change in the potentiometer reading indicated the end point of the titration. The chloride concentration (for 1 ml sample) was determined by multiplying the volume of silver nitrate (in ml) by a factor of 100. Appropriate factors were used for other volumes of sample.

With this method of chloride analysis, the sodium and potassium were usually determined first, so that the approximate chloride concentration could be estimated. This made the titration quicker as there was less chance of missing the end point. If too much silver nitrate was accidently added, a known amount of chloride (usually 1 ml of 15 mEq/l solution) could be introduced to precipitate the excess silver and then subtracted from the final answer.

Although this method was very reliable, it was somewhat time consuming and the volume of sample required meant that it was not always possible to repeat the determination if questionable results were obtained the first time.

II. EEL Model 920 Chloride Meter

This coulometric chloride titrator was used for later analysis. With this machine, four silver electrodes and a stainless steel stirring paddle were immersed in a 75 ml beaker containing about 35 ml of

buffer solution and 0.5 ml of gelatin indicator solution. A measured quantity of sample (0.1 ml) was added to the buffer solution and then the automatic cycle was started.

After five seconds of stirring, a known current started to flow through the solution by way of two of the silver electrodes. Silver ions liberated into the solution by the anode were precipitated as silver chloride until the available chloride in the solution was exhausted. When this occured, silver ions remaining in solution produced a change in the conductivity of the liquid. This change in conductivity was detected by the other two silver electrodes which then automatically stopped the titration. A digital counter ran during the titration and the titrating current had been set to give a counter reading directly in mEq/l chloride for a 0.1 ml sample. Subsequent samples were introduced to the buffer solution and the titration cycle was restarted each time. The counter was automatically reset to zero for each cycle.

Before the first sample was run, the electrodes were well cleaned and the buffer was conditioned by running 0.1 ml of standard solution (90 mEq/l) three or four times to ensure that the end point cut off was accurate and reproduceable. The machine did not respond well to a sample containing less than 15 mEq/l chloride. If any sample gave a reading of less than 18 mEq/l, the buffer was reconditioned to remove any excess chloride which could remain in solution and a larger volume of sample (0.2 or 0.5 ml) was used for the determination. The reading was corrected by the appropriate factor.

The electrodes were cleaned periodically and each lot of buffer was used for no more than a total reading of 2000 mEq/l (eg. 20 samples at 100 mEq/l).

Estimation of chloride concentration in sweat and urine proved to be fast and reliable by this method. The small volume of sample needed for

the determination meant that, if necessary, questionable readings could be repeated several times from the total sample available.

Phosphate Analysis

Determination of inorganic phosphate in urine samples was based on the method of Richterich (1965) for use with a Unicam SP 600 spectrophotometer.

This method was employed because with certain precautions, colour stability could be ensured. It was found however, that the reaction was very temperature sensitive and analysis could only be done reliably on evenings when the ambient temperature in the laboratory was between 18°C and 21°C. If the solutions were allowed to become too warm, colours tended to fade before and during the time they were read. At very low temperatures (10°C) the colour failed to develop. This problem was partially overcome by adjusting the temperature of the reagents before use.

The reagents used for all phosphate determinations were made up in deionized distilled water as follows:-

1.	Stock phosphate standard	100 mg (P)/100 ml
2.	Metabisulphate-borax solution	20 g sodium tetraborate + 18 g sodium metabisulphate/l
3.	Hydroquinone-ascorbate solution	2 g hydroquinone + 0.1 g ammonium ascorbate/100 ml
4.	Ammonium molybdate solution	5 g ammonium molybdate + 12.5 ml conc. sulphuric acid/100 ml
5.	Carbonate-sulphite solution	42 g sodium carbonate (anhydrous) + 7 g sodium sulphate

The only change from the standard method (Richterich, 1965) was to adjust the amount of concentrated sulphuric acid in the molybdate solution. It was found that too little acid (5%) would not produce full colour development, whereas too much (40%) produced excessive effervescence when

the carbonate sulphite solution was added. Small bubbles coming out of solution tended to adhere to the inner surface of the cuvettes; and interfered with spectrophotometer reading.

Standards were made up from the stock solution containing 2.5, 5, 7.5, 10, 15, 20 and 30 mg(P)/100 ml by dilution in 10 ml volumetric flasks. These standards were then tested and read against a reagent blank several times to prove the reliability and linearity of the method over the range used. The responses found for one such set of solutions are shown in Figure 10. These standards were used for urine analysis.

The estimation of phosphate was carried out by adding 0.1 ml of standard or unknown (urine) to 1 ml of metabisulphate-borax solution. Then 0.25 ml each of ammonium molybdate and hydroquinone-ascorbate reagent was added and the contents of the test tube was thoroughly mixed. After being left for 15 minutes to allow the colour to develop, 2.5 ml of carbonate-sulphite solution was added, thoroughly mixed and allowed to stand for a further 10 minutes. The resulting blue coloured solution was then read against the reagent blank at a wavelength of 578 mμ. The same pair of matched cuvettes were used for all phosphate analysis, the blank always being read in the same cuvette.

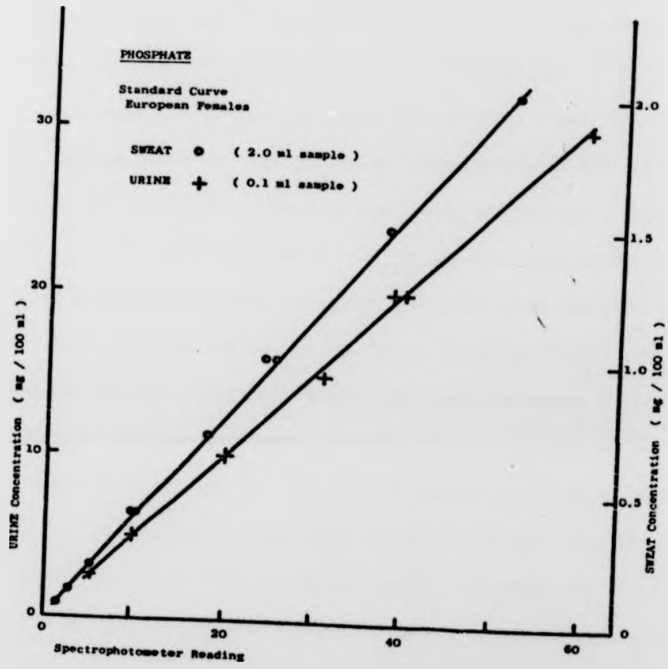
The metabisulphate-borax solution was used to stabilise the colour of the solution and the carbonate-sulphite reagent prevented the interference of readings by precipitates which occurred with some samples.

The hydroquinone-ascorbate served as an oxidizing agent to promote the formation of the blue phospho-molybdate complex of the reaction.

Exceptionally high or low readings were repeated with different sample doses to ensure that the readings were within the range of the standard curve.

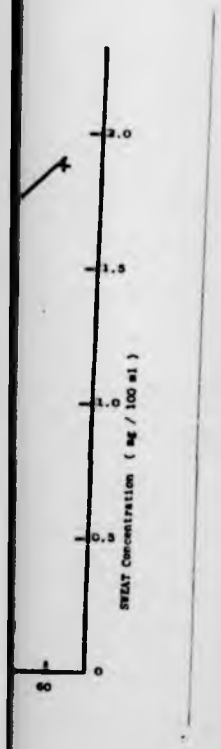
Reagent blanks and one or two standards were run with each batch of samples tested and any time new reagents were made up, full calibration

Figure 10 Example of Standard Curves for the Determination of Inorganic Phosphate in Sweat and Urine



Determination of

ine



curves were run.

Since there was a linear relationship between the phosphate concentration and the spectrophotometer reading (see Figure 10), a dose response line, using the method of least squares, was fitted for each set of reagents. The concentration of any sample tested could then be calculated from the appropriate dose response line.

Because the concentration of phosphate in sweat is much lower than that normally found in urine, the above method proved to be of insufficient sensitivity for the determination of sweat phosphate content. No recommended method for the estimation of phosphate in sweat could be found in the literature but by modifying the urine method, an adequately sensitive procedure was developed.

The standards which were used with sweat covered the range of phosphate concentration found in the samples (0.05 - 2.0 mg/100 ml). Strong colours could then be produced by using 2.0 ml of standard or sample in the otherwise unchanged method. Calibration with the phosphate standards using this modified procedure gave a dose response curve which was reproduciabley stable and linear (see Figure 10).

With this procedure extra precaution was needed to guard against the presence of bubbles forming on the sides of the cuvettes. This was overcome by thorough stirring of the sample immediately after the addition of the carbonate-sulphite solution (using an orbital test tube shaker) and then again before reading. Cuvettes were examined carefully for the presence of bubbles before being placed in the spectrophotometer and after being read. It was found that bubbles could usually be removed from the sides of a cylindrical cuvette by tapping the base sharply but lightly on a bench surface or by placing it in the test tube shaker. When this failed, the sample had to be returned to the test tube and re-decanted. Because of the stability of the colour produced by this

method, delays due to effervescence did not affect the results.

Statistical Analysis of the Data

The number of subjects in each group available for estimations of mean sweat concentrations and urine excretion rates have been given in Appendices 1,2,5 and 6. Except for instances where there were missing data, all results from subjects have been used for statistical analysis. All statistical methods used have been described by Snedicor (1966).

Sweat and urine electrolyte concentrations and excretion rates were found to be log normally distributed within groups. Thus geometric means and 95% confidence limits have been calculated for these parameters and are given in the Appendices. Tests for significant differences between groups for these measurements have been based on the sums and corrected sums of squares of logged (to base 10) data. Sodium/potassium ratios however, were not transformed before analysis so arithmetic means and standard errors are given in the Appendices.

To test for homogeneity between several different groups, analysis of variance has been used. Differences between any two groups have been determined using t-tests. When comparison of repeat tests on groups have been made, paired t-tests have been used where possible to remove the effects of subject variation.

Correlation and regression analyses have been used to examine the relationships between changes in electrolyte concentrations with time and sweat volume. Pairs of measurements for within subject and between subject data were plotted to ensure the relationships were linear over the range of observations before regression analysis was carried out. The dependence of electrolyte concentrations on sweat rate, skin temperature and the duration of sweating was examined using multiple regression techniques. Correlation or regression analyses were only carried out if there were complete data from at least six subjects or sweat samples

within a subject.

Excretion rates corrected for body weight were calculated for each subject. Group means and confidence limits for these measurements are given in Appendices 7 and 8.

Table 2

Mean Values for Sweat Measurements on Army Group III

Test	No. Sub	Concentration				Excretion Rate				Sodium Potassium Ratio	Volume ml/½hr
		Sodium mEq/l	Potassium mEq/l	Chloride mEq/l	Phosphate mg/l	Sodium uM/min	Potassium uM/min	Chloride uM/min	Phosphate ug/min		
1	10	65.8	6.79	60.8	1.25	232	24.0	214	4.40	9.82	106
2	10	59.6	7.00	55.3	1.17	233	27.4	216	4.45	8.65	117

RESULTS

The findings presented in this study are based on the results of the analysis of sweat samples which were collected from the subjects who made up the groups described in Table 1. The statistical analysis of these results has been made at three levels: within subjects, between subjects and between groups. Within subject data are available only from those groups where serial collections were made during the test. These included Army group III and IV (both tests), the unacclimatized female control groups and a number of subjects from the Indian study. For analyses of within group data, a single value for each subject has been used, based on either the weighted mean value of all samples collected during the first half hour of controlled hyperthermia or from the half hour volume and a sample from a collection within this period which included the first ten minutes. For the between group analyses, group means were based on the single value for each subject with the group.

Replication

To test the repeatability of the response of individuals to the bed test (Routine C), a group of twelve volunteers (Army group III) were tested twice, with two to four days free between tests. On the second occasion, two subjects came to the laboratory overheated and continued to sweat throughout the test, so their results were excluded. On this second test, the sodium and chloride levels for these two subjects were considerably reduced as was observed for experiments on Army group II when they were preheated before the test began (Fox,unpublished). On the ten remaining subjects of Army group III, paired t-tests did not show differences between the two tests for sweat rates or sweat electrolyte concentrations. The means for all subjects on the two tests are shown in Table 2.

Table 3

Mean Half Hour Sweat Volume of Unacclimatized British Army Subjects

Group	No. of Sub.	Month of Test	Sweat Volume ml/½hr.
Army I	25	September	236
Army II	8	September	227
Army III	12	November	111
Army IV	14	February	124

Table 4

Significance of Correlation Coefficients for Sweat Measurements of Indian Army Subjects with Season. Troops tested to Third Week in October

Measurement	Northerners	Southerners	Gurkhas
Sodium Concentration	NS	NS	NS
Potassium Concentration	NS	NS	NS
Chloride Concentration	NS	NS	NS
Phosphate Concentration	NS	- *	- **
Sodium Rate	NS	NS	NS
Potassium Rate	NS	NS	NS
Chloride Rate	NS	NS	NS
Phosphate Rate	NS	- *	- **
Sodium/Potassium Ratio	NS	NS	NS
Sweat Rate	NS	NS	NS

N.S. not significant

* $0.05 \geq P > 0.01$

** $0.01 \geq P > 0.001$

Selection of the Unacclimatized Male Control Group

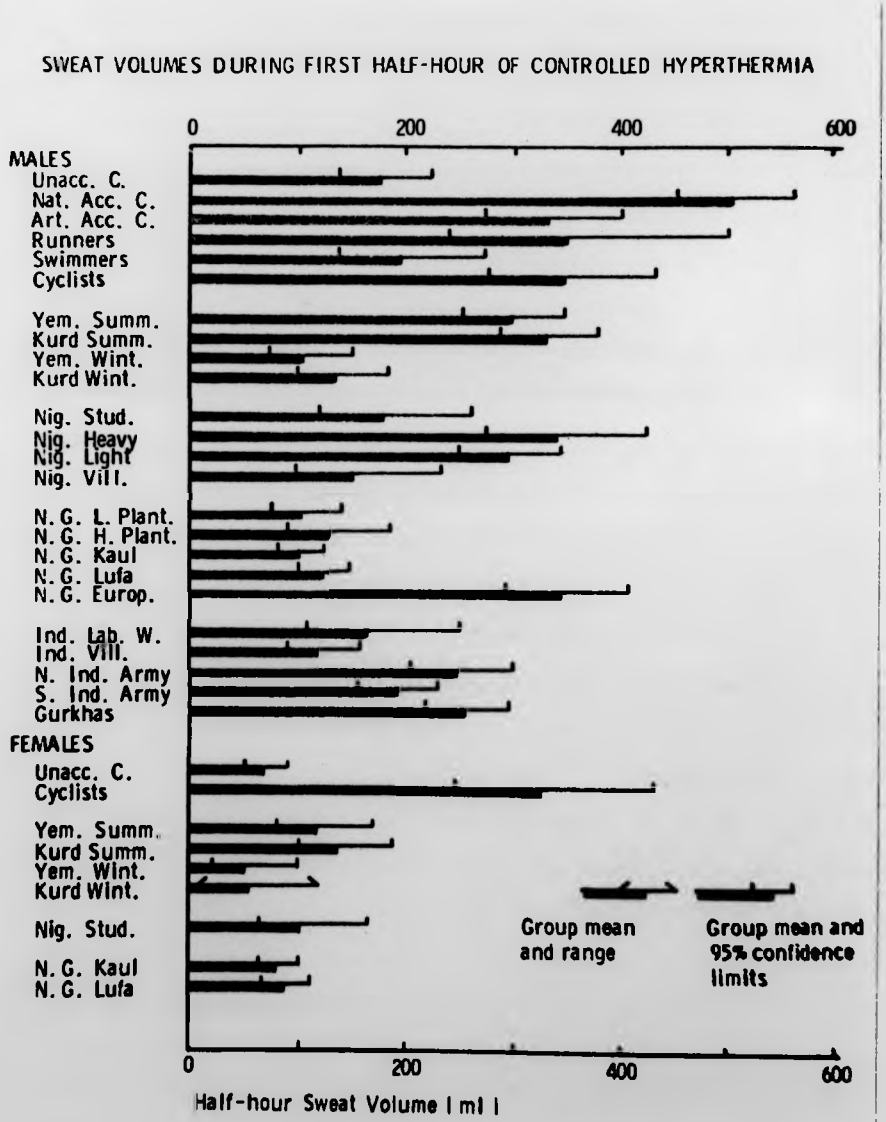
Four groups of army subjects were tested in the unacclimatized state, that is to say with only the level of acclimatization which they would have from carrying on normal duties in Great Britain. They were tested at different times of year however, as shown in Table 3. From the mean half hour sweat volumes of these groups (Table 3) seasonal variation is evident. The results of the four groups were combined to form an unacclimatized control level and included the whole cross section of background levels of acclimatization. Phosphate results were only available from Army groups III and IV, who had lower sweat rates than groups I and II in the unacclimatized state.

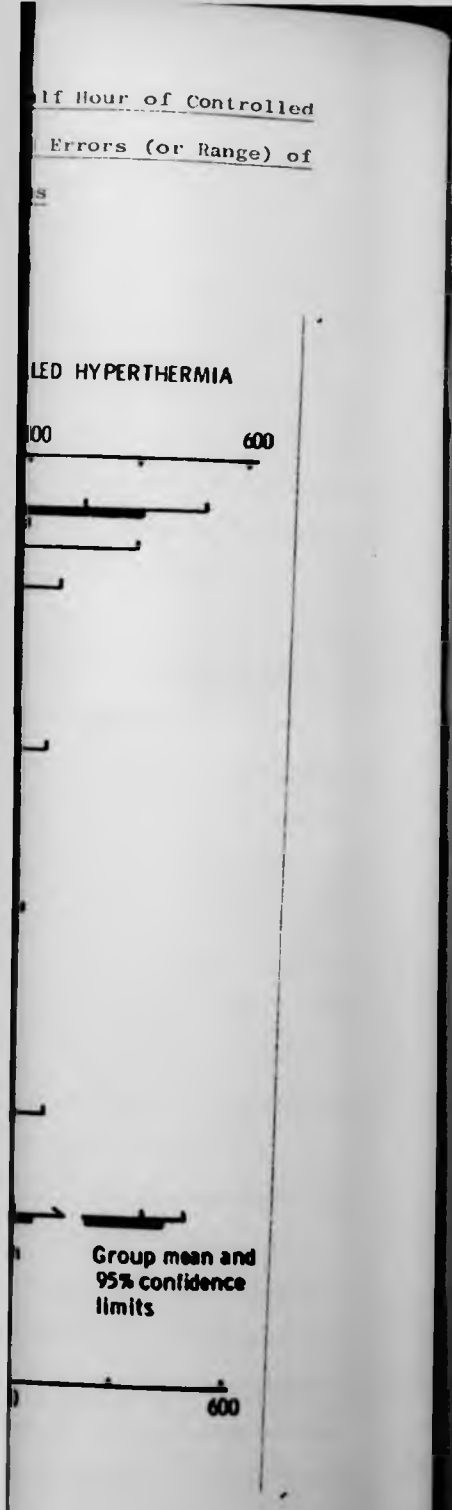
Analyses of variance revealed no significant differences for sodium or chloride concentrations for the four groups but mean potassium concentrations differed at the 1% level with Army group III having the highest level and Army group IV the lowest. Sodium/potassium ratios also differed ($0.01 > p > 0.001$) with group III being the lowest and group IV the highest. Groups III and IV did not differ in phosphate concentration or excretion rate. Because of the higher ($p < 0.001$) sweat rates of group I and II, the differences in the excretion of sodium, potassium and chloride were highly significant ($p < 0.001$).

Selection of Indian Groups

The three groups of Indian soldiers were tested between September and December and it was found that they deacclimatized during this period as the weather became cooler. The sweat rates of these subjects decreased significantly during this period. This meant that each group could not be considered as a whole when comparing their electrolyte concentrations or excretion rates with other groups. When the electrolyte concentrations and excretion rates of subjects tested up to the third week in October were related to time of year however, it was found that the only

Figure 11 Sweat Volumes during the First Half Hour of Controlled Hyperthermia Means and Standard Errors (or Range) of Young Adult Male and Female Groups





significant regressions were for decreasing phosphate concentration and excretion rate with time for the Gurkhas ($0.01 \geq p > 0.001$) and the Southerners ($0.05 \geq p > 0.01$, see Table 4). The Northerners did not show a significant regression for phosphate but the trend was the same as for the other two groups of soldiers.

For this reason, only those troops tested before the third week in October have been included in the Indian groups used for comparisons with other male groups. The phosphate measurements which were correlated with time have not been used for comparisons. The only male groups which could not be compared with the Indian soldiers tested early in the study were the Indian Laboratory workers and Villagers who were tested at the end of the Indian study.

Comparison of Control Groups with other Groups

The control groups (unacclimatized males and females and acclimatized males and females) have been compared with the other young adult groups presented in this study. Sweat rates during the half hour of controlled hyperthermia, sweat sodium, potassium, chloride and phosphate concentrations and the sodium/potassium ratios are shown in Figures 11 to 21, Table 5 and Figure 22. Comparisons with each of the control groups for concentration have been treated separately in the figures. To indicate the sodium, potassium, chloride and phosphate losses during sweating, the excretion rates of these electrolytes in sweat have been presented as well as the concentrations for each group.

Sweat Rate

The sweat volumes for the first half hour of controlled hyperthermia are represented in Figure 11. The mean value for each male and female young adult group has been given along with the 95% confidence limits.

When the male groups were compared, it was found that the sweat

rates of unacclimatized controls did not differ significantly from the swimmers, the winter Kurds, the Nigerian villagers, the High Plantation workers or any of the Indian groups. Lower values than those of the unacclimatized controls were found for the Kauls ($p \leq 0.001$) and for the Low Plantation workers, the Lufas and the winter Yemenites ($0.05 \geq p > 0.01$). All the other male groups had greater sweat rates, with highly significant differences ($p \leq 0.001$) found for the comparisons with the naturally acclimatized controls, the Kurds and Yemenites in summer, the Nigerian Heavy Industry workers and the Europeans in New Guinea.

The naturally acclimatized male group had a mean sweat rate which was significantly higher than any other group. Differences were found at the 1% level for the runners and Nigerian Heavy Industry workers and at the 0.1% level for all other groups.

Comparisons amongst the females showed no differences in sweat rates between the unacclimatized controls and the Yemenites in winter, Kurds in summer or winter or either New Guinea group. Higher sweat rates were found for the Nigerian students ($0.05 \geq p > 0.01$) and the summer Yemenites and the acclimatized female controls ($p \leq 0.001$).

The acclimatized female controls had sweat rates which were higher ($p \leq 0.001$) than any other female group.

The women, in general, had lower sweat rates than the men.

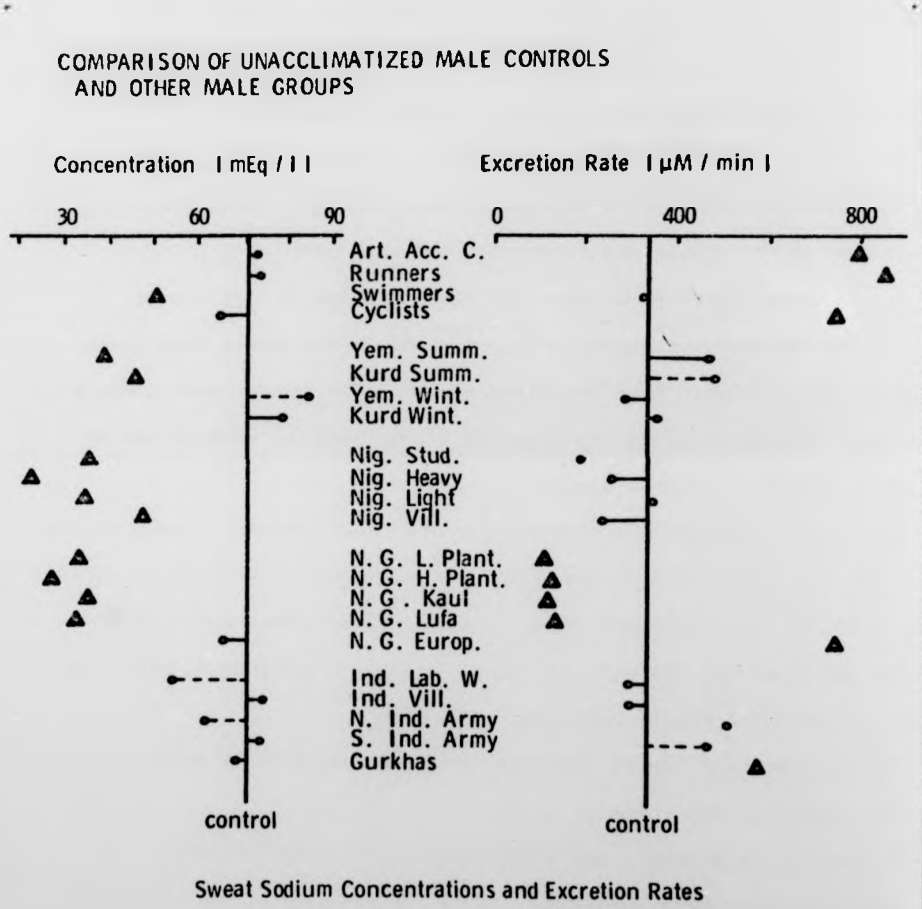
Unacclimatized Male Controls

Comparisons of the sweat electrolyte concentrations and excretion rates between the unacclimatized male control group and the other young adult male groups are shown in Figures 12 to 15.

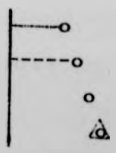
Sodium and Chloride

Only the winter Yemenites had significantly higher sodium ($0.05 \geq p > 0.01$) and chloride ($0.01 \geq p > 0.001$) concentrations than the controls. Many groups had much lower sweat concentrations,

Figure 12 Sweat Sodium Concentrations and Excretion Rates. Comparison of Unacclimatized Male Controls with other Male Groups



Key:- Significance of differences from control level



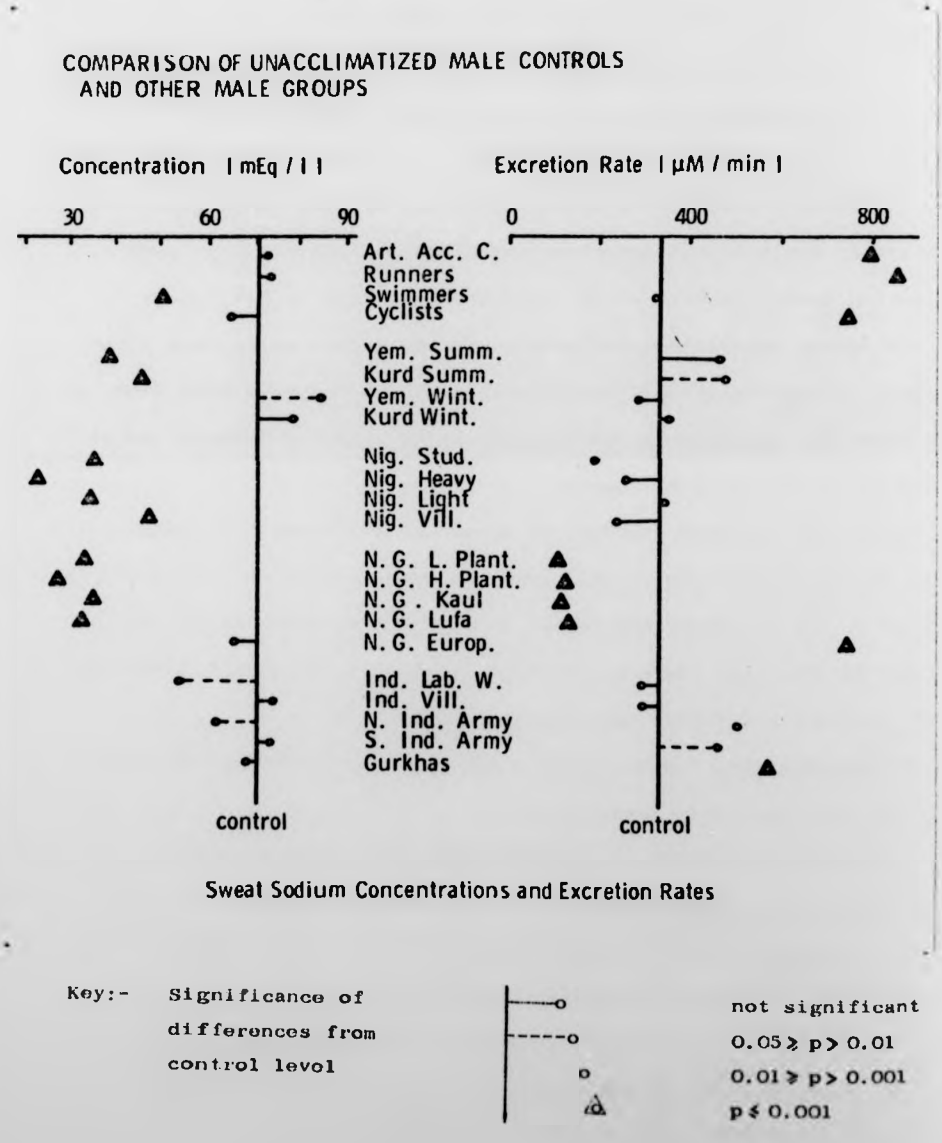
not significant

$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

Figure 12 Sweat Sodium Concentrations and Excretion Rates. Comparison of Unacclimatized Male Controls with other Male Groups



Sweat Sodium Concentrations and Excretion Rates

Key:- Significance of differences from control level

not significant

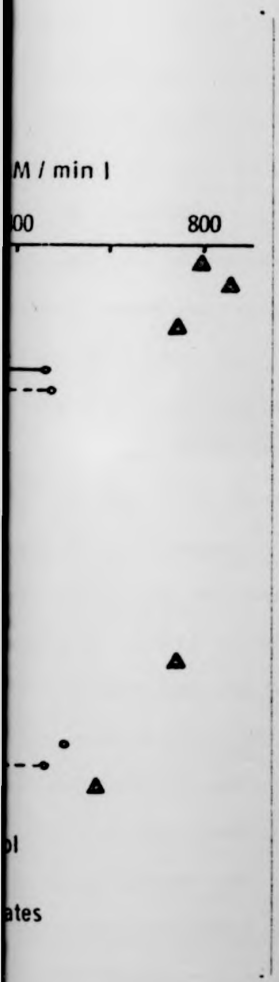
$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

cretion Rates.

Controls with



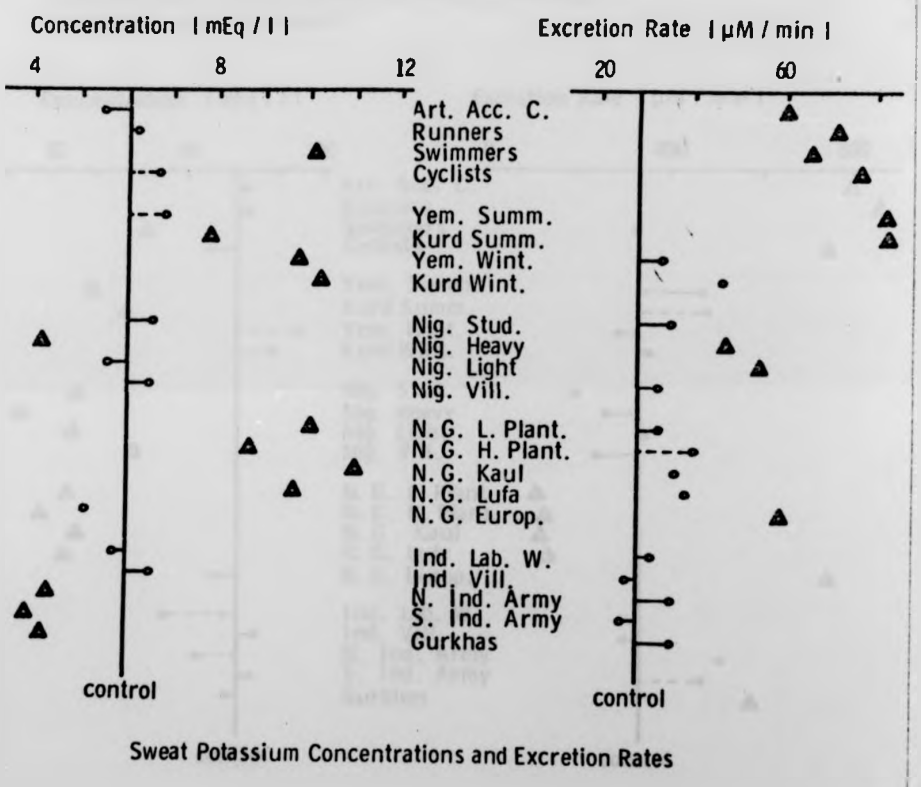
not significant

$0.05 \geq p > 0.01$

$0.01 \geqslant p > 0.001$

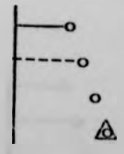
$p \leqslant 0.001$

Figure 13 Sweat Potassium Concentrations and Excretion Rates Comparison of Unacclimatized Male Controls with other Male Groups



Sweat Potassium Concentrations and Excretion Rates

Key:- Significance of differences from control level



not significant

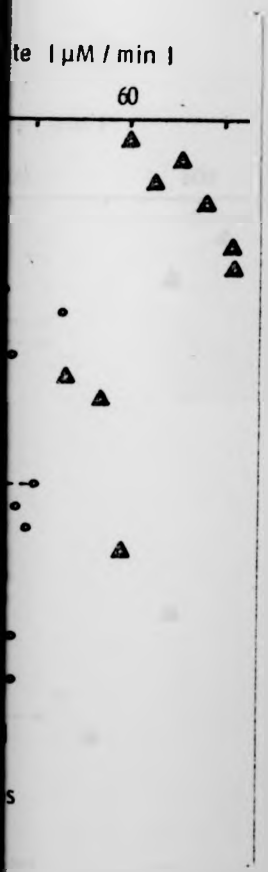
$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

Excretion Rates

ntrols with



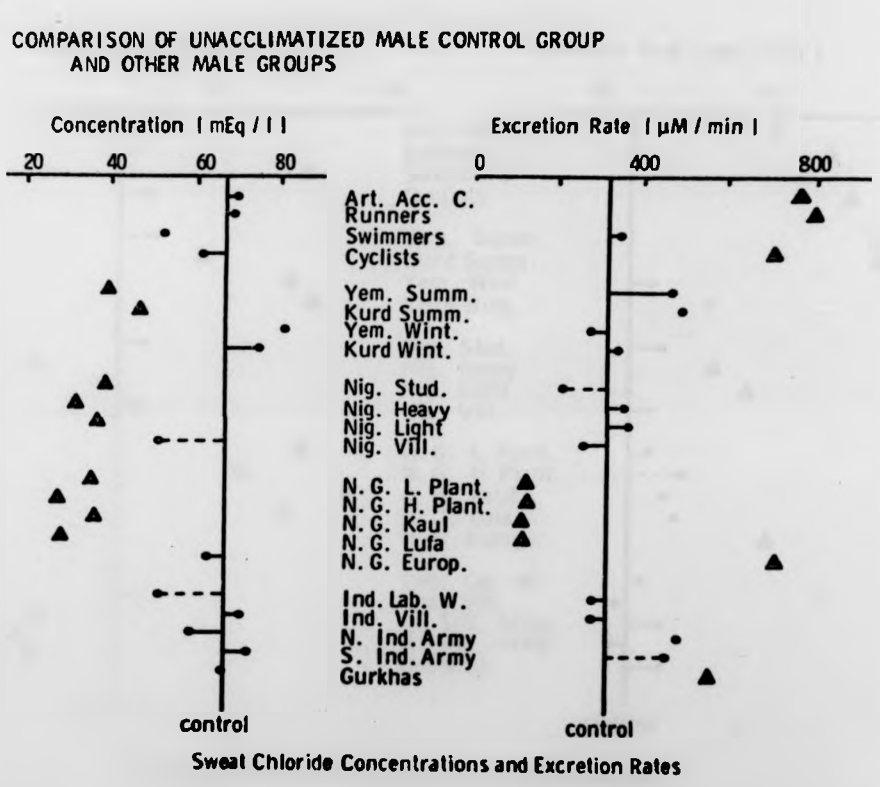
not significant

0.05 ≥ p > 0.01

0.01 ≥ p > 0.001

p ≤ 0.001

Figure 14 Sweat Chloride Concentrations and Excretion Rates Comparison of Unacclimatized Male Controls with other Male Groups



Key:- Significance of differences from control level

not significant

$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

particularly amongst the New Guinea indigenes and the Nigerian groups. The Israelis in the summer and the swimmers also had low sweat sodium and chloride concentrations. For the other groups, the differences were not significant (see Figures 12 and 14).

Because of the difference in sweat rates, much higher sweat sodium and chloride excretion rates were found for the artificially acclimatized control group, the runners and cyclists and the Europeans in New Guinea. Significantly higher excretion rates were also found for the summer Kurds and the Indian army groups. Very low sodium and chloride losses were found for the New Guinea indigenes who differed from the controls at the 0.1% level.

Potassium

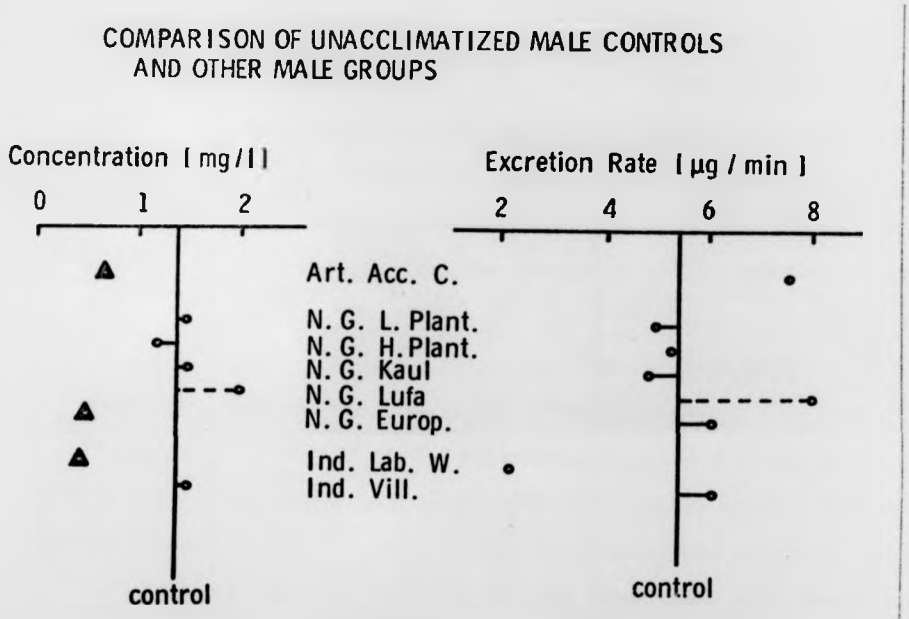
Comparison with the unacclimatized controls showed several groups to have higher sweat potassium concentrations (see Figure 13). Large differences ($p \leq 0.001$) were found for the New Guinea groups, the Kurds and Yemenites in the summer and for the swimmers. Of those groups with lower mean potassium concentrations, significant differences were found for the Indian army groups and the Nigerian Heavy Industry workers ($p \leq 0.001$) and for the Europeans in New Guinea ($0.01 \geq p > 0.001$).

No male group had significantly lower potassium excretion rates than the controls. Much higher rates ($p \leq 0.001$) were found for the artificially acclimatized controls, the runners, swimmers and cyclists, the Israelis in summer, the Europeans in New Guinea and the Nigerian Industrial groups. Despite the fact that the Kauls and Lufas had lower sweat rates than the controls (see Figure 11), the sweat potassium loss in these two groups was significantly higher ($0.01 \geq p > 0.001$).

Phosphate

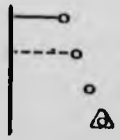
The unacclimatized controls had higher sweat phosphate

Figure 15 Sweat Phosphate Concentrations and Excretion Rates Comparison of Unacclimatized Male Controls with other Male Groups



Sweat Phosphate Concentrations and Excretion Rates

Key:- Significance of differences from control level



not significant
0.05 ≥ p > 0.01
0.01 ≥ p > 0.001
p ≤ 0.001

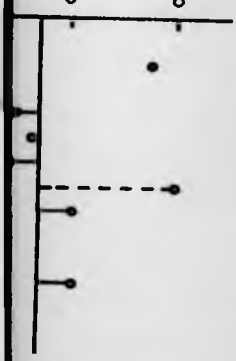
Excretion Rates

ontrols with

TROLS

[µg / min]

6 8



ntrol

Rates

not significant

0.05 ≥ p > 0.01

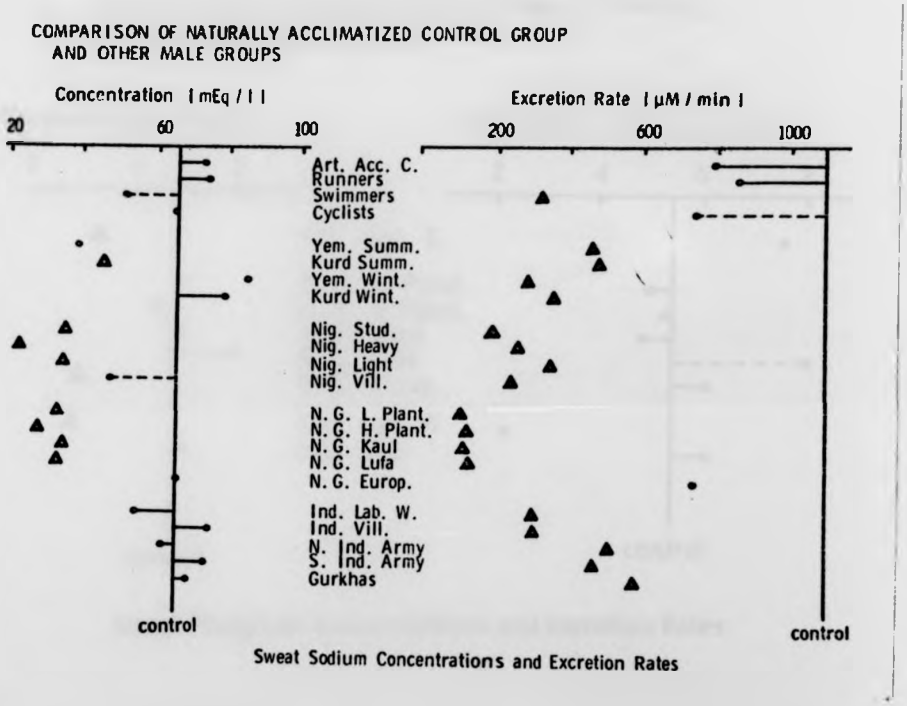
0.01 ≥ p > 0.001

p < 0.001

Figure 16 Sweat Sodium Concentrations and Excretion Rates

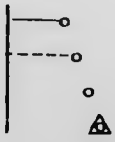
Comparison of Naturally Acclimatized Male Controls

with other Control Groups



Sweat Sodium Concentrations and Excretion Rates

Key:- Significance of differences from control level



not significant

$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

concentrations than the artificially acclimatized group, the Europeans in New Guinea and the Indian Laboratory workers ($p < 0.001$) but the excretion rates were significantly lower only for the last group ($0.01 \geq p > 0.001$), (see Figure 15). Only the Lufas had higher phosphate concentrations and excretion rates than the controls ($0.05 \geq p > 0.01$).

Acclimatized Male Controls

Comparison between the naturally acclimatized male control group and the other male groups are shown in Figures 16, 17 and 18 for sodium, potassium and chloride concentrations and excretion rates. Figure 19 shows similar comparisons for phosphate using the artificially acclimatized control group.

Sodium

Only the winter Yemenites had significantly higher ($0.01 \geq p > 0.001$) sodium concentrations than the naturally acclimatized controls. Much lower concentrations were found amongst the New Guinea, Nigerian and Israeli groups. None of the Indian groups had means differing significantly from the level of the control group (see Figure 16).

The naturally acclimatized controls had the highest sodium excretion rates of all the groups but the means did not differ significantly for comparisons with the artificially acclimatized group or the runners. Differences were seen at the 5% level for the cyclists and at the 1% level for the Europeans in New Guinea. All other groups had much lower sweat sodium excretion rates than the controls ($p \leq 0.001$).

Potassium

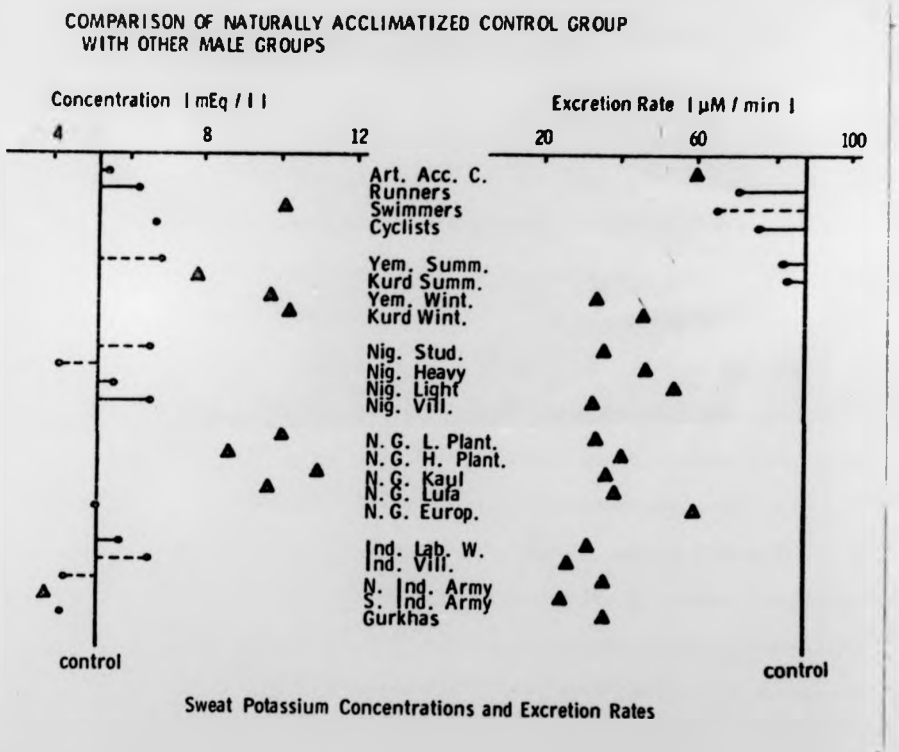
Sweat potassium concentrations were found to be much higher than the naturally acclimatized controls ($p \leq 0.001$) for the swimmers, the summer Kurds, both Israeli groups in winter and all four indigenous New Guinea groups. Significantly higher concentrations were also found for the cyclists ($0.01 \geq p > 0.001$) and for the summer Yemenites,

xcretion Rates

zed Male Controls

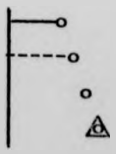
not significant
$0.05 \geq p > 0.01$
$0.01 \geq p > 0.001$
$p \leq 0.001$

Figure 17 Sweat Potassium Concentrations and Excretion Rates Comparison of Naturally Acclimatized Malo Controls with other Malo Groups



Sweat Potassium Concentrations and Excretion Rates

Key:- Significance of differences from control level



not significant

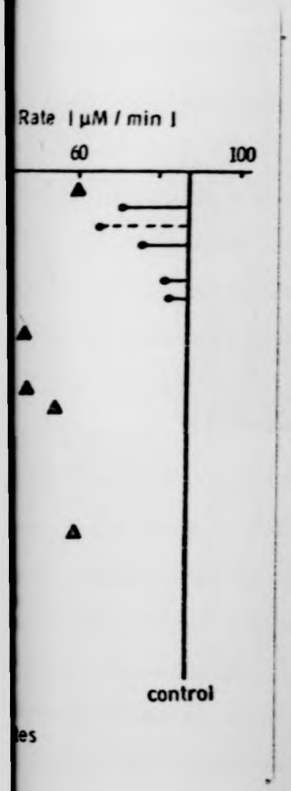
$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

l Excretion Rates

ed Male Controls



les

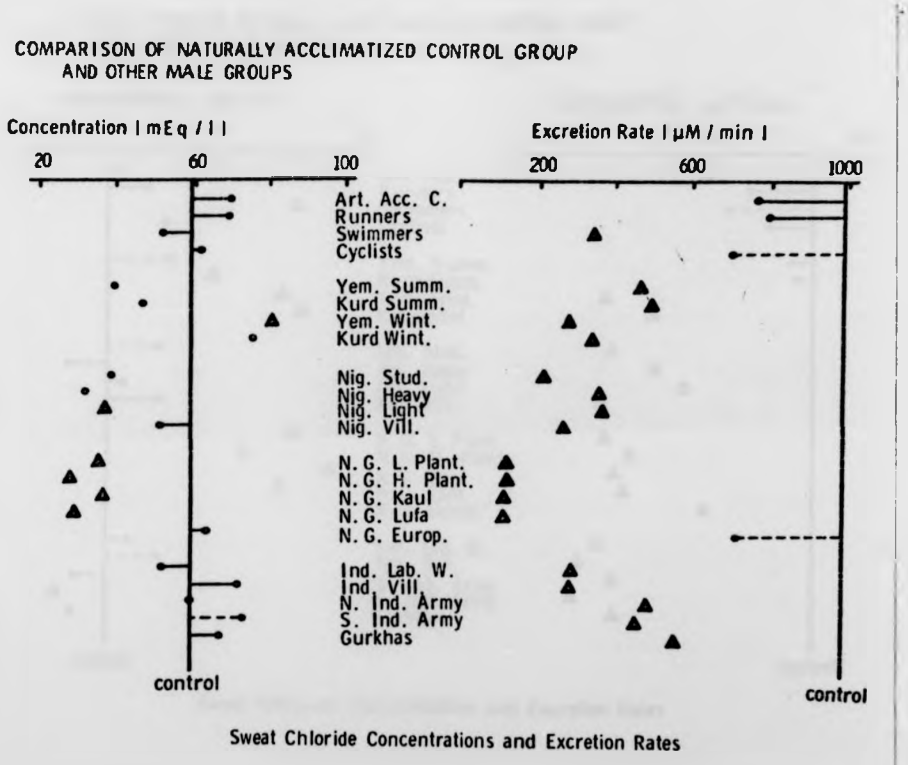
not significant

0.05 ≥ p > 0.01

0.01 ≥ p > 0.001

p ≤ 0.001

Figure 18 Sweat Chloride Concentrations and Excretion Rates Comparison of Naturally Acclimatized Male Controls with other Male Groups



Key:- Significance of differences from control level

o not significant

o $0.05 \geq p > 0.01$

o $0.01 \geq p > 0.001$

△ $p \leq 0.001$

Nigerian students and Indian Villagers ($0.05 \gtrsim p > 0.01$). Lower concentrations than those of the controls were found only for the Nigerian Heavy Industry workers ($0.05 \gtrsim p > 0.01$) and the three Indian army groups, with significant differences at the 5% level for the Northerners, the 1% level for the Gurkhas and at the 0.1% level for the Southerners (see Figure 17).

The naturally acclimatized controls had the highest sweat potassium excretion rates with the means for most groups differing at the 0.1% level. The difference for the swimmers however, was only at the 5% level and those for comparisons with the runners, cyclists and the two summer Israeli groups were not significant.

Chloride

Chloride concentration in sweat was found to be higher for the winter Yemenites ($p \lesssim 0.001$) and Kurds ($0.01 \gtrsim p > 0.001$) and for the South Indian army ($0.05 \gtrsim p > 0.01$) when comparisons were made with the naturally acclimatized control group. Lower concentrations ($p \lesssim 0.001$) were found for all four indigenous New Guinea groups and the Nigerian Light Industry workers. Lower concentrations ($0.01 \gtrsim p > 0.001$) were also found for the summer Israeli groups and the Nigerian students and Heavy Industry workers (see Figure 18).

As with sodium, most groups had much lower chloride excretion rates than the acclimatized controls. The differences were not significant for the artificially acclimatized group or the runners and were significant only at the 5% level for the cyclists and Europeans in New Guinea. The difference for all other groups was at the 0.1% level.

Phosphate

When compared with the artificially acclimatized male control group, higher phosphate concentrations were found for the Lufas ($p \lesssim 0.001$), Kauls ($0.01 \gtrsim p > 0.001$) and Low Plantation workers

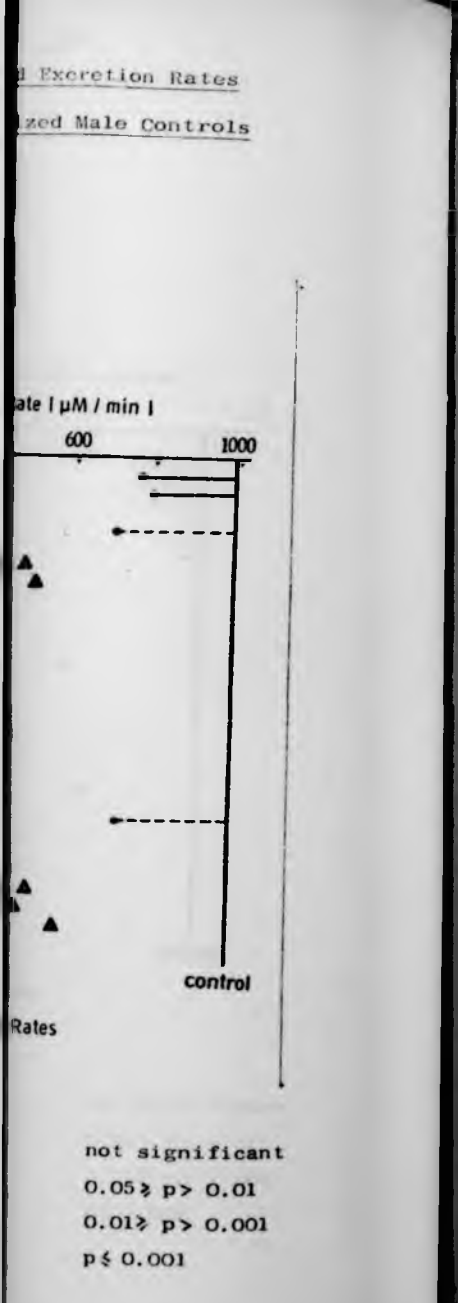
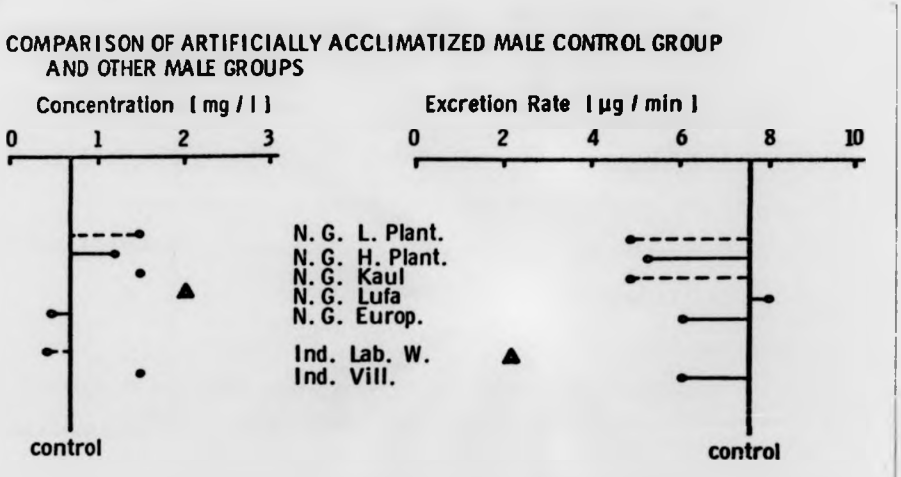


Figure 19 Sweat Phosphate Concentrations and Excretion Rates

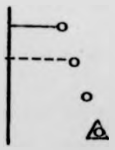
Comparison of Artificially Acclimatized Male Controls

with other Male Groups



Sweat Phosphate Concentrations and Excretion Rates

Key:- Significance of differences from control level



not significant

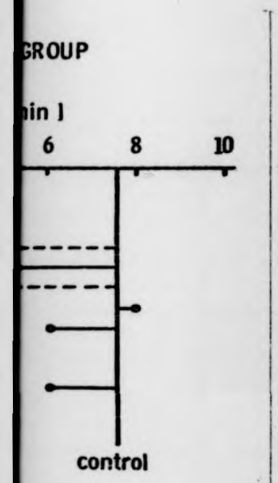
0.05 ≥ p > 0.01

0.01 ≥ p > 0.001

p ≤ 0.001

Excretion Rates

ized Male Controls



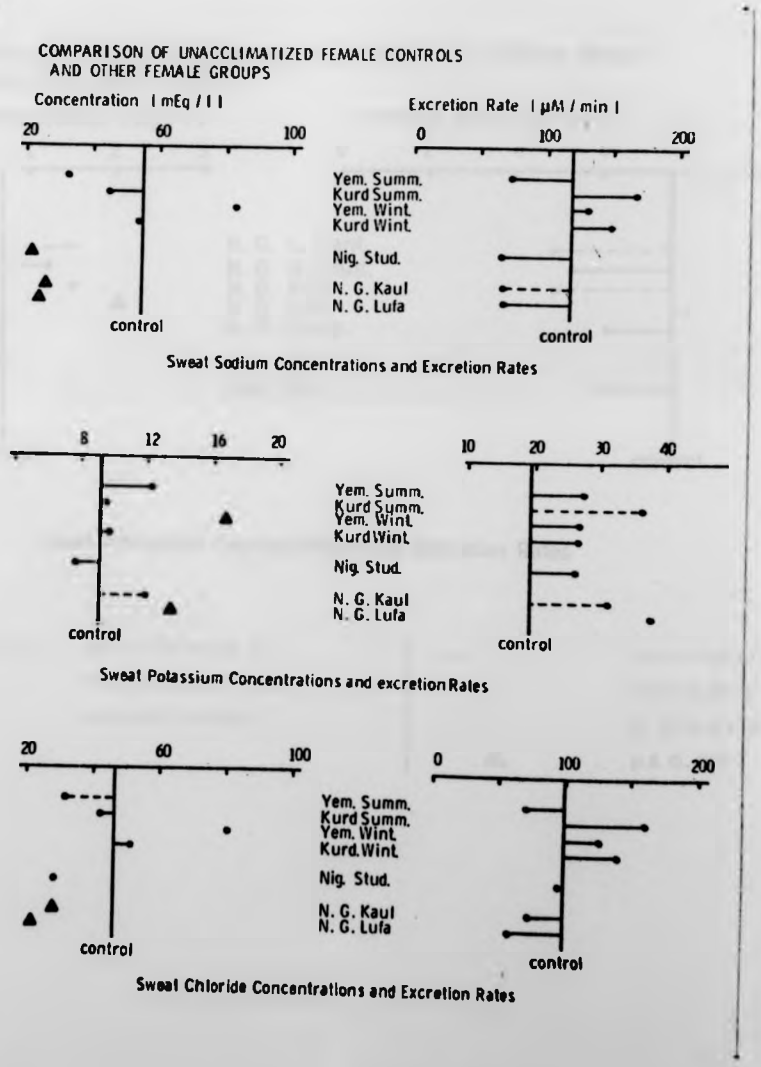
not significant

$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

Figure 20 Sweat Sodium, Potassium and Chloride Concentration and Excretion Rates Comparison of Unacclimatized Female Controls with other Female Groups



Key:- Significance of differences from control level

not significant

$0.05 \geq p > 0.01$

$0.01 \geq p > 0.001$

$p \leq 0.001$

0.05 ≥ p > 0.01). Concentrations were also found to be higher for the Indian villagers (0.01 ≥ p > 0.001) but lower for the Laboratory workers (0.05 ≥ p > 0.01) (see Figure 19). Only the Lufas had higher sweat phosphate excretion rates than the controls but the difference in means was not significant. Lower excretion rates were found for the Indian Laboratory workers (p ≤ 0.001), the Low Plantation workers and the Kauls (0.05 ≥ p > 0.01).

Unacclimatized Female Controls

Comparisons between the unacclimatized female controls and the seven other female groups for sodium, potassium and chloride are presented in Figure 20. Phosphate measurements are given in Table 5 for those groups for whom the chemical analyses were done.

Sodium and Chloride

Sweat sodium and chloride concentrations for the winter Yemenites alone were significantly higher (0.01 ≥ p > 0.001) than those of the unacclimatized female controls. Lower concentrations were found for the Kauls and Lufas (sodium and chloride, p ≤ 0.001) and the summer Yemenites (sodium 0.01 ≥ p > 0.001, chloride 0.05 ≥ p > 0.01) (see Figure 20).

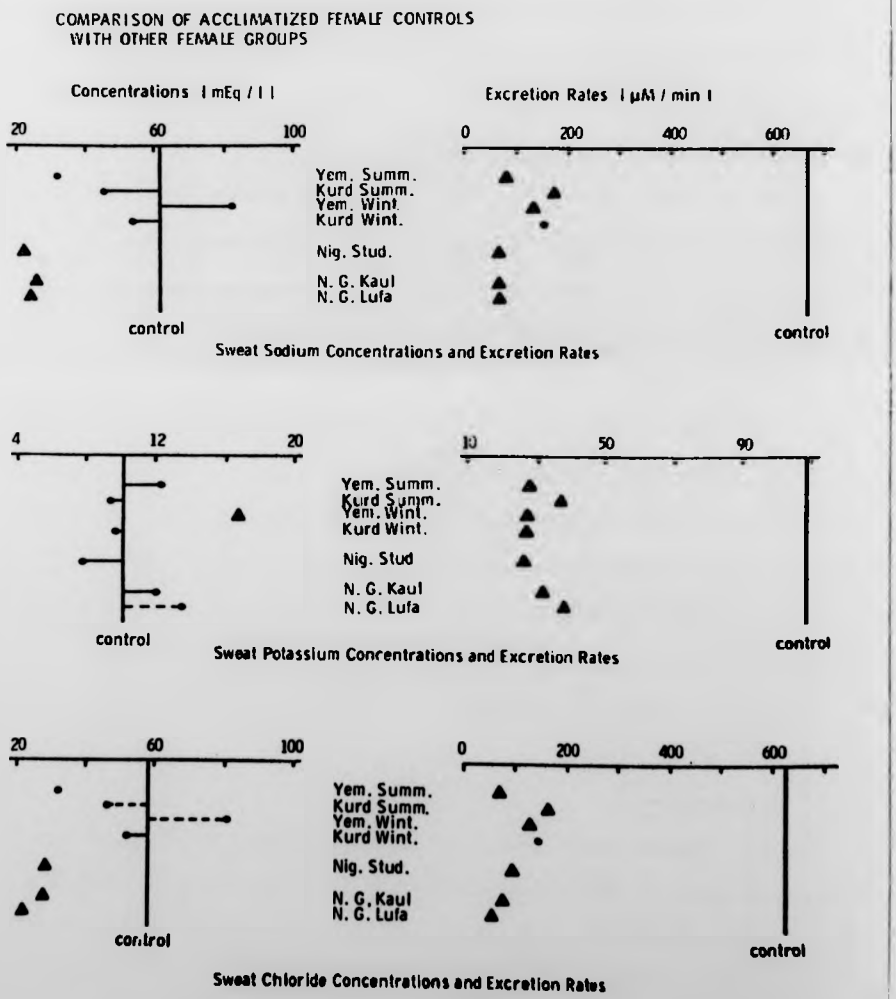
The only female group that differed significantly from the controls for sweat sodium or chloride excretion rate was the Kauls, who had a lower (0.05 ≥ p > 0.01) sodium rate.

Potassium

Higher sweat potassium concentrations were found for the Yemenites in winter, the Lufas (p ≤ 0.001) and the Kauls (0.05 ≥ p > 0.01). Only the Nigerian students had lower potassium concentrations but the mean was not significantly different from that of the controls (see Figure 20).

The controls had the lowest potassium excretion rates with significant differences found for the Lufas (0.01 ≥ p > 0.001), Kauls and summer Kurds (0.05 ≥ p > 0.01).

Figure 21 Sweat Sodium, Potassium and Chloride Concentration and Excretion Rates Comparison of Acclimatized Female Controls with other Female Groups



Key:- Significance of differences from control level

- o — not significant
- o ----- o — 0.05 ≥ p > 0.01
- o — 0.01 ≥ p > 0.001
- ⚠ — p ≤ 0.001

Phosphate

As seen in Table 5, the unacclimatized controls had lower sweat phosphate concentrations and excretion rates than either of the New Guinea female groups. These differences were significant at the 0.1% level.

Table 5 Mean Sweat Phosphate Concentration and Excretion Rates for the Female Groups

Group	Concentration mg/l	Excretion Rate ug/min
Unacc. C.	0.32	0.68
N.G. Kauls	2.38	6.15
N.G. Lufas	3.37	9.43

Acclimatized Female Controls

Comparison between the acclimatized female control group and the other female groups for sodium, potassium and chloride are given in Figure 21. No phosphate measurements were available for these controls.

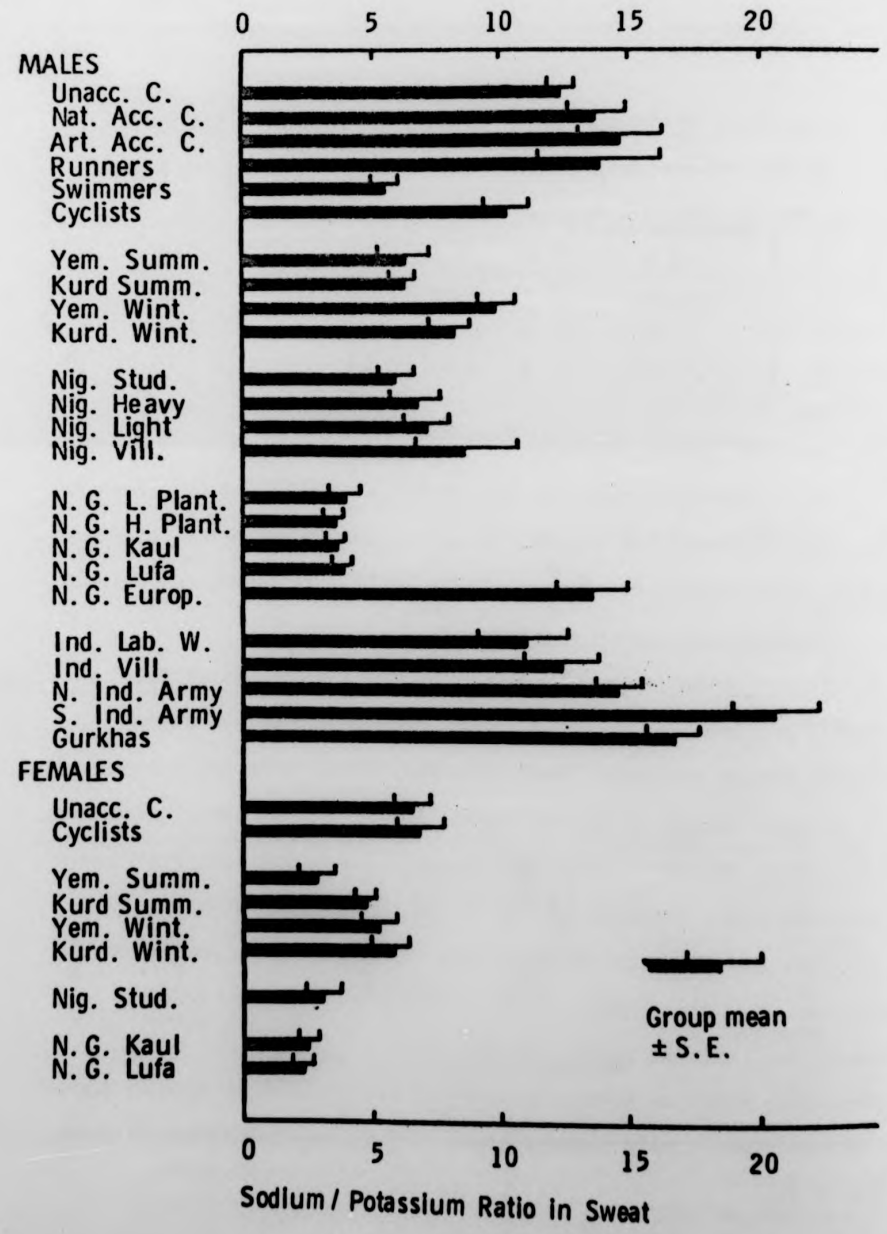
Sodium, Potassium and Chloride

Only the winter Yemenites had higher sodium (not significant) and chloride ($0.05 \geq p > 0.01$) concentrations than the acclimatized female controls. Lower concentrations were found for the Nigerian and New Guinea groups ($p \leq 0.001$) and for the summer Yemenites ($0.01 \geq p > 0.001$) for both sodium and chloride concentration. The summer Kurds also had lower chloride levels ($0.05 \geq p > 0.01$) (see Figure 12).

The only groups which differed from the controls in potassium concentration were the winter Yemenites ($p \leq 0.001$) and the Lufas ($0.05 \geq p > 0.01$), who had higher levels.

Excretion rates of sodium, potassium and chloride were much higher in the acclimatized female control group than in any other female group (see Figure 21).

Figure 22 Sweat Sodium/Potassium Ratios Means and Standard Errors of Young Adult Male and Female Groups



Sodium/Potassium Ratio in Sweat

The mean and standard error of the sweat sodium/potassium ratio for each group is shown in Figure 22. When compared with the unacclimatized male control group no significant difference was found in the mean sodium/potassium ratio for the artificially or naturally acclimatized controls, runners, cyclists, Europeans living in New Guinea or either civilian Indian group. The Indian army groups were the only ones with significantly higher sodium/potassium ratios with means differing for the Northerners at the 5% level and for the Southerners and Gurkhas at the 1% level. All the other groups had lower mean ratios than the unacclimatized controls. Of these, the Nigerian Villagers differed at the 5% level, the Yemenites in winter at the 1% level and for the remainder the difference was highly significant ($p \leq 0.001$).

The control females showed no difference between the unacclimatized and acclimatized state. Both control groups had higher ratios than the other female groups and their means differed significantly from those of the New Guinea ($p \leq 0.001$), Nigerian ($0.01 \geq p > 0.001$) and the Yemenite summer groups ($0.05 \geq p > 0.01$) but did not differ significantly from either the Yemenites in winter or the Kurds in summer or winter.

Within both the male and female groups, the New Guinea subjects consistantly had the lowest sodium/potassium ratios and with the exception of the swimmers, it was found that the British groups and the Europeans in New Guinea had higher ratios than the Israelis and the Nigerians. For each female group the sodium/potassium ratio in the sweat was lower than that for the corresponding male group.

Sex Difference in Sweat Electrolytes

A number of paired male - female groups are shown in Table 6, representing the various ethnic groups. In every case sweat samples taken from the females were found to have lower mean sodium and chloride

Table 6

Sex Differences between Comparable Groups Sweat Measurements and Significant Differences between Means

Group		Concentrations				Excretion Rates				Sodium	Sweat
		Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
		mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
	(M)	70.4	6.01	66.5	1.38	333	28.4	314	5.41	12.3	175
Unacc. C.		**	***	***	***	***	**	***	***	***	***
	(F)	55.1	9.05	46.5	0.32	117	19.3	99.1	0.68	6.58	63.9
	(M)	64.7	6.68	61.1	-	745	76.9	704	-	10.2	345
Cyclists		NS	***	NS		NS	*	NS		**	NS
	(F)	61.7	10.1	58.2	-	667	109	629	-	6.83	324
	(M)	78.6	10.3	74.6	-	351	46.0	334	-	8.12	134
Kurd Wint.		*	NS	*		*	NS	*		NS	NS
	(F)	53.8	9.66	50.2	-	149	26.8	139	-	5.65	83.2
	(M)	45.8	7.82	46.8	-	484	82.5	494	-	6.14	317
Kurd Summ.		NS	NS	NS		***	***	***		NS	***
	(F)	44.1	9.47	42.0	-	168	36.1	160	-	4.72	115
	(M)	84.9	9.77	80.9	-	290	33.3	276	-	9.10	102
Yem. Wint.		NS	***	NS		*	NS	*		**	*
	(F)	82.8	16.8	80.1	-	130	26.2	125	-	5.20	46.9
	(M)	39.0	6.87	39.5	-	463	81.7	469	-	6.20	357
Yem. Summ		NS	*	NS		***	***	***		*	**
	(F)	32.0	12.2	31.3	-	71.3	27.2	69.6	-	2.83	66.8

Kurd Summ.		NS	NS	NS		***	***	***		NS	***
	(F)	44.1	9.47	42.0	-	168	36.1	160	-	4.72	115
	(M)	84.9	9.77	80.9	-	290	33.3	276	-	9.10	102
Yem. Wint.		NS	***	NS		*	NS	*		**	*
	(F)	82.8	16.8	80.1	-	130	26.2	125	-	5.20	46.9
	(M)	39.0	6.87	39.5	-	463	81.7	469	-	6.20	357
Yem. Summ		NS	*	NS		***	***	***		*	**
	(F)	32.0	12.2	31.3	-	71.3	27.2	69.6	-	2.83	66.8

Table 6 continued

Group		Concentrations				Excretion Rates				Sodium	Sweat
		Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
		mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
	(M)	35.3	6.57	38.8	-	190	35.3	209	-	5.93	162
Nig. Stud.		*	NS	NS		**	NS	**		*	NS
	(F)	20.2	7.77	28.4	-	67.3	25.9	94.6	-	3.07	99.9
	(M)	35.0	11.0	36.0	1.47	115	36.1	118	4.81	3.60	97.1
N.G. Kaul		**	NS	**	*	**	NS	**	NS	**	NS
	(F)	25.5	12.0	27.9	2.38	66.1	31.0	72.3	6.15	2.42	77.7
	(M)	32.8	9.64	28.6	1.99	131	38.7	115	8.00	3.81	120
N.G. Lufa		*	**	*	**	**	NS	**	NS	**	*
	(F)	24.1	13.5	21.1	3.37	67.5	37.8	58.9	9.43	2.28	83.8
	(M)	31.9	9.82	29.3	1.41	104	31.9	95.2	4.59	4.17	97.9
N.G. Old		*	NS	**	**	*	NS	*	NS	*	NS
	(F)	20.0	13.8	17.0	3.33	42.9	29.8	36.5	7.17	1.63	64.5

Key:- NS not significant

* $0.05 > p > 0.01$

** $0.01 > p > 0.001$

*** $p < 0.001$

concentrations than those from the males and except for the Kurds in winter, higher potassium concentrations. This resulted in a much lower sodium/potassium ratio for each female group when compared with the respective male group. Apart from the Kurds (both summer and winter) this difference in sodium/potassium ratio was significant to at least the 5% level. All three New Guinea female groups had significantly higher phosphate concentrations than the males ($p \lesssim 0.05$) but the unacclimatized British females had relatively lower concentrations, significant at the 5% level.

With higher sweat rates for every male group, the females all had lower sodium and chloride excretion rates, the differences being significant ($p \lesssim 0.05$) for all groups except the cyclists. The levels of significance for all comparisons are shown in Table 6. Sweat potassium excretion rates were also higher for the males in each comparison except for the cyclists, where the females had the highest value of all.

Phosphate excretion was much higher for the unacclimatized male controls but for the other male - female comparisons the women had higher sweat phosphate excretion rates, although the differences were not significant.

Effect of Correcting Excretion Rate by Body Weight

The excretion of sodium, potassium, chloride and phosphate in sweat have been calculated as rates expressed as μM/min or μg/min and also as rates corrected by the body weight of each individual (μM/min/Kg or μg/min/Kg). When the groups were tested for differences in electrolyte excretion rate the correction by body weight often changed the levels of significance. The changes which were found to affect comparisons with the control groups, have been given in Table 7. In all cases where a significant difference was observed between two groups, the same group had a higher mean for either calculation.

Key:- NS not significant
* $0.05 \gtrsim p > 0.01$
** $0.01 \gtrsim p > 0.001$
*** $p \lesssim 0.001$

Table 7 The Effect on Levels of Significance when each Subject's Excretion Rates are corrected by Body Weight before comparing Groups.

Group I	Group II	Electrolyte	Significance Level Change	Group with Larger Mean	Sig. Change
Male					
Unacc. C.	Yem. Summ.	Chloride	NS - *	II	+
	Kurd Summ.	Sodium	* - **	II	+
	Kurd Wint.	Potassium	** - ***	II	+
	N.G. L. Plant.	Potassium	NS - **	II	+
	N.G. H. Plant.	Potassium	* - **	II	+
	N.G. Kaul	Potassium	** - ***	II	+
	N.G. Lufa	Potassium	** - ***	II	+
	" " "	Phosphate	* - **	II	+
	N.G. Boys	Potassium	*** - NS	I	-
	" " "	Phosphate	** - NS	I	-
	N.G. Old Lufa	Potassium	NS - *	II	+
	N. Ind. Army	Sodium	** - ***	II	+
	" " "	Potassium	NS - **	II	+
	" " "	Chloride	** - ***	II	+
	S. Ind. Army	Sodium	* - **	II	+
	" " "	Chloride	* - ***	II	+
	Gurkhas	Potassium	NS - **	II	+
Nat.Acc.C.	Art. Acc. C.	Sodium	NS - *	I	+
	Yem. Summ.	Chloride	*** - **	I	-
	Nig. Heavy	Potassium	*** - *	I	-
	N.G. Europ.	Potassium	*** - *	I	-
	Swimmers	Potassium	* - **	I	+
	Gurkhas	Sodium	*** - **	I	-
	"	Chloride	*** - **	I	-
Art.Acc.C.	N.G. L. Plant.	Phosphate	* - NS	I	-
	N.G. Kaul	Phosphate	* - NS	I	-
	N.G. Boys	Phosphate	*** - NS	I	-
	Ind. Lab. W.	Phosphate	*** - **	I	-
Female					
Unacc. C.	Yem. Summ.	Potassium	NS - *	II	+
	Nig. Stud.	Potassium	NS - *	II	+
	N.G. Kaul	Sodium	* - NS	I	-
	" " "	Potassium	* - ***	II	+
	N.G. Lufa	Potassium	** - ***	II	+
Cyclists	Kurd Summ.	Potassium	*** - **	I	-

hen each Subject's

Weight before comparing

nce nge	Group with Larger Mean	Sig. Change
*	II	+
**	II	+
***	II	+
**	II	+
**	II	+
***	II	+
***	II	+
**	II	+
NS	I	-
NS	I	-
*	II	+
***	II	+
**	II	+
***	II	+
**	II	+
***	II	+
**	II	+
*	I	+
**	I	-
*	I	-
*	I	-
**	I	+
**	I	-
**	I	-
NS	I	-
NS	I	-
NS	I	-
**	I	-
*	II	+
*	II	+
NS	I	-
***	II	+
***	II	+
**	I	-

Table 7 continued

Male	Female	Electrolyte	Significance Level Change	Group with Larger Mean	Sig. Change
Unacc. C.	Unacc. C.	Potassium	** - NS	M	-
Nat.Acc.C.	Cyclists	Sodium	** - *	M	-
	"	Potassium	NS - *	F	+
	"	Chloride	** - *	M	-
Cyclists	Cyclists	Potassium	* - **	F	+
Yem. Summ.	Yem. Summ.	Sodium	*** - **	M	-
Yem. Wint.	Yem. Wint.	Sodium	* - NS	M	-
	" "	Chloride	* - NS	M	-
Kurd Wint.	Kurd Wint.	Sodium	* - NS	M	-
	" "	Chloride	* - NS	M	-
Nig. Stud	Nig. Stud.	Sodium	** - *	M	-
	" "	Chloride	** - NS	M	-
N.G. Kaul	N.G. Kaul	Chloride	** - *	M	-
N.G. Lufa	N.G. Lufa	Sodium	** - *	M	-
	" " "	Chloride	** - *	M	-
N.G. Old	N.G. Old	Phosphate	NS - *	F	+

Key NS not significant
* $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$
M male
F female
Sig. change - decreases in level of significance
+ increase in level of significance

icance Change	Group with Larger Mean	Sig. Change
– NS	M	–
– *	M	–
– *	F	+
– *	M	–
– **	F	+
– **	M	–
– NS	M	–
– NS	M	–
– NS	M	–
– NS	M	–
– *	M	–
– NS	M	–
– *	M	–
– *	M	–
– *	M	–
– *	F	+

significance
ignificance

cance	Group with	Sig.
hange	Larger Mean	Change
NS	M	-
*	M	-
*	F	+
*	M	-
**	F	+
**	M	-
NS	M	-
NS	M	-
NS	M	-
NS	M	-
*	M	-
NS	M	-
*	M	-
*	M	-
*	M	-
*	F	+

ignificance
gnificance

Table 8

Ethnic Differences in Villagers Sweat Measurements and Significant Differences between Means

Group	Concentrations				Excretion Rates				Sodium	Sweat
	Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
	mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
Male										
Ind. Vill.	74.1	6.51	70.5	1.45	297	26.1	282	6.04	12.3	116
Nig. Vill.	47.8	6.52	51.1	-	237	32.2	252	-	8.56	148
N.G. Kaul	35.0	11.0	36.0	1.47	115	36.1	118	4.81	3.60	97.1
N.G. Lufa	32.8	9.64	28.6	1.99	131	38.7	115	8.00	3.81	120
Ind. Vill., Nig. Vill., N.G. Kaul, N.G. Lufa	***	***	***	-	***	NS	***	-	***	NS
Ind. Vill., N.G. Kaul, N.G. Lufa				NS				**		
N.G. Kaul, N.G. Lufa	NS	NS	*	NS	NS	NS	NS	**	NS	NS
Female										
N.G. Kaul	25.5	12.0	27.9	2.38	66.1	31.0	72.3	6.15	2.42	77.7
	NS	NS	*	NS	NS	NS	NS	*	NS	NS
N.G. Lufa	24.1	13.5	21.1	3.37	67.5	37.8	58.9	9.43	2.28	83.8

Key:- NS not significant * $0.05 \geq p > 0.01$ ** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

N.G. Kaul N.G. Lufa	NS	NS	*	NS	NS	NS	NS	**	NS	NS	NS	
Female												
N.G. Kaul	25.5	12.0	27.9	2.38	66.1	31.0	72.3	6.15	2.42	77.7		
	NS	NS	*	NS	NS	NS	NS	*	NS	NS		
N.G. Lufa	24.1	13.5	21.1	3.37	67.5	37.8	58.9	9.43	2.28	83.8		

Key:- NS not significant * $0.05 \geq p > 0.01$ ** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

In general, correcting by body weight increased the level of significance for the comparisons with the unacclimatized controls and reduced them for the comparisons with acclimatized controls.

The effect of correcting by body weight has also been presented for the male - female comparisons (see Table 7). With the exception of the female cyclists and the old New Guinea subjects, this correction reduced the level of significance of differences between the sexes.

Ethnic Differences

To assess the effects of ethnic differences on sweat elctrolytes, sets of subject groups which are comparable with each other have been chosen and treated separately. Descriptions of the subject groups have been given in Table 1.

Villagers

Four groups of male villagers with similar nontechnological lifestyles have been chosen. These are the Kauls and Lufas from New Guinea and the Nigerian and Indian villagers, all of whom had low standards of living.

It can be seen from Table 8 that between the Kauls and Lufas, the only differences that could be shown were that the Kauls had a higher sweat chloride concentration ($0.05 \geq p > 0.01$) and a lower phosphate excretion rate ($0.01 \geq p > 0.001$). Differences in sweat rate between these two New Guinea groups was not significant.

When the four groups of villagers were compared by analyses of variance, sweat rates and potassium excretion rates were the only measurements that did not differ significantly. Results showed that the sodium and chloride excretion rates, the sodium, potassium and chloride concentrations and the sodium/potassium ratios all differed at the 1% level. From Table 8, it can be seen that the Indians and Nigerians had higher sodium and chloride concentrations than the Kauls and Lufas but

Table 9 Ethnic Differences

Sweat Measurements and Significant Differences in Means

Group	Concentrations				Excretion Rates				Sodium	Sweat
	Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
	mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
Plantation Workers										
N.G. L. Plant.	33.1	10.0	35.3	1.46	111	33.7	119	4.90	3.95	101
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N.G. H. Plant	27.1	8.63	27.6	1.18	127	40.4	129	5.55	3.46	126
Indian Army Groups										
N. Ind. Army	61.4	4.38	59.0	Changing	504	35.9	484	Changing	14.6	246
S. Ind. Army	73.6	3.82	72.4	with	463	24.1	456	with	20.6	189
Gurkhas	68.4	4.25	66.0	Season	577	35.9	557	Season	16.7	253
	NS	NS	NS	NS	NS	***	NS	NS	*	*

Key NS not significant
* $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$

lower potassium concentrations. They also had sodium/potassium ratios which were at least twice as high as either New Guinea group.

Sweat phosphate concentration was not measured for the Nigerian group but no significant differences could be shown for the other three groups. Although significant differences occured ($0.01 \geq p > 0.001$) in the phosphate excretion rates for the Indians and New Guinea groups, when corrected by body weight the differences became non-significant.

Comparisons between the female Kauls and Lufas have also been presented in Table 8. Sweat rates did not differ significantly. However, as with the men, the Kauls had significantly higher sweat chloride concentrations ($0.05 \geq p > 0.01$) but the phosphate excretion rate was also higher ($0.05 \geq p > 0.01$). Correcting the excretion rates by body weight made no difference to the levels of significance.

Plantation Workers

Two groups of males were studied who worked in the plantations on Karkar Island in New Guinea. The Low Plantation group were local people who lived and worked either on the island or had been recruited from the lowland areas of New Guinea. The High Plantation group had come down from the highlands of New Guinea.

The means of the measurements on each group are summarized in Table 9. No significant differences could be shown between the two groups of plantation workers

Indian Soldiers

The results from the groups of Indian soldiers tested up to the third week in October were compared by analyses of variance. As the phosphates were changing with time of year for these groups, these concentrations and excretion rates have been examined by regression analysis.

The means for the three groups and the levels of significance of

Key
NS not significant
* $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$

Table 10 Ethnic Differences in Israel Groups

Sweat Measurements and Significant Differences in Means

Group	Concentrations			Excretion Rates			Sodium	Sweat
	Sodium	Potassium	Chloride	Sodium	Potassium	Chloride	Potassium	Volume
	mEq/l	mEq/l	mEq/l	uM/min	uM/min	uM/min	Ratio	ml/½hr
Yem. Summ. (M)	39.0	6.87	39.5	463	81.7	469	6.20	357
	NS	*	NS	NS	NS	NS	NS	NS
Kurd Summ. (M)	45.8	7.82	46.8	484	82.5	494	6.14	317
Yem. Wint. (M)	84.9	9.77	80.9	290	33.3	276	9.10	102
	NS	NS	NS	NS	NS	NS	NS	NS
Kurd Wint. (M)	78.6	10.3	74.6	351	46.0	334	8.12	134
Yem. Summ. (F)	32.0	12.2	31.3	71.3	27.2	69.6	2.83	66.8
	NS	NS	NS	NS	NS	NS	*	NS
Kurd Summ. (F)	44.1	9.47	42.0	168	36.1	160	4.72	115
Yem. Wint. (F)	82.8	16.8	80.1	130	26.2	125	5.20	46.9
	NS	*	*	NS	NS	NS	NS	NS
Kurd Wint. (F)	53.8	9.66	50.2	149	26.8	139	5.65	83.2

Key NS not significant

* $0.05 \geq p > 0.01$

differences between them have been shown in Table 9. Differences in sweat rate were found to be significant ($0.05 \geq p > 0.01$) with the Southerners having the lowest mean value.

No significant differences were found between the concentrations of sodium, potassium or chloride, although with the lowest sweat rate and potassium concentration, the Southerners had a potassium excretion rate which was lower ($p \leq 0.001$) than the other two groups. The Southerners also had the highest sodium/potassium ratios and the means of the groups differed at the 1% level. Regression analyses of the phosphate measurements revealed no significant difference between the groups but as levels were changing during the period of the field studies, means could not be given in Table 9.

Correcting excretion rates by body weight made no difference to the level of significance of differences between the groups.

Israel

Two Jewish communities from different ethnic origins but living together in Israel were studied in both summer and winter. Male and female Kurds and Yemenites were tested. In the summer, differences were found between the means of the potassium concentrations in the men ($0.05 \geq p > 0.01$) and the sodium/potassium ratios in the women ($0.05 \geq p > 0.01$) (see Table 10). In the winter, the only differences found were for potassium and chloride concentration in the women ($0.05 \geq p > 0.01$).

Comparison of Groups from the same Ethnic Origin with different Occupations

Among the male Nigerian groups, analyses of variance revealed that there were differences significant at the 5% level for sweat sodium concentration with the Heavy Industry group having the lowest mean value and the villagers having the highest (see Table 11). Sweat potassium levels differed at the 1% level for these four groups and again the Heavy Industry workers had the lowest concentrations.

Kurd Wint. (F)	53.8	9.66	50.2	149	26.8	139	5.65	NS 83.2

Key NS not significant
* $0.05 \geq p > 0.01$

Table 11

Comparison of Sweat Measurements on Groups from the Same Ethnic Origen but with Different Occupations

Means and Significant Differences of Means for Male Groups

Group	Concentrations				Excretion Rates				Sodium	Sweat
	Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
	mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
Nigeria										
Students	35.3	6.57	38.8	-	190	35.3	209	-	5.93	162
Heavy Ind.	22.9	4.13	31.3	-	259	46.7	354	-	6.71	339
Light Ind.	34.8	5.58	37.0	-	340	54.3	361	-	7.14	292
Villagers	47.8	6.52	51.1	-	237	32.2	252	-	8.56	148
	*	**	NS		NS	NS	NS		NS	***
New Guinea										
Kaul	35.0	11.0	36.0	1.47	115	36.1	118	4.81	3.60	97.1
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Low Plant.	33.1	10.0	35.3	1.46	111	33.7	119	4.90	3.95	101
Lufa	32.8	9.64	28.6	1.99	131	38.7	115	8.00	3.81	120
	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
High Plant.	27.1	8.63	27.6	1.18	127	40.4	129	5.55	3.46	126
India										
Lab. Workers	54.9	5.71	51.7	0.40	298	31.0	280	2.17	10.8	163
	*	NS	NS	***	NS	NS	NS	**	NS	NS
Villagers	74.1	6.51	70.5	1.45	297	26.1	282	6.04	12.3	116

Key:- NS not significant * $0.05 \geq p > 0.01$ ** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

The sweat potassium excretion rates did not differ except when corrected by body weight, when they differed at the 1% level with the Light Industry workers having the highest mean. Chloride measurements showed differences in the excretion rate corrected by body weight ($0.05 \geq p > 0.01$) with the students having the lowest value and the Light Industry workers the highest value. Differences in the half hour sweat volumes were highly significant ($p \leq 0.001$) with the students and villagers having lower sweat rates than the Industrial workers.

The male groups from the lowlands of New Guinea (Kauls and Low Plantation workers) were compared and no significant differences were found. Comparisons between the men from the highlands of New Guinea however, showed the Lufas to have higher values for phosphate concentration ($0.05 \geq p > 0.01$) than the High Plantation workers (see Table 11).

In the Indian study, the villagers and the Laboratory workers, who all came from the vicinity of New Delhi were different in that the sweat sodium concentrations were lower for the Laboratory workers ($0.05 \geq p > 0.01$) and the phosphate concentrations were much higher for the villagers ($p \leq 0.001$). Phosphate excretion rates were also higher for the villagers ($0.01 \geq p > 0.001$) (see Table 11).

Acclimatization

Several groups of subjects provided material for studying the effects of acclimatization. Where posible, paired t-tests have been performed using each subject before and after acclimatization to heat or with seasonal changes in acclimatization level.

Natural Acclimatization

Army group I was tested in England before being posted to the Middle East. After being stationed in Sharjha for several months these troops were retested there. Sweat sodium, potassium, chloride and volume

Lufa	32.8	9.64	28.6	1.99	131	38.7	115	8.00	3.81	120
	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
High Plant.	27.1	8.63	27.6	1.18	127	40.4	129	5.55	3.46	126
India										
Lab. Workers	54.9	5.71	51.7	0.40	298	31.0	280	2.17	10.8	163
	*	NS	NS	***	NS	NS	NS	**	NS	NS
Villagers	74.1	6.51	70.5	1.45	297	26.1	282	6.04	12.3	116

Key:- NS not significant * $0.05 \geq p > 0.01$ ** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

The sweat potassium excretion rates did not differ except when corrected by body weight, when they differed at the 1% level with the Light Industry workers having the highest mean. Chloride measurements showed differences in the excretion rate corrected by body weight ($0.05 \geq p > 0.01$) with the students having the lowest value and the Light Industry workers the highest value. Differences in the half hour sweat volumes were highly significant ($p \leq 0.001$) with the students and villagers having lower sweat rates than the Industrial workers.

The male groups from the lowlands of New Guinea (Kauls and Low Plantation workers) were compared and no significant differences were found. Comparisons between the men from the highlands of New Guinea however, showed the Lufas to have higher values for phosphate concentration ($0.05 \geq p > 0.01$) than the High Plantation workers (see Table 11).

In the Indian study, the villagers and the Laboratory workers, who all came from the vicinity of New Delhi were different in that the sweat sodium concentrations were lower for the Laboratory workers ($0.05 \geq p > 0.01$) and the phosphate concentrations were much higher for the villagers ($p \leq 0.001$). Phosphate excretion rates were also higher for the villagers ($0.01 \geq p > 0.001$) (see Table 11).

Acclimatization

Several groups of subjects provided material for studying the effects of acclimatization. Where posible, paired t-tests have been performed using each subject before and after acclimatization to heat or with seasonal changes in acclimatization level.

Natural Acclimatization

Army group I was tested in England before being posted to the Middle East. After being stationed in Sharjha for several months these troops were retested there. Sweat sodium, potassium, chloride and volume

Table 12

Changes in Sweat Measurements with Acclimatization Means and Levels of Significane of Differences between Means

Group	Concentrations				Excretion Rates				Sodium	Sweat
	Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
	mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
	Army Group I (25 subjects)									
Unacc.	72.3	6.06	67.5	-	569	47.6	531	-	12.5	236
	*	***	**		***	***	***		**	***
Nat. Acc.	65.5	5.20	58.8	-	1096	87.1	985	-	13.7	503
	Army Group IV (14 subjects)									
Unacc.	72.3	5.31	68.9	1.55	298	21.9	284	6.39	14.6	124
	NS	NS	NS	*	***	***	***	NS	NS	***
Art. Acc.	72.6	5.48	69.4	0.69	795	60.1	761	7.53	14.6	329

Key:-

NS not significant

* $0.05 \geq p > 0.01$

** $0.01 \geq p > 0.001$

*** $p \leq 0.001$

Key:-

NS	not significant
*	$0.05 \geq p > 0.01$
**	$0.01 \geq p > 0.001$
***	$p \leq 0.001$

Table 13 Acclimatization in Israel Groups

Sweat Measurements and Significant Differences

Group	Concentrations			Excretion Rates			Sodium	Volume
	Sodium	Potassium	Chloride	Sodium	Potassium	Chloride	Potassium	ml/½hr
	mEq/l	mEq/l	mEq/l	μM/min	μM/min	μM/min	Ratio	
Kurd Summ. (M)	45.8	7.82	46.8	484	82.5	494	6.14	317
	***	*	***	NS	***	*	*	***
Kurd Wint. (M)	78.6	10.3	74.6	351	46.0	334	8.12	134
Yem. Summ. (M)	39.0	6.87	39.5	463	81.7	469	6.20	357
	***	**	***	NS	***	NS	*	***
Yem. Wint. (M)	84.9	9.77	80.9	290	33.3	276	9.10	102
Kurd Summ. (F)	44.1	9.47	42.0	168	36.1	160	4.72	115
	NS	NS	NS	NS	NS	NS	NS	NS
Kurd Wint. (F)	53.8	9.66	50.2	149	26.8	139	5.65	83.2
Yem. Summ. (F)	32.0	12.2	31.3	71.3	27.2	69.6	2.83	66.8
	***	NS	***	NS	NS	NS	NS	NS
Yem. Wint. (F)	82.8	16.8	80.1	130	26.2	125	5.20	46.9

Key NS not significant
* $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$

measurements only, were made on these soldiers (see Table 12).

With acclimatization there was a significant decrease in the concentration of sodium ($0.05 \geq p > 0.01$), potassium ($p \leq 0.001$) and chloride ($0.01 \geq p > 0.001$). Sodium/potassium ratio increased ($0.01 \geq p > 0.001$) and with the rise in sweat rate ($p < 0.001$), the increase in excretion rate of all electrolytes was significant at the 0.1% level.

Artificial Acclimatization

The subjects of Army group IV were tested for sweat sodium, potassium, chloride, phosphate and sweat rate before and after a course of artificial acclimatization (see Table 12).

When the pre- and post-acclimatization sweat measurements were compared, there were no significant differences for sodium, potassium or chloride concentration. Excretion rates of these electrolytes increased with the sweat rate, each difference being at the 0.1% level of significance. Phosphate concentrations were significantly lower after acclimatization ($0.05 \geq p > 0.01$) but there was no significant change in the excretion rate of phosphate.

Seasonal Changes in Israel

Summer and winter tests were done on Kurd and Yemenite men and women. Only in the Kurd male group were there enough repeated subjects to enable paired t-testing. Compared with the summer results, the winter samples showed a highly significant ($p \leq 0.001$) increase in sodium and chloride concentrations but with the reduction in sweat rate, changes in sodium and chloride excretion rates were not significant. Potassium concentrations increased at the 5% level and the excretion rate was reduced ($0.01 \geq p > 0.001$). The sodium/potassium ratio in the winter was higher and the difference was significant at the 5% level.

Although there were insufficient repeat experiments on individuals for paired t-tests, the number of Kurd females and Yemenite males and

Yem. Wint. (F)	82.8	16.8	80.1	130	26.2	125	5.20	46.9

Key NS not significant
* $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$

Table 14

Significance of Changes with Time of Sweat Measurements on Indian Army Groups during Seasonal Deacclimatization (September to December)

Group	No. Subs	Concentration				Excretion Rate				Sodium Potassium Ratio	Sweat Rate
		Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate		
Repeat Tests on Individuals (paired t-tests)											
Northerners	9	NS	NS	NS	NS	NS	NS	NS	-**	NS	-*
Southerners	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Gurkhas	8	+**	+*	+**	NS	+*	NS	NS	NS	NS	NS
First Test on all Subjects (regression analyses)											
Northerners	25	NS	NS	NS	NS	NS	NS	NS	-*	NS	NS
Southerners	28	NS	+*	NS	NS	NS	NS	NS	-*	NS	-*
Gurkhas	32	NS	NS	+*	NS	NS	NS	NS	NS	NS	-*

Key:- + increase with time

\- decrease with time

NS not significant

* $0.05 \geq p > 0.01$

** $0.01 \geq p > 0.001$

females was adequate to perform t-tests between the means of the groups. Further subjects for the Kurd males were also available for group comparison (see Table 13).

In all groups there was an increase in sweat electrolyte concentrations in winter. For sodium and chloride this was highly significant ($p \lesssim 0.001$) for all groups except the Kurd females who did not show any significant change at all. Potassium concentration changes were significant at the 5% level for the Kurd males and at the 1% level for the Yemenite males but not for the Yemenite females.

Increased winter excretion rates were seen only in the Yemenite females for sodium and chloride but these were not significant. The other three groups all had decreased excretion rates in the winter, with highly significant ($p \lesssim 0.001$) differences for potassium in male groups. A significant decrease ($0.05 \gtrsim p > 0.01$) was also found for the chloride excretion rate in the Kurd males. All groups had higher sodium/potassium ratios in the winter, significant at the 5% level for the men and although all groups had reduced sweat rates, the differences from summer to winter were also only significant for the men ($p \lesssim 0.001$).

Correcting by body weight had no effect on the levels of significance of differences between summer and winter excretion rates.

Indian Army Subjects

Repeat tests were performed on a number of subjects from each of the Indian army groups with at least 25 days between tests during which the environmental temperatures were falling. The level of significance of changes in sweat concentrations and excretion rates are given in Table 14.

No significant differences could be shown in any measurements for the Southerners. The Northerners showed only a reduced sweat rate ($0.05 \gtrsim p > 0.01$) and phosphate excretion rate ($0.01 \gtrsim p > 0.001$) but the tests on the Gurkhas revealed significantly increased sodium and chloride

Southerners	28	NS	+*	NS	NS	NS	NS	NS	NS	-*	NS	-*
Gurkhas	32	NS	NS	+*	NS	NS	NS	NS	-*	NS	NS	

Key:- + increase with time
- decrease with time
NS not significant
* $0.05 \gtrsim p > 0.01$
** $0.01 \gtrsim p > 0.001$

concentrations ($0.01 \geq p > 0.001$) and potassium concentrations ($0.05 \geq p > 0.01$). The sodium excretion rate for the Gurkhas was also higher ($0.05 \geq p > 0.01$) despite the fact that the sweat rate had decreased although not significantly.

As well as examining repeat tests on individuals over the season, the results from all subjects in each Indian army group were compared with time by estimating regression coefficients (see Table 14). In general, increases were observed in sodium, potassium and chloride concentrations with reductions in phosphate concentration and sodium/potassium ratio. The exception to this was for a decreasing potassium concentration and a rising sodium/potassium ratio for the Gurkhas. Significant regressions were seen for the change in potassium concentration for the Southerners and chloride concentration for the Gurkhas ($0.05 \geq p > 0.01$). Sweat rates decreased, the regression being significant at the 5% level for the Southerners and Gurkhas and all excretion rates fell, the decrease being significant for the phosphate of the Northerners and Southerners.

British Females

No repeat tests were available on British females with changes in acclimatization but the unacclimatized and acclimatized control groups have been compared. No difference occurred in the sodium, potassium or chloride concentrations and even the sodium/potassium ratio was not significantly different for the two groups. With the larger sweat rate for the acclimatized controls however, all excretion rates were much higher ($p < 0.001$).

Age

New Guinea Subjects

In New Guinea, the Lufa subjects were composed of a wide age range for both males and females. When comparing young and old adults, no differences could be found within each sex except that the old males had a higher phosphate excretion rate ($0.01 \geq p > 0.001$), although when this was

Table 15 Age Differences between Comparable Groups in New Guinea Sweat Measurements and Significant Differences in Means

Group	Concentrations				Excretion Rates				Sodium	
	Sodium	Potassium	Chloride	Phosphate	Sodium	Potassium	Chloride	Phosphate	Potassium	Volume
	mEq/l	mEq/l	mEq/l	mg/l	uM/min	uM/min	uM/min	ug/min	Ratio	ml/½hr
Lufas										
Young Men	32.8	9.64	28.6	1.99	131	38.7	115	8.00	3.81	120
Old Men	31.9	9.82	29.3	1.41	104	31.9	95.2	4.59	4.17	97.9
Boys	32.6	21.6	29.1	4.81	14.6	9.65	13.0	2.03	1.72	14.6
Young Women	24.1	13.5	21.1	3.37	67.5	37.8	58.9	9.43	2.28	83.8
Old Women	20.0	13.8	17.0	3.33	42.9	29.8	36.5	7.17	1.63	64.5
Men	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
Men and Boys	NS	***	NS	***	***	***	***	***	*	***
Women	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Key NS not significant
* $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$

corrected by body weight for each subject, the difference in means became not significant.

It can be seen from Table 15 however, that when the Lufa boys were added to the two older male groups, large differences ($p \leq 0.001$) were found for potassium and phosphate concentrations and all excretion rates. Sodium/potassium ratios differed at the 5% level. Lufa boys had much lower sweat rates than the men and correcting the excretion rate by body weight failed to remove the significance of differences, although they were reduced to the 1% level for potassium and the 5% level for phosphate.

British Subjects

The subjects of Army group I had ages ranging from 17 years to 40 years. Correlation of sweat sodium, potassium and chloride concentrations and sodium/potassium ratios were calculated against age for this group before and after acclimatization. No significant correlations were found.

The Swimmers whose ages ranged from 14 years to 22 years were examined in the same way as Army group I for age effect. No significant correlations could be found for this group either.

Within Subject Variation

For those tests where serial sweat samples have been collected it has been possible to examine the changes which occur during sweating. In this way, further information is available for the unacclimatized females, Army groups III and IV and some of the Indian subjects.

Influence of Time, Skin Temperature and Sweat Rate upon Sweat Electrolyte Concentration during Controlled Hyperthermia

Time from the start of controlled hyperthermia, average skin temperature and the sweat rate for the relevant serial sweat samples were related in all possible combinations with sodium, potassium, chloride and phosphate concentration in turn for each subject, by means of multiple

Key NS not significant
* $0.05 > p > 0.01$
** $0.01 \geq p > 0.001$
*** $p \leq 0.001$

Table 16 Significant Regression Slopes for Sweat Electrolyte Concentrations on Time, Skin Temperature and Sweat Rate during Controlled Hyperthermia

Sub. No.	Sodium			Potassium			Chloride			Phosphate		
	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.
				Army Group IV before Acclimatization								
1	0.24	-	1.08	-0.03	-	-	-	14.8	-	-0.19	-	-
2	no significant slopes			-	-	-0.38	-	-10.6	-	-	13.2	-
3	0.17	-	-	-0.03	-	-	0.28	-	-	0.16	16.7	-2.60
4	no significant slopes			-0.03	-	-	-	-4.24	-	-	-	0.80
5	0.35	-	-	-	-1.32	0.06	0.17	-	-	-	48.6	-
6	-	-6.19	-	-0.04	-	-	0.10	-	-	no significant slopes		
7	no significant slopes			-0.04	-	-	0.16	-	-	no significant slopes		
8	insufficient data			insufficient data			insufficient data			insufficient data		
9	-	-	-1.10	-0.02	-	-	0.21	-	-	no significant slopes		
10	0.21	-	-	-	3.18	-	0.15	-	-	no significant slopes		
11	no significant slopes			-0.04	1.51	-	0.51	-	-	-0.36	-	-
12	no significant slopes			-0.10	-	-	no significant slopes			no significant slopes		
13	-	11.9	-	-0.03	-	-	0.23	-	-	no significant slopes		
14	-	-23.2	-	no significant slopes			-0.39	-25.8	-0.71	no significant slopes		

10	0.21	-	-	-	3.18	-	0.15	-	-	no significant slopes		
11	no significant slopes			-0.04	1.51	-	0.51	-	-	-0.36	-	-
12	no significant slopes			-0.10	-	-	no significant slopes			no significant slopes		
13	-	11.9	-	-0.03	-	-	0.23	-	-	no significant slopes		
14	-	-23.2	-	no significant slopes			-0.39	-25.8	-0.71	no significant slopes		

Table 16 continued

Sub. No.	Sodium			Potassium			Chloride			Phosphate		
	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.
	Army Group IV after Artificial Acclimatization											
1	no significant slopes			-0.05	-	-	no significant slopes			no significant slopes		
2	no significant slopes			-	-	0.08	-	-24.6	-	-0.30	-23.9	-0.46
3	no significant slopes			-0.07	-	-	0.03	-13.9	-	no significant slopes		
4	no significant slopes			-	1.89	-	-	-	1.34	no significant slopes		
5	no significant slopes			no significant slopes			no significant slopes			-	-10.4	-
6	no significant slopes			-0.03	-	-	-	-8.68	-	no significant slopes		
7	0.17	-15.2	-0.07	no significant slopes			0.17	-	-	-	24.3	-
8	-	-28.4	-	-	-	0.03	0.14	-16.6	-	-	-	0.09
9	no significant slopes			-0.002	3.08	0.08	0.09	-	-	-	-	1.57
10	0.14	-	-	-0.03	-	-	0.51	21.0	0.30	no significant slopes		
11	no significant slopes			-0.03	-	-	no significant slopes			-	-13.2	-
12	no significant slopes			0.03	7.47	0.003	0.12	-	-	-	19.1	-
13	no significant slopes			-0.03	-	-	0.20	-8.35	0.25	-0.14	-	-0.45
14	no significant slopes			-0.02	-	-	0.12	-	-	-0.22	-	-

11	no significant slopes	0.03			no significant slopes				19.2	
12	no significant slopes	0.03	7.47	0.003	0.12	-	-	-	19.1	-
13	no significant slopes	-0.03	-	-	0.20	-8.35	0.25	-0.14	-	-0.45
14	no significant slopes	-0.02	-	-	0.12	-	-	-0.22	-	-

Table 16 continued

Sub.	Sodium			Potassium			Chloride			Phosphate		
No.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.
					Army Group III							
1	0.09	-6.38	-	-0.02	-	-	0.31	-	-	-	-	0.84
2	0.49	-	-	-0.04	-	-	0.42	-	-	-0.11	5.42	-
3	no significant slopes			-0.03	-	-	0.12	-	-	no significant slopes		
4	-	-47.9	-1.24	-0.03	2.68	-	0.38	-38.1	-	-	23.9	-
5	0.14	-	-	-0.06	-	-	0.26	-	-	-0.06	-	-
6	-0.15	-	-	-	-	0.12	-	-18.8	-	-0.28	-	-
7	-	-19.0	-	-0.07	7.52	-	0.21	-19.8	-	-0.74	-	-
8	0.33	-	-	-	-	0.85	-	-	-8.67	-	-	10.4
9	no significant slopes			-0.06	-	-	0.11	-	-	-0.17	-	-
10	no significant slopes			no significant slopes			0.18	1.11	0.03	-0.15	-	-
11	0.15	-	-0.97	-0.08	-	-	0.37	-	-	-0.37	-	-
12	-	-18.4	-2.51	-	3.37	-	0.09	-15.2	-1.00	no significant slopes		

12	-	-18.4	-2.51	-	3.37	-	0.09	-15.2	-1.00	no significant slopes

Table 16 continued

Sub.	Sodium			Potassium			Chloride			Phosphate		
No	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.
					Army Group III repeat							
1	0.26	-6.62	2-28	-0.04	-	-	0.22	-4.36	-	-0.18	-	-
2	insufficient data			insufficient data			insufficient data			insufficient data		
5	no significant slopes			-0.05	-	-	0.14	-	-	no significant slopes		
6	no significant slopes			-0.03	-	-	0.14	-	-	no significant slopes		
7	0.09	-	-	-0.05	0.82	-0.23	0.11	-7.31	-	no significant slopes		
8	insufficient data			insufficient data			insufficient data			insufficient data		
9	-0.09	-	-	-0.07	-	-	-	11.3	-	no significant slopes		
10	0.26	-	-	-	0.41	0.08	0.20	-	-	-0.03	-	-
11	0.14	-	-	-0.02	-	-	0.16	-6.30	-	no significant slopes		
12	insufficient data			insufficient data			insufficient data			insufficient data		

Table 16 continued

Sub No.	Sodium			Potassium			Chloride			Phosphate		
	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.
					Indian Laboratory Workers							
128	0.40	-	0.38	-0.02	-	-	0.45	-	-	-0.20	-	-0.59
133	0.28	11.5	0.61	-0.04	-1.38	-	-	-	-2.45	-0.23	-20.4	-
135	no significant slopes			-0.07	0.60	-0.30	0.19	-	-	no significant slopes		
					Indian Villagers							
147	-0.31	-25.4	-1.94	-	-	-0.17	-0.12	-	-1.68	-	-	1.15
					North Indian Army							
52	no significant slopes			-0.06	-	-	0.94	-	-	-	-	1.07
111	no significant slopes			no significant slopes			no significant slopes			-	10.8	-
112	no significant slopes			-0.03	-2.10	0.03	-	-28.6	-	0.15	-29.5	0.09
115	0.33	19.9	0.23	no significant slopes			0.28	-	-	no significant slopes		
					South Indian Army							
120	no significant slopes			0.07	2.40	0.96	0.30	-	-	no significant slopes		
					Gurkhas							
54	no significant slopes			-0.04	-	0.08	no significant slopes			no significant slopes		
125	no significant slopes			-0.04	3.44	-	0.09	-	1.50	-0.11	-	-

120	no significant slopes	0.07
54	no significant slopes	-0.04
125	no significant slopes	-0.04

South Indian Army								
2.40	0.96	0.30	-	-	no significant slopes			
	Gurkhas							
-	0.08	no significant slopes			no significant slopes			
3.44	-	0.09	-	1.50	-0.11	-	-	

Table 16 continued

Sub. No.	Sodium			Potassium			Chloride			Phosphate		
	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.	Time	Ts	S.R.
				Unacclimatized British Female Controls								
1	-0.22	76.2	-	-0.24	-	-4.49	no significant slopes			-0.78	-	-
2	0.33	11.2	-12.4	-0.01	2.91	-4.92	0.20	-	-3.26	-0.09	-	-
3	-	-10.9	-3.29	no significant slopes			0.34	-	-	no significant slopes		
4	-	-8.78	-	-0.07	5.43	-	-	-14.0	-	-	8.57	-
5	-0.43	-19.6	-1.14	-0.04	2.80	-	-0.28	-24.2	-	-0.06	-	-0.35
6	-	-	-1.70	-0.04	-	-	0.19	-	-	-	-0.02	0.22
7	.0.16	-29.7	-	-0.07	3.29	-	0.36	-26.9	-	-0.05	-	-
8	0.39	-37.9	-	-0.12	-	-	0.51	-32.2	-	-	2.50	-1.04
9	0.24	-	-	-0.04	-3.61	-	0.38	-	-	no significant slopes		
10	-0.28	-	-	-0.15	-	0.84	-0.20	-	-	-0.11	0.84	1.27
11	0.11	-	-	-0.22	-	-	0.35	-	-	-0.07	-	-
12	0.07	-8.57	-	-0.13	-	-9.40	0.22	-	-	-	-	-4.50
13	-	-4.50	-	-0.05	-	-	-	-5.18	-	-0.03	-	-
14	no significant slopes			-0.08	-	-	no significant slopes			-0.04	-	0.44

Key: Ts skin temperature

S.R sweat rate

regression analysis, in an attempt to measure the effect that these factors had on the four electrolyte concentrations. Each subject and each concentration was treated separately and no attempt was made to transform the data before analysis. The resulting analyses of variance were examined to determine which combination of factors resulted in the minimum residual error (Snedicor, 1966). Having found the best combination of factors which may have influenced the concentrations, the slopes of the regressions were tested to ensure that they were significant. These significant slopes are given in Table 16.

Sodium

In many subjects, particularly from the artificially acclimatized controls and Indian army groups, no significant relationships could be found with time, skin temperature or sweat rate. Of the significant slopes found, regression with time was the most common and those with sweat rate least so. Although the majority of slopes for time were positive and those for skin temperature negative, there was no consistant pattern. The number of tests on subjects from Army group IV, with sufficient data for statistical analysis and where significant slopes were found, decreased on acclimatization from 8 out of 13 to 3 out of 14.

Potassium

Potassium was also most commonly related to time but in almost every case, the slope was negative. Significant slopes for skin and sweat rate were less common and although the majority of each of these was positive, there was no consistant pattern.

The females tended to have the steeper slopes for time, the steepest being -0.24. One third of the significant time slopes for the females were greater than the steepest (absolute) value of -0.10 for the men.

Chloride

Like the sodium, chloride concentrations were most

11	0.11	-	-	-0.22	-	-	0.35	-	-	-0.07	-	-			
12	0.07	-8.57	-	-0.13	-	-9.40	0.22	-	-	-	-	-4.50			
13	-	-4.50	-	-0.05	-	-	-	-5.18	-	-0.03	-	-			
14	no significant slopes			-0.08	-	-	no significant slopes			-0.04	-	0.44			

Key: Ts skin temperature
S.R sweat rate

Table 17

Changes in Electrolyte Concentrations during Sweating Regressions on Time during Controlled Hyperthermia

Sub. No.	Sodium mEq/l/min		Potassium mEq/l/min		Chloride mEq/l/min		Phosphate mg/l/min	
	Army Group III test 1							
1	0.097	NS	-0.027	***	0.309	***	-0.063	NS
2	0.488	**	-0.042	***	0.365	***	-0.173	*
3	0.028	NS	-0.038	***	0.164	***	-0.023	NS
4	0.596	***	-0.055	***	0.771	***	-0.172	*
5	0.100	NS	-0.060	***	0.274	**	-0.008	NS
6	-0.146	*	-0.029	*	-0.006	NS	-0.275	*
7	0.042	NS	-0.127	***	0.365	***	-0.617	***
8	0.320	**	-0.029	NS	0.316	**	-0.172	*
9	-0.024	NS	-0.055	***	0.114	**	-0.121	*
10	0.091	NS	-0.001	NS	0.074	NS	-0.150	*
11	0.227	***	-0.075	***	0.373	***	0.159	NS
12	0.188	*	-0.022	*	0.272	NS	0.110	NS
mean	0.279		-0.053		0.332		-0.240	
	Army Group III test 2							
1	0.292	***	-0.036	***	0.287	***	-0.140	***
2	not enough data							
3	subject ommitted							
4	subject ommitted							
5	0.000	NS	-0.054	***	0.166	***	0.085	NS
6	-0.049	NS	-0.033	***	0.141	***	-0.009	NS
7	0.092	*	-0.048	***	0.193	***	0.024	NS
8	not enough data							
9	0.058	**	-0.077	***	0.195	***	0.199	NS
10	0.183	**	-0.007	NS	0.204	**	-0.030	NS
11	0.137	*	-0.022	*	0.159	*	-0.169	NS
12	not enough data							
mean	0.152		-0.045		0.192		-0.140	

weating Regressions

Phosphate mg/l/min	
-0.063	NS
-0.173	*
-0.023	NS
-0.172	*
-0.008	NS
-0.275	*
-0.617	***
-0.172	*
-0.121	*
-0.150	*
0.159	NS
0.110	NS
-0.240	
-0.140	***
0.085	NS
-0.009	NS
0.024	NS
0.199	NS
-0.030	NS
-0.169	NS
-0.140	

Table 17 continued

Sub. No.	Sodium mEq/l/min		Potassium mEq/l/min		Chloride mEq/l/min		Phosphate mg/l/min	
	Army Group IV unacclimatized							
1	0.084	*	-0.034	***	0.136	*	-0.186	*
2	0.121	NS	-0.025	**	0.181	NS	-0.230	*
3	0.203	***	-0.033	***	0.284	***	0.188	NS
4	-0.014	NS	-0.038	***	0.055	NS	-0.012	NS
5	0.329	***	-0.007	NS	0.168	**	0.105	NS
6	0.042	NS	-0.038	***	0.100	**	0.011	NS
7	0.060	NS	-0.046	***	0.184	***	-0.123	NS
8	not enough data							
9	0.137	**	-0.016	*	0.205	***	0.139	NS
10	0.089	*	-0.026	**	0.150	***	0.050	NS
11	0.117	NS	-0.036	**	0.243	**	-0.350	***
12	-0.063	NS	-0.094	**	0.041	NS	0.256	NS
13	0.102	NS	-0.031	***	0.183	***	-0.018	NS
14	0.139	NS	-0.013	NS	0.193	*	0.039	NS
mean	0.168		-0.038		0.177		-0.225	
	Army Group IV artificially acclimatized							
1	0.053	NS	-0.033	**	0.000	NS	-0.008	NS
2	0.051	NS	-0.018	*	0.080	NS	0.085	NS
3	0.083	NS	-0.069	***	0.288	**	-0.356	NS
4	0.070	NS	-0.020	*	-0.230	NS	-0.056	*
5	-0.022	NS	-0.001	NS	0.027	NS	-0.022	NS
6	-0.047	NS	-0.033	***	0.080	*	0.006	NS
7	0.097	*	-0.008	NS	0.132	**	0.051	NS
8	0.248	**	-0.013	NS	0.319	***	0.013	NS
9	0.042	NS	-0.021	**	0.093	*	-0.227	**
10	0.139	**	-0.044	***	0.137	**	-0.009	NS
11	0.247	NS	-0.026	**	0.049	NS	0.064	*
12	0.055	NS	-0.026	*	0.122	*	-0.046	NS
13	0.062	NS	-0.028	**	0.130	***	-0.068	**
14	0.008	NS	-0.024	***	0.123	***	0.035	*
mean	0.161		-0.031		0.158		-0.050	

	Phosphate mg/l/min	
	-0.186	*
S	-0.230	*
*	0.188	NS
S	-0.012	NS
*	0.105	NS
*	0.011	NS
*	-0.123	NS
*	0.139	NS
*	0.050	NS
*	-0.350	***
S	0.256	NS
*	-0.018	NS
	0.039	NS
	-0.225	

tized

	-0.008	NS
	0.035	NS
*	-0.356	NS
	-0.056	*
	-0.022	NS
	0.006	NS
	0.051	NS
*	0.013	NS
	-0.227	**
	-0.009	NS
	0.064	*
	-0.046	NS
*	-0.068	**
*	0.035	*
	-0.050	

Table 17 continued

Sub.	Sodium mEq/l/min		Potassium mEq/l/min		Chloride mEq/l/min		Phosphate mg/l/min	
	Unacclimatized Female Control							
1	-0.167	NS	-0.354	***	-0.013	NS	-0.829	**
2	0.143	*	-0.089	**	0.152	**	-0.089	**
3	0.185	**	-0.016	NS	0.303	**	0.079	NS
4	0.096	NS	-0.153	***	0.233	**	-0.083	NS
5	0.014	NS	-0.096	***	0.203	*	-0.040	***
6	0.186	**	-0.025	***	0.186	***	-0.020	*
7	0.585	*	-0.125	***	0.746	**	-0.048	*
8	0.705	***	-0.093	*	0.730	***	-0.002	NS
9	0.169	***	-0.064	***	0.268	***	0.039	NS
10	-0.349	***	-0.175	***	-0.210	***	-0.149	***
11	0.114	NS	-0.216	***	0.348	**	-0.074	*
12	-0.051	NS	-0.227	**	0.118	**	-0.045	NS
13	0.013	NS	-0.066	***	0.153	**	-0.030	***
14	-0.174	NS	-0.086	***	-0.033	NS	-0.053	**
mean	0.232		-0.136		0.269		-0.148	
	Indian Laboratory Workers							
128	0.331	***	-0.020	***	0.462	***	-0.136	***
133	0.138	***	-0.036	***	0.290	**	-0.102	*
135	-0.031	NS	-0.046	***	0.193	**	-0.013	NS
	Indian Villagers							
147	0.027	NS	0.022	NS	0.109	*	-0.155	*
	North Indian Army							
52	0.127	NS	-0.059	**	0.250	*	-0.140	*
111	0.038	NS	-0.011	NS	0.077	NS	-0.067	*
112	-0.065	NS	-0.026	***	0.069	NS	0.236	**
115	0.327	***	-0.002	NS	0.276	***	-0.033	NS
	South Indian Army							
120	0.045	NS	-0.025	*	0.295	**	-0.011	NS
	Gurkhas							
54	0.080	NS	-0.052	***	0.268	NS	-0.093	NS
56	-0.365	NS	-0.074	**	-0.328	NS	-0.097	NS
125	-0.183	NS	-0.110	**	0.008	NS	-0.263	*
mean‡	0.265		-0.050		0.268		-0.090	

Key:- NS not significant * $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$ *** $p \leq 0.001$
‡ mean of all Indian groups

Phosphate mg/l/min	
-0.829	**
-0.089	**
0.079	NS
-0.083	NS
-0.040	***
-0.020	*
-0.048	*
-0.002	NS
0.039	NS
-0.149	***
-0.074	*
-0.045	NS
-0.030	***
-0.053	**
-0.148	
-0.136	***
-0.102	*
-0.013	NS
-0.155	*
-0.140	*
-0.067	*
0.236	**
-0.033	NS
-0.011	NS
-0.093	NS
-0.097	NS
-0.263	*
-0.090	

01

commonly related to time with only a few significant slopes which were negative. Significant slopes with skin temperature were more often found to be positive than negative but the few positive and negative slopes with sweat rate appeared in equal numbers. Unlike the results for sodium, there were still many significant regression slopes for chloride amongst the post acclimatization tests on Army group IV.

Phosphate

As with potassium, phosphate slopes with time were almost always negative. Like the other electrolytes examined, significant slopes for skin temperature were less common and did not tend to be either negative or positive. For many subjects, no significant slopes could be shown at all.

Changes in Sweat Concentration with Time

Where sufficient serial samples have been available (a total of 72 tests) the concentrations of sodium, potassium, chloride and phosphate have been analysed as regressions on time during the period of controlled hyperthermia. The slopes and levels of significance of these regressions are given in Table 17. A great many of the significant regressions of concentration on time showed the relationship to be linear and so no transformations of the data were performed before the statistical analysis. For sodium, most regression coefficients were positive, with 27 significant slopes ($p \leq 0.05$), 10 of these being significant at the 0.1% level. For the chloride, the results were much the same but with even more (53) significantly positive slopes. For 24 of these the significance was at the 0.1% level.

Potassium concentration decreased during controlled hyperthermia in nearly all tests and 60 significant negative slopes were found, over half of which were at the 0.1% level. Phosphate concentration slopes which were significant to at least the 5% level were both negative (29) and positive

Table 18

Changes in Electrolyte Concentrations during Sweating Regressions on Cumulative Volume during Controlled Hyperthermia

Sub. No.	Sodium mEq/l/ml		Potassium mEq/l/ml		Chloride mEq/l/ml		Phosphate mg/l/ml	
	Army Group III test 1							
1	0.019	*	-0.005	***	0.060	***	-0.012	NS
2	0.290	**	-0.025	***	0.216	***	10.104	**
3	0.005	NS	-0.007	***	0.031	***	-0.004	NS
4	0.128	***	-0.012	***	0.165	***	-0.037	*
5	0.015	NS	-0.009	***	0.040	**	-0.001	NS
6	-0.021	*	-0.004	*	-0.001	NS	-0.038	*
7	0.006	NS	-0.016	***	0.046	***	-0.078	***
8	0.240	**	-0.023	NS	0.242	**	-0.135	**
9	-0.006	NS	-0.014	***	0.028	**	-0.030	*
10	0.037	NS	0.000	NS	0.035	NS	0.023	NS
11	0.059	***	-0.020	***	0.098	***	0.061	NS
12	0.138	**	-0.016	*	0.184	***	0.464	NS
mean	0.122		-0.013		0.111		-0.070	
	Army Group III test 2							
1	0.065	***	-0.008	***	0.064	***	-0.022	*
2	not enough data							
3	subject ommitted							
4	subject ommitted							
5	-0.000	NS	-0.006	***	0.018	***	0.010	NS
6	-0.007	NS	-0.004	***	0.017	***	0.000	NS
7	0.011	*	-0.006	***	0.023	***	0.005	NS
8	not enough data							
9	0.010	**	-0.013	***	0.033	***	0.051	*
10	0.053	**	-0.002	NS	0.059	**	0.000	NS
11	0.046	*	-0.007	*	0.054	*	0.005	NS
12	not enough data							
mean	0.037		-0.007		0.038		0.015	

Sweating Regressions

hermia

	Phosphate mg/1/ml	
*	-0.012	NS
*	10.104	**
*	-0.004	NS
*	-0.037	*
*	-0.001	NS
S	-0.038	*
*	-0.078	***
*	-0.135	**
*	-0.030	*
S	0.023	NS
*	0.061	NS
*	0.464	NS
	-0.070	
*	-0.022	*
*	0.010	NS
*	0.000	NS
*	0.005	NS
*	0.051	*
*	0.000	NS
	0.005	NS
	0.015	

Table 18 continued

Sub. No.	Sodium mEq/l/ml		Potassium mEq/l/ml		Chloride mEq/l/ml		Phosphate mg/l/ml	
	Army Group IV unacclimatized							
1	0.011	*	-0.005	***	0.018	*	-0.024	*
2	0.049	NS	-0.010	**	0.073	NS	-0.091	**
3	0.089	***	-0.015	***	0.124	***	0.076	NS
4	-0.001	NS	-0.004	***	0.006	NS	-0.001	NS
5	0.123	***	-0.003	NS	0.060	**	0.043	NS
6	0.006	NS	-0.005	***	0.014	**	0.001	NS
7	0.014	NS	-0.012	***	0.046	***	-0.028	NS
8	not enough data							
9	0.039	*	-0.005	*	0.062	***	-0.048	NS
10	0.018	*	-0.006	**	0.033	***	0.009	NS
11	0.030	NS	-0.009	**	0.059	**	-0.086	***
12	-0.020	NS	-0.028	**	0.018	NS	0.090	NS
13	0.023	NS	-0.007	***	0.042	***	-0.004	NS
14	0.029	NS	-0.003	NS	0.040	*	0.007	NS
mean	0.056		-0.010		0.050		-0.067	
	Army Group IV artificially acclimatized							
1	0.006	NS	-0.003	**	-0.000	NS	-0.001	NS
2	0.009	NS	-0.002	*	0.013	NS	0.013	NS
3	0.009	NS	-0.008	***	0.033	**	-0.041	NS
4	0.006	NS	-0.002	*	-0.015	NS	-0.004	*
5	-0.002	NS	-0.000	NS	0.003	NS	-0.002	NS
6	-0.003	NS	-0.002	***	0.006	*	0.000	NS
7	0.008	*	0.001	NS	0.011	**	0.004	NS
8	0.010	**	-0.000	NS	0.013	***	0.001	NS
9	0.004	NS	-0.003	***	0.010	NS	-0.028	**
10	0.013	**	-0.004	***	0.013	**	-0.001	NS
11	0.016	NS	-0.002	**	0.003	NS	0.005	*
12	0.008	NS	-0.004	*	0.018	*	-0.007	NS
13	0.009	NS	-0.004	**	0.018	***	-0.009	**
14	0.001	NS	-0.002	***	0.009	***	0.003	*
mean	0.010		-0.003		0.015		-0.007	

	Phosphate mg/l/ml	
	-0.024	*
	-0.091	**
*	0.076	NS
	-0.001	NS
	0.043	NS
	0.001	NS
*	-0.028	NS
*	-0.048	NS
*	0.009	NS
	-0.086	***
	0.090	NS
*	-0.004	NS
	0.007	NS
	-0.067	
natized		
	-0.001	NS
	0.013	NS
	-0.041	NS
	-0.004	*
	-0.002	NS
	0.000	NS
	0.004	NS
*	0.001	NS
	-0.028	**
	-0.001	NS
	0.005	*
	-0.007	NS
*	-0.009	**
*	0.003	*
	-0.007	

	Phosphate mg/l/ml	
	-0.024	*
	-0.091	**
	0.076	NS
	-0.001	NS
	0.043	NS
	0.001	NS
	-0.028	NS
	-0.048	NS
	0.009	NS
	-0.086	***
	0.090	NS
	-0.004	NS
	0.007	NS
	-0.067	
atized		
	-0.001	NS
	0.013	NS
	-0.041	NS
	-0.004	*
	-0.002	NS
	0.000	NS
	0.004	NS
	0.001	NS
	-0.028	**
	-0.001	NS
	0.005	*
	-0.007	NS
	-0.009	**
	0.003	*
	-0.007	

Table 18 continued

Sub. No.	Sodium mEq/l/ml		Potassium mEq/l/ml		Chloride mEq/l/ml		Phosphate mg/l/ml	
	Unacclimatized Female Controls							
1	-0.064	NS	-0.136	**	-0.004	NS	-0.064	NS
2	0.118	**	-0.073	**	0.126	**	-0.115	*
3	0.181	*	-0.019	NS	0.297	***	-0.024	NS
4	0.099	NS	-0.150	***	0.230	**	-0.069	NS
5	0.005	NS	-0.026	***	0.056	*	-0.025	**
6	0.050	**	-0.007	***	0.052	***	-0.023	*
7	0.241	*	-0.051	***	0.305	**	-0.047	*
8	0.415	***	-0.055	*	0.430	***	-0.028	NS
9	0.107	***	-0.041	***	0.169	***	-0.026	NS
10	-0.134	***	-0.067	***	-0.083	***	-0.056	***
11	0.048	NS	-0.091	***	0.147	**	-0.057	NS
12	-0.021	NS	-0.093	**	0.048	**	-0.048	NS
13	0.003	NS	-0.011	***	0.026	**	-0.016	*
14	-0.063	NS	-0.030	***	-0.013	NS	-0.052	*
mean	0.140		-0.064		0.150		-0.048	
	Indian Laboratory Workers							
128	0.065	***	-0.004	***	0.090	***	-0.026	***
133	0.027	***	-0.007	***	0.057	**	-0.021	*
135	-0.003	NS	-0.005	***	0.022	**	-0.002	NS
	Indian Villagers							
147	0.005	NS	0.005	NS	0.022	*	-0.032	*
	North Indian Army							
52	0.026	NS	-0.014	**	0.054	*	-0.032	*
111	0.008	NS	-0.002	NS	0.015	NS	-0.013	*
112	-0.007	NS	-0.003	***	0.007	NS	0.023	**
115	0.072	***	-0.000	NS	0.061	***	-0.007	NS
	South Indian Army							
120	0.025	NS	-0.013	*	0.153	**	-0.007	NS
	Gurkhas							
54	0.018	NS	-0.008	***	0.046	NS	-0.011	NS
56	-0.053	NS	-0.012	***	-0.046	NS	-0.015	NS
125	-0.024	NS	-0.014	**	0.001	NS	-0.035	*
mean‡	0.055		-0.009		0.066		-0.015	

Key:- NS not significant * $0.05 \geq p > 0.01$

** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

‡ mean of all Indian groups

Phosphate mg/l/ml	
-0.064	NS
-0.115	*
-0.024	NS
-0.069	NS
-0.025	**
-0.023	*
-0.047	*
-0.028	NS
-0.026	NS
-0.056	***
-0.057	NS
-0.048	NS
-0.016	*
-0.052	*
-0.048	
-0.026	***
-0.021	*
-0.002	NS
-0.032	*
-0.032	*
-0.013	*
0.023	**
-0.007	NS
-0.007	NS
-0.011	NS
-0.015	NS
-0.035	*
-0.015	

0.01

(3). Of the subjects, who were tested twice, no repeatable significant slopes were found with either replication (Army group III) or artificial acclimatization (Army group IV).

After artificial acclimatization, levels of significance tended to decrease for sodium, potassium and chloride but little change could be observed for phosphate.

When the means for the significant sodium and chloride slopes of each group were compared, values tended to be higher for the females, Army group III on the first test and for the combined Indian groups. Potassium slopes were steeper for the females than for any male group. Significant phosphate slopes varied widely but the flattest mean slopes were found for the artificially acclimatized subjects and the Indians.

Changes in Concentration with Volume of Sweat Secreted

The concentrations of sodium, potassium, chloride and phosphate from the serial sweat samples, collected during controlled hyperthermia, have been analysed as regressions of concentration on the cumulative volume of sweat produced up to the time of each collection. Many of the significant slopes showed the relationship between concentration and cumulative volume to be linear.

For sodium, most regression slopes were positive (see Table 18) and only two significant negative slopes were seen. The unacclimatized control females had the highest mean (of significant slopes) and the artificially acclimatized males the lowest. For Army groups III and IV, the first tests on the subjects produced steeper slopes than subsequent tests. Chloride slopes were much the same as those for sodium.

For potassium, nearly all the slopes were negative and many were highly significant. Among the groups, the mean value of the significant slopes were again steepest for the women and flatter slopes were seen on the second tests for the Army groups III and IV.

Table 19

Regression of Sweat Sodium/Potassium Ratio on Time and Cumulative Volume during Controlled Hyperthermia Slopes and Significance Levels

Subject No.	Time				Volume			
	Test 1		Test 2		Test 1		Test 2	
				Army Group III				
1	0.055	***	0.067	***	0.011	***	0.015	***
2	0.165	***	-		0.097	***	-	
3	0.081	***	-		0.015	***	-	
4	0.162	***	-		0.035	***	-	
5	0.111	***	0.066	***	0.016	***	0.007	***
6	0.033	NS	0.044	***	0.004	NS	0.006	***
7	0.132	***	0.070	***	0.017	***	0.009	***
8	0.091	**	-		0.069	**	-	
9	0.064	***	0.113	***	0.016	***	0.020	***
10	0.017	NS	0.038	***	0.006	NS	0.011	***
11	0.109	***	0.052	*	0.028	***	0.017	*
12	0.041	*	-		0.030	**	-	
mean‡	0.101		0.064		0.033		0.012	
				Army Group IV				
1	0.145	***	0.113	**	0.019	***	0.012	**
2	0.138	***	0.059	*	0.054	**	0.008	**
3	0.062	***	0.117	***	0.027	***	0.013	***
4	0.074	**	0.051	*	0.008	**	0.004	*
5	0.098	**	0.001	NS	0.037	**	0.000	NS
6	0.111	***	0.072	***	0.015	***	0.005	***
7	0.177	***	0.048	NS	0.045	***	0.004	NS
8	-		0.061	**	-		0.002	*
9	0.058	**	0.064	**	0.019	***	0.008	**
10	0.063	**	0.045	***	0.015	***	0.004	***
11	0.167	***	0.111	**	0.041	***	0.007	**
12	0.092	***	0.041	**	0.026	**	0.006	**
13	0.187	***	0.162	***	0.043	***	0.022	**
14	0.043	*	0.079	***	0.009	**	0.006	***
mean‡	0.109		0.081		0.028		0.008	

ge and Cumulative Volume

licance Levels

olume	Test 2	
**	0.015	***
**	-	
**	-	
**	-	
**	0.007	***
S	0.006	***
**	0.009	***
*	-	
**	0.020	***
S	0.011	***
**	0.017	*
**	-	
	0.012	
**	0.012	**
**	0.008	**
**	0.013	***
**	0.004	*
**	0.000	NS
**	0.005	***
**	0.004	NS
	0.002	*
**	0.008	**
**	0.004	***
**	0.007	**
**	0.006	**
**	0.022	**
**	0.006	***
	0.008	

Table 19 continued

Subject No.	Time		Volume	
	Unacclimatized British Female Controls			
1	0.054	***	0.021	***
2	0.038	***	0.031	***
3	0.032	*	0.033	**
4	0.086	***	0.084	***
5	0.075	***	0.020	***
6	0.064	***	0.017	***
7	0.139	***	0.057	***
8	0.165	**	0.097	**
9	0.072	***	0.046	***
10	0.076	***	0.029	***
11	0.092	***	0.039	***
12	0.082	***	0.034	***
13	0.113	***	0.019	***
14	0.085	***	0.030	***
mean‡	0.084		0.040	
	Indian Laboratory Workers			
128	0.069	***	0.014	***
133	0.056	***	0.011	***
135	0.156	***	0.019	***
	Indian Villagers			
147	0.021	NS	-0.005	NS
	North Indian Army			
52	0.093	**	0.021	**
111	0.050	*	0.010	*
112	0.109	***	0.011	***
115	0.076	***	0.016	***
	South Indian Army			
120	0.056	**	0.029	***
	Gurkhas			
54	0.176	**	0.027	**
56	0.143	*	0.024	*
125	0.194	***	0.026	***
mean‡	0.107		0.019	

Key:- NS not significant * $0.05 \geq p > 0.01$
** $0.01 \geq p > 0.001$ *** $p \leq 0.001$
‡ mean of group (all Indian groups combined)

Volume	
.021	***
.031	***
.033	**
.084	***
.020	***
.017	***
.057	***
.097	**
.046	***
.029	***
.039	***
.034	***
.019	***
.030	***
.040	
.014	***
.011	***
.019	***
.005	NS
.021	**
.010	*
.011	***
.016	***
.029	***
.027	**
.024	*
.026	***
.019	
0.01	

oups combined)

Phosphate slopes were all negative for the women but in the male groups many positive slopes were seen although very few were significant. In general, the levels of significance of the phosphate slopes were lower than those for sodium, potassium or chloride and no overall pattern could be seen.

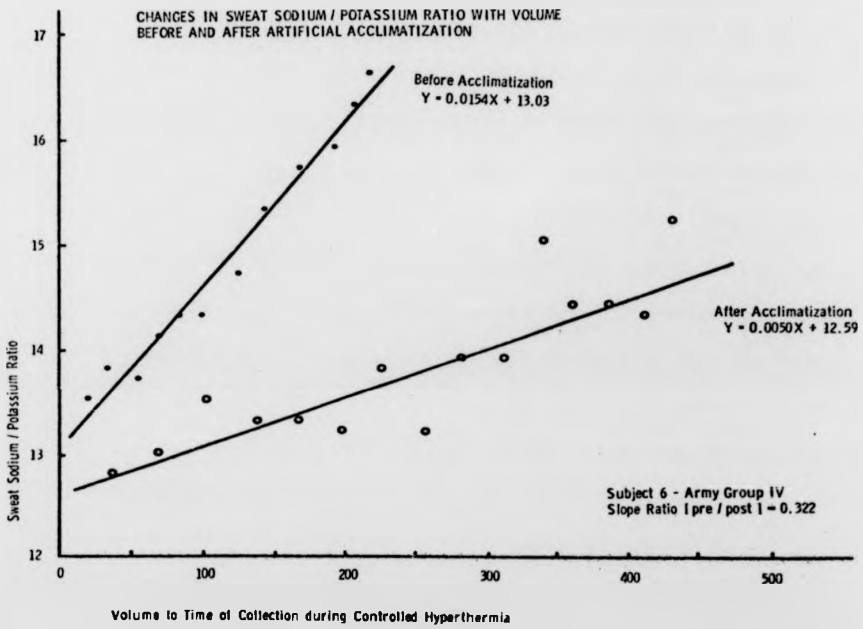
Changes in Sodium/Potassium Ratios during Sweating Episodes

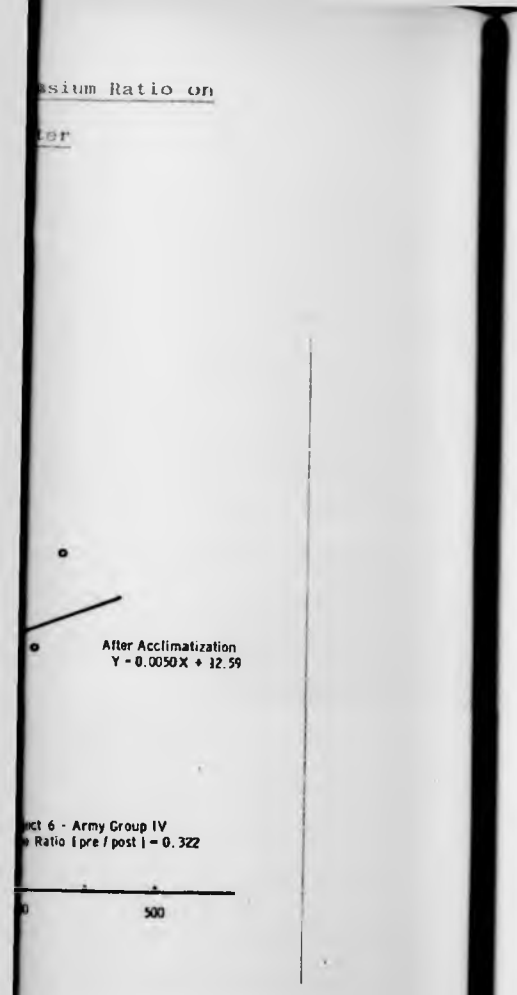
Regression analysis of the serial sweat samples has been used to relate sodium/potassium ratio to the passing of time during controlled hyperthermia and to the cumulative sweat volume. In all cases where there has been a significant regression between sodium/potassium ratio and time or volume, the relationship appeared to be linear and all regression coefficients were positive. The slopes for the regression of sodium/potassium ratio on time and on cumulative volume are given in Table 19, together with the level of the significance of the regression. The mean of the significant slopes for each group has also been given.

For the unacclimatized female control subjects, the regressions were significant at least to the 5% level and usually to the 0.1% level. Significant slopes were also usually found for Army group III and IV, who were tested twice each. Of the 92 analyses on these two groups where there were enough samples, only eight did not show significant slopes. For Army group III, the repeat tests on the subjects showed increased and decreased slopes in about equal numbers. When paired t-tests were used to compare the five subjects who had significant slopes on both tests, no significant difference was found for time or volume.

For Army group IV after acclimatization, when the significant regression slopes of sodium/potassium ratio on time for each subject were compared with those before acclimatization, it was found that in three of the eleven cases, there was an increase in slope and the other eight decreased. For the regression with cumulative volume however, all slopes

Figure 23 Regression of Sweat Sodium/Potassium Ratio on Cumulative Volume before and after Acclimatization





decreased, even those which were not significant. Paired t-tests using these eleven subjects, showed no significant slope changes for time when the results for the two tests were compared but the slope changes for volume were significant at the 1% level. An example of the change in sodium/potassium ratio with volume for an individual subject before and after acclimatization has been shown in Figure 23. The fitted regression lines have also been shown. It can be seen that after artificial acclimatization the slope with volume has decreased to about a third. For this particular subject (No. 6) the slope with time has also decreased (see Table 19) but only to about 2/3 of that of the preacclimatized state.

Of the twelve Indian subjects for whom adequate serial samples were available, regression of sodium/potassium ratio on time all had positive slopes. Six were highly significant ($p \leq 0.001$), three at the 1% level, two at the 5% level and only one was not significant (see Table 19). For the regressions on volume, the level of significance of slopes for each Indian subject was much the same as those for regressions on time.

When the mean value of the significant slopes for each group are compared, it can be seen that the results for regressions on time are much the same for all groups. For regressions on volume however, there is a tendency for the unacclimatized groups, the females in particular, to have steeper slopes.

Relationship of Phosphate with Sodium, Potassium and Chloride in Sweat

Within subject serial samples have been analysed for sodium, potassium, chloride and phosphate. As the concentration of each electrolyte changes in level, the effects of its charges are altered. To see if phosphate compensates for inbalances in the sodium + potassium - chloride relationship, phosphate has been correlated with the sum of sodium and potassium minus chloride electrolyte levels. The sign of the correlation coefficients and the levels of significance for each of the 76

Table 20

Significance of Correlation Coefficients for the Relationship of Phosphate with Sodium + Potassium - Chloride during Controlled Hyperthermia

Sub.	Army Group III		Army Group IV		Unacc Female	Indians				
No.	test 1	test 2	Unacc.	Art. Acc	Controls	Lab. Workers	Villagers	North. Army	South. Army	Gurkhas
1	+ NS	+ NS	+ ***	+ NS	+ ***	+ NS	+ ***	+ ***	- NS	+ NS
2	- NS	+ NS	+ NS	+ **	+ NS	+ *		+ ***		+ ***
3	+ *		+ NS	+ *	- NS	+ NS		+ NS		+ ***
4	+ ***		+ ***	- NS	+ NS			+ NS		
5	+ **	- NS	+ NS	+ NS	+ **					
6	+ **	+ ***	+ NS	+ **	+ NS					
7	+ ***	+ NS	+ ***	- *	+ *					
8	- NS	+ ***	+ NS	+ **	+ NS					
9	+ ***	- NS	+ NS	+ NS	- NS					
10	+ NS	+ NS	+ NS	- NS	+ ***					
11	+ NS	+ **	- NS.	+ NS	+ *					
12	+ NS	- NS	- *	+ **	+ *					
13			- NS	+ *	+ ***					
14			+ NS	+ **	+ **					

Indian subjects in the same order as for other similar tables

Key:- NS not significant * $0.05 \geq p > 0.01$ ** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

9	+ ***	- NS	+ NS	+ NS	- NS
10	+ NS	+ NS	+ NS	- NS	+ ***
11	+ NS	+ **	- NS,	+ NS	+ *
12	+ NS	- NS	- *	+ **	+ *
13			- NS	+ *	+ ***
14			+ NS	+ **	+ **

Indian subjects in the same order as for other similar tables

Key:- NS not significant * $0.05 \geq p > 0.01$ ** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

Table 21

Regression of Phosphate on Sodium + Potassium - Chloride within Subject Groups Slope and Level of Significance

Group	Slope	Significance Level
male		
Army Group III	0.613	NS
Army Group III repeat	0.898	NS
Army Group IV unacc.	1.141	NS
Army Group IV art. acc.	-0.032	NS
Low Plant.	1.668	***
High Plant.	0.358	NS
Kaul	2.298	***
Lufa	2.880	***
Old Lufa	1.294	*
Lufa Boys	-0.092	NS
Europeans	-0.143	NS
Indian Lab. Workers	0.140	NS
Indian Villagers	0.482	NS
Indian North. Army	-0.216	NS
Indian South. Army	-0.158	NS
Gurkhas	-0.462	*
female		
Unacc. Controls	0.265	NS
Kaul	3.044	***
Lufa	1.930	***
Old Lufa	1.685	NS

Key:- NS not significant
* $0.05 \geq p > 0.01$
*** $p < 0.001$

Table 22

Regression of Sodium, Potassium and Phosphate Concentrations and Sodium/Potassium Ratio on Chloride Concentration within Groups

Group	Sodium	Potassium	Phosphate	Sodium Potassium Ratio
Males				
Army Group I unacc.	1.100 ***	-0.006 NS	-	0.193 ***
Nat. Acc. C.	1.189 ***	-0.008 NS	-	0.258 ***
Army Group II	1.115 ***	0.025 NS	-	0.119 *
Army Group III	1.033 ***	0.017 NS	0.090 NS	0.135 **
Army Group III rep.	1.156 ***	0.020 NS	0.321 NS	0.137 ***
Army Group IV unacc.	0.970 ***	-0.001 NS	0.160 NS	0.206 ***
Art. Acc. C.	1.074 ***	-0.005 NS	0.044 NS	0.213 ***
Runners	1.288 ***	-0.029 NS	-	0.308 *
Swimmers	1.111 ***	0.069 NS	-	0.073 *
Cyclists	1.144 ***	0.023 NS	-	0.144 **
Yem. Summer	1.148 ***	0.010 NS	-	0.151 **
Kurd Summer	1.317 ***	0.003 NS	-	0.149 **
Yem. Winter	1.009 ***	0.033 NS	-	0.061 NS
Kurd Winter	1.024 ***	0.119 *	-	0.009 NS
Nig. Students	0.937 ***	0.054 NS	-	0.115 **
Nig. Heavy	1.006 ***	0.030 NS	-	0.178 ***
Nig. Light	0.880 ***	0.012 NS	-	0.147 ***
Nig. Villagers	1.053 ***	-0.041 NS	-	0.216 **
N.G. Low Plant.	1.056 ***	0.061 NS	0.139 NS	0.075 ***
N.G. High Plant.	0.817 ***	0.272 ***	1.360 ***	0.026 NS
N.G. Kaul	0.870 ***	0.208 **	0.677 *	0.033 NS
N.G. Lufa	0.998 ***	-0.058 NS	0.212 NS	0.131 ***
N.G. Old Lufa	0.975 ***	-0.160 NS	-0.209 NS	0.211 ***
N.G. Lufa Boys	0.984 ***	0.317 NS	-0.263 NS	0.029 NS
Ind. Lab. Workers	0.971 ***	-0.012 NS	-0.075 *	0.205 ***
Ind. Villagers	0.923 ***	-0.028 NS	-0.053 NS	0.203 **
N. Ind. Army	0.960 ***	-0.008 NS	0.128 *	0.225 ***
S. Ind. Army	0.953 ***	-0.006 NS	-0.003 NS	0.284 ***
Gurkhas	1.044 ***	0.005 NS	-0.003 NS	0.237 ***
Females				
Unacc. C.	1.029 ***	-0.032 NS	-0.037 NS	0.142 ***
Cyclists	1.219 ***	-0.051 NS	-	0.124 **
Yem. Winter	0.995 **	-0.036 NS	-	0.058 NS
Nig. Students	1.206 ***	0.138 NS	-	0.104 NS
N.G. Kaul	0.961 ***	0.264 **	1.067 **	0.059 ***
N.G. Lufa	1.011 ***	-0.017 NS	0.358 NS	0.122 ***
N.G. Old Lufa	1.012 ***	-0.118 NS	0.755 NS	0.098 **

Key:- NS not significant * $0.05 \geq p > 0.01$

** $0.01 \geq p > 0.001$ *** $p \leq 0.001$

test results are shown
only two were significa
slopes, 16 were signifi
the 5% level.

Table 21 shows t
significance produced
sodium + potassium - c
groups. Positive slop
significant slopes for
groups all had negativ
the 5% level.

Regression of Sodium,

From the mean c
hyperthermia, the sodi
sodium/potassium ratio
regressions on chlorid
the relationship appe

In every group
for analysis, the slo
Table 22). Most slop
steepest being seen f
unacclimatized female
slopes were seen howe
the Kaul males from N

Few significant
the four that were fo
females and males and
ranging from 0.272 ,t

Regression of

oncentrations and

n within Groups

hosphate		Sodium Potassium Ratio	
-		0.193	***
-		0.258	***
-		0.119	*
0.090	NS	0.135	**
0.321	NS	0.137	***
0.160	NS	0.206	***
0.044	NS	0.213	***
-		0.308	*
-		0.073	*
-		0.144	**
-		0.151	**
-		0.149	**
-		0.061	NS
-		0.009	NS
-		0.115	**
-		0.178	***
-		0.147	***
-		0.216	**
0.139	NS	0.075	***
1.360	***	0.026	NS
0.677	*	0.033	NS
0.212	NS	0.131	***
0.209	NS	0.211	***
0.263	NS	0.029	NS
0.075	*	0.205	***
0.053	NS	0.203	**
0.128	*	0.225	***
0.003	NS	0.284	***
0.003	NS	0.237	***
0.037	NS	0.142	***
-		0.124	**
-		0.058	NS
-		0.104	NS
1.067	**	0.059	***
0.358	NS	0.122	***
0.755	NS	0.098	**

0.01

test results are shown in Table 20. Of the 14 negative relationships, only two were significant ($0.05 > p > 0.01$). Of the remaining 62 positive slopes, 16 were significant at the 0.1% level, 10 at the 1% level and 7 at the 5% level.

Table 21 shows the slope of the regressions and levels of significance produced when the relationship of phosphate concentration on sodium + potassium - chloride concentration was analysed for individual groups. Positive slopes were found for the majority of the groups, with significant slopes for most of the New Guinea indigenes. The Indian army groups all had negative slopes, which for the Gurkhas was significant at the 5% level.

Regression of Sodium, Potassium and Phosphate on Chloride

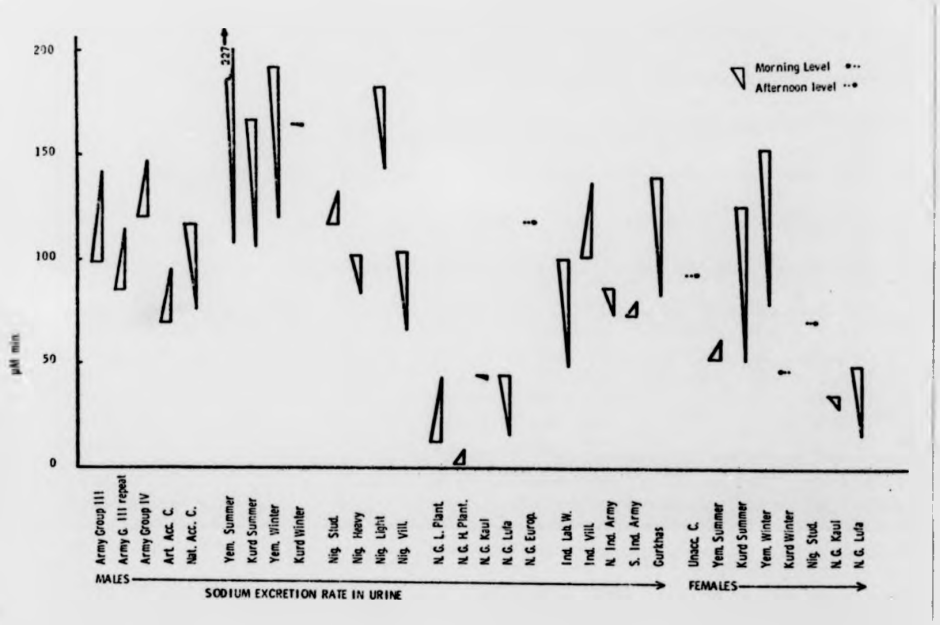
From the mean concentration of each electrolyte during controlled hyperthermia, the sodium, potassium and phosphate concentrations and the sodium/potassium ratio for each subject in a group have been analysed as regressions on chloride. Where a regression was found to be significant the relationship appears to be linear.

In every group where there were sufficient subjects (more than 5) for analysis, the slopes for sodium were highly significant (see Table 22). Most slopes were slightly greater than unity, with the steepest being seen for the Kurd males in summer, the runners, the unacclimatized female controls and the Nigerian female students. Flatter slopes were seen however, especially for the High Plantation workers and the Kaul males from New Guinea and the Light Industry workers in Nigeria.

Few significant regressions were found for potassium on chloride but the four that were found (for the High Plantation workers, the Kaul females and males and the Kurds in winter) were all positive, with slopes ranging from 0.272 to 0.119.

Regression of phosphate on chloride were seldom significant and the

Figure 24 Sodium Excretion Rates in Urine



slopes of those that w
slope was for the High
flattest sodium slope

Regression for
positive and most were
slopes for sodium/pot
concentrations.

Only the Kaul f
regressions and these

Excretion of Electrol

No information
electrolytes for the
study. An indication
subjects however, has
made of urine during
chloride and phosphat
potassium ratios for
rhythms affect the le
means for the subjec
afternoon have both
tested in the mornin
It can be seen from
the horizontal base
afternoon level (rep
level from morning t
phasing of the diurn
statistical comparis
data alone. Combin
bias the results. V

slopes of those that were, ranged from -0.075 to +1.360. The steepest slope was for the High Plantation workers, who had steepest potassium and flattest sodium slopes.

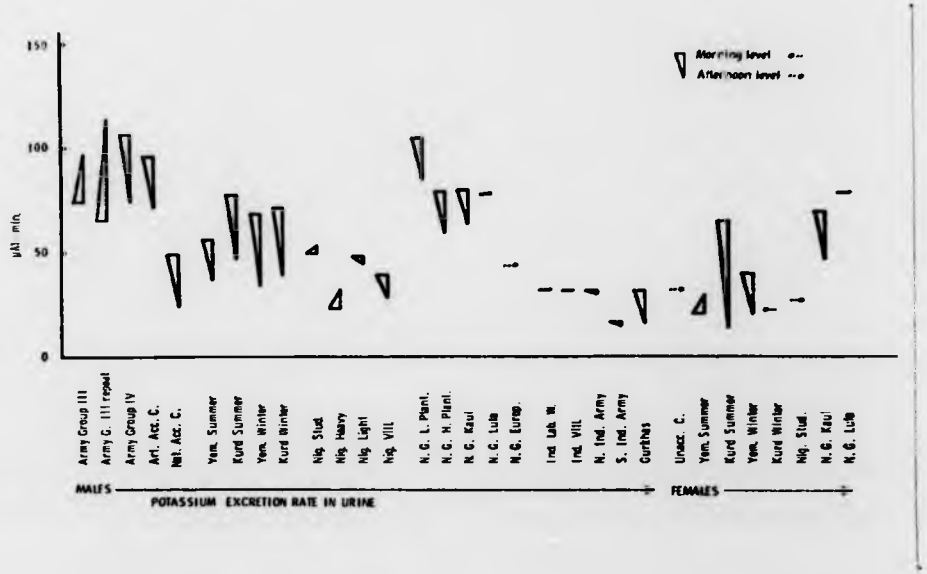
Regression for sodium/potassium ratio, like sodium, were all positive and most were significant. Those groups with non-significant slopes for sodium/potassium ratio were amongst those with high potassium concentrations.

Only the Kaul females had significant slopes for all four regressions and these were significant to at least the 1% level.

Excretion of Electrolytes in Urine

No information was available on the dietary intake of the various electrolytes for the individual subjects who have been examined for this study. An indication of salt intake and body salt balance for many subjects however, has been gained from the timed collections which were made of urine during the bed tests. Excretion rates of sodium, potassium, chloride and phosphate are shown in Figures 24 to 27 and the sodium/potassium ratios for the groups are given in Figure 28. Because diurnal rhythms affect the levels of excretion during the day (Mills, 1966), the means for the subjects tested in the morning and those tested in the afternoon have both been shown. When subjects from a group have only been tested in the morning or in the afternoon the single level has been shown. It can be seen from the figures that the morning levels (represented by the horizontal base of each triangle) may be greater or less than the afternoon level (represented by the apex) and that the difference in the level from morning to afternoon can vary widely. This means that the phasing of the diurnal rhythms of the groups is not synchronous, making statistical comparisons between groups impossible for morning or afternoon data alone. Combining the morning and afternoon data would in many cases bias the results. Visual inspection of the figures however, revealed

Figure 25 Potassium Excretion Rates in Urine



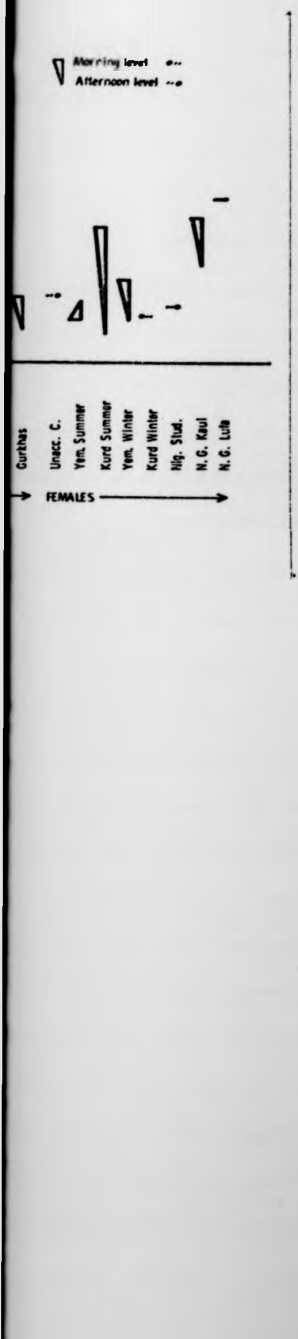
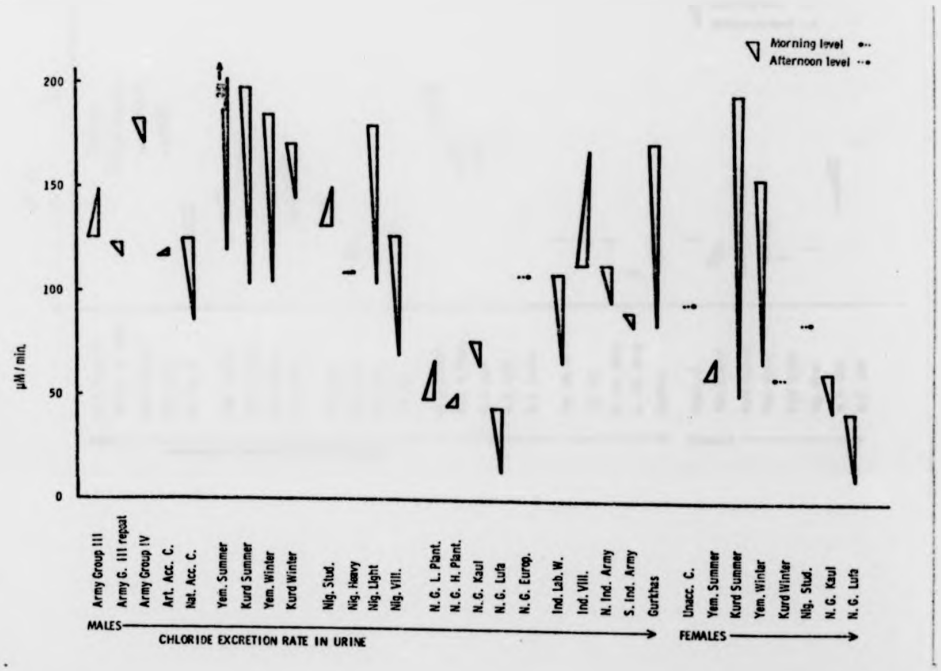

Morning level
Afternoon level
Gurkhas
Unacc. C.
Yem. Summer
Kurd Summer
Yem. Winter
Kurd Winter
Nig. Stud.
N.G. Kaul
N.G. Lulu
FEMALES

Figure 26 Chloride Excretion Rates in Urine



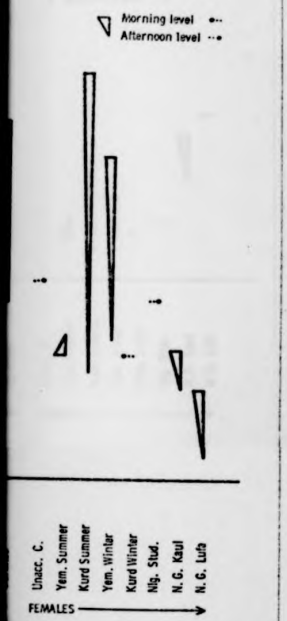
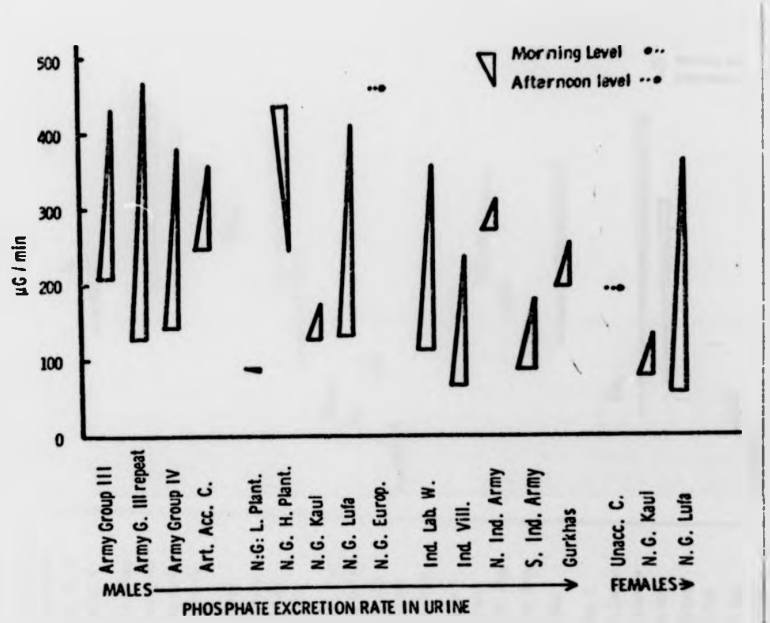

Morning level
Afternoon level
Unacc. C.
Yem. Summer
Kurd Summer
Yem. Winter
Kurd Winter
Nlg. Stud.
N. G. Kaul
N. G. Lufa
FEMALES

Figure 27 Phosphate Excretion Rates in Urine




ling Level •···
ncon level ···•
Gurkhas
Unacc. C.
N. G. Kaul
FEMALES
N. G. Lula

Figure 28 Sodium/Potassium Ratios in Urine

obvious differences b

Within each sex

found for the New Gui

Israelis (see Figures

also had high sodium

the Indians, European

which tended to be lo

of the New Guinea gro

High potassium

and the indigenes of

the lowest for the ma

Large morning

excretion in many gro

low values (see Figu

Sodium/potassiu

army and the Gurkhas

were found for all N

Excretion rate

the males and female

Comparison of Sodium

When sodium/po

sweat (see Figures 2

for the indigenous N

sweat and urine in t

British army groups

potassium ratios tha

fact that the urine

Although the n

East and the Europea

obvious differences between the groups.

Within each sex, the lowest sodium and chloride excretion rates were found for the New Guinea subjects and the highest rates were for the Israelis (see Figures 24 and 26). The Nigerian Light Industry workers also had high sodium chloride excretion rates. The other Nigerian groups, the Indians, Europeans in New Guinea and the British groups had values which tended to be lower than the Israelis but certainly higher than those of the New Guinea groups.

High potassium excretion rates were found for Army groups III and IV and the indigenes of New Guinea but the values for the Indians were among the lowest for the male groups (see Figure 25).

Large morning to afternoon variation was found for phosphate excretion in many groups but the Low Plantation workers had consistantly low values (see Figure 27).

Sodium/potassium ratios in the urine were high for the South Indian army and the Gurkhas and low for Army groups III and IV. Very low ratios were found for all New Guinea indigenes (see Figure 28).

Excretion rates and morning to afternoon changes were similar for the males and females in the Kaul and Lufa groups.

Comparison of Sodium/Potassium Ratios in Sweat and Urine

When sodium/potassium ratios in urine were compared with those in sweat (see Figures 22 and 28), low values for both measurements were found for the indigenous New Guinea groups. High values were seen for both sweat and urine in the Indian groups. This however, was not the case for British army groups tested in England, who had higher sweat sodium/potassium ratios than either the Nigerian or Israeli groups despite the fact that the urine values were lower.

Although the naturally acclimatized controls tested in the Middle East and the Europeans in New Guinea both had higher urine sodium/potassium

ratios than the troops tested in England, the sweat sodium/potassium ratios were similar for all these groups.

The female controls differed from the Army groups in that although the sodium/potassium ratio in their urine was much higher, the value in sweat was lower. This low ratio in the female sweat was not due to a lower sweat rate, since the acclimatized females had a similar sodium/potassium ratio despite having much higher sweat rates.

DISCUSSION

Ethnic Differences in Sweat Composition

The purpose of this study has been to determine if differences occur in the sweat of the various ethnic groups examined. The results show that many significant differences have been found. The question to answer is why do these differences occur?

Sweat Rates

Figure 11 shows that a great deal of variation in sweat rate has been found among the various groups. The reason for many of these differences can be explained by acclimatization to heat. The primary physiological role of sweat is the dissipation of heat for the regulation of deep body temperature (Kuno, 1956). Within the British, European and Israeli groups, those subjects who had been heat stressed for some period before the test responded to the thermal stimulus with high sweat rates. The Nigerian Heavy Industry workers, who spent up to 11 hours per shift in factory conditions with W.B.G.T. index levels ranging up to 34°C and with energy expenditures of at least 4 Kcal/min (Ogikuto, Fox, Davies & Davies, 1972), had higher sweat rates than the more sedentary students and villagers who were not exposed to such high stresses.

Exposure to heat however, did not result in high sweat rates for the indigenous New Guinea groups and the contrast with the Europeans living in the same climate was striking. The low sweat rate for the New Guinea indigenes can be partially explained by their lower body weights and levels of energy expenditure (Budd, Fox, Hendrie & Hicks, in press) but this cannot fully account for sweat rates which were less than half as great as those of the Europeans in New Guinea.

For most groups, previous prolonged exposure to heat stress goes far to explain the variation in sweat rates but for the groups indigenous to

tropical climates, especially those from New Guinea who had lower sweat rates when compared with the acclimatized British and European groups, some other factor must also influence sweat rate. Another possible explanation for these differences in sweat rates is revealed by the examination of the sweat sodium concentrations and excretion rates which will be discussed below.

Sodium in Sweat and Urine

Many significant differences were found in sweat for the sodium concentrations and excretion rates of the various groups. With the exception of the Indian groups, the men indigenous to hot countries and acclimatized to hot environments had lower sweat sodium concentrations than either the unacclimatized or acclimatized British and European groups (see Figures 12 and 16).

With acclimatization, reduced sweat sodium concentrations have often been reported (Bass, Kleeman & Quin, 1953; Berenson & Burch, 1953; Ohara, 1966) and this has been attributed to the need for the body to conserve sodium and avoid depletion (McCance, 1938; Conn, 1949a). From the results presented in Figure 24, it is seen that the ethnic groups studied varied widely in urine sodium excretion rates during the bed test. Since this is a reflection of the dietary intake and body sodium balance of these groups, corresponding variation in the sweat sodium concentrations would be expected (Conn & Johnston, 1944). Comparisons between the groups in this study however, show that this was not always the case. The Israeli males in summer had urine sodium excretion rates higher than those of the unacclimatized British army subjects (see Figure 24) but their sweat concentrations were significantly lower (see Figure 12). The New Guinea subjects, with lower sodium urine excretion rates than the Nigerian subjects, had sweat concentrations which were just as high.

A more uniform relationship was found between urine and sweat

sodium excretion rates. This relationship was seen to apply for those groups who were living in a climate to which they were indigenous and to which they had become acclimatized for normal levels of activity. The British troops acclimatized to English conditions, most Nigerian groups and the Indian civilians in New Delhi had much the same rate of sodium excretion in urine (see Figure 24) and most of the sweat sodium excretion rates for these groups did not differ significantly despite the fact that concentrations for the Nigerian groups were significantly lower ($p \leq 0.001$, see Figure 12). The indigenous groups of New Guinea had the lowest excretion rates in sweat and urine and the Israeli men in summer had higher values than the unacclimatized controls for both measurements. Of the sodium excreted in each of these five sets of ethnic groups, roughly the same proportion (about 75%) was lost in sweat when they were subjected to the same heat stress during the bed test.

This adjustment of sweat sodium loss was seen to be effected by control of both sweat rate and sweat sodium concentration. The summer Israelis, with large amounts of sodium available for excretion had high sweat rates. The Nigerian Heavy Industry workers with less sodium available for excretion had very low concentrations with the high sweat rates they would normally need for thermoregulation. The New Guinea subjects who were at risk of sodium depletion (seen from the extremely low urine excretion rates) had the lowest sweat sodium losses due to limitation of both concentration and sweat rate. The low sweat rates of these New Guinea groups then, may be due to the need to conserve sodium which would be lost in the sweat. Without further sweat sodium concentration reductions, these subjects could hardly have increased their sweat rates without becoming sodium depleted.

This relationship between sweat and urine sodium excretion rates however, was not seen to apply to those groups which were acclimatized to

a level different from that which would be normal for the population from which they had come. The unacclimatized, naturally and artificially acclimatized British army groups and the Europeans in New Guinea all had similar urine sodium excretion rates (see Figure 24) and their sweat concentrations (see Figures 12 and 16) did not differ significantly. If all these groups had been acclimatized to the temperate climate to which they were indigenous, their sweat rates would also be much the same. If under these conditions their sweat sodium concentrations remained the same, the excretion rates in the sweat for a given heat stress would also be proportional to those in urine. The British groups who had been acclimatized by heat or exercise however, lost a much greater proportion of their excreted sodium by sweating (up to about 90%) when compared with those groups who were acclimatized only to the environment to which they were indigenous. Comparisons within the Nigerian male groups showed that the lower sweat sodium excretion rates of the students may have been due to the fact that they were not acclimatized to the same extent as the others. This is supported by the fact that their exercise tolerance was the lowest of any of the male Nigerian groups (Ogikuto, Fox, Davis & Davis, 1972).

It is seen then, that at levels of acclimatization which are normal for any ethnic population, the proportion of sodium excretion lost through sweating is limited by the sweat rates and concentrations.

Potassium in Sweat and Urine

As seen in Figure 13, considerable variation has been found between the ethnic groups for potassium concentration and excretion rate in sweat. Two main factors were seen to affect the potassium losses in sweat. These were the requirement for the body to conserve potassium, and a side effect of the mechanism for sodium conservation. Figure 13 shows that these factors influenced potassium concentrations in

sweat to a greater extent than the excretion rates. Highest sweat potassium excretion rates were found mostly for those groups with high sweat rates. High concentrations however, were found among the male groups with the lowest rates.

Conservation of potassium in sweat would be expected of those groups with low potassium excretion in the urine and high sweat rates. This was certainly found for the Israeli men and the Heavy Industry workers (see Figures 13 and 25). Although potassium excretion in the urine of the Israeli groups was the same in the summer and winter, the summer sweat concentrations were lower, reducing the potassium loss for the equivalent amount of sweat. The Nigerian Heavy Industry workers with high sweat rates and low urine potassium excretion rates also had low sweat potassium concentrations. By producing reduced sweat concentrations, these groups had overcome excessive losses of both sodium and potassium due to high sweat rates.

The Indian soldiers and New Guinea groups showed a different relationship between sodium and potassium. With low to moderate sweat rates (see Figure 11) these two sets of groups had an inverse relationship between sodium and potassium sweat concentrations which was also seen in the urine excretion rates. Like the Heavy Industry workers, the South Indian army subjects had very low potassium urine excretion rates and sweat concentrations but they had high sweat sodium concentrations. The relationship between the sodium and potassium sweat concentrations and urine excretion rates of the New Guinea and Indian subjects can also be seen from the sodium/potassium ratios of sweat (Figure 22) and urine (Figure 28), which were very low for the New Guinea subjects and high for the Indians.

This difference may be explained by the mechanism of the sweat secretion in the sweat gland (Dobson & Sato, 1972). The precursor fluid

for the production of sweat is isotonic to blood plasma for sodium and potassium and therefore much the same for any ethnic group provided plasma concentrations are similar. Changes in plasma concentration due to salt depletion have been found to be very small when compared with changes in sweat concentration (Malhotra, Sharma & Sivaraman, 1959). The reabsorption of sodium from the sweat however, is stimulated by the need for the body to retain sodium (Conn, 1949a). The work of Slegers (1967) suggests that the active reabsorption of sodium in the sweat gland duct is accompanied by partial exchange with potassium resulting in higher sweat potassium concentrations.

In the New Guinea subjects, the urine excretion rates indicate that potassium was highly expendable and sodium was at a premium. Reduced outward sodium transport in the coil for precursor fluid and increased sodium reabsorption in the duct before the sweat emerged on the skin would result in low losses of sweat sodium. If freely expendable potassium is partially exchanged for the sodium in the reabsorption process, reduced osmotic work would be required by the sweat glands. Since more potassium was present in the sweat, less chloride need have been passively reabsorbed with the sodium and osmotic work would be further reduced.

In the Indian army subjects, the sodium - potassium balance was the other way round and sodium could be more freely transported outward for precursor fluid production. With this plentiful supply of sodium, the need for reabsorption would not be acute and since less potassium was available for excretion, the reduced exchange with sodium in the reabsorption process would help to conserve body potassium supplies.

The losses of potassium in the sweat of the groups studied therefore indicate that concentrations may be influenced by the need to conserve potassium or sodium.

The sodium/potassium ratios in the sweat and urine (Figures 22 and 28)

of the New Guinea subjects indicated that there was proportionally much less sodium available for excretion and that this was conserved in the sweat glands at the expense of potassium. The measurements on the Indian subjects showed that sodium was more plentiful and it was this electrolyte which was allowed to be lost in the sweat. Although the urine sodium/potassium ratio in the Israelis was similar in summer and winter, when sweat rates were greater, preferential retention of sweat sodium was indicated.

It has been reported that with lower sweat rates, sodium concentrations are lower (Schwarz & Thaysen, 1956), indicating that the reabsorption of sodium is greater with respect to sweat volumes. This may be so when sweat rates are different within an individual due to various levels of heat stress but it was not found for the differences in the groups examined in this study where the heat stress was the same and sweat rates were a function of the level of acclimatization of the subjects.

Several groups were tested in both the unacclimatized and acclimatized states and although sweat rates were very different, little change was found in the sweat sodium/potassium ratio (see Figure 22). With natural acclimatization, there was a slight increase in sodium/potassium ratio (12.5 to 13.7) but this may have been an effect of potassium depletion, since the urine potassium excretion rates in this naturally acclimatized state were much lower than for any other British army group (see Figure 25). This may have been due to the possibility that while stationed in the Middle East, sweat sodium losses were replaced by additional sodium chloride in the diet but potassium losses were not replaced. Before and after artificial acclimatization sodium/potassium ratios in the urine were much the same (see Figure 28), and although mean sweat rates increased from 4.1 ml/min to 11.0 ml/min for the same heat stress, mean sweat sodium/potassium ratios stayed exactly the same (Table 12).

for the Israelis, although urine sodium/potassium ratios were much the same from summer to winter, sodium/potassium ratios were even found to be lower with the higher summer sweat rates (see Table 13).

It can be seen then that although sodium and potassium concentrations may vary from group to group and may also vary with sweat rate within an individual when the levels of heat stress are altered, provided the body balance of sodium and potassium remain the same, the sodium/potassium ratio in the sweat remains the same for a given heat stress, even if the sweat rates are different due to changes in the level of acclimatization.

Chloride and Phosphate in Sweat

The mean sweat chloride concentration for each group was generally similar to the sodium concentration. The relationship between these concentrations however, was not the same for all the groups as was seen from the results of regression analysis of the sodium on chloride presented in Table 22. Although most regression slopes were slightly greater than unity, some groups, the High Plantation workers and the Kaul males in particular, had much lower slopes. Whereas for most groups, only sodium was related to chloride, in these two New Guinea groups increases in both sodium and potassium combined to balance increases in sweat chloride concentration. This means that the negative relationship between potassium and chloride concentrations reported by Locke, Talbot, Jones and Worcester (1951) does not apply where sweat sodium/potassium ratios are very low. In fact no significant negative regression slopes were found within any of the groups studied.

In any solution containing electrolytes, the positive and negative charges should balance. Sodium and potassium are the major mineral cations present in sweat although calcium and magnesium can also contribute to the ionic pool (Consolazio, Johnson & Pecora, 1963). Chloride is the major anion found in sweat but lactate, sulphate and

phosphate also contribute to balancing the cations. Although all these components and traces of others make up the electrical balance in sweat, phosphorous was chosen as a convenient mineral to compare with the excess of sodium and potassium over chloride.

In all groups except the Nigerian Heavy Industry workers and female students, the negative charge of the chloride was less than the sum of the positive charges of the sodium and potassium (by as much as 24 mEq/l). Within the New Guinea groups, increased phosphate concentrations were seen to contribute significantly toward compensating for this ionic difference. The New Guinea boys had the largest sodium + potassium - chloride differences and the highest phosphate concentrations. Table 21 shows that the regression of phosphate on the sodium + potassium - chloride balance was significant within five of the New Guinea groups. Correlations of within subject samples (table 20) also showed this relationship for other subjects during sweating.

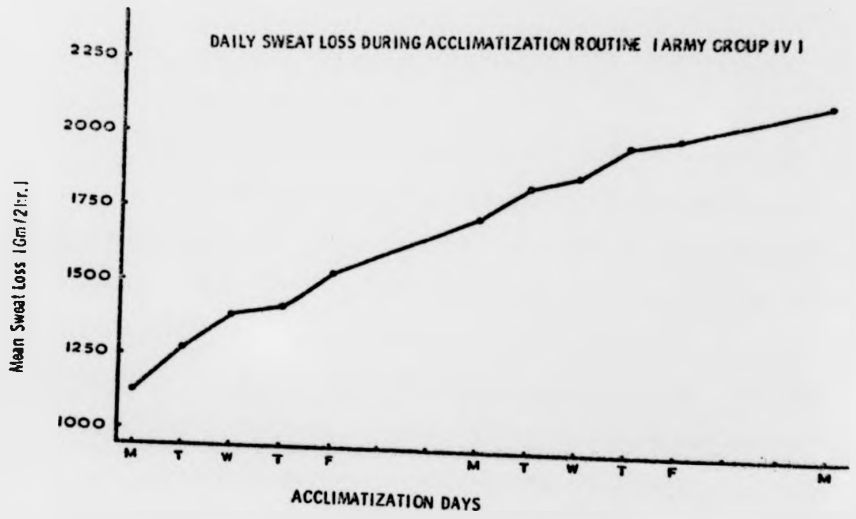
In all the groups studied, the sweat chloride concentration was found to be primarily a function of sodium concentration but it was increased with potassium concentration and decreased with increasing phosphate.

Sex Differences in Sweating

From the comparisons which have been presented in Table 6, significant differences were found for each of the comparable male and female groups. Differences in sweat rate are largely explained by the low rates of metabolic heat production (Consolazio, Johnson & Pecora, 1963), and sweat gland training of women (Fox & Ferris, 1968).

The lower sodium and chloride and higher potassium concentrations of almost every female group were not due to this difference in sweat rate. There was no reason why the female cyclists, who generally supplemented their diets with sodium chloride, should have become any more salt

Figure 29 Daily Sweat Losses during Artificial Acclimatization



depleted than the male
the males, they had lo
Ratios for the female
female controls. Lowe
in Table 6 was not lik
their urine sodium exc
those for the comparab
potassium ratios for
the comparable male g
were consistently low

Acclimatization

The experiments
were designed to inve
acclimatization to he
increased significant
excretion rates in sw

The artificiall
in the concentrations
Table 12) despite th
rates were somewhat
reasons why the sweat
urine rates. Firstli
as to suggest seriou
of the sweat glands
the sudden increase
mechanism may not ha
concentration of the
Thirdly, it is known
sweat in response to

depleted than the male cyclists but, with sweat rates nearly as high as the males, they had lower ($0.01 > p > 0.001$) sweat sodium/potassium ratios. Ratios for the female cyclists were similar to those for the unacclimatized female controls. Lower sweat sodium concentrations for each female group in Table 6 was not likely to be due to greater sodium depletion, since their urine sodium excretion rates (see Figure 24) were often as high as those for the comparable male groups. Despite the fact that urine sodium/potassium ratios for most female groups were at least as high as those for the comparable male groups (see Figure 28) sweat sodium/potassium ratios were consistently lower (see Table 6).

Acclimatization

The experiments on Army group I and IV and on the Israeli groups were designed to investigate the changes in sweating which occur with acclimatization to heat over weeks or months. In all cases, sweat rates increased significantly but changes in the electrolyte concentrations and excretion rates in sweat were not consistent.

The artificially acclimatized troops showed no significant changes in the concentrations of sodium, potassium or chloride in their sweat (see Table 12) despite the fact that the urine sodium and chloride excretion rates were somewhat reduced (Figures 24 and 26). There are three possible reasons why the sweat sodium concentrations had not been reduced with the urine rates. Firstly, the sodium excretion rates in urine were not so low as to suggest serious depletion and the reabsorption mechanism in the duct of the sweat glands may not have been strongly stimulated. Secondly, with the sudden increase in sweat rate over a period of days, the reabsorption mechanism may not have developed to the extent that it could reduce the concentration of the still increasing volumes of sweat (see Figure 29). Thirdly, it is known that the increased reabsorption of sodium from the sweat in response to salt depletion can be delayed for several days (Conn, 1949a).

In many ways these explanations are similar but after acclimatization, increased power of the sweat glands to maintain levels of reabsorption of sodium in exchange for potassium has been shown from the regressions of sweat sodium/potassium ratio on the volume of sweat produced (see Figure 23).

It is probable therefore that the reabsorption mechanism has not had time to respond to the somewhat greater need to reduce sweat sodium levels in the artificially acclimatized group.

The naturally acclimatized group, with very high sweat losses, did show significantly reduced sweat sodium concentrations (see Table 12). Their urine sodium excretion rates were much the same as those for the unacclimatized British troops (see Figure 24) but these were not maintained by the reduction in sweat concentrations and so in these troops increased sodium chloride intake was probable. This indication of dietary supplementation of sodium chloride is supported by the low potassium levels in the urine and significantly ($p \lesssim 0.001$) reduced potassium sweat concentrations which would occur if sweat losses of sodium and potassium were high but only sodium were replaced.

The Israeli groups had larger sweat sodium, potassium and chloride concentration differences with acclimatization. For these groups, high levels of acclimatization would be a normal feature in the summer months and concentrations of sodium, potassium and chloride in the sweat were reduced considerably, particularly for the male subjects where increases in sweat rate were highly significant (see Table 13). By lowering the sweat sodium concentrations with acclimatization, differences in sodium excretion rate between winter and summer were not significant and, for the Yemenite females, the rate of sweat sodium loss in the summer was even reduced. It can be seen from Figures 24 and 26, that the sodium and chloride excretion rates in urine were high and there was no suggestion of salt depletion in these subjects. In the land of their origins however, (Yemen and

Kurdistan) the availability of salt for supplementing the diet in the hot summer months would not be as likely as in modern Israel. By reducing sodium, potassium and chloride sweat concentrations in the summer months, these people have adapted to the climate in such a way that they can produce large volumes of sweat for thermoregulation while reducing the risk of salt depletion.

From the results of these three groups of acclimatized people, it can be seen that the artificially acclimatized subjects have not reacted to the effects of salt depletion due to losses in the sweat. The naturally acclimatized group, who had been living in the Middle East for several months/reacted to salt depletion by producing somewhat reduced sweat concentrations. The Israelis however, who were indigenous to countries with hot summers had greatly reduced their sweat concentrations, despite the fact that there was no evidence of salt depletion since the urine excretion rates remained high.

Changes during Sweating

Although low sodium concentrations have often been associated with acclimatization, this has been attributed to the sodium depletion which occurs when sweat losses are high (Sigal & Dobson, 1968). Both the secretion of sweat precursor in the coil of the sweat gland and the reabsorption in the duct for the production of the final product which is excreted at the skin surface are metabolic processes depending on the active transport of sodium (Sato & Dobson, 1970). Since the mean sodium concentrations in the sweat of Army group IV before and after artificial acclimatization had not changed (see Table 12), these processes were increased at the same rate. The decreasing sweat rates during controlled hyperthermia, when the demand for thermoregulatory cooling remains the same, may be due to either hydration of the skin (Kerslake, 1972) or the reduced ability of the secretory mechanism to maintain levels of functional

activity (sweat gland fatigue) (Thaysen & Schwartz, 1955).

In the vapour barrier suit, once sweating has started, the skin is bathed in sweat, so that suppression due to hydration of the skin is the most likely influence on the sweat rate. If hydration of the skin produces progressive mechanical obstruction by swelling around the sweat duct at the skin surface, a condition found in miliaria (O'Brien. 1950), this could result in hydrostatic pressures gradually building up in the sweat gland (Schulz,1969). This process would affect acclimatized subjects at least to the same extent as unacclimatized individuals.

Sweat precursor is produced by the active transport of sodium into the intercellular canaliculi of the secretory segment of the sweat gland. This is followed by the diffusion of water, and other solutes permeable to the secretory membrane to form a solution isotonic to blood plasma (Dobson & Sato, 1972). When sweat flow is restricted during hidromeiosis, pressures of up to 500 mm Hg can occur(Schulz, 1969). This could result in the production of a hypertonic precursor fluid, since the increased hydrostatic pressure would offset the osmotic pressure and restrict the movement of water, potassium and other solutes which are freely permeable to the secretory membrane, as they pass into the intercellular canaliculli to form the precursor fluid (Davson & Danielli, 1952). Under these conditions, increased ductal reabsorption of sodium would be required to maintain the sodium/potassium ratio in the sweat which is finally expelled onto the skin surface.

Increased sweat sodium/potassium ratios, therefore, may be due to a similar increase in the precursor fluid. Less water would be passively secreted for the same amount of sodium actively transported in the coil, This would also result in a reduction in sweat rate and an increase in sodium concentration. Increased pressure in the sweat gland would mean that sweat rate could be reduced further by increased

reabsorption of water in the proximal duct (Siegers, 1967). Increased reabsorption of water, when pressure was applied to the sweat gland, was noted by Schuster (1968) and could result in further concentration of sweat sodium and potassium.

Brebner and Kerslake (1964) have described the time course in the decline of sweat rate due to wetting of the skin as exponential and tending toward an asymptote in the region of zero to twenty grams of sweat per hour under the conditions of their experiments. They also showed that immersion of the skin in a 15% saline solution would arrest hidromeiosis but not reverse its effects. Kerslake (1972) has suggested that this exponential decline can be explained by random blockage of active sweat glands. When the skin is soaked in water, swelling occurs in the epithelium and in particular the keratin ring or tube around the orifice of the sweat gland duct where it opens onto the skin surface. As the orifices gradually become constricted by swelling, they could become blocked by cellular debris in the sweat producing the exponential decline in the sweat rate tending toward zero. Immersion in 15% saline would arrest the swelling and stop further blockage of the patent ducts. If the skin were allowed to dry, the keratin rings would shrink, releasing the debris and recovery from hidromeiosis would be rapid.

A different explanation for the exponential decrease in sweat rate could come from the concurrent increases in sweat concentrations. If the sweat ducts were to become gradually constricted at the skin surface but not completely blocked, the resulting increased interluminal pressure due to restricted sweat flow would help to maintain sweat rates. At the same time, the increasingly concentrated sweat, which would be in intimate contact with the keratin rings, would reduce the rate of swelling and thus reduce the rate of sweat suppression. With sweat glands remaining functional, although at lower rates, the effect of immersion in saline

on the keratin rings would be reduced. This could help explain why the saline does not reverse the effects of hidromeiosis.

Changes in sweat rate, due mainly to changes in sweat concentrations and pressures as the sweat passes out through the keratin rings however, would not necessarily predict a decline tending toward zero. In conditions where the skin is ventilated, the combined effect of increased sweat concentrations and pressures and further concentration of sweat on the skin due to the evaporation of water, would result in a stabilization of the degree of hydration of the skin and the sweat rate. With a greater sweating drive (thermal stress) and more effective evaporation from the skin surface, higher asyptotic sweat rates would be predicted. The results of Brebner and Kerslake (1964) indicate that even when the skin was immersed in plain tap water in their experiments, sweat rates may have been tending toward 10 or 20 gm/hr rather than towards zero.

Observations which have been made during experiments when the sweating skin has been kept wet indicate that hidromeiosis is probably the major cause of changes which have been found during the bed tests used in this study. Other observations however, indicate that fatigue of the sweat production mechanism may also contribute to these changes.

It has been reported by Furman and Beer (1963) that increases in sweat sodium/potassium ratio during sweating episodes are negatively related to acclimatization. This suggests that these increases could be due to failure of the sodium reabsorption in the duct since increased precursor sodium concentration due to pressures from hidromeiosis, in either acclimatized or unacclimatized subjects would occur at the same rate. If any differences did occur, the high sweat rates and lower sweat concentrations of acclimatized subjects would probably result in more rapid hydration and greater hydrostatic pressure changes within the gland.

If the reabsorption capabilities of the glands of the acclimatized

subjects are more powerful and more resistant to fatigue however, increases in sweat sodium/potassium ratios during sweating would be less marked. This view has been supported by the lower mean regression slopes of sweat sodium/potassium ratio on time which were found for Army group IV after acclimatization (0.109 to 0.081/min, see Figure 19). This resistance to fatigue of the reabsorptive mechanism has also seen from the changes in sodium/potassium ratio relative to the volume of sweat which had been processed (Figure 23 and Table 19). Means for significant volume slopes before and after acclimatization were reduced from 0.028/ml to 0.008/ml, a difference which was significant at the 1% level. Even with only one previous heat exposure which was not sufficient to increase the sweat rates of Army group III, changes in sodium/potassium ratio during controlled hyperthermia were reduced (see Table 19).

These results fit in with the findings of Dobson (1960) who reported that glycogen in the sweat gland, a source of metabolic energy for sodium transport (Sato & Dobson, 1970), is depleted quickly on first exposure to heat but remains in supply during subsequent sweating episodes.

For unacclimatized people, who had not been subjected to high heat stresses before the bed test, the sweat glands were not able to maintain low sodium/potassium ratios during sweating. This was found for the first tests on the British army groups and the unacclimatized females who had the steepest slopes for the regression of sweat sodium/potassium ratio on cumulative volume (see Table 19). The Indian groups, who were used to moderately high heat stresses, had lower slopes for volume than the unacclimatized British groups. Although slopes for the Indian subjects were much steeper than those for the artificially acclimatized controls, the Indians had not previously been exposed to heat stresses as great as those imposed during the bed tests.

These findings indicate that the reabsorptive mechanism can be

affected by fatigue due to decreased metabolic energy resourses. If so, the secretory mechanism may also be affected in the same way. Reduced active transport in the secretory cells would not in itself affect precursor concentrations but volumes could be reduced.

ADDENDUM

At the oral examination for this thesis, the results of experiments presented in two papers were brought to my attention. This information bears upon conclusions 8 and 10 which follow.

Randall and Peiss (1957) have shown that in finger tip sweating, depression of sweat rate due to hydration of the skin occurs when the sweating fingers are soaked in aqueous solutions. The degree of sweat suppression was shown to be dependent upon the concentration of the solution, suggesting that concentration of the sweat itself probably has little effect on hidromeiosis.

A second paper (Brown, W.K. & Sargent II, F. (1965). Hidromeiosis. Arch. Environ. Hlth. 11, 442-453) describes the concurrent changes in sweat rate and sweat chloride concentration from stripped (removal of the stratum corneum) and non-stripped forearm skin. In these experiments, removal of the keratinized skin resulted in higher sweat rates and sweat gland counts when compared with results from non-stripped skin. This indicates that hidromeiosis is reduced if the keratinized surface of the skin is removed and thus sweat flow is not impeded by blockage of the ducts. The concentration of sweat chloride from stripped and unstripped skin did not appear to differ at any time during sweating. These findings indicate that restriction of sweat flow due to hydration of the skin has little effect on chloride concentrations in the sweat.

CONCLUSION

Sweat rates and sweat composition varied widely amongst the groups which have been included in this study. Many of these groups had been exposed to heat stresses which would be considered "normal" in the country (England, Israel, Nigeria, New Guinea or India) to which they were indigenous. Other groups had become used to "abnormally high" heat stresses due to either intense physical activity (highly trained British athletes) or residing in hot countries (British troops stationed in the Middle East and Europeans living in New Guinea).

From the discussion of the results which have been presented and the literature which has been cited, the following conclusions have been drawn.

1. Significant differences were found in the composition of sweat collected from the various ethnic groups which were studied.

2. Amongst those male groups who had been exposed to "normal" heat stresses, sweat sodium excretion rates, regardless of sweat rates, were related to the excretion rates in urine. For these groups, sweat losses accounted for about 75% of the total sodium which was excreted in the sweat and urine during the bed test.

3. Groups who had been exposed to "abnormally high" heat stresses, lost proportionally more (up to 90%) of their sodium through sweating.

4. Sweat potassium concentrations were positively related to urine potassium excretion rates, but were also increased when urine sodium excretion rates were very low.

5. Sweat chloride concentrations were mainly a function of sodium concentrations in the sweat but were also positively related to potassium concentrations when these were high.

6. Sweat phosphate contributed toward balancing the ionic differences between sodium, potassium and chloride.

7. Female groups were consistently found to have lower sweat sodium concentrations and sodium/potassium ratios than comparable male groups. This finding was observed to be independent of differences in sweat rates and urine composition.

8. Hydration of the skin was probably the main reason for the changes in sweat rates and sweat composition, which were observed during the bed tests.

9. Fatigue of the metabolic processes for sweat production may also have contributed to changes which occurred during sweating episodes, particularly the increases in sodium/potassium ratio which were significantly reduced in acclimatized subjects.

10. Increasing interluminal pressure probably occurs during hidromeiosis. Under these conditions, increased sweat sodium concentrations and decreased sweat rates could be due to reduced outward diffusion of water through the secretory membrane of the sweat glands.

ACKNOWLEDGEMENTS

The work involved in the preparation of this thesis was carried out in the Division of Human Physiology, National Institute for Medical Research. I would like to thank Dr. O.G. Edholm, head of the division, for his continual interest and encouragement and valuable advice.

I must also thank Dr. R.H. Fox, my supervisor for initiating this study and giving me the opportunity to carry out the research. Dr. Barbara E. Tredre provided the chemical analysis for some of the early experiments and has given valued friendship and criticism throughout.

Special thanks goes to my wife, Patricia, who has done the statistical analysis and the typing.

REFERENCES

Adachi, K. & Yamasawa, S. (1966). Enzymatic basis for active transport of Na^+ in the sweat gland unit. J. invest. Derm. 46, 510-511.

Ahlman, K.L., Eranko, O., Karvonen, M.J. & Leppanen, V. (1952). Effects of hard competitive muscular work on electrolyte concentration of thermal sweat. J. appl. Physiol. 4, 911-915.

Allen, J.A., Armstrong, J.E., & Roddie, I.C. (1973). The regional distribution of emotional sweating in man. J. Physiol. 235, 749-759.

Amatruda, T.T.Jr. & Welt, L.G. (1953). Secretion of electrolytes in thermal sweat. J. appl. Physiol. 5, 759-772.

Ashworth, A. & Harrower, A.D.B. (1967). Protein requirements in tropical countries: nitrogen losses in sweat and their relation to nitrogen balance. Brit. J. Nutr. 21, 833-843.

Bass, D.E., Kleeman, C.R. & Quinn, M. (1953). Changes in body fluid compartments and sweat composition during acclimatization to heat. Fed. Proc. 12, 11.

Bass,D.E., Mager, M. & Barrueto, R.B. (1959). Effect of a vapor barrier on rates of excretion of sweat solutes. J. appl. Physiol. 14, 431-434.

Berenson, G.S. & Burch, G.E. (1953). A study of the sodium, potassium, and chloride contents of thermal sweat of man collected from small isolated areas of skin. J. Lab. clin. Med. 42, 58-77.

Bischoff, F., Maxwell, L.C. & Hill, E. (1931). Studies in hyperthermia III. The phosphorous equilibrium. J. biol. Chem. 90, 331-339.

Brebner, D.F. & Kerslake, D. McK. (1963). The effects of soaking the skin in water on the acclimatization produced by a subsequent heat exposure. J. Physiol. 166, 13-14P.

Brebner, D.F. & Kerslake, D.McK. (1964). The time course of the decline in sweating produced by wetting the skin. J. Physiol. 175, 295-302.

Brown, G. & Dobson, R.L. (1967). Sweat sodium excretion in normal women. J. appl. Physiol. 23, 97-99.

Budd, G.M., Fox, R.H., Hendrie, A.L. & Hicks, K.E. A field survey of thermal stress in New Guinea villages. Phil. Trans. in press.

Bulmer, M.G. & Forwell, G.D. (1956). The concentration of sodium in thermal sweat. J.Physiol. 132, 115-122.

Cage, G.W. & Dobson, R.L. (1965). Sodium secretion and reabsorption in the human eccrine sweat gland. J. clin. Invest. 44, 1270-1276.

Chalmers, T.M. & Keele, C.A. (1952). The nervous and chemical control of sweating. Brit. J. Derm. 64, 43-54.

Collins, K.J. (1962). Composition of palmar and forearm sweat. J. appl. Physiol. 17, 99-102.

Collins, K.J. & Weiner, J.S. (1960). Sweat gland failure on the body surface and on the forearm enclosed in an arm bag. J. Physiol. 154, 62-63P.

Collins, K.J. & Weiner, J.S. (1962). Observations on arm-bag supression of sweating and its relationship to thermal sweat-gland 'fatigue'. J. Physiol. 161, 538-556.

Collins, K.J. & Weiner, J.S. (1965). The effect of heat acclimatization on the activity and numbers of sweat-glands: a study on Indians and Europeans. J. Physiol. 177, 16-17P.

Conn, J.W. (1949a). The mechanism of acclimatization to heat. Advanc. intern. Med. 3, 373-393.

Conn, J.W. (1949b). Electrolyte composition of sweat. Clinical implications as an index of adrenal cortical function. Arch. intern. Med. 83, 416-428.

Conn, J.W. & Johnston, M.W. (1944). The function of the sweat glands in the economy of NaCl under conditions of hard work in a tropical climate, J. clin. Invest. 23, 933.

Conn, J.W., Johnston, M.W. & Louis, L.H. (1946a). Acclimatization to humid heat: a function of adrenal cortical activity. J. clin. Invest. 25, 912-913.

Conn, J.W., Johnston, M.W. & Louis, L.H. (1946b). Relationship between salt intake and sweat salt concentration under conditions of hard work in humid heat. Fed. Prod. 5, 230.

Conn, J.W., Louis, L.H., Johnston, M.W. & Johnson, B.J. (1948). The electrolyte content of thermal sweat as an index of adrenal cortical function. J. clin. Invest. 27, 529-530.

Consolazio, C.F., Johnson, R.E. & Peccora, L.J. (1963). Physiological Measurements of Metabolic Functions in Man, p.29, pp.430-432. New York: Mcgraw-Hill.

Consolazio, C.F. Matoush, L.O., Nelson, R.A., Isaac, G.J. & Canham, J.E. (1966). Comparisons of nitrogen, calcium and iodine excretion in arm and total body sweat. Amer. J. clin. Nutr. 18, 443-448.

Costa, F., Calloway, D.H. & Margen, S. (1969). Regional and total body sweat composition of men fed controlled diets. Amer. J. clin. Nutr. 22, 52-58.

Cramer, E. (1890). Arch. f. Hyg. 10, 231-282. Cited by Robinson, S. & Robinson, A.H. in Physiol. Rev. 1954, 34, 202-220.

Crockford, G.W., Davies, C.T.M. & Weiner, J.S. (1970). Circadian changes in sweating threshold. J. Physiol. 207, 26-27P.

Custance, A.C. (1965). The use of small skin surface areas for whole body sweating assessment. Canad. J. Physiol. Pharmacol. 43, 971-977.

Dale, H.H. & Feldberg, W. (1934). The chemical transmission of secretory impulses to the sweat glands of the cat. J. Physiol. 82, 121-128.

Davson, H. & Danielli, J.F. (1952). The Permeability of Natural Membranes, 2nd ed. pp18-37. Cambridge University Press.

Dill, D.B., Hall, F.G. & Edwards, H.T. (1938). Changes in composition of sweat during acclimatization to heat. Amer. J. Physiol. 123, 412-419.

Dill, D.B., Hall, F.G. & Van Beaumont, W. (1966). Sweat chloride concentration: sweat rate, metabolic rate, skin temperature, and age. J. appl. Physiol. 21, 99-106.

Dobson, R.L. (1960). The effects of repeated episodes of profuse sweating on the human eccrine sweat glands. J. invest. Derm. 35, 195-198.

Dobson, R.L. (1962). The correlation of structure and function in the human eccrine sweat gland. In Advances in Biology of Skin, Vol.3, ed. Montagna, W., Ellis, R.A. & Silver, A.F. Oxford: Pergammon Press.

Dobson, R.L. (1967). Sweat sodium excretion in normal men, women and children. Mod..Probl. Pediat. 10, 23-31.

Dobson, R.L. & Sato, K. (1972). The secretion of salt and water by the eccrine sweat gland. Arch. Derm. 105, 366-370.

Ferguson, I.D., Hertzman, A.B., Rampone, A.J. & Christensen, M.L. (1956). Magnitudes, variability and reliability of regional sweating rates in humans at constant ambient temperatures. W.A.D.C. Report No. 56-38. Ohio: Wright Air Developement Center.

Ferris, E., Fox, R.H. & Woodward, P. (1968). Thermoregulatory function in men and women. J.Physiol. 200, 46P.

Folk, G.E.Jr. & Peary, R.E.Jr. (1953). The reduction of accumulation of perspiration by impermeable barriers worn next to the skin of the extremities. Abstr. XIX int. physiol. Congr. 354.

Fox, R.H., Crockford, G.W., Hampton, I.F.G. & MacGibbon, R. (1967). A thermoregulatory function test using controlled hyperthermia. J. appl. Physiol. 23, 267-275.

Fox, R.H., Crockford, G.W. & Lofstedt, B. (1968). A thermoregulatory function test. J. appl. Physiol. 24, 391-400.

Fox, R.H. & Ferris, E. (1968). Thermoregulatory function in athletes. Abstr. XXIV int. Congr. physiol. Sci.

Furman K.I. & Beer, G. (1963). Dynamic changes in sweat electrolyte composition induced by heat stress as an indication of acclimatization and aldosterone activity. Clin. Sci. 24, 7-12.

Gordon, R.S.Jr. & Cage, G.W. (1966). Mechanism of water and electrolyte secretion by the eccrine sweat gland. Lancet, 1, 1246-1250.

Gordon, C. & Schwarz,V. (1971). Cyclic AMP, bradykinin and sweat gland function. J. Physiol. 213, 68-69P.

Hancock, W., Whitehouse, A.G.R. & Haldane, J.S. (1929). The loss of water and salts through the skin and the corresponding physiological adjustments. Proc. Roy. Soc. Lond. Ser. B. 105, 43-59.

Henschel, A. (1967) Comparative Methodology for Heat Tolerance Testing, Tech. Rept. No. 44, Occupational Health Program, National Center for Urban and Industrial Health, Public Health Service.

Herrman, F. & Mandol, L. (1955). Studies of pH of sweat produced by different forms of stimulation. J. invest. Derm. 24, 225-246.

Hertig, B.A., Riedesel, M.L. & Belding, H.S. (1961). Sweating in hot baths. J. appl. Physiol. 16, 647-651.

Johnson, R.E., Pitts, G.C. & Consolazio, F.C. (1944). Factors influencing the chloride concentration in human sweat. Amer. J. Physiol. 141, 575-589.

Kerslake, D.McK. (1972). The Stress of Hot Environments, pp.145-160. Cambridge: Cambridge University Press.

Kittsteiner, C. (1911). Arch. f. Hyg. 73, 275. Cited by Robinson, S. & Robinson, A.H. in Physiol. Rev. 1954, 34, 202-220.

Kittsteiner, C. (1917). Arch. f. Hyg. 78, 275-326. Cited by Robinson, S. & Robinson, A.H. in Physiol. Rev. 1954, 34, 202-220.

Kuno, Y. (1956). Human Perspiration. Springfield: Thomas.

Kuno, Y. (1965). The mechanism of human sweat secretion. Proc. 23rd int. Congr. Physiol. Sci. Excerpta Med. int. Congr. Ser. No. 87, 3-16.

Ladell, W.S.S. (1945a). Changes in the chloride concentration of sweat with acclimatization. Biochem. J. 39, xivii-xiviii.

Ladell, W.S.S. (1945b). Thermal sweating. Brit. med. Bull. 3, 175-179.

Lieberman, J. (1966). Cyclic fluctuations of sweat electrolytes in women: effect of polythiazide upon sweat electrolytes. JAMA, 195, 629-635.

Lobitz, W.C. & Osterberg, A.E. (1947). Chemistry of palmar sweat. II. Chloride. Arch. Derm. Syph. 56, 462-467.

Locke, W., Talbot, N.B., Jones, H.S. & Worcester, J. (1951). Studies on the use of measurements of sweat electrolyte composition and rate of sweating as an index of adrenal cortical activity. J. clin. Invest. 30, 325-337.

Malhotra, M.S. (1966). People of India including primative tribes: a survey on physiological adaptation, physical fitness and nutrition. In The Biology of Human Adaptability, ed. Baker, P.T. & Weiner, J.S. Oxford: Clarendon Press.

Malhotra, M.S., Sharma, B.K. & Sivaraman, R. (1959). Requirements of sodium chloride during summer in the tropics. J. appl. Physiol. 14. 823-828.

McCance, R.A. (1938). The effect of salt deficiency in man on the volume of the extracellular fluids, and on the composition of sweat, saliva, gastric juice and cerebrospinal fluid. J. Physiol. 92, 208-218.

McCance, R.A. (1969). Ethnic variations in the response of the sweat glands to pilocarpine: the Sudanese. J. Physiol. 203, 61-62P.

McCance, R.A. & Purohit, G. (1969). Ethnic differences in the response of the sweat glands to pilocarpine. Nature, Lond. 221, 378-379.

McCance, R.A., Rutihauser, I.H.E., & Knight, H.C. (1968). Response of sweat glands to pilocarpine in the Bantu of Uganda. Lancet i, 663-665.

Mills, J.N. (1966). Human circadian rhythms. Physiol. Rev. 46, 128-171.

Montagna, W. (1956). The Structure and Function of Skin, 2nd ed. pp.312-338. London: Academic Press.

Morimoto, T. & Johnson, R.E. (1967). Ammonia and the regulation of acidity in human eccrine sweat. Nature, Lond. 216, 813-814.

Morimoto, T., Slabochova, Z., Naman, R.K. & Sargent,II, F. (1967). Sex differences in physiological reactions to thermal stress. J. appl. Phyiol. 22, 526-532.

O'Brien, J.P. (1950). The etiology of poral closure: an experimental study of miliaria rubra, bullous impetigo and related diseases of the skin. I. An historical review of the causation of miliaria. J. invest. Derm. 15, 95-152.

Ohara, K. (1966). Chloride concentration in sweat; its individual, regional, seasonal and some other variations, and interrelations between them. Jap. J. Physiol. 16, 274-290.

Ojikuto, R.O., Fox, R.H., Davies, T.W.. & Davies,C.T.M.(1972). Heat and exercise tolerance of rural and urban groups in Nigeria. In Human Biology of Environmental Change, ed. Vorster, D.J.M. Old Woking: Gresham Press.

Peiss, C.N. & Randall, W.C. (1957). The effect of vapor impermeable gloves on evaporation and sweat suppression in the hand. J. invest. Derm. 28, 443-448.

Peiss, C.N., Randall, W.C. & Hertzman, A.B. (1956). Hydration of the skin and its effect on sweating and evaporative water loss. J. invest. Derm. 26, 459-470.

Randall, W.C. & Peiss, C.N. (1957). The relationship between skin hydration and the suppression of sweating. J. invest. Derm. 28, 435-441.

Rebell, G. & Kirk, D. (1962). Patterns of eccrine sweating in the human axilla. In Advances in Biology of Skin, Vol. 3, ed. Montagna, W., Ellis, R.A. & Silver, A.F. Oxford: Pergamon Press.

Richterich, R. (1965). Klinische Chemie (Theorie und Praxis), Basel: S. Krager.

Robinson, S. (1962). The regulating of sweating in exercise. In Advances in Biology of Skin, Vol. 3, ed. Montagna, W., Ellis, R.A. & Silver, A.F. Oxford: Pergamon Press.

Robinson, S., Dill, D.B., Wilson, J.W. & Nielsen, M. (1941). Adaptations of white men and nergoes to prolonged work in humid heat. Amer. J. trop. Med. Hyg. 21, 261-287.

Robinson, S., Gerking, S.D., Turrell, E.S. & Kincaid, R.K. (1950). Effect of skin temperature on salt concentration of sweat. J. appl. Physiol. 2, 654-662.

Robinson, S., Kincaid, R.K. & Rhamy, R.K. (1950). Effect of salt deficiency on the salt concentration in sweat. J. appl. Physiol. 3, 55-62.

Robinson, S., Maletich, R.T., Robinson, W.S., Rohrer, B.B. & Kunz, A.L. (1956). Output of NaCl by sweat glands and kidneys in relation to dehydration and salt depletion. J. appl. Physiol. 8, 615-620.

Robinson, S., Nicholas, J.R., Smith, J.H., Daly, W.J. & Pearcy, M. (1955). Time relation of renal and sweat gland adjustments to salt deficiency in men. J. appl. Physiol. 8, 159-165.

Robinson, S. & Robinson, A.H. (1954). Chemical composition of sweat. Physiol. Rev. 34, 202-220.

Sanghvi, L.D. (1966). Genetic adaptation in man. In The Biology of Human Adaptability, ed. Baker, P.T. & Weiner, J.S. Oxford: Clarendon Press.

Sargent II, F. (1962). Depression of sweating in man: so-called "sweat gland fatigue". In Advances in Biology of Skin, Vol. 3, ed. Montagna, W., Ellis, R.A. & Silver, A.F. Oxford: Pergamon Press.

Sato, K. & Dobson, R.L. (1970). Enzymatic basis for the active transport of sodium in the duct and secretory portion of the eccrine sweat gland. J. invest. Derm. 55, 53-56.

Sato, K. & Dobson, R.L. (1971). Glucose metabolism of the isolated eccrine sweat gland. I. The effects of mecholyl, epinephrine and ouabain. J. invest. Derm. 56, 272-280.

Sato, K., Dobson, R.L. & Mali, J.W.H. (1971). Enzymatic basis for the active transport of sodium in the eccrine sweat gland: localization and characterization of Na-K-adenosine triphosphatase. J. invest. Derm. 57, 10-16.

Schulz, I.L. (1969). Micropuncture studies of the sweat formation in cystic fibrosis patients. J. clin. Invest. 48, 1470-1477.

Schuster, S. (1968). In Cystic Fibrosis, ed. Porter, R. & O'Connor, M. pp.135-136. London: Churchill.

Schwartz, I.L. & Thaysen, J.H. (1956). Excretion of sodium and potassium in human sweat. J. clin. Invest. 35, 114-120.

Schwartz, I.L., Thaysen, J.H. & Dole, V.P. (1954). Sodium and potassium excretion in human sweat. Amer. J. Physiol. 179, 671.

Schwarz, V. (1968). In Cystic Fibrosis, ed. Porter, R. & O'Connor, M. pp. 132-139. London: Churchill.

Sigal, C.B. & Dobson, R.L. (1968). The effect of salt intake on sweat gland function. J. invest. Derm. 50, 451-455.

Slegers, J.F.G. (1967). A mathematical approach to the two-step reabsorption hypothesis. Mod. Probl. Pediat. 10, 74-87.

Snedicor, G.W. (1966). Statistical Methods, 5th ed. Iowa: University Press.

Szabo, G. (1962). The number of eccrine sweat glands in human skin. In Advances in Biology of Skin, Vol. 3, ed. Montagna, W., Ellis, R.A. & Silver, A.F. Oxford: Pergamon Press.

Taylor, J.R., Sato, K. Morris, D. & Dobson, R.L. (1969). Variation in sweat gland function during the menstrual cycle. J. invest. Derm. 53, 234-237.

Thaysen, J.H. & Schwartz, I.L. (1955). Fatigue of the sweat glands. J. clin. Invest. 34, 1719-1725.

Thomson, M.L. (1954). A comparison between the number and distribution of functioning eccrine sweat glands in Europeans and Africans. J. Physiol. 123, 225-233.

Van Heyningen R. & Weiner, J.S. (1952). The effect of arterial occlusion on sweat composition. J. Physiol. 116, 404-413.

Wada, M., Arai, T., Takagaki, T. & Nakagawa, T. (1952). Axon reflex mechanism in sweat response to nicotine, acetylcholine and sodium chloride. J. appl. Physiol. 4, 745-752.

Weiner, J.S. (1945). The regional distribution of sweating. J. Physiol. 104, 32-40.

Weiner, J.S. & Van Heyningen, R.E. (1952a). Relation of skin temperature to salt concentration of general body sweat. J. appl. Physiol. 4, 725-733.

Weiner, J.S. & Van Heyningen, R.E. (1952b). Salt losses of men working in hot environments. Brit. J. industr. Med. 9, 56-64.

Weiner, J.S., Willson, J.O.C., Wheeler, E.F. & El-Neil, H. (1972). The effect of work level and dietary intake on sweat nitrogen losses in a hot climate. Hum. Biol. Oceania. 1, 314-315.

Wyndham, C.H. (1966).Southern African ethnic adaptation to temperature and exercise. In The Biology of Human Adaptability, ed. Baker, P.T. & Weiner, J.S. Oxford: Clarendon Press.

Wyndham, C.H., Morrison, J.F. & Williams, C.G. (1965). Heat reactions of male and female Caucasians. J. appl. Physiol. 20, 357-364.

Wyndham, C.H., Strydom, N.B., Morrison, J.F. Williams, C.G., Bredell, G.A.G., Von Rahden, M.J.E., Holdsworth, L.D., Van Graan, C.H., Van Rensburg, A.J. & Munro, A. (1964). Heat reactions of Caucasians and Bantu in South Africa. J. appl. Physiol. 19, 598-606.

Wyndham, C.H., Strydom, N.B., Ward, J.S., Morrison, J.F., Williams, C.G., Bredell, G.A.G., Von Rahden, M.J.E., Holdsworth, L.D., Van Graan, C.H., Van Rensburg, A.J. & Munro, A. (1964). Physiological reactions to heat of Bushmen and of unacclimatized and acclimatized Bantu. J. appl. Physiol. 19, 885-888.

Appendix 1 Sweat Electrolyte Concentrations. Male groups

Group	No. of Subs	Sodium Mean mEq/l	Sodium Confidence Limits	Potassium Mean mEq/l	Potassium Confidence Limits	Chloride Mean mEq/l	Chloride Confidence Limits	Phosphate Mean mg/l	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Sodium/Potassium Ratio ±St.Err.
Army Group I unacc.	25	72.3	64.7 - 80.9	6.06	5.66 - 6.49	67.5	60.5 - 75.4	-		12.5	0.7
acc.	25	65.5	57.6 - 74.4	5.20	4.64 - 5.83	58.8	52.2 - 66.4	-		13.7	1.1
Army Group II	8	70.8	56.7 - 88.5	6.26	5.50 - 7.14	70.0	57.4 - 85.4	-		11.6	1.0
Army Group III	12	64.2	58.2 - 70.7	6.64	6.07 - 7.26	59.4	53.8 - 65.7	1.20	0.95 - 1.51	9.80	0.50
repeat	10	59.6	51.2 - 69.4	7.00	6.54 - 7.50	55.3	48.1 - 63.6	1.17	0.87 - 1.57	8.65	0.52
Army Group IV unacc.	14	72.3	59.0 - 88.7	5.31	4.84 - 5.83	68.9	55.3 - 86.0	1.55	1.02 - 2.35	14.6	1.4
acc.	14	72.6	56.6 - 93.1	5.48	4.76 - 6.31	69.4	54.5 - 88.5	0.69	0.50 - 0.95	14.6	1.7
Cyclists	13	64.7	51.8 - 80.8	6.68	6.03 - 7.40	61.1	49.8 - 75.0	-		10.2	0.9
Runners	11	73.4	57.8 - 93.3	6.16	4.83 - 7.86	68.6	58.0 - 81.1	-		13.8	2.5
Swimmers	13	50.9	39.4 - 65.7	10.1	8.59 - 11.8	52.1	41.9 - 64.8	-		5.37	0.56
Yemenite summer	7	39.0	24.4 - 62.2	6.87	5.93 - 7.94	39.5	26.1 - 59.7	-		6.20	0.99
winter	16	84.9	73.1 - 98.6	9.77	8.44 - 11.3	80.9	70.7 - 92.7	-		9.10	0.73
Kurd summer	16	45.8	39.9 - 52.6	7.82	6.91 - 8.85	46.8	42.6 - 51.6	-		6.14	0.44
winter	16	78.6	68.5 - 90.2	10.3	8.29 - 12.8	74.6	65.0 - 85.6	-		8.12	0.78
Nig. students	14	35.3	26.5 - 47.1	6.57	5.32 - 8.10	38.8	28.8 - 52.3	-		5.93	0.74
Nig. Heavy Ind.	24	22.9	16.8 - 31.2	4.13	3.57 - 4.78	31.3	24.8 - 39.6	-		6.71	0.87
Nig. Light Ind.	14	34.8	25.4 - 47.7	5.58	4.69 - 6.63	37.0	24.7 - 55.5	-		7.14	0.93
Nig. Villagers	6	47.8	28.3 - 80.9	6.52	5.00 - 8.51	51.1	31.4 - 83.0	-		8.56	2.08

Appendix 1 Sweat Electrolyte Concentrations. Male groups

Group	No. of Subs	Sodium Mean mEq/l	Sodium Confidence Limits	Potassium Mean mEq/l	Potassium Confidence Limits	Chloride Mean mEq/l	Chloride Confidence Limits	Phosphate Mean mg/l	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Sodium/Potassium Ratio ±St.Err.
Army Group I unacc.	25	72.3	64.7 - 80.9	6.06	5.66 - 6.49	67.5	60.5 - 75.4	-		12.5	0.7
acc.	25	65.5	57.6 - 74.4	5.20	4.64 - 5.83	58.8	52.2 - 66.4	-		13.7	1.1
Army Group II	8	70.8	56.7 - 88.5	6.26	5.50 - 7.14	70.0	57.4 - 85.4	-		11.6	1.0
Army Group III	12	64.2	58.2 - 70.7	6.64	6.07 - 7.26	59.4	53.8 - 65.7	1.20	0.95 - 1.51	9.80	0.50
repeat	10	59.6	51.2 - 69.4	7.00	6.54 - 7.50	55.3	48.1 - 63.6	1.17	0.87 - 1.57	8.65	0.52
Army Group IV unacc.	14	72.3	59.0 - 88.7	5.31	4.84 - 5.83	68.9	55.3 - 86.0	1.55	1.02 - 2.35	14.6	1.4
acc.	14	72.6	56.6 - 93.1	5.48	4.76 - 6.31	69.4	54.5 - 88.5	0.69	0.50 - 0.95	14.6	1.7
Cyclists	13	64.7	51.8 - 80.8	6.68	6.03 - 7.40	61.1	49.8 - 75.0	-		10.2	0.9
Runners	11	73.4	57.8 - 93.3	6.16	4.83 - 7.86	68.6	58.0 - 81.1	-		13.8	2.5
Swimmers	13	50.9	39.4 - 65.7	10.1	8.59 - 11.8	52.1	41.9 - 64.8	-		5.37	0.56
Yemenite summer	7	39.0	24.4 - 62.2	6.87	5.93 - 7.94	39.5	26.1 - 59.7	-		6.20	0.99
winter	16	84.9	73.1 - 98.6	9.77	8.44 - 11.3	80.9	70.7 - 92.7	-		9.10	0.73
Kurd summer	16	45.8	39.9 - 52.6	7.82	6.91 - 8.85	46.8	42.6 - 51.6	-		6.14	0.44
winter	16	78.6	68.5 - 90.2	10.3	8.29 - 12.8	74.6	65.0 - 85.6	-		8.12	0.78
Nig. students	14	35.3	26.5 - 47.1	6.57	5.32 - 8.10	38.8	28.8 - 52.3	-		5.93	0.74
Nig. Heavy Ind.	24	22.9	16.8 - 31.2	4.13	3.57 - 4.78	31.3	24.8 - 39.6	-		6.71	0.87
Nig. Light Ind.	14	34.8	25.4 - 47.7	5.58	4.69 - 6.63	37.0	24.7 - 55.5	-		7.14	0.93
Nig. Villagers	6	47.8	28.3 - 80.9	6.52	5.00 - 8.51	51.1	31.4 - 83.0	-		8.56	2.08

Appendix 1 continued

Group	No. of Subs	Sodium Mean mEq/l	Sodium Confidence Limits	Potassium Mean mEq/l	Potassium Confidence Limits	Chloride Mean mEq/l	Chloride Confidence Limits	Phosphate Mean mg/l	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Sodium/Potassium Ratio ±St.Err.
N.G. Low Plant.	19	33.1	24.6 - 44.6	10.0	8.51 - 11.8	35.3	26.8 - 46.6	1.46	1.04 - 2.04	3.95	0.55
N.G. High Plant.	19	27.1	21.5 - 34.2	8.63	7.09 - 10.5	27.6	21.9 - 34.7	1.18	7.21 - 1.95	3.46	0.36
N.G. Kaul	40	35.0	30.6 - 40.0	11.0	9.45 - 12.8	36.0	31.7 - 40.9	1.47	1.06 - 2.04	3.60	0.29
N.G. Lufa	30	32.8	28.9 - 37.2	9.64	8.33 - 11.2	28.6	25.0 - 32.8	1.99	1.50 - 2.64	3.81	0.33
N.G. Lufa Old	11	31.9	23.8 - 42.8	9.82	7.05 - 13.7	29.3	21.9 - 39.2	1.41	0.81 - 2.46	4.17	1.00
N.G. Boys	10	32.6	23.6 - 45.0	21.6	15.8 - 29.6	29.1	20.4 - 41.5	4.81	3.13 - 7.38	1.72	0.30
N.G. Europeans	14	65.2	53.8 - 79.0	5.18	4.47 - 6.00	62.6	52.3 - 75.0	0.47	0.29 - 0.78	13.5	1.4
Ind. Lab. Workers	10	54.9	39.1 - 77.1	5.71	5.16 - 6.32	51.7	35.6 - 75.0	0.40	0.26 - 0.63	10.8	1.8
Ind. Villagers	13	74.1	64.6 - 85.0	6.51	5.52 - 7.69	70.5	60.5 - 82.1	1.45	1.00 - 2.11	12.3	1.4
North Indian Army[1]	21	61.4	55.6 - 67.9	4.38	3.97 - 4.83	59.0	53.0 - 65.6	-[2]		14.6	0.9
South Indian Army[1]	20	73.6	63.4 - 85.4	3.82	3.40 - 4.29	72.4	62.0 - 84.5	-[2]		20.6	1.7
Gurkhas[1]	18	68.4	59.7 - 78.3	4.25	3.91 - 4.62	66.0	57.8 - 75.4	-[2]		16.7	1.1

1 Subjects tested between September and mid October

2 Phosphate concentrations changing with time of year

\- No measurements made

Appendix 2 Sweat Electrolyte Concentrations. Female Groups

Group	No. of Subs	Sodium Mean mEq/l	Sodium Confidence Limits	Potassium Mean mEq/l	Potassium Confidence Limits	Chloride Mean mEq/l	Chloride Confidence Limits	Phosphate Mean mg/l	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Sodium/Potassium Ratio ±St.Err.
Unacc. Controls	15	55.1	46.2 - 65.7	9.05	7.85 - 10.4	46.5	38.6 - 56.0	0.32	0.23 - 0.45	6.58	0.66
Acc. Controls	14	61.7	49.4 - 77.2	10.1	8.66 - 11.8	58.2	48.2 - 70.4	-		6.83	0.78
Yemenite summer	4	32.0	18.4 - 55.9	12.2	4.07 - 36.8	31.3	17.2 - 56.7	-		2.83	0.73
winter	6	82.8	62.8 - 109	16.8	12.2 - 23.0	80.1	61.9 - 104	-		5.20	0.70
Kurd summer	5	44.1	34.5 - 56.3	9.47	6.73 - 13.3	42.0	32.5 - 54.1	-		4.72	0.37
winter	3	53.8	16.9 - 172	9.66	3.71 - 25.2	50.2	17.1 - 147	-		5.65	0.70
Nig. Students	8	20.2	11.9 - 34.5	7.77	5.03 - 12.0	28.4	20.8 - 38.8	-		3.07	0.64
N.G. Kaul	38	25.5	21.4 - 30.4	12.0	10.4 - 13.8	27.9	24.0 - 32.5	2.38	1.78 - 3.17	2.42	0.22
N.G. Lufa	30	24.1	18.8 - 30.9	13.5	11.7 - 15.6	21.1	17.0 - 26.1	3.37	2.75 - 4.14	2.28	0.40
N.G. Lufa Old	9	20.0	15.1 - 26.3	13.8	10.6 - 18.0	17.0	13.0 - 22.2	3.33	2.27 - 4.89	1.63	0.27

- No measurements made

Appendix 3 Sweat Electrolyte Excretion Rates and Sweat Rate during Controlled Hyperthermia. Male Groups

Group	Sodium		Potassium		Chloride		Phosphate		Sweat Rate	
	Mean μM/min	Confidence Limits	Mean μM/min	Confidence Limits	Mean μM/min	Confidence Limits	Mean μg/min	Confidence Limits	Mean ml/½hr	Confidence Limits
Army Group I unacc.	569	471 - 686	47.6	42.2 - 53.8	531	440 - 642	-		236	202 - 276
acc.	1096	906 - 1326	87.1	75.6 - 100	985	820 - 1184	-		503	451 - 560
Army Group II	537	402 - 717	47.4	37 0 - 60.8	530	401 - 701	-		227	159 - 324
Army Group III	239	163 - 350	24.7	16.7 - 36.6	221	153 - 321	4.46	2.88 - 6.90	111	74.1 - 168
repeat	233	145 - 373	24.0	14.6 - 39.2	214	136 - 339	4.40	2.53 - 7.65	106	63.8 - 176
Army Group IV unacc.	298	214 - 415	21.9	16.5 - 29.0	284	201 - 401	6.39	4.57 - 8.93	124	92.8 - 164
acc.	795	585 - 1081	60.1	46.7 - 77.4	761	564 - 1028	7.53	5.23 - 10.8	329	271 - 400
Cyclists	745	518 - 1071	76.9	61.3 - 96.5	704	495 - 1001	-		345	275 - 432
Runners	851	549 - 1320	71.5	52.8 - 96.8	796	531 - 1191	-		348	242 - 500
Swimmers	329	218 - 497	65.2	51.1 - 83.2	337	230 - 493	-		194	139 - 271
Yemenite summer	463	272 - 789	81.7	66.2 - 101	469	286 - 770	-		357	270 - 472
winter	290	198 - 424	33.3	24.1 - 46.0	276	187 - 407	-		102	69.5 - 151
Kurd summer	484	384 - 610	82.5	71.2 - 95.5	494	404 - 605	-		317	270 - 372
winter	351	260 - 474	46.0	36.0 - 58.7	334	246 - 452	-		134	97.6 - 184
Nig. students	190	125 - 288	35.3	25.1 - 49.6	209	136 - 320	-		162	108 - 242
Nig. Heavy Ind.	259	178 - 377	46.7	36.7 - 59.5	354	258 - 488	-		339	272 - 423
Nig. Light Ind.	340	242 - 478	54.3	43.8 - 67.7	361	238 - 547	-		292	248 - 343
Nig. Villagers	237	91.3 - 613	32.2	23.1 - 45.1	252	101 - 630	-		148	94.3 - 233

Appendix 3 continued

Group	Sodium		Potassium		Chloride		Phosphate		Sweat Rate	
	Mean µM/min	Confidence Limits	Mean µM/min	Confidence Limits	Mean µM/min	Confidence Limits	Mean µg/min	Confidence Limits	Mean ml/½hr	Confidence Limits
N.G. Low. Plant.	111	78.5 - 158	33.7	26.9 - 42.1	119	84.4 - 167	4.90	3.50 - 6.85	101	72.3 - 140
N.G. High Plant	127	86.5 - 187	40.4	31.8 - 51.5	129	91.8 - 181	5.55	3.88 - 7.94	126	86.7 - 184
N.G. Kaul	115	91.8 - 144	36.1	31.2 - 41.7	118	94.8 - 147	4.81	3.81 - 6.06	97.1	76.9 - 122
N.G. Lufa	131	105 - 165	38.7	33.4 - 44.9	115	90.1 - 147	8.00	6.12 - 10.4	120	98.7 - 147
N.G. Lufa Old	104	57.2 - 187	31.9	22.5 - 45.1	95.2	51.2 - 177	4.59	3.20 - 6.59	97.9	59.1 - 162
N.G. Lufa Boys	14.6	6.11 - 34.7	9.65	4.41 - 21.1	13.0	5.17 - 32.8	2.03	0.87 - 4.74	14.6	6.96 - 30.6
N.G. Europeans	744	602 - 920	59.1	49.1 - 71.2	715	587 - 871	6.03	4.27 - 8.53	343	298 - 407
Ind. Lab. Workers	298	188 - 471	31.0	20.3 - 47.3	280	170 - 462	2.17	1.16 - 4.08	163	105 - 251
Ind. Villagers	297	217 - 405	26.1	19.0 - 35.9	282	204 - 389	6.04	4.17 - 8.75	116	85.1 - 159
North Indian Army[1]	504	400 - 635	35.9	30.6 - 42.2	484	384 - 611	-[2]		246	203 - 298
South Indian Army[1]	463	375 - 572	24.1	20.0 - 29.0	456	365 - 569	-[2]		189	155 - 231
Gurkhas[1]	577	470 - 709	35.9	30.0 - 42.9	557	465 - 681	-[2]		253	218 - 295

1 Subjects tested between September and mid October

2 Phosphate excretion rates changing with time of year

\- No measurements made

Appendix 4 Sweat Electrolyte Excretion Rates and Sweat Rate during Controlled Hyperthermia. Female Groups

Group	Sodium		Potassium		Chloride		Phosphate		Sweat Rate	
	Mean μM/min	Confidence Limits	Mean μM/min	Confidence Limits	Mean μM/min	Confidence Limits	Mean μg/min	Confidence Limits	Mean ml/½hr	Confidence Limits
Unacc. Controls	117	78.7 - 175	19.3	14.3 - 26.0	99.1	66.1 - 149	0.68	0.48 - 0.96	63.9	47.1 - 86.7
Acc. Controls	667	454 - 978	109	83.6 - 143	629	443 - 894	-		324	245 - 429
Yemenite summer	71.3	18.5 - 278	27.2	14.9 - 50.0	69.6	17.4 - 278	-		66.8	13.0 - 343
winter	130	54.4 - 308	26.2	10.8 - 63.9	125	54.8 - 286	-		46.9	22.5 - 97.7
Kurd summer	168	98.9 - 286	36.1	26.1 - 50.1	160	96.4 - 266	-		115	59.1 - 222
winter	149	19.0 - 170	26.8	5.53 - 130	139	21.7 - 893	-		83.2	28.6 - 242
Nig. Students	67.3	40.6 - 112	25.9	20.0 - 33.5	94.6	66.2 - 135	-		99.9	59.9 - 166
N.G. Kaul	66.1	50.5 - 86.6	31.0	24.9 - 38.7	72.3	55.8 - 93.8	6.15	4.62 - 8.20	77.7	61.0 - 99.1
N.G. Lufa	67.5	47.1 - 96.8	37.8	29.4 - 48.6	58.9	42.3 - 82.0	9.43	7.32 - 12.1	83.8	63.4 - 111
N.G. Lufa Old	42.9	24.5 - 75.2	29.8	17.5 - 50.7	36.5	20.9 - 63.7	7.17	4.58 - 11.2	64.5	36.2 - 115

- No measurements made

Appendix 5 Urine Electrolyte Excretion Rates during the Bed Test. Male Groups

Group and No.		Time of Day	Sodium Mean µM/min	Sodium Confidence Limits	Potassium Mean µM/min	Potassium Confidence Limits	Chloride Mean µM/min	Chloride Confidence Limits	Phosphate Mean µg/min	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Ratio ±St.Err.
Army Gp. I acc.	13	AM	117	63.1 - 218	49.5	33.3 - 73.7	121	71.0 - 205	-		2.84	0.50
	12	PM	75.8	42.6 - 58.8	28.7	14.0 - 58.8	81.4	48.5 - 137	-		4.26	1.38
Army Gp. III	6	AM	98.5	48.7 - 200	74.5	57.3 - 97.0	125	75.7 - 208	207	109 - 393	1.50	3.30
	6	PM	143	61.7 - 330	97.0	40.9 - 230	148	75.8 - 289	429	172 - 1072	1.85	0.59
Army Gp. III repeat	6	AM	85.0	46.7 - 155	65.0	45.0 - 93.8	123	78.9 - 191	127	42.6 - 381	1.37	0.18
	6	PM	114	70.5 - 184	114	66.6 - 194	116	72.1 - 186	463	277 - 775	1.77	0.39
Army Gp. IV unacc.	6	AM	120	73.8 - 194	106	58.9 - 192	182	123 - 267	141	78.9 - 253	1.35	0.31
	7	PM	146	88.7 - 241	74.3	47.4 - 117	170	117 - 247	379	176 - 814	2.08	0.27
Army Gp. IV acc.	6	AM	68.6	52.6 - 89.5	95.8	66.3 - 138	116	78.3 - 170	244	169 - 352	0.73	0.06
	7	PM	94.7	37.3 - 241	71.4	39.5 - 129	120	61.3 - 234	355	204 - 618	1.48	0.27
Yemenite summer	11	AM	227	184 - 281	55.2	37.2 - 81.9	251	201 - 314	-		4.69	0.80
	11	PM	107	70.4 - 164	36.5	24.7 - 53.8	119	79.7 - 177	-		3.37	0.47
Yemenite winter	7	AM	191	150 - 244	67.8	43.5 - 106	184	145 - 234	-		2.96	0.37
	9	PM	119	101 - 140	34.1	23.9 - 48.7	104	84.2 - 128	-		3.78	0.59
Kurd summer	10	AM	167	95.0 - 293	77.1	45.0 - 132	196	116 - 330	-		2.41	0.37
	10	PM	105	81.9 - 135	46.1	34.7 - 61.3	103	82.3 - 129	-		2.49	0.35
Kurd winter	8	AM	164	104 - 260	71.6	53.9 - 95.2	170	129 - 223	-		2.52	0.38
	7	PM	164	103 - 261	38.7	23.9 - 62.6	143	85.5 - 191	-		4.04	0.55

Appendix 5 continued

Group and No.		Time of Day	Sodium Mean µM/min	Sodium Confidence Limits	Potassium Mean µM/min	Potassium Confidence Limits	Chloride Mean µM/min	Chloride Confidence Limits	Phosphate Mean µg/min	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Ratio ±St.Err.
Nig. Students	7	AM	116	49.8 - 270	48.8	30.8 - 77.2	130	62.6 - 272	-		2.52	0.66
	8	PM	133	94.0 - 188	52.3	31.7 - 86.3	148	113 - 194	-		2.77	0.43
Nig. Heavy Ind.	9	AM	102	77.8 - 133	22.7	16.2 - 31.7	108	81.6 - 143	-		4.56	0.68
	13	PM	83.8	56.6 - 124	31.9	23.7 - 42.9	109	85.3 - 140	-		3.45	0.57
Nig. Light Ind.	8	AM	181	111 - 295	47.1	20.3 - 109	177	101 - 313	-		5.12	1.42
	6	PM	143	76.9 - 265	44.3	29.5 - 66.6	103	27.3 - 391	-		3.15	0.73
Nig. Villagers	4	AM	103	45.1 - 236	38.8	24.6 - 61.4	125	65.7 - 239	-		2.95	0.71
	3	PM	65.7	26.1 - 165	27.4	11.0 - 68.5	68.3	51.8 - 89.9	-		2.40	0.06
N.G. Low Plant.	6	AM	12.4	3.15 - 49.2	104	64.3 - 168	48.2	28.5 - 81.5	83.7	20.9 - 335	0.24	0.12
	13	PM	42.9	22.1 - 83.6	83.4	55.4 - 126	66.8	41.5 - 107	82.2	43.8 - 154	0.67	0.13
N.G. High Plant.‡	2	AM	1.83	0.43 - 7.79	77.9	72.1 - 84.2	44.9	40.4 - 49.9	431	369 - 504	0.06	0.05
	18	PM	8.89	2.73 - 28.9	58.0	44.3 - 75.9	50.3	31.5 - 80.4	241	161 - 359	0.55	0.22
N.G. Kaul	22	AM	44.3	29.2 - 67.2	79.0	54.1 - 115	75.6	53.6 - 107	126	68.5 - 232	0.76	0.10
	19	PM	42.9	24.5 - 74.9	62.1	50.5 - 76.3	64.6	48.5 - 86.0	172	125 - 237	1.08	0.17
N.G. Lufa	14	AM	44.3	23.6 - 83.3	76.5	58.5 - 100	44.3	27.6 - 70.9	129	69.5 - 239	0.75	0.14
	16	PM	15.5	7.23 - 33.4	77.0	44.7 - 133	13.6	7.48 - 24.8	403	236 - 687	0.59	0.17
N.G. Lufa Old	10	AM	37.1	14.0 - 98.4	59.3	39.5 - 88.9	37.6	13.7 - 103	106	34.1 - 327	0.98	0.19
N.G. Boys	4	AM	34.0	3.22 - 360	33.3	14.7 - 75.3	34.1	4.37 - 266	44.3	8.85 - 222	2.03	0.67
	6	PM	7.00	1.10 - 44.8	65.2	31.6 - 134	6.78	1.19 - 38.5	240	130 - 447	0.52	0.36
N.G. Europeans	11	PM	117	81.8 - 167	43.0	28.8 - 64.2	107	69.0 - 165	454	370 - 556	3.02	0.47

Appendix 5 continued

Group and No.		Time of Day	Sodium Mean uM/min	Sodium Confidence Limits	Potassium Mean uM/min	Potassium Confidence Limits	Chloride Mean uM/min	Chloride Confidence Limits	Phosphate Mean ug/min	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Ratio ±St.Err.
Ind. Lab. Workers	4	AM	99.6	45.7 - 217	31.2	17.7 - 54.9	108	51.1 - 229	111	22.9 - 542	3.22	0.46
	5	PM	48.4	12.3 - 190	32.0	24.7 - 41.4	65.6	22.4 - 192	350	227 - 539	2.14	0.75
Ind. Villagers	8	AM	100	64.5 - 155	31.2	19.1 - 50.9	112	74.1 - 170	60.8	22.3 - 166	4.37	0.30
	4	PM	135	80.7 - 226	30.8	18.1 - 52.5	166	97.5 - 284	234	99.6 - 548	4.69	1.00
North Ind. Army[2]	15	AM	85.2	58.3 - 125	31.5	24.7 - 40.1	113	80.5 - 157	265	180 - 400	3.08	0.39
	14	PM	73.3	51.7 - 104	29.7	21.1 - 41.9	91.8	73.1 - 115	305	220 - 423	3.02	0.40
South Ind. Army[2]	15	AM	72.3	53.5 - 97.6	16.7	10.5 - 26.6	89.7	65.3 - 123	82.5	42.5 - 160	5.20	1.11
	13	PM	79.5	58.1 - 109	14.8	11.7 - 18.7	82.3	61.4 - 110	177	119 - 265	5.81	0.70
Gurkhas[2]	18	AM	138	115 - 165	30.7	25.2 - 37.5	170	141 - 205	191	111 - 329	4.63	0.28
	15	PM	81.9	71.3 - 94.0	15.3	11.9 - 19.8	84.0	74.2 - 95.2	247	178 - 342	5.74	0.61

1 Range instead of confidence limits

2 All possible subjects

Appendix 6 Urine Electrolyte Excretion Rates during the Bed Test. Female Groups

Group and No.		Time of Day	Sodium Mean µM/min	Sodium Confidence Limits	Potassium Mean µM/min	Potassium Confidence Limits	Chloride Mean µM/min	Chloride Confidence Limits	Phosphate Mean µg/min	Phosphate Confidence Limits	Sodium/Potassium Ratio Mean	Sodium/Potassium Ratio ±St.Err.
Unacc. Controls	15	PM	94.1	66.8 - 133	31.9	18.3 - 55.7	94.3	66.9 - 133	184	94.1 - 361	4.01	1.02
Yemenite summer	5	AM	51.8	16.0 - 168	20.0	3.20 - 125	58.7	17.7 - 194	-		2.89	0.67
	7	PM	61.7	33.0 - 115	28.7	16.0 - 51.6	68.0	41.3 - 112	-		2.25	0.27
Yemenite winter	3	AM	151	87.6 - 260	39.0	11.7 - 129	153	74.9 - 311	-		4.10	1.03
	3	PM	77.1	13.7 - 433	20.1	3.84 - 105	66.3	13.5 - 326	-		3.91	0.54
Kurd summer	5	AM	124	24.6 - 628	63.6	16.8 - 242	192	47.7 - 775	-		2.37	0.59
	4	PM	51.2	14.0 - 188	13.7	2.97 - 63.5	51.0	18.4 - 141	-		4.03	0.89
Kurd winter	4	AM	45.9	6.91 - 305	22.0	5.66 - 85.5	58.7	14.2 - 244	-		2.31	0.52
Nig. students	8	PM	69.3	41.8 - 115	26.1	16.6 - 41.0	84.7	50.2 - 143	-		2.76	0.28
N.G. Kaul	22	AM	35.0	20.3 - 60.4	68.4	46.4 - 101	61.8	42.1 - 90.9	76.6	32.9 - 152	0.70	0.08
	18	PM	28.7	17.8 - 46.3	45.8	35.7 - 58.7	43.8	30.8 - 62.3	129	84.8 - 197	0.74	0.11
N.G. Lufa	12	AM	48.8	21.1 - 113	54.6	29.9 - 100	43.0	19.0 - 97.5	56.5	29.1 - 110	1.38	0.27
	15	PM	17.2	6.91 - 42.7	89.1	50.0 - 159	10.9	5.62 - 21.2	355	150 - 844	0.88	0.54
N.G. Lufa Old	10	PM	13.3	5.75 - 31.0	105	53.0 - 207	11.9	6.65 - 21.5	234	112 - 492	0.36	0.15

- No measurements made

Appendix 7 Sweat Electrolyte Excretion Rates expressed per unit Body Weight Male Groups

Group	Sodium		Potassium		Chloride		Phosphate	
	Mean µM/min/Kg	Confidence Limits	Mean µM/min/Kg	Confidence Limits	Mean µM/min/Kg	Confidence Limits	Mean µg/min/Kg	Confidence Limits
Army Group I unacc.	8.26	6.86 - 9.95	0.69	0.62 - 0.77	7.72	6.40 - 9.30	-	
acc.	16.2	13.5 - 19.5	1.29	1.12 - 1.49	14.6	12.2 - 17.4	-	
Army Group II	8.03	5.68 - 11.4	0.71	0.54 - 0.93	7.94	5.67 - 11.1	-	
Army Group III	3.86	2.61 - 5.73	0.40	0.27 - 0.59	3.58	2.43 - 5.25	0.072	0.047 - 0.112
repeat	3.76	2.30 - 6.14	0.39	0.24 - 0.64	3.47	2.16 - 5.58	0.071	0.041 - 0.124
Army Group IV unacc.	4.34	3.05 - 6.17	0.32	0.24 - 0.43	4.13	2.87 - 5.95	0.093	0.065 - 0.133
acc.	11.6	8.38 - 16.0	0.87	0.67 - 1.14	11.1	8.04 - 15.3	0.170	0.075 - 0.160
Cyclists	10.5	7.51 - 14.8	1.09	0.88 - 1.34	9.96	7.16 - 13.9	-	
Runners	13.8	9.13 - 21.0	1.16	0.88 - 1.53	12.9	8.95 - 18.7	-	
Swimmers	4.46	3.08 - 6.46	0.88	0.71 - 1.10	4.57	3.20 - 6.52	-	
Yemenite summer	7.73	4.22 - 14.1	1.36	1.10 - 1.68	7.83	4.47 - 13.7	-	
winter	4.50	3.03 - 6.71	0.52	0.37 - 0.72	4.29	2.89 - 6.38	-	
Kurd summer	7.60	6.06 - 9.51	1.30	1.12 - 1.50	7.76	6.39 - 9.43	-	
winter	5.56	4.14 - 7.47	0.73	0.57 - 0.93	5.28	3.90 - 7.13	-	
Nig. students	2.84	1.81 - 4.44	0.52	0.36 - 0.75	3.12	1.97 - 4.94	-	
Nig. Heavy Ind.	4.16	2.86 - 6.05	0.75	0.59 - 0.95	5.70	4.15 - 7.83	-	
Nig. Light Ind.	6.33	4.49 - 8.91	1.01	0.82 - 1.26	6.72	4.43 - 10.2	-	
Villagers	3.83	1.44 - 10.2	0.52	0.37 - 0.74	4.09	1.59 - 10.5	-	

Appendix 7 continued

Group	Sodium		Potassium		Chloride		Phosphate	
	Mean µM/min/Kg	Confidence Limits	Mean µM/min/Kg	Confidence Limits	Mean µM/min/Kg	Confidence Limits	Mean µg/min/Kg	Confidence Limits
N.G. Low Plant.	2.05	1.45 - 2.88	0.62	0.50 - 0.78	2.18	1.57 - 3.05	0.090	0.065 - 0.125
N.G. High Plant.	2.04	1.40 - 2.97	0.65	0.51 - 0.82	2.07	1.49 - 2.88	0.089	0.062 - 0.128
N.G. Kaul	2.16	1.68 - 2.77	0.68	0.57 - 0.80	2.22	1.73 - 2.83	0.090	0.067 - 0.121
N.G. Lufa	2.22	1.76 - 2.80	0.65	0.55 - 0.77	1.94	1.51 - 2.49	0.135	0.103 - 0.177
N.G. Lufa Old	1.97	1.12 - 3.45	0.61	0.43 - 0.85	1.81	1.01 - 3.26	0.087	0.063 - 0.120
N.G. Lufa Boys	0.45	0.20 - 1.04	0.30	0.14 - 0.63	0.40	0.17 - 0.98	0.062	0.028 - 0.139
N.G. Europeans	10.5	8.01 - 13.8	0.86	0.69 - 1.08	10.1	7.84 - 13.1	0.086	0.062 - 0.120
Ind. Lab. Workers	5.39	3.44 - 8.43	0.56	0.38 - 0.82	5.07	3.11 - 8.27	0.039	0.022 - 0.070
Ind. Villagers	6.23	4.57 - 8.48	0.55	0.40 - 0.75	5.92	4.31 - 8.14	0.126	0.088 - 0.183
North Indian Army[1]	8.45	6.71 - 10.7	0.60	0.51 - 0.71	8.12	6.41 - 10.3	-[2]	
South Indian Army	8.18	6.59 - 10.2	0.43	0.35 - 0.51	8.05	6.42 - 10.1	-[2]	
Gurkhas[1]	10.6	8.62 - 13.1	0.66	0.55 - 0.79	10.3	8.37 - 12.6	-[2]	

1 Subjects tested between September and mid October
2 Phosphate excretion rates changing with time of year
- No measurements made

Appendix 8 Sweat Electrolyte Excretion Rates expressed per unit Body Weight Female Groups

Group	Sodium		Potassium		Chloride		Phosphate	
	Mean µM/min/Kg	Confidence Limits	Mean µM/min/Kg	Confidence Limits	Mean µM/min/Kg	Confidence Limits	Mean µg/min/Kg	Confidence Limits
Unacc. Controls	1.90	1.25 - 2.90	0.31	0.23 - 0.42	1.61	1.05 - 2.46	0.011	0.008 - 0.015
Acc. Controls	10.6	6.97 - 16.0	1.73	1.29 - 2.31	9.97	6.80 - 14.6	-	
Yemenite summer	1.57	0.70 - 3.50	0.60	0.49 - 0.73	1.53	0.66 - 3.53	-	
winter	2.70	1.48 - 4.92	0.55	0.26 - 1.13	2.61	1.48 - 4.59	-	
Kurd summer	2.87	1.32 - 6.22	0.62	0.36 - 1.07	2.73	1.29 - 5.79	-	
winter	2.75	0.21 - 35.8	0.49	0.05 - 4.71	2.57	0.22 - 29.9	-	
Nig. Students	1.27	0.71 - 2.28	0.49	0.37 - 0.65	1.79	1.21 - 2.65	-	
N.G. Kaul	1.30	0.99 - 1.70	0.61	0.49 - 0.75	1.42	1.09 - 1.84	0.121	0.090 - 0.161
N.G. Lufa	1.32	0.92 - 1.88	0.74	0.57 - 0.95	1.15	0.83 - 1.59	0.184	0.140 - 0.237
N.G. Lufa Old	0.91	0.51 - 1.60	0.63	0.37 - 1.05	0.77	0.44 - 1.34	0.151	0.099 - 0.230

- No measurements made