N71-25393

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HUMAN ACCLIMATION AND ACCLIMATIZATION TO HEAT

A Compendium of Research

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December 1970

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CONTENTS

INTRODUCTION

The purpose of this compendium is to gather together under one cover the majority of works that elucidate the mechanisms of short-term acclimatization and acclimation to heat. Additional studies are included that provide background information in the form of reviews or classic descriptions of the process. Wherever possible a detailed annotation is provided under the subheadings: (*a*) definition of acclimation or acclimatization; (*b*) purpose of the study; (*c*) subjects used; (*d*) environmental conditions; and (*e*) results and conclusions. The abstracts cover material through December 1967. The abstracts are listed in alphabetical order by first author and an index is provided. Additional references are provided in the bibliography.

The terms that describe the facets of adaptation to various environmental conditions have been used ambiguously. The representative definitions given below indicate the diversity of opinion and the magnitude of the confusion.

Definition	Source
Acclimatization A gradual return of the ability to work with little or no discomfort in the heat.	Bass, D. E., C. R. Kleeman, M. Quinn, A. Henschel, and A. H. Hegnauer. Mechanisms of acclimatization to heat in man. *Medicine* vol. 34: 1955, pp. 323-380.
Acclimatization A process by which man adapts himself to work in the heat. He then works as efficiently as in temperate environments without subjective complaints and with little or no disturbance of bodily functions.	Bean, W. B., and L. W. Eichna. Performance in relation to environmental temperature. Reactions of normal young men to simulated desert environment. *Federation Proc.* vol. 2: 1943, pp 144-158.
Acclimatization Manifested by improved cardiovascular response to work.	Beetham, W. P., Jr., and E. R. Buskirk. Effects of dehydration, physical conditioning, and heat acclimatization on the response to passive tilting. *J. Appl. Physiol.* vol. 13: 1958, pp. 465-468.
Acclimatization A reduction in physiological strain produced by a given environmental stress.	Brebner, D. F., J. C. Clifford, D. McK. Kerslake, J. D. Nelms, and J. L. Waddell. Rapid acclimatization to heat in man. R.A.F. Institute of Aviation Medicine, Farnborough, Hants, England. I.A.M. Memo S 38, July 1961, 10 pp.
Acclimatization The process by which man, plants, and animals become adapted to a climate different from that in which they are indigenous.	Castellani, A. Climate and acclimatization. *J. Trop. Med. and Hygeine* vol. 32: 1929, pp. 173-185, 189-200.

Acclimatization Alterations in physiological response to heat induced by continued exposure to conditions of high temperature or to the combination of high temperature and high humidity.

Christensen, W. R. Long term acclimatization to heat. *Am. J. Physiol.* vol. 148: 1947, pp. 86-90.

Acclimatisation Implies adaptation to tropical conditions and is sometimes applied to cold climates. For the latter situation there is no alternate term, unless it be hardening or conditioning.

Critchley, M. Remarks on acclimatisation. *Proc. 9th International Congress of Industrial Medicine*. Bristol: 1948, John Wright, pp. 250-253.

Adaptation The all-inclusive term which includes all the acute or chronic established adjustments of organisms due to environmental stimulation regardless of the portion or the extent of the mass of the particular organism exposed.

(*a*) *Genetic adaptation* Alterations which favor survival of a strain in a particular environment, which alterations have become part of the genetic heritage of the particular species or strain.

(*b*) *Acclimatization* To a complex of environmental factors, as in seasonal or climatic changes.

(*c*) *Acclimation* To a single environmental factor, as in controlled experiments.

(*d*) *Habituation* A change in physiological response or in sensation resulting from a diminution in the responsiveness of the central nervous system to certain stimuli.

(*e*) *Nonspecific adaptation* Used where knowledge of the environmental conditions, the nature of the stimulus or exposure, or the alterations in the organism are not well enough defined to warrant the assignation of any of the other terms.

Eagan, C. J. Introduction and terminology. *Federation Proc.* vol. 22: 1963, pp. 930-932.

Amongst the many important findings from chamber experiments are that men can develop heat adaptation or acclimatization (the terms are to some extent, synonymous) even if they are only exposed for a short period each day. . . .

Edholm, O. G. The physiology of adaptation. *Eugenics Rev.* vol. 58: 1966, pp. 136-142.

Acclimatization The development of adaptive mechanisms that permit work to be performed at nearly the same rectal temperature as in a cool environment. Acclimatization restores the normal relationships whereby once again the rectal temperature is determined by the metabolic rate.

Eichna, L. W., C. R. Park, N. Nelson, S. M. Horvath, and E. D. Palmes. Thermal regulation during acclimatization in a hot, dry (desert type) environment. *Am. J. Physiol.* vol. 163: 1950, pp. 585-597.

(*a*) *Adaptation* . . . The process of compensation . . . on the phylogenetic level at which the mechanisms both for the production of direct responses to temperature and the mechanisms for the anticipation of seasonal changes have been fixed in the heritage of the species.

(*b*) *Acclimatization* Long-term responses operating throughout the life of the individual and indeed possibly influencing a succeeding generation through nongenic parental influence.

(*c*) *Acclimation* . . . Day to day changes in its systematic and cellular organisation in direct response to changes in a given identity.

Fry, F. E. Temperature compensation. *Ann. Rev. of Physiol.* vol. 20: 1958, pp. 207-224.

Acclimatization Any environmental change which produces an immediate response will also provoke slow adjustments to counteract this response, and it is these slow adjustments which constitute acclimatization.

Glaser, E. M. Circulatory adjustments in the arid zone. *In: Environmental Physiology and Psychology in Arid Conditions: Arid Zone* Research XXII. Paris: 1963, UNESCO, pp. 131-151.

(*a*) *Adaptation* Adjustment to environmental conditions; modification of an organism or of its parts or organs fitting it more perfectly for existence under the conditions of its environment and resulting from the action of natural selection upon variation. . . .

(*b*) *Acclimatization* Adaptation or increased tolerance of a species to a changed environment in the course of several generations; to adapt to a new temperature, altitude, climate, environment, or situation.

(*c*) *Acclimation* Acclimatization; the usual physiological adjustment that an individual organism exhibits to a change in its immediate environment.

Gove, P. B. (Ed.). *Websters Third New International Dictionary.* Springfield, Mass.: 1965, G. & C. Merriam Company.

Habituation The reduction of a response resulting from repeated stimuli.

Greenwood, R. M., and P. D. Lewis. Factors affecting habituation to localized heating and cooling. *J. Physiol.* vol. 146: 1959, pp. 10-11.

The concept of acclimatization embodies the integration of gradual changes in an individual or population induced by its exposure to a new climate.

(*a*) *Adaptation* . . . Those investigations in which groups of species from different latitudes have been compared . . . . Here the species in question may be properly spoken of as being "adapted" to the climates in question through evolution.

(*b*) *Acclimatization* (natural physiological adjustments) . . . investigations of changes brought about in the lifetime of animals by changes of climates in nature.

(*c*) *Acclimation* (conditioning) . . . those investigations in which animals have been exposed in the laboratory for more or less prolonged periods to various constant levels of a specific environmental factor, temperature, all other factors being the same.

Hart, J. S. Climatic and temperature induced changes in the energetics of homeotherms. *Rev. Canad. Biol.* vol. 16: 1957, pp. 133-174.

Acclimatization An adaptive process which results in a reduction in the physiological strain produced by the application of a constant environmental stress. . . . The term *artificial acclimatization* is generally used to describe those changes seen in the laboratory, because it has been assumed that they constitute, or form part of, the adaptation to high environmental temperatures that occurs naturally in newcomers to hot climates, and results in an increased ability to work in the new environment and a reduction in the discomfort experienced. Natural acclimatization is produced by residence in hot climates.

Hellon, R. F., R. M. Jones, R. K. MacPherson, and J. S. Weiner. Natural and artificial acclimatization to hot environments. *J. Physiol.* vol. 132: 1956, pp. 559-576.

(*a*) *Acclimatizement* The result of the physiological process of adaptation which increases the tolerance and performance of an individual sojourning in a new climate. (*b*) *Acclimatization* The adaptation phase of the organism.	Henane, R. Bases physiologiques de l'acclimatement à la Chaleur. Incidences medico-militaires. *Revue des Corps de Santé des Armées, Terre, Mer, Air (Paris)* vol. 7: 1966, pp. 293-318.
Acclimatization A series of physiological adjustments that reduce the dibilitating effects of the heat.	Henschel, A., H. L. Taylor, and A. Keys. The persistence of heat acclimatization in man. *Am. J. Physiol.* vol. 140: 1943, pp. 321-325.
Artificial acclimatization The sum of the physiological adjustments which occur as a result of repeated exposures to hot environments.	Hertig, B. A., H. S. Belding, K. K. Kraning, D. L. Batterton, C. R. Smith, and F. Sargent II. Artificial acclimatization of women to heat. *J. Appl. Physiol.* vol. 18: 1963, pp. 383-386.
Acclimatization The conditioning process occurring in an organism leading to an optimal response to stress.	Horvath, S. M., and W. B. Shelley. Acclimatization to extreme heat and its effect on the ability to work in less severe environments. *Am. J. Physiol.* vol. 146: 1946, pp. 336-343.
Acclimatization Includes those functional and morphological changes which occur within the individual upon repeated or continuous exposure to new environmental conditions. Disorders of vital functions produced by new environmental factors may gradually be alleviated by the changes, and the acclimatization is considered to have been accomplished when the individual is able mentally and physically to lead a normal life in the new environment.	Kuno, Y. The acclimatization of the human sweat apparatus to heat. *In:* Y. Kuno, *Human Perspiration.* Springfield, Illinois: 1956, Thomas pp. 318-335.
Acclimatization The series of physiological adjustments that occur when men who are accustomed to living in a cool climate are suddenly transferred to a hot climate, and which ameliorate the physiological strain experienced on the initial exposure to heat.	Lind, A. R. Acclimatization to Heat. *In:* C. S. Leithead and A. R. Lind, *Heat Stress and Heat Disorders.* London: 1964, Cassell. pp. 16-30.
Acclimatization The process of adjustment where the application of a constant environmental stress results in a diminished physiological strain.	MacPherson, R. K. The physiology of adaptation. *Med. J. Australia* vol. 51: 1964, pp. 905-907.
Acclimatization The development of protective mechanisms during repeated work in the same hot environment on successive days which allows the subject to control his temperature at a level compatible with satisfactory physiological function, and to work nearly as easily in the heat as in a cool environment.	Park, C. R., and E. D. Palmes. Thermal regulation during early acclimatization to work in a hot day environment. Medical Department Field Research Laboratory. Fort Knox, Kentucky. *MDFRL Report 2-17-1, Report 7*: June 30, 1947, 17 pp.
Acclimatization A marked improvement in body temperature regulation and in the ability to perform the task without distress.	Piwonka, R. W., S. Robinson, V. L. Gay, and R. S. Manalis. Preacclimatization of men to heat by training. *J. Appl. Physiol.* vol. 20: 1965, pp. 379-384.
Adaptation A word which has numerous meanings in biology. It broadly relates differences within and between organisms to environmental variation. For some biologists, adaptation refers to genetically determined, usually morphological characters by which an animal or plant is fitted for its environment. For physiologists, the term refers to environmentally determined as well as to genetic variations. We shall use "physiological adaptation" to mean any property of an organism which favors survival in a specific environment, particularly a stressful one. An	Prosser, C. L. Perspectives of adaptation: theoretical aspects. *In: Handbook of Physiology* Section 4, "Adaptation to the Environment." American Physiological Society: 1964, Washington, D. C., pp. 11-25.

adaptation permits maintenance of physiological activity and survival when the environment alters with respect to one or more parameters. . . . Those "adaptive variations" which are genetically determined can be separated from those which are environmentally induced by acclimation or acclimatization and ultimately by breeding experiments.

Acclimatization The changes under natural conditions, as seasonal, climatic, or geographic differences, where multiple parameters vary.

Acclimation The compensatory alterations in an animal during maintenance under laboratory conditions altered for one stressful parameter.

The use of the term *acclimatization* has been purposely avoided in this paper, since it is not always clear if this term refers to the routine of accustoming a man to the heat or if it refers to the physiological changes which are responsible for the adaptation.

Whitney, R. J. Circulatory changes in the forearm and hand of man with repeated exposures to heat. *J. Physiol.* vol. 125: 1954, pp. 1-24.

The definitions given in the papers of Fry (1958), Hart (1957), Prosser (1964), and especially Eagan (1963) provide an unambiguous set of terminology that should be adapted by workers in this field. Thus, the term *adaptation* would be used only in reference to changes on the phylogenetic level that have been fixed in the heritage of any particular species.

Acclimatization (natural acclimatization) would be defined as long-term responses throughout the life of an individual to the complex of environmental variables. The term *heat acclimatization* could not be used if reference was only to the effects of heat on the organism. The term *acclimation (artificial acclimatization)* would refer to the day-to-day organismic changes due to the effect of a single environmental variable as would be used in controlled laboratory conditions. *Habituation* would be defined as a change in physiological response resulting from a decreased response of the central nervous system to constant stimuli.

1. **Adam, J. M., R. H. Fox, G. Grimby, D. J. Kidd, and H. S. Wolff**
Acclimatization to heat and its rate of decay in man.
J. Physiol. vol. 152, 1960, pp. 26P-27P.

Authors' Summary

In the present study 16 soldiers, aged 18 to 22-1/2 years, were formed into two teams of 8. The 4-hr daily routine consisted of alternating half-hour periods of work, performing a load-carrying task, and of resting seated, with an average energy expenditure of 100 kcal/($m^2 \cdot$hr). Standing pulse rates, sweat production, rectal temperature and energy expenditure were measured. After training in a cool climate with a dry-bulb temperature of approximately 10° C [50° F] for 7 days, the subjects were tested once in an accurately controlled hot climate with dry-bulb temperature 35.6° C [96° F], wet-bulb temperature 31.7° C [89° F] and air speed 25.4 cm/sec [50 ft/min] (1st uniformity trial). During each of the subsequent 12 days one team (team A) performed the routine in the hot climate to develop their acclimatization status, while the control team (team B) worked in the cool climate. Both teams were then re-examined once in the hot climate (2nd uniformity trial). After 2 days working in the cool environment, the subjects were all exposed once to an even hotter climate, with dry-bulb temperature 40° C [104° F], wet-bulb temperature 32.8° C [91° F] and air speed 25.4 cm/sec [50 ft/min] (high-temperature test). After 6 days without exposure to heat the subjects were again tested in the original hot-wet climate (3rd uniformity trial) and received their final exposure to this climate after a further 28 days (4th uniformity trial).

Between the 1st and 2nd uniformity trials there was an increase in sweat production ($P < 0.001$) and a decrease in the rise in rectal temperature ($P < 0.01$) in team A subjects during the 4-hr exposure, whereas team B showed no change. There was no evidence of any change in energy expenditure by either team. The difference between the two teams was also clearly shown in the high-temperature test, team A subjects having not only higher sweat rates ($P < 0.01$) and smaller increases in rectal temperature ($P < 0.02$) than team B but also smaller increases in pulse rate ($P < 0.05$). The re-test of team A subjects after 6 days without exposure to heat revealed that they had lost a substantial part of the improved tolerance to heat, and 28 days later the decay in acclimatization was virtually complete. The results show that the acclimatization to heat induced as described was relatively rapidly lost when exposure to heat ceased.

2. **Adolph, E. F.**
Heat exchanges of man in the desert.
Am. J. Physiol. vol. 123, 1938, pp. 486-499.

Annotation

This was one of the papers from the Harvard Desert Expedition at Boulder City, Nevada, in the summer of 1937. Some of the fundamental observations concerning heat acclimatization were made here and have been amplified by subsequent investigators; these include:

1. In exercise tests, in the acclimatized person, the correlation between the rate of rise of rectal temperature and the rate of evaporation indicated that large accumulations of heat occurred only with high rates of evaporation. That is, the rate of sweating reached an asymptote (sweat gland fatigue?) when there were high rates of heat exchange, leaving a larger excess of heat in the body.
2. A marked increase in the rate of sweating was observed for a given rise of rectal temperature; the increased sweating leveled off after about 10 days.

Author's Summary

Partial heat balances were measured in desert conditions by comparing rates of heat production, of gain by radiation from the sun, of loss by evaporation, and of heat accumulation.

In rest radiation may add heat to the body faster than heat is produced chemically. In exercise, along with high rates of heat production, radiation and convection added heat, so that the loss by evaporation alone exceeded heat production.

Recovery from exercise required 1.0 to 1.5 hours for the dissipation of the heat that had accumulated.

During exercise the pulse rate and the systolic arterial pressure increased with rates of heat loss, *indicating that the circulation took a prominent part in the increased rates of heat exchange.*

Changes with successive days of exposure occurred in the rates with which evaporation took place, in heat accumulated, in pulse rates, and in choices of behaviors that prevented the access of heat to the body.

Individual differences were noted which suggest that not all persons are equally able to preserve heat balances.

3. **Adolph, E. F.**
Physiological fitness for the desert.
Federation Proc. vol. 2, 1943, pp. 158-164.

Author's Summary

Acclimatization. The difficulties presented to the human by hot atmospheres are easiest seen in their extremes. In early work in hot rooms I found [Adolph, E. F., *Am. J. Physiol.* vol. 67, 1924, p. 573] that men became exhausted to a state of *circulatory* failure. This shock-like collapse represented an inability of the peripheral blood flow to fulfill the demands made upon it. It meant that the transport of heat to the body surface taxed the circulation continuously and immoderately. At that time it was not suspected that the circulation of blood has any means of obviating its difficulties.

Many years later, this time in the desert itself, I saw the processes of acclimatization going on [Adolph, E. F., *Am. J. Physiol.* vol. 123, 1938, p. 486]. I saw myself doing tasks on the tenth day after arrival in June in Boulder City, Nevada, that were utterly impossible on the first day. Acclimatization was a real thing; it involved circulatory adjustments to promote losses of heat whereby the body temperature stayed low even in rapid work. . . . Heat was now dissipated by more ready production of sweat. It was also apparent that individuals differed enormously both before and after acclimatization [Dill, D. B., *Life, Heat and Altitude.* Cambridge, Harvard Univ. Press, 1938, p. 42].

The sweat glands functioned more readily after acclimatization. During standard walks, instead of freely secreting sweat only after the rectal temperature became elevated 2 or 3 Centigrade degrees, the body now formed enough sweat before the temperature had risen one degree. Dill, et al. [*Am. J. Physiol.* vol. 123, 1938, p. 412] showed also that the concentration of salts in the sweat diminished when the body temperature stayed lower; this resulted in a marked conservation of salt in the body, as though faster sweating involved less escape of solute.

Yet acclimatized individuals differed among themselves in respect to circulatory performance, sweat formation and salt conservation. Those individuals who sweated easily were not always the same ones who secreted the most dilute sweat. In fact there was no apparent correlation; and this illustrates the fact that separate sieves are required to detect the various virtues which men may possess.

The changes in response of the body to repeated or continuous exposure often make the difference between success and failure in the desert. The striking aspect is that *all* the known changes tend toward success and comfort. In a sense, a new physiological constitution is temporarily acquired.

The circulatory system behaves differently after exposures to heat by reducing the initial venous engorgement [Scott, J. C. et al., *Am. J. Physiol.* vol. 129, 1940, p. 102] by promoting blood flow without pooling in the periphery, and by diminishing the pulse rate. The body temperature is thus kept low during moderate effort [Adolph, E. F., *Am. J. Physiol.* vol. 123, 1938, p. 486]. Sweating is now elicited more readily through the usual reflexes and through the humoral and local stimulations of sweat glands. The body has become prepared for actions that combat heat at a lesser provocation. Somewhat more water is used to dissipate the heat, for the body temperature is lower despite somewhat more gain of heat from the environment.

Other circulatory changes upon exposure to warm temperatures have been described. Such are: transient increase in plasma volume and in whole blood volume [Bazett, H. C., et al., *Am. J. Physiol.* vol. 129, 1940, p. 69], temporary increase in cardiac output, increase in blood flow in fingers [Scott, J. C., et al., *Am. J. Physiol.* vol. 129, 1940, p. 102] and gradual decrease in rate of basal oxygen consumption [Burton, A. C., et al., *Am. J. Physiol.* vol. 129, 1940, p. 84]. It is noteworthy that most of these modifications are temporary, as though they were first aids to getting along with the heat: these aids later become unnecessary. Even the loss of heat by radiation is said to improve after the first two or three days of exposure [Burton, A. C., et al., *Am. J. Physiol.* vol. 129, 1940, p. 84].

One important question is: does acclimatization to heat hold equally for conditions of intense radiation, of high convection, and of humid tropical atmospheres? Or is it specific for each? No doubt the responses of acclimatization overlap considerably; but insofar as heat is dissipated differently in the several environments, different degrees of modification may exist in the constituent processes. Acclimatization occurs even when no work is done. In fact it is likely that there are just as many kinds of acclimatization as there are kinds of fitness; and fitness is by definition different for each precise environment and each kind of duty.

How it feels to be catapulted into the desert unacclimatized is vividly pictured by Stott [*Indian Med. Gaz.* vol. 71, 1936, p. 712]. Engine trouble required an airplane to land 13 men in Arabia at 4 a.m. of a summer day. By noon the temperature was 125° F and the men were unable to stand without breathlessness. When a rescue plane arrived at 2 p.m. only 11 of the 13 were able to walk with the greatest difficulty the mile necessary to board the new plane.

What is this acclimatization which does such great things physiologically? It seems to be a latent capacity that comes to realization under appropriate stimulation. One hypothesis is that the range of environments may be so great that the organism cannot at one time be ready to cope with all of them to the optimal extent. Hence it shifts its readiness so as to meet the most prevalent circumstances. The properties which allow this shift are nonetheless inherent, insofar as they come to realization when elicited.

But the ability to acclimatize varies greatly *among* individuals [Dreosti, A. O., *J. Chem. Met. Min. Soc. So. Afr.* vol. 36, 1935, p. 102]. Just as circulatory functions and neuromuscular responses differ, so the modifications that these functions and responses undergo when stimulated also differ.

Acclimatization to the desert is as rapid as it is dramatic. For two or three days in the summer desert a man is uncomfortable and lazy. Upon about the fourth day he suddenly finds life enjoyable again. He wants to be vigorous. In some individuals changes can still be detected after ten days [as, in rates of sweating, Adolph, E. F., *Am. J. Physiol.* vol. 123, 1938, p. 486]; and it is very likely that some processes are still approaching asymptotic rates for many weeks or months.

Fortunately, acclimatization to the desert once acquired is retained for several weeks of nonexposure. Intermittent exposure is efficacious in inducing the characteristic changes; indeed, development of them probably proceeds in intervening periods. A few hours of initial exposure have detectable effects a week or two later, for then the pulse is not so greatly accelerated by a given stress.

The characteristics of men which change with acclimatization to heat are, therefore:

Pulse rate	decreases
Pulse pressure	decreases
Body temperature	decreases
Rate of sweating	increases
Concentration of sweat	decreases
Basal O_2 consumption	decreases
Work output	increases
Endurance	increases

4. **Adolph, E. F.**
The initiation of sweating in response to heat.
Am. J. Physiol. vol. 145, 1946, pp. 710-715.

Author's Summary

1. Rates of evaporative loss were measured in men initially exposed to hot dry air [122° F (50.0° C) 10% humidity]. A probable increase in rate of evaporation due to sweating, amounting to 2-1/2 fold, occurred within the 5 minutes before the men could be weighed.

2. The measured acceleration began at 7 minutes in one subject and 12 minutes in another subject. The rates rapidly increased to a maximal rate of 10 fold above that in a cool atmosphere, which was attained in 20 minutes.

3. It is concluded that the promptness of onset of sweating among individuals is no indication of their tolerances or acclimatization to heat.

4. The slow onset of full sweating suggests that the stimulus required is an appreciable increase in the heat content of the body as a whole.

5. **Adolph, E. F.**
Tolerance of man toward hot atmospheres.
Public Health Reports, supp. 192. Washington: U.S. Government Printing Office, 1946, 38 pp.

Author's Summary

1. A practical limit to tolerance for heat is signalled by the premonition of collapse (heat exhaustion) experienced by acclimatized men. The collapse represents an inadequate circulation of the blood, with or without high bodily temperatures.

2. At temperatures below this practical limit, considerable physiological strain and discomfort prevail. They indicate definite disadvantages for human activities. No amount of morale can compensate for the physiological strains imposed by a hot atmosphere.

3. The wet-bulb temperature is a useful index to intolerable conditions. Temperatures above 90° F [32.2° C] can rarely be endured indefinitely. During work the intolerable temperatures may be as low as 80° F [26.7° C] or less.

4. The effective temperatures (sensibly, equivalent temperatures) are an accurate index of physiological stress, insofar as those temperatures have been determined at particular physical activities and in scant clothing.

5. Initial acclimatization is in the majority of persons nearly complete after four exposures of 2 hours each to limiting temperatures. There is suggestion of additional slower acclimatization requiring a month or more.

6. The variability in heat tolerances among individuals is reduced by their acclimatization. The range of the remaining variability is still vast, and may at present be put to advantage only by assay of individuals at the assigned tasks.

7. Factors that help men to endure high temperatures are: shade, breeze sufficient to keep the skin dry, no clothing if already shaded, acclimatization to heat, plenty of water and salt, physical fitness, and adequate sleep Factors known to threaten endurance are radiation, heavy or impermeable clothing, heavy work, alcohol, diarrhea or vomiting, lack of appetite for food, and wounds or infections.

6. **Adolph, E. F., and Associates.**
Physiology of Man in the Desert. New York: Interscience, 1947, 357 pp.

Authors' Summary

Acclimatization

By acclimatization we mean those functional changes that occur within the individual with continued or repeated exposures. We shall consider two kinds of acclimatization: that to heat and that to dehydration.

Acclimatization to *heat* is manifested in maintenance of lower body temperature, lower pulse rate, and readier sweating. In order that these measured quantities may be demonstrably diverse with repeated exposures, conditions and activities must be highly standardized. The changed functions can then be measured; they are found to correspond with the feeling of comfort that comes to the man who has become acclimatized. Undoubtedly, many additional factors change, and their study could profitably be extended. It remains to be ascertained which are the most crucially important for high performance in the desert.

Acclimatization was observable in the course of each of our experiments where individuals had undergone repeated exposure. We here limit the report to results found in ourselves when we went to the desert in 1943. In response to a fixed exercise the pulse rate becomes higher on the first day than upon subsequent exposures, and rectal temperatures tell the same story. The chief part of the known acclimatization process lasts about a week. Since it has no sharply defined termination, it is possible that some changes may continue for many weeks. The maximal air temperatures were uniform on the test days, varying only between 103 and 108° F [39.4 and 42.2° C].

Acclimatization was evident not only in the response of pulse rate to standard exercise, but also in the response to standing. The increase in "standing" pulse rates was less and the modifications with successive days of life in the desert were slighter, as compared with exercise pulse rates, being significant in only three out of six individuals. When lying down, pulse rates showed no change with acclimatization. Evidently, some stress other than heat alone is required to bring about an acceleration of pulse in the unacclimatized person.

Rate of sweating during the standard exercise showed no significant change with acclimatization to heat in our temperature tests. Indirectly, however, an increase can be inferred, for when rectal temperature and body surface temperature rise higher, less cooling has occurred. Since all sweat formed has also evaporated, the accumulation of more heat in the body during exercise means less output of sweat.

Other physiological properties of man undoubtedly change with acclimatization to heat, but they have not been measured quantitatively. Our impression is that flushing of the skin, edema of the hands, and ventilation of the lungs all decrease with successive days of test. There is evidence that when man is first exposed to solar radiation, sweat gland activity is inhibited. This is one factor that tends to make the new arrival in the desert liable to hyperthermia.

Acclimatization to heat was observed in our laboratory in several series of tests. Many other investigators have studied it indoors, as reported fully by Bean and Eichna [*Federation Proc.* vol. 2, 1943, p. 144]. The first of our series failed to demonstrate acclimatization; we learned from this the need of standardizing the activities of the subjects as well as the conditions of environment and measurement. In the subsequent three series, carried out in the laboratory with subjects kept fully hydrated, full corroboration was obtained of the diminished pulse rates and rectal temperatures. Even pulses counted while lying down were slightly diminished in successive exposures.

In the laboratory, no consistent changes in the total plasma concentration (as measured by the refractive index) were found on different days, whether samples were taken before or during exposure to heat, so long as the subject remained in water balance (94 samples from four subjects). It may be said, therefore, that at present the known changes with acclimatization to heat are limited to circulatory ones. Whether circulatory readjustments alone account for the remarkably increased tolerance to heat which is conferred by acclimatization is doubtful.

Acclimatization to *dehydration* has not yet been found. We made a special study to discover whether it exists, for if so there would be good reason to expose men to dehydration as a training procedure. Each exposure, in that case, would be borne with less deterioration, and we would have a physiological basis for the supposed improvement in man's tolerance to shortage of water. The method of test was to expose men to dehydration on each of several days, at least 4.4 and usually 6 per cent of their weights being lost during the hours of any one exposure. With conditions uniform, and the men already fully acclimatized to heat, further modifications of pulse rate, rectal temperature, and total serum concentration might be found.

Two series of experiments were carried through in the laboratory hot room on a total of 12 men, and one series in the desert on five men. In each case half the subjects dehydrated every second day for four to seven exposures, while the others dehydrated on the first and last exposures only. None of the functions studied were significantly different at the last dehydration from that at the first. Neither pulse rate nor onset of exhaustion nor rectal temperature reacted more favorably after repeated exposure to dehydration. In the outdoor series of experiments, the pulse rates were actually higher after acclimatization to dehydration than before it. But since in our two other series of tests this did not prove to be so, we draw no conclusion from this finding.

We searched particularly for modification in the maintenance of plasma concentration, and by inference, of plasma volume. If, after repeated dehydrations, the circulating blood volume were less affected by dehydration it would mean that men could become more resistant to dehydration exhaustion. A few early tests gave promise of decreasing the change in plasma concentration with growing water deficit. . . . But on the whole, no such modification with successive exposures to dehydration could be proved, either in the laboratory, or in the desert itself; yet the same methods had demonstrated the acclimatization to heat. It is, of course, always possible that greater refinements of experimental procedures would reveal small changes. In many instances. the tolerance which has been credited to dehydration should really be credited to heat, for the man acclimatized to heat can withstand more dehydration.

The conclusion that no significant acclimatization occurs to repeated dehydration has wide consequences. It means that men cannot be trained by exposures to withstand dehydration. They can become experienced in noting the symptoms of dehydration, and they can overcome their fears of it; but they are not appreciably better able to endure it. Members of our laboratory group have been dehydrated as many as fifteen times, but showed no evidence of becoming hardened to deficit of water, once their heat acclimatization was accomplished. For men who are forced to be without water at times, it is sad that no acclimatization to dehydration appears to exist. The desertworthy man is a person who is good at avoiding dehydration and at finding water; but his body, thick-skinned as it appears to be sweats just as fast and compensates for water shortage just as poorly as the tenderfoot's.

7. **Asmussen, E.**
The cardiac output in rest and work in humid heat.
Am. J. Physiol. vol. 131, 1940, pp. 54-59.

Author's Summary

Acclimatization to humid heat seems to involve such regulations that the circulation in rest and during work in a steady state can be kept at a practically normal level. A blood volume increased by about 5 per cent [Forbes, W. H., et al., *Am. J. Physiol.* vol. 130, 1940, p. 739] and a slightly higher pulse rate are assumed to be the two main factors in this regulation. Circulatory failure during work develops rather fast in humid heat owing to the fact that the heat dissipation is made difficult. A larger amount of blood is demanded for the skin circulation, making maintenance of an adequate cardiac output increasingly difficult.

8. **Baker, P. T.**
Racial differences in heat tolerance.
Am. J. Phys. Anthrop. vol. 16, 1958, pp. 287-305.

Author's Summary

The physiological responses of American White and Negro soldiers were studied under hot-wet and hot-dry conditions (not specified). Under hot-wet conditions 40 pairs of men matched for body fat, weight and stature were walked around a course at 5.6 km/hr for one hour. Under hot-dry conditions 8 pairs of acclimatized men also matched for body fat, weight, and stature were studied under 8 different conditions which included combinations of clothing, sun, shade, walking, and sitting. The results indicated:

1. In the hot-wet conditions with both Negroes and Whites clothed and walking, the Negroes had a higher physiological tolerance.
2. In hot-dry conditions with both groups clothed, walking, or sitting they had about equal tolerance.
3. Under hot-dry conditions with both groups nude and exposed to the sun, sun-tanned Whites had the higher tolerance.

9. **Barbour, H. G.**
The heat-regulating mechanism of the body.
Physiol. Rev. vol. 1, 1921, pp. 295-326. (Review)

Author's Summary

A. Water and heat. Water is the central factor in the regulation of bodily heat
B. Heat regulation in the lower animals
C. Heat regulation in man
   1. The basal metabolism
   2. Diurnal variations in body temperature
   3. Influence of age
   4. Temperature topography
   5. Average body temperature
D. Regulation against cooling
   1. Chemical regulation
   2. Physical regulation

E. Regulation against overheating
  1. Chemical regulation
  2. Physical regulation
  3. Climate and heat regulation
  4. Effects of uncompensated overheating
F. Nervous control of heat regulation
  1. Decerebration experiments
  2. Experiments on cord section
  3. Investigations on the brain
G. Heat regulation and the endocrine glands
  1. Heat production in fever
  2. Heat elimination in fever
  3. Nervous regulation in fever
  4. Water and salt balance in fever
H. Pharmacology of heat regulation
  1. Pyretics
  2. Depressants
  3. Antipyretics
I. Heat regulation and carbohydrate metabolism
J. Body temperature is regulated by water-shifting, but under nerve control

10. Bass, D. E.

Thermoregulatory and circulatory adjustments during acclimatization to heat in man.
In J. D. Hardy (Ed.): Temperature, Its Measurement and Control in Science and Industry. Vol. 3, Part 3: Biology and Medicine, New York. Reinhold, 1963, pp. 299-305.
(Review)

Author's Summary

On the first day of work in the heat, great strain is placed on two important regulatory functions: cardiovascular and thermoregulatory. The cardiovascular system adequately meets its thermoregulatory requirements, but does not at the same time continue to supply the rest of the body, particularly the brain, with adequate blood flow. The sweating mechanism, on the other hand, fails to meet the thermoregulatory requirements fully; this is due, not to fatigue of the sweat glands, but to some inadequacy in the sweating mechanism. As a result, the body is faced with two threats: one is to continued normal function (i.e., work) in the heat, with fainting as the end-point. The other threat is to life itself – the end-point being heat stroke. The heart is certainly capable of increasing its output more than actually occurs, but is not stimulated to do so or is possibly even inhibited from so doing. This failure, often disconcerting to both investigator and test subject, is essentially a protective response which, in normal circumstances, prevents the individual from continuing work to the point of heat stroke. Figuratively, then, the body bows its head to the less dangerous foe – syncope – thus avoiding or at least postponing engagement with the more ominous enemy – heat stroke.

What does acclimatization accomplish? It apparently returns cardiac function and thermoregulation into "phase" with each other. That is, cardiovascular function becomes directed

more toward maintaining effective circulation to areas other than the skin, and the sweat mechanism becomes more precisely geared to dissipating body heat.

In summary, the evidence supports the concept that the prepotent physiological adaptation occurs somewhere in the thermoregulatory system. This adaptation is manisfested in the higher sweat rate as acclimatization occurs. This is essentially the concept expressed by Eichna et al. [*Am. J. Physiol.* vol. 163, 1950, p. 585]. However, their concept that all the cardiovascular improvements can be explained by increased sweating may be an oversimplification.

Practical Implications

A rational consideration of the acclimatization process can lead to important practical decisions in many areas of human activity, e.g., industry, medicine, sports, military, even Arctic living. The following are pertinent considerations:

1. *Duration and retention of acclimatization.* Acclimatization to a given combination of work-cum-heat requires 4 to 7 days; however, if the total load is excessive, it is wise to induce acclimatization in 2 stages, beginning with a lower heat load and ending with the desired load. Each stage should last at least 3 days [Wyndham, C. H., *J. Appl. Physiol.* vol. 4, 1951, p. 383]. With regard to retention of acclimatization, it is commonly stated that retention may last from 2 weeks to several months. However, there is a rapid loss over so short a period as a weekend. This loss is transitory and is quickly made up so that by Tuesday or Wednesday a man is as well acclimatized as he was on the preceding Friday. If, however, there is a week or two of no exposure, decay is such that regain of acclimatization requires the usual 4 to 7 days.
2. *Activity level.* Acclimatization, within the present context, refers to muscular effort in the heat. The extent to which sedentary activity, e.g., writing, fine manipulation, vigilance, is improved by acclimatization is not known.
3. *Salt and water requirements.* Thirst is normally an adequate regulator of water intake, and the average diet contains sufficient salt. However, it has been shown that acclimatization will not occur if the salt intake is less than 5 to 6 g per day. Furthermore, under conditions of heavy sweating over protracted periods, especially in hot-humid environments, the thirst mechanism is inadequate; this can impair acclimatization by giving rise to dehydration.
4. *Physical condition.* Men who are convalescing from a debilitating illness, or have "hangovers" or insufficient sleep, lose significant amounts of their acclimatization; an important consideration here is dehydration which frequently accompanies the foregoing situations.
5. *Motivation.* Acclimatization undoubtedly can reduce the risk of heat stroke in a given work-heat situation. This, however, should not lead to a false sense of security since exceptionally well-motivated men can ignore the warning signs of over-exertion in the heat to the point where they may work themselves directly into a case of fatal heat stroke. This was tragically demonstrated during the Summer Olympics in Rome in 1960.

11. **Bass, D. E., E. R. Buskirk, P. F. Iampietro, and M. Mager.**
Comparison of blood volume during physical conditioning, heat acclimatization and sedentary living.
J. Appl. Physiol. vol. 12, 1958, pp. 186-188.

Annotation

Purpose. To study the effects of physical conditioning, and of a combination of physical conditioning and heat acclimatization on plasma and blood volumes.

Subjects. Fifteen healthy young soldiers divided into 3 groups: I, sedentary, II, physically conditioned by cross-country running; and III, physically conditioned and heat acclimatized.

Conditions.

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Group III Week 1 32.2/26.7/65	80.5	?	5.6 km/hr on a treadmill at a 10% grade
Weeks 2 and 3 49.0/26.7/18	80.5	?	5.6 km/hr on a treadmill at a 5% grade for three 30-min periods each morning for the 3 weeks

Plasma volumes measured with Evans blue dye.

Results and Conclusions

1. There was no significant change in basal plasma, blood or red cell volumes after physical conditioning either separately or in combination with acclimatization to heat. The volumes for all three groups did not change during the 3-week experimental period.

12. **Bass, D. E., and A. Henschel.**
Responses of body fluid compartments to heat and cold.
Physiol. Rev. vol. 36, 1956, pp. 128-144. (Review)

This paper reviews the effects of heat and cold on body fluids, with particular emphasis on the responses of man.

Authors' Summary

A. Seasonal variations
B. Effects of heat
   1. *Responses to acute heat stress*
      (*a*) Plasma water
      (*b*) Plasma and blood volumes
      (*c*) Sweat secretion and renal function
      (*d*) Discussion and summary

2. *Prolonged exposure to heat.* To summarize, the general pattern of blood volume changes with prolonged heat exposure is one of gradual increase beginning within an hour, and progressively increasing to a peak of 20-30 per cent during the first week. There is evidence that, with exposures longer than 7 days, blood volume decreases toward control values.

3. *Acclimatization to heat.* It is important to realize that simple exposure to heat for several days is not synonymous with acclimatization to heat. The latter is a well recognized and easily induced phenomenon; it has recently been reviewed in great detail. . . . Briefly, acclimatization to heat is the dramatic improvement in ability to *work* in the heat which occurs within 4 to 7 days of first exposure. This improvement is associated with disappearance of subjective discomfort and reduction of physiological strain during work. The physiological adaptations are: (a) reduction in cardiovascular strain, (b) improved maintenance of body temperature and (c) increased secretion of a more dilute sweat. Mere exposure to heat without work confers but little acclimatization. In a strict sense, then, none of the studies of prolonged heat exposure reviewed in the previous section are referable to acclimatization to work in the heat. The heat stress was usually mild, activities were sedentary and the subjects were not acclimatized to heat by the usual indices. These objections have been eliminated in a recent study in which body fluid compartments and various metabolic balances were measured in five young men who were demonstrably acclimatized to heat under carefully controlled conditions [Bass, D. E., et al., *Medicine* vol. 34, 1955, p. 323]. This latter paper presents an interpretation of mechanisms of acclimatization which differs from those of other workers in that it assigns a major role to the kidney and to body fluid changes, instead of to increased working sweat rate and decreased sweat concentration. In addition, the authors picture the adrenal cortex as playing a permissive role rather than the prepotent one suggested by Conn and his group.

4. *Discussion and summary.* The problem of mechanisms of acclimatization to heat is far from solved. The body fluid changes cannot by themselves account for several important aspects of acclimatization. For example, daily administration of desoxycorticosterone acetate (DCA) can mimic the water and electrolyte patterns found during acclimatization even to the time required for maximal increases in PV. Yet pretreatment with DCA does not result in either preacclimatization or an increased rate of acclimatization to heat. This does not necessarily negate the importance of early body fluid changes, since DCA may merely supplant the usual response which would have occurred in the absence of DCA. It is well known that acclimatization is readily induced by short (2-hr) daily exposures to work in the heat. Moreover, it can be retained during 1-2 weeks of either no exposure or actual cold exposure during which changes in PV or ISF would not be maintained. . . . Finally, even continuous heat stress eventually results in a fall of BV toward control levels without impaired ability to work in the heat. The foregoing indicates the occurrence of other adaptations which may render fluid changes less important. Increases in venomotor tone may be important here. There is little doubt that the veins are contractile. . . ; increased venous constriction could, by reducing the volume of the

vascular bed, permit maintenance of cardiovascular function in the heat with a smaller effective blood volume. It has been estimated that 25 per cent of the BV can be made available through changes in venomotor tone to compensate for blood loss or pooling. Interestingly, this figure approximates the increases in BV reported during fever and acclimatization to heat. Increased peripheral resistance and decreased forearm volumes have been reported after full acclimatization; these findings are consistent with the occurrence of venous constriction. This problem deserves further study.

C. Effects of cold

1. *Acute cold exposure*
   - (*a*) Cold diuresis
   - (*b*) Hemoconcentration and fluid compartments
   - (*c*) Hypothermia
   - (*d*) Discussion and summary
2. *Prolonged exposure to cold*
3. *Acclimatization to cold*

D. Concluding remarks. The various summaries and conclusions included in the body of this review eliminate the need for yet another such section. We shall therefore conclude by pointing out a few of the many unanswered questions that have been raised. Among these are: (1) What mechanisms underlie the expansion of the ECF during acclimatization to heat? It has been suggested that 'volume' receptors may be a factor. . . . (2) Does ECF remain expanded with extended exposure to heat, i.e., beyond 2 weeks, or does it return to normal as does blood volume? (3) Is physical conditioning in part a form of acclimatization to 'endogenous' heat stress? (4) Are alterations in venomotor tone important in permitting heat acclimatization to be maintained without an expanded blood volume? (5) What are the mechanisms of increased electrolyte excretion during acute cold stress? Are 'volume' receptors involved here? (6) What factors of acclimatization, diet, genetics, etc.. are involved in the unusually high blood volumes of Eskimos?

13. **Bass, D. E., and E. D. Jacobson.**
Effects of salicylate on acclimatization to work in the heat.
J. Appl. Physiol. vol. 20, 1965, pp. 70-72.

Annotation

Purpose. To determine whether daily high doses of salicylate would enhance or inhibit acclimatization to work in the heat.

Subjects. Twelve healthy young soldiers, divided into two equal groups.

Conditions.

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
48.9/26.7/18	?	?	Walking on level treadmill (first uniformity trial) at 6.1 km/hr for 2/3 hr for 1 day
48.9/26.7/18	?	?	Walking on level treadmill (acclimatization period) at 5.6 km/hr for 2 hr for 10 days

DBT/WBT/RH	Air	$kcal/(m^2 \cdot hr)$	Exercise
Rest for 3 days			
48.9/26.7/18	?	?	Walking on level treadmill (second uniformity trial) at 5.6 km/hr for 2 hr for 1 day
Rest for 1 day			
48.9/26.7/18	?	?	Walking on level treadmill (third uniformity trial) at 5.6 km/hr for 2 hr for 1 day

Sodium salicylate was administered to the experimental group (7.8 g/day) during the first two days of the acclimatization period and was reduced to 5.9 g/day for the remaining 8 days. The control group received no salicylates during the acclimatization period. Neither group received the drug during the second uniformity trial, but both groups received 7.8 g/day during the third uniformity trial. The drug was divided into four equal doses and administered by mouth during the 18 hr preceding the walk. Water (600 ml/hr) was administered during the walk.

Results and Conclusions

1. Both groups had acclimatized to heat by the last exposure.
2. The degree of acclimatization in the salicylate group as measured by rectal temperature was less than the control group; i.e., salicylate group had significantly higher (0.4° F) rectal temperature.
3. There was no significant difference between groups with respect to rectal and skin temperatures, pulse rate or sweat rate in the second uniformity trial; the control group was unchanged but there was a significant improvement in the salicylate group.
4. On the third uniformity trial when both groups received the full original dose of salicylates, the control group had a significantly higher sweat rate and no increase in rectal temperature and the salicylate group had a higher sweat rate and rectal temperature compared with the second uniformity trial.
5. It was concluded that:
   (a) Acclimatization to work in heat occurs in spite of large doses of salicylates.
   (b) The apparently adverse effect of the drug is temporary and depends upon continued administration of the drug.
   (c) The process of acclimatization does not eliminate the acute effect of salicylates on men working in the heat.
   (d) The action of salicylate on men working in the heat is one of imposing an added, small endogenous heat load on thermoregulatory process which are already nearly maximally stimulated in the absence of the drug.

14. **Bass, D. E., C. R. Kleeman, M. Quinn, A. Henschel, and A. H. Hegnauer.**
Mechanisms of acclimatization to heat in man.
Medicine vol. 34, 1955, pp. 323-380.* (Review)

Annotation

Definition. A gradual return of the ability to work with little or no discomfort in the heat.

Purpose To investigate (1) the changes in body water distribution accompanying heat acclimatization; (2) the mechanisms underlying any fluid shifts; and (3) any altered indices of adrenocortical activity during the acclimatization process.

Subjects. Five young soldiers, ages 20 to 23.

Conditions.

DBT/WBT/RH	Air	kcal/(m^2·hr)	Exercise
Control			
24-25/21/70	?	?	21 days; four 1/2-hr periods of walking at 6.4 km/hr on a motor-driven treadmill
Heat			
7 A.M.-7 P.M.			
49/30.4/28	?	?	14 days; same as control
7 P.M.–7 A.M.			
37.8/?/?	?	?	
Recovery			
24-25/21/70	?	?	12 days: same as control

The men lived in the constant temperature chamber continuously throughout all periods. The diet consisted of Army C-rations.

Authors' Results and Conclusions

1. An attempt has been made to elucidate some of the mechanisms underlying the process of acclimatization to heat in man. Studies were made of the effects of prolonged heat exposure on body fluid distribution, adrenocortical activity, sweat composition and nitrogen and electrolyte metabolism.
2. Five young men were acclimatized to heat by living and working for 14 consecutive days in a chamber maintained at 120° F [48.9° C] during twelve daytime hours, and at 100° F [37.7° C] during the night. The heat period was preceded by three weeks of control at 76° F [24.4° C] and was followed by eleven days of recovery at 76° F [24.4° C]. The men performed a standard amount of work daily. The following measurements were made: antipyrine, thiocyanate, and T-1824 spaces; sweat concentrations of Na, Cl, K, N, and creatinine; nitrogen and electrolyte balances; indices of adrenocortical activity (circulating eosinophils and urinary 17-ketosteroids); pulse rates and rectal temperatures during exercise.

*Also: Bass, D. E., C. R. Kleeman, M. Quinn, T. F. Maliszewski, I. T. Dobalian, A. R. MacLeod, and M. E. Pillion. Mechanisms of acclimatization to heat in man: The effect of prolonged heat exposure on body water distribution and electrolyte and nitrogen metabolism. Quartermaster Climatic Research Laboratory, Lawrence, Massachusetts. *Report 214,* June 1953, 72 pp.

Progressive dehydration and salt deficiency was minimized by replacing sweat losses with 0.2 percent saline.

3. Under the conditions of this study, it was found that:

(a) Successful acclimatization to heat was attained within the first week.

(b) The sweat glands progressively excreted more water relative to all solutes measured during the first week, with little change thereafter.

(c) There was an "isotonic" expansion of the "extracellular" fluid in all subjects. This was accomplished by renal retention during the first four days of sodium and chloride in excess of that required to support sweat losses of these electrolytes. The average increase above controls was 16 percent on the fifth day, and 15 percent by the last (14th) day in the heat.

(d) Plasma volumes increased to a proportionately greater extent on the fifth day than did "extracellular" fluid volume; this was accompanied by an increase in total circulating protein. By the last day in the heat, however, the plasma volumes had dropped so that the average percent increase from controls differed little from that of the ECF. This was accompanied by a drop in total circulating protein to control levels.

(e) Total body water and "intracellular" water showed no consistent changes.

(f) Nitrogen, phosphorus, and potassium balances were negative during the heat period and positive during recovery. Potassium left intact cells in excess of that made available from tissue breakdown during the heat period. During recovery, potassium returned to cells in excess of that required for protein anabolism.

(g) Circulating eosinophil and total leukocyte counts did not differ from controls during the heat period. Urinary 17-ketosteroids were lower than controls during heat exposure.

(h) Plasma magnesium did not change significantly.

4. The major physiologic adaptations resulting in an improved ability to work during the early days of acclimatization to heat are probably cardiovascular in nature. The kidney has an important role in these adaptations. This organ "conserves" sodium and chloride in excess of amounts required to compensate for sweat losses, with the result that plasma and interstitial fluid volumes are "isotonically" expanded.

5. Increased activity of the pituitary-adrenal system was not a prepotent factor in the adaptations observed in this study.

15. Bazett, H. C.

Physiological responses to heat.

Physiol. Rev vol. 7, 1927, pp. 531-599. (Review)

This paper is one of the classic reviews on the physiology of heat regulation, and the section on acclimatization is presented in its entirety.

Author's Summary

Symptoms and acclimatization to temperature. Exposure to high temperatures sufficient to cause a rise of body temperature is usually accompanied by symptoms induced by the hyperpnea and vascular dilatation; the former of these is particularly in evidence the more rapid the temperature rise, and the discomfort seems due to an inability of the organism to adapt the acid-base equilibrium to the new conditions, although the opposite change from a high to a normal body temperature can apparently be made as rapidly as desired with no symptoms in spite of the induction of a somewhat subnormal ventilation rate [Bazett, H. C., et al. *Am. J. Physiol.* vol. 70, 1924, p. 430; Landis, E. M., et al., *Am. J. Physiol.* vol. 76, 1926, p. 35]. The dehydration which results from sweating may cause symptoms of collapse [Adolph, E. F., *Am. J. Physiol.* vol. 67, 1924, p. 573; Bazett, H. C., et al., *Am. J. Physiol.* vol. 70, 1924, p. 430], which were observed in the case of one subject after a loss of sweating of some 3 to 4 per cent of the body weight. Under such circumstances an extreme restlessness may be noted, which is relieved by raising the lower limbs, and which appears similar to that seen after hemorrhage or in surgical shock, when venous return to the heart is subnormal. The muscular movements may, perhaps, be regarded as a reflex tending to assist venous return.

Vernon [*Brit. Med. Res. Council Report 73,* 1923, p. 116] experimenting with muscular work under warm room conditions found considerable evidence of acclimatization. Conditions which at first produced considerable changes in pulse rate later produced much less change, and the same was true of the effect on respiratory rate. He pointed out that Sutton's figures [*J. Path. Bact.* vol. 13, 1909, p. 62] showed less increase in metabolism with similar body temperature changes in his later experiments. A respiratory acclimatization was noted by myself [*Am. J. Physiol.* vol. 70, 1924, p. 412], even though these experiments were spread over a long period of time, and circulatory adaptation has also been noted in my laboratory in some unpublished experiments made by a group of students. Six students remained simultaneously for one hour in a room saturated with moisture and kept between 35° and 37° C. Of these subjects all showed some increase in pulse rate, but in two subjects in the earlier experiments both the systolic and diastolic blood pressure fell considerably, in one subject they both rose, while in the other three the changes were slight and indefinite. After the experiments had been repeated 10 to 12 times, the blood pressure changes were gradually reduced and had become negligible in all subjects, though the pulse rate changes were still present.

The acclimatization of natives to their own climatic conditions is well recognized. This may be noted even among the varying climates of one country; thus the high room temperatures common in American houses, and often criticized, merely reproduce the ordinary "comfortable" summer temperature of the locality and are in consequence higher in the southern than in the more northern states. The tendency seems to be to maintain conditions as uniform as possible. Similarly the cold rooms in England merely reproduce the ordinary average summer temperature of that country. The capacity of the individual to adapt himself to such conditions is, however, harder to understand; it certainly cannot be accounted for on a basis of the degree of fat covering (which is less perhaps, rather than greater, in England than in America), but must rather depend on a metabolic or circulatory adaptation. It has been noted by both Knipping [*Zeitschr. f. Biol.* vol. 78, 1923, p. 259] and Eijkmann [*Lancet* vol. 1, 1924, p. 887] that those acclimatized to the tropics sweat to a much less extent than do the newcomers, so that they do not have a wasteful dehydration from fluid which drips off, though possibly they evaporate as much water as do the others. Comparison of Americans from southern with those from northern states readily confirms such statements. On the other hand, in hot room experiments Borchardt [*Pflüger's Arch.* vol. 214, 1926, p. 169] found that those subjects who did not withstand the conditions well, and who readily showed a hyperthermia, were those who reacted with sweating of a low grade.

Muscle cramps, consisting of tonic and clonic contractions, are well recognized as an effect of exposure to heat for a long period, as in such occupations as stoking. They are commonly accompanied by headache, lassitude, vomiting and diarrhea, and may occur even when the body temperature is almost normal [Schmidt, *Arch. f. Schiffs. u. Tropenhyg.* vol. 207, 1901, p. 245]. The symptoms are particularly liable to occur in subjects who have drunk large quantities of water [Madsen, abstracted in *Kongresszentralbl. f. de ges. inn Med.* vol. 16, 1920, p. 513]. The symptoms observed are very similar to those described by Rowntree [*Physiol. Rev.* vol. 2, 1922, p. 116] as the result of water intoxication. Moss [*Proc. Roy. Soc. B,* vol. 55, 1923, p. 181] found that miners working under excessively warm conditions consumed more salt with their food than did other individuals and that the more acclimatized workers had a higher rate of sweat production than did the others. He found that the symptoms of cramps were less liable to occur if the miners drank saline (about 0.2 per cent) instead of water, and noted that once a miner had experimented with drinking saline, he perferred it to water. It seems probable that such symptoms are caused by abnormal proportions of salts and water in the blood or tissues.

High temperatures are apt to cause a hyperemia of the conjuctiva, which may progress to a mild inflammatory reaction. McConnell and Houghton [*Trans. Amer. Soc. Heat. Vent. Eng.* vol. 29, 1923, p. 127] found that this was reproducible by the instillation into the conjunctival sac of a small quantity of sweat; they therefore considered that this reaction is caused simply by sweat running into the eyes. This however would not account for the occurrence of a similar conjunctivitis in rabbits in Heyman's experiments [*Arch. Intern. Pharm. Therap.* vol. 35, 1919, p. 1], where the blood was warmed by being passed through a cannula joining the carotid artery and jugular vein. Hence, this reaction has not yet received an adequate explanation.

16. **Bazett, H. C.**
Blood volume and cardiovascular adjustments.
Am. Heart J. vol. 21, 1941, pp. 423-439. (Review)

This review paper summarizes the relationships between the blood and the circulation with emphasis on the effects of seasonal changes.

Annotation

Three Fundamental Axioms

1. The blood volume and the capacity of the vascular bed must always be the same. There are two conditions under which blood volume can vary:
   (a) A primary change in the volume of blood to which the size of the vascular bed is adjusted; decreases – hemorrhage, dehydration, surgical shock, and anemia; increases – venous infusion, blood transfusion, and polycythemia vera.
   (b) A primary change in the size of the vascular bed to which the blood volume is adjusted; decreases – myxedema; increases – polycythemia, cardiac disease, congestive heart failure, and hyperthyroidism.
2. Starling's hypothesis of fluid balance: the outward movement of fluid from the capillaries due to hydrostatic pressure is balanced by the inward movement of fluid due to osmotic forces exerted by the colloidal plasma proteins, with some modifying influence due to tissue pressure.
3. Starling's law of the heart: the force of its contraction varies with the degree of diastolic filling.

Important Factors in Blood Volume Control

1. Minor changes in blood volume may be of considerable importance – they may be the last straw that breaks the camel's back.
2. Continuous exposure to environmental temperature near tolerable limits induces large changes in blood volume – up to 40 percent.
3. The venous muscular coat is of importance for 73 percent of the blood in the splanchnic system can be contained in the venules and veins and 46 percent in the larger veins themselves.
4. A dehydrated (3.1 percent of body weight) subject in a hot bath exhibited a marked increase in arteriolar constriction despite skin vasodilatation.
5. Changes in blood volume in subjects exposed to various climates are probably secondary to changes in the vascular system.
6. The increase in blood volume in the spring is probably due to skin vasodilatation. If the warmth is near the limit for adaptation to acute changes, marked peripheral vasodilatation is possible only with concomitant extensive vasoconstriction in other areas to provide blood for the skin. The person "bleeds" into his skin vessels. The response to warmth is an initial reduction in both plasma protein and erythrocytes with a more rapid return to normal protein than to normal erythrocyte concentration.
7. The sequence of adaptation to cold is the opposite to that of heat. Cold induces peripheral vasoconstriction with an initial rise in blood pressure and loss of fluid from the blood. Full skin constriction requires the displacement of a large volume of blood to a more central area, necessitating marked dilatation of veins and arterioles to obtain their reservoir effect. The plasma proteins may rise considerably above normal and the hematocrit may remain elevated.
8. The reaction to heat or cold depends upon the subject's condition and depends upon the previous adaptive state. "The return to cool conditions following a period of warmth may be compared with the retirement of an army to defensive positions after an offence. The ground may be the same as that covered at some stage of the offence, but the position is very different."
9. Posture and diurnal changes play an important part in the circulatory adjustments to changes in climatic conditions.
10. The increase in blood volume in the warmth may be regarded as very similar to that in cardiac failure; in the former the person "bleeds" into the skin veins and in the latter into the deeper, large veins.
11. Cardiac failure can occur without venous engorgement caused by an increased blood volume. Failure may develop acutely by a generalized arterial constriction that occurs rapidly before compensatory increases in blood volume occur and the effects of intense vasoconstriction are prevented by toxemia, vasomotor fatigue, increased permeability of the capillaries in shock, etc.

17. **Bazett, H. C., F. W. Sunderman, J. Doupe, and J. C. Scott.**
Climatic effects on the volume and composition of blood in man.
Am. J. Physiol. vol. 129, 1940, pp. 69-83.

Annotation

Purpose. To investigate the changes in extracellular fluid and blood volume and composition in relation to climatic changes.

Method. Seven males, ages 20-51, were exposed to various warm (DBT, 28.6 to 32.6° C; WBT, 20.4 to 26.3° C; RH, 47 to 61 percent) and cool (DBT, 21.1 to 24.6° C; WBT, 14.9 to 18.0° C ; RH, 51 to 53 percent) environments in an air-conditioned room (air motion less than 6.1 m/min) during the winter, spring, and summer seasons in 1937 to 1939. Each experiment lasted between 1 and 6 days at any particular set of temperatures. The subjects followed their ordinary routine and were exposed to outside temperatures only 1 to 2 hr/day.

Authors' Conclusions

1. Exposure of an individual to environmental temperatures maintained at different levels for periods of several days is accompanied by significant changes in blood volume.
2. These changes are found whether blood volume be measured by injection of Congo red or T-1824 into the plasma or by the combination of carbon monoxide with hemoglobin.
3. Blood volume is increased in the warmth, decreased in the cold.
4. The changes are associated with changes in the same direction both in the total circulating hemoglobin and in the total plasma protein so that at acclimatization there is little change in their concentrations.
5. The changes in plasma volume develop more rapidly than those in the cells and the initial changes in blood volume are consequently associated with temporary changes in the opposite direction in hemoglobin concentration and hematocrit and sometimes also in the plasma protein concentrations.

18. **Bean, W. B., and L. W. Eichna.**
Performance in relation to environmental temperature. Reactions of normal young men to simulated desert environment.
Federation Proc. vol. 2, 1943, pp. 144-158.

Annotation

Definition By a process of acclimatization man adapts himself to work in the heat. He then works as efficiently as in temperate environments without subjective complaints and with little or no disturbance of bodily functions.

Purpose. To study the reactions of normal young men to a simulated desert environment.

Subjects. Fifty-six American enlisted soldiers, ages 17 to 43; only 3 over 30, the majority between 20 and 28. All were healthy but manifested varying degrees of physical fitness. The subjects were divided into four groups: I, walking; II, bicycling; III, resting; and IV, intermittent exposure.

Conditions

DBT/WBT/RH	*Air*	*kcal(m²·hr)*	*Exercise*
Daytime (8 A.M.–5 P.M.)			
48.9/25.5-28.3/15-22%	?	?	Walking at the rate of 4.8 km/hr for 50 min with a total distance of 20.1 km/day
Night (6 P.M.–6:30 A.M.)			
32.2/?/?			

Men usually wore cotton shorts, socks, and regulation Army shoes. Men drank 0.1% saline.

Authors' Results and Conclusions

1. Performance in hot environments depends greatly on the state of acclimatization.
2. A man acclimatized to heat works in the heat with a lower body temperature, lower heart rate and a more stable blood pressure, than when not acclimatized. Nevertheless, acclimatization to heat cannot be measured by these criteria alone, as they do not necessarily correlate with the man's behavior and ability to work. The man as a whole must be considered and evaluated.
3. Acclimatization to heat begins with the first exposure, progresses rapidly and is well developed by the third or fourth day.
4. Subjects in good physical condition acclimatize more quickly and are capable of a greater work output in the heat than are men in poor physical condition.
5. Continued training in cool environments beyond that necessary to attain good physical fitness does not further increase the ability to work in the heat nor shorten the period of acclimatization.
6. Resting for three or four days in the heat, with activity limited to that required for subsistence, results in definite, but only partial acclimatization. Some work in the heat is necessary for complete acclimatization.
7. Full acclimatization (the ability to perform a maximum amount of strenuous work in the heat) is attained most quickly by graded, progressively increasing work in the heat.
8. Strenuous work on first exposure to the heat is not well tolerated and will often result in disability. If such work is maintained for several days many men will become incapacitated and those who continue to work do so ineffectively and inefficiently.
9. Tolerance to heat on first exposure, even to the point of heat exhaustion, does not retard the rate of acclimatization or lessen the degree which is finally attained, provided work is discontinued when symptoms appear, water and salt are given, and subsequent work is within the capacity of the subject.
10. Three or four exposures to heat of 3 or 4 hours duration, with two one-hour work periods during each exposure will produce a considerable degree of acclimatization. These exposures may be separated by intervals of two days in a cool environment.
11. The pattern of acclimatization is the same for short severe exertion as for moderate work of long duration.
12. Inadequate rest at night results in less work or less efficient work on the ensuing day, even by the well acclimatized man.
13. Acclimatization is well retained for one to two weeks, after which it is lost at a variable rate. Most men lose the major portion of their acclimatization in one month – a few are

able to retain it for two months. Men who remain in good physical condition retain their acclimatization best. Repeated exposures to heat are required at intervals not exceeding one month, if a high degree of acclimatization is to be maintained for long periods of time.

14. The amount of work accomplished on first exposure to heat can be increased by drinking water in amounts equal to the weight (sweat) lost during work. The rate and final degree of acclimatization attained are not influenced by the water intake (forced, moderately restricted, or taken as desired) during the first two or three days of work in the heat, provided that after this initial period men are permitted as much water as desired.

15. Suddenly restricting the water intake of men working in the heat leads to a deterioration of morale and motivation, reduces greatly the efficiency with which work is performed, decreases the total work output and causes disabling symptoms in many men. This holds for even the well-acclimatized man. Gradual reduction of water intake induces changes similar to sudden restriction, differing only in that they are produced more slowly.

16. Acclimatization to hot dry (desert) environments increases markedly the ability of men to work efficiently and effectively in hot moist (jungle) environments.

19. **Bedrak, E., G. Beer, and K. I. Furman.**
Fibrinolytic activity and muscular exercise in heat.
J. Appl. Physiol. vol. 19, 1964, pp. 469-471.

Authors' Abstract

The fibrinolytic activity of whole blood is increased by exposure to environmental heat stress. The increased fibrinolytic activity of muscular exercise is further increased if the muscular activity is performed in heat. In resting or exercising subjects who are heat acclimatized, the increased fibrinolytic activity due to heat exposure is less than that which occurs in the unacclimatized state.

20. **Beetham, W. P., Jr., and E. R. Buskirk.**
Effects of dehydration, physical conditioning, and heat acclimatization on the response to passive tilting.
J. Appl. Physiol. vol. 13, 1958, pp. 465-468.

Annotation

Heat acclimatization is manifested by improved cardiovascular response to work.

Purpose. To investigate the effects of dehydration on the cardiovascular response to orthostasis and to determine if physical conditioning and heat acclimatization would improve the response to passive tilting after dehydration.

Subjects. Fifteen healthy young American men, divided into three groups: AC, acclimatized and conditioned ; C, conditioned, physical exercise in a cool environment; and S, sedentary.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Week 1 (AC)			
32.2/26.7/65	80.5	?	Walking on treadmill at 5.6 km/hr for 1.5 hr for 4 days at a 10% grade
Weeks 2 and 3 (AC)			
48.9/26.7/18	80.5	?	Walking on a treadmill at 5.6 km/hr for 1.5 hr for 8 days at a 5% grade

Dehydrated overnight – 46.1 DBT and 26.7 WBT at 15% RH on two occasions to about 5.5% of their body weight.

Authors' Results and Conclusions

Dehydration was associated with the following modifications of the "normal" orthostatic response:

1. An essentially unchanged systolic pressure, a consistent rise in diastolic pressure and a moderate decrease in pulse pressure.
2. The pulse rate increased more rapidly with time in the upright position after dehydration than when hydrated.
3. Physical conditioning, either with or without heat acclimatization, produced no apparent improvement in the pulse rate or blood pressure response to passive tilting after dehydration.

21. **Belding, H. S., and T. F. Hatch.**
Relation of skin temperature to acclimatization and tolerance to heat.
Federation Proc. vol. 22, 1963, pp. 881-883.

Annotated Summary

The authors describe the changes at the skin temperature (T_s) during heat acclimatization.

1. Increased conductance.
2. Increased sweating, more conspicuous in wet than in dry heat.
3. A fall in threshold skin temperature for the onset of sweating, i.e., an equivalent rate of sweating occurs at a lower skin temperature after acclimatization.
4. An earlier onset of sweating due, presumably, to onset at lower skin temperature.
5. A better distribution of sweat over the skin.

Emphasis is given to (3) above; the importance of the fall in T_s for the onset of sweating is that it facilitates the transfer of metabolic heat across the skin at a lower core temperature and/or with less strain on the circulatory system. Thus, after acclimatization the larger core to skin temperature gradient decreases the original circulatory strain about 30 percent and it could make exposure at 57° C as tolerable as 45° C after acclimatization.

This examination of the improvement in tolerance which accompanies acclimation to both dry and wet heat emphasizes the fundamental importance of the downward shift in threshold skin temperature for sweating. It also provides an explanation for the puzzling observation that acclimation has little effect on sweat rate in dry atmospheres but results in a marked increase in wet ones. The analysis also is consistent with the hypothesis that an increase in effective conductance of the skin accompanies acclimation.

At the moment, however, a change in effective conductance remains to be demonstrated. Although the explanation for the downward shift in threshold skin temperature for sweating might lie in that mechanism alone, it is not possible on present evidence to choose between this and other possibilities, including change in position or sensitivity of skin receptors, change in central response to stimuli, or even a change in sensitivity of the sweat glands to stimulation.

22. **Belding, H. S., and B. A. Hertig.**
Sweating and body temperatures following abrupt changes in environmental temperature.
J. Appl. Physiol. vol. 17, 1962, pp. 103-106.

Authors' Abstract

Human subjects were transferred between environments imposing different levels of heat stress. Analyses of measurements obtained after a reasonably steady state had been achieved in each of several environments revealed equally good correlation between (*a*) sweat rate and ear temperature (tympanic membrane), and (*b*) sweat rate and calculated deep skin temperature (hypothetical). The correlations are consistent with adjustment of sweating in response to either hypothalamic temperature or temperature of skin receptors or some combination of the two. However, during the first 20 min after transfer, changes in sweat rate and skin temperature occurred together and in the same direction, but were not accompanied by any consistent change in ear temperature. Thus, to the extent that ear temperature represents hypothalamic temperature, an hypothesis of control of sweating based on hypothalamic temperature alone is not tenable. Alternative physiological explanations are given for data developed elsewhere and used in support of an hypothesis of sweat control solely from the hypothalamus.

23. **Berdan, C., and M. Pafnote.**
Experimental research on urinary elimination of 17-ketosteroids and on eosinophilia during body adjustment to high temperatures.
Proc. 13th Inter. Congr. Occupational Health. New York, 1960, pp. 845-847.

Annotation

Purpose. To investigate the effects of heat on the neuroendocrine system.

Subject. Six subjects, 25 to 30 years old.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
40/22-25/20-30%	?	?	Rested for 4 hr/day for 14 days

Urinary 17-ketosteroids were measured in basal conditions at 22-24° C and after 4 hr of heat exposure and after 12 and 24 hr, the latter two presumably at 22-24° C (not stated in article). Eosinophils were measured before and after the 4-hr heat exposure.

Results and conclusions

1. The 24-hr excretion of 17-ketosteroids on the first day of heat exposure was elevated about 4 mg over basal levels and then they declined to about basal levels (9 mg/24 hr) by the 14th exposure.
2. During the first exposure the eosinophils declined from a basal level of about 100 to about 55. By the 9th day the eosinophil count had essentially returned to normal.

24. **Blatt, W. F., and J. Kerkay.**
The effect of repeated heat and cold exposure on serum protein composition in man.
Canad. J. Physiol. Pharmacol. vol. 45, 1967, pp. 571-575.

Authors' Abstract

Total protein, serum protein, and lipoprotein electrophoretic distribution and hematocrit values were determined in two groups of men during acclimatization to 6 weeks of cold and 11 days of heat respectively. After 3 weeks of cold exposure total serum protein and albumin content decreased, while the globulin fractions increased; thus, the calculated albumin/globulin ratio was significantly depressed. During the last 2 weeks, these parameters gradually returned to control values. Overall, the protein changes during heat acclimatization were minimal, although the globulins decreased slightly, yielding a small increase in the albumin/globulin ratio. The hematocrit levels were significantly lowered during both environmental exposures, whereas the lipoprotein distribution remained essentially unchanged.

25. **Bradbury, P. A., R. H. Fox, R. Goldsmith, and I. F. G. Hampton.**
The effect of exercise on temperature regulation.
J. Physiol. vol. 171, 1964, pp. 384-396.

The purpose of this study was to confirm the conclusion that exercise does not play an essential part in acclimatization to heat.

Authors' Summary

1. The aims of the experiment were to test the effects on sweat loss of different levels of energy expenditure during controlled hyperthermia at 38.5° C and also to investigate the effect of the different routines on the development of heat acclimatization.
2. Twenty subjects were divided into five equal groups. Three groups were acclimatized to heat by twelve daily sessions of 1 hr of controlled hyperthermia while they were either resting or working at one of three different levels of energy expenditure. The other two groups acted as controls.
3. All the subjects were tested before and again after the period of acclimatization in a series of three standard tests to measure the changes in their levels of acclimatization.
4. There were marked differences between the physiological responses of the groups in the first set of standard tests. This made it difficult to evaluate the effects of working compared with resting on acclimatization, but no obvious difference was observed.
5. The results obtained during the sessions of controlled hyperthermia showed that sweat losses during work were significantly higher than at rest ($P < 0.01$ to < 0.001).

6. The most likely explanation of these observations is that exercise directly stimulates sweating.
7. It is suggested that the rise in deep body temperature normally observed during exercise is due partly to the proportional nature of the control mechanism and partly to the fall in skin temperature which locally inhibits the heat dissipating responses.

26. **Braun, W. E., J. T. Maher, and R. F. Byrom.**
Effect of exogeneous d-aldosterone on heat acclimatization in man.
J. Appl. Physiol. vol. 23, 1967, pp. 341-346.

Annotation

Purpose. To study the effects of d-aldosterone on heat acclimatization under conditions of long duration hormone administration, a strenuous exercise program, severe heat stress, and a prolonged exposure time.

Subjects. Six healthy, unacclimatized Caucasian males.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m^2·hr)*	*Exercise*
Days 1-8			
21.1/10.0/20	minimal	?	Control training period; walked 5.6 km/hr on a level treadmill
Days 9-18			
48.9/26.7/18	minimal	?	Acclimatization period. Walked 5.6 km/hr for 90 min continuously; then sat in heat at 25° C DBT for an additional 5 hr

The program included one 18-day session in May and another in January. In May three of the six subjects received d-aldosterone and three did not. The groups were reversed in January and each man served as his own control.

During exercise in the heat the men wore shorts, socks, and low-quarter shoes. Water was permitted ad libitum during days 1 through 8 and during the 17-1/2 hr of days 9 through 18 spent at 25° C. During the 6-1/2 hr of days 9 through 18 at 48.9° C 400 ml of water was given each 20 min while marching (total 1,600 ml) and every hr during rest (total 2,400 ml). One-half mg d-aldosterone in sesame oil (1.0 mg/ml) was injected IM at 7:30 A.M. and P.M. on days 6 through 14. The placebo injection was 0.5 ml saline. Diet was partially controlled: May, 2,312 kcal and 208 mEq Na; January, 2,753 kcal and 149 mEq Na.

Results and conclusions

1. The reactions to aldosterone in cool control conditions resulted in the expected urine sodium retention and potassium excretion and weight gain without blood pressure elevation.
2. With heat exposure, blood pressure, body weight, EKG changes, and serum, urine, and sweat electrolytes were not significantly different with or without aldosterone.

3. With aldosterone the men (*a*) could march longer during the first 3 days, (*b*) had lower pulse rates during the first 4 days, and (*c*) had lower rectal temperatures during the first 5 days.
4. There was no shortening of total acclimatization time of the drug group as judged by total time of walking at 48.9° C.

27. **Brebner, D. F., J. C. Clifford, D. McK. Kerslake, J. D. Nelms, and J. L. Waddell.**
Rapid acclimatization to heat in man.
R.A.F. Institute of Aviation Medicine, Farnborough, Hants, England. *I.A.M. Scientific Memo S. 38,* July 1961, 10 pp.

Annotation

Definition. A reduction in the physiological strain produced by a given environmental stress.

Purpose. To investigate the acclimatizing effect of relatively short periods of immersion in hot baths without exercise.

Subjects. Four healthy men, 30 to 37 years of age, the authors of this paper.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
First assessment test			
36.0/31.6/73	15.2	?	Day 1: bench stepping, 30.5 cm, 12 steps/min, four work bouts during a 4-hr exposure
Immersion period			
45/36-39/56-68	15.2	?	Days 2-11; no exercise in bath of 40-min duration
Second assessment test			
36.0/31.6/73	15.2	?	Day 12; same as first assessment test

During assessment tests 2 liters of water at room temperature were consumed.

Results and conclusions

1. The assessment tests. In general, the oral temperatures and pulse rates were significantly reduced ($P < 0.01$) and sweat rates were increased ($P < 0.001$), comparing test 2 with test 1. The increase in sweating was confined to the first 2 hr of the test.
2. Hot baths. There were no differences in the rate of rise or final oral temperature and there was no clear change in pulse rates over the 10 exposures.
3. It was concluded that "the ability to sweat more is an important factor in acclimatization to heat," and "immersion in hot baths without work is sufficient to induce physiological acclimatization and an improvement in performance and subjective comfort in the heat."

28. **Brebner, D. F., and D. McK. Kerslake.**
The effect of soaking the skin in water on the acclimatization produced by a subsequent heat exposure.
J. Physiol. vol. 166, 1963, pp. 13P-14P.

Authors' Summary

The increase in sweating which occurs when a subject is acclimatized to heat appears to depend on the activity of the sweat glands during the acclimatization routine. Fox, Goldsmith, Hampton, and Lewis [*J. Physiol.* vol. 162, 1962, pp. 59-60] inhibited sweating from one arm during a series of heat exposures by cooling the arm in water at 13° C. Exposures without local cooling before and after this series showed the increase in sweat production characteristic of heat acclimatization to be absent from this arm, but to be present elsewhere.

Prolonged immersion in water considerably inhibits sweating during a subsequent heat exposure [Hertig, B. A., et al. *J. Appl. Physiol.* vol. 16, 1961, pp. 647-651] and permits the effect of sweat inhibition to be studied without changing the skin temperature during the acclimatizing heat exposures. Four subjects have been examined in this way. Inhibition of sweating was produced by immersion up to the neck in a bath of stirred water at between 34.5 and 35.0° C for 4 hr [room air 38° C, 30% r.h., 25 cm/sec]. The acclimatizing stimulus was a similar immersion for 40 min at 39.0 ± 0.1° C, a severe heat exposure which raised the mouth temperature to 39.2 ±0.2° C. The performance of the sweating mechanism was assessed by measuring the rate of weight loss in a saturated environment at mouth temperature [Brebner, D. F., et al., *J. Physiol.* vol. 162, 1962, pp. 244-258]. Such assessments were made one day before and after two consecutive daily heat exposures both of which were either preceded by 4 hr immersions (pre-soak) or followed by them (post-soak). Two subjects were given pre-soak exposures the first week and post-soak the second. The order was reversed for the other two subjects. The sweat loss during the hot bath was approximately halved by the pre-soak.

All subjects showed a marked increase in sweating in the assessment trial following the post-soak exposures. In contrast, the pre-soak exposures did not increase the sweating response to the assessment environment. The results support the view that the increase in sweating seen in acclimatization to heat is dependent on the secretory activity of the sweat glands.

29. **Brebner, D. F., D. McK. Kerslake, and D. G. Soper.**
Some effects of exposure to an environment of saturated air at mouth temperature.
J. Physiol. vol. 162, 1962, pp. 244-258.

The purpose of this study was to attempt to devise an experimental procedure to standardize the physiological stimulus on sweat production so the latter may be directly related to the stimulus "by arranging that the thermal state of the subject may be reproduced on different occasions regardless of the varied physiological responses he may show."

Authors' Summary

1. Subjects were weighed continuously while exposed to an environment of saturated air at mouth temperature.
2. After the first 10 min mouth temperature increased steadily with time. The rate of weight loss at first increased with time and rising temperature, later reached a maximum and then decreased.

3. The most constant parameter examined was the maximum increase in rate of weight loss for a rise of temperature of 0.4° C (*G*).

4. The value of *G* for an exposure in the afternoon could be predicted from the observed value the same morning with 95% confidence limits of about ±30%.

5. The value of *G* and the rate of weight loss at 38.4° C (near the maximum) increased several times during daily exposures terminated at mouth temperatures of 38.4-38.6° C.

6. The possible use of this type of exposure as an index of the sensitivity of the sweating mechanism is discussed.

30. **Burton, A. C., J. C. Scott, B. McGlone, and H. C. Bazett.**
Slow adaptations in the heat exchanges of man to changed climatic conditions.
Am. J. Physiol. vol. 129, 1940, pp. 84-101.

Authors' Summary

1. Data accumulated in four experiments in which the subjects remained for several days in an air-conditioned room kept at either relatively high [DBT, 28.6 to 32.6° C; WBT, 20.4 to 26.3° C; RH, 47 to 61%] or relatively low [DBT, 21.1 to 24.6 ° C; WBT, 14.9 to 18.0° C; RH, 51 to 53%] temperatures have been studied to determine the changes in heat exchange and its partition in various channels during slow adaptation to the conditions [air movement less than 6.1 m/min].

2. Deep body temperature was maintained at normal levels. A slight shift with new conditions tended to be compensated as acclimatization proceeded.

3. Average caloric intake was significantly greater in cool than in warm conditions. Foods of higher caloric value per gram, which had a lower equivalent respiratory quotient, were chosen in the cooler conditions. Increased appetite plays a part in acclimatization to cold.

4. In acclimatization to heat, an increase in the total evaporative loss in the first one or two days is followed by a gradual reduction in later days. This is accompanied by changes in the loss by radiation and convection of a complementary nature, i.e., an initial fall followed by a progressive rise. The latter is associated with the increasing peripheral circulation described in another paper.

5. When cool climatic conditions follow a period of heat the evaporative loss, which may be supernormal on the first day, falls by the third day to a minimum value which is much below accepted standards. In the basal condition this is shown to be explained on physical grounds by the low value of skin temperature reached. The low values maintained throughout the day however are physiologically subnormal. The possibility of this subnormality being dependent on osmotic factors is shown. In later days of cold the evaporative loss rises towards normal values.

6. Radiation and convection is supernormal at the start of a cold period following heat, but falls with the evaporative loss in the first few days. This fall is associated with the slow decrease of skin temperature and peripheral circulation. In later days radiation and convection losses remain at the lower level or rise slightly.

7. The total heat exchange is deduced from the foregoing and by reference to basal values measured daily. In the heat there is evidence of a slow fall as acclimatization proceeds. In the initial days of cold there is a marked fall followed, after the second or third day, by a steady rise. Correlation of basal metabolic rates with average temperature of the body tissues suggests the operation of hormonal changes, possibly of the thyroid.

8. Since the increased caloric intake is not accompanied by an increased but by a decreased heat production in the first few days of cold, there is a marked metabolic unbalance on these days. Simultaneously there is a large diuresis continuing for several days and presumably a loss of body fluid, which is to some extent balanced by the storage of food in the body. Weight changes then are less than the changes of fluid content of the body.

9. Calculations of complete fluid balance are made but it is shown that these are as unreliable as the weight changes in the absence of metabolic balance.

10. It is concluded that the processes of acclimatization involve changes in both total heat exchange and its partition. In the heat radiation and convection losses eventually play a greater role, in the cold they decrease as adaptation proceeds. The maintenance of the new partitions involves less strain on the organism after changes of the fluid volume of the body have taken place.

31. **Buskirk, E. R., P. F. Iampietro, and D. E. Bass.**
Work performance after dehydration: Effects of physical conditioning and heat acclimatization.
J. Appl. Physiol. vol. 12, 1958, pp. 189-194.

Annotation

Purpose. To determine if physical conditioning and heat acclimatization might ameliorate the impaired ability to do work when dehydrated.

Subjects. Fifteen American men, divided into three groups of five men each: AC, acclimatized and conditioned; C, conditioned; and S, sedentary.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Week 1			
32.2/26.7/65	80.5	?	Walking on treadmill at a 10% grade at 5.6 km/hr for 1.5 hr/day for 4 days
Weeks 2 and 3			
48.9/26.7/18	80.5	?	Walking on treadmill at a 5% grade at 5.6 km/hr for 1.5 hr/day for 8 days

Dehydrated overnight – 46.1 DBT and 26.7 WBT to about 5.5% body weight.

Results and conclusions. The responses to work after dehydration was determined by the changes in pulse rate, rectal temperature, and maximal O_2 uptake.

1. Pulse rates during and after walking were elevated with dehydration. This elevation was reduced in groups AC and C, but not in S.
2. Rectal temperature was elevated in walking with dehydration. This elevation was not changed in all three groups.

3. Physical conditioning elicited an elevation in maximum O_2 uptake. The elevation was not different in groups AC and C. All groups exhibited equal decrements in maximum O_2 with dehydration, but group AC and C maintained a relatively higher maximum O_2 than group S.
4. It was concluded that physical conditioning was associated with enhanced work performance during dehydration, whereas heat acclimatization did not appreciably supplement this effect.

32. **Christensen, W. R.**
Long term acclimatization to heat.
Am. J. Physiol. vol. 148, 1947, pp. 86-90.

Annotation

Definition. Alterations in physiological response to heat induced in the human body by continued exposure to conditions of high temperature or to the combination of high temperature and high humidity.

Purpose. To observe the reactions of young men performing exercise under conditions of high temperature and humidity for a period of 25 weeks.

Subjects. Seven young, healthy soldiers physically conditioned by two weeks of field exercise.

Conditions

DBT/WBT/RH	*Air*	*kcal/($m^2 \cdot hr$)*	*Exercise*
Preliminary period			
32.2/30.0/85	?	?	Walking on treadmill at 5.6 km/hr for 1 hr for 20 days, plus resting 1 hr before and 1 hr after exercise, 5 days/wk for 1 month
Experimental period			
32.2/30.0/85	?	?	Same as above only the 30 experimental sessions extended from December to May

Drinking water was prohibited during the hour of marching. While marching, the subjects wore cotton shorts, light wool socks, and jungle boots. Time of day for marching was not controlled.

Results and conclusions

1. Five of the seven subjects exhibited a definite decrease in sweat rate over the 5-month period and the other two no change. The latter two subjects had the lowest initial rates of sweating.
2. At the end of the 5 months there was no evidence that the progressive decline in sweat rate had ceased.

3. Rectal temperatures and pulse rates showed no significant variations (T_r varied from 37.9 to 38.1° C and pulse rates from 110 to 125).
4. There was no consistent relationship between rectal temperature and rate of sweating.
5. There was no increase in the working ability over the 5 months.
6. Thus acclimatization, as evidenced by decrease in sweat rates, seems to be a continuous process.

33. Collins, K. J.
Endocrine control of salt and water in hot conditions.
Federation Proc. vol. 22, 1963, pp. 716-720. (Review)

Author's Summary

A. Salt and water balance in the heat.
 1. An unacclimatized man working hard in the heat may have a daily combined sweat and urinary loss of salt of 20 g or more.
 2. Salt depletion following heavy sweating leads to a rapid fall in the urinary salt excretion followed by a reduction in the salt output in sweat.
 3. Restoration of salt equilibrium is associated by alterations in water balance and involves the salt-retaining hormones of the adrenal cortex plus the anti-diuretic hormone (ADH).
 4. Salt deficiency may lead to impaired work performance, exhaustion, fainting, and muscular cramps and may be diagnosed by findings of dehydration, hypochloremia, and a very low urinary output of salt.
 5. During the first few days of acclimatization exposures there is an isotonic expansion of the plasma volume and extracellular fluid volume brought about by oliguria and renal salt conservation.

B. Excretion of antidiuretic hormone.
 1. After sweating there is an increase in the excretion of ADH probably due to the increase in the plasma osmotic pressure (sweat is hypotonic to plasma).
 2. Little is known regarding the changes in excretion of ADH during heat acclimatization.

C. Involvement of adrenocortical hormones.
 1. Adrenocorticosteroids are involved in salt and water adjustments in the heat because (*a*) urinary excretion of aldosterone is increased, and (*b*) administered hormones mimic the effects of heat on electrolyte changes in sweat and urine.
 2. When subjects are acclimatizing to heat and perform little work and do not incur negative salt and water balances there appears to be no significant increase in urinary aldosterone, but those who work with a limited water and salt intake show a definite increase.
 3. Salt deficiency in man in the heat is associated with negative nitrogen balances. Adrenocorticotropic hormone (ACTH) administration decreases salt output in sweat and urine and leads to negative nitrogen balances. Deoxycorticosterone acetate (DOCA) administration results in salt conservation without negative nitrogen balance. It appears the increase in aldosterone in hot conditions is independent of ACTH, because there is no rise in the output of 17-hydroxysteroids or

17-ketosteroids. The excretion of aldosterone in the heat is, for the most part, independent of consistent changes in glucocorticoid excretion. Thus, it is unlikely that the persistent negative nitrogen balance in the heat can be caused by glucocorticoid activity: perhaps it is due to a reduction in lean body mass.

4. The secretion of aldosterone during heat exposure is probably related to readjustments in the volume of body fluid compartments, particularly the ECF, via "volume receptors" located in some central vascular compartment.

D. Influence of adrenocortical steroids on sweat glands.

1. In the presence of a general negative salt balance, the salt content of sweat falls during heat acclimatization due, probably, to adrenocortical activity (DOCA and aldosterone).
2. There is some evidence that salt-active adrenocortical hormones directly affect the sweat glands as well as the kidneys.

34. **Collins, K. J., G. W. Crockford, and J. S. Weiner.**
The local training effect of secretory activity on the response of eccrine sweat glands.
J. Physiol. vol. 184, 1966, pp. 203-214.

Authors' Summary

1. The influence of repeatedly raising the body temperature by radiant heat to a level at which acclimatization to heat is normally acquired was investigated in two series of experiments, the first without the subjects sweating, the second with sweating.
2. In a second investigation local sweat-gland activity was induced by drug injections on successive days without raising the body temperature.
3. These experiments show that the increased sweating capacity characteristic of acclimatization to heat is a result of sweat-gland activity and does not appear to be induced by or to depend on an elevated body temperature.
4. Secretory activity results in a loss of glycogen from sweat-gland cells on the first day of heat exposure but not after the glands have been 'trained' by acclimatization to heat.
5. The state of acclimatization has no influence on the threshold concentration of acetylcholine required to elicit sweating when injected intradermally.

35. **Collins, K. J., K. Hellmann, R. M. Jones, and J. B. Lunnon.**
Aldosterone activity in the urine of men exposed to hot environments.
J. Endocrinol. vol. 13, 1955, p. viii.

Authors' Summary

Previous studies on the effect of exposure to high environmental temperature and humidity on adrenocorticosteroid excretion in man [Hellmann, K., et al., *J. Endocrinol.* vol. 10, 1954, p. xviii] have shown that there is no detectable change in the excretion of compounds E, F, and tetrahydrocortisone. Since it is believed that in man salt retention occurs on exposure to high temperature and humidity [Weiner, J. S., and R. E. van Heyningen, *Brit. J. Industr. Med.* vol. 9, 1952, p. 56] it seemed desirable to reinvestigate the problem with respect to aldosterone excretion.

Experiments were carried out on eight healthy young men who were exposed nude and in a sitting position for periods of 2 hr on 9 successive days at a mean temperature of 36.5° C dry bulb,

35.5° C wet bulb. Urine collections were made on 4 days, the 1st day being a control day at ordinary temperatures and conditions, and pre-heat and post-heat collections being made on the 1st, 5th, and 8th days of heat exposure. The urines were extracted as in our previous experiments, but the chromatography of the extracts so obtained was modified. Bioassays were made by the $^{24}Na/^{42}K$ method of Simpson & Tait [*Endocrinology* vol. 50, 1952, p. 150], and the responses of the extracts were compared with standard doses of aldosterone. The results indicate a significantly greater aldosterone content in the samples affected by heat treatment than in the control samples. An analysis of the Na/K ratio in saliva before and after heat exposure showed no significant variation.

From a consideration of the average sweat loss of the heat-exposed subjects and their salt intake it was unlikely that the increased aldosterone excretion could be accounted for by a negative salt balance. It seems therefore that the increased aldosterone excretion reflects an increased aldosterone secretion as a result of exposure to heat and humidity.

36. **Conley, C. L., and J. L. Nickerson.**
Effects of temperature change on the water balance in man.
Am. J. Physiol. vol. 143, 1945, pp. 373-384.

Authors' Summary

1. The effect of changes in the external temperature on the fluid and electrolyte balance has been studied on six normal male subjects under carefully controlled dietary and environmental conditions [Experiment 1: August 10-15, 1940. Chamber temperature: DBT, 15.8; WBT, 7.0° C; R H, 24%. Experiment 2: December 17-24, 1940. Chamber temperature. December 17-21: DBT, 26.8; WBT, 17.5° C; RH, 40%. December 21-24: DBT, 15.6; WBT, 8.6° C; RH, 37%. Experiment 3: December 17-24, 1941. Chamber temperature. December 17-21: DBT, 17.9; WBT, 8.7° C; RH, 26%. December 21-24: DBT, 30.4; WBT, 21.9° C; RH, 48%. Air motion in all three experiments was 4.3 m/min].
2. The extrarenal water loss was quite constant during any period of uniform temperature. Upon change of the environmental temperature, the extrarenal water loss and the skin temperature quickly attained new levels. There was no evidence of slow acclimatization.
3. The renal excretion of sodium and chloride appeared to reflect the difference between the intake of these substances and the quantities lost in the sweat.
4. A pronounced and prolonged increase in plasma volume was found on exposure to heat. On exposure to cold the plasma volume was reduced but tended to return toward normal within a few days.

37. **Conn, J. W.**
The mechanism of acclimatization to heat.
Adv. Int. Med. vol. 3, 1949, pp. 373-393.

Author's Summary and Conclusions

It is a well-established fact that man suddenly confronted with the necessity of performing work in the heat, is capable of making certain physiologic adjustments, which result, after a variable number of days of such exposure, in a vast improvement in his ability to perform a given task with relative ease and without untoward symptoms. This adaptive phenomenon has been called acclimatization to heat. Careful studies to determine differences in physiologic processes between the unacclimatized and the acclimatized man indicate that the major differences exhibited by the latter consist of an improved peripheral circulation and an enhanced ability to resist depletion of body salt. This second difference manifests itself mainly as a capacity to produce sweat which is much lower in its concentrations of sodium and chloride than was the case prior to acclimatization. Since under conditions of work in the heat the major loss of body salt occurs via sweating, this adjustment assumes primary importance.

The mechanisms by which these adjustments are accomplished *during the process of acclimatization* have not been known. Extensive metabolic studies done in our laboratory in the past five years appear to establish the details of this mechanism. On the basis of the metabolic phenomena observed repeatedly, it is believed that in man the process of acclimatization to heat consists of an increased activity of pituitary adrenocorticotropic hormone and that the resulting enhancement of the production and liberation of adrenal cortical steroids is responsible for bringing about the physiologic adjustments characteristic of state of acclimatization. Under the conditions of our experiments, the need for the conservation of body salt constitutes the stimulus which "fires" the mechanism and which raises the level of activity of the pituitary-adrenal axis.

1. The mechanism by which man adapts himself to physical work in the heat consists of increased physiologic activity of the adrenal cortices in response to enhanced release or activity of the pituitary adrenocorticotropic hormone.
2. Increased adrenocortical activity is evidenced by a metabolic pattern consisting of the simultaneous appearance of salt-retaining influences and a protein catabolic effect.
3. Since both the salt-retaining and the protein catabolic effects can be reversed by administration of desoxycorticosterone acetate, which, in itself, has no effect upon protein metabolism, the depressing effect of DCA is exerted upon the production of pituitary adrenocorticotropic principle rather than upon adrenal function directly.
4. The stimulus which initiates increased adrenocorticotropic activity in response to work in the heat, though not sharply defined, is clearly related to the need for conserving body salt. In this particular instance, the protein catabolic effect appears to be merely an accompanying manifestation of increased adrenocortical activity. When the need to produce large amounts of salt-retaining cortical steroids is diminished by the administration of exogenous DCA or sufficient salt, the protein catabolic effect soon disappears.
5. The physiologic process of acclimatization to heat is impeded by substituting exogenous adrenocortical steroids for endogenous ones. While the peripheral effects of the administered steroid are similar to those observed in full acclimatization, cessation of such substitution discloses depression of the pituitary-adrenal mechanism, the very one which must be stimulated to increased activity, if physiologic acclimatization to heat is to be accomplished.

38. **Conn, J. W., and M. W. Johnston.**
The function of the sweat glands in the economy of NaCl under conditions of hard work in a tropical climate.
J. Clin. Invest. vol. 23, 1944, p. 933.

Authors' Summary

Acclimatized men performing hard work [4000 to 4200 cals per 24 hours] in humid heat [85° F (29.4° C) and 85 per cent humidity] and producing 4 to 9 liters of sweat per 24 hours, remain in NaCl balance and retain physical 'fitness' on a total dietary intake of NaCl as low as 5 grams per day. This is accomplished by the ability of the sweat glands to produce a fluid containing progressively lower concentrations of NaCl as the supply of salt in the diet is diminished and as urinary NaCl falls off sharply (indicating a need to conserve body salt).

With work, sweat volume, and sweat NaCl concentration constant, an abrupt change from high to low NaCl intake produces the following sequence of events: (1) A marked fall in urinary NaCl; (2) followed in 1 to 2 days by a significant fall in sweat NaCl concentration; (3) a gradual rise in urinary NaCl until urine plus sweat losses approximate total NaCl intake; (4) continuation of the newly acquired level of more dilute sweat.

When, under the same conditions of low salt intake and continued existence in humid heat, work periods are discontinued for several days (abruptly lowering total sweat volume), there occurs: (1) a rapid rise in urinary NaCl; (2) followed by an increase of sweat NaCl concentration. If increased sweating is now produced by heavy clothing without work, urinary NaCl falls followed by a decrease in sweat NaCl concentration.

Under conditions of these experiments, an average diet, containing 10 to 15 grams of NaCl, provides sufficient protection in acclimatized men to make the use of salt supplements unnecessary.

39. **Conn, J. W., M. W. Johnston, and L. H. Louis.**
Acclimatization to humid heat: A function of adrenal cortical activity.
J. Clin. Invest. vol. 25, 1946, pp. 912-913.

Authors' Summary

Our studies indicate that the process of acclimatization to heat is characterized metabolically by (1) negative nitrogen balance, independent of the composition of the diet, and (2) sharply falling concentrations of sodium and chloride in sweat and urine. Similar findings have been observed in normal animals treated with large doses of adrenal cortical extract.

If, during acclimatization, the negative N balance represents a secondary expression of increased adrenal cortical activity, the primary stimulus for which the need is to conserve salt, the administration of desoxycorticosterone acetate (D.C.A.) should serve as a useful tool in dissecting the mechanism since (1) it could remove the pressure on the adrenals for the production of a substance capable of retarding body losses of salt, and (2) *per se*, it has no significant effect upon protein metabolism.

D.C.A. was administered to men (1) unacclimatized to heat and living in a temperate climate, (2) undergoing acclimatizatior to heat, and (3) fully acclimatized to heat.

Authors' Results

1. It always diminishes markedly the concentration of sodium and chloride in sweat and urine, the most persistent effect being upon sweat.
2. During acclimatization (with an existent negative N balance) it results in a sharp approach to nitrogen equilibrium.
3. *Upon cessation of D.C.A.* a very marked rise in the concentration of sweat salt always occurs. The process of acclimatization is temporarily impeded, and in fully acclimatized men acclimatization is temporarily lost.

Authors' Conclusion

1. Increased adrenal cortical function is importantly involved in the process of acclimatization to heat.
2. Correction by exogenous D.C.A. of the negative N balance characteristic of the process of acclimatization indicates that production of endogenous adrenal cortical substance (which affects both electrolyte and nitrogen metabolism) has been diminished; and that the original stimulus to the adrenals (under these conditions) represents the need to conserve body salt.
3. Temporary loss of acclimatization and loss of the ability to produce sweat dilute in sodium chloride upon withdrawal of D.C.A. suggests that it requires several days for the adrenal cortices to again reach a high degree of functional activity, after having been put at relative functional rest by a few days of aid from an exogenous source (D.C.A.).

40. **Consolazio, C. F., L. O. Matoush, R. A. Nelson, J. B. Torres, and G. J. Isaac.**
Environmental temperature and energy expenditures.
J. Appl. Physiol. vol. 18, 1963, pp. 65-68.

Authors' Abstract

Metabolic rates were compared on seven young men performing three levels of physical activity at three environmental temperatures of 70, 85, and 100° F [21.1, 29.4, and 37.8° C]. This study indicates that as the environmental temperature increases there is also an increase in metabolic rate of men performing a fixed activity. It has been shown that there was a significantly higher metabolic rate for men working at 100° F than at 85 and 70° F. These increases averaged 11.4% for the rest period, 13.3% for the moderate activity, and 11.7% for the heavier activity. Body temperatures also were significantly higher at 100° F than at 85 and 70° F environments ($P < 0.005$). They averaged 99.6° F [37.6 ° C] for the 100 ° F temperature, and 99.1° F [37.3° C] for both the 85 and 70° F temperatures. The findings in this study indicate that the metabolic rate of a fixed physical activity is increased in the heat and that this increase is not due to acclimatization or training.

41. Crowden, G. P.
A survey of physiological studies of mental and physical work in hot and humid environments.
Trans. Roy. Soc. Trop. Med. Hyg. vol. 42, 1949, pp. 325-340.

Discussion by Sir Henry Tidy

Dr. Weiner spoke of training and acclimatization. I have had some experience of training with athletes, and to a considerable extent one can measure fitness in training by the amount of sweating. When a man commences training he sweats a great deal more than he does later on. If he gets stale, which is a curious point that nobody can define, he sweats again. Obviously this is a different matter from acclimatization. One can have both training and acclimatization, but they are different points. I ask the question: What is the relation between training and acclimatization?

Discussion by Lt. Col. J. C. Watts

I feel that the apparent paradox raised by Sir Henry Tidy is explained by the fact that in training we are increasing muscular efficiency and thus lowering heat production, whereas in acclimatization we are increasing our ability to lose heat. Obviously, heat production by the body and heat loss are intimately linked and we cannot consider one without the other.

42. **Daly, C., and D. B. Dill.**
Salt economy and humid heat.
Am. J. Physiol. vol. 118, 1937, pp. 285-289.

Authors' Summary

The salt content of sweat produced by three subjects during moderate work under natural sweating conditions was studied for three weeks in the moist summer heat of Boston. Maximum daily temperatures averaged 83° F [28.3° C] with an average relative humidity of 78 per cent. For the first six days of work in humid heat, during acclimatization, the concentration of chloride in sweat averaged 27 mEq/*l*. During the following twelve days of work, after acclimatization, sweat chloride dropped to 17 mEq/*l*. Sweat sodium closely followed the changes in chloride concentration while potassium and nitrogen failed to show significant variations. Our experiments indicate that sweat secreted in moderate activity at moderate temperatures may contain less salt than sweat produced under extreme laboratory and industrial conditions.

43. **Davis, T.R.A.**
Effect of heat acclimatization on artificial and natural cold acclimatization in man.
J. Appl. Physiol. vol. 17, 1962, pp. 751-753.

Annotation

Purpose. To determine the influence of heat acclimatization upon seasonally and artificially cold-acclimatized subjects.

Subjects. Twelve men, six artificially cold acclimatized and six naturally cold acclimatized. Both groups were subsequently heat acclimatized.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Artificial cold acclimatization group			
13.5/?/?		?	Resting in a chamber for 8 hr daily for a period of 28 days; then heat acclimatized at 49° C
40.5/?/?	?	?	Walking on a treadmill at 5.6 km/hr for 20 min/hr, 8 hr/day for 21 days

DBT/WBT/RH	Air	kcal/(m²·hr)	Exercise
Naturally cold acclimatized group			
14.1/?/?			A 1-hr test once per month between October and February; then heat acclimatized at 49° C
49/33/35	?		Walking on a treadmill at 5.6 km/hr for 20 min/hr, 8 hr/day for 21 days

After each heat acclimatization routine a standard cold exposure at 13.5° C was performed during which time O_2 consumption, shivering, and rectal and skin temperature measurements were made.

Results and conclusions

1. Shivering decreased ($P < 0.01$) as a result of the artificial and natural cold exposure.
2. Heat production decreased ($P < 0.05$) in both groups but it never reached basal values.
3. Skin temperature in the naturally acclimatized group exhibited no change, but a significant fall ($P < 0.05$) occurred in the artificial group.
4. There was no change in the rectal temperature of the natural group, but a significant fall ($P < 0.01$) in the artificial group.
5. In both groups the changes induced by the cold exposures were not influenced by heat acclimatization.
6. It was concluded that: (*a*) artificially or seasonally acquired cold acclimatization is unaffected by heat acclimatization; (*b*) the physiological changes induced by both cold and heat acclimatization can "coexist" in the same individual; and (*c*) "the loss of one occurs not as a result of the presence of the other but as a result of the absence of the adequate acclimatizing stimulus."

44. Davy, J.,
XXII. On the temperature of man within the tropics.
Phil. Trans. Royal Soc. London. Part 2, 1850, pp. 437-466.

These observations were made while Dr. Davy made a trip from July 1845 to November 1848 to the West Indies. The temperatures were taken, presumably, with a mercury-in-glass thermometer.

Author's Conclusions

The following are some of the conclusions that appear to be either proved or rendered probable by the preceding results, or by those given in the Tables appended – supposing, as it is believed, that, were the observations extended to many individuals, no material discrepancy would be witnessed.

1. That the average temperature of man within the tropics is a little higher, nearly 1° F, than in a temperate climate, such as that of England.
2. That within the tropics, as had before been found in cooler regions, the temperature of the body is almost constantly fluctuating – varying according to the variety of agencies to which it is subject, some of which are distinct, others obscure.
3. That the order of fluctuation observed there is different from that in a cooler climate, the minimum degree of temperature being commonly early in the morning, after the night's rest, and not at night previous to going to rest.

4. That all exertion, whether of body or mind, except it be very gentle, coming under the designation of passive rather than active exercise, has a heightening effect on the temperature, while the latter, the passive kind, has rather a lowering tendency, especially carriage exercise.

5. That heavy clothing, especially if tight and close, obstructing the admission and circulation of air, tends to raise the temperature unduly, especially under active exercise: and that close, ill-ventilated rooms, especially when crowded, have in a marked manner the same tendency.

6. That when the body is in a healthy state, then on rest after exercise or exposure to any other exciting cause, it rapidly recovers its normal condition as to temperature.

7. That when labouring under disease, however slight, the temperature is abnormally elevated: and that – judging from observations made, but not recorded, in the Tables its undue degree is some criterion of the intensity of the diseased action.

8. That within the tropics there is comparatively little difference of temperature between the surface of the body, especially the extremities and the internal parts – and that there the skin is more active in its function of transpiration and the kidneys are less active as secreting organs; with which it may be conjectured is connected a rapid production and desquamation of cuticle, and the absence, in great part or entirely, of lithic acid in the urinary secretion. This latter fact, however, may be explained in a different manner, on the supposition that the acid is not formed in the blood, or if formed, in a greatly diminished quantity.

9. That the effect of wine, unless used in great moderation, is commonly lowering, that is as to temperature, whilst it accelerates the heart's action, followed after a while by an increase of temperature.

10. That the tendency of sea-sickness is to check what may be considered the natural fluctuation of the temperature, and when severe, like disease, to elevate the temperature.

11. That the tendency of a sea voyage, apart from sea-sickness, is to equalize the temperature without elevating it, an equilization that is best witnessed in voyaging in a tropical sea, where the atmospheric temperature is so little variable.

12. That even at sea, with a change of atmospheric temperature, there is a tendency to change of temperature of the body, the average increasing in proceeding toward the tropics, and diminishing in receding from them.

These conclusions obviously admit of application, and that variously in relation to health and disease. It would be unsuitable to the occasion to dwell on this part of the subject; I shall merely remark, that it is a happy circumstance for man, and seems wisely ordered, that fluctuation of temperature should be connected with a healthy state of the system, and probably conducive to it, in whatever manner produced, whether by change of climate, or atmospheric variation, or by exercise, whether of body or mind. The excellent health which the crews of the West Indian steam-packets have, that are in constant transition from heat to cold, is a striking proof of this, and other instances of a like kind, were it necessary, might be adduced in confirmation.

. . . The thermometer with which the preceding observations were made was broken immediately after my return to England, when traveling by railway, no special precaution having been taken in the packing of it, as by inclosing it in elastic horse-hair; and in consequence I had not the means at once of making further trials on temperature for the purpose of comparison. Recently, having had another thermometer constructed as delicate as that before used and divided with the same minuteness – each degree of *Fahrenheit* into ten parts – I have been enabled to continue the trials; as yet, however, only for one month, that of April, without interruption. They have been made thrice daily, at about the same hours as those recorded in my former paper. The results, under ordinary circumstances of health, exercise, etc., have accorded with those then obtained, the highest temperature having been found to be immediately on rising in the morning after the night's rest, and the lowest at night, just before retiring to rest. This accordance will probably be received in proof that the difference of results in the West Indies and in England has been mainly owing to difference of climate and the habits of life connected therewith; and apart from these, to no change in the individual, the subject of the trials.

Dr. Davy probably made the first observation of the elevating effects of dehydration on body temperature:

It is deserving of remark, that whenever wine was used, except in great moderation, though never to the excess of an inebriating effect, on the following morning the temperature under the tongue was found to be more or less above the average, and the pulse commonly quicker than usual. It is also worthy of remark, that occasionally the effect at night was to increase the temperature of the body, and that in a marked manner; but whether from some peculiar quality of the wine used, or from some deranged state of the system or other adventitious circumstance, I have not been able to determine. . .

It appears from these few observations, that under the influence of sea-sickness, the morning temperature was higher than ordinary and the pulse somewhat quicker; when the former was lowest, as on the 18th of May, then the vessel being in smooth water, there was scarcely any uneasiness experienced. Comparing the several observations, perhaps the inference may be justifiable, that the tendency of sea-sickness, when not in its severest form, is of an equalizing kind in relation to the temperature, pulse and respiration – a tendency no doubt promoted by the little variation to which the sea atmosphere is liable, especially within the tropics. On so obscure a subject, however, as sea-sickness, this remark is offered with some hesitation.

45. **Dill, D. B., F. G. Hall, and H. T. Edwards.**
Changes in composition of sweat during acclimatization to heat.
Am. J. Physiol. vol. 123, 1938, pp. 412-419.

Annotation

Purpose. To measure changes in the composition of sweat during acclimatization to heat.

Subjects. Six men.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Boston			
43/20.1/10	?	200	Walking on a moderate grade on a treadmill
Boulder City			
?			Walking over a standard course at a uniform rate, playing tennis, or sitting in the sun

Sweat was collected in a bathtub by washing the subject and his clothes or by the use of a rubber glove.

Authors' Results and Conclusions

1. Sweat tends to become more concentrated as it becomes more profuse; the more active the sweat glands, the less effectively is the chloride ion held back.
2. Sweat in man acclimatized to high temperature must be looked upon as a secretion in which one constituent, K^+ has about the same concentration as in interstitial fluid.
3. Na^+ and Cl^- may be one-tenth as concentrated as in interstitial fluid, while H^+, NH_4^+, and the lactate ion may be raised to much higher concentrations than are observed in the body.
4. In man adapted to life in the hot desert lactic acid excretion is kept at a low level; it may be balanced in part by excretion of ammonia and calcium.
5. The properties of sweat depend on acclimatization, the rate of sweating, inherent characteristics of the individual, and probably other factors.
6. It becomes more dilute with adaptation to hot atmospheres.
7. Its inorganic constituents increase in concentration as sweating becomes more profuse; at the same time, nitrogen excretion diminishes.
8. The susceptibility of some individuals to heat cramps no doubt depends in part on the inability of their sweat glands to reduce sodium chloride loss to a low level.

46. Dill, D. B., B. F. Jones, H. T. Edwards, and S. A. Oberg.
Salt economy in extreme dry heat.
J. Biol. Chem. vol. 100, 1933, pp. 755-767.

Authors' Summary

The composition of sweat produced in extreme dry heat has been studied. While laboratory examination of sweat may indicate a salt concentration nearly as great as in serum, such high concentrations are not maintained in profuse and continued sweating. Our results indicate that there is an adaptive response on the part of the organism, the concentration of salt in sweat decreasing after the first days in the hot environment. After adaption, sweat contains about 15 milli-equivalents of NaCl although one of the six individuals studied put out sweat with half this concentration.

The one proved function of sweat in normal man is its part in temperature regulation. There would be no disadvantage to the organism if sweat were free of dissolved electrolytes since the kidneys and the lungs are quite able to maintain the normal acid-base equilibrium. The sweat glands may upset this equlibrium disastrously, heat cramps occurring from loss of salt. However, such an event is uncommon; if there has been an opportunity for acclimatization the product of the sweat glands is so dilute that 10 liters per day may be secreted without the necessity of an abnormal salt intake.

47. **Dreosti, A. O.**

The results of some investigations into the medical aspect of deep mining on the Witwatersrand.

J. Chem. Metal. Mining Soc. So. Africa vol. 36, 1935, pp. 102-129.

This is one of the truly classical descriptive experimental studies of acclimatization in males. The results were obtained from over 20,000 native underground workers of the City Deep Mine between 1932 and 1935.

Annotated Results

Induction of acclimatization

1. The heat tolerance test involved shoveling rock at a rate of approximately 9,000 ft-lb/hr (1,249 kg-m/hr) for two consecutive half-hour periods at temperatures of 35/35 and RH of 88%. After the hour of work the natives went to a cooling chamber for one hour at temperatures of 26.7/22.2 and RH of 68%. No water was available during the heat tolerance test but was available during the cooling process. "Strangely enough, very few natives make use of this facility."
2. The greatest proportion of natives who had a temperature above normal after an hour's rest in the cool chamber were those natives whose final temperature upon completion of the heat tolerance test was highest. Thus, the natives who heated up more rapidly took longer to cool, implying an inability to dissipate heat.
3. Acclimatization was assumed to be established when the oral temperature remained consistently below 38.1° C [100.6° F] throughout the heat tolerance test.
4. One performance of the heat tolerance test was enough to stimulate some degree of acclimatization in a great majority of the natives.
5. The rise in oral temperature was an index of the degree of acclimatization acquired in underground work; it also indicated the severity of the atmospheric conditions where the work was done.
6. Acclimatization took place in most natives after only 14 days of underground work and the degree of acclimatization varied in different individuals. Acclimatization was progressive at least up to one month.
7. Acclimatization *cannot* be obtained if the subject worked in a cool place.
8. The process of acclimatization involved the improved ability to sweat, but in the hot-humid environment of the Rand it was not "an improved ability to sweat profusely, but rather a more regulated production of sweat."
9. Some natives appeared to require no formal heat acclimatization exposure since they were already capable of dealing with the environment. A few heat-intolerant natives acclimatized only with great difficulty.

Characteristics of acclimatization

1. The average initial temperature of the acclimatized natives was lower than that of the unacclimatized natives. Thus, the heat-regulating mechanism was adjusted to working at a lower body temperature and allowed for an increased body temperature without a pathological rise.
2. Natives from tropical areas were more acclimatized than natives from cooler areas.

3. No correlation was observed between the loss of weight (sweat) and the rise in body temperature.
4. No correlation could be established between the rise in oral temperature and pulse rate. The pulse rate was not an indicator of the efficiency of body temperature control.

Loss of acclimatization

1. A discontinuation of work in a hot-humid environment resulted in a rapid loss of acclimatization for this environment. The acquired acclimatization conferred no permanent immunity for the individual. The loss of acclimatization occurred within one month, particularly if illness occurred during the deacclimatization period.

General observations

1. Muscular work increased heat production, which is commensurate with the intensity of the work.
2. The rise in body temperature alone produced no pathological effects, and those natives with very high final oral temperatures showed no appreciable signs of fatigue or discomfort when compared with natives who had lower final temperatures.

48. **Eagan, C. J.**
Introduction and terminology.
Federation Proc. vol. 22, 1963, pp. 930-932.

An outline of terminology is presented in regard to the changes that occur in organisms resulting from various thermal stimulations.

Author's Summary

Adaptation. Includes all the acute or chronic established adjustments of organisms due to environmental stimulation regardless of the portion or the extent of the mass of the particular organism exposed.

1. *Genetic adaptation* ... used for alterations which favor survival of a species or of a strain in a particular environment, which alterations have become part of the genetic heritage of the particular species or strain.
2. *Acclimatization* ... to a complex of environmental factors, as in seasonal or climatic changes.
3. *Acclimation* ... to a single environmental factor, as in controlled experiments.
4. *Habituation* ... change in physiological response or in sensation resulting from a diminution in the responsiveness of the central nervous system to certain stimuli.
5. *Nonspecific adaptation* , ... used where knowledge of the environmental conditions, the nature of the stimulus or exposure, or the alterations in the organism is not well enough defined to warrant the assignation of any of the categorical terms listed above.

49. **Edholm, O. G., R. H. Fox, J. M. Adam, and R. Goldsmith.**
Comparison of artificial and natural acclimatization.
Federation Proc. vol. 22, 1963, pp. 709-715.*

Annotation

Purpose. To compare the effects of natural and artificial acclimatization on performance of individuals going to a hot climate and engaging in a wide range of different activities.

Subjects. Fifty-four British Army men, ages 18 to 25, mean 21 years, divided into three groups for phase 2, outlined below: (1) unacclimatized, continued training in Scotland in cool environment; (2) natural acclimatization, sent to Aden and continued training in hot environment; and (3) artificial acclimatization, 4 weeks of heat exposure at Hampstead in London.

*From Army Personnel Research Committee. *Med. Res. Council Rept.* 61/25, London, 1961.

Conditions. Phase 1, an initial period of testing for all 54 men and first uniformity test; phase 2, second uniformity test at Hampstead, all three groups flown to Aden for the field trial, and third uniformity test at Hampstead.

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
40/32/57%	15.2	110	Bench stepping, 30.5 cm at 12 steps per min

Results and conclusions. In the second uniformity test, all three groups showed some increase in sweat loss and a substantial decrease in body temperature. The largest pulse rate decrease occurred in the artificially acclimatized group, whereas the naturally acclimatized and unacclimatized groups had small and approximately equal falls. In the third uniformity test, the sweat losses of the unacclimatized group showed a substantial increase. The hot, humid climate for the uniformity tests allowed a large part of the increase in sweat loss to drip off without conferring the benefits of evaporative cooling and consequent lowering of body temperatures and pulse rates.

1. The most striking result of this study was the very marked superiority of the naturally acclimatized subjects over the other two groups on the basis of subjective field test scores.
2. The unacclimatized group probably developed a measure of acclimatization during their period in Scotland, probably as the result of the metabolic heat stress of intensive physical training.
3. The findings strongly indicate that natural acclimatization in the hot region in which the subjects will have to work confers additional benefits to those of simply training the thermoregulatory mechanisms.

50. **Edholm, O. G., R. H. Fox, R. Goldsmith, I. F. G. Hampton, and K. V. Pillai.**
A comparison of heat acclimatization in Indians and Europeans.
J. Physiol. vol. 177, 1964, pp. 15P-16P.

Annotation

Purpose. To investigate possible differences between ethnic groups in their physiological responses to heat acclimatization.

Subjects. Nineteen Indian men, mean age 23, height 169 cm, weight 60.8 kg; and eighteen European men, mean age 21, height 172 cm, weight 68.0 kg.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
40/32/57	15.2	110	Bench stepping, 30.5 cm high at 12 steps/min

The Indians were tested while still naturally acclimatized to heat upon arrival from India (test 1); again after 3 months in England without heat exposure (test 2); and finally after 10 days of intensive artificial acclimatization (test 3). The initially unacclimatized Europeans were tested before (test 2) and after artificial acclimatization (test 3).

Results and conclusions.

1. Natural acclimatization: the Indians had the same sweat loss but lower body temperatures ($P < 0.01$) than the unacclimatized Europeans.
2. After 3 months in England: the Indians sweated less ($P < 0.001$) but had the same body temperatures as the unacclimatized Europeans.
3. After artificial acclimatization: the sweat loss of the Indians only returned to their initial naturally acclimatized level, but the Europeans sweated significantly more ($P < 0.001$). At the end of the test the Indians' body temperatures were higher ($P < 0.01$) than those of the Europeans.

It was concluded that the differences in response of the Indian subjects are not due to their smaller body size; rather, they appear to indicate either an ethnic difference or a difference resulting from the long natural exposure to a hot climate.

51. **Edholm, O. G., R. H. Fox, R. Goldsmith, I.F.G. Hampton, C. R. Underwood, E. J. Ward, H. S. Wolff, J. M. Adam, and J. R. Allen.**
Acclimatization to heat. The effect of heat on food and water intake on acclimatized and unacclimatized men.
National Institute for Medical Research, Hampstead, London, NW 3. Army Personnel Research Committee Project P. 21, 64/16, June 1964, 239 pp.

Annotation

Forty-eight men of the 16th Parachute Brigade were studied to determine (1) the effects of heat on food and water intake and any modifications due to heat acclimatization, and (2) the magnitude of heat stress on exceptionally fit men inured to hardship.

The study was divided into three phrases of 12 days each. Phase 1 was carried out in the United Kingdom with 24 unacclimatized men from the 1st Battalion of the Parachute Brigade. Phase 2 was conducted in Aden comparing the 24 men from phase 1 with 24 acclimatized men from the 3rd Battalion who had been stationed in Aden for 9 months. At the end of phase 2 both platoons were flown to the United Kingdom where phase 3 was carried out. In each phase, the first 4 days were spent in the field, the second 4 days in the barracks, and the last 4 days in the field. In the field the food was standard 24-hour pack rations and the Compo ration was eaten during the intermediate days in the barracks. A mobile canteen visited the men in the field in the evenings. In Aden, supplementary fresh fruit was occasionally added to the standard rations both in the field and in the barracks.

Authors' Conclusions

1. The food intake of men working in the heat was reduced by approximately 25% compared with the intake when the same work was carried out in a temperate climate.
2. There was a similar reduction in food intake in both acclimatized and unacclimatized men.
3. The proportion of calories provided by protein, fat and carbohydrate was alike in acclimatized and unacclimatized men in the heat, and these proportions were similar during the period of the trial in a temperate climate.

4. Many items of the 24-hour pack were wasted both in the temperate and hot conditions. Over 70% of the biscuit, plain and sweet, was discarded in Aden and over 60% in the U. K. In Aden, chocolate and sweets were wasted more than in the U. K. Seventy-nine percent of the chocolate was discarded in Aden compared with 10% in the U. K.

5. With the exception of chocolate, the order of popularity of the items in the 24-hour pack was similar in temperate and hot conditions.

6. The calculated energy balances of the two groups of men were identical in temperate conditions. In the heat, both groups had a calorie deficit but the unacclimatized group had a larger deficit by the end of the 12-day trial than the acclimatized.

7. There was a large weight loss in the unacclimatized men during the 12-day trial in Aden, and only a small weight loss in the acclimatized men in the same period.

8. In the heat, body temperatures rose higher after exercise in the unacclimatized men than in the acclimatized. The difference was considerable during the first 4 days, but diminished and was insignificant by the end of the trial.

9. Heart rate, after exercise in the heat, was significantly higher in the unacclimatized men only on the first day in Aden. When the subjects were not exercising, the unacclimatized men had, in general, a higher heart rate.

10. The water intake of both groups of men was high during the trial in the heat, but the acclimatized men had consistently a larger intake than the unacclimatized men. In the three parts of the Aden trial, i.e., the first 4 hard days, the next 4 soft days and the final 4 hard days, the water intake of the unacclimatized men averaged 7.5 litres/day, 4.9 litres/day, and 8.8 litres/day. The corresponding figures for the acclimatized men were 8.6, 5.3, and 10.1 litres/day.

11. In the heat, the calculated sweat loss of the acclimatized men was greater than in the unacclimatized. There was an increase in sweat loss in both groups in the second period of hard work compared with the first period.

12. The urine output in the heat was higher in the unacclimatized men than in the acclimatized.

13. In the heat, the incidence of casualties from all causes was much higher in the unacclimatized men. Of a total of 21 cases of heat illness, 19 came from the unacclimatized platoon. Eighteen of these 21 cases of heat illness occurred during the first 4 hard days.

14. Subjects who became heat casualties were significantly heavier and had thicker skinfolds, drank less water, ate less food and had lower sweat rates than those men who did not suffer from heat illness.

15. Biochemical changes in blood and urine were similar in the two groups, both in Aden and the U. K. There was evidence in both groups of a haemo-dilution in the heat, accentuated by exercise. This effect was probably due to an increased plasma volume.

16. There were no significant differences between the two platoons during the third phase in the U. K. in any of the observations made.

17. The differences between acclimatized and unacclimatized men in the heat are striking, including differences in performance, and these effects are very evident even when exceptionally fit men of high morale, with excellent leadership, are studied.

52. **Eichna, L. W., W. F. Ashe, W. B. Bean, and W. B. Shelley.**
The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments.
J. Indust. Hyg. Toxicol. vol. 27, 1945, pp. 59-84.*

Annotation

Purpose. To define the environmental ceiling for work in heat and emphasize the necessity for controlling the state of acclimatization, nature of the environment (temperature, humidity, wind, radiation, etc.) the type and intensity of the work, the physical fitness and morale of the subjects, their clothing, diet, and salt and water intake.

Subjects and conditions. Thirteen men, first acclimatized to dry and moist heat. Subjects then worked in 14 environments ranging from DBT of 93° to 121° F [33.9-49.4° C] and WBT of 90° to 96° F [32.2-35.6° C].

Authors' Results

The WBT is the important limiting factor determining the ability of men to work in hot environments. The DBT has a minor influence. The limiting WBT is approximately 2° F higher at a DBT of 100° F [37.8° C] than at 120° F [48.9° C].

Near the upper limits, the range of WBT from an environment in which men work with "relative ease" to one in which work is "impossible," is very narrow: 4 to 5° F for a given DBT.

Below a WBT of 91° F [32.8° C] men work easily and efficiently.

Between WBT of 91° F [32.8° C] and 94° F [34.4° C] men can work but with difficulty, loss of vigor and alertness, and undesirable physiologic changes.

At WBT of 94° F [34.4° C] and higher, less than an hour of sustained work is possible; acute disability with marked physiologic changes occurs.

Near the upper limits sweating averaged 2.5 liters per hour and reached 3.5 liters in some men.

Undesirable physiologic changes encountered near the upper limits include: (1) Heart rates of 150 to 180; (2) rectal temperatures of 102 to 103.5° F [38.9 to 39.7° C]; (3) average (weighted) skin temperatures approaching 101° F [38.3° C]; and (4) violent and protracted headache, nausea, copious vomiting, abdominal cramps, severe weakness, vertigo, dyspnea, paresthesias, stumbling, disorientation, and collapse with syncope.

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*Same as: Bean, W. B., L. W. Eichna, and W. F. Ashe. The upper limits of heat and humidity tolerated by acclimatized men working in hot environments. *J. Lab. Clin. Med.* vol. 30, 1945, pp. 357-358.

53. **Eichna, L. W., and W. B. Bean.**
Orthostatic hypotension in normal young men following physical exertion, environmental thermal loads, or both.
J. Clin. Invest. vol. 23, 1944, p. 942.

Authors' Summary

Symptomatic, and usually disabling, orthostatic hypotension was a common occurrence in healthy young men subjected to strenuous physical exertion or hot environments or both. The exertions ranged from severe, quickly exhausting effort to prolonged endurance hikes. The climatic stresses consisted of hot, dry [120° F (48.9° C) relative humidity 15 to 20 per cent] and hot, humid [90° F (32.2° C) relative humidity 95 per cent] environments.

The syndrome occurred with equal frequency in fit and unfit men and its manifestations were similar, regardless of the inducing stress. Bradycardia occurred often and in 2 men progressed to asystole which in one man persisted for 19 seconds. The duration of the hypotension varied from: (*a*) a fraction of an hour to several hours after short severe exertion, (*b*) several hours to half a day after moderate prolonged exertion, (*c*) one to several days during rest and work in hot environments. The hypotension induced by a specific stress disappeared with repetition to the stress when it was exertion or with a continuation of it when thermal (acclimatization). It reappeared when the stress (especially thermal) was repeated after a long lapse. While erect, the symptoms and circulatory manifestations were prevented or, when present, alleviated rapidly by (*a*) moving the legs, (*b*) occluding the arterial circulation to the legs, and (*c*) removal to a cool room when the stress was thermal.

Orthostatic hypotension is a common occurrence in normal men subjected to various stresses and represents one of the manifestations of the failure of the circulation to cope with the load imposed.

54. **Eichna, L. W., W. B. Bean, W. F. Ashe, and N. Nelson.**
Performance in relation to environmental temperature. Reactions of normal young men to hot, humid (simulated jungle) environment.
Bull. Johns Hopkins Hosp. vol. 76, 1945, pp. 25-58.

Annotation

Purpose. To study the reactions of normal young men to a hot, humid environment and to derive several general principles which govern the acclimatization.

Subjects. Sixty-four healthy American enlisted soldiers, ages 19-33 years; all but six were between 19 and 24 years, and were in differing states of physical fitness.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²•hr)*	*Exercise*
Daytime (8 A.M.-5 P.M.)			
31.7-34.2/30.6-33.3/88-100%	?	?	Walking and carrying 20-lb pack, at the rate of 5.1 km/hr for 47 min with a total distance of 20.1 km/day
Night (6 P.M.-7 A.M.)			
25.6-30.6/20.1-28.4/60-85%	?	?	

Men lived in hot room day and night from 8 days to 4 weeks. Men usually wore regulation Army jungle coveralls, shorts, socks, and jungle boots. Men drank 0.1% saline ad lib.

Authors' Results and Conclusions

1. Men adapt themselves to work in humid heat by a process of acclimatization which enables them to work more efficiently and with less risk of illness than when first exposed.
2. The acclimatized man works with a lower heart rate, lower skin and rectal temperature, more stable blood pressure and less discomfort than when unacclimatized.
3. Acclimatization to heat begins with the first exposure, is achieved most rapidly and completely by progressively increased work in the heat, and is complete in 7 to 10 days.
4. Resting in humid heat induces but little acclimatization.
5. Physically fit men acclimatize more rapidly than unfit men and when acclimatized are capable of more efficient work.
6. Acclimatization develops most rapidly when the original environment is warm (summer) and is retained longest when the return is into a warm climate.
7. Strenuous work on first exposure to humid heat is not well tolerated and leads to disability which, however, need not retard nor decrease the final acclimatization attained, provided rest, water, and salt are supplied.
8. There is a measure of cross acclimatization between hot-dry and hot-humid environments.
9. The performance of acclimatized men in humid heat is impaired most seriously by lack of adequate water intake and lack of physical fitness.
10. It is also affected adversely, but not so severely, by lack of rest and sleep, by added clothing and equipment, alcohol and long periods of work.
11. Sweating in humid heat is profuse, grossly inefficient, wastes water and salt and is independent of the fluid intake.
12. Replacement of the lost water and salt is essential to efficient performance.
13. Thirst is a lagging guide to these needs.
14. With continued exposure to heat, the voluntary water intake during work increases and more nearly approaches the sweat loss: smaller water deficits result and performance is aided. It is not clear whether this voluntary increase in water intake is the result of the removal of symptoms masking thirst, an increased sensitivity of the thirst mechanism, or merely a learning of the need for water.
15. Acclimatization was retained best by those men who had remained physically fit in the interval between exposures to humid heat.

55. **Eichna, L. W., C. R. Park, N. Nelson, S. M. Horvath, and E. D. Palmes.**
Thermal regulation during acclimatization in a hot, dry (desert type) environment.
Am. J. Physiol. vol. 163, 1950, pp. 585-597.

Annotation

Definition. The development of adaptive mechanisms that permit work to be performed at nearly the same rectal temperature as in the cool. "The process of acclimatization restores the normal relationship whereby once again the rectal temperature is determined by the metabolic rate."

Purpose. To study the thermal balance during heat acclimatization.

Subjects. Three healthy men physically conditioned by treadmill and road marching during a period of 14 days.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Cool control-pre			
25.6/16.7/39%	137.2	185	4 km/hr for 1 hr for 9 days on treadmill at 2.5% grade; 4 hr rest; 4 km/hr for 2 hr on treadmill at 2.5% grade plus 20-lb packs
Hot experiments			
50.6/26.7/15%	137.2	176	4 km/hr for 1 hr for 10 days on treadmill at 2.5% grade; 4 hr rest; 4 km/hr for 2 hr on treadmill at 2.5% grade plus 20-lb packs
Cool control-post			
25.6/16.7/39%	137.2	178	4 km/hr for 1 hr for 2 days on treadmill at 2.5% grade

Salted water (0.1% NaCl) at body temperature was drunk to equal sweat loss. The men walked nude except for shoes and socks. The authors studied three aspects of thermal balance: heat content and heat distribution, heat interchanges between the man and environment, and the flow of heat within the body. Partitional calorimetry was used to estimate thermal interchanges and total thermal balance.

Authors' Results and Conclusions

One may postulate the following events when an unacclimatized man works in a hot environment. The body gains heat rapidly, at the surface by convection and radiation and internally by metabolic heat production. Due to the high environmental temperature the skin temperature rises. This results in a reduction in the external thermal gradient and hence in a lessening of the environmental heat gains. On the other hand, the internal thermal gradient is also decreased. Heat flow from deep to surface tissues is impaired and deep tissue temperature rises. Sweating becomes profuse but the increased evaporative cooling proves inadequate to dissipate all of the heat gains and deep tissue temperature rises progressively. Because of the small internal thermal gradient a large "peripheral blood flow" is required to transport to the surface the heat which is dissipated, leaving an inadequate blood flow for the needs of all of the other organs. The two cardinal manifestations of the unacclimatized state have resulted, (1) an elevated body temperature and (2) an overtaxed, unstable circulation.

During acclimatization thermo-regulating adjustments develop so that temperature is again regulated with respect to metabolic rate and rectal temperature returns to the level attained when the same work was performed in a cool environment. Moreover, only deep tissue temperature is so regulated. Thus, equal increases in deep tissue heat content occurred in the cool environment and when acclimatized in the heat, in contrast to the markedly different heat contents of the peripheral tissues in the two environments. This substantiates Nielson's findings that the temperature of the deep tissues or some part of these tissues is normally regulated by the metabolic rate of a given task and is apparently critical for normal physiologic function. Skin temperature is not similarly adjusted, may vary widely, and tends to approach environmental temperature. . . . The tolerance of the skin for large temperature changes serves temperature regulation in two ways: (*a*) changes in peripheral heat content, occurring without significant changes in deep tissue temperature, temporarily buffer critical deep tissue temperature against sudden, transient changes in environmental heat loads, (*b*) the change in skin temperature toward environmental temperature diminishes heat interchanges with the environment.

The principal adaptation of acclimatization which returned deep tissue temperature to normal was increased sweat secretion. The resultant increase in evaporative cooling largely restored the thermal balance, accounting for 90 per cent of the reduction in body heat content achieved by day 4 and for at least 75 per cent of the reduction on day 10. The small decrease in metabolic heat production (4%) played at best a minor role but could have accounted for approximately one-fourth of the fall in body heat content achieved by day 10. Moreover, its slow, steady fall differed from the initially more rapid changes observed in all other indices of acclimatization.

We may now summarize what the process of acclimatization achieves. Deep tissue temperature is returned to the normal level set by the metabolic rate of the task in a cool environment, but neither total body temperature nor mean skin temperature are returned to their levels in the cool environment. Mean skin temperature is adjusted to a level which permits thermal equilibrium between the body and the environment on the one hand, and on the other, maintains an internal thermal gradient which permits the transport of the deep heat to the surface without overtaxing the circulation. In the hot, dry environment of this study these conditions were attained almost wholly as a result of the increased evaporative cooling which an increased sweat secretion produced.

Authors' Summary

1. The acclimatization process returned the elevated deep tissue (rectal) temperature to the normal level determined by the metabolic rate of the task in a cool environment and set the peripheral tissue (mean skin) temperature at a level which permitted thermal equilibrium between the body and environment on the one hand, and on the other, permitted the transport of deep heat to the periphery without overtaxing the circulation.
2. The principal adaptive mechanism of acclimatization which produced these changes was a further increase (10%) in sweat production. The resultant increase in evaporative cooling accounted for 75 to 90 per cent of the reduction in body temperature and heat content. A small decrease (4%) in metabolic heat production accounted for only 5 to 20 per cent of the reduction in body heat content.
3. The increased evaporative cooling of the acclimatized state lowered the skin temperature and produced thereby two dissimilar effects: (*a*) heat gains by convection and radiation increased (8%) and this necessitated twice as large an increase in sweat secretion as would have been required had the skin temperature not fallen, (*b*) the internal thermal gradient widened so that a smaller (70%) "peripheral blood flow" sufficed to transfer the required deep heat to the periphery.

56. **Eijkman, C.**
Some questions concerning the influence of tropical climate on man.
Lancet vol. 1, 1924, pp. 887-893.

Author's Summary: Acclimatisation

We have seen that the old notions formed about the process of acclimatisation have as yet not been confirmed by direct investigation. It has not been possible to prove the existence of what might be called physiological anaemia. In a condition of rest and of moderate labour the metabolism, and consequently the heat production, has been found by us to be on the same level in the two races, and not more considerable in a cool climate than in a hot one. In accordance with the assumption that there is a lack of chemical heat regulation, we see the physical one in the hot environment coming very much in evidence.

The chief objectively perceptible difference between the two races consists in the function of the skin. The coloured man is by his pigmentation better protected against the chemical active rays of the sun, and he is not so subject to excessive sweating. Now, in those two respects there can be, in some degree, a question of acclimatisation for the white, though not to such an extent that he can compare with the coloured man. For the rest it would appear to me that the much-discussed acclimatisation consists rather in an external than an internal process; rather in making, by imitation and custom, a second nature of a manner of living more adapted to the climate than in adequate changes of the bodily organisation as such. Hence, let us have no manner of living, no house arrangements and clothing such as tyrannical fashion prescribed in Europe, and which are but too often slavishly imitated in the tropics. Indeed, the native's frugality both in respect to food and drink, his, as a rule, calm, resigned view of life, his rule of *festina lente,* would deserve, *from a purely sanitary standpoint,* to be set as an example to the white sojourner in the tropics; at the risk, however, of his being after all no more in the full sense the pushing power, so necessary for the development of tropical countries. In the meantime, it would be rash to conclude from the results of comparative race physiology that the former pessimistic views ought to be absolutely relegated to the realm of myths, as some, partly on the strength of my experiments, have already done. The latter are, if I may say so with due modesty, "plus royalistes que le roi." Our investigations in the tropics have been limited to the condition of rest or light labour. What would have been the results could they have been extended to heavy labour, and especially of long duration, which makes higher demands on the bodily functions, and not the least on the compensatory actions? Will not, then, the heat regulation in the white prove to be sooner insufficient, and will not the fatigue, the ultimate exhaustion, set in sooner than in the coloured man? Will habituation, adaptation, training, in short, acclimatisation, appear possible then? These questions cannot be answered, as has been done, by postulating equality, even with regard to the climate, on the strength of anthropological theories. Although we accept the unity of origin of mankind, it will remain, no doubt, true for ever that what ages and climate have separated cannot be brought together again at once by an authoritative pronouncement.

It is true that coloured man, too, does not walk under palm trees with impunity; he, too, suffers from the heat; he, too, is as a rule, studious of his ease. But still, there is no denying that the atmosphere of the tropics, often so windless, so leaden, oppresses him less than it does the white, to whom continuous mental and physical strain can become quite a torture. There are, indeed, instances of whites in the tropics braving fatigues when out hunting or on military marches, although we must not overlook the fact that not a few have fallen victims to these exertions, or that

such strenuous efforts were followed by an ample time of rest. This is not the same as continuous rather heavy labour, even during the hottest part of the day, such as is performed by an agricultural population.

It has been pointed out that on streamers in the torrid zone the European stokers are advantageously replaced by Negroes and East Indians. Schmidt, on the contrary, found that with the same amount of labour, the Negroes were not superior to the whites. He could not discover any difference in the increase of body temperature, the pulse, and the respiratory frequency. Hilger, however, found that after labour in an overheated space the body temperature of a Negro returned sooner to the normal than that of a couple of whites. And even Schmidt questions whether, as is the case with the native, the white's working power will in the long run maintain itself in the tropical heat, which is after all the principal thing.

What it really is that makes the heat so exhausting we are far from apprehending. The physiology and pathology of fatigue are still a little explored field. By the adoption of toxins as products of muscle metabolism not all cases are explained, ours among the rest; for fatigue in the heat makes itself felt often immediately after waking in the morning, and is often lessened by slight bodily exercise. The state of weariness and listlessness coupled with psychical irritability, to which the European gradually becomes subject in the tropics, has always reminded me of the syndrome to which has been given the name of neurasthenia or nervous exhaustion. So far it would be better to speak of tropical neurasthenia than of tropical anaemia, only we should then easily form an exaggerated notion of it. If no naturally weak nervous system, no mental or physical overstrain, no illness, no aggravating circumstances of a social or moral nature have contributed their share the phenomena are pretty transient; they disappear as soon as fresher air surrounds us.

57. **Ejsmont, W., B. Lewalski, J. Waskiewicz, and A. Went.**
The problem of acclimatization to hot-climate regions. I. Some physiological indicators in persons examined in the high temperature chamber.
Bull. Inst. of Marine Med. in Gdansk (Poland) vol. 15, 1964, pp. 185-192.

Annotation

In this study 360 men, ages 21 to 56 (mean 33), were tested at rest for 110 min and during the following 10 min during exercise equal to 80 kgm. The first 30 min were spent at 36° C DBT, 31.9° C WBT, 40% RH, and air motion of 2.4 m/min; the following 90 min were spent at 36° C DBT, 34.5° C WBT, 90% RH, and air motion of 1.8 m/min. Of the 360 subjects, 85 were selected as being partially acclimatized due to their occupation as engine-room workers on ships.

The results are summarized as follows:

1. The 2-hr heat exposure led to an acceleration of the heart rate, increased vital capacity, fall in systolic and diastolic blood pressures, and an increased minute volume of the heart.
2. Nonacclimatized subjects had a greater increase in heart rate and minute volume than the engine-room workers.
3. The subjects over 40 years of age had a decreased tolerance when compared with the younger men.

58. **Falbriard, A., A. F. Muller, R. Neher, and R. S. Mach.**
Étude des variations de l'aldostéronurie sous l'éffet de surcharges en potassium et de deperditions renáles et extrarénales de sel et d'eau.
Schweizerische Medizinische Wochenschrift vol. 85, 1955, pp. 1218-1220.

Authors' Summary

Aldosterone definitely increases in the urine of normal subjects after a potassium load, the administration of a carbonic anhydrase inhibitor, or the combination of both, as well as during profuse perspiration. This effect seems to be due to the loss of sodium and water which these different factors produce. However, during an overload of potassium, one cannot exclude the direct action of this electrolyte on the secretion of aldosterone.

During perspiration, the loss of water is relatively more pronounced than that of sodium. The decrease in the extracellular volume could be suspected as a primary cause of hormonal hyperactivity.

The secretion of aldosterone seems to be an important mechanism of adaptation and conservation of salt and water.

59. **Fletcher, K. A., C. S. Leithead, T. Deegan, M. A. Pallister, A. R. Lind, and B. G. Maegraith.**
Aldosterone excretion in acclimatization to heat.
Ann. Trop. Med. Parasit. vol. 55, 1961, pp. 498-504.

Authors' Summary

Aldosterone was measured in consecutive 24-hour urine specimens collected from nine men for three days before departure from the United Kingdom and for five days following arrival in the extreme summer heat of Kuwait. It was also measured in 24-hour samples of urine from five residents in the United Kingdom and from eight British expatriates resident in Kuwait. The subjects were all healthy young men. The conclusions from the investigation were as follows:

1. The range and mean value of aldosterone found in 32 24-hour urine specimens collected in the United Kingdom from 14 subjects were, respectively, 1.8-19.2 μg and 8.7±3.7 μg.
2. In the five days following their arrival in the heat, there was no significant increase in the urinary aldosterone of six subjects who performed only light duties and maintained a generous intake of water and salt.
3. There was, however, an increase in the urinary aldosterone of three subjects who commenced work on the day after arrival in the heat, limited their water-intake to little more than the requirements of thirst, and took no extra salt.

4. The range and mean values of aldosterone found in single 24-hour specimens from eight British expatriates resident for some years in Kuwait were, respectively, 5.0-25.0 μg and 13.4±6.8 μg.

60. **Forbes, W. H., D. B. Dill, and F. G. Hall.**
The effect of climate upon the volumes of blood and of tissue fluid in man.
Am. J. Physiol. vol. 130, 1940, pp. 739-746.

Authors' Summary

A group of ten white laboratory workers on moving to a hot, damp climate for the summer showed on the average a small increase in the volumes of both blood and plasma, both absolute and relative to body weight and to surface area. The average change was 12 per cent.

The interstitial fluid, defined as the fluid outside the cells and outside the blood vessels, decreased in the heat 11 per cent on the average but the range was from -34 to +26 per cent.

There was no difference between the colored sharecroppers, the white sharecroppers, and the laboratory workers while in Mississippi in respect to plasma volume per unit of surface area but the interstitial fluid volume was 25 per cent higher in the Negroes than it was in the white sharecroppers or the white laboratory workers.

61. **Fox, R. H., R. Goldsmith, I.F.G. Hampton, and T. J. Hunt.**
The influence of acclimatizing man to heat on his temperature regulation at rest in a comfortable environment.
J. Physiol. vol. 183, 1965, pp. 18-19.

Annotation

This study examined four possible explanations for the observed drop in oral temperature after heat acclimatization: (*a*) a change in the normal level for body temperature regulation; (*b*) a change in the body core to surface temperature gradients; (*c*) a change in the diurnal temperature pattern; and (*d*) a more prompt correction of set-point deviations for temperature control due to heightened sensitivity of the thermoregulatory mechanisms. Acclimatization was induced by a passive technique of controlled hyperthermia with ten 2-hr heating periods at 38.2° C and 3 periods at 39.0° C. Results are summarized below:

1. The average values of the four internal body temperatures were all lower after acclimatization: aural -0.12° C, oral -0.19° C, rectal -0.17° C, and intestinal -0.17° C.
2. Intestinal and aural temperatures were lower at night as well as during the day. Skin temperature did not change.
3. The pattern of the diurnal temperature changes was not changed by acclimatization.

Authors' Conclusions

The results confirm that heat acclimatization produces a small decrease in the level at which internal body temperature is regulated, when the measurements are made with subjects sedentary and living in a thermally comfortable environment; they exclude alternative explanations based on changes in the diurnal rhythm pattern, core to periphery temperature gradients, or sensitivity of the thermoregulatory mechanisms to minor deviations from the set-point for temperature control.

62. **Fox, R. H., R. Goldsmith, I.F.G. Hampton, and T. J. Hunt.**
Heat acclimatization by controlled hyperthermia in hot-dry and hot-wet climates.
J. Appl. Physiol. vol. 22, 1967, pp. 39-46.

Authors' Abstract

Acclimatization by controlled hyperthermia [38.2° C for 2 hr daily for 12 days] of one group of subjects in hot-dry conditions was compared with the same exposure of a second group in hot-wet conditions. Compared in the same standard tests both groups initially responded equally and after acclimatization both had developed marked and similar improvements in response. However, arm sweat measurements showed that there was a difference in the effects of the two climates on the sweat suppression phenomenon. Arms that had been exposed to hot-wet conditions throughout acclimatization developed a reduced rate of sweat suppression not seen in the arms exposed throughout to hot-dry conditions. This difference between acclimatization in hot-wet and hot-dry conditions could be important in determining the subject's subsequent tolerance to heat, especially when the exposure is prolonged and the conditions are humid. It is suggested that when sweat rate is used as an index of acclimatization both the maximum sweating capacity for a given increase in body temperature and the rate of sweat suppression need to be measured.

63. **Fox, R. H., R. Goldsmith, I.F.G. Hampton, and H. E. Lewis.**
The nature of the increase in sweating capacity produced by heat acclimatization.
J. Physiol. vol. 171, 1964, pp. 368-376.*

Annotation

Purpose. To investigate the effects of repeated local heating on the local sweating response and the effects of suppressing sweating locally while acclimatizing the subject as a whole.

Subjects. Twelve soldiers, ages 18 to 24.

Conditions

Group 1: 37.9° C oral temperature, 2 hr/day for 15 days resting in vapor-barrier suits. Arm immersed in water at 13° C inside a plastic bag.

Group 2: Same as group 1; arm immersed at 37° C.

Group 3: Same as group 1; arm immersed at 43° C.

Group 4: Not acclimatized. Seated in a cool room. Arm immersed at 43° C for 2 hr/day for 15 days.

Two standard tests were performed before and after the acclimatization procedures similar to the acclimatization sessions except the oral temperature was 38.5° C and both arms were enclosed in the plastic arm bags and not immersed in water.

Sweat loss was estimated from changes in body weight. Skin temperatures were not measured.

Authors' Results and Conclusions

1. The results of the arm sweat loss measurements in the standard tests show that heating one arm to 43° C daily without acclimatizing the subject as a whole leads to an increase in

*Same as: Fox, R. H., R. Goldsmith, I.F.G. Hampton, and H. E. Lewis. The mechanism of the increase in sweating capacity induced by heat acclimatization. *J. Physiol.* vol. 162, 1962, pp. 59P-60P.

the sweating capacity of the heated arm. Immersing the arms in water at 13 ° C during acclimatization prevented the local increase in sweating capacity, immersion at 37° C had no effect, and immersion at 43° C augmented the local response.

2. The sessions of controlled hyperthermia increased total body sweat loss 1-1/2 times, whereas the sweat rates of the control arms rose fourfold.

3. There was no evidence that the local temperature of the arm affected total body sweat loss during the acclimatization period.

4. It is concluded that the local skin temperature influences the local sweat rate and thereby also influences the local increase in secretory capacity resulting from repeated heat exposures. The results are consistent with the theory that the increase in sweating capacity which occurs during heat acclimatization is primarily a local training response of the sweat glands and not the result of an increased intensity of stimulation by the central nervous system.

64. **Fox, R. H., R. Goldsmith, D. J. Kidd, and H. E. Lewis.**
Blood flow and other thermoregulatory changes with acclimatization to heat.
J. Physiol. vol. 166, 1963, pp. 548-562.*

Annotation

Purpose. To investigate the changes in peripheral blood flow in relation to elevation in oral temperature before and after a period of heat treatment.

Subjects. Twenty soldiers, ages 18 to 27, from the Scots Guards, Irish Guards, and the Queen's Own Buffs.

Authors' Summary

1. The vasomotor and sudomotor responses of twenty subjects to a standardized heat-stress test were studied before and after acclimatization to heat. Peripheral blood flow, oral temperature, pulse rate, the time of sweat onset and the sweat rate were measured with the subjects sitting in a water-bath, the temperature of which was slowly raised. The effects of increased heat elimination by evaporation of sweat were minimized in order that the rises of body temperature should be similar on both occasions.

2. Blood flow in the vasoconstrictor release areas (the hand and ear) rose steadily from the time of the onset of heating, while in the forearm and chest there was a pronounced increase in the rate of rise of blood flow associated with the onset of sweating.

3. Blood flow of all areas studied increased relative to body temperature after acclimatization; in the forearm the increase was about one-third, while in the hand it was only about one-tenth.

4. Pre-heat body temperatures were, on average, 0.19° C lower after acclimatization.

5. After acclimatization the onset of sweating occurred when the body temperature was 0.18° C lower and the water-bath temperature 0.36° C lower. Both before and after acclimatization sweating began when body temperature was still below the pre-heating levels. Sweat rate was higher relative to body temperature after acclimatization.

6. Resting pulse rate, and pulse rate relative to blood flow were lower after acclimatization.

*Same as: Fox, R. H., R. Goldsmith, D. J. Kidd, and H. E. Lewis. Changes in peripheral blood flow with heat acclimatization. *J. Physiol.* vol. 157, 1961, pp. 57P-58P.

7. There was no evidence of a lessening of subjective discomfort after acclimatization.
8. The results are discussed in relation to previous studies and it is considered that the decrease in peripheral blood flow previously shown was due to improved heat elimination leading to lower body temperatures. It is suggested that the increased blood flows found here may, in part, be due to repeated vasodilatation.
9. The lower resting body temperature and the earlier onset of sweating are attributed to an increased sensitivity of the thermoregulatory system.

65. **Fox, R. H., R. Goldsmith, D. J. Kidd, and H. E. Lewis.**
Acclimatization to heat in man by controlled elevation of body temperature.
J. Physiol. vol. 166, 1963, pp. 530-547.*

Annotation

Purpose. To describe a method of achieving a controlled elevation of body temperature and the acclimatization response evoked by the procedure.

Subjects. Twenty-one healthy soldiers of the Scots Guards ages 20 to 23, mean 21.2.

Conditions. Body temperature was elevated on 12 days to three different levels – 37.3°, 37.9°, and 38.5° C – for 1/2, 1, and 2 hr in all combinations by encasing the subjects in plastic vapor-barrier suits. A uniformity test was given before and after the 12 exposures and consisted of stool-stepping [30.5 cm high at 12 steps per min, 110 kcal/($m^2 \cdot$hr)] at 40 DBT, 32 WBT, and wind speed 25 cm/sec, for two 1/2-hr periods with 1/2-hr rest between exertions.

Results and conclusions

1. The sweat rates increased progressively over the 12 days, but there was either no change or an increase in the heart rates at raised temperature and the subjects' sensations of discomfort deteriorated rather than improved. Pulse rates during temperature elevation were either unchanged or higher.
2. The results of the uniformity tests indicated that the heat treatment elicited increases in sweat rates, but the changes in pulse rates and oral temperatures were not always greater for the heat-treated than for the untreated subjects. By changing the humidity of the uniformity tests to 20 percent so all the sweat would evaporate, the final oral temperatures and pulse rates showed large reductions and subjective discomfort was markedly reduced. A part of the large decrease in pulse rates normally observed when using the conventional technique may be due to the improved cardiovascular efficiency resulting from the repeated performance of a particular physical exercise, and such a training effect might be greater than usual when the cardiovascular demands of a high peripheral blood flow are added to those of the working muscles.
3. When heat acclimatization is induced by exposure to a known hot environment, the specific or primary adaptive change, the primary adaptive change in response to heat of an improved heat eliminating capacity causes secondary changes such as a lower pulse rate and reduced subjective discomfort and both types of response proceed simultaneously. The results from the heat-treatment period indicate that the primary adaptive response to heat is a higher

*Same as: Fox, R. H., R. Goldsmith, D. J. Kidd, and H. E. Lewis. Acclimatization of the sweating mechanism in man. *J. Physiol.* vol. 157, 1961, pp. 56P-57P.

sweat rate for a given rise in body temperature, and that the total secretory activity of the sweat glands during the period of heat exposure very largely determines the degree of adaptation induced.

66. **Garden, J. W., I. D. Wilson, and P. J. Rasch.**
Acclimatization of healthy young adult males to a hot-wet environment.
J. Appl. Physiol. vol. 21, 1966, pp. 665-669.

Annotation

Definition. The ability of the human organism to adjust physiologically to high environmental temperatures.

Purpose. To determine the optimal time for acclimatization to hot-wet conditions as judged by performance and physiological measurements.

Subjects. Thirty-eight young male American Marines.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Group I			
36.7/32.2/74	61	?	Walking on a level treadmill at 5.6 km/hr for 0.83 hr for 10 days
Group II			
36.7/32.2/74	61	?	Walking on a level treadmill at 5.6 km/hr for 1.6 hr for 10 days
Group III			
36.7/32.2/74	61	?	Walking on a level treadmill at 5.6 km/hr for 1.83 hr for 10 days

A modified Balke test was performed one week prior to heat exposure, after the first five heat exposures and after the tenth exposure.

Results and conclusions

1. The 1-hr exposure in group I resulted in significant increases in the sweat rate and decreases in sweat electrolytes, but not in heart rate or rectal temperature.
2. Groups II and III had significantly lower rectal temperatures, heart rates, and sweat electrolyte concentrations and higher sweat rates on day 9 compared with day 2.
3. All three groups significantly improved their performance at the end of the first week of exercise in the heat compared with the pretraining scores. No further improvement was observed in groups I and III, and group II showed a significant decline when comparing values from week 2 with week 1.

4. It was concluded that:

(*a*) Adaptation to a hot-wet environment is different from that to a hot-dry environment because in the former evaporative heat loss is a limiting factor, whereas in the latter thermal equilibrium may be reached.

(*b*) 1-2/3 hr of heat exposure for 10 days consisting of 80 min of walking and 20 min rest is the minimum requirement for acclimatization to a hot-wet environment.

(*c*) Since significant changes in sweat rates and sweat electrolyte concentrations were observed in group I, the authors feel the term "*acclimatization* should be clearly defined and used only when the component environmental and physiologic factors are precisely stated."

67. **Glaser, E. M.**
Acclimatization to heat and cold.
J. Physiol. vol. 110, 1950, pp. 330-337.

Author's Summary

1. An appreciable degree of acclimatization to cold can be achieved after 3 days in a moderately cool environment.
2. Exercise or severe shivering during periods of cooling may inhibit acclimatization to cold.
3. Frequent changes of temperature may be beneficial to those who must adapt themselves to extreme climatic conditions.
4. Between the first and third day of exposure to cold there was a statistically significant increase of the skin temperature and the rectal temperature of 6 men. This was accompanied by greater subjective comfort, and it was taken to be a sign of acclimatization to cold.
5. Acclimatization to heat and cold was accompanied by apparent changes in the rate of superficial blood flow and the total blood volume, but it did not alter the distribution of blood in the body.
6. Repeated changes of the environmental temperature enhanced the facility with which the volume and the distribution of the blood could be varied.

68. **Glaser, E. M.**
Circulatory adjustments in the arid zone.
In: Environmental Physiology and Psychology in Arid Conditions: Arid Zone Research XXII. Paris: UNESCO, 1963, pp. 131-151. (Review)

Author's Definition

Any environmental change which produced an immediate response will also provoke slow adjustments to counteract this response, and it is these slow adjustments which constitute acclimatization.

Author's Results and Conclusions

People living in arid zones are generally able to cope with the stresses imposed upon their circulation.

The immediate effects of warming are an increase of the deep and superficial body temperature, peripheral vasodilatation (especially in the skin of the extremities), a speeding of the heart rate and the circulation time, a lowering of the blood pressure, and a transfer of blood from the deep tissues to the surface of the body. This is triggered off by stimulation of skin receptors and by direct effects of heat upon the brain; heat-sensitive areas of the brain are chiefly in the hypothalamus, but the cerebral cortex, the mid-brain and the medulla may also initiate heat-regulating responses. The main reflex response of the circulation to thermal stimulation is an inhibition of the peripheral sympathetic vasoconstrictor tone, causing passive vasodilatation, and in theory all other effects of heat upon the circulation could take place in consequence of this, simply as a compensation for the opening-up of the skin vessels. In fact, there is evidence of active peripheral vasodilatation through sympathetic vasodilator fibres and humoral mechanisms. There is also evidence that a rise of blood temperature may cause cardiac acceleration through a direct effect upon the heart in man. Since exercise causes both an increase of the body temperature and a further demand upon the circulation, heat illness is more likely during exercise than at rest. Integrated control, aided by feedback mechanisms, helps to overcome the stresses imposed by the immediate effects of heating, even when heating is complicated by exercise.

If the circulatory adjustments to warming are inadequate to limit the increase of body temperature, sweating sets in by active reflex, and it can lead to the loss of much water as well as of electrolytes. Insensible perspiration is an inevitable evaporative loss through the skin and respiratory passages, which can be fairly extensive in a hot and dry environment. Sweating and insensible water losses between them can cause rapid dehydration, which acts as a severe strain upon the circulation and predisposes to circulatory heat stress. Replacement of water lost in sweat over a long time, without replacement of all the lost electrolytes, can also lead to a loss of extracellular fluid and heat illness. Both circulatory failure and overheating are aided by dehydration.

The effects of continued or repeated thermal stimuli can progressively diminish as a result of acclimatization. The effect of heat acclimatization upon the circulation is that the rise of body temperature, the increase of heart rate, the fall of blood pressure, and the shifts of blood from the deep tissues to the body surface, which take place in a given hot environment, become gradually less pronounced. The blood pressure and cardiac output also fall less on standing up in a hot environment after acclimatization than before. Exercise is better tolerated and heat illness is less likely (though still possible).

Acclimatization takes place rapidly. There is evidence of it after a few days, and it is probably complete, insofar as the circulation is concerned, after about one month. It persists for at least two or three weeks but is gradually lost after about four to six weeks. Being accustomed to hot environments probably facilitates acclimatization to other types of hot environments or subsequent acclimatizations to the same environment.

Acclimatization (like immediate responses to changes of temperature) is an integrated response, largely controlled by the brain. The principal physiological mechanism that brings about acclimatization is habituation, a non-specific adaptive process based on changes of synaptic conductivity in the brain, which allows the setting-up of inhibitory pathways, and a lessening of arousal, so that a given stimulus gradually produces a lesser response and fewer sensations. This is the main slow mechanism whereby an individual adapts to a change of environment. Conditioning plays a small but significant part, enabling heat-regulating responses to take place, through the action of conditioned stimuli, before heat-sensitive areas are effectively stimulated. This would ensure that a response which has been diminished by habituation has an optimal effect. Conscious processes of learning and reasoning may help by bringing about behaviour likely to prevent excessive heat gains. Endocrine changes may play a part in generally lowering heat production, thus reducing body temperature and lessening the strain upon the circulation. Habituation (and also conditioning, learning or reasoning) can be inhibited by anxiety and by other psychological factors, such as mental fatigue or lack of motivation. Lack of physical fitness or ill health may also counteract acclimatization.

Cold nights or cold seasons can also be well tolerated by the inhabitants of arid zones. Generally speaking, the immediate responses of the circulation to cold are the opposite of the immediate responses to heat, and acclimatization to cold is accompanied by a diminution of the responses to cold, again brought about chiefly by habituation. In other words, heat and cold affect the circulation in opposite directions, and acclimatization to both has the effect of restoring the body temperature and the circulation to its physiological range of fluctuation, or if the heat and cold stresses are severe, the departures from the normal range of fluctuations are lessened by acclimatization. Habituation to different stimuli may take place at the same time, and acclimatization of the circulation to heat and cold may be present together. It seems probable that the inhabitants of arid zones are often in such a state of simultaneous heat and cold acclimatization. Rapid changes of temperature probably facilitate heat-regulating responses and acclimatization.

As far as physiological principles are concerned, rapid responses are possible to small changes of the thermal state and to comparatively weak thermal stimuli. Each response depends not only on the character and intensity of the appropriate thermal stimuli, since the base line from which a response takes place will partly determine the magnitude of that response. This magnitude will depend, further, on other stimuli applied at about the same time, which may reinforce or inhibit the response. If the appropriate stimulus has been recently and frequently or continuously applied, then storage of information about this stimulus will modify the response, and this is habituation. Storage of information about stimuli other than the appropriate ones for a thermal response can cause conditioning, and a complex pattern of stored information can lead to learning or behavioural changes, all of which can reinforce the effects of habituation, and all of which depend, in common with habituation, on the setting-up of appropriate neuronal circuits in the brain. Finally, endocrine changes, especially of the thyroid, or other influences such as physical fatigue or illness can modify the state of the responding organism, and this can improve or lessen the effects of other adaptations. It would seem right to conclude that adjustments of the circulation to arid zones should be discussed in terms of stimuli, responses, storage of information, neuronal circuits, and modifications to the state of the responding organism.

If it is desired to express the above in terms of thermostats, it may be said that the human body responds readily to changes of temperature outside or inside the controlled system, that it has a load error, may display hunting, is well served with negative feedbacks, and is able to store information about previous temperature changes. It can compute the effects of present and recent temperature changes affecting various parts of the system, and relate present changes to earlier ones, varying the sensitivity of the controlling system in the light of such information. The sensitivity of the controlling system also increases with the magnitude of the departure from the normal range of fluctuations. As in many other systems, certain extreme thermal states may lead to a lessened efficiency of the controlled system, but unlike most other thermostats, the controlling system of the body can improve the properties of the controlled system to suit thermal states which have been recently and frequently encountered.

69. **Glaser, E. M., M. S. Hall, and G. C. Whittow.**
Habituation to heating and cooling of the same hand.
J. Physiol. vol. 146, 1959, pp. 152-164.*

Authors' Summary

1. The sensations and responses which accompany immersion of a hand at 47° C and at 4° C were abolished or greatly diminished after repeated immersions of one hand at both these temperatures for 9-15 days. Sensations and responses during control immersions of the opposite hand were unaffected.
2. The results suggest the possibility that in man adaptation to heat and to cold can be retained at the same time.
3. There was no evidence that any localized change in the hand could have caused the diminution of responses observed, and the underlying mechanism appeared to be habituation.
4. After the responses to immersions at 47° and 4° C had diminished, 75 mg of chlorpromazine by mouth caused them to return towards normal, which conforms to previous findings that this drug inhibits habituation.
5. Further evidence was obtained that anxiety or changes of interest may inhibit habituation.

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*Same as: Glaser, E. M., M. S. Hall, and G. C. Whittow. Adaptation to localized warming and cooling. *J. Physiol.* vol. 140, 1958, pp. 42P-43P.

70. **Glaser, E. M., and R. J. Shephard.**
Simultaneous experimental acclimatization to heat and cold in man.
J. Physiol. vol. 169, 1963, pp. 592-602.*

Annotation

Definition. All these results were changes of responses observed only when thermal stimuli were present and could have been brought about only if information had been stored about previous experience of these stimuli. Habituation is the most likely mechanism to have caused this.

Purpose. To test whether acclimatization could be, in part, an acquired ability to modify responses to recently experienced stimuli.

Subjects. Fifteen men, ages 19 to 37.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Hot room			
35/29/68	<5		Subjects seated
Cold room			
3-6/?/?	<7		

Two experiments were conducted, one on eight men and the other on seven men. Days 1 and 13 were control days: on nine of the intervening days, 3 hr in the morning were spent in the hot room and 3 hr in the afternoon in the cold room. There were two days of rest in the middle of each experiment. Cotton shorts and shoes were worn in the hot room, and woolen trousers and cotton shirts in the cold room.

Authors' Results and Conclusions

1. Fifteen men spent 3 hr every morning at 35° C (dry bulb) and 29° C (wet bulb) and 3 hr every afternoon at 3-6° C for 9 days. Evidence of simultaneous acclimatization to the two environments was obtained.
2. In the hot room the mean mouth temperatures became gradually less on successive days, the skin temperatures tended to become less, and in two subjects so investigated the amount of blood displaced from the lower limbs by an anti-g suit increased progressively. In the cold room the skin of the hands and fingers became progressively warmer on successive days and shivering diminished.
3. An index of discomfort suggested that both environments became progressively more tolerable, but this was not significant in the hot room.
4. Responses of the blood pressure and of the heart rate to immersion at 47 and 4° C were diminished at the end of the experiment. There was also a fall of mouth temperature at the time when they would have been entering the cold room, suggesting some change of diurnal rhythms.
5. The acclimatizations which have been observed appear to have been brought about by the central nervous system.

*Same as: Glaser, E. M., and R. J. Shephard. Simultaneous acclimatization to heat and cold in man. *J. Physiol.* vol. 156, 1961, pp. 8P-9P.

71. **Glickman, N., F. K. Hick, R. W. Keeton, and M. M. Montgomery.**
Blood volume changes in men exposed to hot environmental conditions for a few hours.
Am. J. Physiol. vol. 134, 1941, pp. 165-176.

Authors' Conclusions

1. Subjects were exposed to environments having a dry bulb of 37.2° and 44.7° C and wet bulb temperatures of 20.1° to 27.5° C. The globe thermometer showed less than 0.4° C difference between its surface and the surrounding air. Air currents were minimal. The periods of exposure ranged from 59 to 160 minutes. In 6 experiments there was an increase in circulating serum proteins, all of which would be expected on the assumption that the new fluids were contributed by blood from the body reservoirs (spleen, and inactive capillary beds in muscles, lungs, and viscera).
2. In 4 other experiments in which the dry and wet bulbs showed approximately the same ranges, there was a decrease in the circulating blood plasma and variable changes in the red cell mass. The periods of exposure ranged from 69 to 226 minutes. The changes in the plasma proteins, red and white cell counts, were such as would be explained on the assumption that water was lost by evaporation from the blood plasma.
3. In 14 experiments on subjects exposed to the same type of environments there were no significant changes in circulating plasma volume, serum proteins, or blood counts. There were slight but definite increases in the red cell volume in 11 out of 14 experiments. The lack of change in plasma volume was attributed to a summation of the two adjustment factors described above which tend to neutralize each other.
4. In steady states the increase in pulse rate correlates well with rises in rectal temperature. If the plasma volume increases, the rise in pulse rate per degree rise in rectal temperature is less than in those subjects whose plasma volume remains unchanged or decreases.
5. A considerable quantity of fluid can be requisitioned from the tissues and evaporated from the blood plasma without affecting the circulating blood volume.

72. **Goldman, R. F., E. B. Green, and P. F. Iampietro.**
Tolerance of hot, wet environment by resting men.
J. Appl. Physiol. vol. 20, 1965, pp. 271-277.

Authors' Abstract

Studies were conducted on 10-man groups exposed at rest to 51 different hot, wet environmental conditions. "Tolerance times" of unacclimatized volunteers established objectively, as the time of occurrence of a rectal temperature of 102.5° F [39.2° C] and/or a heart rate of 180 beat/min, were similar to reported values established on a subjective basis. The wet and dry bulb index (WD) of environment was the best predictor of tolerance time. Prior acclimatization to work in hot, dry conditions did not result in prolonged tolerance for resting men exposed to hot, wet environments; neither did it alter the rates of sweat production, the final skin temperatures, or the rates of increase in heart rate or rectal temperature during these resting, hot, wet environmental exposures. Finally, "passive" resting in hot, wet environments (up to 3 hr/day) did not prolong tolerance times or induce other manifestations of heat acclimatization during subsequent resting exposures to hot, wet environments for either unacclimatized or prior. hot, dry, acclimatized subjects.

73. **Goldsmith, R., R. H. Fox, and I.F.G. Hampton.**
Effects of drugs on heat acclimatization by controlled hyperthermia.
J. Appl. Physiol. vol. 22, 1967, pp. 301-304.

Authors' Abstract

Experiments were performed to investigate the influence of aspirin, hyoscine, and pilocarpine, administered orally, on the process of heat acclimatization. Forty male subjects took part. Heat acclimatization was effected by a series of controlled hyperthermia sessions during which sweat and pulse rates were measured under the influence of the drugs. Acclimatization status was assessed at the beginning and end of the experiments by comparing the effects of a standard work-in-the-heat test on sweat and pulse rates and rises in body temperatures. The administration of aspirin (1 g) had no significant effect on either sweat or pulse rates. Pilocarpine (16 mg) did not significantly effect sweat rate, though it did increase the pulse rate at raised body temperature. Hyoscine (2 mg) depressed the sweat rate significantly during controlled hyperthermia, and consequently retarded the development of heat acclimatization.

74. **Greenleaf, J. E.**
Lack of artificial acclimatization to heat in physically fit subjects.
Nature vol. 203, 1964, p. 1072.

Annotation

During five 2-hr acclimatization walks at 49° C DBT and 28° C WBT, the usual progressive decrease in pulse rate and rectal temperatures and sweat rate increases were not observed. Comparison of the results of walks 1 and 5 shows that the average pulse rate decreased 1 beat/min, the rectal temperature decreased 0.3° C, and the sweat rate decreased 66 g/hr.

It was hypothesized that heat effects were precluded by the physiological changes induced in the subjects as a result of their high level of physical fitness. Thus, the subjects were able to perform as though they were heat acclimatized.

75. **Greenleaf, J. E., L. G. Douglas, J. S. Bosco, M. Matter, Jr., and J. R. Blackaby.**
Thirst and artificial heat acclimatization in man.
Int. J. Biometeorol. vol. 11, 1967, pp. 311-322.

Annotation

Purposes. (1) To investigate the relationship between voluntary water intake, water balance, and serum osmotic changes before and after artificial heat acclimatization. (2) To test Dill's hypothesis that the heat acclimatized man would come closer to maintaining his water balance than the unacclimatized man.

Subjects. Four male college athletes; ages 22 to 29; height, 164 to 178 cm; weight, 53.5 to 73.0 kg.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m² ·hr)*	*Exercise*
Control			
23.8/16.0/44	24		50 min exercise and 10 min rest each hr for 2 hr; 6.4 km/hr on a motor driven treadmill
Heat			
47.2/31.2/33	8		Same as above

Results and conclusions

1. The subjects exhibited the usual signs of heat acclimatization: increased total body sweat rates, decreased sweat electrolyte concentration, decreased pulse rates, and increased plasma and red-cell volumes.
2. After acclimatization, the increased serum osmolality was associated with an increased frequency and volume per drink.
3. Voluntary water intake was considerably decreased when serum osmolality was reduced to normal levels in the presence of a deficit of total body water of 2.5 to 3.3 per cent.
4. There was essentially no difference between the control and acclimatized water balances during exercise or recovery. The increased water consumption during the acclimatization exercise periods was balanced by the increased sweat rates.
5. Compared with control values, involuntary dehydration was not reduced following acclimatization.
6. The acclimatized man took one day longer than control to regain his baseline body weight.

It was concluded the results substantiate Dill's hypothesis that heat acclimatized men drink more than unacclimatized men during exercise in the heat in response to an elevated serum osmotic pressure caused by the secretion of larger volumes of hypotonic sweat after acclimatization. However, there was no change in water balance after acclimatization because the increased water intake balanced the increased sweat loss.

76. **Greenwood, R. M., and P. D. Lewis.**
Factors affecting habituation to localized heating and cooling.
J. Physiol. vol. 146, 1959, pp. 10P-11P.

Authors' Summary

"Habituation" indicates the reduction of response occurring with repeated stimuli. In earlier experiments, a hand was immersed several times daily in water at 47° C and 4° C, and after 9 to 15 days there was a diminution or disappearance of the rise of heart rate and of blood pressure that normally accompanies such immersions [Glaser, E. M. et al., *J. Physiol.* vol. 140, 1958, p. 42]. In those experiments there was an interval of 30 min between hot and cold stimuli, and it was thought of interest to study the changes in the cardiac and vascular responses when series of alternating hot and cold immersions were made on successive days.

Four students immersed a hand in water at 31° C for a control period of 15 to 30 min; then the hand was placed successively in water at 47°, 31°, 4°, and 31° C, remaining 1 min in each

water-bath. This cycle was repeated six times each day. Initially, arterial blood pressure and heart rate increased during both hot and cold immersions. After 7 days, these responses had decreased by half. It is concluded that habituation to heating and cooling is unaffected by the alternation of hot and cold stimuli.

It was also thought of interest to determine the effect of a gradual change of hot and cold bath temperature on the responses of heart rate and blood pressure. Another group of four students, on the first day of the experiment, immersed a hand in water at 47° C six times for 1 min, with an interval of 1 min between each immersion. After 15 to 30 min in water at 31° C, the hand was placed six times in water at 4° C. On the second, third, and fourth days, the hot and cold bath temperatures were respectively 43.5° and 14.5° C; at these there were no responses. Subsequently, the hot bath temperature was increased daily by 0.5° C and the cold bath temperature lowered by 1.5° C until the original temperatures were reached. Responses increased day by day, and those of the first and last day were equal. It is concluded that although habituation can occur at the same time to different repeated stimuli, it will not take place unless each repeated stimulus is constant.

77. **Hale, H. B., J. P. Ellis, Jr., B. Balke, and R. C. McNee.**
Excretion trends in men undergoing deacclimatization to heat.
J. Appl. Physiol. vol. 17, 1962, pp. 456-460.

Authors' Abstract

In an effort to characterize metabolic changes associated with heat deacclimatization under natural conditions, urinary determinations were made on 21 healthy men during the transition period from summer to fall. Two overnight urine specimens per subject per week were analyzed for sodium, potassium, phosphate, urea, uric acid, creatinine, and 17-hydroxycorticosteroids (17-OHCS). No trends were found for urine output, uric acid, urea, or sodium. Creatinine excretion rate and Na/K ratio fell as environmental temperature fell; potassium/creatinine ratio and potassium excretion rate increased. These four variables showed linear trends, but phosphate/creatinine ratio increased in a stepwise manner and urea/creatinine ratio increased only after temperature had fallen far below the summer level. Excretion of 17-OHCS (as rate or ratio) declined (two-stage shift). Subjects who did not exercise regularly showed upward shifting in phosphate excretion; nonexercising subjects as a group showed a cyclic tendency; and those who exercised daily showed essentially no change in phosphate excretion. This retention of one summer characteristic in the latter group is consonant with the literature on heat acclimatization in that it shows that physical fitness is a factor that delays heat deacclimatization.

78. **Hale, H. B., J. P. Ellis, Jr., and D. D. van Fossan.**
Seasonal variation in human amino acid excretion.
J. Appl. Physiol. vol. 15, 1960, pp. 121-124.

Authors' Abstract

Amino acid excretion was studied in young, healthy men during summer, fall and winter months in a southwestern U.S. location. Both untimed and timed urine samples were employed. The amino acids determined were alanine, arginine, cysteine, glutamic acid, glutamine, glycine, histidine, lysine, methyl histidine, serine, threonine and valine. Supplemental determinations included urine volume, creatinine, uric acid, urea, sodium and potassium. Using untimed urine samples and expressing values as ratios with creatinine, significant seasonal variation was found for alanine, arginine, cysteine, glutamic acid, glycine, lysine and serine.

79 **Hale, H. B., E. W. Williams, and J. P. Ellis, Jr.**
Catecholamine excretion during heat deacclimatization.
J Appl. Physiol. vol. 18, 1963, pp. 1206-1208.*

Authors' Abstract

Sympathoadrenal activity was appraised in ten heat-acclimatized men over a 10-week period, beginning in late summer and ending in autumn. Two overnight urine samples per subject per week were analyzed for norepinephrine, epinephrine, creatinine, and urea. Evidence of relatively high sympathoadrenal activity was obtained in late summer, since a progressive decline appeared in autumn. The catecholamines were shown to relate either to weekly mean maximum temperature or to weekly mean solar radiation. Catecholamine excretion also tended to vary inversely with urea excretion.

80. **Hellman, K., K. J. Collins, C. H. Gray, R. M. Jones, J. B. Lunnon, and J. S. Weiner.**
The excretion of urinary adrenocortical steroids during heat stress.
J. Endocrinol. vol. 14, 1956, pp. 209-216.**

Annotation

Purpose. To investigate adrenocortical activity in subjects in hot environments utilizing urinary excretion of adrenocortical steroids.

Results and conclusions

1. Heat and work had no significant effect on the urinary outputs of cortisone, cortisol, tetrahydrocortisone, tetrahydrocortisol, or 17-hydroxycorticoids.
2. Successive heat exposures did result in increased urinary excretion of aldosterone, presumably without activation of ACTH, since cortisone and cortisol excretions were unchanged.

81. **Hellon, R. F., R. M. Jones, R. K. MacPherson, and J. S. Weiner.**
Natural and artificial acclimatization to hot environments.
J. Physiol. vol. 132, 1956, pp. 559-576.

Annotation

Definition. "... an adaptative process which results in a reduction in the physiological strain produced by the application of a constant environmental stress.... The term *artificial acclimatization* is generally used to describe these changes seen in the laboratory, because it has been assumed that they constitute, or form part of, the adaptation to high environmental temperatures that occurs naturally in newcomers to hot climates, and results in an increased ability to work in the new environment and a reduction in the discomfort experienced."

Purpose. To determine if "natural acclimatization" produced by residence in a hot climate is identical with "artificial acclimatization" produced in the laboratory.

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*Same as: Hale, H. B., E. W. Williams, and J. P. Ellis, Jr. Catecholamine excretion in heat-acclimatized men. U.S.A.F. School of Aerospace Medicine, Brooks Air Force Base, Texas. SAM–TDR–63–20, March 1963, 5 pp.

**Same as: Collins, K. J., K. Hellman, R. M. Jones, and J. B. Lunnon. Aldosterone activity in the urine of men exposed to hot environments. *J. Endocrinol.* vol. 13, 1955, p. viii.

Authors' Conclusions

1. Residence in the tropics for an average period of 18 months results in an increased ability to withstand the stress of hot environments.
2. Since in these two investigations all the factors which contribute to environmental stress, including the rate of energy expenditure and amount of clothing worn, were accurately controlled, this process of "natural acclimatization" must involve physiological as well as behavioural adaptation.
3. The phenomenon of natural acclimatization to tropical climates if not identical with, at least has the same physiological basis as the "artificial acclimatization" produced experimentally in the laboratory.

Authors' Summary

1. In order to determine whether the "natural acclimatization" produced by residence in a hot climate is identical with the "artificial acclimatization" produced in the laboratory, two identical series of experiments were performed, one in England and the other at Singapore.
2. The thirty-two subjects in both series of experiments were similar in every respect except that the tropical group had spent on the average 18 months in the tropics.
3. Each man was exposed to hot conditions twice with an interval of 4 days between exposures.
4. On the first occasion (uniformity trial) all men experienced the same environmental conditions, and worked at the same rate. On the second occasion the subjects were divided into sixteen pairs by lot, and each pair was exposed to one of the sixteen combinations provided by a factorial experiment with two levels each of air temperature, humidity, air speed, and energy expenditure.
5. The results of the factorial experiment were corrected by means of analysis of covariance using the results of the uniformity trial, and thus the effects of a wide range of conditions were determined without repeated exposure of the subjects with consequent acclimatization.
6. The two uniformity trials showed that the tropical group secreted more sweat, their rectal temperatures rose less, their pulse rates were lower, and their mean skin temperatures were also lower. The skin temperature behaved differently in the two groups. In the tropical group it fell with work and rose on resting; in the nontropical group it rose on working and fell with rest.
7. The results of the factorial experiments confirmed these findings, except that there was no significant difference between the rectal temperatures in the two groups. The effect of varying the level of the various factors was similar in the two groups.
8. These results and their relationship to the phenomenon of acclimatization are discussed. It is pointed out that the differences observed between the tropical and the nontropical group are those that occur during the "artificial acclimatization" which results from repeated exposure to hot environments in the laboratory.
9. It is concluded that the superior ability to withstand hot environments exhibited by those who live in the tropics involves physiological as well as behavioural adaptation, and that the physiological basis of this "natural acclimatization" is identical with that of the "artificial acclimatization" produced in the laboratory.

82. **Hellon, R. F., and A. R. Lind.**
Circulation in the hand and forearm with repeated daily exposures to humid heat.
J. Physiol. vol. 128, 1955, pp. 57P-58P.

Authors' Abstract

There is some disagreement as to the circulatory changes which occur with daily exposure to heat. Scott, Bazett, and Mackie [*Amer. J. Physiol.* vol. 129, 1940, pp. 102-122] observed a progressive increase in finger blood flow; Eichna, Park, Nelson, Horvath, and Palmes [*Amer. J. Physiol.* vol. 163, 1950, pp. 585-597] calculated that there was a progressive decrease in peripheral blood flow in the first few exposures; Wyndham [*J. Appl. Physiol.* vol. 4, 1951, pp. 383-395] similarly found a reduction in both the hand and forearm blood flows; and Whitney [*J. Physiol.* vol. 125, 1954, pp. 1-24] showed no consistent trend in the combined hand and forearm flow in three subjects, with an increased hand flow in a fourth subject.

Four young men were exposed to heat on consecutive days for 2 hr daily, while sitting in open-backed chairs. Dry- and wet-bulb temperatures were 36.5/36.0° C for the first 3 days, 36.5/36.2° C for the fourth day, and the mean temperature over the last 5 days was 36.3/34.8° C. Air movement was 160 ft/min [48.77 m/min]. Forearm plus hand and forearm blood flows were measured at half hourly or more frequent intervals by the method of Whitney [*J. Physiol.* vol. 121, 1953, pp. 1-27], and from these values hand flows were calculated [Whitney, R. J., *J. Physiol.* vol. 125, 1954, pp. 1-24].

One of the subjects fainted on the first day after 20 min exposure. He successfully endured the succeeding exposures, but no progressive changes were found in either his hand or forearm blood flows. Of the remaining three men, only one showed a change in calculated hand flow and that was a day-to-day reduction. The same three subjects all exhibited a reduction in forearm blood flow with successive exposures. The mean reduction between the final measurements of the first and fourth days was about 50% for the three subjects.

Values for hand blood flows were high and showed great day-to-day variability. This would appear to explain the disagreement between previous workers when measuring finger, hand, or combined hand and forearm flows.

83. **Henschel, A., H. L. Taylor, and A. Keys.**
The persistence of heat acclimatization in man.
Am. J. Physiol. vol. 140, 1943, pp. 321-325.

Annotation

Definition. A series of physiological adjustments that reduces the debilitating effects of the heat.

Purpose. To study the rate at which heat acclimatization is lost in a cool environment.

Subjects. Twenty-four college men ages 19 to 28.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Daytime			
25.6/13.1-13.7/20-25	?	?	Walking on a motordriven treadmill at 5.2 km/hr and 7.5% inclination; six 10-min work periods
43.3/24.1-25.5/20-25			
48.9/27.7-29.4/20-25			
Night			
29.4-32.2/?/?	?	?	?

Experiments were performed during the winter months in Minneapolis, Minn. Four series of experiments involved intervals from 1 week to 4 weeks between heat exposures. For each experiment, the routine consisted of work during two successive afternoons at 25.6° C followed by two full days of work at 43.3° C in the mornings and 48.9° C in the afternoons. Night temperatures ranged from 29.4° to 32.2° C. Each half day's work consisted of six 10-minute work periods alternating with 10-minute rest periods. The subjects worked in cotton shorts, shoes, and socks. Cotton-drill battle dress was worn during the evenings. A constant diet contained about 3,100 kcal and was normally balanced in protein, carbohydrate, fat, and vitamins, and contained 1.5±2 g NaCl/day. Water was allowed ad libitum.

Results and conclusions

1. There was no significant difference or trend in the rate of sweating during work, fluid intake, urine output or weight loss between the first and second exposure to heat in any of the four series.
2. The work pulse rate was the most sensitive index of the condition of the subject in the heat. The rectal temperature was less reliable, and the Crampton test the least reliable.
3. The principal components of the process of heat acclimatization in increasing order of importance are: (*a*) heart, (*b*) blood volume and (*c*) constriction and dilatation of the appropriate blood vessels.
4. It was concluded that following comparisons made in performances in the heat on two occasions of 2 days each separated by from 1 to 4 weeks of cold weather that work pulse rates, rectal temperatures, and, to a lesser degree, vasomotor stability tests indicated that heat acclimatization persists during at least 3 weeks of cold weather, but the advantages conferred by this acclimatization decreases from week to week.

84. **Hertig, B. A., H. S. Belding, K. K. Kraning, D. L. Batterton, C. R. Smith, and F. Sargent, II.**
Artificial acclimatization of women to heat.
J. Appl. Physiol. vol. 18, 1963, pp. 383-386.

Annotation

Definition. The sum of the physiologic adjustments that occur as a consequence of repeated exposures to hot environments.

Purpose. To present quantitative evidence for heat acclimatization in women.

Subjects. Nine women, ages 20 to 43; five tested at the University of Pittsburgh and four at the University of Illinois.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Pittsburgh			
21/?/?	100	124	Walking on a level treadmill at 4.8 km/hr for 2 hr for 3 days
45/25.5/21	100	125	Walking on a level treadmill at 4.8 km/hr for 2 hr for 10 days
50/26.5/17	100	134	Walking on a level treadmill at 4.8 km/hr for 2 hr for 1 day
21/?/?	100	124	Walking on a level treadmill at 4.8 km/hr for 2 hr for 1 day
Illinois			
40.5/30/48	15	?	Walking on a level treadmill at 5.6 km/hr for 2 hr for 10 days

For the Pittsburgh tests, the subjects wore brassieres, cotton shorts, and sleeveless T-shirts, shoes and socks. Water was given to equal sweat loss but voluntary dehydration prevented complete maintenance of body water balance. These experiments were carried out in January and February. Three men were studied for comparison (they walked at 5.6 km/hr).

For the Illinois tests, the subjects wore brassieres, cotton shorts, shoes and socks, and rested 40 min at 24 ° C before entering the chamber.

Results and conclusions

1. By the usual criteria (reduced pulse rate, reduced rectal temperature rise, lower skin temperature, ability to complete the assigned task, and subjective comfort) all subjects became acclimatized to heat.
2. Menstrual irregularities were reported by some subjects during or after the exposures. One of the Illinois subjects experienced very heavy flow and withdrew after the seventh exposure. Three of the Pittsburgh subjects reported that flow started 5 to 7 days earlier than usual, and one had abnormally severe cramps. None of the athletically inclined subjects reported any menstrual irregularities.
3. The available evidence indicates women may be less able to deal with heat stress than men:
   (*a*) For equal sweat rates per unit of body surface area women's skin temperatures were about 1° C higher than the men's.
   (*b*) Rectal temperatures were essentially equal in the men and women resulting in a smaller core to skin temperature gradient for the women.
4. It was concluded that women acclimatize to heat, but compared with men "the physiologic cost of maintaining heat balance in a thermally stressful environment appears to be greater for women."

85. **Hertig, B. A., and F. Sargent, II.**
Acclimatization of women during work in hot environments.
Federation Proc. vol. 22, 1963, pp. 810-813.

Authors' Conclusions

On the basis of these data the tentative conclusion may be drawn that females reach limits of endurance in hot environments easily tolerated by males. Two factors appear to be operating to put the female at a disadvantage in the heat: (*a*) lower thermal gradient for removal of metabolic heat, and (*b*) less reserve capacity to move blood to the skin.

This study has demonstrated that women can be artificially acclimatized to heat, manifesting the same physiological adjustments associated with acclimatization in males: reduced pulse rate; reduction in body core and skin temperature rise; onset of sweating at a lower skin temperature; and lessened discomfort. The extrapolation from this experience with nine subjects to women in general remains to be validated, though there are no obvious reasons why it should not hold.

86. **Horvath, S. M., and W. B. Shelley.**
Acclimatization to extreme heat and its effect on the ability to work in less severe environments.
Am. J. Physiol. vol. 146, 1946, pp. 336-343.

Annotation

Definition. Acclimatization is a term applied to the conditioning process occurring within an organism leading to an optimal response to stress.

Purpose. To study the influence of acclimatization to extreme heat on the ability to work in less severe environments.

Subjects. Sixteen soldiers, ages 19 to 33, mean 24, trained for 2 weeks prior to the experiment by marching 17.7 km/day at 4.8 km/hr carrying a 20-lb pack.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m².hr)*	*Exercise*
48.9/31.1-33.9/29-37	55	139	4.7 km/hr, 0.5 to 4.0 hr, for 27 days, marching with 20-lb pack

The subjects marched 17.7 km each day. They wore Army herringbone twill uniform plus shorts, socks, and shoes; 0.1% saline was permitted ad lib; water balance was ±0.5 kg.

Results and conclusions

1. The pulse rate and skin and rectal temperature changes were virtually complete by the seventh exposure, but sweat rates continued to increase through the 27th exposure. There was a continual improvement in the ease with which the men walked throughout the exposures.
2. Acclimatization to 1 hr of work at 48.9° / 33.9° C enabled men to do 4 hr of work at either 48.9° / 32.2° C or 48.9° / 31.1° C. Thus, acclimatization to 1 hr of work at a higher environmental load ensures full acclimatization to a similar workload for 1 hr at any lower stress.

87. **Iampietro, P. F., and R. F. Goldman.**
Tolerance of men working in hot, humid environments.
J. Appl. Physiol. vol. 20, 1965, pp. 73-76.

Author's Abstract

Tolerance of acclimatized men working in eight hot, humid environments was studied. Results show that the upper limits for completion of 3 hr of work at a caloric expenditure of 350 kcal/hr are 95° F [35.0° C] DBT and 90° F [32.2° C] WBT. Rectal temperature is not a good indicator of tolerance under the conditions of our study, while skin temperature and heart rate are. A good relationship is evident between the rapid changes in skin temperature during work (first 10 min of exposure) and tolerance time; thus, these rapid changes may be used to predict tolerance time. Of the physical indexes of thermal stress the best relationship was established between WD (WD = 0.15 DB and 0.85 WB) and tolerance time.

88. **Ito, S., and J. Adachi.**
The influence of repeated applications of a hot-air bath on the activity of the sweat glands.
J. Orient. Med. vol. 21, 1934, p. 93.

Authors' Summary

The perspiration was measured by Kuno's method on two symmetrical parts of both forearms of two healthy men while sweating was produced by putting one leg into hot water. After having proved that the amount of sweat was not very different in both forearms, an electric dry hot-air bath at 80° to 90° C was applied to one forearm once a day or every two days, each application lasting 30 minutes. Before each application, in about 24 hours or more after the last application, the same test of the amount of sweat was made. It was found that the amount of sweat became larger on the heated forearm with repetition of the heat applications. The difference in amount between both forearms became distinctly noticeable after three to five applications, and very considerable after eight to twelve applications. In some experiments, the amount of sweat on the heated side was found to be three times as large as that on the opposite side. Further applications were then stopped, and the length of time of this result was observed. The difference in amount remained remarkable for 120 hours or longer after the last application, and the normal condition was restored after 170 to 190 hours.

Repeated applications of heat seem to exert little influence on the excitability of the sweat centres, since the features of the sweating on the unheated forearm remained similar before and after the procedures. The increase in the amount of sweat on the heated forearm should therefore be attributed to a local effect of heat. The skin capillaries of the heated forearm were investigated

by means of a skin microscope, but no noticeable changes could be detected. There was also no significant difference in the skin temperature between both forearms.

The above effect of the repeated heatings was less striking in the experiments made in the summer than in the winter, perhaps because the sweat glands had already been activated on account of the hot weather.

89. **Johnson, R. E.**
Applied Physiology.
Ann. Rev. Physiol. vol. 8, 1946, pp. 535-558. (Review)

Author's Summary: Acclimatization

One of the most spectacular adaptations in normal human physiology is the rapid acclimatization which ensues when a man fully trained for a fixed task in a temperate environment is forced to perform the same fixed task repeatedly in a hot environment. In any treatment of acclimatization one must bear in mind three important considerations. First, even a fully acclimatized man can be thrown into a state of exhaustion indistinguishable from that of his first day if all the conditions listed in Table 1 are not met. Second, sharp distinction has to be made among rest, work at a rate that can be carried out in a steady state after acclimatization, and work at a pace which can never be carried out in a steady state no matter how good acclimatization may be. Third, there are large differences among men in tolerance to heat both before and after acclimatization. Certain features are well established. Comfort is greatly increased, duration of effort prolonged, and susceptibility to exhaustion decreased [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Bean, W. B., and L. W. Eichna, *Federation Proc.* vol. 2, 1943, p. 144. Eichna, L. W., W. B. Bean, W. F. Ashe, and N. Nelson, *Bull. Johns Hopkins Hosp.* vol. 76, 1945, p. 25. Taylor, H. L., A. F. Henschel, and A. Keys, *Am. J. Physiol* vol. 139, 1943, p. 583. Henschel, A. F., H. L. Taylor, and A. Keys, *Am. J. Physiol.* vol. 140, 1943, p. 321]. Acclimatization to one set of conditions gives complete acclimatization for less severe but only partial for more severe

Table 1. Conditions for the best performance of young men working in the heat

1.	*General*	
	a.	No chronic or acute debilitating diseases
	b.	Good general physical condition
2.	*Heat balance*	
	a.	Complete acclimatization for the particular environment and work encountered
	b.	Avoidance of unfavorable environmental conditions and excessive rates of work
	c.	As little clothing as consistent with protection against radiation and trauma
3.	*Nutrition*	
	a.	Maintenance of complete hydration hour by hour
	b.	Maintenance of adequate salt intake day by day
	c.	Maintenance of adequate intake of carbohydrate, total calories, and water soluble vitamins

conditions [Robinson, S., E. S. Turrell, H. S., Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Bean, W. B., and L. W. Eichna, *Federation Proc.* vol. 2, 1943, p. 144], and acclimatization for a given dry environment provides only partial acclimatization for a moist environment of the same equivalent temperature [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Bean, W. B., and L. W. Eichna, *Federation Proc.* vol. 2, 1943, p. 144]. Once achieved, acclimatization persists for a considerable time after the last exposure to heat [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Henschel, A. F., H. L. Taylor, and A. Keys, *Am. J. Physiol.* vol. 140, 1943, p. 321]. In rest and steady state work, rises in rectal and skin temperatures are minimized and the efficiency of sweating, i.e., the effective cooling power of a given amount of sweat, is greatly increased [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168]. In work which cannot be carried out in a steady state rectal and skin temperatures rise maximally, but the efficiency of sweating is still high. In rest and moderate work, rises in pulse rate are minimized, dependent edema is ameliorated, and orthostatic hypotension and malar flush no longer appear. [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Bean, W. B., and L. W. Eichna, *Federation Proc.* vol. 2, 1943, p. 144. Eichna, L. W., W. B. Bean, W. F. Ashe, and N. Nelson, *Bull. Johns Hopkins Hosp.* vol. 76, 1945, p. 25. Taylor, H. L., A. F. Henschel, and A. Keys, *Am. J. Physiol.* vol. 139, 1943, p. 583. Henschel, A. F. H. L. Taylor, and A. Keys, *Am. J. Physiol.* vol. 140, 1943, p. 321]. In exhausting work manifestations of cardiovascular difficulty can be equally severe before and after acclimatization [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Eichna, L. W., W. F. Ashe, W. B. Bean, and W. B. Shelley, *J. Ind. Hyg. Toxicol.* vol. 27, 1945, p. 59]. In moderate work pulmonary ventilation and oxygen consumption are usually decreased [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168]. In rest and steady-state work, there is usually an increased rate of sweating [Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath, *Am. J. Physiol.* vol. 140, 1943, p. 168. Bean, W. B., and L. W. Eichna, *Federation Proc.* vol. 2, 1943, p. 144. Eichna, L. W., W. B. Bean, W. F. Ashe, and N. Nelson, *Bull. Johns Hopkins Hosp.* vol. 76, 1945, p. 25. Taylor, H. L., A. F. Henschel, and A. Keys, *Am. J. Physiol.* vol. 139, 1943, p. 583] and in exhausting work there is a consistent marked increase in capacity to sweat [Robinson, S., E. S. Turrell, and S. D. Gerking, *Am. J. Physiol.* vol. 143, 1945, p. 21. Eichna, L. W., W. F. Ashe, W. B. Bean, and W. B. Shelley, *J. Ind. Hyg. Toxicol.* vol. 27, 1945, p. 59]. Sweat chloride tends to decrease in rest and steady-state work, but in hard work there is no change [Johnson, R. E., G. C. Pitts, and F. C. Consolazio, *Am. J. Physiol.* vol. 141, 1944, p. 575]. Some of the disagreements in the literature on sweat chloride during acclimatization have been in part reconciled by the finding that the levels of sweat chloride and sodium, but not potassium, are related to a central factor, measured by rectal temperature and rate of sweating, to a local factor measured by skin temperature, and to personal idiosyncrasy as measured by large differences between individuals even when rate of sweating, skin temperature, and rectal temperature are the same. Therefore one would expect sweat chloride to decrease during acclimatization for a fixed task in a fixed environment, because of the well recognized decreases in rectal and skin temperatures; but not to decrease in exhausting work when these remain high. These expectations were verified experimentally [Johnson, R. E., G. C. Pitts, and F. C. Consolazio, *Am. J. Physiol.* vol. 141, 1944, p. 575]. No consistent changes have been observed in formed elements or constituents of the blood. No systematic studies have as yet been reported of biochemical balance, nervous, endocrine, digestive, or excretory systems. Any hypothesis on the mechanism of acclimatization must be rather unsatisfactory until the role of the endocrines and nervous system is elucidated. One hypothesis which fits most of the known facts concerns the vasomotor centers of the thalamohypothalamic regions. On first exposure to heat there is inefficient capillary circulation in the skin, with inefficient cooling of the blood and inefficient venous return from the skin. This might account for the great discomfort, increased rectal temperature, inefficient cooling power of a given volume of sweat, high pulse rate, and dependent edema. After the thalamic centers secure control over the skin capillary bed as a result of subsequent exposures to the heat, the above extreme displacements of homeostasis are minimized. Changes in respiratory functions may be explained on the basis of changes in body temperature.

The practical application of present knowledge of acclimatization is clear. Men exposed to an unaccustomed hot environment must become acclimatized before being asked to work to full capacity. This can be achieved best by their working on the first few days of exposure, but only moderately hard and with careful watch for signs of exhaustion.

90. **Johnson, R. E., G. C. Pitts, and F. C. Consolazio.**
Factors influencing chloride concentration in human sweat.
Am. J. Physiol. vol. 141, 1944, pp. 575-589.

Authors' Summary

1. A study has been made of the concentration of chloride in human sweat in relation to factors previously reported to have a controlling influence. A survey of the literature revealed: complete agreement that sweat chloride (*a*) increases as work is prolonged, (*b*) varies between individuals, (*c*) varies in different regions of the body, (*d*) varies inversely as the supply of drinking water; majority agreement that sweat chloride, (*e*) increases as the rate of sweating increases, and (*f*) decreases during acclimatization; complete lack of agreement that sweat chloride is affected, (*g*) by body temperature, (*h*) by intake of salt, (*i*) by plasma chloride; and insufficient or no attention to (*j*) skin temperature, (*k*) plasma protein, and (*l*) the relation of sweat chloride to physical fitness for work in the heat.
2. Experiments were conducted on men marching out of doors in the summer time and in a heated room in the winter.
3. The present experiments confirm and extend conclusions (*a*), (*b*), (*d*), and (*e*) in (1) above. In addition they indicate that the sweat chloride increases with increasing body temperatures, increases with local skin temperature, decreases more after ingestion of saline solution than after an equal volume of water and within wide limits is independent of plasma protein, plasma chloride and physical fitness.
4. It is suggested that three primary factors are concerned with the concentration of chloride in sweat. These are: (*a*) the local factor of skin temperature; (*b*) a central factor of which rectal temperature and rate of sweating are probably the most important indices; and (*c*) the factor of individual idiosyncrasies. The general level of sweat chloride appears to be dominated by this central factor, and increases with increased rectal temperature and rate of sweating. Superimposed on this general level are fluctuations which appear to be correlated with the local skin temperature. The interplay of these factors plausibly explains changes heretofore ascribed to duration of work, environmental conditions, intake of water, intake of salt and acclimatization.

5. A new interpretation is presented concerning sweat chloride during acclimatization. On the basis of (4) above one would theoretically expect a progressive lowering of the sweat chloride to be associated with the progressive decrease of rectal and skin temperatures which is characteristic of acclimatization in men performing a fixed daily task. Experimentally it was shown that if the rectal and skin temperatures were the same, the sweat chloride was the same before and after acclimatization.

91. **Kraning, II, K. K., H. S. Belding, and B. A. Hertig.**
Use of sweating rate to predict other physiological responses to heat.
J. Appl. Physiol. vol. 21, 1966, pp. 111-117.

Authors' Abstract

Two acclimatized male subjects were exposed to graded combinations of exercise and environmental temperature to determine whether physiological cost, in terms of rectal temperature (T_r) and heart rate (*HR*), is different per kcal of exercise metabolism (*M*) and per kcal of heat stress from the environment (*HS*). Data of Robinson on four subjects exposed under a variety of conditions were examined in the same way. The effect of a unit of *M* on *HR* in the six subjects was about twice as great as the effect of a unit of *HS*, but the effect of a unit of *M* on T_r was not significantly different from the effect of a unit of *HS*. In 30 combinations tried on one subject cardiac output was found to increase by different amounts for equal amounts of *M* and *HS*. This suggests that no two combinations of *M* and *HS* elicit the same combination of *HR*, cardiac output and T_r.

92. **Kuno, Y.**
The acclimatization of the human sweat apparatus to heat.
In: Y. Kuno, *Human Perspiration.* Springfield, Illinois: Thomas, 1956, Chapter XI, pp. 318-335.

Author's Definition

Acclimatization includes those functional and morphological changes which occur within the individual upon repeated or continuous exposure to new environmental conditions. Disorders of vital functions produced by new environmental factors may gradually be alleviated by the changes, and the acclimatization is considered to have been accomplished when the individual is able mentally and physically to lead a normal life in the new environment.

Annotation Observations

1. Man sweats more profusely when he has been exposed repeatedly to high temperatures.
2. As acclimatization proceeds, the increase in sweat loss is due to subjects' sweating faster at a given rectal temperature. When subjects had been sweating almost maximally, sweat rate declines, and the decline occurs earlier in the nonacclimatized than in the acclimatized person.
3. Man sweats more promptly and profusely in summer than in winter. The seasonal changes appear to be of a transitory nature.

4. The changes in the ability to sweat result, essentially, from changes in the excitability of the sweat center plus local conditions of the sweat glands themselves brought about by training.
5. After training by repeated heat applications, the number and localization of the sweat pores discharging sweat were the same as before training, indicating that no new glands were activated, but that the secretion from the glands was simply increased by training.
6. Repeated applications of cold to the skin have a depressing effect on sweat gland activity.
7. The decrease in the sweat chloride concentration appears to be a more reliable indication of the degree of adaptation, or the tolerance of the subject to hot weather than the increase in the rate of sweating.
8. The increase in the rate of sweating and the decrease in sweat chloride concentration are transitory effects of heat training and can be regarded as two different processes. Changes in sweat rate occur with alteration in local conditions, while reduction of sweat chloride results only when the whole body is exposed to heat.
9. Newcomers to the tropics are always bathed in sweat but seem to sweat less continuously after residence for some years, while natives at rest remain comparatively dry. Thus, humans acquire by acclimatization the ability to avoid excessive sweating beyond the limits of rational heat regulation.
10. The sweat glands of tropical natives have developed fully and copious sweating can be produced if necessary. "Training of the nervous system governing sweat reflexes has, however, resulted in a lesser response to stimuli. Impulses to the sweat glands may therefore be regulated from the sweat centers in such proportion as may be necessary from the thermoregulatory point of view. The process of acclimatization is therefore entirely different in the sweat glands and in the nervous system, and the latter seems to play a more important role than the former. In foreign settlers immigrated subsequent to childhood, the sweat glands can be trained at least in part, but it is impossible to increase their number. Training of the nervous system is effective only in some of the settlers who have lived for years in the torrid zone. All the characteristics of the sweat glands and of the sudorific nervous system can be fully acquired by races of the temperate zone when they are born in the tropics."

93. **Ladell, W.S.S.**
Changes in the chloride concentration of sweat with acclimatization.
Biochem. J. vol. 39, 1945, pp. xlvii-xlviii.

Author's Abstract

The chloride concentration in serial sweat samples from the arms of subjects working in a hot humid environment rises as the exposure continues. In some subjects the rise may be as much as from 0.3 to 0.6% in 160 min. This increase is independent of rises in rectal temperature and of changes in the rate of sweating. The sweat glands must do osmotic work to excrete the sweat which is always hypotonic, in all instances, but less work in being done when a more concentrated sweat is excreted – hence this rise in chloride concentration with duration of sweating may be a manifestation of fatigue; further evidence of fatigue is that the rate of sweating falls off at the end of a long exposure to heat.

In a series of consecutive exposures (rapid acclimatization) of a number of subjects the chloride concentration of sweat from a given subject at a given time varied irregularly. If the total salt loss of the body is calculated from the sweat losses over each period and the chloride concentration of the arm sample collected during that period (evidence will shortly be published that this is a valid calculation), it is found that the total salt loss is practically constant in a given individual from day to day for a given total of sweat lost so long as the rate of sweating remains the same. Thus in rapid acclimatization there is no fall in sweat chloride concentration such as has been described by Dill and others [Dill, D. B., et al., *Amer. J. Physiol.* vol. 123, 1938, p. 412].

But when a subject lived in the hot room day and night at such day temperatures that he was sweating profusely for up to 8 hr a day, after the first few days' sojourn the chloride concentration of his sweat no longer rose with time. This change, which amounts to a fall in chloride concentration when total losses are considered, was not due to a salt lack as the subject was not losing weight and plasma chloride level was normal. After leaving the hot room he lost this acclimatization effect and, on being re-exposed to the heat some weeks later, the expected rise in chloride concentration with time was seen again.

Subjects exposed to the heat for some hours every day over a period of many months show the same effect but less markedly. The table shows the salt losses from two men at various times during an 18-month period during which they were in continual use as experimental subjects in the hot room. The salt losses for small losses of sweat (1-2 liters) has not varied much during this period, but the salt losses for heavy sweating have become less, showing once more the diminished liability of the sweat glands to fatigue.

This diminution in the salt losses from the sweat which occurs with hyper-acclimatization is not to be confused with the effect of salt deficiency. McCance [*J. Physiol.* vol. 92, 1938, p. 208] showed that in severe salt deficiency there is a fall in the chloride concentration of sweat; in the present series of experiments a diminution of the salt intake, even though short of that needed to give rise to salt deficiency, resulted in a fall in the chloride concentration of sweat.

94. Ladell, W.S.S.

Acquired heat tolerance of temperate climate men living in the tropics.
Abstracts XVIII Inter. Physiol. Cong., Copenhagen, 1950, pp. 320-322.

Author's Summary

By courtesy of the Assistant Director of Medical Services, Nigeria District, West Africa, it has been possible to investigate the reactions to heat of a group of British soldiers serving in Nigeria. Twelve volunteers, all of whom had been in West Africa for at least six months and been through one hot season, were tested at several different rates of work in artificially produced climates of varying severity, ranging from "normal Lagos" conditions [90° F (32.2° C) DB, 81° F (27.2° C) WBT] to the severe test conditions used in the heat acclimatization studies in Great Britain [100° F (37.8° C) DBT, 94° F (34.4° C) WBT]. Their reactions were compared on the one hand with previously recorded figures obtained on artificially acclimatized Europeans [Ladell, W.S.S., *Brit. Med. Bull.* vol. 3, 1945, p. 175; *Brit. Med. Bull.* vol. 5, 1947, p. 5] and on the other with figures obtained in West Africa [Ladell, W.S.S., *J. Physiol.* vol. 112, 1950, p. 15] on both trained and untrained Africans.

From the ratio – Sweat production in index period/Rectal temperature rise in same period – observed during a standard routine in the "acclimatization climate," the heat tolerance of the "residentially acclimatized" Europeans was found to be equivalent to that that would be obtained by 11 to 12 days of artificial acclimatization. The sweat production of these men, however, was less than that recorded for men who had been hyperacclimatized to heat by successive exposures over many months to climates of varying severity [McArdle, B., et al., *Med. Res. Coun.* (London) R.N.P., No. 391, 1947; Ladell, W.S.S., *J. Physiol.* vol. 108, 1949, p. 440] in each of the climates in which they were tested. Mean final rectal temperatures were about 1° F higher in the residentially acclimatized subjects.

The residentially acclimatized but untrained Europeans sweated more than local Nigerians (Negroes) of low economic status who had not been specially trained for work in the heat. These latter had an inherent acclimatization, judged from the – Sweat rate/Rectal temperature rise – ratio equivalent to 2 to 3 days of artificial acclimatization. Over a short exposure the Europeans sweated approximately the same, per man, as Africans who had been trained to work in the heat by twelve days successive exposures to the "acclimatization climate"; but sweat production per unit area of body surface was greater in the "near fully" acclimatized Africans. With exposures lasting more than two hours, however, untrained Europeans sweated more than the trained Africans. It is suggested that this is due to the greater susceptibility to fatigue of Negroes' sweat glands.

After exposures to moderate climates the final rectal temperatures were the same for the Europeans as for the untrained Africans; but with more severe climates the Europeans had higher rectal temperatures; e.g., after 4 hours at 92° F [33.3° C] DBT, 89° F [31.7° C] WBT, mean metabolic rate 111 kg cal/metre^2/hour, both sets of subjects had mean final rectal temperatures of 100.3° F [37.9° C]. But after 160 min. working slightly harder, in 100° F [37.8° C] DBT,

94° F [34.4° C] WBT, the final rectal temperatures were 102.26° and 102.60° F [39.0° and 39.2° C] for the untrained Africans and the residentially acclimatized Europeans, respectively. The corresponding figure for trained subjects was, for both Africans and Europeans, 101.73° F [38.7° C].

In severe climates failures to complete experiments due to collapse were more numerous among the residentially acclimatized Europeans than among even the untrained Africans. But Europeans showed less signs of sweat gland fatigue than Africans, trained or untrained.

The chloride content of sweat secreted by the residentially acclimatized Europeans was less than of sweat from Europeans tested under artificial conditions in Great Britain, but greater than that of sweat from Africans, trained or untrained. The mean chloride content of samples collected at corresponding times in identical routines under the same conditions was, for Europeans in Great Britain 0.396%, For Europeans in Nigeria 0.310%, and for Nigerian negroes 0.213%, expressed as sodium chloride.

Care was taken throughout the tests on the European subjects to space the exposures so that they did not become artificially acclimatized.

95. **Ladell, W.S.S.**
Inherent acclimatization of indigenous West Africans.
J. Physiol. vol. 112, 1951, pp. 15P-16P.

Author's Abstract

The inherent acclimatization to severe heat and humidity of a group including all main Nigerian tribes was equivalent to that acquired by nonacclimatized Europeans in England from 3 days' artificial acclimatization. Artificial acclimatization of Nigerians improved their performance in the heat, but their rate of improvement fell off earlier than it had done with Europeans being acclimatized in London. The Africans reached in 6 days the same total sweat production per exposure that the Europeans had taken 10 days to reach: in both cases sweating was not increased markedly with further exposures. Sweat per unit surface area was, however, greater for "near-fully acclimatized" Africans than it had been for "near-fully acclimatized" Europeans. Sweat-gland fatigue developed earlier in Africans than in Europeans, total cessation of visible sweat sometimes occurring within 90 min. The chloride content of sweat from Africans was significantly less than that of sweat from Europeans.

96. **Ladell, W.S.S.**
Assessment of group acclimatization to heat and humidity.
J. Physiol. vol. 115, 1951, pp. 296-312.

Annotation

Definition. Full acclimatization can only be acquired by successive, repeated exposures while working in a severe climate over a period of time.

Purpose. To describe a numerical scale to assess the degree of acclimatization utilizing the rise in rectal temperature and sweat rate.

Subjects. The regressions were performed on prior data from seventeen men [Ladell, W.S.S., *Brit. Med. Bull.* vol. 5, 1947, p. 5].

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
37.8/34.0/71	15	87	Bench stepping, 30.5 cm height, at 12 times/min with 5 min work and 15 min rest for two of the first four 20-min cycles and 24 times/min for the last two cycles

In the daily exposures (weekdays only) the subjects were nude and sweat was collected in arm-bags. The first seven subjects were not allowed to drink and the other ten drank to equal their sweat losses.

Results and conclusions

1. The course of the acclimatization could be divided into two phases: (*a*) the initial phase (2-3 days) characterized by a decrease in the heart rate and a lowering of the threshold rectal temperature for sweating; (*b*) a second phase characterized by an increase in the sweat rate for a given rectal temperature and a decrease in sweat gland fatigue.
2. Initial resting temperatures became lower as the subjects became acclimatized, but the rate of the rise in rectal temperature was about the same in all exposures.
3. Total sweat loss, corrected to a body weight of 65 kg, for the first five cycles rose from 1100 g on day 1 to 1560 g on day 9.
4. Resting and working heart rates increased throughout the course of each exposure. After the third exposure the heart rates at any given point in the exposure did not change substantially from one exposure to the next. Since the work load was relatively light, no training effect was noted in heart rates.
5. Stamina increased with successive exposures. "To estimate the degree of acclimatization of a group of subjects. . . each individual needs to go through the standard routine in the standard climate only once. Measurements of weight and rectal temperature are required just before the first work and at the end of the fourth cycle, 80 min later. Drinking may be allowed, but the fluid balance must be recorded. The corrected sweat loss is calculated separately for each individual." The acclimatization index is then calculated as the mean corrected sweat loss/mean rectal temperature rise for the whole group. The corrected sweat loss was calculated by multiplying the gross sweat loss by the two-thirds power of the ratio standard weight (65 kg)/actual weight $(65/W)^{2/3}$.

   The index is applicable only to groups of subjects and should not be used on the individuals separately.

97. **Ladell, W.S.S.**
    Applied physiology in Nigeria.
    West African Med. J. vol. 1, 1952, pp. 35-37.

Author's Comments

The results so far show that unless he has been specially trained the Nigerian worker is not much more tolerant of severe conditions than are temperate climate men; the slight advantage that the Nigerian has initially is lost in training and there is nothing to choose between the fully trained Nigerian and the fully trained European worker as far as the objective measurements are concerned when it comes to working under severe conditions. There are, however, certain interesting differences; thus an African will go on longer, even when untrained, and he is less likely to collapse than an European, even though he may appear to be, physiologically, in as bad a condition as the European; Africans do not appear to be so susceptible to heat cramp; this might be due to slightly diminished losses of salt in the sweat or to differences in the fluid distribution within the body. Per unit surface area fully trained Africans sweat more than fully trained Europeans; but this difference is not usually apparent as Europeans will so often "go out in the midday sun" and indulge in strenuous exercise, so fully trained (for heat) Europeans are, paradoxically, more common than fully trained Africans. As a result the average European is often drenched with sweat, while the average African, under identical conditions, is only sweating gently. It is a physiological curiosity, however, that a fully trained man usually sweats many times faster than he needs, to keep himself cool, and even untrained men sweat enough in humid climates for full evaporative cooling, hence the trained man is at an apparent disadvantage as he needs more water to keep in balance.

98. **Ladell, W.S.S.**
The effects of water and salt intake upon the performance of men working in hot and humid environments.
J. Physiol. vol. 127, 1955, pp. 11-46.

Author's Summary

1. The effects of drinking water or saline, of not drinking at all and of taking salt alone, on fully acclimatized men working in a hot and humid environment were investigated in a number of experiments; in some tests the amount of water drunk, and/or of salt taken, was equated to the amounts of these substances lost in the sweat; in others saline of fixed strength was given in varying amounts.
2. Subjective effects were more marked than objective effects. The chances of failure to complete a given task in the heat increased with increasing water deficit. Fatigue, usually sudden in onset, was more pronounced when the water debt was high.
3. Sweat rate tended to be lower in men drinking saline. Abstention from water had no effect on the sweat rate, until water debts of more than 2.5 liters had been incurred. In this respect sweat secretion behaves similarly to urine excretion and salivation during dehydration.
4. Thermal equilibrium was established at a higher level in men who abstained from drinking than in those who did drink, and in those not taking salt than in those taking salt.
5. The heart rate in recovery increased with rectal temperature less rapidly when the subjects were taking salt or saline than when they were not drinking or drinking only water. In those taking salt the heart rates were faster at low rectal temperatures, and slower at high rectal temperatures, than in those taking water only. Exercise tolerance was better maintained by subjects when they drank water or saline than when they did not drink or took salt only.
6. The chloride content of the sweat was higher when salt was taken.
7. The changes in thermal equilibrium and in heart rates may be predicted from the changes in intracellular fluid volume (ΔI) which can themselves be predicted with reasonable accuracy from the water and salt losses using the equation given.

8. Apparently contradictory responses to given conditions by different men at the same time, or even by the same man at different times, can be traced to variations in sweat rate and especially to differences in the sodium chloride losses in the sweat, which shift the water and salt balance in different ways.
9. Further modifications of the response to heat may be the result of alterations in adreno-cortical activity or of changes in renal function.

99. Lee, D.H.K., and G.P.B. Boissard.
The effect of exercise in hot atmospheres upon the pulse rate.
Med. J. Australia vol. 2, 1940, pp. 664-668.

Annotation

Purpose. To investigate pulse rate responses to various levels of water replacement and exercise in hot-wet and hot-dry environments.

Subjects. Seven healthy males between 18 and 45 years of age.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
30.8/28.6/87 (28.3 effective temperature)	?	?	The subjects remained in air-conditioned rooms for 7-1/2 hr/day, 5 days/wk for 4 wk and either marched 4.8 km/hr or lifted a 16.6-kg weight 107 cm once each 15 sec for 30 min in each environment
38.3/26.1/38 (29.2 effective temperature)	?	?	

Three levels of water and saline administration were given: (*a*) none, (*b*) half replacement, and (*c*) full replacement.

Results

1. Afternoon exercise gives rise to a greater heart rate than morning exercise, attributed partly to accumulated fatigue and also to eating lunch.
2. Acclimatization with half water replacement had only a minor effect on the pulse rate reaction to exercise in the hot-wet atmosphere and a somewhat greater increase in nonacclimatized subjects in the hot-dry environment.
3. During exercise full water replacement affords no definite improvement over half replacement. Half replacement gives some improvement over no water in the hot-wet and pronounced improvement in the hot-dry environment – an improvement that becomes proportionately greater as the day progresses.
4. In marching, half replacement with saline gives some improvement in hot-wet atmospheres but appears to be a disadvantage in the hot-dry environment.
5. In both environments, a 2-hr delay in half fluid administration leads to increased pulse rates in all exercise and rest conditions. When saline was given the recovery is delayed or transient.

6. Weight lifting tends to result in somewhat higher pulse rates compared to marching in the hot-wet environment at all levels of fluid intake. In the hot-dry environment, weight lifting is less exacting than marching particularly when water is withheld.
7. "While there is no difference between the effects of the two atmospheres when ample water is given, the hot-dry atmosphere has some heightening of effect when only half quantities are given, especially with the longer periods of marching. When no water is given, the greater effect of the hot-dry atmosphere is very apparent. The administration of saline solution shows up the preponderant effect of the hot-dry atmosphere more than does the corresponding administration of water."
8. There is a certain margin of reserve of body water that can be traded upon if necessary.

100. Lee, D.H.K., R. E. Murray, W. J. Simmonds, and R. G. Atherton.
The effect of exercise in hot atmospheres upon the salt-water balance of human subjects.
Med. J. Australia vol. 2, 1941, pp. 249-258.

Annotation

Purpose. To investigate the effects of exercise and three levels of water and saline replacement in a hot-wet and a hot-dry environment on the salt-water balance.

Subjects. Seven healthy males, 18 to 45 years of age.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
30.8/28.6/87 (28.3° effective temperature)	?	?	The subjects remained in air-conditioned rooms for 7-1/2 hr/day, 5 days/wk for 4 wk and either marched 4.8 km/hr or lifted a 16.6-kg weight 107 cm once each 15 sec for 30 min in each environment
38.3/26.1/38 (29.2° effective temperature)	?	?	

Three levels of water and saline replacement were given: (*a*) none, (*b*) half replacement, and (*c*) full replacement. Frequent administration was compared with the same total amount at longer intervals.

Results

1. The rate of sweating was increased (*a*) by increasing the rate of water intake in the hot-dry environment from nil to ample, (*b*) by substitution of the hot-dry for the hot-wet environment, (*c*) by exercising, and (*d*) in the afternoon.
2. The rate of sweating was decreased by drinking saline instead of water in the hot-dry environment.
3. The rate of sweating was not appreciably affected by (*a*) acclimatization, or (*b*) the substitution of larger amounts of fluid given infrequently for smaller amounts of fluid given frequently. The Queensland subjects were probably long-term acclimatized to heat when the study began: their sweat chloride concentrations were rather low.
4. The sweat chloride concentration was increased (*a*) by the substitution of the hot-dry for the hot-wet environment, and (*b*) in the afternoon.

5. The sweat chloride concentration was decreased by (*a*) an increase in the rate of water administration, and (*b*) the drinking of saline rather than water in the hot-dry environment.
6. The sweat chloride concentration was not affected by (*a*) acclimatization, (*b*) the frequency of fluid administration, or (*c*) the rate of sweating.
7. Saline was more beneficial than water in the retention of body water. Frequent drinking of small amounts was more beneficial than infrequent drinking of large amounts, particularly in the hot-dry environment.
8. Urine volume tended to be reduced with heat acclimatization.
9. Urine chloride concentration and the rate of chloride loss were reduced by heat acclimatization, following saline administration, and when fluid administration was delayed.

101. **Lewalski, B., and W. Ejsmont.**
The problem of acclimatization to hot-climate regions. II. Uropepsin contents in the urine from men staying in the chamber of high temperature.
Bull. Inst. Marine Med. in Gdansk (Poland) vol. 15, 1964, pp. 193-198.

Annotation

The purpose was to study the urinary excretion of uropepsin in 168 men, of which 40 were partially heat acclimatized from work in a ship's engine-room and galley, 8 were partially cold acclimatized (they worked in the refrigerator room), and the balance of the subjects were considered normal. The environmental conditions were 30 min resting at 36° C DBT, 31.9 ° C WBT, 40% RH, and air motion of 2.4 m/min followed by 80 min rest and 10 min exercise at 80 kg at 36° C DBT, 34.5° C WBT, 90% RH, and air motion of 1.8 m/min.

The results showed that urinary uropepsin increased fivefold in the cold-adapted men, over threefold in the normal group, and over twofold in the heat-acclimatized group. It was concluded that uropepsin excretion reflected the degree of stress imposed on the men.

102. **Lind, A. R.**
Acclimatization to heat.
In: Leithead, C. S., and A. R. Lind, *Heat Stress and Heat Disorders.* London: Cassell,1964, pp. 16-30. (Review)

Annotation

Definition. The series of physiological adjustments that occur when men who are accustomed to living in a cool climate are suddenly transferred to a hot climate, and which ameliorate the physiological strain experienced on the initial exposure to heat.

Summary. This section of the book briefly summarizes the current status of heat acclimatization knowledge with particular emphasis on practical work situations. The review is divided into the following subheadings:

A. Physiological changes
    1. The cardiovascular system
    2. Expenditure of energy
    3. The pituitary-adrenal endocrine system

B. Characteristics of acclimatization
C. Rate of acclimatization
D. Long-term effects
E. Retention of acclimatization
F. Factors affecting the development of acclimatization
    1. Dehydration
    2. Salt intake
G. Causes of acclimatization
H. Methods of induction of acclimatization

103. **Lind, A. R., and D. E. Bass.**
Optimal exposure time for development of acclimatization to heat.
Federation Proc. vol. 22, 1963, pp. 704-708.*

Annotation

Purpose. To compare four different work routines on the development of full acclimatization; and to test the hypothesis that the rate of decay may be more accurately assessed by (1) the rate of reacclimatization than (2) a single re-exposure.

Subjects. Thirteen young, fit soldiers, divided into four teams: A, walk 50 min each morning (four subjects); B, walk 50 min each morning and afternon (three subjects); C, walk 100 min each morning (three subjects); and D, walk 100 min each morning and afternoon (three subjects).

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Cool			
21.1/15.0/52	61	est. 300	5.6 km/hr for 6 days on level treadmill
Acclimatization			
48.9/26.7/18	61	est. 300	5.6 km/hr for 9 days on level treadmill

Subjects wore boots, socks, trousers, and vests in cool walks, and boots, socks, and athletic shorts in hot walks. Teams A and B were exposed again on the tenth day for 100 min. Water was allowed ad libitum after the first 20 min of walking. No evidence of progressive dehydration from morning body weights. Rectal temperature, pulse rate, and weight loss were measured.

Results and conclusions

1. For teams C and D the acclimatization process had attained a plateau by the eighth day of exposure. The physiological responses of teams A and B showed no clear evidence of reaching a plateau by the ninth day.

*Same as: Bass, D. E., and A. R. Lind. The economic period of daily exposure to heat for the development of acclimatization. *J. Physiol.* vol. 161, 1962, p. 55.

2. The most significant characteristic of acclimatization (teams C and D) was the earlier departure each day from the nearly linear response of rectal temperature on day 1 to a plateau that was established each day at progressively lower levels. Pulse rates followed a similar pattern.
3. During the re-exposure periods most of the subjects showed unchanged or slightly lower rectal temperatures while pulse rates were generally slightly higher. This suggests that the cardiovascular system may begin to decay before thermoregulatory adaptation. The thermoregulatory failure is probably due to inadequate sweating responses.
4. There is practically no loss in heat acclimatization up to 8 days following the last exposure.
5. The retention of acclimatization is satisfactorily indicated from the results of a single re-exposure to heat.
6. The most economical procedure for attaining full acclimatization is by a single daily exposure of 100 min while walking at 5.6 km/hr.

104. MacDonald, D.K.C., and C. H. Wyndham.
Heat transfer in man.
J. Appl. Physiol. vol. 3, 1950, pp. 342-364.

The authors describe physical models of the body for the qualitative and semiquantitative analysis of heat transfer in man. Data were collected from measurements of rectal and skin temperatures and sweat rates when heat loads were imposed from within (exercise) and from without (environment).

Annotated Summary

1. Any hot-room experiments should provide for a minimum equilibrating period of 1 hr before imposing any new heat load. In partional calorimetry experiments it would be best to take measurements during the second hour to limit the error in the determination of the change in the heat content of the body.
2. In general, the adjustments of skin and rectal temperatures to new heat loads, either from exercise or environment, appear to be essentially independent, although symmetrical. The independent behavior of T_s and T_r breakdown, i.e.. they not only change at the same rate but can be essentially at the same temperature in the early stages of heat acclimatization and again when the acclimatized subject is subjected to greater heat loads from exercise and the environment.
3. "Such a marked increase in K_{int} (internal heat conductance) appears to be the primary physiological response to heat. In order to achieve this great increase in K_{int} a strain is imposed on the cardiovascular system and this is, of course, responsible for the frequency of circulatory insufficiency, observed in the first few days of exposure to heat. Acclimatization may be regarded essentially as an adjustment between K_{int} and K_{evap} whereby the latter is increased by greater evaporative heat loss which thereby allows K_{int} to reduce and so relieve the circulatory strain. . . . The body is thus once more able to function as two heat capacities."
4. Both K_{int} and K_{evap} have been shown to be under the control primarily of the rectal temperature and to a lesser extent of skin temperature and both operate in a highly nonlinear fashion, giving the body a considerable margin of environmental safety.
5. "Both the increased sensitivity of the sweat mechanism on successive exposure to heat and the exhaustion phenomenon of sweating which occurs with time in a single exposure at high temperatures have a close parallel with the characteristics of training and of exhaustion observed in psycho-motor activities."

105. **MacFarlane, W. V., B. Howard, J. F. Morrison, and C. H. Wyndham.**
Content and turnover of water in Bantu miners acclimatizing to humid heat.
J. Appl. Physiol. vol. 21, 1966, pp. 978-984.

Authors' Abstract

Water content and turnover were determined with tritiated water in 10 Bantu from Angola, acclimatizing during one week to work at 86° F and for the second week to 90° F wet-bulb temperature in a deep Rand mine. Water content averaged 77% of body weight initially. This fell while average weight increased during exposure to heat. There was no general increase in water turnover amongst these tropical Bantu during acclimatization. Water turnover ranged from 73 to 162 ml/kg per 24 hr during work in the heat with a high coefficient of variation in water turnover between subjects. The average volume of water used was 6.07 liters/24 hr in the first week, 6.78 liters/24 hr in the second week. Functional individuality of responses was apparent. Those subjects in whom body temperature was well controlled increased water turnover, while those with oral temperatures frequently above 101° F [38.3° C] during work, decreased turnover by 11%. Urinary sodium concentration was reduced relative to potassium during the first 3 days of exposure to each temperature.

106. **Machle, W., and T. F. Hatch.**
Heat: Man's exchanges and physiological responses.
Physiol. Rev. vol. 27, 1947, pp. 200-227. (Review)

The purposes of this study were (1) to review the applications of physical laws of heat transfer to the analysis of the thermal relationships between man and his environment; (2) to review studies on the physiological responses of man to heat. An annotated summary is given here.

Mathematical Considerations

Heat balance equation

$$M = \pm R \pm C - E \pm V \pm S$$

where

M = metabolic rate
R = rate of exchange by radiation
C = rate of exchange by convection
E = rate of exchange by evaporation (always negative)
V = rate of exchange by respiration
S = rate of change of body heat content (storage)

Thus, the above equation may be rewritten to include the coefficients of heat exchange and temperature and vapor pressure gradients:

$$M - V + S = K_r A(t_s - t_w) + K_c A(t_s - t_a) + K_e A(VP_s - VP_a)$$

where

A = body surface area (meters^2)
t_s = average skin temperature
t_w = mean radiant temperature of surroundings
t_a = air temperature
VP_s = vapor pressure of water at temperature t_s
VP_a = vapor pressure of moisture in the air (= % relative humidity × VP at t_a)
K_r = coefficient of heat exchange by radiation
K_c = coefficient of heat exchange by convection (and conduction)
K_e = coefficient of heat exchange by evaporation

The temperature and vapor pressure gradients can be determined by direct measurement. The coefficients must be determined experimentally.

Coefficients of heat exchange

1. Radiation

$$R = KA_r(T_s^4 - T_w^4) = K_r(A_r/A)A(t_s - t_w)$$

where

K = 4.92×10^{-8} kcal/m^2/hr
A_r = effective radiation area of body
T_s = mean radiant temperature (absolute) of body surface
T_w = mean radiant temperature (absolute) of surroundings

A = total body surface area (m^2)

K_r	t_w	t_s
5.2	20	32
5.7	30	33
5.9	40	35
6.3	50	38

A_r/A = 0.71 to 0.75, sitting nude and lightly clothed; 0.93, standing, nude

2. Convection

K_c = $1.04\sqrt{v}$ (cm/sec) in still air with vertical air movement
K_c = $0.74\sqrt{v}$ (cm/sec) in a wind tunnel with horizontal air movement
v = wind velocity
K_c = 2.0 for still air

3. Evaporation

Maximum evaporative capacity

K_e = $1.84\, v^{0.37}$ (v = wind velocity in cm/sec) for standing nude men in a linear horizontal air stream
K_e = 3.0 at v = 8.5 cm/sec, vertical air velocity

Less than maximum evaporation

$$E = K_e(A_e/A)A(VP_s - VP_a)$$

where

A_e = effective evaporative surface

A = maximum evaporative surface

$A_e/A = M - V - R - C/E_{max}$ at equilibrium

Since A_e/A is a function of skin temperature and the environmental conditions, it cannot be calculated without an independent means of predicting t_s.

Equilibrium state

$$S = sW(a\ \Delta t_r + b\ \Delta t_s)$$

where

s = specific heat of body

W = body weight

Δt_r = rate of change of internal body temperature

Δt_s = rate of change of skin temperature

a, b = weighting factors which proportion body heat in relation to internal and skin temperatures, respectively

This heat storage is independent of the environmental temperature and the rate of body heat production. However, the ultimate equilibrium level toward which the subject is tending is a function of the metabolic rate.

Equivalent environments

1. Operative temperature (t_o)

$$t_o = K_r t_r + K_c t_a / K_r + K_c$$

and it properly weights the effect of R and C; all environments having the same t_o are said to be equivalent in that they impose the same caloric demand by R and C. This is true only if $K_r + K_c$ remains constant.

Physical instruments for measuring equivalence

Physiological Effects of Heat

Body temperature and gradients

Peripheral blood flow: vasomotor regulation

Circulation

1. Instability of circulation
2. Adequacy of circulation

Sweating

Salt depletion

Metabolism and nutrition

1. Caloric requirements and specific dynamic action of proteins
2. Vitamin requirements

Gastroenteric tract

Thermal regulation

Acclimatization. Man is a homothermic animal capable of great increases in internal heat production. He, moreover, lives in a constantly changing thermal environment, all of which requires continuous regulation to maintain thermal equilibrium at his normal level of internal temperature. Even short bursts of work with its high heat production or minutes of interference with heat dissipation (hot rooms, excess clothing, etc.) will increase heat storage and elevate internal temperature. . . . With sustained increased level of heat production or continued interference with dissipation, a new level of thermal equilibrium is established by the individual. As this is repeated or continued for days there is rapid acquisition of the ability to maintain the same or lower level of thermal equilibrium under the same conditions of stress, at less cost to the individual. When the shift in temperature is moderate, the initial load on the homeostatic mechanisms is minimal and often unnoticed. Slight increases in rectal temperature and pulse rate are nonetheless usual. . . . When the change is great, and to an environment of high thermal stress, with initial marked physiological effects, the subsequent improvement in performance and reduction in load upon homeostatic mechanisms is spectacular. This acquired capacity entails complex readjustments, the mechanism for which is often conjectural. It has been suggested that shift of vasomotor control to thalamic centers is entailed. . . . Without regard to hypothesis, the process of acclimatization is characterized by certain phenomena and changes which have been well studied and described in investigations carried out within tolerable thermal limits. . . ."

1. General state. "Beginning with the first day and continuing at a decreasing rate for from 8 to 10 days there is progressive improvement in the appearance and behavior of men. Incidence of heat exhaustion, headache, dizziness, polypnea, gastroenteric tract symptoms, incoordination, irritability and depression decrease progressively. Most of the improvement occurs in the first 4 or 5 days and when acclimatization is achieved the subject will often perform as willingly and well in the heat as was formerly possible under temperature conditions. "
2. Circulation. "Circulatory system instability which is closely related to the production of many of the above symptoms, follows the same general course during the acclimatization. . . . Changes in heart rate are dramatic, the principal reduction occurring in the first 4 or 5 days."
3. Rectal temperature. "The general course of the rectal temperature is progressively downward during acclimatization, the reduction being more gradual than that of changes in circulation or performance. At low levels of heat stress, normal levels may be reached in from 7 to 10 days - in general, levels of from a few tenths to a degree or more above normal still are encountered after 10 days."
4. Sweating. "Rates of sweating uniformly increase during acclimatization though the magnitude of increase is widely variable. Increases in rates of sweating usually begin later (after from 3 to 5 days) than do other changes and may continue longer and even augment later. . . . The lack of relation between this phenomenon and the mean skin and rectal temperatures was demonstrated in Horvath's. . . study of 16 men acclimatized to severe conditions (T_W 93° F). Chloride concentration tends to decrease during acclimatization. . . except in the presence of exhausting work.

   There has been good agreement among most observers that the performance and appearance of men, degree of vascular instability, cardiac rate and rectal temperatures when evaluated together, are so closely related to the state of acclimatization as to comprise the most reliable indices of the state. The practical limits of work and environment for which acclimatization can be achieved are reviewed below. Limits for acclimatization are not only sharply defined but the adjustments involved in the acclimatization are easily disturbed. Thus, a fully acclimatized man may exhibit any or all of the disturbances characteristic of the unacclimatized state if excessive rates of work are imposed. . . or if there is intercurrent infection. . . , loss of sleep, or alcoholic indulgence. . . . More importantly, failure to maintain complete hydration. . . , caloric intake. . . or salt intake. . . will lead to prompt deterioration in performance. The same factors which enable good performance in the cool and which are related to good initial capacity to perform in, and acclimatize to heat, are similarly important to the maintenance of the acclimatization. The acclimatized state is not only unstable with respect to the above factors but is also a temporary adjustment in that it persists for a limited time only. With reduction in thermal stress, acclimatization is lost more slowly than it was acquired, the rate being influenced directly by the magnitude of the difference in the ambient temperatures. . . . A good state of acclimatization is maintained for 1 or 2 weeks with gradual loss thereafter; some men retain a fair degree at the end of 2 months. In studies in the winter months persistence for at least 3 weeks is usual. . . . Repeated exposures at least 1 month apart are required to maintain good acclimatization. . . "

5. Factors influencing acclimatization. "A number of factors influence the ability to acquire acclimatization and the rate of its development. Resting in the heat is associated with a limited adjustment, but work within limits of tolerance is necessary for full development. Exposure and work in hot, dry environments results in a partial acclimatization to hot humid conditions. Repeated brief (1-1/2 to 3 hr) daily bouts of work in the heat will acclimatize men but fullest adjustment is attained most quickly by graded, progressively increasing work in the heat.

After acclimatization to one level of thermal stress, further acclimatization may be acquired for more severe environments. . . , and acclimatization to a high level of heat stress enables greatly enhanced performance in less severe heat. . . .

Long-term changes have not been studied under controlled conditions though the performance of men after months or years of work and residence in environments of high thermal stress is a matter of great practical importance and short-term studies cannot be expected to elucidate these slowly changing factors. These may be associated with deterioration, rather than improvement in adjustment and performance. . . . Several reports. . . have called attention to the instability of the sweating mechanism that may appear after months of residence in the heat and Collings et al. . . . noted stoppage of sweating in 26 per cent of steelworkers prior to breakdown - many of the men having had years of exposure. Certainly when the stress is high, deterioration can occur in a matter of hours or days. . . . The character of the changes at low orders of stress maintained for years is not indicated. Investigation of the problem of deterioration is most urgent."

Work in hot environments

Upper limits of tolerance

Heat disease

107. **MacPherson, R. K.**
Acclimatization status of temperate-zone man.
Nature vol. 182, 1958, pp. 1240-1241.

Author's Definition

When men accustomed to living in a temperate climate are repeatedly or continuously exposed to natural or artificial hot environment they rapidly develop a greatly increased capacity to withstand heat, and this adaptation is accompanied by profound and readily demonstrable physiological changes.

Annotated Summary

1. When men are transferred from a temperate to a cold environment they do not display any rapidly increased tolerance to the new environment nor are profound physiological changes present.
2. The lack of change to cold appears to result from the assumption that the temperate climate represents a neutral state and increase in heat or cold should be accompanied by increasing physiological strain.
3. The environment in which man would be in a "neutral state" appears to be that of a tropical forest with its small diurnal temperature variation and protection from radiant heat gain or loss.
4. Man's capacity for heat loss via cutaneous vasodilatation and sweating is not matched by comparable heat conservation mechanisms.
5. Naturally acclimatized people living in the tropics are capable of a considerable range of adaptation to both hotter and colder conditions.
6. "It is to be concluded, therefore, that a temperate climate does not represent the neutral condition in which environmental stress is minimum and from which adaptation is possible both to hotter and to colder conditions to an equal degree. On the contrary, man in a temperate climate is approaching the extreme range of adaptation to cooler conditions – that is, maximum adaptation to cold. It follows that it is fruitless to attempt to demonstrate profound physiological changes in temperate man on exposure to severe cold because, the greater part of the possible adaptation in this direction having already been made in a temperate climate, any further changes must necessarily be small."

108. **MacPherson, R. K. (Ed.).**
Physiological responses to hot environments.
Med. Res. Council (London), Spec. Rept. Series 298, 1960.

This extensive group of investigations was undertaken to provide the Board of Admiralty tentative recommendations concerning the conditions of warmth acceptable in Her Majesty's ships at sea in tropical waters. The studies have also "extended knowledge of the physiological mechanisms involved in the process of adaptation to hot environments and have indicated the direction for future research."

Author's Definition

Acclimatization is an adaptive process which results in a diminution of the physiological strain produced by the application of a constant environmental stress.

Chapter Outline

1. The establishment of the Royal Navy tropical research unit.
2. A preliminary study in the tropics of the effects of air temperature, humidity, and air speed on naturally acclimatized men.
3. Further experiments on naturally acclimatized men.
4. The effects of environmental stress: Measurements on artificially acclimatized men.
5. The nature and degree of natural acclimatization.
6. The contribution of radiant heat to environmental stress.
7. Energy expenditure in relation to environmental stress.
   (*a*) Treadmill-walking at six speeds and one level of climatic stress.
   (*b*) Sweat losses in different patterns of energy expenditure.
   (*c*) The energy expenditure of step-climbing.
8. The upper limits of tolerance of environmental stress.
   (*a*) The effect of water intake in the heat.
   (*b*) Upper tolerable levels of warmth.
   (*c*) The incapacitation of men at rest in hot humid conditions.
9. Ancillary investigations in Singapore.
10. Conclusions.
   (*a*) The assessment of environmental heat stress.
   (*b*) The desirable limits of warmth.
   (*c*) The phenomenon of acclimatization. " 'Naturally acclimatized' men in Singapore possessed an ability to withstand the effects of environmental warmth that was superior to that of their counterparts serving in temperate waters who had not previously been exposed to tropical conditions. The tolerance of hot conditions possessed by such naturally acclimatized men was, however, not the greatest they could achieve and on exposure daily to conditions of increasing severity their tolerance was greatly improved. Such 'artificially acclimatized' men then possessed the same degree of tolerance of hot conditions as those men who had been similarly 'artificially acclimatized' at the National Hospital in London. The acclimatized subjects used in the experiments in London thus possessed a greater degree of acclimatization than that possessed by naval ratings serving in the tropics."

Appendix: Experiments in a temperate climate on men artificially acclimatized to hot conditions.
   (*a*) Ability to work in severe heat.
   (*b*) The effects of air movement in severe heat.
   (*c*) Prediction of the physiological effects of warm and hot environments: The P4SR index.

109. Martin, C. J.

Thermal adjustment of man and animals to external conditions.

Lancet vol. 2, 1930, pp. 561-567, 617-620, 673-678. (Review)

This paper, divided into three parts, was presented as the Croonian Lectures before the Royal College of Physicians of London on June 12th, 17th, and 19th, 1930. The topical outline will be noted along with pertinent comments.

Lecture 1 (pp. 561-567)

A. *Mechanism of homoeothermism*

1. The different means of heat loss and the proportion dispersed by each under different circumstances

B. *Nervous mechanism of thermotaxis*

1. Location cf a thermotactic "centre" by successive ablations of the anterior end of the central nervous system
2. Sensitivity of different portions of the thermotactic nervous apparatus to temperature

C. *History of homoeothermy*

Lecture 2 (pp. 617-620)

A. *Regulation of temperature by varying production: the source of animal heat*

1. Evidence for chemical regulation in man.

B. *Basal metabolism in the tropics*

Lecture 3 (pp. 673-678)

A. *On heat regulation in a warm environment*

B. *The conditions which determine sweating*

1. Material lost to the body by sweating

C. *Sunshine and heat*

1. The contribution of sunshine to the thermal profit and loss account

D. *Work and high external temperature*

110. Mason, E. D.
Daily measurements of basal metabolism, body temperature and pulse rate during a journey to the tropics.
Indian J. Med. Res. vol. 32, 1944, pp. 27-30.

Author's Summary

On a journey from San Francisco to India a woman whose basal metabolism was known to be 10 per cent lower in the tropics (Madras) than in a temperate climate (New York and Boston) was measured daily with the purpose of finding out how long an exposure to the tropics was necessary for this adaptation in heat production to be established. The measurements were made before rising in the morning, with a Benedict-Roth metabolism apparatus. The conditions throughout the journey were approximately uniform with respect to diet and activity and the transition from comfortably cool to hot humid tropical climate was abrupt.

On the first two days after exposure to tropical heat both the basal metabolism and oral temperature rose slightly. From the third day the metabolism began to fall and at the end of a week in the tropics was 10 per cent lower than the average rate for this subject in temperate climate. During the second week it fluctuated and fell slightly more. The oral temperature did not return to this subject's normal until the end of the second week and it is suggested that the second week was a period of stabilization of the heat balance.

These results are consistent with those of a similar experiment on himself reported by Martin, and support the hypothesis that the mechanism for this relatively slow adjustment of heat

production on entering the tropics, beginning about the third day and not completed for approximately one week, is reduced activity of the thyroid gland.

111. **McConahay, T. P., S. Robinson, and J. L. Newton.**
d-Aldosterone and sweat electrolytes.
J. Appl. Physiol. vol. 19, 1964, pp. 575-579.

Authors' Abstract

Men worked (BMR 190 kcal/m^2·hr) in the heat (45-50° C DBT; 26° C WBT) for periods of 5-7 hrs, maintaining water and salt balance by drinking appropriate saline solutions. d-Aldosterone was administered by continuous intravenous infusion at 1.5 μg/(kg · hr) during the third to seventh hours without altering the Na or Cl concentration of the men's sweat from control values determined during the first 2 hr of the exposures, or from the values observed during separate control experiments. Na and Cl concentrations of sweat secreted the day following the infusion experiments were not significantly different from those of samples collected the day after control experiments. The sodium-conserving responses of the men's sweat glands 7-24 hr following salt depletion (-140 to -230 mEq) were not significantly altered by infusion of 2.0-4.5 μg/(kg · hr) of d-aldosterone. Continuous infusion of d-aldosterone at 1.8 μg/(kg · hr) into one brachial artery did not alter the Na or Cl concentration of sweat being secreted by the infused arm, either from simultaneously collected samples from the man's other arm or from control values in both arms before the infusion was started. In all cases, pronounced reductions in urinary Na:K ratios were observed during and after d-aldosterone administration.

112. **Mefferd, R. B., Jr.**
Adaptive changes to moderate seasonal heat in human subjects.
J. Appl. Physiol. vol. 14, 1959, p. 995.

Author's Abstract

The excretion patterns of 29 members (including children) of 7 south Texas Caucasian familes of varying economic status were determined each November (neutral-cool, averaging 68.7° F) and May (warm, averaging 81.6° F) for three consecutive years, to determine whether heat-adaptive mechanisms were stimulated by a moderate increase in average temperature as contrasted to intense heat. Four timed overnight samples from each person were analyzed in each period for five electrolytes, five nitrogenous waste products and thirteen amino acids. Excretion rates of most substances were lower in November than in May. Creatinine and the magnesium/calcium ratio were elevated, however, and the urine volume, magnesium, urea, glutamic acid, arginine and the sodium/potassium and uric acid/creatinine ratios did not change significantly. The excretion patterns of the heat-adapted human subjects were strikingly similar to those seen in heat-adapted rats.

113. **Mills, C. A.**
Metabolic acclimatization to tropical heat.
J. Lab. Clin. Med. vol. 30, 1945, pp. 358-359.

Author's Summary

With the large military forces now seeing enforced activity in regions of tropical moist heat, it is especially important that most careful consideration be given to the effects such heat may exert.

Unfortunately, several recent articles from investigators engaged in government-sponsored research projects have presented an incomplete and erroneous picture of what may be expected in such acclimatization. While *vasomotor* adaptation to hot environments is usually complete after three to five days of exposure, all studies have tended to indicate that *metabolic* acclimatization takes place much more slowly – that it begins late in the second week of continuous exposure and is largely accomplished by the end of the third week.

Previously published and new evidence will be presented to prove the existence of this two- to three-week lag in metabolic adaptation and to deal particularly with the question of heightened thiamine and choline needs in tropical heat. New studies have shown that the heightened need for these two factors continues even when the diets contain 0.5 per cent sulfaguanidine; hence, heat depression of intestinal synthesis cannot account for the findings.

The heightened need in tropical heat is most emphatic for choline. Animals on choline-free diets in the heat and cold show no difference during the first week, and during the first half of the second week acute hemorrhagic nephritis causes an equal number of deaths in the two environments. After the second week, however, growth in the cold goes on practically as well without as with choline in the diet, while in the heat, growth is sharply affected.

Johnson, Taylor, Keys, and Holt have claimed that animal findings fail to hold for man and that human tropical needs are not different from those of temperate climates. However, all their published data were based upon only a few hours to a few days of heat exposure and provide no just basis for any deductions whatever regarding nutritional needs in the continuous moist heat of tropical lowlands. Human studies along this line must take into account the two- to three-week lag in metabolic acclimatization.

114. **Molnar, G. W., E. J. Towbin, R. E. Gosselin, A. H. Brown, and E. F. Adolph.**
A comparative study of water, salt and heat exchanges of men in tropical and desert environments.
Am. J. Hyg. vol. 44, 1946, pp. 411-433.

Authors' Summary

Field studies in the California desert and the Florida tropics showed that the thermal stress in the desert is about 2 to 3 times greater than in the tropics. A tropical jungle-swamp, however, may exert a stress similar to that of the desert shade.

Average 24-hour fluid intakes and sweat outputs were about two times greater in the desert than in the tropics, but the average urinary volume and urinary salt excretion were the same in both environments. Thus men increased their water and salt intakes in proportion to increased losses.

Evaporative losses were correlated with solar intensity and dry-bulb temperature, but no correlation could be shown with relative humidity, air movement, or rectal temperature. Clothing diminished evaporative loss by about 100 grams per hour. In the tropics, about 72 per cent of the heat due to work was lost by evaporation, but in the desert all of this heat must be lost by evaporation.

115. **Moreira, M., R. E. Johnson, A. P. Forbes, and F. Consolazio.**
Adrenal cortex and work in the heat.
Am. J. Physiol. vol. 143, 1945, pp. 169-176.

Authors' Summary

1. The effects of large doses of extract of adrenal cortex (45 ml of whole beef extract) were studied in (2) healthy young men living on a constant adequate diet and marching 3-1/2 hours daily in moist heat [32.2° C DBT; 29.0° C WBT; 80% RH and air motion 134.1 m/min].
2. In comparison with the striking influence of water drunk during work the extract had no effect beneficial or otherwise on the subjects' performance or feelings.
3. The adrenal cortical extract had no consistent effects on the following physiological or chemical functions in the course of marching or during the whole day: (*a*) heat balance as measured by pulse rate, rectal temperature, rate of sweating and skin temperature; (*b*) respiratory exchange as measured by pulmonary ventilation, oxygen consumption and carbon dioxide excretion; (*c*) blood pressure, either systolic or diastolic; (*d*) serum chloride, sodium, potassium or non-protein nitrogen; (*e*) daily urinary excretion of sodium and of chloride.
4. On days when extract was injected, the urinary excretion of potassium was increased.
5. Suggestive but not unequivocal evidence was obtained that the extract lowered the concentration of chloride and sodium in the sweat and raised the concentration of potassium.
6. A previous hypothesis concerning the normal regulation of sweat chloride is extended to sweat sodium. Both are present in sweat in almost identical concentrations usually much lower than in the serum and appear to be correlated with 3 important factors: (*a*) personal idiosyncrasy; (*b*) a central factor measured by rectal temperature and rate of sweating; and (*c*) a peripheral factor associated with skin temperature. The general level rises with increasing rectal temperature and rate of sweating. Superimposed on this general level are fluctuations associated with changing local skin temperature. In contrast with sodium and chloride, potassium apparently cannot be included in the above hypothesis and is actively secreted by the sweat glands.

116. **Moroff, S. V., and D. E. Bass.**
Effects of overhydration on man's physiological responses to work in the heat.
J. Appl. Physiol. vol. 20, 1965, pp. 267-270.

Authors' Abstract

The question was asked whether men could work in the heat with less physiological strain if they drank in excess of expected fluid losses than if they merely replaced their losses as they worked. Thirty volunteer soldiers walked on 2 successive days for 90 min at 3.5 mph on a level treadmill, at a temperature of 120°/80° F dry bulb/wet bulb. Each man drank 2,000 ml water before the walk on one day and no water before the walk on the other; 1,200 ml were drunk during the walk on both days. Overhydration resulted in significantly lower rectal temperatures and pulse rates and significantly higher sweat rates than did the control state. Two matched groups of six men each were then acclimatized to heat by daily 100-min walks under the conditions described above. One group was overhydrated during each day of the acclimatizing period; the other was not. Overhydration did not affect the pattern of acclimatization to heat; conversely, acclimatization to

heat did not alter the above-described acute response to overhydration. The hypothesis that overhydration is beneficial to men working in the heat was supported by this study.

117. **Moss, K. N.**
Some effects of high air temperatures and muscular exertion upon Colliers.
Proc. Roy. Soc. vol. 95, 1923, pp. 181-200.

Author's Summary

1. The sodium chloride content of the sweat as determined is much lower than the figure generally given in text books. Thus Luciani, who in his *Physiology* gives a full account of existing knowledge in relation to sweating, gives the percentage of sodium chloride in sweat as about 0.6. The maximum and minimum percentage contents as determined in these experiments will be seen to be 0.325 and 0.118, respectively, with an average of 0.224 per cent. This result confirms the findings of Dr. E. H. Hunt in experiments conducted by him at Oxford. Dr. Hunt collected sweat with careful precautions to prevent errors from evaporation and previous contamination of the skin. [See *Journal of Hygiene*, vol. 12, 1913, p. 479].
2. For fixed conditions of temperature and humidity an increase in the work output is accompanied by an increase in the sweat loss, and apparently also of its sodium chloride concentration. Also, if the work output be maintained constant, an increase in the loss of sweat and its sodium chloride content accompanies an increase in temperature. Where there is much sweating the loss of chloride from the body is very large and may be enormously greater than the loss by the urine. This great loss of chloride by sweating is evidently related to the extra quantity of salt in the diet of miners working in hot mines. It also throws clear light on the requirements for salt and the incidence of a salt tax in a hot climate.
3. There is a marked difference in the amount of sweating between the man acclimatized to hard manual work under high temperature conditions, and men who take just sufficient exercise to keep fit. It will be seen that for the same work output under nearly equal conditions of temperature and humidity the collier loses more than twice as much weight by sweating as does A.P.V. When, in a further experiment, the collier was pressed by an increase in the dry and wet bulb temperature he lost 5.8 lb per hour by sweating, which is a remarkable figure. I am enabled to quote evidence from Dr. Hunt in the same direction. In a letter from Singareni, India, to Dr. J. S. Haldane he gives the following information: (1) While taking violent exercise, such as a hard single at tennis, in an air temperature of, say, 102° F [38.9° C], or a little more, the loss of body weight is 4 lb per hour, as against the loss of 2 lb in the Oxford Turkish Bath. (2) A healthy 110-lb weight Dravidian coolie can lose 10 lb weight in five hours without any apparent symptoms, though this represents 10 per cent of his total body weight (109 lb to 99 lb). He could doubtless lose more before he commenced to suffer badly.
4. The distribution of chloride excretion between the kidneys and the sweat glands is of considerable interest. It will be seen that in the cases of F. R. and more particularly S. C. there was a very marked relative increase in the excretion of chloride by the sweat glands with increase of work at high temperatures, whereas in the case of A.P.V. there was no such increase.

118. **Orlov, V. V., I. Prerovsky, and B. Burianova.**
A study of the possibility of conditioning the vasodilation produced by cutaneous warming or muscular exercise in man.
Cor Vasa vol. 8, 1966, pp. 124-131.

Authors' Summary

In healthy subjects the authors studied the possibility of establishing conditioned reflexes on the basis of vasodilation produced by cutaneous warming (2 persons) or muscular exercise (3 persons). Digital and forearm blood flows were measured with occlusion plethysmography. Infra-red heating of the distal forearm and hand produced within 1-3 min increase of blood flow in fingers of the heated and of the contralateral, unheated, extremity. 150 reinforcements did not suffice to condition this phenomenon to a metronome. Moderate muscle exercise in the hand resulted in raised forearm flow with no change on the contra-lateral side. More than 150 reinforcements did not suffice to condition this effect to the sound of a buzzer.

119. **Park, C. R., and E. D. Palmes.**
Thermal regulation during early acclimatization to work in a hot dry environment.
Army Medical Research Laboratory, Fort Knox, Kentucky. *MDFRL Rept.* 2-17-1, June 30, 1947, 17 pp.

Annotation

Conditions. Partitional calorimetric measurements and clinical observations were made on three men working in 48.9/26.7/18% and 152 m/min wind velocity at a metabolic rate of 180 kcal/(m^2 · hr) for 1 hr per day on 10 successive days.

Summary

1. At the beginning of work, heat was rapidly gained by metabolism, convection, and radiation, and peripheral and deep body temperatures rose rapidly.
2. The increase in skin temperature reduced the environmental stress because of the diminished thermal gradient for radiation and convection. However, the deep temperature rose excessively in spite of a greatly elevated peripheral blood flow.
3. The principal thermal adjustment of acclimatization was the increase in the rate of sweating. The added evaporative cooling lowered skin temperature and aided the internal to surface thermal gradient and the resulting increased heat outflow permitted a reduction in peripheral blood flow.
4. As a result of the increased sweat rate and reduction in peripheral blood flow, the signs of circulatory stress diminished greatly.
5. After acclimatization, the body heat content remained high, but the peripheral tissues absorbed the heat and the critical core temperature was maintained at near normal levels.

120. **Pearcy, M., S. Robinson, D. I. Miller, J. T. Thomas, Jr., and J. DeBrota.**
Effects of dehydration, salt depletion and Pitressin on sweat rate and urine flow.
J. Appl. Physiol. vol. 8, 1956, pp. 621-626.

Authors' Summary

Four 25-hour experiments were performed on each of four healthy young men. In all experiments the subjects started at 8 A.M. and walked on the treadmill [MR 190 cal/(m^2·hr)] in the hot room [44.4° C DBT; 26.4° C WBT] during the first 4 hours [sweat rate 1.1 kg/hr] and rested in a cool room [26° C] thereafter except for three 70-minute walks in the heat beginning at 7, 12.5 and 24 hours, respectively, after the start. In one experiment the men maintained water and NaCl balance by drinking appropriate salt solutions throughout the experiment; in another experiment

NaCl balance was maintained but they were dehydrated by 3.1% of body weight in the first 4 hours and remained so through the 25th hour; in another they were dehydrated by 3.4% and depleted of an average of 157 mEq of NaCl; and in still another they attempted to maintain water balance but were depleted of NaCl by an average of 169 mEq.

When the men were deliberately dehydrated, their sweat rates during work in the heat were consistently reduced by about 15% below the rates observed when they were fully hydrated, even though skin and rectal temperatures were elevated in dehydration. Sweating of the men was reduced in the 1st hour of dehydration; when reduced by dehydration during an experiment it could be elevated to normal within an hour by rapidly restoring the men's water balance. There was a strong tendency for sweat rate to vary inversely with the variations of chloride concentration in the extracellular fluid occurring in relation to changes in water balance or salt balance.

Urine flow was lowest (23 cc/hr) when the men were depleted of both water and salt. When they attempted to maintain water balance by drinking water during salt depletion there was a reduction of serum chloride, marked diuresis and secondary dehydration. Urine flow in the working men began to increase or decrease in the second hour after a rapid change in water balance, whereas the sweat rate began to change in the first hour. The lowest urine flows and the lowest sweat rates occurred in the same experiments, and vice versa. Pitressin administered to fully hydrated men working in the heat produced a marked antidiuretic effect without altering sweat rate, thus indicating that the antidiuretic hormone is probably not responsible for the reduction of sweating in dehydration.

121. **Peter, J., and C. H. Wyndham.**
Activity of the human eccrine sweat gland during exercise in a hot humid environment before and after acclimatization.
J. Physiol. vol. 187, 1966, pp. 583-594.

Authors' Summary

1. Six unacclimatized African mine labourers were subjected to exercise for 4-1/2 hr in a hot humid environment [90°-93° F (32.2°-33.9° C) wet-bulb/dry-bulb; approximately 90% RH].
2. The patterns of glandular activity and the densities of active glands on the chest and back were assessed half-hourly from plastic impressions.
3. Acclimatization increased and prolonged glandular activity. The increment in activity of the sweat glands on the back was greater than that on the chest.
4. There was no significant increase in the *maximum* number of active glands on either site after acclimatization.
5. Acclimatization greatly reduced the number of inactive glands, subsequent to the maximum count, on the back, but this was not observed on the chest.
6. The increased sweat rates with acclimatization were due mainly to increased glandular activity.
7. The decline in sweat rates and activity on prolonged exposure to hot humid environment was attributed to glandular fatigue. Other factors, such as increased body temperature, hydration of the skin and fatigue of the central nervous system, suggested by other investigators as possibly causing the decline in sweat rates, did not have support in this study.

122. **Pitts, G. C., R. E. Johnson, and F. C. Consolazio.**
Work in the heat as affected by intake of water, salt and glucose.
Am. J. Physiol. vol. 142, 1944, pp. 253-259.

Authors' Summary

1. The best performance of fully acclimatized young men on a good daily diet, performing intermittent hard work in the heat, is achieved by replacing hour by hour the water lost in sweat. Any amount of water considerably less than this leads in a matter of hours to serious inefficiency and eventually to exhaustion.
2. Replacement of salt hour by hour under such circumstances has no demonstrable advantage.
3. Administration of glucose is of little if any advantage when compared with the great benefit of large amounts of water.
4. When practical problems of transportation and supply, lack of appreciation of the importance of water and salt, or the anorexia which is so common in hot environments, interfere with adequate intake, it may become desirable to supply salt in the drinking water, or less satisfactorily, in the form of tablets.

123. **Piwonka, R. W., and S. Robinson.**
Acclimatization of highly trained men to work in severe heat.
J. Appl. Physiol. vol. 22, 1967, pp. 9-12.

Authors' Abstract

In a study conducted in April 1963, five highly trained distance runners appeared to be well acclimatized to work [MR, 240 kcal/(m^2·hr)] in the heat [40° C DBT, 23.5° C WBT] even though none of them had been exposed to heat since the preceding summer. Four of the men continued their training program, and during April of the following year an attempt was made to acclimatize them further by daily performances of the same work in a more intense heat stress [50° C DBT, 28° C WBT]. They wore shoes, socks, and 8-oz cotton twill suits. All of them experienced marked elevations of body temperature and heart rate in the first exposures followed by significant improvements in heat tolerance in the succeeding days. Their principal adjustments with acclimatization involved a greatly increased cutaneous blood flow and a higher sweat rate per degree rise of rectal temperature. The intensive training program of the runners completely conditioned them for work in moderate heat, and it apparently improved their capacities for acclimatization to a severe heat stress.

124. **Piwonka, R. W., S. Robinson, V. L. Gay, and R. S. Manalis.**
Preacclimatization of men to heat by training.
J. Appl. Physiol. vol. 20, 1965, pp. 379-384.*

Annotation

Definition. Acclimatization is characterized by marked improvement in the regulation of body temperature and the ability to perform the task without distress.

Purpose. To determine the effects of a program of strenuous training during the winter season on the tolerance of young men for work in the heat.

Subjects. Six college athletes (five runners and one swimmer), ages 18 to 29; and seven untrained college men, ages 21 to 24.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Heat experiment			
40/23.5/25	?	?	Walking on treadmill at 5.6 km/hr for 1.4 hr for 1 day at a 5.6% grade
Cool experiment			
20-25/?/?	?	?	Walking on a treadmill at 5.6 km/hr for 1.4 hr for 1 day at a 5.6% grade

In both environments the subjects wore 8-oz khaki twill pants and shirts and Army service shoes. The subjects drank 500 ml of tap water during the first hour of the walk.

Results and conclusions

1. During work in the heat the sweat rate of the untrained men averaged 370 g/(hr·m^2) per °C rise in rectal temperature compared to 900 g in the runners.
2. Two factors aided the runners to work more efficiently in the heat: (*a*) a lower heat production in relation to surface area, and (*b*) a higher tissue heat conductance.
3. It was hypothesized that the apparent preacclimatized state of the runners probably resulted from the daily elevations of central temperature in their strenuous workouts during the preceding winter months.

125. **Pugh, L.G.C.E., J. L. Corbett, and R. H. Johnson.**
Rectal temperatures, weight losses, and sweat rates in marathon running.
J. Appl. Physiol. vol. 23, 1967, pp. 347-352.

Authors' Summary

Body weight and rectal temperature changes were followed in athletes competing in a marathon race (42 km). Ambient temperature was 23° C [17° C WBT] and relative humidity 58%. There were 77 competitors. Average results for those completing the race were: speed, 13 km hr^{-1}; estimated O_2 intake, 44 ml kg^{-1} min^{-1}; weight loss, 2.85 kg; rectal temperature, 39.0° C. The winner's time

*Same as: Piwonka, R. W., S. Robinson, V. L. Gay, and R. S. Manalis. Preacclimatization of man to heat by training. *Physiologist* vol. 6, 1963, p. 255.

was 2 hr, 38 min; his average speed was 16 km hr^{-1}; estimated O_2 intake was 54 ml kg^{-1} min^{-1}; weight loss 5.23 kg; fluid loss 5.1 liters or 6.7% of body weight. Rectal temperature was 41.1° C and average sweat rate was 1.8 liters hr^{-1}. Unexplained partial collapse occurred in four runners 0.5-1 hr after the race. It was concluded that heat elimination limits performance for some runners even in comparatively mild conditions and that successful marathon runners have sweat rates equal to the highest values seen in heat-acclimatized nonathletes and can tolerate exceptionally high rectal temperatures.

126. **Renbourn, E. T.**

Seasoning fluxes and fevers of acclimatization. An introduction to the history of tropical adaptation.

J. Trop. Med. Hyg. vol. 66, 1963, pp. 193-203.

Author's Conclusions

During the last war intense studies were carried out on the physiological response of man to a tropical environment, but for obvious reasons they were done in controlled climatic chambers on fit young men of high morale. It is to be stressed, however, that the climatic chamber cannot fully simulate the solar spectrum, the peculiar meteorological phenomena of temperature or humidity, desert sand, monsoon rain, tropical storms, etc. or the disease-bearing pests of a tropical climate. Although valuable physiological data have been obtained from short-term experiments in the controlled laboratory, this cannot throw light on the impact of interacting clinical, psychological and social factors on residents living a full life in tropical environments.

Moseley [*A Treatise on Tropical Diseases and the Climate of the West Indies,* London, 1787] and other clinicians believed that newcomers sometimes oversweated in a tropical climate. This was pointed out by Knipping and Eijkmann some half century ago and brought up recently by Japanese workers [Yoshimura, et al., *Essential Problems in Climatic Physiology*, Kyoto, 1960]. It may well be that the high rate of sweating (among other changes in physiological function arising during the first weeks of acclimatization) may represent only the early change which may become modified with long residence in the tropics.

In the past, clinicians fully accepted the supposition that acclimatization (not always successful) was a long and slow process which involved both the individual and his progeny. This supposition is now being accepted by the physiologist.

The purpose of this essay is not to survey the present-day controversial ideas of the mechanism of acclimatization to heat, but to review, in the light of our present-day knowledge, its long and continuous history. If it has shown that some of our beliefs have evolved from the experience of the great tropical clinicians of the past, their musty tomes can be closed and be replaced on the library shelf.

127. **Robinson, S.**
Physiological adjustments to heat.
In: L. H. Newburgh (Ed.) *Physiology of Heat Regulation*, Philadelphia: Saunders, 1949, pp. 193-231. (Review)

This chapter outlines information concerning the mechanisms and limitations of man's adaptation to hot environments. It contains some information on the changes occurring in heat acclimatization. The topical outline is given here.

A. Heat exchange
  1. Radiation
  2. Convection
  3. Evaporation
B. Circulatory adjustments to heat
  1. Cutaneous circulation
  2. Conductance
  3. Posture
  4. Blood volume
  5. Dehydration
C. Water exchange
  1. Sweating
    (*a*) The control of sweating
    (*b*) The rate of sweating
  2. Kidney function
  3. Water intake
D. Salt loss in sweat
E. Metabolism
F. Body temperature
G. Respiration

128. **Robinson, S., H. S. Belding, F. C. Consolazio, S. M. Horvath, and E. S. Turrell.**
Acclimatization of older men to work in heat.
J. Appl. Physiol. vol. 20, 1965, pp. 583-586.

Authors' Summary

Four men, ages 44 to 60, repeated daily work experiments in the heat by which they had demonstrated on themselves rapid acclimatization to work in a hot climate 21 years earlier. The work, heat stress, and duration of exposure were those originally found to cause marked hyperpyrexia and circulatory strain in unacclimatized men (mean age 31 years) on the first day in the heat. Under these conditions, the subjects sweated at 1.3-1.5 kg/hr. Tolerance of the men on the first day of exposure was no less than when they were younger. Body temperatures and heart rates of the older men were lowered in successive days of exposure and the work was judged progressively easier. Final values of body temperature reached after 5 to 7 days of exposure were about the same as observed originally after the same number of exposures. Thus, these older men exhibited about the same degree of strain during work in the heat as they did 21 years earlier and acclimatized as well.

129. **Robinson, S., D. B. Dill, J. W. Wilson, and M. Nielsen.**
Adaptation of white men and Negroes to prolonged work in humid heat.
Am. J. Trop. Med. vol. 21, 1941, pp. 261-287.

Authors' Summary

The two environments [Bloomington and Boston, 15 to 25° C DBT, 45% RH; Mississippi, 28 to 33° C DBT, 80% RH. All subjects walked on a motor-driven treadmill at 5.6 km/hr up a grade of 8.6% for 2 hours duration] produced differences in the adaptations of the laboratory group to prolonged walking on the treadmill. The rate of sweating was twice as great after 10 days and 2-1/2 times as great after 6 weeks in Mississippi as in the northern experiments. Body temperature remained within comfortable limits in the North but in most of the men it rose to intolerable levels in Mississippi. The marked elevation in the body temperatures of the subjects in the Mississippi experiments was due to limited radiation and evaporation imposed by the hot, humid environment. Heart rate followed closely the changes in rectal temperature until limiting values were approached. Some of the men were more efficient and performed the task with lower heat production in the hot environment than in the cool one. There was a progressive decline in efficiency during work which tended to be more rapid the greater the elevation of body temperature.

The Negro sharecroppers who went through the experiments in the hot Mississippi laboratory maintained lower body temperatures than any other group studied including those in the northern experiments. They remained cooler than the Negroes in the North because they were more efficient and were favored by a higher ratio of body surface to weight. The white sharecroppers who were studied in Mississippi were less successful in regulating body temperature than the Negro sharecroppers only because they were less efficient. When walking in the sun with skin exposed the Negro sharecroppers were superior in temperature regulation to partially acclimatized white men of the laboratory staff.

During work the white sharecroppers had a higher rate of sweating than the Negroes - this was associated with their greater elevation of rectal and skin temperatures. Negroes are capable of much higher rates of sweating as evidenced by data on two Negro servants in Mississippi who underwent marked elevation of temperature during the experiments. Sweat produced by the Negro sharecroppers during work contained lower concentrations of total nitrogen, ammonia and urea, and higher concentrations of chloride than the sweat of white men. Both Negro and white sharecroppers drank water more freely than the laboratory group.

Mean values of RQ for the various groups during work in both environments were characterized by their close similarity. Blood sugar values were also very similar. Blood lactate was moderately lower in the northern experiments than in the South.

130. **Robinson, S., S. D. Gerking, E. S. Turrell, and R. K. Kincaid.**
Effect of skin temperature on salt concentration of sweat.
J. Appl. Physiol. vol. 2, 1950, pp. 654-662.

Authors' Summary

Men were exposed to severe work and heat stress in an attempt to determine the effect of varying the temperature of the skin and sweat glands on the salt concentration of sweat collected from the subjects' hands and forearms in elbow-length rubber gloves. When the 2 hands and forearms of each subject were simultaneously kept at different temperatures, the sodium and chloride concentrations

of sweat collected from the cooler hand were significantly lower than from the other. The salt concentration of sweat from a single hand was raised or lowered within 30 minutes by a corresponding raising or lowering of the hand temperature. This direct effect of local temperature on sweat chloride was independent of the men's rectal temperatures observed during the exposures, was not dependent upon an increased rate of sweating from the region of higher temperature, and it was found at all stages of acclimatization to heat.

The concentration of salt in hand-sweat was reduced by acclimatization involving the secretion of large volumes of sweat by the men during daily exposures to work in the heat. In two series of experiments in which the men sweated 5 to 6 kg/day, acclimatization produced significant reductions of sweat chloride on the second and third days of exposure even when the rates of sweating, rectal temperature and hand temperature were increased by greater stress.

131. **Robinson, S., R. K. Kincaid, and R. K. Rhamy.**
Effects of desoxycorticosterone acetate on acclimatization of men to heat.
J. Appl. Physiol. vol. 2, 1950, pp. 399-406.

Annotation

Purpose. To determine the effects of desoxycorticosterone on the salt balance, temperature regulation, and circulatory responses of men during acclimatization to work in a hot environment.

Subjects. Four healthy males.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
21.6/13.7/40	?	180	Walking on treadmill at 5.6 km/hr for 2 hr for 4 days at a 2.5% grade
50.5/26.4/15	?	210	Walking on treadmill at 5.6 km/hr for 1-1/2 to 3 hr for 5 days at a 2.5% grade

Water [36° C] was drunk equal to sweat loss in the heat exposures. A controlled diet was eaten containing 80 mEq Cl and 75 mEq Na 4 days prior and during the 5 days of heat exposure. The experiments were conducted in the winter in Bloomington, Indiana. In one series, DCA was injected IM 2 to 3 days before and the first day of heat exposure. Dosages of 5 mg/day for 3 predays with 2-1/2 mg on the first heat day were as effective as double those amounts. Blood volumes (T-1824) were performed during the second hour of work. The men worked in pairs, one experimental and one control subject. In the second series, 5 weeks later, they reversed the treatments.

Authors' Summary

On the first exposure in each series the men showed the elevations of heart rate, body temperature, metabolism and sodium chloride concentration in the sweat which are characteristic of unacclimatized men working in hot environments. They underwent normal acclimatization during the 5 days of exposure with gradual reductions in all of the above measurements. Further evidence of acclimatization was a gradual rise in the average daily sweat secretion from 4.3 kg the first day to

4.9 kg the fifth day. During the first exposure there was an increase of 11 per cent in their blood volumes over control values determined in a cool environment.

Associated with the administration of DCA were higher concentrations of plasma sodium and lower concentrations of sodium and chloride in the men's sweat during the first 2 days in the heat. Under the conditions of these expriments none of the other measurements were significantly altered by exogenous DCA.

132. **Robinson, S., R. K. Kincaid, and R. K. Rhamy.**
Effect of salt deficiency on the salt concentration in sweat.
J. Appl. Physiol. vol. 3, 1950, pp. 55-62.

Authors' Results and Conclusions

Data are presented which confirm previous reports in the literature that when unacclimatized men perform daily work in hot environments and sweat rapidly they may or may not show a gradual decrease in the concentration of chloride in the sweat. The data give the following lines of evidence which indicate that such a reduction in chloride concentration in the sweat with acclimatization depends upon the development of a chloride deficiency due to excessive loss of salt in the sweat by the subject. (*a*) The response occurred readily when large volumes [4 to 7 kg] of sweat were secreted daily by unacclimatized men consuming 52 to 203 mEq of chloride per day. In these cases the output of chloride in the sweat during the first 2 or 3 days exceeded the intake and a salt deficit was developed. (*b*) The reduction occurred under these conditions even when the subjects' body temperatures were elevated. (*c*) It did not occur when men consuming 200 mEq of chloride per day were exposed to the same heat stress for shorter periods so that the total chloride output [46-99 mEq] in the sweat was considerably lower than the intake. (*d*) The response was reversed by raising the chloride intake to exceed the output of men who, in daily exposures to heat, had previously reduced the chloride concentration in their sweat to low levels following the development of a salt deficit. The sweat chloride began to rise in these men on the third day after their intake was increased even though the same exposures were continued and their daily sweat output remained the same. The reversal occurred in spite of improved temperature regulation and lower body temperature. (*e*) Salt deficits previously produced in unacclimatized men during cool weather without activity of the sweat glands resulted in the secretion of sweat with reduced chloride concentration even on the first day of work in the heat.

133. **Robinson, S., R. T. Maletich, W. S. Robinson, B. B. Rohrer, and A. L. Kunz.**
Output of NaCl by sweat glands and kidneys in relation to dehydration and to salt depletion.
J. Appl. Physiol. vol. 8, 1956, pp. 615-620.

Authors' Summary

Four 25-hour experiments were performed on each of four healthy young men. In all experiments the subjects started at 8 A.M. and walked on the treadmill [MR 190 cal/m$^2 \cdot$ hr] in the hot room [44.4° C DBT; 26.5° WBT] during the first 4 hours (sweat rate 1.1 kg/hr) and rested in a cool room [26° C] thereafter except for three 70-minute walks in the heat beginning at 7, 12.5, and 24 hours, respectively, after the start. Sweat and urine samples were collected during each 70 minutes of work, urine during the rest periods and venous blood for serum analysis just before the start and at

7 and 24 hours. In one experiment the men maintained water and NaCl balance by drinking appropriate salt solutions throughout the experiment; in another experiment NaCl balance was maintained but they were dehydrated by 3.1% of body weight in the first 4 hours and remained so through the 25th hour; in another they were dehydrated by 3.4% and depleted of an average of 157 mEq of NaCl, and in still another they attempted to maintain water balance but were depleted of NaCl by an average of 169 mEq. When salt balance was maintained and dehydration produced in the men there were significant increases of serum, chloride in the 7th and 24th hours, of urinary chloride output in the first 14 hours and sweat chloride in the 14th and 25th hours, as compared with the results in experiments in which both water and salt were maintained. In the salt depletion experiments serum chloride was increased slightly in dehydration but was decreased significantly when water was replaced. The salt-conserving responses of both kidneys and sweat glands to salt depletion were definitely less marked when the men were dehydrated than when their water losses were replaced during the experiments.

134. **Robinson, S., J. R. Nicholas, J. H. Smith, W. J. Daly, and M. Pearcy.**
Time relation of renal and sweat gland adjustments to salt deficiency in men.
J. Appl. Physiol. vol. 8, 1955, pp. 159-165.

Authors' Summary

Sodium chloride deficiencies of 113-407 mEq were produced gradually in men by having them sweat at 0.8 to 1.3 kg/hr during work in the heat [46° C] for periods up to 6 hours, and in other experiments by sweating at 0.5-0.7 kg/hr during rest in more severe heat [51° C] for continuous periods up to 20 hours. In 25-hour salt depletion experiments with intermittent stress the men started by working in the heat [46° C] for 3 or 4 hours and rested in a cool environment thereafter except for three work periods in the heat in the 8th, 14th, and 25th hours. The rate and amount of salt depletion of the men were determined in each experiment by controlling the subject's hourly intake of salt, taking into account his current output as measured in sweat and urine. In response to gradual salt depletion in these experiments the men's kidneys began to decrease their salt output in 1 to 2 hours and completed the adaptive salt conserving response in 5-14 hours. Work and continuous heat stress tended to facilitate salt retention by the kidneys. On the other hand the sweat glands responded much more slowly to salt deficiency, not beginning to decrease the sodium and chloride concentrations in the sweat until the 8th hour, even under the most favorable conditions, which were encountered in the 25-hour experiments with intermittent stress. When salt depletion was combined with continuous stress (heat and work, or heat alone) the initial decrease in sweat concentration was delayed beyond 20 hours. Following the initial decrease in sweat concentration in salt deficiency further reduction was very slow as compared with the rapid reduction of salt in the urine. Previous studies have shown that several days are required for the sweat glands to complete their adaptation to a given salt deficiency. In alternate periods of rest and work in the heat, renal output of salt was lower in work than in rest while both the sweat concentration and hourly salt output in the sweat were much higher in the work periods than in rest.

135. **Robinson, S., E. S. Turrell, H. S. Belding, and S. M. Horvath.**
Rapid acclimatization to work in hot climates.
Am. J. Physiol. vol. 140, 1943, pp. 168-176.

Annotation

Purpose. To measure (1) quantitatively the improvement in the ability to work in the heat following acclimatization; and (2) how quickly the improvement occurs and how soon it is lost when returning to a cooler environment.

Subjects. Six men, the authors plus W. Holmes and F. Consolazio in such physical condition that they could walk 40 mi in one day.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
40/23/23	?	315	5.6 km/hr for 1to 1-1/2 hr for 10 to 23 days on a motor-driven treadmill at a 5.6% grade

Subjects wore standard Army summer cotton trousers, shirt, tie, woolen socks, and service shoes.

Authors' Results and Conclusions

1. During the winter, experiments were carried out in which men walked on a motor-driven treadmill from 1 to 1-1/2 hours a day in a room where desert conditions were simulated.
2. When the men first began to take the walks the work was severe enough and sufficiently long to bring on symptoms of heat exhaustion.
3. The comfort and ease with which the men repeated the same walks which originally exhausted them increased rapidly during about 7 days and thereafter more slowly up to 23 days.
4. The heart rates of the men during the latter part of the walks declined from an average of 178 in the beginning to 155 on the seventh day.
5. The average skin temperature and rectal temperature of the men at the end of the work experiments declined from 98.4 to 96.5° F, and from 103.4 to 101.7° F, respectively, during the same period.
6. This rapid improvement in temperature regulation during the first 7 days amounted to about 80 per cent of the entire improvement in 23 days. It was accompanied by an increase in the rate of sweating in one man and decreases in metabolic rate during work in the others. The slow improvement in temperature regulation occurring after the seventh day was not accompanied by continued lowering of metabolic rate nor by increase of sweating during the experiments. However, the capacity for sweating in harder work than the standard experiments did increase.

136. **Robinson, S., E. S. Turrell, and S. D. Gerking.**
Physiologically equivalent conditions of air temperature and humidity.
Am. J. Physiol. vol. 143, 1945, pp. 21-32.

Authors' Summary

Two hundred twelve experiments of 2 to 6 hours' duration were carried out on men in an air-conditioned room operated with dry bulb temperatures ranging from 23 to 50° C in combination with various relative humidities. About one-half of the experiments were performed on men wearing shorts and the others on men clad in Army jungle uniforms. Three sets of exposures to the environments were made on all subjects, one with the subjects sitting, another with them walking at an easy pace on the treadmill, and the third with them performing moderate work on the treadmill.

The physiological effect of the environment in each exposure was expressed as an "index of physiological effect," by weighting equally the elevation of the subject's heart rate, rectal temperature, skin temperature, and rate of sweating from the base values of these functions determined in a cool environment on each subject in each activity. The effects of the environment on the men in relation to their activity and clothing are illustrated by six contour graphs in which their indexes of physiological effect are plotted in relation to dry bulb and wet bulb temperatures and relative humidity.

Experiments were run to determine the most severe environmental conditions in which men could maintain thermal equilibrium after the second hour of six-hour exposures. The men walking in shorts maintained thermal equilibrium from the second through the sixth hours of exposures at 34° C with 91 per cent relative humidity and at 50° C with 21 per cent humidity when their metabolic rates were 188 cal/m^2 per hour. With metabolic rates of 130 cal/m^2 per hour they maintained equilibrium at 35° C with 96 per cent humidity and at 50° C with 32 per cent humidity. With resting metabolic rates of 46 cal/m^2 per hour the men in shorts could maintain equilibrium at 36° C with 98 per cent humidity and at 50° C with 34 per cent relative humidity. An air movement of 55 m per minute prevailed during all experiments. The clothed men maintained thermal equilibrium at the respective metabolic rates only in environments distinctly less severe than those listed above for the men in shorts.

137. **Rowell, L. B., K. K, Kraning, II, J. W. Kennedy, and T. O. Evans.**
Central circulatory responses to work in dry heat before and after acclimatization.
J. Appl. Physiol. vol. 22, 1967, pp. 509-518.

Annotation

Purpose. To determine if circulatory changes during heat acclimatization were consistent with (1) a central redistribution of peripheral blood, (2) decreased cardiac output resulting from reduced demands for cutaneous blood flow, or (3) decreased cardioacceleration resulting from a cooler "functional" environment.

Subjects. Seven normal sedentary or moderately physically active men, aged 21 to 27 years.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Preliminary			
23-25/?/?	45	163	Walking on level treadmill at 5.6 km/hr until heart rates and O_2 uptakes were stabilized
Experimental			
48.4/25.6/17	45	175	Walking on level treadmill at 5.6 km/hr until exhausted or until T_r reached 40° C on weekdays only for 11 or 12 days

Catheterization was performed on days 1 and 11 only.

Results and conclusions

1. Heart rate, skin and rectal temperatures, and total sweat loss followed the usual course with acclimatization: Hr, T_s, and T_r progressively decreased and sweat rate increased. Work O_2 uptake was unchanged.
2. In five men work cardiac output and central blood volume were unchanged.
3. The decreased heart rate during acclimatization was associated with an increased stroke volume, not decreased cardiac output.
4. The increased stroke volume resulted from a lower heart rate most likely due to lower surface and core temperatures and increased sweating (a cooler functional environment rather than an increased central blood volume via thoracic redistribution of peripheral blood).

138. **Scott, J. C., H. C. Bazett, and G. C. Mackie.**
Climatic effects on cardiac output and the circulation in man.
Am. J. Physiol. vol. 129, 1940, pp. 102-122.

Authors' Summary

1. Observations on pulse rates, blood pressures, pulse wave velocities, and cardiac outputs calculated from such values, as well as determined by acetylene, are reported in six subjects exposed to moderately warm or cool rooms continuously for several days. The total observations involved 87 subject-days. The reactions of the individuals are found to be modified by their previous thermal history. Two subjects kept in the same room usually reacted similarly. Greater differences were seen between two experiments than between two subjects in any single experiment.
2. Cardiac outputs with the subjects lying down are increased at first in the warmth and then subside to normal or high normal basal values. In the cold they are at first reduced to subnormal levels and return to normal levels.
3. Cardiac outputs with the subject standing show marked differences according to the thermal history of the subjects. After adaptation to cool conditions the cardiac output with the subject standing is much below that observed with the subject lying down. In the early stages of warmth this reduction is exaggerated. In later stages of adaptation to warmth there is on the other hand little or no such reduction in cardiac output. A series of 42 observations of cardiac output in the standing posture made on 2 subjects within a period of 2 weeks is subjected to statistical analysis to demonstrate this point.
4. In any given individual these effects of adaptation to warmth may be absent if the subject is dehydrated. Dehydration may exist even though the subject may be free of symptoms at the time of examination.
5. The differences between the pulse rates while lying and standing are exaggerated in the early stages of exposure to warmth and are reduced later. If exposure to cold follows warmth they are at first reduced still further, and then later increased.
6. The efforts of prolonged but relatively mild changes in environmental temperatures on the blood pressures are an initial rise and later fall in the warmth and an initial fall and later rise in the cold. This sequence leads to pressure levels which considerably exceed those control values which precede it. The possible causes are discussed.
7. Marked differences may be seen in the same subject examined both in the morning and in the afternoon in his reaction to standing. As judged by increases in pulse rate and change in blood pressure on standing, or by cardiac output while standing, an individual may appear

to become daily less fit in the mornings on the same series of days during which he appears to be becoming more fit in the afternoons. Fitness tests are complicated by the changes here reported.

8. The maximal rate of blood flow attained in the fingers steadily increased in a warm room with acclimatization of the subject and reached values much above those commonly found. Warming of the legs decreased, rather than increased, these flows and the decrease was greater the less the subject was acclimatized. The decrease was also greater if the subject showed signs of dehydration. These changes are attributed to a blood volume relatively inadequate for the demands of the circulation in the early period of exposure to warmth. On exposure to cold several days were required to attain maximal constriction in the fingers. This is attributed to a large blood volume.

9. The veins of the forearm examined by infrared photographs showed a slight, though somewhat indefinite, gradual increase in size during acclimatization to warmth. They also showed an incapacity to constrict maximally to a mild stimulus of cold in the first few days of such exposure.

139. **Senay, L. C., Jr., M. Christensen, and A. B. Hertzman.**
Cutaneous vascular response in finger and forearm during rising ambient temperatures.
J. Appl. Physiol. vol. 15, 1960, pp. 611-618.

Authors' Abstract

During slowly rising ambient temperatures, digital vasodilatation often preceded that in forearm skin; the two vasodilatations proceeded together in spring but not in summer experiments. The curvilinear relation of local skin temperature to local skin blood flow in the forearm often showed an abrupt inflection, suggesting the appearance of an additional influence on the vessels; however, a regular relation to local sweating was not apparent, vasodilatation in forearm skin often continued to increase even when local skin temperature had stabilized or fallen slightly, and the forearm vascular events were prevented by local cooling. During repeat cycles of ambient temperature, complete dissociation of the cutaneous vascular events in finger and forearm and of forearm vasodilatation and sweating often occurred. Digital vasomotor waves were not accompanied by similar waves in forearm skin. Of multiple factors possibly controlling the forearm skin circulation, the local temperature seemed most important. The maximum vasodilatation in forearm during heat exposure was not augmented by acetyl-β-methylcholine.

140. **Shelley, W. B., L. W. Eichna, and S. M. Horvath.**
The effect of clothing on the ability of men to work in intense heat.
J. Clin. Invest. vol. 25, 1946, pp. 437-446.

Annotation

Purpose. To study the role of clothing on the upper limits of heat tolerance in highly acclimatized men working for four hours at about 250 kcal/hr.

Subjects. Ten healthy male soldiers, ages 20 to 24, pretrained by a two-week physical conditioning program in a cool environment.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
49/31/27	?	250	Marching around a room carrying a 20-lb pack 4.8 km/hr for 4 hr for 21 days
Test environments			
35.0/34.4/97			Marching 3 days in each new environment to assure full acclimatization; 4 hr each morning, followed by a 3-hr period, nude, in the heat each afternoon. At night, slept in barracks at 21° C
33.9/33.3/97			
48.9/33.3/35			
48.9/32.2/31			
48.9/31.1/25			

Each man was studied: (*a*) in the nude, wearing only shoes and socks; (*b*) clothed in a standard two piece herringbone twill Army fatigue uniform; and (*c*) clothed in a special herringbone twill uniform impregnated with a special paraffin mixture.

Authors' Summary

The upper limiting wet bulb temperature for successful group performance of 4 hours of marching at 3 mph [4.8 km/hr] [250 cal per hour] in an environment with DBT 120° F [48.9° C], was 92° F [33.3° C] for nude men, 90° F [32.2° C] for herringbone twill clothed and 88° F [31.1° C] for men wearing an impregnated herringbone twill uniform. The upper limiting wet bulb temperature at a DBT of 93° to 95° F [33.9° to 35.0° C], was 94° F [34.4° C] for nude men and 92° F [33.3° C] for men clothed either in treated or untreated herringbone twill uniforms.

At the upper limits of environmental heat, the wearing of a single layer herringbone twill (8 oz.) uniform imposes a heat load equivalent to a 2° F increase in the wet bulb temperature.

141. **Smith, J. H., S. Robinson, and M. Pearcy.**
Renal responses to exercise, heat and dehydration.
J. Appl. Physiol. vol. 4, 1952, pp. 659-665.

Authors' Summary

Renal plasma flow and glomerular filtration rate were studied in six normal men during rest and prolonged moderate exercise (*a*) in a cool environment, (*b*) in a hot environment and (*c*) when dehydrated by 4 to 8 per cent of the body weight in a hot environment. Dehydration in the heat reduced the average glomerular filtration rate by 12 per cent below controls in the resting men. Average decreases of 19 and 51 per cent from the control level of glomerular filtration rate were observed respectively during exercise in the heat and during exercise in the heat with dehydration. Exercise reduced renal plasma flow by an average of 22 per cent in the cool environment, 31 per cent in the heat and 56 per cent when the men were dehydrated in the heat. The filtration fraction increased from rest to exercise in all experiments. When water reabsorption was maximal in dehydration, there was a linear relationship between urine flow and glomerular filtration rate.

142. **Spealman, C. R., E. W. Bixby, J. L. Wiley, and M. Newton.**
Influence of hemorrhage, albumin infusion, bed rest, and exposure to cold on performance in the heat.
J. Appl. Physiol. vol. 1, 1948, pp. 242-253.

Annotation

Purpose. To investigate the ability of young men to carry out various physical activities in the heat during the course of experiments in which blood volume was altered artificially to an extent that occurs normally during acclimatization.

Subjects. Ten men, ages 20 to 38 years (one Jamaican, seven Anglo-Saxon); two subsequently dropped out.

Conditions

DBT/WBT/RH	*Air*
Heat	
33/28.5/72	30

Subjects spent 24 to 48 hours in the hot room and were then tested on the Crampton test, bicycle ergometer, and tilt table. The subsequent intermittent heat exposures induced only partial acclimatization. The independent variables were:

1. Hemorrhage (500 cc) was performed 10 to 12 hr before the above standard tests were begun.
2. Serum albumin (100 cc of a 25% solution) was infused before the standard tests were performed.
3. Bed rest – the subjects remained in bed for 24 hr.
4. Cold – 20 DBT, 18 WBT.

One final experiment was performed at 24° C DBT, 21° C WBT to determine the magnitude of the effect of environmental temperature. Total hemoglobin (blood volume) was determined by a carbon monoxide method accurate between 5 and 10 per cent.

Authors' Summary

1. Removal of 500 cc of blood (venesection) resulted in an immediate and marked decrease in ability to carry out physical activities (active and passive standing, exercising on bicycle ergometer) in the heat. Several days elapsed before control level of performance was attained again. Performance was affected adversely, but to a lesser degree, following removal of 200 cc of blood. Subjects also performed poorly following confinement to bed and exposure to cold. Infusion of serum albumin in quantity equivalent to 500 cc of blood plasma improved performance.
2. These various procedures also altered the level of hemoglobin concentration (increase in concentration following experiments on bed rest and exposure to cold; decrease following venesection and albumin infusion) and blood volume. Performance in these experiments correlates well with estimated levels of blood volume, but there is not any consistent relationship between performance and hemoglobin concentration.

143. **Spealman, C. R., W. Yamamato, E. W. Bixby, and M. Newton.**
Observations on energy metabolism and water balance of men subjected to warm and cold environments.
Am. J. Physiol. vol. 152, 1948, pp. 233-241.

Authors' Summary

1. Studies of energy metabolism and water balance were made on two subjects living in a controlled temperature room. In one experiment, a warm period [33° C DBT, 28° C WBT] of four days was followed by six days of cold [21° C DBT, 16° C WBT] and a terminal period of four days of heat. A second experiment consisted of two days of cold followed by seven days of heat and a final brief period of cold. Four other subjects were studied in a series of experiments consisting of exposure for a single day to either heat or cold.
2. Energy metabolism was not affected greatly by these environmental extremes as judged by records of caloric intake, dietary composition, basal metabolism and resting, fasting respiratory quotients. Values for basal metabolism in one experiment were on the average slightly higher following exposure to cold for a few days than they were prior to exposure, but the differences are small. Diets consumed in the heat contained somewhat more fat and less carbohydrate or protein than diets consumed in the cold. The increased milk consumption, which was responsible for the additional dietary fat in the heat, did not seem to be the result of any specific "appetite" or "desire" for fat.
3. Evidence for storage of water on changing from a cold to a warm environment and loss of water under opposite circumstances was obtained from water balance studies and observations of body weight. The quantities of water involved ranged from a few hundred cubic centimeters to more than a liter.

144. **Stein, H. J., R. A. Bader, J. W. Eliot, and D. E. Bass.**
Hormonal alterations in men exposed to heat and cold stress.
J. Clin. Endocrinol. vol. 9, 1949, pp. 529-547.

Authors' Summary and Conclusions

1. Three healthy, white males were exposed successively to a preliminary two-week period of physical conditioning; to 19 five and one-quarter hour periods of heat [41.7° C DBT; 31.7° C WBT; wind 80.4 m/min]; to 14 five-hour periods of cold [-9° C, wind 80 to 107 m/min]; to 5 re-exposures to heat; a five-week interval of no exposure to environmental stress; and finally to 3 re-exposures to heat.
2. Measurements of circulating eosinophils, absolute number of lymphocytes, urinary uric acid-creatinine ratio, 24-hour 17-ketosteroid excretion, and administration of ACTH were used to evaluate adrenal cortical responses. Basal metabolic rates were used as an index of thyroid activity.
3. Evidence indicative of a decrease in circulating eosinophils during environmental and exercise stress is presented and the relation of this observation to the secretion of the carbohydrate hormone of the adrenal cortex is discussed.
4. No significant differences in the excretion of the 17-ketosteroids were noted in any of the experimental periods.

5. Adrenal cortical function with respect to environmental stress was not successfully assessed on the basis of daily urinary uric acid-creatinine ratios or absolute lymphocyte counts, due to marked daily variations of these indices.
6. The use of adrenocorticotropic hormone for the assessment of adrenal cortical reserve yielded only suggestive evidence of a reduction of adrenal cortical functional reserve after periods of environmental stress. The difficulty of interpreting these observations is discussed.
7. No significant differences in basal metabolic rates were observed in any of the exposure periods.

145. **Stein, H. J., J. W. Eliot, and R. A. Bader.**
Physiological reactions to cold and their effects on the retention of acclimatization to heat. *J. Appl. Physiol.* vol. 1, 1949, pp. 575-585.

Annotation

Definition. The process of adapting to a new environment in such a way that tolerance and ability to function in a new environment are increased.

Purpose. To investigate the mechanism of acclimatization to cold and to ascertain the loss of acclimatization in heat-acclimatized men subjected to prolonged cold exposures, utilizing cardiovascular and metabolic indices.

Subjects. Three healthy white men, ages 20 to 26 years.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Physical conditioning			
20/12.3-13.9/40-50	80.5	?	Walking on treadmill at 5.6 km/hr for 2 hr for 10 days, wearing light clothing
Heat exposures			
41.7/31.7/50	80.5	175	Walking on treadmill at 5.6 km/hr for 1-1/2 hr for 19 days, wearing shorts and sneakers
Cold exposures			
-29/?/?	?	sitting	Walking on treadmill at 4.8 km/hr to keep extremity temperatures up to 10° C, wearing standard Army arctic clothing

There were 14 cold exposures, 5 re-exposures to heat, and finally after a 5 week interval with no intervening physical conditioning, heat or cold exposures, 3 re-exposures to heat. Fluid (0.1% saline) was given to equal sweat losses in the heat.

Authors' Summary

1. Through the entire experimental periods, measurements were made of cardiovascular and metabolic functions, water and chloride balance and body water partition. The results of these studies reveal that:

(*a*) In heat-acclimatized men, no acceleration of de-acclimatization is caused by repeated intermittent exposures to cold.

(*b*) Acclimatization to heat may be maintained for periods of several months by occasional re-exposure to the original environmental stress.

(*c*) Toe temperatures during repeated cold exposures decreased more rapidly with successive exposures suggesting more rapid and complete vasoconstriction, which does not necessarily represent acclimatization to cold since no increased tolerance to cold was demonstrated.

(*d*) Marked diuresis and negative chloride balance were observed throughout the entire period of cold exposures and these phenomena tended to persist during subsequent re-exposures to heat.

(*e*) No significant differences in total blood, plasma or "available fluid" (thiocyanate space) volumes were found in any of the experimental periods although the plasma proteins and hematocrit values suggested hemodilution in heat and hemoconcentration in cold.

146. **Streeten, D.H.P., J. W. Conn, L. H. Louis, S. S. Fajans, H. S. Seltzer, R. D. Johnson, R. D. Gittler, and A. H. Dube.**
Secondary aldosteronism: metabolic and adrenocortical responses of normal men to high environmental temperatures.
Metabolism vol. 9, 1960, pp. 1071-1092.

Authors' Abstract

Metabolic balance studies and measurements of urinary adrenocortical steroids were performed on 4 normal male subjects during a control period followed by a period of sodium restriction (35 mEq/day), a period of exposure to high temperature while sodium restriction continued, and a final control period. On the low sodium diet alone, all subjects achieved sodium equilibrium, and urinary aldosterone increased only slightly. On exposure to heat, the following changes were observed: (1) In 2 of the subjects, Na balance was slightly negative for 2 days; because the Na concentration in the sweat decreased abruptly, little weight loss, no change in hematocrit and few symptoms occurred. In the other 2 subjects, Na balance continued to be strongly negative, resulting in large cumulative losses of Na, large losses of body weight, an increased hematocrit and symptoms of heat exhaustion. In the latter subjects the concentration of sodium in the sweat was higher initially and decreased more slowly than in the first two subjects. (2) K balance was negative because of losses in the sweat, and in spite of slight but consistent reduction in the urinary K. (3) Urinary excretion of 17-hydroxycorticoids and 17-ketosteroids was generally increased on the first 1-3 days of exposure to heat. Thereafter, 17-hydroxycorticoid excretion tended to return to control levels, whereas 17-ketosteroid excretion was consistently and significantly depressed. (4) Urinary aldosterone increased greatly in all subjects. (5) Infusions of isotonic saline were followed in every instance by retention of Na, gain in body weight and fall in hematocrit. (6) Fasting blood sugar rose, glucose tolerance decreased, and urinary excretion of uric acid, nitrogen and creatinine increased; all of these changes outlasted the period of increased 17-hydroxycorticoid excretion. The process by which man acclimatizes to heat involves a greatly increased elaboration of aldosterone. The stimulus to increased output is probably not mediated by greater production of corticotropin, nor initiated by a reduction in total body water or exchangeable Na, but may result from reduced plasma and/or extracellular fluid volume. The responsiveness of the sweat glands to the sodium-saving effects of aldosterone appears to be a critical factor in man's ability to adapt rapidly to a change from a temperate to a hot environment.

147. **Strydom, N. B.**
Some physiological aspects of adaptation to heat.
So. African Med. J. vol. 28, 1954, pp. 112-113.

Some of the major physiological changes that occur during the heat acclimatization process are described.

Author's Summary

1. There is first an *increased peripheral blood flow.* The skin blood vessels act like the radiator of a car; the bigger the surface the better the cooling. Capillaries open up, more arterio-venous anastomoses develop and a general dilation takes place.
2. Then there is an *adjustment of blood pressure.*
3. The most important factor in the adaptation to heat is, however, an *increase in blood volume.* Because of the vasodilation mentioned above a diminished venous return and a faster-beating heart are inevitable during the first day or two. After an exposure of only 2 or 3 days, however, the deficit between demand and supply is compensated for in an increased volume of blood. Increases of up to 30% have been recorded.
4. This increase in blood volume contributes to the progressive *slowing of the pulse rate.*
5. As a result of increased efficiency and better economy the *metabolic rate is decreased.* This change is reflected in the *gradual lowering of work temperature as well as resting body temperatures.* The temperature-regulating mechanism seems to be set at a new low level and sweating starts sooner than during the first few days. Basal metabolic rates 10% lower than normal have been measured in acclimatized subjects.
6. During acclimatization and usually after the above-mentioned changes have taken place an *adjustment of the water and mineral exchange is made.* The amount of sweat given off is increased and there is to be reason to believe that the salt secretion is diminished.

148. **Strydom, N. B., and C. H. Wyndham.**
Natural state of heat acclimatization of different ethnic groups.
Federation Proc. vol. 22, 1963, pp. 801-808.

Authors' Summary

Samples of males from various populations were subjected to a standard 4-hr heat load in a portable low-cost climatic tent. The environmental conditions were 90° F [32.2° C] with the air almost saturated with vapor and a wind velocity of 50-80 ft/min [15.24-24.38 m/min]. The workload was kept constant at about 5 kcal/min by varying the step height according to body weight. Hourly observations of rectal temperature, pulse rate, and sweat rate were made.

Caucasians living and working in desert and tropical environments are partially acclimatized to heat as judged by the results obtained from highly acclimatized subjects. They do not differ from each other or from the local inhabitants of such areas in their physiological reactions to heat except for the fact that white Australians sweat significantly more than the Aborigines. The Caucasians living in the temperate climate of Johannesburg showed no signs of partial acclimatization to heat and differed significantly from the others in all three physiological responses.

In their natural state the Bushmen, Aborigine, Arab, and Bantu groups all show partial adaptation to heat. They do not differ from each other in body temperature response to heat stress but the Bushmen have pulse rates which are significantly lower than those of the other groups. The sweat rates of Arabs and Bushmen, both living in desert conditions, are significantly higher than those of the natives from tropical and temperate regions. These two groups sweated almost as much during the standard test as did acclimatized Bantu.

The Bantu and white South African groups differ markedly from each other in their natural state of acclimatization, the latter group showing higher rectal temperatures, pulse rates, and sweat rates during heat stress. These differences disappear entirely after a process of acclimatization except for the higher sweat rates of the whites during the last 2 hr. It seems that there is but little difference between ethnic groups in heat tolerance provided that they have been similarly active in the same environmental conditions. There is, however, a big difference in the manner in which various groups respond to heat with regard to pulse and sweat rates.

149. **Strydom, N. B., C. H. Wyndham, C. G. Williams, J. F. Morrison, G.A.G. Bredell, A.J.S. Benade, and M. von Rahden.**
Acclimatization to humid heat and the role of physical conditioning.
J. Appl. Physiol. vol. 21, 1966, pp. 636-642.

Annotation

Purpose. To investigate the effects of prior physical training on the responses to heat acclimatization.

Subjects. Ten young men: five Nyasa mine workers, ages 18 to 24 (group A) and five other men of the same age range (group B).

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Group A			
39.3/36.1/80	?	about 160 (1,560 ft-lb/min)	Bench stepping (30.5 cm) at a rate of 12 steps/min for 5 hr/day for 12 days during a 3-week period
Group B			
39.3/36.1/80	?	about 160	Day 1, same exposure as group A
23.7/15.5/42	?	about 160	Days 2-14, bench stepping on a bench of variable height at 12 steps/min for 5 hr/day for 12 consecutive days

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
39.3/36.1/80	?	about 160	Days 14 and 15, same as group A

Results: Group A

1. The heart rates, rectal temperatures showed the characteristic rapid decrease over the first few days of heat exposure, while the sweat rates increased more slowly during acclimatization. "The important feature about body temperature response in acclimatized men to the stress of work under these conditions of heat is that it takes 2-3 hr to level off." The maximum activity of the sweat glands was delayed until after the first hr of exposure, but this did not show up until the tenth exposure.
2. The volume of water consumed (temperature and composition not specified) increased during the first four exposures and showed no consistent change thereafter. Voluntary dehydration increased steadily and reached values of over 1 liter [2-3% of body weight] by the tenth exposure. This level of water deficit did not seem to influence sweat production or thermal balance.

Results: Group B

1. Upon re-exposure to heat following the training period, this group exhibited signs of partial acclimatization: average rectal temperatures and heart rates were lower but sweat rates were essentially unchanged when compared with the pre-training heat exposure.
2. The training brought the level of tolerance of the raw recruits on their first exposure to that of the experienced miners (group A) on their first exposure in the climatic room.

Conclusion. Although training may improve performance in the heat, it cannot replace acclimatization.

150. Sundstroem, E. S.
The physiological effects of tropical climate.
Physiol. Rev. vol. 7, 1927, pp. 320-362. (Review)

This is an excellent review of many of the early works in climatic physiology. The author distinguishes three periods pertaining to the effect of tropical climate on the individual: (1) the immediate response; (2) the adjustment period; and (3) the attainment of equilibrium. The first period above is not considered in this review. A brief synopsis of the major sections of this paper follows.

Annotation

Historical

1. The first era of tropical physiology commenced with colonization by the European nations.
2. Davy began the second era in which easily procurable data regarding body temperature, pulse and respiration rate, etc., were considered adequate for judging the effects of a tropical climate.

3. The third was begun by R. Virchow (Ueber Acclimatisation, Tageblatt 58 Versamml. deutsche Naturforscher u. Ärzte, Strassburg, 1885), who laid down some of the principles that have guided subsequent researchers. In this era there was an increasing emphasis on biochemical and animals studies to supplement human observations.

Medical meteorology of the tropics

Effect of light. The ill effects from insolation are probably due to absorption mainly of the longer rays and to a failure in the heat regulation.

Body temperature. It may be slightly elevated in tropical climates but the results are inconclusive due to lack of suitable baselines for comparison.

Skin temperature. Usually elevated.

Partition of heat loss in the tropics

Heat loss and skin area

Mass of metabolizing protoplasm

Basal metabolism. Results inconclusive, but probably decreased slightly.

Blood distribution. Results inconclusive.

Water regulation. Results inconclusive.

Urinary excretion. A reduction of urinary flow due to sweating.

Acid-base equilibrium

Blood sugar. Lower in the tropics.

Non-protein nitrogen

Phosphorus of the blood. Decreases in the tropics.

Lipoid constituents of the blood. Results inconclusive.

Suspension stability of red cells. Decreases.

Number of red corpuscles. No change.

White blood corpuscles. Slight decrease.

Pulse rate. Inconclusive.

Blood pressure. Variable, but unchanged after acclimatization is complete.

Respiration rate and volume. Results inconclusive.

Growth. Not sufficient data for conclusions on man.

Reproduction. Decreased.

Growth of hair and nails. Decreased in the tropics.

Pigmentation. Increased by sunlight.

Endocrinal functions. Thyroid decreases in size in heat and basal metabolism decreases slightly. Adrenal cortex may be affected by heat and interstitial cells of rat testes may become proliferated in animals reared in the heat.

Nervous system. Results inconclusive.

Author's Summary

There may be some truth in the severe criticism of a writer who characterizes the output in the tropical physiological field as "a number of hypotheses in chaotic disorder without proofs and without a leading idea being manifest in the various considerations."

This paper is not the proper place for outlining the practical issues which could conveniently be included in such a program. Among problems of a more general physiological interest may be mentioned: (1) the water regulation in connection with the heat regulation; (2) cellular permeability and hydration phenomena; (3) the interaction of endocrinal glands; (4) the muscular efficiency in connection with the lactic acid problem; (5) the blood as a system; (6) growth, reproduction, and longevity; (7) morbidity and mortality as affected by physiological changes. The list is chosen at random and is far from complete. Finally, we may say that a single firmly proven qualitative biochemical change will be more valuable in demonstrating a real effect of the tropical climate than a score of quantitative measurements of altered physiological manifestations.

151. **Talbott, J. H., H. T. Edwards, D. B. Dill, and L. Drastich.**
Physiological responses to high environmental temperature.
Am. J. Trop. Med. vol. 13, 1933, pp. 381-397.

Authors' Summary and Conclusions

The responses to a high external temperature of two groups of normal men were studied. The first group is composed of laborers at Hoover Dam, and the second of seven laboratory workers temporarily stationed in Boulder City. These studies were made in the summer of 1932.

The history of the workmen regarding previous exposure to high temperatures before coming to Boulder City showed a satisfactory adaptation. Their adjustment to the heat at Hoover Dam was likewise satisfactory. The significant changes in the body associated with adaptation are discussed. There was a slight loss of body weight during the summer. The low nitrogen excretion in the urine, after the onset of hot weather, probably indicated a decreasing protein intake. The urinary secretion per hour was 35 per cent greater during work than during rest. The chloride excretion in the urine was above 3 grams per day. This was the amount believed to be sufficient to indicate safety from heat cramps.

Comparison of the constituents of the blood, before and after work, showed a decrease in oxygen combining capacity after work in 20 of 25 observations. No satisfactory explanation for this was offered. The serum chloride concentration increased during work in all but 3 of 25 observations. The average increase was 1.0 mEq with no observation below 102 mEq. The serum protein increased in all of the subjects except two, in June, July, and August.

Studies of the constituents of the blood of the laboratory workers in Boston and later in Boulder City showed an elevation of the serum protein concentration. The drop in oxygen capacity was 0.3 volume per cent. There was no appreciable effect of the changes in environment on the blood volume of the four members on whom these determinations were made. The changes in the serum electrolytes were small.

The observations reported permit the following inferences as to the mechanism of adaptation to high climatic temperatures.

1. There is a loss of body weight in the first days after going to such an environment.
2. The fluid intake is greatly increased and closely related to the elevation of the temperature.
3. The volume of urine undergoes little change, but the specific gravity increases to 1030 or 1035. This returns to 1015 or 1020 after the period of adaptation.
4. The twenty-four hour excretion of nitrogen in the urine is less than in temperate climates. A lowered protein intake is partially responsible for this effect.

5. The amount of sodium chloride lost in the sweat is greater in the first days after going into a high climatic temperature. This is accompanied by a diminished excretion of chloride in the urine. When adjustment is effective, the salt concentration in the sweat decreases and the amount of chloride in the urine increases.
6. The changes from normal in the constituents of the blood are small, when adaptation has been satisfactory.

152. **Tanaka, M., T. Matsuda, F. Eguchi, T. Kawata, H. Iwasaki, T. Chihaya, K. Masuko, and S. Hiramatsu.**
Studies on the seasonal variation of blood water of human body. (Studies on the seasonal correlation between the metabolism and the thermal regulatory function. Part II).
J. Physiol. Soc. Japan vol. 15, 1953, pp. 524-533.

Annotated Summary

The seasonal variation of the water content of blood was studied at monthly intervals in five adult males in the basal condition. The following results were obtained:

1. The water content of serum and blood increased in the summer and decreased in the winter, due to changes in total circulating plasma volume and its absolute water content.
2. Accompanying the change in environmental temperature, the plasma volume is altered by the shift of tissue fluid into or out of the blood vessels. The cause of the fluid shift was presumed to be the vasodilatation or vasoconstriction of the cutaneous vessels.
3. The main cause of the seasonal change in blood water is, presumably, that the vascular bed and the total volume of circulating blood cells are changed by thermoregulatory and some other mechanism with the lapse of season, and thus the circulating plasma volume is changed. As the seasonal change of the serum salt concentration differs from that observed in the experiment of changing room temperature, it is necessary to consider additional influences of seasonal variation upon the total body water content.

153. **Taylor, H. L., A. F. Henschel, and A. Keys.**
Cardiovascular adjustments of man in rest and work during exposure to dry heat.
Am. J. Physiol. vol. 139, 1943, pp. 583-591.

Annotation

Purpose. To study: (1) how fast men acclimatize to heat; (2) individual variation; (3) whether it is possible to predict which men respond best to heat; and (4) the sequence of adjustments during heat acclimatization.

Subjects. Volunteer soldiers and hired men students, ages 18 to 46. A total of sixty-six subjects.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Day			
48.9/29.4/25	?	280	5.2 km/hr for 5-1/3 hr on a motor driven treadmill at a 7.5% grade
Night			
29.4/18.3/34	?	?	

Three different experiments were done: series I, 6 men were studied in an 8-day exposure; series II, 12 men were studied during 3-1/2 days exposure; and series III, 25 men were studied during 2-1/2 days exposure. A 2-day control period preceded each of the three series.

During the hot periods the subjects lived continuously in the controlled environmental quarters. The diet contained 3,100 kcal with 95 g protein, 120 g fat, and 15±2 g NaCl. On some occasions salt was reduced to 5.8±2 g. Water was allowed ad libitum except during work on the treadmill.

Authors' Results and Conclusions

1. Seven thousand observations on pulse, blood pressure, rectal temperature and rate of sweating in work and rest are reported on 43 subjects (202 subject days) on a constant salt diet before and during exposure to dry heat for 2 to 8 days. Additional observations were made on 23 other subjects for 147 subject days. Observations of pulse and blood pressure before and after elevation on a tilt table were made morning and evening. Modified Crampton scores of cardiovascular fitness were calculated from these figures.
2. Marked deviations from control values in cool conditions were observed in work pulse rates, rectal temperatures and Crampton scores during the first days in heat.
3. Ten cases of heat exhaustion occurred; four of these were clear cut examples showing collapse with hypotension, tachycardia, vertigo and vomiting. Rest without removal from the hot environment sufficed to restore the ability to perform work in these men.
4. A rapid improvement in work pulse rate, rectal temperature and Crampton score took place and was complete in 4 to 5 days. No significant change took place in these variables from the fifth to eighth days.
5. The primary adjustment involved in acclimatization to heat is an improvement in cardiovascular efficiency. A decrease in the accumulation of heat, as measured by the rectal temperature during work, is probably secondary to cardiovascular improvement.
6. The average daily sweat loss is not affected by acclimatization. The rate of sweating during work tends to increase as acclimatization proceeds but a large part (one-half) of this change occurs after the more important adjustments, as indicated by the rectal temperature and pulse rate during work, have taken place.
7. The failure of the work pulse rate to show improvement over the value of the first day is a sign of impending heat exhaustion; similarly, poor cardiovascular postural adjustment in the evening is a danger sign.
8. None of the variables studied in the cold (control) are useful in the prediction of the ability to acclimatize in subsequent exposure in heat.

154. **Taylor, H. L., B. Metz, A. Henschel, and A. Keys.**
Individual variability in capacity to acclimatize to high temperature.
Am. J. Physiol. vol. 167, 1951, p. 831.

Authors' Abstract

Twelve normal young men were exposed to a 6-day period of a hot dry environment, 118° F [47.8° C] preceded by a 2-day control period at 78° F [25.6° C]. In both periods, the subjects followed a daily routine of intermittent grade walking on a treadmill. Plasma volume, maximal oxygen consumption and the score of a physical fitness test were determined at 78° F. Resting

and work pulse rates and rectal temperatures, the scores of a postural adjustment test and the rates of sweating were obtained in both cool and hot conditions. The increments of the mean work pulse rate and the mean work rectal temperature were obtained between the control and the following periods: first afternoon, first 2 days and the last 2 days of the hot conditions. One hundred and twenty-five correlations between these increments and data obtained in the control period were computed. The diurnal rectal temperature variation in the control period was related to the work rectal temperature increment in the first afternoon by an r of 0.74 and to the work rectal temperature increment of the 5th and 6th days by an r of 0.56. The correlation coefficient between the plasma volume per m^2 of body surface and the work rectal temperature increment of the last 2 days in heat was -0.56. The correlation coefficient between the fitness score and the work pulse rate increment of the 5th and 6th days was -0.58.

155. **Vernon, H. M.**

The index of comfort at high atmospheric temperatures.

Med. Res. Coun. Rept. Series, London, 73, 1923, pp. 116-144.

Vernon made a series of studies on himself in environments between 60° C and 90° F [15.6-32.2° C] in which the air was (a) either saturated or (b) 50 to 70% saturated. Numerous observations were made on body temperature, heart rate, respiration rate, and the rate of sweating at rest and during exercise (step climbing). His conclusions regarding acclimatization (some of the first) are presented below.

Author's Conclusions

The endurable limit of air temperature depends on the wet-bulb temperature, but it is greatly affected by *acclimatization*, and in the final experiments it was about 6° F [14.4° C] higher than in those made a month earlier (e.g., when no clothes were worn, it was 88.5° [31.4° C] and 82.5° [28.1° C], respectively).

At first the experiments in moist air were found to be much more trying than those in relatively dry air, and they induced faintness followed by bad headaches, but after acclimatization they were less trying than the dry air experiments. The heart showed considerable acclimatization for at a given body temperature (100.7° F) [38.2° C] the pulse averaged 131 in the earlier observations, and 120 in the final ones. The respiration rate, which sometimes quickened to over 100 per minute towards the end of the experiments, showed more acclimatization than the pulse. The rate of perspiration increased with acclimatization, and in the final experiments the sweat measured over 5 pints [2.3 liters] in three hours.

156. **Weiner, J. S.**

Observations on the working ability of Bantu mineworkers with reference to acclimatization to hot humid conditions.

Brit. J. Indust. Med. vol. 7, 1950, pp. 17-26.

Annotation

Purpose. To study Bantu mineworkers under standardized working conditions so the results might be compared with data from European and American studies.

Subjects and conditions. Eight experienced (acclimatized) and eight completely inexperienced Bantu workers were compared at 32.2° C DBT, 31.7° C WBT, 92% RH, and 50.3 m/min air motion.

Results

1. The performance by the novice group did not indicate any high degree of natural heat tolerance.
2. Acclimatization was acquired in three days and the Bantu were able to work at 110 kcal/($m^2 \cdot$ hr) for four hours.
3. The progressive changes in pulse rate, rectal temperature, and sweat rate characteristic of acclimatization were observed in *both groups.*
4. The Bantu with 4 to 6 months experience was not quite up to the same state of acclimatization as Europeans artificially acclimatized in experimental hot rooms.
5. Repeated work stress brings the Bantu to the European level as regards rate of sweating.

It was concluded that (*a*) caution must be exercised, when comparing levels of acclimatization, in using standards based on different acclimatization routines; and (*b*) standards based on the performances of European men should be cautiously applied to workers in other circumstances.

157. **Weiner, J. S., and R. van Heyningen.**

Lactic acid and sweat gland function.

Nature vol. 164, 1949, pp. 351-352.

Sweat was collected at half-hour intervals on successive days of exposure to 45.6 (DBT), 29.4 (WBT), 30% (RH) and air speed about 15 ft/min [4.57 m/min].

Authors' Summary

Sweat collected from normal male subjects carrying out work at high temperatures and humidities was analysed for chloride, lactic acid and urea. The osmotic pressure, as estimated by the freezing point in two hundred samples, is found to be accounted for by the osmotic pressure of these three

constituents added together to the extent of about 95 per cent. Sodium chloride, on the average, accounts for about 80 per cent; lactate accounts for about 11 per cent.

Changes of osmotic pressure (by freezing-point determinations) and of the three components were followed through, before, during and after acclimatization to hot conditions. The osmotic pressure of the sweat in the acclimatized subject is lower than in the unacclimatized – a result to be expected from the large contribution made by sodium chloride (the correlation coefficient with freezing point is 0.86) and therefore in line with previous findings [Dill, D. B., et al., *J. Biol. Chem.* vol. 100, 1933, p. 755].

The lactic acid concentration, which may be as high as 300 mgm per cent in the pre-acclimatized state, settles down to about 100 mgm per cent after ten to fifteen 3-hourly exposures. . . .

The reduction in sweat lactic acid in the acclimatized or "trained" state suggests an analogy with muscle, and the analogy is strengthened by the finding that in an arm rendered ischaemic for 15-20 minutes in every 30 minutes sweating, over an experimental period of three hours, the lactic acid percentage is markedly increased as compared with that in the unoccluded arm. . . .

These observations, which will be reported in detail elsewhere and which are being extended, point to the importance of lactic acid production in the work of the sweat glands and in the changes in their activity with acclimatization. It may be added that glycogen is known to be present in cells of the sweat gland in considerable quantity [Bunting, H., et al., *Anat. Rec.* vol. 100, 1948, p. 61], and may therefore be a precursor of the lactic acid of the sweat.

158. **Weiner, J. S., and R. E. van Heyningen.**
Salt losses of men working in hot environments.
Brit. J. Indust. Med. vol. 9, 1952, pp. 56-64.

Authors' Discussion

The foregoing experiments are in agreement with those of Black and others [*J. Physiol.* vol. 102, 1944, p. 406], Conn and others [*J. Clin. Invest.* vol. 25, 1946, p. 912], and Robinson and others [*J. Appl. Physiol.* vol. 2, 1950, p. 399] in affirming that a reduction in the chloride concentration (and output) of body sweat occurs only when the intake of dietary salt is insufficient to prevent the occurrence of a negative salt balance induced by sweating. It is very likely that this process of adjustment underlay the original observations of the phenomenon by Dill et al. [*J. Biol. Chem.* vol. 100, 1933, p. 755]. The "salt conservation" response is not a necessary part of the acclimatization process; it may be induced after the individual has been in the heat for shorter or longer periods, as in our experiments, and in those of Robinson and others or, as has been shown, it may be entirely absent in the acclimatization period if the salt intake is maintained at a high level. The fact that on a high salt diet the sweat chloride concentration in arm bag sweat (unlike general body sweat) falls, is not an indication of salt conservation. As we have shown, the salt loss does not decrease. The fall in arm bag sweat concentration is bound up with the acclimatization process itself since it is attributable to the very large increase in sweat loss within the arm bag.

The reason for the relatively greater increase in output of sweat within the arm bag during acclimatization is not known, but must, in some way, be due to the higher temperature and humidity therein.

Authors' Summary

The sweat and urinary loss of chloride have been studied in individuals working in hot conditions for short periods.

Acclimatization to heat is only accompanied by a decrease in the chloride concentration of general body sweat if a negative chloride balance is induced by restriction of the chloride intake.

Sweating for short periods (2 hours) in unacclimatized subjects brings about a compensatory reduction of urinary chloride manifested after the subject leaves the hot room. This reduction is so great that the total loss of chloride may be less on days on which sweating occurs than on the control days.

Attention is drawn to the limitations to the use of sweat collected in arm bags as a method of assessing the bodily salt balance.

The bearing of these findings on the desirability of supplementing the salt intake in the diet is discussed.

159. **Weinman, K. P., Z. Slabochova, E. M. Bernauer, T. Morimoto, and F. Sargent, II.**
Reactions of men and women to repeated exposure to humid heat.
J. Appl. Physiol. vol. 22, 1967, pp. 533-538.

Authors' Summary

Ten healthy young subjects, five men and five women, underwent a series of experiments, walking on a treadmill for 4 hr under conditions of 33.9° C DBT, 32.2° C WBT, and 88% relative humidity. Measurements were made of sweat rate, skin and rectal temperatures, pulse rate, blood pressure, and metabolic rate. Two similar experiments under temperate ambient conditions served as bases for evaluating the influence of the work in the humid heat and that of the work itself. The increment of rectal temperature was smaller in the men than in the women and decreased progressively. Total body sweat rate was significantly higher in the men and rose during the course of the repeated exposures. Among women the increment of pulse tended to reach a plateau within 2 hr; it did not in men. No differences nor changes were found in the blood pressure, skin temperature, and total heat production. The results suggest sex differences in acclimation mechanisms.

160. **Whitney, R. J.**
Circulatory changes in the forearm and hand of man with repeated exposures to heat.
J. Physiol. vol. 125, 1954, pp. 1-24.

Annotation

Definition. The use of the term *acclimatization* has been purposely avoided in this paper, since it is not always clear if this term refers to the routine of accustoming a man to the heat or it if refers to the physiological changes which are responsible for the adaptation.

Purpose. To investigate the changes in peripheral circulation when man is exposed to the heat.

Subjects. Four men of the Royal Navy; none had had service in tropical climates for at least 12 months prior to the experiment. Ages 20 to 29; height, 166 to 173 cm; weight, 55.5 to 91.5 kg.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Training period			
21.1/15.6/56	24	?	Bicycle ergometer; a 20-min rest period followed by 3 each 20-min alternating periods of work and rest on 5 separate days
Heat period			
45.5/29.4/30	24	(see below)	Bicycle ergometer; same protocol as above.

Subject A, worked at 41.0 kcal/hr for 8 heat exposures; subject B, worked at 61.4 kcal/hr for 3 heat exposures; Subject C, worked at 41.0 kcal/hr for 10 heat exposures; and subject D, worked at 54.6 kcal/hr for 8 heat exposures.

Author's Summary

1. Using the mercury-in-rubber strain gauge on the forearm, the circulation of the forearm and hand during repeated exposure to a hot, humid (? 30% RH) environment has been investigated on four normal, male subjects. Parallel observations of overall sweat rate, of metabolic rate, and of rectal and body temperatures were made. The circulatory measurements included: mean blood flow to the forearm and hand combined; partition of blood flow between forearm and hand (one subject only); pulse rate; change in size of the forearm venous reservoir; distensibility of the forearm venous reservoir.
2. After repeated exposure to heat, the forearm volume decreased during exposure to heat with all four subjects. The number of daily exposures to heat required to produce this response varied from subject to subject, and an increase in forearm volume was typically recorded during the earlier exposures to heat.
3. The changes in forearm volume are considered to be due, very largely, to changes in the size of the forearm venous reservoir. The possible importance of peripheral veneconstriction in relation to circulatory collapse in the heat is discussed. The physiological mechanism of peripheral veneconstriction was not investigated. Changes in forearm venous tone, as indicated by changes in the pressure distensibility of the forearm venous reservoir, were not found to be simply related to changes in peripheral veneconstriction of the forearm.
4. None of the other physiological parameters investigated showed a response to heat which was consistent for all subjects.
5. The effect of arterial occlusion applied to the wrist on the ipsilateral forearm volume and forearm blood flow is described and discussed.

161. **Whittow, G. C.**
Some factors affecting the magnitude of the pressor, cardio-accelerator and pain response to cold of heat-acclimatized subjects.
Clin. Sci. vol. 17, 1958, pp. 339-348.

Author's Summary

1. Some factors affecting the magnitude of the pressor, cardio-accelerator and pain responses to localized cooling of heat-acclimatized subjects have been studied.
2. The magnitude of the systolic and diastolic pressor responses was significantly correlated with the temperature of the cold water in which the hand was immersed, but variations in the temperature of the hand before the cold immersion had no significant effect on the pressor responses.
3. The pressor responses of heat-acclimatized subjects appeared to be greater than those of people living in cold or temperate countries, and they were also altered by exposure of the body to different environmental temperatures.
4. The rise of the heart rate during the cold immersion was not affected by variations in the cold-bath temperature within the range 1° C-16° C, but the heart rate rose significantly less at high than at low environmental temperatures.
5. The amount of pain which the subjects felt during cold immersions diminished when the temperature of the cold bath was increased in steps of 5° C, from 1° C to 16° C. The pain responses also decreased in magnitude when the environmental temperature was raised and most pain was felt during immersions in a cold room.
6. Some evidence was obtained which suggested that a change in the magnitude of the cold pressor response can occur without a consensual change in the subjective assessment of pain.
7. None of the responses was significantly greater when the hand and part of the forearm were immersed in water at 4° C than when the fingers alone were immersed.

162. **Wilkinson, R. T., R. H. Fox, R. Goldsmith, I.F.G. Hampton, and H. E. Lewis.**
Psychological and physiological responses to raised body temperature.
J. Appl. Physiol. vol. 19, 1964, pp. 287-291.

Authors' Abstract

The performance of 12 male volunteers in an adding test and in a test requiring prolonged vigilance was measured at normal body temperature and while temperature was maintained at 37.3, 37.9, and 38.5° C. Each subject was measured at each level of body temperature on four occasions. Both the extent and the direction of the effect on performance varied with (1) the task being carried out, and (2) the degree of temperature elevation. Compared with performance at normal temperatures, the ability to add was impaired and vigilance was improved at 38.5° C. At 37.3° C, on the other hand, smaller changes reflected in general an improvement in adding and an impairment of vigilance. As a result of the repeated sessions of controlled hyperthermia, the subjects became heat acclimatized but there was no corresponding improvement in performance at raised body temperature, indicating the absence of short-term adaptation of the central nervous system functions tested to repeated elevations of body temperature.

163. **Williams, C. G., G.A.G. Bredell, C. H. Wyndham, N. B. Strydom, J. F. Morrison, J. Peter, P. W. Fleming, and J. S. Ward.**
Circulatory and metabolic reactions to work in heat.
J. Appl. Physiol. vol. 17, 1962, pp. 625-638.

Authors' Abstract

Oxygen consumptions were measured at various levels of work up to the individual's maximum. At submaximal work they were significantly lower in heat than in comfortable temperatures, but maximum oxygen intakes were not significantly different. In comfortable conditions cardiac output and A-V difference both contributed to rise in oxygen intake during submaximal work. At maximal effort increase in arteriovenous difference accounted for the ultimate rise in oxygen intake. Both heart rate and stroke volume contributed to increase in cardiac output up to 1.0 liters/min oxygen intake; above this heart rate was the sole factor. In heat the major change in hemodynamics was an increase in heart rate with an associated fall in stroke volume. Neither cardiac output nor arteriovenous difference was signficantly altered from comfortable conditions. "Excess" lactate occurred at significantly lower levels of work in heat than in comfortable conditions. Working muscles were therefore relatively more anoxic in heat at submaximal work, and this accounted for lower oxygen intakes. At maximal work the degree of anoxia was the same in both temperature conditions.

164. **Williams, C. G., C. H. Wyndham, and J. F. Morrison.**
Rate of loss of acclimatization in summer and winter.
J. Appl. Physiol. vol. 22, 1967, pp. 21-26.

Authors' Abstract

The rate of loss of acclimatization to heat when men are withdrawn from work in hot conditions in a mine to work in cool conditions for periods of 1, 2, and 3 weeks, both in summer and in winter, is examined. Samples of 20 men who had been working in a hot area of a mine were withdrawn and subjected to a 4-day period of acclimatization. This had the effect of bringing all the subjects to the same state of acclimatization. There was a progressive rise in rectal temperature and heart rate and fall in sweat rate in the groups exposed to 4 hr of moderate work at 90° F WB after being in cool conditions for 1, 2, and 3 weeks. There was no significant difference between summer and winter values. The values for these physiological measurements in a control group of unacclimatized men were significantly higher in winter than in summer. The practical implication of these results is that men who have been away from work in hot conditions for 1 week should be reacclimatized for 1 day before going back to work in hot conditions.

The losses in acclimatization of (1) heart rate and sweat rate were: after 1 week, 50%; after 2 weeks, 80%; after 3 weeks, 100%; and of (2) rectal temperature were: after 1 week, 25%; after 2 weeks, 40%; after 3 weeks, 50%.

165. **Wilson, O.**

Physiological changes in blood in the Antarctic. A preliminary report.

Brit. Med. J. vol. 2, 1953, pp. 1425-1428.

Author's Summary

Continuous monthly blood tests were made on 15 members of the N.-B.-S. Expedition to the Antarctic, 1949-52, during the two-year study and the trip there and back.

Red-cell counts showed no changes or seasonal fluctuations. Haemoglobin values showed a typical seasonal fluctuation as a function of outdoor activity, not related to the usual summer maximum and winter mimimum shown in Scandinavia. No measurable increase of adrenaline in the blood was found. During acclimatization to Antarctic climate and back again to normal climate fasting blood-sugar values as well as morning white-cell counts showed a characteristic dip of acclimatization in their curves. After acclimatization the fasting blood sugar showed an increased level of 9%, while morning white-cell counts stayed 25% below normal. Morning white-cell values were more stable and showed the general trend of acclimatization, while afternoon values were more sensitive indicators of temporary conditions. The white cells of smokers seemed to be more sensitive to reactions in the Antarctic and stayed at a considerably higher level.

166. **Wood, J. E., and D. E. Bass.**

Responses of the veins and arterioles of the forearm to walking during acclimatization to heat in man.

J. Clin. Invest. vol. 39, 1960, pp. 825-833.*

Authors' Summary

1. Seven normal young men were acclimatized to heat on eight occasions by walking on a treadmill for 30 minutes four times a day at an environmental temperature of 120° F [48.9° C] DBT and 80° F [26.7° C] WBT. Four subjects were acclimatized to heat in this manner for nine days in the summer and four subjects were acclimatized to heat in an identical study for six days in the fall.
2. The responses to exercise of the veins and arterioles of the forearm during acclimatization to the heat were measured by plethysmographic techniques.
3. The forearm veins constricted with walking in a control environment (25° C) as well as with walking in the hot environment. The degree of venoconstriction with walking was greatest on the third and fourth days of exposure to the hot environment.
4. The forearm arterioles dilated during walking at normal environmental temperatures. This dilatation with walking was greater in the hot environment. The degree of dilatation was less on the third and fourth days during walking in the hot environment than on the first and second or on the final days in this environment.
5. The disappearance of the symptoms of heat exhaustion with exercise (dizziness, weakness and nausea) coincided with the onset of maximal venoconstriction and minimal arteriolar dilatation on the third day of the acclimatization process. The maximal venoconstriction and minimal arteriolar dilatation with walking did not persist after the fourth day in the hot

*Same as: Wood, J. E., and D. E. Bass. Venomotor responses to exercise during acclimatization to heat in man. *Federation Proc.* vol. 18, 1959, p. 172.

environment. Subjective and objective evidences of acclimatization to heat were nevertheless well maintained for the remainder of each of the studies.

6. The results of these studies support the concept that important adaptations in acclimatization of man to exercise in a hot environment take place in the cardiovascular system. The peripheral vascular adaptations as observed in the forearm blood vessels appear to be an important aspect of the cardiovascular responses to exercise in the heat.

167. Wyndham, C. H.
Effect of acclimatization on circulatory responses to high environmental temperatures.
J. Appl. Physiol. vol. 4, 1951, pp. 383-395.

Annotation

Purpose. To study the underlying circulatory adjustments during repeated exposure to hot environments.

Subjects. Five men.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
(*A*)			
48.9/30.6/28	22.9	110	Bench stepping, 30.5 cm at 12 cycles/min for 2 hr/day for 12 days
(*B*)			
45.6/29.4/32 followed by 6 days at condition *A*	22.9	110	Work intermittent in *A* and *B*
(*C*)			
same as condition *B*	22.9	160	Work continuous in *C*

Results and conclusions

1. Acclimatization to heat is associated with an increase in total peripheral resistance, a reduction in peripheral blood flow, a progressive decrease in heart rate, pulse pressure, and cardiac output.
2. After acclimatization, the circulatory adjustments in severe heat are a marked reduction in total peripheral resistance, which appears to be accounted for mainly by vasodilatation in muscle and skin, and an increase in cardiac output, heart rate, and pulse pressure.
3. The two opposing tendencies in terms of dissipation of body heat, decreased peripheral blood flow and an increase in deep tissue – skin temperature difference, are so adjusted by acclimatization that at similar skin temperature, less storage of heat occurs in the body.

168. **Wyndham, C. H.**
Role of skin and of core temperatures in man's temperature regulation.
J. Appl. Physiol. vol. 20, 1965, pp. 31-36.

Author's Abstract

The response characteristics have been studied of the curves relating heat conductance and sweat rate to change in rectal temperature at different levels of skin temperature, and vice versa. The increase in these responses with deviation in rectal temperature from the "neutral" setting is highly nonlinear; the neutral point and the curve shift to the right and the slope decreases with lowering of skin temperature and vice versa when it is raised. With further deviation of rectal temperature these responses reach maximum values, i.e., become "saturated." All of these features are analogous to servomechanisms with negative feedback, giving sensitive and stable control. Control of these responses by skin temperature is more linear, characterizing passive control systems which are insensitive and less stable. Quantitatively, the effect at skin temperature of 26° C of 1° C rise in rectal temperature on heat conductance and sweat rate is 10 times greater than the same rise in skin temperature; at a neutral skin temperature of 33°-34° C, a rise of 1° C in rectal temperature is 6-7 times greater; at a high skin temperature of 36°C, a rise in rectal temperature of 1° C is 4-5 times greater.

169. **Wyndham, C. H.**
Effect of acclimatization on the sweat rate/rectal temperature relationship.
J. Appl. Physiol. vol. 22, 1967, pp. 27-30.

Author's Abstract

A sample of 13 acclimatized Bantu males and a fresh sample of between 6 and 10 unacclimatized Bantu at each heat stress condition (making a total of 353 unacclimatized Bantu) were exposed to 45 different combinations of air temperature (with the air saturated with water vapor), wind velocity, and work rate. A table was constructed of the mean sweat rate for 0.3° F class intervals of rectal temperature. The mean sweat rates were based on different sample sizes in the various class intervals of rectal temperature. An exponential equation of the form $Y = K(I - ae^{-bx^m})$ was used to express the relationship and the curves so derived fitted the data very well indeed. Comparison of the curve for the acclimatized and unacclimatized men showed that they were significantly different (at the 5% level) and that in the acclimatized men: (1) the origin of the steep part of the curve is shifted by over 1° F to the left; (2) the steepness of the slope of the curve is increased; and (3) the asymptote, or maximum value, of sweat rate is higher. From these results it can be concluded that there is an increase in "sensitivity" and an increase in "capacity" of the regulation of sweat rate by the temperature of the hypothalamus (as represented by the rectal temperature).

170. **Wyndham, C. H.,W. v. d. M. Bouwer, M. G. Devine, and H. E. Paterson.**
Physiological responses of African laborers at various saturated air temperatures, wind velocities, and rates of energy expenditure.
J. Appl. Physiol. vol. 5, 1952, pp. 290-298.

Authors' Summary

In mild conditions, 86° F [30.0° C] saturated air temperature and below, body temperature levels of acclimatized African men depend solely upon rate of work and are uninfluenced by environmental factors such as wind velocity. Above 86° to 90° F [32.2° C] environmental factors are operative and body temperature level rises progressively per unit increase in environmental temperature. Wind velocity also exerts a significant effect. These acclimatized non-European African laborers were better adapted to hot, humid conditions than were Europeans examined under conditions of comparable heat stress severity in Britain. The much smaller sweat rate of Africans, 300 per cent in severe conditions, is especially noteworthy.

171. **Wyndham, C. H. and G. E. Jacobs.**
Loss of acclimatization after six days of work in cool conditions on the surface of a mine.
J. Appl. Physiol. vol. 11, 1957, pp. 197-198.

Authors' Abstract

Seventy-three men were acclimatized to work in an area of a mine with a wet bulb temperature of 91° F [32.8° C]. They then spent 6 days on the surface of a mine in relatively cool conditions. On return to work in the hot area mouth temperature was significantly increased, viz., a mean increase of 0.7° F. One further day of work in heat decreased mouth temperature significantly, viz., the increase following cool exposure fell from a mean of 0.7° F to 0.2° F. The logical step therefore when large groups of men are required to work in heat is always to expose them to 1 or 2 days of work in heat if they are moved to cool conditions, for any reason, for 6 or more days.

172. **Wyndham, C. H., R. K. McPherson, and A. Munro.**
Reactions to heat of aborigines and Caucasians.
J. Appl. Physiol. vol. 19, 1964, pp. 1055-1058.

Authors' Abstract

A study was made of the physiological reactions to heat of samples of Australian aborigines and Australian Caucasians in the hot, humid tropics. Their results were then compared with those of unacclimatized and acclimatized Caucasians (South Africa). The Australian shows signs of a partial degree of acclimatization in that his heart rate and rectal temperature are lower and his sweat rate is higher than those of the unacclimatized South African Caucasian. The aborigine presents a less clear picture in that his rectal temperature is lower but his heart rate and sweat rate is the same as the unacclimatized Caucasian. A striking difference between the Caucasians and aborigines in Australia is the much higher sweat rates of the Caucasians. The lower sweat rates of the aborigine might result from the morphological feature of a greater surface area:mass ratio whereby he loses heat by radiation and convection more adequately than the Caucasian and therefore is able to conserve sweat; alternatively, he appears to have a more sensitively adjusted thermoregulatory control channel between rectal temperature and sweat rate.

173. **Wyndham, C. H., B. Metz, and A. Munro.**
Reactions to heat of Arabs and Caucasians.
J. Appl. Physiol. vol. 19, 1964, pp. 1051-1054.

Authors' Abstract

The physiological reactions to heat of samples of French servicemen and of Arabs in the Sahara Desert were compared with those of South African Caucasians. Both Sahara groups displayed evidence of partial acclimatization; their reactions were better than those of the unacclimatized, but not as good as those of acclimatized South African Caucasians. The French servicemen were slightly better acclimatized than the Arabs; they had lower rectal temperatures and heart rates, and higher sweat rates. This paradoxical finding indicates that the Arabs, although their ancestors have lived in the Sahara Desert for some centuries, display no greater adaptation to hot conditions than recent Caucasian inhabitants. The morphology of the Arab gives him a greater surface area:mass ratio than the Caucasian. This favors heat loss, but under the test conditions the Arabs had no apparent advantage in physiological reactions. The differences in morphology of the Arab and Caucasian appear to be related more to their nutritional state and physical activity levels than to any structural adaptation to heat.

174. **Wyndham, C. H., J. F. Morrison, and C. G. Williams.**
Heat reactions of male and female Caucasians.
J. Appl. Physiol. vol. 20, 1965, pp. 357-364.

Annotation

Purpose. To study the reactions of unacclimatized women to humid heat and to compare their pattern of acclimatization with that of men.

Subjects. Unacclimatized: thirty males and twenty-six females. Acclimatized: ten males and four females.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Unacclimatized			
33.9/32.2/89	15-24	men = 163 women = 183	Stepping at 12 steps/min on an adjustable bench for one 4-hr period
Acclimatized men			
35.0-35.6/33.9/82	15-24	163	Same bench stepping, 4 hr/day for 11 days
Acclimatized women			
33.9/32.2/89	15-24	183	Same bench stepping, 4 hr/day for 4 days
35.6/33.9/82		183	Same bench stepping, 4 hr/day for 5 days
Acclimatized			
33.9/32.2/89	15-24	men = 163 women = 183	Same bench stepping, one 4-hr period

Water was available ad libitum; the men wore shorts and the women bikini-type clothing.

Results and conclusions

Unacclimatized

1. The females had more severe reactions than the males to work in the heat; 92% of the females were unable to complete the 4-hr work period compared with 50% of the males, due to a more rapid rise in heart rates and rectal temperatures in the females.
2. Some of the females exhibited marked aggressiveness and irritability and others broke down and wept. This latter reaction occurred in some of Sargent's subjects in the Illinois study [*J. Appl. Physiol.* vol. 18, 1963, p. 383].
3. The oxygen consumptions were slightly lower (0.904 vs. 1.027 l/min) and the rates of sweating were significantly lower in the females compared with the males.

Acclimatized

1. The females responded more slowly to the acclimatization process. Both males and females ended with heart rates of 140/min and rectal temperatures of 38.9° C. The women had a lower sweat rate than the men by about the same percentage as they had after the first unacclimatized exposure. The heat production after acclimatization between the sexes was remarkably similar when expressed per square meter of body surface.

   "Possibly the most surprising fact that emerges from this study is the lack of relationship between sweat rates and levels of rectal temperature in the two sexes. In the unacclimatized state the females sweat much less than males in the 1st hour and, associated with this difference, rectal temperatures and heart rates of the females rise much more rapidly than the males. However, in the 2nd and 3rd hr, the discrepancy between female and male sweat rates decreases, but the females continue to show the more rapid rise in rectal temperature. What appears to be paradoxical is that after acclimatization the differences between female and male sweat rates are even greater than before acclimatization, but now the rectal temperatures of the females are closely similar to those of the males. Moreover, the sweat rates of the acclimatized females now fall off much more rapidly with time than the males, so that the differences between the two sexes in sweat rate actually increase from the 1st to the 4th hr. In spite of this observation, the rectal temperatures of the females are identical to those of the males at the end of the 4th hour. It would appear from this difference between sexes in sweating that the male in these hot, humid conditions is a prolific, wasteful sweater whereas the female adjusts her sweat rate better to the required heat loss. In this respect the female behaves in a manner similar to the Bantu male."
2. It was concluded that in spite of the fact that females are lighter and smaller than males and have greater skinfold thicknesses which would inhibit heat transfer, they can achieve a comparable state of acclimatization as the male.

175. **Wyndham, C. H., N. B. Strydom, H. M. Cooke, and J. S. Maritz.**
The temperature responses of men after two methods of acclimatization.
Arbeitsphysiologie vol. 18, 1960, pp. 112-122.

Authors' Summary

The risks are assessed of African labourers developing heat-stroke levels of body temperature, i.e., a mouth temperature of 105° F [40.6° C] working moderately hard in a saturated air temperature of 92° F [33.3° C] and an average wind velocity of 450 ft/min [137.16 m/min] on the *first* day after the Chamber of Mines two-stage method of acclimatization (12 days) and after an abbreviated form comprising 3 days in hot air conditions.

Approximately 100 men were studied in each method of acclimatization. The mean mouth temperatures of both groups, the standard deviations and the distributions of mouth temperatures on the first day in the cool area during acclimatization were not significantly different. Hence it can be assumed that the two samples were from the same population in terms of their temperature responses to work in heat.

On the *first day after* acclimatization, the means and standard deviations of the mouth temperatures of both groups were similar but the number of mouth temperatures in the upper range was greater after 6-day than after 12-day acclimatization. From the confidence limits to the curves fitted to the mouth temperatures we are 95% sure that the risk of a mouth temperature of 105° F being exceeded is less than 1/1,000,000 on the *first* day after 12-day acclimatization, and 4/1,000 on the *first* day after 6-day acclimatization.

176. **Wyndham, C. H., N. B. Strydom, J. F. Morrison, F. D. du Toit, and J. G. Kraan.**
Responses of unacclimatized men under stress of heat and work.
J. Appl. Physiol. vol. 6, 1954, pp. 681-686.

Authors' Summary

During work, rectal temperatures of raw recruits rose to new equilibrium levels. These levels were closely related to the rates of work and in certain air temperature ranges, namely up to 90° F [32.2° C] during light work, up to 87° F [30.6° C] during moderate work and up to 84° F [28.9° C] during hard work, they were uninfluenced by changes in wind velocity. During rest and during work in various degrees of environmental heat stress, the level of rectal temperature of raw recruits was uniformly higher, namely 1.3° F, than that of acclimatized men. This difference gives acclimatized men an advantage of 3°-6° F, saturated air temperature, at which similar rectal temperatures will be attained as raw recruits. The differences in responses of raw and acclimatized men when exposed to various degrees of heat stress, can be explained by the more sensitive setting of the thermostatic control of sweating by the central thermosensitive centers.

177. **Wyndham, C. H., N. B. Strydom, J. F. Morrison, C. G. Williams, G.A.G. Bredell, J. S. Maritz, and A. Munro.**
Criteria for physiological limits for work in heat.
J. Appl. Physiol. vol. 20, 1965, pp. 37-45.

Authors' Abstract

New physiological criteria are put forward for setting the limits for men at work in hot conditions. They are based upon the fact that the curves relating rectal temperatures to conductances and rectal temperatures to sweat rates have two components. One is where the increases in the sweat rates and conductances, with rise in rectal temperature, are relatively large, i.e., there is a "sensitive" range of control; the second is where the curves of sweat rates and conductances against rectal temperatures reach asymptotes, i.e., become "saturated." The upper limit of the sensitive range is a rectal temperature of 100.5° F [38.1° C] and the saturated range begins at rectal temperatures of 102.5° F [39.4° C]. These concepts explain the "easy," "difficult," or "excessive" ranges of conditions of the Fort Knox and Human Sciences Laboratory studies. The great advantage of these criteria over others proposed is that the extent of the physiological strain on the workmen can be assessed, directly and simply, by a measurement of oral or rectal temperatures during the shift, and from these results limits for work can be set for work at specific hot jobs.

178. **Wyndham, C. H., N. B. Strydom, J. F. Morrison, C. G. Williams, G.A.G. Bredell, and J. Peter.**
Fatigue of the sweat gland response.
J. Appl. Physiol. vol. 21, 1966, pp. 107-110.

Annotation

Purpose. To investigate the diminution in the sweat gland response by measuring (1) the sensitivity of the sweat response to similar stressors, and (2) the maximum capacity for sweating.

Subjects. Ten males, nationality and ages not specified.

Conditions

DBT/WBT/RH	*Air*	*kcal/(m²·hr)*	*Exercise*
Acclimatization			
35.0/33.9/86		166	Bench stepping (30.5 cm, 12 steps/min) for 5 hr/day for 2 weeks excluding week-ends

After the acclimatization process each subject worked for 5 hr under ten different environmental conditions at five different metabolic rates making a total of 50 exposures for each subject. The range of the environmental conditions were DBT 29.4-36.1; WBT 27.2-33.9; air motion 17-244 m/min. The five levels of energy expenditure averaged 49, 102, 150, 224, and 259 kcal/(m^2·hr).

Results and conclusions

1. Three distinctly different zones were observed in the curves of sweat rate versus rectal temperature.
   - (*a*) 36.7 to 37.5° C: very little increase in sweat rate with the increase in rectal temperature.
   - (*b*) 37.5 to 38.6° C: very large increase in sweat rate with the increase in rectal temperature – the sensitive zone of temperature regulation.
   - (*c*) Above 38.6° C [101.5° F]: a small increase in sweating with the increase in rectal temperature – the zone of saturation of sweating.
2. The sweat rate versus rectal temperature curves were affected by time.
   - (*a*) The slope of the curves in the sensitive range decreases with time, particularly after the third hour of exposure, suggesting a diminution in the sensitivity of the sweat response with the rise in rectal temperature.
   - (*b*) There is a fall in the saturation levels of the sweat rate from 1,440 ml/hr in the first hour to 620 ml/hr in the fifth hour.
3. It was concluded that there is
   - (*a*) A shift down from 100.5° F [38.1° C] to 99.5° F [37.5° C] of the neutral range of rectal temperature.

(*b*) An increase in sensitivity of the sweat gland response with rise in rectal temperature occurs in the sensitive zone of the curve relating sweat rate/rectal temperature.

(*c*) A marked increase results in the maximum capacity of the sweat response.

The first of these two phenomena suggest that the temperature-regulating center in the hypothalamus both shifts its neutral point and increases its sensitivity to a rise in body temperature. The third phenomenon is undoubtedly due to an improvement in blood circulation to the skin.

179. **Wyndham, C. H., N. B. Strydom, J. F. Morrison, C. G. Williams, G.A.G. Bredell, M.J.E. von Rahden, L. D. Holdsworth, C. H. van Graan, A. J. van Rensburg, and A. Munro.**
Heat reactions of Caucasians and Bantu in South Africa.
J. Appl. Physiol. vol. 19, 1964, pp. 598-606.

Authors' Abstract

Heat reactions of 20 Caucasian and 22 Bantu males were compared, first in the unacclimatized state and then in the acclimatized state. The study was conducted at temperatures of 90° F wet-bulb and 93° F dry-bulb at a work rate of 1 liter O_2/min consumption. The performances of the unacclimatized Bantu were superior to those of the Caucasians. All 22 Bantu completed the 4-hr experiment, while 10 Caucasians failed. The mean rectal temperature of the Bantu was significantly lower than that of the Caucasians, but not the mean heart rate and mean sweat rate. When both groups were highly acclimatized all men from both groups completed the 4-hr experiment, and their reactions to heat were significantly different from their reactions in the unacclimatized state. Sweat rates, particularly, increased very much. The differences between the two highly acclimatized groups in rectal temperatures, heart rates, and sweat rates (except the 4th hr) were not significant. Although superior in the unacclimatized state, the Bantu does not appear to have an inherent advantage in the ability to regulate the body temperature.

180. **Wyndham, C. H., N. B. Strydom, A. Munro, R. K. MacPherson, B. Metz, G. Schaff, and J. Schieber.**
Heat reaction of Caucasians in temperate, in hot, dry, and in hot, humid climates.
J. Appl. Physiol. vol. 19, 1964, pp. 607-612.

Authors' Abstract

Heat reactions of Australian Caucasians living in hot, humid climates and of French Caucasians living in hot, dry climates were compared to unacclimatized and highly acclimatized male Caucasians living in Johannesburg. The experiments were conducted in climatic chambers at temperatures of 90° F WBT and 93° F DBT, and a workload of 1 liter O_2/min consumption. The Australians did not differ significantly from the French in the three reactions to heat, except for a slightly significantly higher sweat rate in the first hour. The French and Australians had lower mean rectal temperatures and heart rates and higher sweat rates than the unacclimatized South Africans. Although the trend is toward a significant difference for all hours, the differences are not always significant. Living and working in the hot, humid tropics and in the hot, dry desert evidently confers a certain measure of acclimatization to heat. Quantitatively this can be expressed as 50% of the difference between unacclimatized and acclimatized men. This is, however, considerably less than the condition achieved by systematic artificial acclimatization.

181. **Wyndham, C. H., N. B. Strydom, J. S. Ward, J. F. Morrison, C. G. Williams, G.A.G. Bredell, M.J.E. von Rahden, L. D. Holdsworth, C. H. van Graan, A. J. van Rensburg, and A. Munro.** Physiological reactions to heat of Bushman and of unacclimatized and acclimatized Bantu. *J. Appl. Physiol.* vol. 19, 1964, pp. 885-888.

Authors' Abstract

Bushmen in the Kalahari desert fulfill two criteria for acclimatization to heat. They exercise actively, in hunting, in relatively severe heat in midsummer. Compared with unacclimatized Bantu they have higher sweat rates per square meter and lower heart rates. However, rectal temperatures are not much lower than those of unacclimatized Bantu. River Bushmen present a paradoxical picture. In summer sweat rates are higher than in winter, but are not as high as desert Bushmen. Summer heart rates are, however, higher than in winter. Rectal temperatures in the two seasons are similar. The higher sweat rates in summer are good evidence of better acclimatization than in winter; the higher heart rates may be a reflection of differences in physical fitness in the two seasons.

182. **Wyndham, C. H., N. B. Strydom, C. G. Williams, J. F. Morrison, G.A.G. Bredell, J. Peter, C. van Graan, L. D. Holdsworth, A. van Rensburg, and A. Munro.** Heat reactions of some Bantu tribesmen in southern Africa. *J. Appl. Physiol.* vol. 19, 1964, pp. 881-884.

Authors' Abstract

Samples of 20 Bantu each from various tribes in southern Africa have been subjected in the late summer in Johannesburg to the established "standard heat-stress test" and were compared with a sample of mixed Bantu, studied in Johannesburg in the late winter. The mean rectal temperatures of the summer group were significantly lower than the mean of the winter group. Heart rates and sweat rates were not different. Intertribal comparisons revealed no significant differences in resting values or in heat reactions. An outstanding feature was that only 3 men of the 120 unacclimatized Bantu reached a rectal temperature of 104° F, and only one collapsed (this is 3% compared to the 50% of Caucasians who did not complete the test). No distinctions can be made between these Bantu tribes in their states of acclimatization in spite of the fact that some came from temperate and others from subtropical regions. The range of climates in the tribal territories is, however, small. Expressed as basic effective temperatures, the January climates – a hot, summer month – vary from 71° to 79° F in these different regions.

183. **Yoshimura, H., S. Oohara, Y. Yamamoto, M. Tanaka, W. Takaoka, F. Eguchi, and T. Mori.** Studies on the seasonal variations of water and salts metabolism of human body. (Studies on the seasonal correlation between the metabolism and the thermal regulatory function, Part I.)
J. Physiol. Soc. Japan vol. 15, 1953, pp. 47-57.

Annotated Summary

The water and salt content of the serum were determined monthly on five adult male students throughout one year; the blood being drawn from the cubital vein with the subjects in a basal condition. The urinary output of salts was also measured on three of the subjects who consumed a diet of constant composition for one week in each of the four seasons. The results were as follows:

1. The serum water content increases in summer and decreases in the winter. The change is accompanied by seasonal variations of total circulating blood volume, and bears an important relationship for the regulation of heat elimination from the body.
2. Seasonal changes of serum salt concentration differ according to whether the salt is of extracellular (Na, Cl, Ca) or of intracellular origin (K, P). The changes of the latter are much greater than those of the former.
3. Serum Na, Cl, and Ca decrease in summer and increase in winter. The changes are mainly due to the seasonal dilution or condensation of the blood mentioned above.
4. Serum concentration of P rises with the increase of ultraviolet rays of sunshine in summer, while it falls with the decrease in ultraviolet in the winter.
5. On the other hand, serum K falls in the summer and rises in the winter. As the K level follows the metabolic rate, these changes are probably correlated with the seasonal changes in metabolic rate, especially basal metabolism, i.e., heat production, determined on the subjects in this study.
6. The physiological roles of these changes of serum salts were discussed and their intimate relationships with seasonal adaptation of thermal regulation were deduced. Thus, the extracellular salts are involved in physical regulation while K from the cells is involved with chemical regulation.
7. The serum acid-base balance undergoes no serious variation with a change of seasons, though, in winter, the blood pH falls slightly and the urinary output of acid radicals and the base economy increase (latent acidosis).

184. **Young, W. J.**
Observations upon the body temperature of European living in the tropics.
J. Physiol. vol. 49, 1915, pp. 222-232.

Author's Conclusions

1. The temperature of the mouth of Europeans living in the tropics is often considerably lower than that of the rectum, and this difference is generally much more marked after exercise just as in temperate climates. The temperature of the mouth is thus not reliable as a measure of the body temperature.
2. During complete rest the rectal temperature did not show any marked variations from the limits of temperature observed in Europe.
3. A considerable rise in the rectal temperature was produced by slight muscular work, and this was usually maintained for some time after the work had ceased.
4. The high rectal temperatures observed throughout the day were due solely to muscular exertion.

SUBJECT INDEX

(THE NUMBERS REFER TO THE ABSTRACT NUMBERS)

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