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**HEALTH FACTORS INVOLVED
IN WORKING UNDER
CONDITIONS OF HEAT STRESS**

Report of a WHO Scientific Group

WORLD HEALTH ORGANIZATION

GENEVA

1969

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**WHO SCIENTIFIC GROUP
ON HEALTH FACTORS INVOLVED IN WORKING
UNDER CONDITIONS OF HEAT STRESS**

Geneva, 29 August - 4 September 1967

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HEALTH FACTORS INVOLVED IN WORKING UNDER CONDITIONS OF HEAT STRESS

Report of a WHO Scientific Group

A WHO Scientific Group on Health Factors Involved in Working Under Conditions of Heat Stress met in Geneva from 29 August to 4 September 1967. The meeting was opened on behalf of the Director-General by Dr J. Karefa-Smart, Assistant Director-General. He pointed out that the standards of living and health of the community are bound up with industrial productivity and this in turn with the efficiency and well-being of the worker. Occupational health is consequently of particularly great importance in developing countries where skilled labour is scarce and its replacement is often a difficult problem. Dr Karefa-Smart stressed that protection of workers against potentially harmful physical environments was of major importance and that, in this respect, heat was one of the commonest hazards. The problem of heat stress was obviously more serious in developing countries, since most of these were located in the tropical and sub-tropical belts.

Dr H. S. Belding was elected Chairman, Dr F. Lavenne Vice-Chairman, and Dr A. R. Lind Rapporteur.

1. GENERAL INTRODUCTION

In industries such as mining, steel or glass manufacture, agriculture, and road building, workers are often exposed to severe environmental heat stress, which may even threaten survival. Hard physical work or exercise in hot surroundings is rightly considered the main hazard, for the total heat load on the body is in fact the sum of environmental and metabolic heat. Physiologists, engineers, and doctors have paid increasing attention to the problem, with the result that much is known about the measurement and evaluation of three important aspects. These are (a) the components of heat stress—notably metabolic heat, air temperature, humidity, air movement, and radiant temperature; (b) man's responses to working in heat, in terms of body temperature, heart rate, and sweat loss; and (c) the kind of hot conditions that men tolerate well, not so well, or for strictly limited periods of time only.

The study of these factors is described in its own adopted terms, of which *heat stress*, *heat strain*, *tolerance limits*, and *optimum conditions* are

examples.¹ The investigation of various industrial heat problems provides information that is often of no more than local significance. On the other hand, the research worker's need for strict control of the environmental and human factors involved in heat stress was early appreciated, and for many years studies have been conducted in laboratory hot-rooms. Unfortunately, few texts are available that make a serious attempt to provide Governments, industrial management, engineers, medical officers, and hygienists with all the information available, expressed in reasonably understandable language.

In addition, the information available deals almost exclusively with industry in developed countries and cannot be applied without reservations to circumstances in tropical countries. In the tropics, the worker is expected to cope with the combined effects of industrial and climatic heat—with the probability, indeed, of having to work hard in hot spaces during an eight-hour shift, and of living for many months at a stretch without complete relief from heat stress at any time of the day or night. To complicate matters, his diet may well be inadequate to support him in this ordeal. The need for more quantitative information in this respect is emphasized and made more urgent by the current industrial development of countries in the tropical zones. It is the responsibility of governments and industrial managements—and in some instances of trade unions—to stimulate research into those aspects of the work environment that directly affect the health, efficiency, and comfort of the work force. Financial support for these studies should be provided where necessary. Due attention must be given to occupational considerations, such as the construction of the factory, air conditioning, the engineering control of localized heat sources, the provision of cool rest rooms, suitable methods and hours of work, the provision of adequate supplies of potable water, medical examinations and the provision of certain items of personal protective clothing. The importance of such matters as adequate housing and diet must also be fully recognized.

2. MAN'S RESPONSES TO HEAT

2.1 General considerations

Man's thermoregulatory system is complex, serving the need to maintain thermal equilibrium of the core tissues of the body within a relatively narrow range of temperatures. If the deep body temperature is to be maintained

¹ The terms "stress" and "strain" are used in the conventional engineering senses. *Heat stress* is the burden or load of heat that must be dissipated if the body is to remain in thermal equilibrium, and is represented by the sum of metabolic rate (minus external work) and gain or loss by convection and radiation. *Heat strain* is the physiological or pathological change resulting from heat stress, e.g., increase in heart rate and body temperature, sweating, heat syncope, or water and salt imbalance.

in equilibrium, then the amount of heat gained by the body must be equalled by the amount of heat lost from it. Since the amount of heat involved can vary considerably, depending on the energy expenditure and the environmental conditions, the mechanisms controlling heat loss must necessarily be both flexible and efficient. Ultimately, the amount of heat exchanged between the body and its environment depends on the differences of temperature and of vapour pressure that exist between the skin and its surroundings. Three mechanisms are involved: (1) Heat is lost from, or gained by, the body by convection when the air temperature is respectively lower or higher than skin temperature and, as the air movement increases, so does the rate of convective heat exchange. (2) When the surface temperature of the surroundings is above or below the skin temperature, radiant heat is gained or lost by the body. (3) Evaporation of sweat results in the loss of heat from the body; the amount of sweat that can be evaporated, and hence the efficiency of sweating for cooling, depends on the difference between the vapour pressure of the environment and that of the skin and is increased as air movement increases. The coefficients of heat exchange through these three channels have been determined experimentally for men and can be applied to the calculation of heat gain or loss if the air temperature, the humidity, the amount of radiant heat and the air speed are known. With the additional knowledge of the metabolic heat production, a simple arithmetical heat balance can be written: $M \pm C \pm R - E = \pm S^1$ where M represents metabolic heat production; C , R and E , convective, radiant, and evaporative heat exchanges; and S the amount of heat stored in the tissues or lost from the tissues with a consequent rise or fall of body temperature. If the body maintains thermal equilibrium, then S is zero.

These purely physical relationships are in turn affected by the dynamic action of two physiological mechanisms, namely, those that regulate cardiovascular function and sweating. In addition to changing the rate of heat transfer from the deep body tissues to the periphery, these two mechanisms can alter both the temperature of and the vapour pressure on the surface of the skin and thereby influence the rate of heat transfer between the body and its environment. These dynamic physiological exchanges cannot be undertaken without cost to the organism as a whole, and there are many associated physiological reactions—for example, those affecting salt and water balance and humoral functions—that involve the thermoregulatory system during exposure to hot climates.

It is to be expected, then, that the physiological strain experienced by a man seated or working in a hot environment will be related to the total heat stress to which he is exposed. This logical supposition has been

¹ This formula was first expressed by Winslow, Herrington & Gagge in 1936 (*Amer. J. Physiol.*, **116**, 641); it has been used since by many people. The letter S , representing bodily heat storage, is nowadays sometimes replaced by the letter Q .

the subject of a good deal of investigation, often with the supplementary aim of constructing a heat stress scale by which to assess conditions producing equivalent physiological strain ; some of these scales are described below. When attempting to define different metabolic and environmental conditions that may give rise to the same physiological strain, it is necessary to measure the levels of, or the changes in, several bodily functions, and it is appropriate to measure those that are the product of thermoregulation or are intimately associated with it. Obviously, the temperature of the deep tissues of the body or of the skin must provide some indication of the degree of strain to which the thermoregulatory system is being subjected. Similarly, the heart rate may be considered a simple and readily observable indicator of the demands imposed by work and heat load on the circulatory system, and the amount of sweat produced can reasonably be expected to reflect the heat strain, since the evaporation of sweat constitutes the body's main defence against overheating. In fact, it is now generally possible to analyse the factors responsible for the changes in these functions in response to different levels of metabolic and environmental stress and to determine which measurements are likely to be most suitable for different purposes. The ways in which this can be done are described in the section dealing with heat stress indices. Most investigators attempt to measure two or more of the physiological functions and to integrate them into a single index of the heat strain in any given set of circumstances. This is a wise procedure, since thermoregulation, so simple in concept, is a highly complicated mechanism and since it appears that its component functions may be affected differently, depending on the circumstances of climatic heat stress and metabolic activity. Nevertheless, it may not always be feasible, at the work site, to make reliable measurements of all relevant factors simultaneously. Not infrequently, however, there is a need to examine one or other of these factors, either separately or together. It is worthwhile to discuss the implications of each of these measurements in turn, and to decide whether, in practice, they provide a reliable indication of whether or not an individual is suffering over-strain during a given exposure to heat.

Naturally, most of the data available have been derived from experimental laboratory investigations. There is insufficient information about the industrial situation. It is highly desirable that this state of affairs be rectified, particularly as there are many practical features of the industrial situation that may affect the thermoregulatory responses observed in experimental studies. For example, there is a dearth of information concerning the metabolic rates of industrial workers in many tropical countries, where body weights are substantially lower than in Europe and the USA ; too little is known also about the extent to which the state of nutrition and health and variations in economic, technical or housing conditions may influence physiological responses to industrial heat exposures. There

are also a number of personal factors, some of which are known to influence thermoregulation. It is necessary to discuss some of these factors before considering the specific physiological measurements.

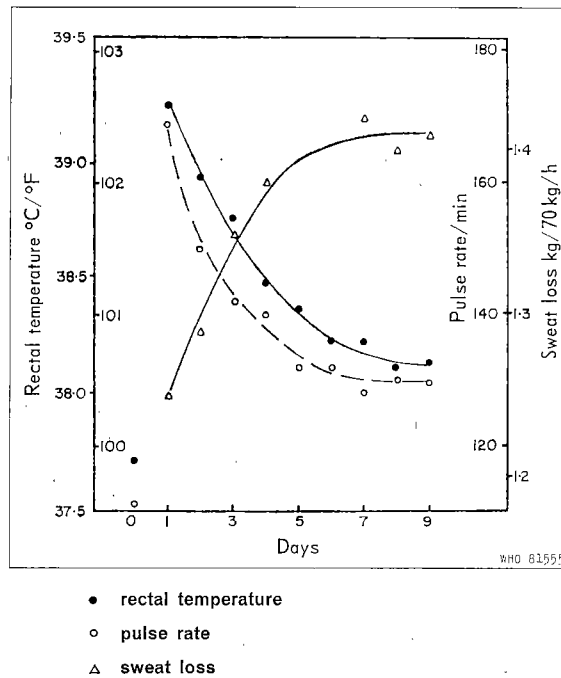
2.2 Personal factors

There are a number of factors that complicate the assessment of the effects of heat exposure ; some of these are easily recognized and measured, others are not. Again, a wealth of information is available about some of these factors, while little is known of others. When investigations are carried out on groups of people exposed to heat, it is frequently found that the responses of one or more persons are quite different from those of their fellows. These differences may simply reflect differences in physiological condition due to acclimatization, age or physical fitness, or they may result from differences in sex, body build or ethnic origin. In addition, clothing is an important factor, because it is in intimate association with the skin and thereby modifies the relationship between the body and the environment. The various factors that affect responses to heat exposure are discussed below.

Acclimatization

Heat acclimatization is the name given to the series of physiological adjustments that occur when persons who are accustomed to living in a cool climate are suddenly transferred to a hot climate. Similar adjustments occur in those who live in warm countries in response to seasonal increases in temperature, particularly when those increases are sudden, or as a result of a change from a sedentary occupation to one involving physical activity. These environmental changes impose a physiological strain which is reduced by acclimatization. In fact, acclimatization to heat is one of the most dramatic examples of physiological adaptation to a changed environment. It is not proposed here to describe the events in detail since they are published elsewhere. Essentially, during the first exposure to heat an unacclimatized man displays a high rectal temperature and pulse rate and a low sweat loss (Fig. 1); he experiences discomfort and even distress which under certain conditions may be so severe that further exposure has to be avoided. Acclimatization results in a reduction of the discomfort and distress and the rectal temperature and heart rate fall, while sweat loss increases. There is good reason to believe that the benefits of acclimatization are due to an increased sweat production and a lower skin temperature. The process of acclimatization largely occurs within the first 4-6 days of repeated or continuous daily exposure and is complete, or nearly so, within two weeks. Acclimatization is relative, in the sense that men who have become fully acclimatized to their conditions of work are not fully acclimatized to conditions in which the heat load is higher. Since the total heat

FIG. 1. CHANGES IN RECTAL TEMPERATURE, PULSE RATE AND SWEAT LOSS DURING ACCLIMATIZATION



On day 0, the men worked for 100 minutes at an energy expenditure of 300 kcal/h in a cool climate. On days 1 to 9, they performed a similar amount of work, but in a hot climate with a dry-bulb temperature of 48.9°C and a wet-bulb temperature of 26.7°C.

Adapted from Lind, A. R. & Bass, D. E. (1963) *Fed. Proc.*, 22, 704.

load includes a metabolic component, it follows, for example, that a sedentary worker in a hot climate is not acclimatized to hard work in that climate, and if he does attempt hard work he will suffer discomfort or distress. The benefits of acclimatization seem to decay quickly at first, although they may not be entirely lost for about three to four weeks. Obviously, excessive heat strain is likely to occur more frequently in men not fully acclimatized to work in the heat, and heat disorders may be expected in newcomers during the first week in a hot climate and also in those returning to their place of work after an absence of two days or more.

Age

Information about the effects of aging on the physiological responses to heat is sparse. The available evidence suggests that older men acclimatize well, but generally the physiological strain due to moderate and

high levels of heat stress increases with age, probably mainly because of reduced cardiovascular capacity. It has been clearly shown that the maximum heart rate and maximum work capacity decrease gradually with age. Metabolic heat production for a given amount of external work shows little, if any, increase with age. There is no evidence to suggest that the maximum tolerated levels of rectal temperature are reduced with age. The response of the sweat glands to temperature changes becomes more sluggish as age increases, so that sweating becomes less effective as a mechanism for controlling body temperature. In view of the wide age range of industrial employees, much more information is urgently needed to permit quantitative statements of the extent of increased heat strain with aging.

It must not be forgotten that in certain industries adolescents may have to work in hot environments; special medical and employment considerations may have to be given to such groups by management and occupational medical officers.

Sex

The high proportion of females in some industries calls for greater understanding of the differences in thermoregulation between the sexes. The information available suggests that there is little difference in the capacity of men and women to sweat adequately in hot climates once they are acclimatized, but there is some evidence to show that women do not become acclimatized as well as men do, possibly because of their inherently smaller cardiovascular capacity. Pregnancy is accompanied by extensive changes in many physiological systems, of which the cardiovascular system is particularly important in this context, and it may therefore be expected to increase the physiological strain of exposure to heat.

In many countries there are national laws placing certain limitations on the employment of women, pregnant and otherwise. In addition there are international recommendations on the same subject (see Annex).

Ethnic differences

The reactions of several ethnic groups to heat exposure have been studied on a comparative experimental basis. Surprisingly, perhaps, the overall differences between the groups were small when allowance was made for the differences in body build. Much more information, both in the laboratory and in the field, is required on this subject.

Body build

On simple theoretical grounds, physique might be expected to have a marked effect on thermoregulatory capacities. Certainly, it has been amply demonstrated that obese men succumb more readily to heatstroke

than do men of slighter build. This may be due partly to the fact that they have a smaller ratio of surface area (for heat dissipation) to body weight (for heat generation) and partly to poorer circulatory function. Men of slight body build may experience a relatively greater degree of heat stress when performing any set task, since they tend to have lower maximum work capacities and hence to use up a greater proportion of their maximum capacities in performing the set task. Apart from these considerations, there is little reason to believe that different kinds of body build affect the physiological responses to heat.

Physical fitness

Although physical fitness is difficult to define, it is a well recognized concept. There is no doubt that men acclimatize more readily to heat and to work in a hot environment if they are physically fit. Much of this better performance is undoubtedly attributable to a larger cardiovascular capacity, but whether other factors are involved is uncertain.

Clothing

In many industrial situations, much more than minimum clothing is necessary to protect the skin against cuts, abrasions or noxious substances. The intimate contact between the clothing and the skin can profoundly affect heat exchanges, and therefore the heat stress of any situation. The effects of clothing are difficult to assess, since it reduces heat loss by evaporation as well as heat exchange by radiation and convection; the extent of the reduction through each of these channels may vary according to the thickness of the material concerned, its colour, and whether or not the clothing is loose-fitting.

Indoor workers exposed to infrared radiation and outdoor workers exposed to solar radiation can reduce the radiant heat load appreciably by wearing clothing, but at the same time this reduces the cooling capacity through evaporation. Consequently, if the effect of clothing has to be assessed it is desirable to analyse these factors separately. Broadly speaking, in hot climates where the radiant heat load is low, as little clothing should be worn as other circumstances permit, but where there is a high radiant heat load it is more suitable to wear full clothing to cut down the radiant heat gain.¹ In either case, the garments should be loosely-fitting and made of light-weight material.

¹ See Hertig, B. A. & Belding, H. S. (1963) *Evaluation and control of heat hazards*. In: Hardy, J. D. ed., *Temperature: its measurement and control in science and industry*, vol. 3, part 3, New York, Rheinhold, pp. 347-355; and Givoni, B. & Berner, E. (1967) *Effect of solar radiation on physiological heat strain in relation to work and clothing*, Haifa, Technion (Research report No. BSS-OH-ISR-2 to the US Public Health Service).

It must be pointed out that special protective clothing for specific duties may contribute to the total heat stress, particularly if the clothing is impervious to water vapour and thus severely limits, or prevents, heat loss through evaporation. But special clothing ventilated with cool air from an outside source can be used to protect men in restricted work spaces when the heat stress is severe.

2.3 Heart rates

The heart rate can be counted, for most practical purposes, by simple palpation at the wrist. More refined techniques are readily available. The heart rate responds rapidly and consistently to energy expenditure. In addition, it has been established that, in stable conditions of work and heat, changes in the heart rate closely reflect changes in the rectal temperature. These considerations make the heart rate particularly useful as an index of physiological strain in working men exposed to heat and must surely outweigh any disadvantages of the method. The main disadvantages are the use of a single criterion when several homeostatic mechanisms are involved simultaneously and the fact that the heart rate responds to many different stimuli, of which psychological stress is an outstanding example.

There are three possible measures of the heart rate that can be used as an index of thermoregulatory strain. They are: the actual heart rate during or at the end of work; the increment in heart rate over a working period or day; and the time taken for the heart rate to return to its resting level after work. These three measures are discussed, where appropriate, below. It should be noted that although particular consideration has been given to the effects of working in a hot environment, the response of the heart rate to sitting in hot surroundings must also be considered.

In prolonged daily exposures to work in the heat, the actual heart rate at the end of the day's work may sometimes be less significant than peak heart rates achieved intermittently throughout the day, or than the increment in heart rate over the course of the day. Peak heart rates imply peak periods of work and/or heat and may be considered separately, in terms of severe or time-limited exposures to such conditions. Heart-rate increments can be examined in relation to the whole working shift, or to periods of intermittent work and rest throughout the day. For example, it has been postulated by Brouha that if the heart rate is 110 beats per minute, or less, when measured for the first 30 seconds after the first work period and if the deceleration in the heart rate during the first three minutes after work is at least 10 beats per minute, no increasing cardiac strain occurs when the same work is repeated throughout the day under the same conditions of heat exposure. This assumption can be readily tested, and, if found to be valid, the procedure can be incorporated into safety precautions

for any industrial situation with obvious problems in terms of work in the heat. There are not enough appropriate data available at present to permit recommending the general application of this procedure to hot factory or outdoor conditions in any part of the world.

A promising approach for assessing the combined work and heat stress is measurement of the heart-rate recovery time, i.e., the resting time necessary for the heart rate to return to the pre-work resting level on completion of work. A recent experiment at the Max Planck Institute of Occupational Physiology showed that heart-rate recovery times vary considerably with different combinations of work and heat, and that recovery may take several hours if the subject is unable to maintain thermal equilibrium during the working period. This type of observation may be repeated in any industrial situation where other approaches appear inadequate. Many observations are required, however, before any quantitative value can be attached to recovery times; the research worker should be aware that some subjects show an "overshoot" phenomenon, which is an early, rapid, but not sustained recovery of heart rate after stopping work.

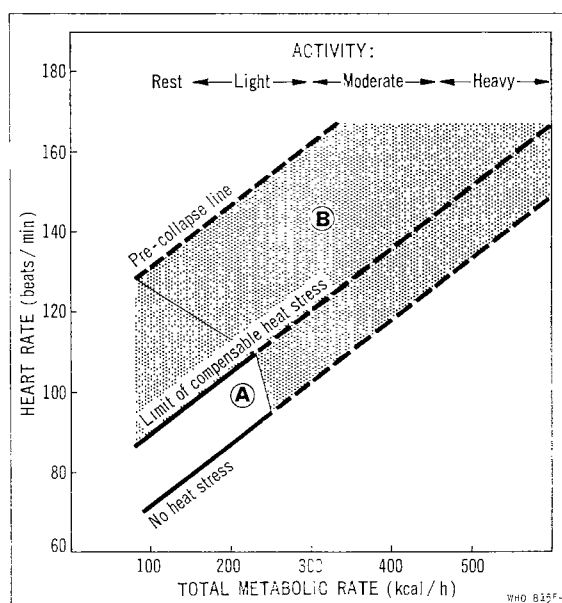
If the actual heart rate during work is to be used as an index of physiological strain, appropriate equipment will be needed for recording heart rates without interfering with the work programme. In laboratory studies on fit young men, heart rates of 160 beats per minute could be endured for brief periods without apparent harm. There are at present considerable difficulties in applying the results of such studies to industry. First of all, it has to be remembered that laboratory subjects, with attendant skilled observers, are at considerably less risk than industrial workers in otherwise similar conditions. Secondly, even if an answer could be obtained to the fundamental question of what an actual heart rate means in terms of safety, and therefore of what is the optimum heart rate during work, allowance would have to be made for differences in the basic health of workers in different parts of the world. Obviously more information is required.

Some indication of the meaning of heart rates observed during industrial work may be obtained by comparing them with typical values recorded for fit young men in laboratory studies. Fig. 2 depicts the pattern of responses in this select population.¹

The bottom diagonal line of the figure indicates the relationship between heart rate and level of energy expenditure when environmental heat stress is not a factor. This "work-specific" heart rate shows an approximately linear increase with energy expenditure. Above 250 kcal/h the solid line changes to a broken line, in recognition of the observation by the Max

¹ The heart rate values and the classification of grades of activity at the top of the figure are in accordance with Christensen, E. H. (1964) *Man at work: Studies on the application of physiology to working conditions in a subtropical country*, Geneva, ILO (*Occupational Safety and Health Series*, No. 4).

FIG. 2. EFFECT OF HEAT STRESS ON HEART RATE AT DIFFERENT LEVELS OF ENERGY EXPENDITURE



The figure shows observed heart rates of fit young men at different levels of energy expenditure, with and without heat stress. For explanation of the significance of the three diagonal lines and the shaded areas, see text.

Planck Institute of Occupational Physiology that the capacity for energy expenditure during an eight-hour shift will not ordinarily exceed 2000 kcal.

The middle diagonal line shows the approximate heart rates observed on fit young men when they are at the upper limit of compensating successfully for warm environmental conditions. The criterion of successful compensation is ability to maintain body core temperature undisturbed from the level prevailing in a thermally neutral environment. Lind has suggested that the requirements of prolonged daily occupational exposure should be within this zone of "compensable heat stress". The upper limit of "compensable heat stress" is shown as a broken line above 110 beats/minute, since there is serious doubt whether the average heart rate over a work shift can exceed this value without development of cumulative fatigue. The "pre-collapse" line is intended to indicate, as has frequently been observed, that higher heart rates may occur for short periods, but that an acceptable steady state is not achievable.

Two examples will suffice to show how Fig. 2 may be used in interpreting a heart rate exhibited by an individual worker. In the first instance (position A on the diagram), a rate of 100 beats/minute is counted on a

worker while engaged in steady, "light" work. Interpretation: this combination of work and heat makes demands on this worker which would not be expected to prove excessive or have cumulative effects if he is in good health.

In the second example (position B), a rate of 142 beats/minute is counted on a man while engaged in "moderate" work in the heat. Interpretation: this combination of work and heat would be tolerated at least for a few minutes by a fit young man, but long exposures would make excessive demands, both because of a rise in body core temperature and because the grade of work would be excessive. Recovery periods are a physiological necessity to prevent cumulative effects and fatigue.

Thus, some meaning may be ascribed to observed heart rates by relating them to Fig. 2. However, the intended user is cautioned that the exact positions of the lines in the figure will vary, even among fit young men. Furthermore, the real meaning of observed heart rates may be modified by such factors as age, sex and general status of health.

The heart rate is not the best index of physiological strain in seated or otherwise resting men exposed to heat. Laboratory investigations have suggested 110/min as an allowable maximum, but again, this figure cannot be applied to industry without all the reservations listed above.

From the considerations reviewed in the foregoing paragraphs, it is recommended that research on heart rates during work and in the recovery period should be given priority.

2.4 Deep body temperature

The thermoregulatory system controls the temperature of all the tissues of the body. It is clear, however, that whereas the temperature of the limbs and the peripheral tissues of the rest of the body can be allowed to vary widely, the temperature of the deep-lying tissues of the head, neck and trunk must be kept within quite narrow limits if inefficiency, illness or disability, and possibly even death, are to be avoided. The possibility that the rectal or some other deep-tissue temperature, by itself, might provide an accurate measure of heat strain is complicated by the fact that it is affected by muscular exercise, the ingestion of food, diurnal variation or illness. Nevertheless, it is possible to use deep body temperature as a yardstick of thermal stress if the circumstances are carefully defined.

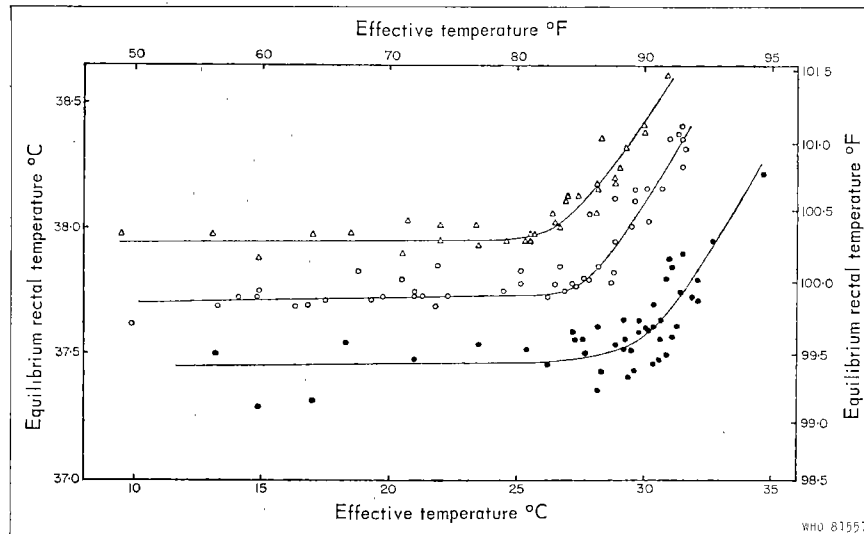
In considering the desirable deep-body temperature limits for prolonged daily exposures in industry, one ought, ideally, to be able to base suggestions on adequate information on the effects of daily exposure to heat over many years. Regrettably, such information is not available. In its absence, the only safe assumption is that any increase in deep body temperature due to environmental heat stress is undesirable from the point of view of general health.

It has been shown by Nielsen¹ that in a wide range of cold, cool and comfortable environments the deep body temperature rises during work to a level that is controlled by the rate of work and is not affected by the environment, and it is also well known that work in hot climates increases the deep body temperature. Several investigations have been undertaken with the intention of increasing the thermal stress of the environment to a point at which the deep body temperature could no longer remain dependent solely on the rate of work but would be forced to rise to a higher equilibrium level than in cool and comfortable environments. In fact, it was found that the deep body temperature was never completely independent of the temperature of the environment, even in cool and comfortable climates, but increased as the temperature rose. This effect was most marked in seated subjects and became less marked as the work rate increased. Over a wide range of cool and comfortable climates, then, the deep body temperature was nearly independent of the temperature of the environment, but above a certain level small increases in environmental temperature resulted in a marked increase in the equilibrium level of the deep body temperature. The heart rates behaved in an essentially similar manner and, in fact, it has been argued that the changes in deep body temperature are a consequence of cardiovascular function but the deep body temperatures are less subject to fluctuation and therefore show the effect of environmental temperature changes more clearly. For prolonged daily exposure to heat, a limiting value can be set defining the environmental condition below which the deep body temperature is primarily a function of the metabolic rate and not of climatic heat stress. That can be done for different rates of work and by using the corrected effective temperature (CET) scales, which are described below in section 3.2 and which provide an assessment, in a single value, of the various climatic factors in the environment. Fig. 3 illustrates what is meant; for the sake of clarity, results from one subject have been shown to typify the results of many. Using this approach, environmental limits in CET values appear to be 30°C for sedentary and light work (2.6 kcal/kg/h), 28°C for moderate work (4.3 kcal/kg/h) and 26.5°C for heavy work (6 kcal/kg/h).

Various factors commonly found in the industrial situation, such as individual variation, the age of the men exposed, the pattern of the day's work and the expectation of heat illnesses, might be expected to affect the critical environmental limits, but it has been shown that, in fact, they do not. The limits given above refer to unacclimatized or slightly acclimatized men. Acclimatization is one factor that is known to affect these limits and it would be realistic to expect that all the values given could be increased by 2°C CET for acclimatized men. It is recommended that these critical limits of environmental stress be applied in industry.

¹ Nielsen, M. (1938) *Skand. Arch. Physiol.*, **79**, 193.

FIG. 3. EQUILIBRIUM RECTAL TEMPERATURES AT DIFFERENT RATES OF WORKING UNDER VARIOUS CLIMATIC CONDITIONS



- energy expenditure of 2.6 kcal/kg/h
- energy expenditure of 4.3 kcal/kg/h
- △ energy expenditure of 6.6 kcal/kg/h

All measurements refer to the same subject.

From Lind, A. R. (1963) *J. appl. Physiol.*, 18, 51.

It is essential to realize that these limits are derived from investigations in which the relative humidity of the environmental conditions was never lower than 40%. Consequently, these environmental limits for prolonged exposures ought not to be applied when the relative humidity of the environment is low (see also the criticisms of CET scales in section 3.2). In any case, it is considered inadvisable for the deep body temperature to exceed 38°C for prolonged daily exposures in heavy work; the levels of deep body temperature that should not be exceeded for lower rates of work are indicated in Fig. 3.

The rectal temperature is commonly used to indicate when to terminate acute and severe exposures to heat in the laboratory. Under such controlled conditions, where deep body temperatures are continuously monitored, a high rectal temperature alone is not usually considered sufficient reason for terminating exposures unless it reaches values of the order of 39°C. In laboratory investigations, a close watch is kept for any untoward event and some subjects may have to be removed from the exposure because of imminent or actual heat syncope or heat exhaustion before their deep body

temperature has reached the limiting value. The proportion of men so affected will vary with the state of acclimatization and possibly also with differences in age, physical fitness or other factors. It is not a simple matter to set a specific rectal temperature limit for men engaged in acute exposures to severe environmental heat stress, for instance in mine rescue work, since some acute heat illnesses, particularly heat syncope, can occur at quite low rectal temperatures. Where exposures have to be time-limited and where deep body temperatures are expected to reach 38°C, expert opinion should be sought.

2.5 Sweat loss

Man's capacity to perform work while exposed to thermal environments near or above his body temperature is attributed to his well developed sweating mechanism. He may produce 1 litre of sweat per hour and, under circumstances favourable to evaporation, could theoretically achieve the removal of 600 kcal/h of body heat. In most circumstances, the evaporative efficiency will not be as high.

Sweating must be considered from two points of view : (a) the problem of maintaining a balance of body water and salt, and the operating capacity of the sweat glands ; (b) its usefulness as a criterion of the total heat load placed on the thermoregulatory system.

As to (a), it is on record that one individual in a laboratory exposure produced 2 litres of sweat within a period of half an hour and it is common for men to sweat for short periods at the rate of 1.5–2 litres/h. However, for periods of 24 hours, the values recorded do not exceed 12 litres. Observations on industrial workers performing the most difficult jobs in the heat indicate that some men produce a litre or more per hour over an eight-hour shift. The indications are that, in the usual types of job performed in the heat, this capacity to produce sweat is sufficient to meet the requirement for the maintenance of heat balance. The real strain is on the water and salt balance of the body. Laboratory and field evidence firmly supports the need for an unrestricted supply of potable and tastefully cool water for men working in the heat, and this must be the responsibility of management. Men should be encouraged to increase their fluid intake, because thirst does not always provide adequate stimulation for the replacement of lost fluid. Delay of intake for a period of hours—as sometimes practised in industry—has been shown to be detrimental to both performance and well-being. Furthermore, dehydration is detrimental to the development of acclimatization.

It appears that, in many countries, the dietary intake of sodium chloride will support the production of a minimum of 5 litres of sweat per eight-hour shift in acclimatized men, without disruption of the salt balance. When occupations require higher rates of sweating, a supplementary intake of salt is recommended.

As regards the value of sweating as a criterion of heat load, it appears that under conditions where thermal equilibrium can be established by sweating, the rate will be regulated by the body to a level just adequate to meet the requirement for maintaining heat balance. There are, of course, situations that exceed either the maximum capacity of sweat production or the capacity of the environment to evaporate the sweat. If the sweating response is inadequate, as may be the case with unacclimatized men, body temperature will rise with results that can represent a real risk to health. If the high humidity of the environment limits the evaporation of sweat a positive feedback may result. The skin temperature increases and forces the deep body temperature to rise, and both these events stimulate a greater output of sweat; the additional sweat is of no value in thermoregulation since it does not evaporate but merely drips from the skin or further wets the clothes.

In environmental conditions where the vapour pressure is high, a mechanism that seems designed to conserve body water comes into play, leading to a reduction in sweat output. This phenomenon, sometimes called hydromeiosis, follows a distinctive pattern—sweat production is reduced after an hour or two of exposure to humid environmental conditions, but not to a degree that would seriously lower the actual evaporative cooling in that climate.

It is important to note that the sweating mechanism has sufficient capacity to allow the production of large quantities of sweat, often without evidence of great physiological strain if the environmental vapour pressure is low, whereas if the vapour pressure is high the physiological strain may be excessive.

It is clear that the sweat rate provides a good indication both of the heat load and, under conditions of high vapour pressure, of the extent to which evaporation of the sweat is impeded. The sweat rate may or may not indicate the physiological strain on a particular individual in any given circumstances. For example, a sweat rate of 1 litre/h in a desert environment may achieve thermal equilibrium against a metabolic and environmental heat load of 600 kcal/h (100% efficiency), with little real cardiovascular strain and no rise in body temperature. However, the same rate of sweating while wearing clothing in a humid environment might be accompanied by great strain, if only 0.5 litre/h were evaporated effectively and some of the sweat were deposited in the clothing or simply dripped off the skin.

The predicted four-hour sweat rate (P4SR) is a widely used index of heat stress and McArdle has found that when the P4SR exceeds 4.5 an increasing number of acclimatized men will find the conditions beyond their endurance. A description of the P4SR scale and its limitations is given in section 3.3.

3. HEAT STRESS INDICES

3.1 Introduction

Many attempts have been made to integrate, into a single index, the effects of two or more of the several factors that influence heat exchanges between man and his environment. These attempts have taken the form of either (a) designing instruments intended to act as integrating mimics of the human body or (b) devising formulae or nomograms, on theoretical or on empirical grounds, to estimate the stress inflicted by a wide range of conditions of work and climate, or to estimate the physiological strains in response to those stresses.

A minimum of four measurements is required to describe a hot environment. These are air temperature (ta), wet bulb temperature (twb), black globe temperature or other measure of radiant heat (tg), and air velocity (V). The water vapour pressure of the air (humidity) can be derived with the aid of a psychrometric chart from ta and twb . The mean radiant temperature of the solid surround is obtained from ta , tg and V . On the basis of these measurements, and basic data on body size, clothing, level of metabolic activity and work profile, the heat load and heat exchanges of the body can be estimated. These represent the minimum acceptable data for assessing occupational heat stress. Only if they have all been recorded can conditions in one investigation be compared with those in another.

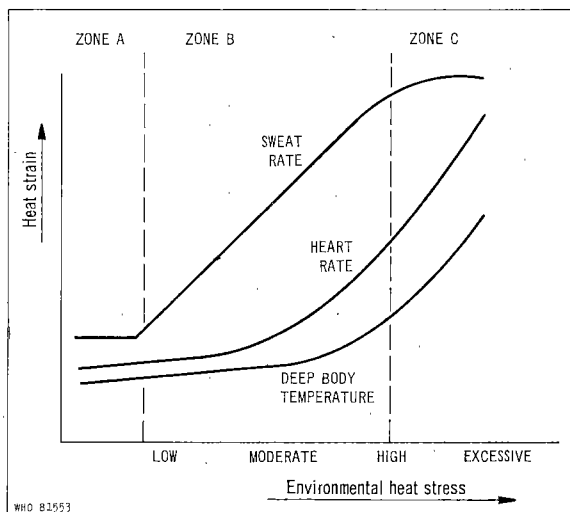
Many heat stress indices have been devised. No index that has been examined adequately has been found to be valid in all the possible complexities of work rate, air temperature, air movement, humidity, radiant temperature, and clothing. The situation is improving continuously, however, as more data are collected and heat-exchange coefficients are elaborated.

For the reasons stated below, the following four indices of heat stress are recommended for use in industry: the *corrected effective temperature scales* (CET), the *predicted four-hour sweat rate* (P4SR), the Belding and Hatch *heat stress index* (HSI), and an *index of thermal stress* (ITS), recently described by Givoni. These indices are of different types. All of them attempt to present a scale on which a given number can represent a variety of combinations of climatic variables and clothing and, in most cases, work. Both the CET scales and the P4SR scale are presented as nomograms constructed empirically from experimental findings, with no description of how they were derived. Thus, later findings cannot be assimilated into these scales to extend their scope or improve their accuracy. This is a serious drawback, since these scales are intended to be used in conditions that require extrapolation from the original findings. The HSI and the

ITS scales are both constructed on the basis of established heat-exchange coefficients and their scope and accuracy depend on the limitations of those coefficients. Both scales have therefore the advantage that they can be continuously improved in scope and accuracy as fresh information on heat exchange is acquired.

It is worth considering some of the implications of the physiological responses to increasing heat stress in terms of the best physiological measurement(s) to choose for the construction of heat stress indices. This is illus-

FIG. 4. CHANGES IN SWEAT LOSS, HEART RATE AND DEEP BODY TEMPERATURE WITH INCREASING CLIMATIC HEAT STRESS



ZONE A: No heat stress.

ZONE B: Zone of increasing heat stress where sweat loss increases rapidly and nearly linearly but through a large part of the zone, body temperature is not greatly affected. Strain in terms of heart rate increases exponentially. Sweat loss is a good physiological indicator of the heat strain experienced.

ZONE C: Zone of increasing heat stress where sweat loss approaches or reaches its maximum and can no longer be used as an index of stress or strain. Heart rate and body temperature now rise rapidly and are the best physiological measures of the strain experienced.

trated in Fig. 4, which presents in a stylized fashion the changes in sweat loss, heart rate, and deep body temperature with increasing heat stress.

Heat stress is represented on the abscissa and heat strain on the ordinate. At low environmental heat stress (first part of zone B), for a given rate of work, as the stress increases so does the sweat loss, while heart rate and deep body temperature remain practically unchanged. Clearly, the rapid rise in the sweat rate provides a better index of the heat stress under these

conditions than do heart rate and deep body temperature, either separately or together. In any case, it has been shown that, in this region of heat stress, equivalent amounts of metabolic and of environmental heat have different effects on heart rate and deep body temperature. Thus the heart rate response to an increase of 100 kcal of metabolic heat is twice that to the same increase in environmental heat, whereas deep body temperature is affected about equally in each case. The heat stress in zone B in Fig. 4 can be regarded as ranging from low, at the initiation of sweating, to high as the sweat loss approaches its maximal value. Zone C can therefore be regarded as a zone of excessive heat stress, and since there is little change in the rate of sweat loss with increasing heat stress, that function cannot reasonably be expected to provide a satisfactory measure of the stress. It is in this zone that the greatest changes are found in the heart rate and deep body temperature for an exposure of stated duration, and if a stress index is to be based on physiological responses, then, for excessive heat stress, it would be logical to use one or both of these functions. Otherwise, the index should be some combination of the environmental factors.

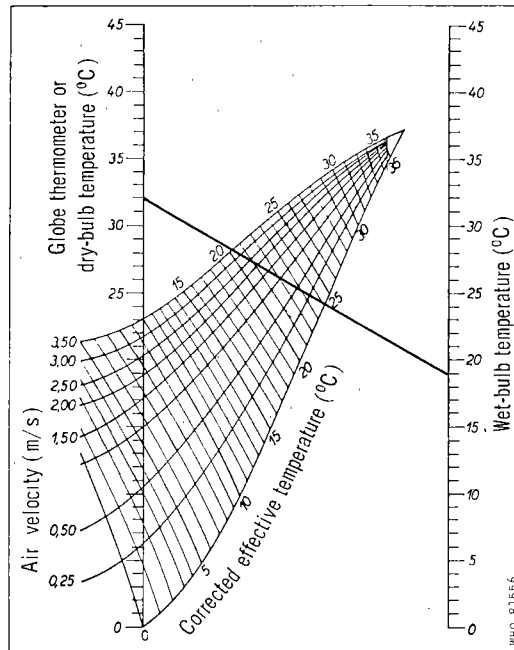
As will be seen below, the P4SR and HSI are the most reliable heat stress indices for conditions of low, moderate and high heat stress, but they are not recommended for excessively high heat stress conditions; similar considerations apply to the ITS but, as it is a recent scale, it should be used with caution until its validity has been established. These indices are based on the sweat losses in the heat. The CET, however, is only moderately satisfactory as an index of low and moderate heat stress, and, owing to inherent errors in the construction of the scale, it is quite inaccurate if the heat stress is excessively high.

3.2 The corrected effective temperature scales

The effective temperature (ET) scales and the corrected effective temperature (CET) scales have been in existence for 40 years and 20 years, respectively. They have been widely applied and have the advantage that they are familiar and are easy to use. The ET scales were devised originally as scales of comfort for men seated or engaged in light work, but it was thought later that they might also have a more general application as an index of industrial heat stress. Two scales are available, one of which refers to men who are stripped to the waist and the other to men who are fully clad in indoor clothing. As initially designed, the scales were intended to assess the subjective comfort of any combination of dry- and wet-bulb temperatures and air movement, using as a reference the still, saturated environment in which the immediate sensations of warmth experienced were identical to those experienced in the test climate. Later, the air-temperature reading was replaced by the globe-thermometer reading, to

allow for radiant heat ; the scales then became known as corrected effective temperature scales. The validity of this procedure for taking the radiant heat of the environment into account has been supported from experiments with radiant heat loads involving increases in mean radiant temperature of up 18°C. No allowance has been made for different rates of energy expenditure. The "basic" CET scale, which refers to men stripped to the waist, is shown in Fig. 5. The "normal" CET scale, which refers to men wearing full, indoor clothing, can be found elsewhere.¹

FIG. 5. "BASIC" CORRECTED EFFECTIVE TEMPERATURE SCALE FOR MEN STRIPPED TO THE WAIST



From Lavenne, F. (1965) *Rev. Inst. Hyg. Mines*, 20, No. 1, p. 3.

The CET of an environment is obtained by connecting the air temperature (or globe-thermometer temperature) and the wet-bulb temperature and noting the point at which this line intersects the family of curves running diagonally upwards from left to right at the appropriate air velocity. It is very important to recognize the inaccuracies of prediction inherent in the original design, and inevitable if the scales are to be used in circum-

¹ See, for example, Smith, F. E. (1955) Indices of heat stress, *Memor. med. Res. Coun. (Lond.)*, No. 29, London, H. M. Stationery Office; and Leithead, C. S. & Lind, A. R. (1964) *Heat stress and heat disorders*, London, Cassell, p. 276.

stances outside the original design. The scales are known to exaggerate the effects of high dry-bulb temperatures in air movements of 0.0–3.5 m/s, and to underestimate the deleterious effects of low air movements in hot and humid environments. It is by now clear that widely different climates sharing the same CET do not impose the same physiological strain in terms of tolerance times, rectal temperatures, and heart rates. Caution is therefore advised in using the ET or CET scales as the basis of legislative restrictions on industrial practices, without making sufficient allowance for these discrepancies. Furthermore, ET and CET values are virtually meaningless without reference to the rate of work of the men exposed.

The scales are satisfactory in mild heat stress, provided that there is a circumscribed range of relative humidity. It is suggested that the scales should not be used to compare climates, any one of which has a relative humidity of less than 40%.

3.3 The predicted four-hour sweat rate (P4SR)

The P4SR scale was devised empirically¹ from the results of a large series of observations of the sweat losses of men exposed in the laboratory to a variety of climates, different levels of energy expenditure, and wearing shorts, or overalls. Within wide ranges, the heat stress of any combination of dry- and wet-bulb temperatures, globe temperature, air movement, the level of clothing worn, and the rate of work can be assessed from a nomogram. The assessment is in terms of the average amount of sweat loss to be expected, within the limits of sampling error, in a group of young, fit, acclimatized men exposed to the conditions in question for 4 hours. The name “predicted four-hour sweat rate” is misleading, since the value obtained is not a “sweat rate” but a “sweat loss”. It is important also to remember that it provides an index of heat stress, not of heat strain, and that the subjects of the observations were young, fit, acclimatized, European men.

The use of the P4SR nomogram to derive a value for a given heat stress, is adequately described in the literature,² and requires no repetition. Apart from its main purpose in evaluating heat stress, the nomogram provides a useful prediction of the order of sweat losses and therefore the water requirements of a group of men exposed to the conditions in question.

Although the P4SR scale is of most value when applied to conditions within the range in which the original observations were made, the scope of applicability is nonetheless considerable. On the other hand, the scale

¹ McArdle, B. et al. (1947) The prediction of the physiological effects of warm and hot environments, *Royal Naval Personnel Research Committee, med. Res. Coun. (Lond.)*, Report No. 47/391, London, H. M. Stationery Office.

² See, for example, the references given in footnote 1 above and in the footnote on page 24.

is not susceptible to any modification or improvement, which certainly limits its interest to users. There are, however, more fundamental failings. It is inaccurate when applied to environments of low humidity, and is therefore not recommended for use below a relative humidity of 40%. An inherent defect is the choice of sweat loss as the reference unit, since it is abundantly clear that sweat production rises with acclimatization. In hot dry climates this rise is of the order of 10–15%, whereas in hot humid climates it may be as much as 60%. In addition, work in severe heat at high humidity leads rapidly to a fall-off in thermal sweating, which has been referred to above.

Naturally, many of these reservations are equally relevant to other indices of heat stress, and this is true also of the difficulty of applying the P4SR scale to an industrial situation where men work an eight-hour shift, dividing the day between hot and cool environments. The P4SR scale is acceptable for use in moderate to high heat stress, particularly in circumstances that remain fairly stable throughout a period of about 4 hours.

3.4 Heat balance indices

The concept of partitional calorimetry, that is, the computation according to physical principles of the amounts of heat exchanged through the various channels, was introduced by Winslow et al. in 1936. The original coefficients were improved upon some ten years later, and Belding & Hatch used them in a new heat stress index (HSI) in 1955.¹ This index was derived from the coefficients for environmental heat exchange by radiation and convection ($R + C$) and for metabolic heat production (M), which together represented the total heat load to be dissipated by evaporation (E_{req}) for maintenance of bodily heat balance. The likelihood that balance would be attained was judged from the ratio of E_{req} to the calculated maximum evaporative capacity (E_{max}), assuming the skin to be fully wetted with sweat.

The HSI did not, however, satisfactorily predict the critical point where the ratio between E_{req} and E_{max} is 1.0 and beyond which heat balance is unattainable, partly because of the inaccuracy of the coefficients that were adopted for C and E_{max} (which were derived on semi-nude men) and partly because of failure to recognize that even the wearing of light-weight clothing reduces heat transfer by R , C and E . Steps were taken by the authors to overcome both these disadvantages. The coefficients currently used to compute the values for the "standard" 70-kg semi-nude men are :

$$R = 11 (t_w - 35) \text{ kcal/h}$$

¹ Belding, H. S. & Hatch, T. F. (1955) *Heat Pip. Air Condit.*, 27, 129.

The mean radiant temperature, t_w , is determinable from the black globe temperature, t_g ($^{\circ}\text{C}$), the air speed V (m/s) and the air temperature, t_a , by the relationship :

$$t_w = t_g + 14.4V^{0.5}(t_g - t_a)$$

Under the same circumstances of exposure :

$$C = 6V^{0.6}(t_a - 35) \text{ kcal/h}$$

In both cases "35" is an approximate value for the skin temperature, which will apply at the critical level where $E_{\text{req}} = E_{\text{max}}$.

E_{max} is a function of the potential gradient in water vapour pressure between fully wetted skin at 35°C , which is 42 mm Hg, and the vapour pressure of the surrounding air, P_a .

$$E_{\text{max}} = 12V^{0.6}(42 - P_a) \text{ kcal/h}$$

To make a rough allowance for the effect of wearing light clothing it was tentatively recommended that each of these coefficients be reduced by one third. This is an empirical adjustment arrived at from limited data, and it has been stated on theoretical grounds that adjustments of the coefficients will depend on particular characteristics of environmental conditions, for example, on the shade of clothing worn in sunlight and on the windspeed.

The index of thermal stress

Givoni's index of thermal stress (ITS) is derived from a set of equations that form a mathematical model to describe the biophysical mechanisms involved in the preservation of thermal balance between the body and its environment, taking into account the variable cooling efficiency of sweating.¹ Like the HSI, the ITS computes the amount of sweat needed to provide sufficient evaporative cooling to maintain bodily thermal balance, and allowance can be made for the influence of various types of clothing and solar radiation, but it has not yet been examined in conditions of long-wave radiant heat. The ITS provides a continuous linear estimation of the thermal stress, and may be used to evaluate the physiological strain under conditions where the sweat rate reflects the thermal load. Above that limit the index may be used only to estimate the stress but not the physiological strain. Like the P4SR and HSI, the ITS may be used for the determination of water requirements. The predictive accuracy of the scale in

Givoni, B. (1962) *The influence of work and environmental conditions on the physiological responses and thermal equilibrium of man*. In: *Proceedings of a UNESCO Symposium on Arid Zone Physiology and Psychology, Lucknow, India*.

a wide range of environmental conditions is similar to that of the P4SR under the conditions in which the latter is applicable. The limitation of the ITS is that it is based only on sweat rate and cannot therefore be used to evaluate conditions in which pulse rate and rectal temperature are limiting.

The basic formula of the ITS is :

$$S = (M \pm C \pm R) \times \left(\frac{1}{f}\right) = E \left(\frac{1}{f}\right)$$

Where S is the required sweat rate, M is the metabolic heat production, C and R are convective and radiative heat exchanges (all in kcal/h), f is the cooling efficiency of sweating, and E is the required evaporative cooling or the total heat load.

C , R and f depend on the clothing, and are computed according to the following general formulae :

$$C = \alpha V^{0.3} (t_a - 35)$$

$$R = k_{cl} (k_e \cdot k_p) I_N [1 - a (V^{0.2} - 0.88)]$$

$$\frac{1}{f} = e^{0.6} \left(\frac{E}{E_{\max}} - 0.12 \right)$$

$$E_{\max} = \beta V^{0.3} (42 - P_a)$$

Where α , k_{cl} , a and β are coefficients depending on the clothing, k_e depends on the albedo of the surroundings, k_p depends on posture, t_a is air temperature ($^{\circ}\text{C}$), I_N is the intensity of radiation measured normal to the solar beam (kcal/h), V is air velocity (m/s), e is the base of the natural logarithms, E_{\max} the evaporative capacity of the air (kcal/h), and P_a the vapour pressure of the air (mm Hg).

The combined radiation coefficients for environmental albedo and posture ($k_e k_p$) for different environments and postures are given in the following table :

Environment	Radiation coefficient	
	sitting with back to sun	standing with back to sun
high (desert)	0.396	0.324
low (forest)	0.377	0.266

The values of α , p , k_{cl} and a , as related to clothing, are given in the following table :

<i>Clothing coefficient</i>	<i>Semi-nude</i>	<i>Light summer clothing</i>	<i>Military overalls</i>
a	15.8	13.0	11.6
β	31.6	20.5	13.0
k_{cl}	1.0	0.5	0.4
a	0.35	0.52	0.52

Conclusion

All the indices of heat stress described above, as well as a number of others not considered, are regarded as having proved useful within specified limits. In the long run, the thermal balance approach appears likely to have the widest applicability, because it is aimed at the development of a rational index, based on the physics of heat transfer. However, the important problem of relating the values to actual physiological strains, such as elevation of heart rate and body temperature, is still largely unsolved.

4. RECOMMENDATIONS FOR RESEARCH

During the discussions of the Scientific Group it was apparent that knowledge relating to occupational heat exposures is inadequate in many respects. The following problems on which further research is needed are listed in descending order of priority.

1. The physiological mechanisms underlying changes in heart rates during and after occupational exposures to heat stress are still incompletely understood. Further studies are therefore needed to permit better interpretation of heart rates. A standard method is also required for collecting data on recovery rates, particularly with reference to timing of observations and posture of the subject.

2. The indices of thermal balance currently available do not specifically predict the physiological strain to be expected from exposure to heat; there is evidence that their interpretation is partly dependent on the metabolic rate. Research is needed to determine correlations between index

values, on the one hand, and heart rate and body-core temperature on the other.

3. Little is known about the effects of long-term heat exposures (either occupational or due to living in hot climates) on well-being and performance. It has been assumed that as long as occupational heat exposures do not disturb body-core temperature they will not be harmful to health. Epidemiological research using industrial health and performance records should help to test this assumption.

4. Relatively little is known about the influence on stress and strain of intermittent work in heat and about the applicability of heat stress indices to these situations. Information is needed on the following: the influence of the heat capacity of the clothing in diminishing loss and gain of heat; the influence of thermal shock, due to cold recovery environments, on infectious respiratory disease; the optimum spacing of work and recovery intervals; the over-all effects of occupational heat exposures where workers live in very cold (low-humidity) environments; and methods for rating strain from intermittent exposures.

5. Some studies indicate that heat stress affects such functions as concentration, learning, vigilance, psychomotor performance, and accidents, but quantitative information is lacking.

6. The combinations of factors affecting the heat load are very large and no single investigation has taken all of them into consideration. There is an urgent need for intensive studies on the effects of various controlled combinations of work and environmental heat. These should include a wide variety of subjects differing in physical characteristics such as age, sex, and body build. Exchange of information on this subject and cross-checking of conditions from laboratory to laboratory, and from laboratory to industry, are essential. Modern computer methods should be applicable for rationalizing these complex data.

7. Descriptions of energy expenditure and heat exchanges are generally related to a standard man. For some kinds of work, these values may be adjusted to other body sizes and builds by simple proportion on the basis of body weight, but for jobs that require the performance of external work, such as lifting or carrying, this simple adjustment is not necessarily adequate. To allow for differences in muscular strength and other physical characteristics, the relations should be determined by actual experiments.

8. Additional studies are needed to determine more precisely the effects of clothing on exchanges of heat by various routes.

9. A study is needed to determine quantitatively the significance of skin temperatures, in combination with other factors, for the understanding and rating of stress-strain relations.

10. New methods are needed to facilitate the study of the heat-work profile of workers engaged in diverse tasks. It might eventually be possible to design a thermal stress integrator that could be carried about by the worker.

11. Information is needed on the special problems of heat transfer and thermal injury to tissues when the body is in direct contact with solids or liquids of high conductivity.

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Annex**CONVENTIONS AND RECOMMENDATIONS
OF THE INTERNATIONAL LABOUR OFFICE
WITH SECTIONS RELATED TO WORK IN HEAT**

- Convention No. 89 : *Night Work of Women Employed in Industry*
(Revised 1948), Article 7
- Convention No. 90 : *Night Work of Young Persons Employed in Industry* (Revised 1948), Article 4
- Convention No. 120 : *Hygiene in Commerce and Offices* (1964),
Article 10
- Convention No. 127 : *The Maximum Permissible Weight to be Carried by one Worker* (1967)
- Recommendation No. 97 : *The Protection of the Health of Workers in Places of Employment* (1953), Article 2
- Recommendation No. 120 : *Hygiene in Commerce and Offices* (1964)
Part IV. Ventilation
Part VI. Temperature
Part VIII. Drinking Water
- Recommendation No. 128 : *The Maximum Permissible Weight to be Carried by one Worker* (1967), Article 13
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