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SPACE TRAVEL AND HUMAN THERMAL LIMITS: A SELECTED BIBLIOGRAPHY

SPECIAL BIBLIOGRAPHY
SB-61-33

FEBRUARY 1962

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Compiled by
ROBERT C. GEX

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ABSTRACT

This selected bibliography, partially annotated, is divided into 14 sections:

1. Physiological mechanisms of temperature regulation.
2. Metabolism.
3. Thermal properties of tissues.
4. Comfort criteria.
5. Thermal indices and units.
6. Compensable zone- high temperature.
7. Compensable zone- low temperature.
8. Hyperthermic zone- non-compensable.
9. Hypothermic zone- non-compensable.
10. Heat and/or cold resistant clothing including ventilated pressure suits.
11. Combined thermal and other stresses (hypoxia, acceleration, etc.)
12. Acclimatization.
13. Hibernation.
14. Thermal models of humans.

The 424 references are listed alphabetically by author under each category. Emphasis was placed on the literature since 1957.

Search completed Oct 1961

INTRODUCTION

Man's adjustment to the thermal environment of space travel is a major area of research as man begins his exploration of things extraterrestrial. Both extreme heat and extreme cold are conditions man must be prepared to encounter in space. This bibliography is a collection of references deemed important to an understanding of this important subject. It is not a definitive bibliography on the subject.

This compilation was commissioned by Bob Thomas of the Life Support Systems Research group of Dept. 53/11. He is responsible for preparing a section of the Space Materials Handbook on the criteria for man's comfort and survival in the space environment.

The primary need was for information on transient extreme environmental temperatures, that is temperatures at which there is body heat gain or loss and that therefore endanger human life. The emphasis was thus placed there. However other facets of the effects of heat and cold on man were also investigated and the more pertinent literature listed.

Listed below are three bibliographies which supplement this compilation.

1. Culver, Wave E.
   EFFECTS OF COLD ON MAN; AN ANNOTATED BIBLIOGRAPHY, 1938-1951. Physiological Reviews, Supplement no. 3, Oct. 1959. 524p. 2736 ref.

2. Hardy, James D.
   THE PHYSIOLOGY OF TEMPERATURE REGULATION. Naval Air Development Center. Rept. no. NADC-MA-6015. June 9, 1960. 296p. 851 ref. ASTIA AD-242 363.

3. Fenning, W. H., et al.
   REFERENCE STUDIES IN THE PHYSIOLOGY OF EXTREME ENVIRONMENTS. Michigan U. Engineering Research Institute. Rept. no. 2167-2-P. May 1954. 59p. 173 ref. ASTIA AD-32 854.

TABLE OF CONTENTS

PART I

PHYSIOLOGICAL MECHANISMS OF TEMPERATURE REGULATION

1. Adams, T.

   THE CONTROL OF BODY TEMPERATURE.

   Washington U. Dept. of Physiology and

   Biophysics. July 60, 32p.

2. Adolph, E.F.

   Ontogeny of physiological regulations in

   the rat. QUART. REV. BIOL. v. 32, p. 89-137,

   1957.

The development of body regulations of heat, oxygen, and water in the rat are discussed and compared. Factors considered under heat regulation include heat production, oxygen consumption, extra metabolism in cold surroundings, heat loss, insulation, cooling rates, nervous factors, adrenal activities, lethal body temperatures, and the effects of body temperatures on pulse rate, oxygen consumption and breathing. Important considerations in oxygen consumption are blood composition, the relation between tolerance to anoxia and tolerance to hypothermia, the composition of the brain and its enzymic activities, chemo-reflexes, respiration processes, and tissue metabolism in general. Water and salt diuresis, blood-circulatory factors, renal structures and activities, and water intake are factors discussed under water regulation. Each of the above regulatory factors undergoes progressive changes during the early life of the animal.

3. Adolph, E.F. and Richmond, J.

   Water exchange of isolated mammalian

   tissues at low temperatures. AMER.

   J. PHYSIOL. v. 187, p. 437-444, 1956.

4. Bartlett, R.G., Jr., et al
Gross muscular activity and temperature regulation in the restrained rat. PROC. SOC. EXPTL. BIOL. AND MED. v. 92, p. 457-459, 1956.

5. Bass, D.E. and Henschel, A.
Responses of body fluid compartments to heat and cold. PHYSIOL. REVS. v. 36, p. 128-144, 1956.

6. Benzinger, T.H.
The human thermostat. SCI. AMER. v. 204, p. 134-147, 1961.

A newly discovered sensory organ in the brain precisely measures the body temperature and trips the heat-dissipating mechanisms that maintain the temperature within a fraction of one degree.

7. Benzinger, T.
The mechanism of heat regulation in man. ZEITSCHR. NATURFORSCH. v. 4b, p. 412-413, 1959. (In German)

The conclusions drawn are: (1) The temperature sense of the skin does not alone have the function of serving as the sensory component in the autonomous system of physical temperature regulation. (2) The temperature-sensitive structures in the front of the hypothalamus are a highly efficient terminal sensory organ, since they are able to function without afferent impulses. Man has 2 anatomically and physiologically separate and complete mechanisms of temperature control which work together for the same function: by conditioned reflexes, with the skin as a sensory organ and the cerebral cortex as a coordinating center and with the entire muscular system as a responsive system, the inner temperature is roughly regulated against the sharpest changes in external conditions (movement from unfavorable to favorable

7. (Cont'd)

surroundings, laying off clothing and covers, stretching out and huddling-up, and so on). As a result of the feeling of warmth and coordination by the hypothalmus and with sweat glands and vessels of the skin as organs of response, the autonomic system takes over the function of final regulation with almost unconceivable accuracy.

8. Benzinger, T.H.

On physical heat regulation and the sense of temperature in man. PROC. NATL. ACAD. SCI. v. 45, p. 645-659, 1959.

The roles of specific sensory-receptor organs, effector organs, and coordinating center of the central nervous system are reviewed. Experiments were conducted with calorimetry, thermometry, and cutaneous and internal body temperatures were separately modified. The sense of temperature in the skin with its afferent impulses, and the thalamo-cortical neural mechanism in which these are received and translated into highly coordinated motor activity, form an independent and complete thermoregulatory system. Virtually all skeletal muscles may serve in it as the effector components. By conditioned reflexes in that system, some preconditioning of human body temperature is accomplished, even under the most adverse climatic conditions. The hypothalamic involuntary mechanism supplies more concise control of temperature than does the autonomic system. The combination of these 2 sensory systems, complete and independent, working in concert, provides the basis for endurance of the wide range of climates feasible for man, while maintaining the precision of the control system.

9. Bernstein, L.M., et al

Body composition as related to heat regulation in women. J. APPL. PHYSIOL. v. 9, p. 241-256, 1956.

10. Blatteis, C.M.

Renal, cardiovascular and respiratory responses and their interrelations. AMER. J. PHYSIOL. v. 192, p. 357-363, 1958.

11. Brunt, D.
Some physical aspects of the heat balance of the human body. PHYSICAL SOCIETY. PROCEEDINGS v. 59, p. 713-726, 1947.

12. Burns, N.M., et al
ENVIRONMENTAL REQUIREMENTS OF SEALED CABINS FOR SPACE AND ORBITAL FLIGHTS: A BIBLIOGRAPHY OF PSYCHOPHYSIOLOGICAL STUDIES RELEVANT TO SPACE AND ORBITAL FLIGHT. Naval Air Material Center. Air Crew Equipment Lab. Rept. no. NAMC-ACEL-441, 26 Oct 60, 152p.

A title bibliography is presented of selected physiological and psychological studies concerning the environmental requirements of sealed cabins for space and orbital flight. A total of 582 categorized entries from military reports, books, and journal literature are presented on standard bibliographic file card forms.

13. Burton, A.C.
Research in applied physiology of the cold. REV. CANADIENNE BIOL. v. 16, p. 83-95, 1957.

14. Carlson, L.D.
Requirements for monitoring physiological functions in space flight. IRE TRANSACTIONS - FIFTH NATIONAL SYMPOSIUM ON SPACE ELECTRONICS AND TELEMETRY p. 6.1, Sep 60.

15. Covino, B.G. and Hegnauer, A.H.

Ventricular excitability cycle:

Its modification by pH and temperature.

AMER. J. PHYSIOL. v. 181, p. 553-558,

1955.

16. Cummings, V.

A study of thermoregulatory and emotional

sweating in man by skin ion transfer.

SCIENCE v. 131, n. 3414, p. 1675-76, 1960.

Local introduction of atropine and dibenzyline into human skin was carried out by iotophoresis. Both thermoregulatory and emotional sweating were blocked by atropine but were not blocked by dibenzyline. It would seem that emotional sweating produced as a result of a physical stress situation is partly or predominantly under cholinergic control.

17. Davis, T.R.A.

Thermogenic factors during cooling and

in the stabilized hypothermic state. In

Hypothermia. ANN. NEW YORK ACAD. SCI.

v. 80, p. 500-514, 1959.

Two main sources of thermogenesis during cooling are a shivering source and a nonshivering source. Shivering does not seem to be a simple stimulus-response mechanism. Nonshivering thermogenesis in both the unacclimatized and acclimatized state probably use humoral, neural, biochemical, and enzymatic systems. In the acclimatizing homeotherm, substantial physiological changes greatly modify not only thermogenic factors, but also resistance to the pathological conditions associated with cooling. In man there is a substantial decrease in energy requirements for a given cold stress, due in large part to the decreased heat loss via the respiratory system. In the stabilized hypothermic state, both shivering and nonshivering thermogenic factors may be demonstrated. The assumption that heat and cold acclimatization are mutually exclusive can no longer be upheld.

18. Donhoffer, S., et al
The dynamics of chemical thermoregulation in the rat. ACTA PHYSIOL. ACAD. SCI. HUNGARIAE v.13, p. 37-56, 1957. (In German)

19. Donhoffer, S., et al
Localization of the increased heat-production in chemical heat-regulation. PFLUGER'S ARCH. GES. PHYSIOL. v. 265, p. 97-103, 1957. (In German)

20. Donhoffer, S.G., et al
Thermoregulatory heat production in the brain. NATURE v. 184 (Suppl. 13) p. 993-994, 1959.

21. Edhom, O.G., Fox, R.H. and MacPherson, R.K.
The effect of body heating on the circulation in skin and muscle. J. PHYSIOL. v. 134, p. 612-619, 1956.

22. Fenning, W.H., Jackson, P.L. and Kelley, R.J.
REFERENCE SOURCES IN THE PHYSIOLOGY OF EXTREME ENVIRONMENTAL TEMPERATURES. Michigan U. Engineering Research Institute. Rept. no. 2167-2-P, May 54, 59p. (Contract no. DA-20-018-ORD-13146).
A short discussion and conclusions are presented concerning articles and reports on which the recommendations of physiological criteria for evaluating

22. (Cont'd)

systems for heating, cooling, and ventilating combat tanks are based. The reports found to be most pertinent are listed, together with short abstracts of their content.

23. Ferguson, I.D. and Hertzman, A.B.

REGULATION OF BODY TEMPERATURE DURING CONTINUOUS EXPOSURE TO HEAT. St. Louis U. School of Medicine, July 58, 17p.

24. Fine, B.J. and Gaydos, H.F.

Relationship between individual personality variables and body temperature response patterns in the cold. PSYCHOL. REPTS. v. 5, p. 71-78, 1959.

Seventy Ss were exposed nude to successive climatic conditions of 70°F, 50°F, and 78°F for periods of 30, 75, and 115 minutes, respectively. Rectal temperatures, morphological measurements, ratings of subjective feelings of cold and personality measurements (MMPI) were obtained. Ss, whose combined scores on the MMPI-derived Anxiety Index and Internalization Ratio deviated widely from the group norm, book significantly longer than less deviant Ss to show a rise in rectal temperature following exposure to cold. Heavy, large men felt warmer than light, small men during exposure to the same cold condition. The meaning of the data is discussed.

25. Fox, R.H.

Local cooling in man. In Hypothermia and the effects of cold. BRIT. MED. BULL. v. 17, n. 1, p. 14-18, 1961.

This paper reviews the following: (1) Effects of cooling on blood flow, (2) Effects of cooling on muscles, joints and tendons, (3) The effect of cooling on nerves, and (4) Local acclimatization to cold.

26. Fregly, M.J., Iampietro, P.F. and Otis, A.B.

EFFECT OF PROPYLTHIOURACIL TREATMENT AND ADRENALECTOMY ON HEAT PRODUCTION AND HEAT LOSS DURING ACUTE EXPOSURE TO COLD. School of Aviation Medicine. Rept. no. 61-46, Apr 61, 9p. ASTIA AD-257 595.

Thyroidectomy (propylthiouracil treatment) and adrenalectomy increased rate of cooling of rats restrained and subjected to air at 5 C. At the same colonic temperature during cooling, both thyroidectomized and adrenalectomized rats maintained higher skin temperatures than did control rats. Heat production (measured by oxygen consumption) was determined for thyroidectomized and control rats only. At the same colonic temperatures during cooling thyroidectomized rats had the same heat production as controls. Calculation of heat loss at a given colonic temperature during cooling, however, revealed it to be greater for thyroidectomized than for control rats. The inability of thyroidectomized rats to tolerate cold as well as the control rats did under these conditions is due almost entirely to a more rapid loss of body heat. Failure to conserve heat may be related to changes in vascular reactivity induced by the hypothyroid state.

27. Froese, G. and Burton, A.C.

Heat losses from the human head.

J. APPL. PHYSIOL. v. 10, p. 235-241, 1957.

28. Fusco, M.M., Hardy, J.D. and Hammel, H.T.

Interaction of central and peripheral factors in physiological temperature regulation.

AMER. J. PHYSIOL. v. 200, p. 572-580, 1961.

29. Gagge, A.P. and Herrington, L.P.
Physiological effects of heat and cold.
ANNUAL REVIEW OF PHYSIOLOGY v. 9,
p. 409-428, 1947.

30. Gellette, R., Gentiline, P. and Spagnolo, G.
Experimental research on the onset of
shivering during induced hyperthermia.
SPERIMENTALE v. 110, n. 3, p. 203-214,
1960. (In Italian)

Febrile shivering was studied in patients subject to vaccine therapy. When the patient was exposed to cold during the period immediately proceeding the onset of spontaneous shivering. It was possible to induce shivering fits by a stimulus lower than that necessary in normal conditions. A "Latent state of shivering" is the first manifestation in order of time of the fever cycle. It is suggested that this cold exposure can be usefully applied in cases of hyperthermia which are not preceded by clinically evident shivering.

31. Glaser, E.M. and Newling, P.S.B.
The control of body temperature in thermal
balance. JOUR. PHYSIOL. v. 137, p. 1-11,
1957.

Three men at rest were exposed to 4 different environments after periods of controlled cooling or warming lasting 5 minutes. When the subjects were in thermal balance, the deep and superficial temperatures were correlated with the environmental temperature. Short periods of previous cooling caused a reduction and short periods of previous warming caused an increase of the level of skin and mouth temperature at which thermal balance was achieved in any 1 environment. This observation was significant with respect to the skin temperature of the face and extremities, and within the zone of temperature regulation by vasomotor control. It implies that the level at which thermal balance is achieved may depend partially on the previous thermal state. When thermal equilibrium was upset, the time required for restoration was proportional to the magnitude of the disturbance. Under physiological conditions, fluctuations of the level over which thermal balance could be maintained were

31. (Cont'd)

effectively limited by sweating and shivering. Physiological variations of blood pressure and heart rate at rest appear to be somewhat dependent temperature changes at which heat losses and heat gains are balanced.

32. Glaser, E.M., Hall, M.S. and Whittow, B.C.

Habituation to heating and cooling of the same hand. JOUR. PHYSIOL. v. 146, p. 152-164, 1959.

Measurements of blood pressure, heart rate, skin temperature, and appraisal of subjective sensations were made in 5 subjects during immersion of one hand in water at high (47° C) temperatures. Repeated immersion at these temperatures resulted in adaptation to the hypertensive and algesic effects observed initially. Adaptation involved only the hand immersed, and held only for the thermic state experienced. In 1 group, alternate immersion in the 47° C bath following by immersion in the 4° C bath resulted in adaptation to the pressor and painful effects of both temperatures. Evidence is presented for concluding that the mechanism of this adaptation is one of central diminution of sensitivity to afferent impulses; rationale against the proposal that local tissue changes, histamine release, change in blood supply to the hand, etc. are important in this adaptation is discussed. Chloropromazine (75 mg, p.o.) has the property of inhibiting this type of thermal habituation.

33. Glickman, N., <u>et al</u>

Physiological adjustments of human beings to sudden change in environment. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 53, p. 327-356, 1947.

34. Glickman, N., <u>et al</u>

Physiologic adjustments of normal subjects and cardiac patients to sudden change in environment. AMER. SOC. HEAT. VENT. ENGINEERS. TRANSACTIONS v. 55, p. 27-38, 1949.

35. Haist, R.E., Hawkins, R.S. and Kovacs, G.V.

Effect of environmental temperature on

metabolic changes following physical injury.

JOUR. APPL. PHYSIOL. v. 15, p. 13-17, 1960.

Rats in shock resulting from limb ischemia showed no significant differences in the rise in blood nonprotein nitrogen (N.P.N.) when kept at different environmental temperatures after the period of limb ischemia. Under these conditions the elevation in blood inorganic phosphorus was inversely related to the environmental temperature. In the shocked rats the tolerance for orally administered carbohydrate was less and the hepatic glycogen values were higher at 21°-32°C than at 10°C. However, at similar times the residue of reducing substances in the gut was greater at 10°C than at 21°C-32°C. There was no significant difference in the tolerance for intravenously administered glucose at 10°, 20° and 30°C in the shocked rats, but control rats, with clamps left in position, showed a significantly better tolerance at 10°C than at 20° or 30°C. Under the conditions used, environmental temperature had little influence on blood N.P.N. changes in shock, but did influence the blood inorganic phosphorus levels and the tolerance for orally administered carbohydrate.

36. Hardy, J.D.

THE PHYSIOLOGY OF TEMPERATURE REGULATION.

Naval Air Dev. Ctr. Aviation Medical

Acceleration Lab. Rept. no. NADC-MA 6015,

1960, 296p. ASTIA AD-242 363.

A review of 3000 articles on the physiological responses to cold and heat and on the physiology of temp. regulation.

37. Hardy, J.D., et al

Responses of the rat. to thermal radiation.

AMER. J. PHYSIOL. v. 189, p. 1-5, 1957.

38. Hardy, J.D.
SUMMARY REVIEW OF HEAT LOSS AND HEAT PRODUCTION IN PHYSICAL TEMPERATURE REGULATION. Naval Air Development Center. Rept. no. NADC-MA-5413, Oct 54, 46p. ASTIA AD-55 217.

39. Hellon, R.F., Lind, A.R. and Weiner, J.S.
The physiological reactions of men of two age groups to a hot environment. J. PHYSIOL. v. 133, p. 118-131, 1956.

40. Helmendach, R.H. and Meehan, J.P.
THE CONTROL OF THERMOREGULATORY RESPONSES IN THE DOG AFTER ALTERATION OF PERIPHERAL SENSITIVITY. Paper presented at 44th. annual meeting of Federation of American Societies for Experimental Biology, Chicago, Illinois, 11-15 Apr 60.

The control of thermoregulatory responses in the dog after alteration of peripheral sensitivity.

41. Heroux, O.
The effect of intermittent indoor cold exposure on white rats.

41. (Cont'd)

CANADIAN JOURNAL OF BIOCHEM.

AND PHYSIOL. v. 38, p. 517-521,

1960.

Recently it has been shown that when white rats are kept in individual cages and exposed indoors to constant cold temperature or when they are exposed in groups to the outdoor winter conditions, they develop similar degrees of cold resistance and similar metabolic adjustments but they differ in endocrine, insulative, and peripheral adjustments. In an attempt to determine whether variations alone could be responsible for the type of adjustments developed indoors, white rats were kept at 30° C for 4 weeks but exposed to 6°C for a few hours every day. Through these intermittent cold exposures, the animals developed the same type of acclimation, but to a lesser degree. Adrenals tended to hypertrophy, body and muscle growth tended to increase, and over-all insulation appeared to decrease. In contrast to continuously exposed rats, however, they showed no cold injury, no change in ear vascularization, and no thickening of the ear epidermis, probably because the skin was never cooled long enough at any given time for the cold temperature to produce cellular alterations that could not be corrected during the warm periods.

42. Hertzman, A.B.

Some relations between skin temperature and

blood flow. AMERICAN JOURNAL OF PHYSICAL

MEDICINE v. 32, p. 233-251, 1953.

Calorimetric data and measurements of surface temperature are indirect criteria of the level of blood flow in the skin. Quantitation of the relation between the cutaneous blood flow on the one hand and skin temperature and the delivery of heat to the skin on the other hand requires the separate estimation of the two processes of heat delivery by conduction and vascular convection. Conduction may be approximated when the temperature gradients and thermal conductivity of the superficial tissues are known. Vascular convection is obtained then as the difference between surface heat loss and conduction.

43. Hertzman, A.B.

STUDIES ON CUTANEOUS HEAT LOSSES. PART I.

A METHOD OF PARTITIONAL CALORIMETRY OF

43. (Cont'd)

INDIVIDUAL SKIN AREAS. St. Louis U. School of Medicine. USAF Technical Report 6680, Part I, Nov 51, 14p. ASTIA AD-128 684.

A method of partitional calorimetry which is applicable to the measurement of the radiative, convective and evaporative heat losses from a limited skin surface (forehead, palm, thigh, etc.) was based on measurements of skin and environmental temperatures and cutaneous evaporative rates. Radiation was calculated from the Stefan-Boltzmann equation; convection was estimated from the air insulation which in turn was approximated from the application of the diffusion equation to the evaporation of water. The local evaporative rates were measured by means of dessicating capsules. The sources of error are described. The total body losses of heat via radiation and convection from the skin cannot be obtained from the sum of the weighted regional rates. For reasons given in the text, this is not a criticism of regional partitional calorimetry. Total cutaneous evaporation is closely approximated by the sum of the weighted regional rates.

44. Higginbotham, A.C., et al

STUDIES ON CUTANEOUS HEAT LOSSES. PART 9. CUTANEOUS TEMPERATURE GRADIENTS, HEAT LOSSES AND BLOOD FLOWS IN THE DOG'S FOOTPAD. St. Louis U. School of Medicine. USAF Technical Report 6680, Part 9. Dec 52.

45. Howath, S.M., et al

Metabolic cost of shivering. J. APPL. PHYSIOL. v. 8, p. 595-602, 1956.

46. Houghten, F.C., et al

Radiation as a factor in the sensation of warmth. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 47, p. 93-122, 1941.

47. Hsieh, A.C.L. and Carlson, L.D.
Role of the thyroid in metabolic response to low temperature. AMER. J. PHYSIOL. v. 188, p. 40-44, 1957.

48. Hudson, J.W.
Reaction of blood pressure to shivering. TOHOKU JOUR. EXPTL. MED. v. 72, p. 237-42, 1960.

49. Ingle, D.J.
Endocrine mechanisms in adaptation to cold. (In Symposium on metabolic aspects of adaptation of warm-blood animals to cold environment). FEDERATION PROC. v. 17, p. 1064-1065, 1958.

50. Inouye, T., Glickman, N. and Keeton, R.W.
Dynamics of evaporative heat loss for a rapidly cooling human body. PROC. SOC. EXPER. BIOL. AND MED. v. 8, p. 80, 1949.

The dynamics of evaporative heat loss for a rapidly cooling human body in a 'comfortable' environment after having been exposed to a hot environment was studied on 6 healthy young men. The subjects were clothed in 90% cotton union suits containing variable amounts of moisture accumulated as a result of 1 or 2-hour exposures to a hot environment. The hot room was maintained at 37°C. with a water vapor pressure of 41.1×10^3 dynes/cm.^{2} and the 'comfortable' room at 24.4°C. with water vapor pressures of 9.1×10^3, 18.2×10^3, and 24.3×10^3 dynes/cm.^{2} with air velocity minimal and constant. Observations included weight loss and skin temperatures obtained at short intervals for 1 hour. The equation governing evaporative heat loss was theoretically derived for the dynamic state. Hitherto, this was applied only

50. (Cont'd)

on subjects in approximate equilibrium with the environment with the introduction of wettedness as a calculated factor to account for an interdeterminate variable. Under dynamic conditions, available moisture in the union suit and on the skin was found to adequately express wettedness. The inclusion in the equation of the amount of available moisture yielded a linear correlation for each of the 36 tests with an average correlation coefficient of 0.992. Thus, for subjects under rapidly changing physiological conditions, the amount of evaporation heat loss was proportional to the gradient of water vapor pressure between the skin and the ambient environment, amount of available moisture on the skin and in the union suit, surface area and time.

51. Inouye, R., et al

Physiological responses to sudden changes in atmospheric environment; studies of normal subjects, obese, hyperthyroid and hypothyroid patients. HEATING, PIPING AND AIR CONDITIONING v. 26, n. 7, p. 131-134, 1954.

Three groups of women who might logically have an abnormality of body temperature regulation were studied during one hour in a comfortable room, and then moved for one hour into a hot humid room. The groups were obese, hyperthyroid and hypothyroid. The promptness and ease of their thermal adjustments on entering the hot room confirmed the findings on normal women. The hyperthyroid patients could not endure the heat (98.6°F, 66% relative humidity) without a rise in rectal temperature. The quantity of sweat trapped in the clothing accounts for the cool sensation on return to the comfortable room, and explains the need for time to make a complete adjustment. This factor is widely variable from patient to patient, as well as variable between groups of subjects. It should be of much interest to engineers interested in air conditioning.

52. Ivanov, K.P. and Den Su-I.

The electrical activity of the muscles and chemical thermoregulation in albino rats of various ages. FIZIOL. ZHUR. SSSR. (TRANSL.) v. 46, p. 76-84, 1960.

Chemical thermoregulation in albino rats was associated with definite changes in the electrical activity of the muscles, when the animals were in complete

52. (Cont'd)

rest. Increased respiratory exchange during cooling coincided with intensification of electrical activity in the muscles. Reduction of respiratory exchange with a relatively high surrounding temperature was associated with diminution of the electrical activity in the muscles. The development of elements of chemical thermoregulation in young rats at the age of 10-11 days, coincided with the appearance of tonic reactions in the skeletal muscles to change of surrounding temperature, similar to the reactions in adult animals. Depression of the tone of the muscles in hypoxia (as judged by their electrical activity) was associated with suppression of the chemical thermoregulatory reaction to cooling in both the adult rats and the young rats of suitable age. It is suggested that the liberation of energy in the tonic reactions of skeletal muscles was a factor in chemical thermoregulation.

53. Jirka, M. and Kotas, J., et al

Changes in the sweat composition following hyperthermic procedures. FYSIATRICKY VESTNIK v. 37, n. 1, p. 37-39, 1959. (In Czech)

54. Khvoinitskaya, M.A.

The effect of high environmental temperature on the water distribution in the body. BIUL. EKSPERIM. BIOL. I MED. (TRANSL.) v. 47, p. 578-581. (In Russian)

Water distribution among various compartments was studied in rabbits under high external temperatures (+43°, + 45°C) by concurrent determination of the volume of blood and cellular fluid, with the aid of radioactive isotopes. The total water loss and the changes of certain hematological indices were also investigated. Water loss during a 3-hour exposure of the rabbit to heating with no water to drink, amounted to from 2 to 2.5% of the body weight. Urine flow decreased or was completely absent. All water losses occurred at the expense of the extrarenal losses. The volume of the extracellular water increased, while that of the blood plasma slightly increased. Intracellular water served as a source of the water loss and of its increase in the extracellular spaces.

55. Kozlov, N.B.

Influence of internal high temperature on the metabolism of substances in the animal organism. TR. SMOLENSK. MED. INST. v. 1957, n. 7, p. 68-75, 1957. (In Russian)

Dogs and rabbits were placed in a heat chamber with a temperature of 50-60°. The level of sugar in the blood of rabbits increased with the degree of overheating. In some dogs an increase of the sugar concentration in the blood was noted (13 mg%); in others a decrease (17 mg%). Changes of the sugar level depended on the degree of overheating and individual peculiarities of the animals. The concentration of lactic acid in the blood increased. In a majority of the animals under excess heat, an increase was observed of pH to 0.2-0.3. Under excessive overheating, when the respiratory movements were restricted, the pH of the blood began to fall. Under slight heating of the animals, when the body temperature changed insignificantly, the concentration of NH_3 in the urine decreased; during excessive overheating, the concentration of NH_3 increased. Generally, N of the urine decreased somewhat, usually toward the end of heating. Of the changes noted, there was, under slight heating no increase of residual N; during excessive overheating, the concentration of residual N increased 100-173%. Thus, a degradation of the tissue proteins and impairment of the kidney function was observed in the organism during overheating.

56. Kurelova, L.M.

Reaction of cutaneous reception to local, reflex, and general thermal influences. BULLETIN OF EXPERIMENTAL BIOLOGY AND MEDICINE v. 49, p. 211-214, 1960.

In studying the reaction of thermoreceptors the author used the method of investigating the functional mobility. It was shown that during local heating or cooling of short duration there occurs a rapid and considerable demobilization of the receptor elements responding to both heat and cold at the site of application of the thermal stimuli. Evidently, in this case the thermoregulation processes of the organism are not disturbed and therefore the reaction is only local. With a prolonged action of T stimulation extended over a larger surface of the skin - a reflex reaction of the thermoreceptor system is observed which is manifested in the changed adjustment of cutaneous thermoceptors, not subjected to the effect of thermal stimulation. In this instance a differentiated reaction to heating and cooling is being noted:

56. (Cont'd)

heating provides demobilization, while cooling - mobilization of the thermoreceptors. With this temperature changes of outside or inside air a reciprocal relationship is observed between the reaction of cold and heat receptor systems of the skin. The data obtained demonstrate that the cold receptor system reacts more rapidly and adequately to changes of external temperature while the heat receptor system responds more readily to the temperature changes in the body.

57. LeBlanc, J.A.

Effect of environmental temperature on energy expenditure and caloric requirements.

J. APPL. PHYSIOL. v. 10, p. 281-283, 1957.

58. Levine, S.Z. and Adolph, E.F.

Heat regulation. TRANS. CONF. PHYSIOL. PREMATURITY v. 4, p. 9-52, 1960.

A discussion of body heat regulation of premature infants.

59. Lim, T.P.K.

Central and peripheral control mechanism of shivering and its effects on respiration.

JOUR. APPL. PHYSIOL. v. 15, p. 567-574, 1960.

Central and peripheral contributions to the initiation of shivering have been studied in anesthetized dogs employing a thermal dissociation technique. Shivering was elicited invariably during differential cooling of the head or the trunk alone as well as in the course of whole-body cooling. Either "peripheral" or "central shivering" could be produced repeatedly and also inhibited by elevation of subcutaneous temperature in central shivering or brain temperature in peripheral shivering. In part 2 of this study, respiratory effects of shivering have been assessed during the steady state of hypothermia in the anesthetized animal. During shivering, O_2 intake and CO_2 output were doubled or tripled but the respiratory exchange ratio remained essentially unchanged. Total ventilation increased linearly with metabolic rate and yet arterial pH, pCO_2 and buffer base revealed no significant changes with or without shivering. Although alveolar-ventilation was increased almost three times, no marked alterations occurred in physiological dead space. Moderate hemoconcentration and a consistent elevation of pulse pressure were seen during shivering.

60. Longwell, B.B.

Methods and apparatus for the study of

stress reactions and metabolic changes.

AVIATION MED. SELECTED REVS. AGARD.

v. 25, p. 45-58, 1958.

Since the concept of "stress" is broad and includes the regulatory effect of both the nervous and endocrine systems upon metabolic processes of almost, if not all tissues of the body, the author is forced to limit his dissertation primarily to methods and apparatus which had been or could be applied to the study of "stress" on the endocrine system and certain closely related metabolic processes. Specifically, the endocrine glands and electrolyte and water balance studies were chosen as subjects for discussion. With regard to the former, recent and current methods applicable to the pituitary and endocrine system are covered; e.g. the thyroid by assay of serum protein-bound iodine and radioactive iodine uptake; the pituitary by assay of thyrotropic hormones; the adrenal cortex by chemical and bio-assay determinations of the corticosteroids in human urine and blood; and the adrenal medulla through determination of the plasma and urinary contents of epinephrine and norepinephrine. Recent methods and techniques suitable for determining variations in water and electrolyte balances produced by short periods of acute stress are reviewed. Particularly, electrolyte variations in plasma and urine, blood volume changes, alterations in total extracellular fluid, water balance and the relation of these to hormonal control by aldosterone are covered. Also highly selected and useful references are cited.

61. MacDonald, D.K.C. and Wyndham, C.H.

Heat transfer in man. J. APPL. PHYSIOL.

v. 3, p. 342-364, 1950.

62. MacPherson, R.K.

The effect of fever on temperature

regulation in man. CLIN. SCI. (LONDON)

v. 18, p. 281-287, 1959.

A man engaged in a series of experiments in which he was exposed to varying levels of heat stress in a climatic chamber, suffered from a respiratory tract infection accompanied by fever but continued to participate in the experiments. Throughout his illness his rectal and mean skin temperatures

62. (Cont'd)

during the experiments accurately reproduced the expected patterns, but at a new higher level determined by the height of his fever. His sweat loss was unaffected. It was concluded that at moderate levels of fever body temperature regulation is unimpaired.

63. Masuko, K.

Studies on the characteristic features of thermoregulatory function in women. I. Sexual differences of thermal regulation. (In Japanese with English summ.). JOUR. PHYSIOL. SOC. JAPAN v. 20, p. 192-203, 1958.

At high air temperatures (40° to 45°C) skin temperature rose throughout the body surface, particularly on the upper and lower extremities; the temperature elevation was higher in women than in men, although the maximal rate of perspiration was greater in men than in women. The rectal temperature rose 1.3° to 2.7°C, with no significant difference between sexes. Thus, there seems to be no difference in the thermoregulatory function between the sexes for the maintenance of body heat. In the cold (11° to 13.5°C) skin temperature fell throughout the body surface, particularly on the upper and lower extremities, the fall being more pronounced in women than in men. Oxygen consumption rose as shivering appeared (earlier and with more force in men). Females can resist cold much longer than males.

64. Masuko, K.

Studies on the characteristic feature of the thermoregulatory function in women. II. Sexual differences of seasonal variations in thermoregulatory functions of resting subjects estimated under habitual clothing state. (In Japanese with English summ.) JOUR. PHYSIOL. SOC. JAPAN v. 20, p. 204-213, 1958.

The mean skin temperature of both sexes is the same in summer, but that of the female lower in winter, and is always below that of the male below 25°C

64. (Cont'd)

(the difference decreases at higher temperatures). It is concluded that the thermoregulatory function in female adapts to normal seasonal changes of environmental temperature. This is attributed to her ability to adjust her skin temperature, higher dermal insulation and ability to perspire less and at a lower metabolic rate.

65. Meehan, J.P.

Avenues of heat loss and peripheral circulation.

In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE, MAR. 1957. New York. Josiah Macy, Jr. Foundation, p. 291-320, 1958.

66. Miller, A.T., Jr. and Blyth, C.S.

Lack of insulating effect of body fat during exposure to internal and external heat loads.

J. APPL. PHYSIOL. v. 12, p. 17-19, 1958.

67. Milstein, S.W. and Coolson, R.E.

Depot fat depletion following thermal trauma.

AMER. J. PHYSIOL. v. 193, p. 75-78, 1958.

The effects of moderate to lethal thermal injury by water scalding on that degree of peripheral body fat depletion in the rat were studied by the direct measurement of changes in the fatty acid content of a characteristic depot. Following a nonlethal burn, loss of fat and body weight was consistently less than in pair-fed controls for about 1 week. Later phases of this postburn period indicate that the normal capacity to deposit fat is not restored in burned rats during the interval when pair-fed mates reach control levels. In a lethal burn, fat depletion is rapid and extensive despite a normal intake of food that permits pair-fed controls to resume normal lipid economy.

68. Mirchev, M.A.

Experimental application of contemporary physiological methods of investigations in the study of the reaction of the organism to microclimate. TR. LENINGRAD. SAN.-GIGIEN. MED. INST. n. 26, p. 8-44, 1956. (In Russian)

The effects of various air temperatures (T^{o}) of the environment upon man were ascertained. The most convenient and revealing method for investigations of microclimate used both unconditioned reflex changes and conditioned reflex activity. The reflex was elaborated with the sound of a bell and local chilling action in ten men. Plethysmographic registration of vascular, and pneumographic registration of respiratory unconditioned and conditioned reflex reactions showed that these methods are too complicated for practical hygienic investigations. Still less adaptable was the pneumatic registration of the blinking reflex. The method of symmetrical skin temperatures with thermopars appeared to be simple and easy to apply. Interrogation of 384 men concerning heat sensation, carried out under various T^{o} conditions, supplemented the objective data of physiological investigations. The optimal development of the vascular and respiratory reactions and also of the symmetry of skin T^{o} was observed at 18-20^{o}C air T^{o}. These functions showed disturbances at 16^{o} and 20.5^{o}.

69. Myakishev, B.K.

Thermographic investigation of febrile patients. KLIN. MED. v. 34, n. 6, p. 69-73, 1956. (In Russian)

Thermograms of febrile patients were taken with Waldman's thermograph, registering the dynamics of thermoregulatory disturbances in various diseases and the effect of antipyretics and other medical procedures. The temperature of the abdominal skin, covered with clothes or blankets, did not differ from that of the subaxillary area. The thermograms registered secondary "waxes, reflecting changes in the microclimate" under the clothes as well as those produced by variations of energy processes in the body during 24-hour periods, independent of the phasic variations of thermoregulation. In the opinion of the author thermography contributes to the clinical functional diagnosis in disturbances of thermoregulation.

70. Newburgh, L.H.

PHYSIOLOGY OF HEAT REGULATION AND THE SCIENCE OF CLOTHING. W.B. Saunders Co., Phil., 1949.

Contents:

1. Adaptations to climate among non-European peoples. F.R. Wulsin
2. Thermometry. C.P. Yaglou
3. Heat transfer. J.D. Hardy
4. The Regulation of Body Temperatures. H.C. Bazett
5. Physiological adjustments to heat. S. Robinson
6. Physiologic adjustments to cold. C.R. Spealman
7. Regional heat loss. R. Day
8. The Range of physiological response to climatic heat and cold. L.P. Herrington
9. Indices of comfort. C.P. Yaglou
10. Physical properties of clothing fabrics. L.Fort and M. Harris
11. Laboratory and field studies - General principles, Desert, Tropics, Protection against dry cold, Wet cold, Water, Special problem of hands.
12. Clothing and climate. P.A. Siple.

71. O'Connor, J.M.

The stability of the body temperature. IRISH JOUR. MED. SCI. v. 374, p. 49-58, 1957.

72. Ohara, K.

Studies on the validity of the "vasodilatatorischer quotient, (VDQ)", with additional reports on the quantitative relation between skin temperature and cutaneous blood flow. (In Japanese with English summ.) JOUR. PHYSIOL. SOC. JAPAN v. 19, p. 1315-1322, 1957.

The possibility of calculation of the cutaneous blood flow from the skin temperatures was previously proposed. The skin temperature (tH) was a function

72. (Cont'd)

of the temperature of the skin surrounding air (tU) under a condition of stationary blood flow, and a straight lined relationship was obtained between tH and tU (tH-tU-line). The position and slope of the tH-tU-line was altered corresponding to the cutaneous blood flow. The greater the blood flow, for example, the higher the line and the flatter its slope. When the slope of tH-tU-line is expressed in terms of the gradient $\Delta tU/\Delta tH$, the slope of such a line (which corresponds to the condition of the maximal cutaneous blood flow) by θ_o, the maximal time volume of the blood flow by V_o, and the slope of such a tH-tU-line (which corresponds to the cutaneous blood flow of 1/n of that of the maximal flow) by θn, the following formula was theoretically induced.

$$\frac{K}{eVo}(1-n) = \frac{\theta o}{\theta o-1} \cdot \frac{\theta n-1}{\theta n}$$

$\frac{K}{eVo}(1-n)$ was calculated from the values of θo and θn, and was considered as an index, which might indicate the grade of the cutaneous blood flow relative to that of the maximal vasodilatation, and was therefore termed by the author as "Vasodilatatorischer Quotient" (VDQ). The validity of this theoretically induced VDQ was examined by comparison of its values with that of plethysmographically measured blood flows. Consequently the VDQ blood flow-relation curve could be calibrated, and as a result, the advantage of this quotient as an index of the cutaneous blood flow was experimentally confirmed. In addition, a further knowledge of quantitative relation between skin temperature and cutaneous blood flow was obtained. The skin temperature-blood flow-relation curve indicated that a change of cutaneous blood flow by 16% would result in a change of skin temperature of 1°C in a local environmental temperature of 20°C.

73. Otis, A.B. and Jude, J.
Effect of body temperature on pulmonary gas exchange. AMER. J. PHYSIOL. v. 188, p. 355-359, 1957.

74. Potter, V.R.
Possible biochemical mechanisms underlying adaptation to cold. (In Symposium on metabolic aspects of adaptation of warm-blood animals to cold environment). FEDERAL PROC. v. 17, n. 4, p. 1060-1063, 1958.

75. Recent advances in physiological knowledge and their bearing on ventilation practice. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 45, p. 111-122, 1939.

76. Roddie, I.C., Shepherd, J.T. and Whelan, R.F. A comparison of the heat elimination from the normal and nerve-blocked finger during body heating. JOUR. PHYSIOL. v. 138, p. 445-448, 1957.

Heat eliminations from a nerve-blocked and an intact finger were compared before and during body heating in 4 subjects using standard calorimeters. During heating, the heat elimination from the intact finger approached but did not exceed that from the nerve-blocked finger. Apparently sympathetic activity during body heating does not result in the formation of a stable vasodilator substance in digital skin.

77. Roddie, I.C., Shepherd, J.T. and Whelan, R.F. The contribution of constrictor and dilator nerves to the skin vasodilatation during body heating. JOUR. PHYSIOL. v. 136, p. 489-497, 1957.

Blood flow through both forearms was determined in 8 young healthy men by venous occlusion plethysmography before and during body heating. Intra-arterial atropine, 0.1 mg/minute for 3-4 minutes, infused on one side before heating, reduced and delayed the dilatation for about 20 minutes and abolished sweating, though normal vasodilatation and sweating occurred on the control side. Infusions of atropine at the height of body heating did not alter the forearm blood flow. Other results indicate that during body heating, a small amount of vasoconstrictor tone is 1st released in the forearm skin. This is followed by the major vasodilatation which is mediated through sympathetic cholinergic fibers. Results of atropinization of the whole hand or body of the hand and subsequent heating did not provide evidence for the existence of cholinergic fibers to the hand blood vessels. It is concluded that in the vasodilator response of the forearm skin vessels to body heating, vasodilator nerves play the dominant role while in the hand skin, the dilator response is probably due solely to release of vasoconstrictor tone.

78. Senay, L.C., Jr., Christensen, M.L. and Hertzman, A.B.

CUTANEOUS BLOOD FLOWS IN CALF, FOREARM, CHEEK AND EAR DURING CHANGING AMBIENT TEMPERATURE. St. Louis University. Rept. no. WADD TR 61-190, Mar 61, 19p. (Contract AF 33(616)7077).

When seminude subjects were exposed to heat, the onset of cutaneous vasodilatation occurred simultaneously in the calf, forearm, cheek and ear. Progress of vasodilatation in the calf and toe often differed from that in the forearm, cheek and ear. Vasodilatation in the calf was either small or stabilized early.

79. Stoll, A.M.

The role of the skin in heat transfer. JOUR. HEAT TRANSFER. SER. C v. 82, p. 239-242, Aug 1960.

Consideration is given to lines of fundamental research and the impact of human factors in the area of thermal exchange. An assessment is made of the human skin (in terms of its physical dimensions and thermal and optical properties) as a medium through which heat must flow in both directions to maintain man in his environment in a functional capacity. In this respect, the skin may be considered to be a multiple-layer covering of a heat source through which heat passes at a measurable rate; a servomechanism for the regulation of this heat passage; an alarm system to detect and transmit signals indicating dangerous extremes of temperature; a living organ generating, dissipating, and modulating the flow of heat between the entire organism and its environment; and finally, an indispensable, vulnerable yet highly regenerative and adaptable thermal integument having remarkable ability to alter its properties, thus inhibiting heat loss in the cold and augmenting heat loss in the heat. The possibility and risks of modulating sensations of heat and cold at the cortical or perceptual level in order to expand the limits of the comfort zone are discussed.

80. Stone, G.H., Donnelly, C. and Frobese, A.S.
The effect of lowered body temperature on the cerebral hemodynamics and metabolism of man. SURG. GYNCEOL. AND OBSTET. v. 103, p. 313-317, 1956.

81. Timmerman, J.C., Folk, G.E., Jr., and Horvath, S.M.
Day-night differences of body temperature and heart rate after exercise. QUART. HOUR. EXPTL. PHYSIOL. v. 44, p. 258-263, 1959.

A study of day-night differences in body temperature and heart rate was undertaken to evaluate the relative importance of daily activity and central nervous factors in the control of 24-hr. rhythms. The effects of about of moderate exercise upon body temperature and heart rate at 11 A.M. and 11 P.M. were studied in a series of ten male subjects. The results of the study indicate that the day-night differences of heart rate and body temperature are governed partly by environmental factors, but also by intrinsic factors. Evidence was found that the two rhythms represented by these differences are normally dissociated in some subjects.

82. Treff, W.M.
Energy investigation of dermal pain through the measurement of heat radiation. I. Methods. ZEITSCHRIFT BIOL. v. 109, n. 5, p. 360-366, 1957. (In German)

83. Van Der Horst, J.N.
THE NORMAL REACTION OF THE SKIN TEMPERATURE OF MEN TO VARIOUS ENVIRONMENTAL TEMPERATURES. University of Utrecht. Holland. Thesis, 1958, 89p. (In Dutch)

84. Vere, D.W.

Heat transfer measurement in living skin.

JOUR. PHYSIOL. v. 140, p. 359-380, 1958.

A method using a very small thermocouple is described for measuring temperature gradients and heat flows in living skin with minimal local disturbance. The advantages and disadvantages of this method as compared with other methods is discussed. Preliminary results are presented, and indicate the importance of small pressures made by apparatus placed on the skin to determine temperature. Temperature gradients in hair follicles differ from those obtained by direct skin puncture, probably because of differences in local anatomy. Direct puncture gradients are extremely difficult to obtain, and the accuracy of one result is discussed.

85. Vesyelkin, P.N.

Biological significance of febrile reactions.

ARKHIV PATOL. v. 19, n. 1, p. 3-20, 1957.

(In Russian)

In contradiction to the theory which defines fever (F) as a functional insufficiency of the thermoregulatory mechanism, and as an inability to decrease the body's temperature to normal, data and opinions are cited which favor the concept that the adaptive functions of the thermoregulatory mechanism remain untouched and are fully preserved at all times. Only in certain infectious diseases, during the late and final stages which have to be considered specific complications, insufficiency of the thermoregulatory mechanism may be observed. From the biological point of view, F is a specialized reaction of the thermoregulatory apparatus and is related with the general reactivity of the body. The temperature increase in F is not invariably accompanied by increase in gaseous interchange. In simple hyperthermia the gaseous interchange grows in proportion to the increase in body temperature according to the Vant-Hoff maxim, while in F, the general level of oxidizing processes is limited by the high point of the increase in body temperature. In infectious processes and intoxications, F plays a positive role as it stimulates a number of defensive mechanisms, such as immunogenesis, phagocytosis, the defensive functions of the liver and of other organs, the secretion of ACTH and of corticosterones. The increase in body temperature during heavy physical work presents an analogy to F. Also discussed here is the utilization of standardized pyrogens for purposes of therapy, applied side by side with hypothermia and hyperthermia.

86. Veselkin, P.N.

A symposium on the physiology and pathology of heat exchange and its nervous and humoral regulation. (English translation In Sechenov Physiolog). J. USSR v. 45, n. 8, p. 126-128, Aug 1959.

A symposium was held at the Institute of Experimental Medicine of the Academy of Medical Sciences of the U.S.S.R. on February 26-27, 1959, in the field of physiology and pathology of heat exchange and heat regulation. The first session discussed general theoretical problems of heat exchange and heat regulation; the second and third sessions dealt with the public health and clinical aspects, and particularly with the problems in hypothermia and hyperthermia. Re-examination of the classical concepts of energy metabolism and the mechanism of heat production was suggested.

87. von Eiff, A.W.

THE INFLUENCE OF HYPNOSIS ON TEMPERATURE SENSATION AND HEAT CONTROL. Aerospace Technical Intelligence Center. (Trans. no. MCL-931 of Zeitschrift f.d. Gesamte Experimentelle Medizin v. 117, p. 261-273, 1951). ASTIA AD-259 621.

88. Weiss, A.K.

An analysis of the metabolic responses of rates exposed to cold. AMER. JOUR. PHYSIOL. v. 196, p. 913-916, 1959.

When young Holtzman rats (150 gm) were exposed to +5 ± 2°C for 10 days their metabolic rate (measured at 28°C) was elevated. Injection of sodium pentobarbital (30 mg/kg, i.p.) just prior to the metabolism determination lowered the metabolic rate of both control and cold-exposed animals, but did not alter the general pattern of the cold-induced elevation of the

88. (Cont'd)

metabolic rate, so that the metabolism of the rats exposed to cold was still higher than that of the controls. When older rats (300 gm and more) were exposed to -5 ± 2°C for up to 10 days, the metabolic rate of the survivors was elevated also. In these animals, however, sodium pentobarbital administration lowered the metabolic rate of the cold-exposed animals to about the same level as that of the controls. This indicates that the older rats exposed to -5°C achieve protection against the cold environment primarily through changes which may be of neurogenic origin.

89. Winslow, C.E.A., Gagge A.P. and Herrington, L.P.

Heat exchange and regulation in radiant environments above and below body temperature.

AM. J. PHYSIOL. v. 131, p. 79-92, 1940.

It is shown that, when the body is subjected to markedly cold or hot conditions, storage can not be estimated from changes in skin temperature and rectal temperature. Both these temperatures may be maintained by the vaso-motor system at a stable level for considerable periods, in spite of the fact that appreciable heating or chilling of less vascular tissues is taking place. Storage, under such conditions, can be measured most adequately by difference-from the algebraic sum of metabolic heat production, evaporative heat loss and gain, or loss by radiation and convection. With a cold-air hot-wall situation skin and rectal temperatures are somewhat lower- for a given operative temperature- than with equal wall and air or with hot-air and cold walls. The difference is slight (0.5-1.0°C) and can be accounted for by the cooling effect of the cold air upon the membranes of the nose and throat, and, perhaps, also by additional heat loss to the metal supports of the subject's chair and to increased convective heat loss due to movements of the arms and legs.

90. Winslow, C.E.A., Herrington, L.P. and Gagge, A.P.

Physiological reactions of the human body to varying environment temperatures. AM. J. PHYSIOL. v. 120, p. 1-22, 1937.

The experiments here reported were conducted with two unclothed subjects, observed in a semi-reclining position. One of the subjects was stout, the other slender. The atmosphere had a relative humidity generally varying between 40 and 50%. In all experiments there was a turbulent air movement of 15 to 20 feet per minute. The air temperature varied over a wide range 6.5 to 35.5°C; and the radiation effect from surrounding copper walls varied over an even wider range (equivalent black-body temperature of 19° to 57°C).

90. (Cont'd)

Metabolism remained approximately constant through the range of experiments. At a critical operative temperature of 31° and 32°, the heat produced by metabolism is balanced by the heat lost through radiation plus convection, and through evaporation, these two components being approximately equal. The release of the sweat-secreting mechanism is intimately related to a critical surface temperature. A decrease in operative temperature from 31° to 20° is accompanied by a fall in mean skin temperature from 34.5° to 29°. This decrease in skin temperature tends, of course, to limit heat loss from the body and thus to check positive storage (chilling). This adaptation, unlike that effected in a warm environment by sweating, is, however, incomplete. At points with operative temperature below 31°, there is positive storage or chilling, which becomes progressively greater with lower operative temperatures, and in our coolest environments is equal to the metabolism.

91. Winslow, C.E.A., Herrington, L.P. and Gagge, A.P. The reactions of the clothed human body to variations in atmospheric humidity. AMERICAN JOURNAL OF PHYSIOLOGY v. 124, p. 692-703, 1938.

92. Winslow, C.E.A., Herrington, L.P. and Gagge, A.P. The relative influence of radiation and convection upon the temperature regulation of the clothed body. AMERICAN JOURNAL OF PHYSIOLOGY v. 124, p. 51-61, 1938.

It appears from these studies that when a given operative temperature is produced by (a), air and walls of approximately the same temperature, and (b) cooler air and warmer walls, the physiological reactions of the clothed human body differ in the two cases, as follows: (a) Mean skin temperatures are lower for the cold-air warm-wall situation, chiefly as a result of lower skin temperatures for upper and lower extremities, the head and trunk temperatures being less affected. (b) Conductance of the skin is very much lower for the cold-air warm-wall situation, particularly in the hot region. (c) As a result of lower skin temperatures, negative storage (heating of the body) is greater in the hot region, and positive storage (chilling of the body) is less in the cold region, for the cold-air warm-wall situation. (d) Wetted area is less for the cold-air hot-wall situation in the hot region. (e) As a result of the physiological reactions noted above, discomfort is less in the hot region and greater in the cold region for the cold-air warm-wall situation.

93. Winslow, C.E.A. and Herrington, L.P.

TEMPERATURE AND HUMAN LIFE. Princeton

University Press, Princeton, N.J., 1949.

Chapter I. Production of heat in the life process.
Chapter II. Avenues of heat loss from the body.
Chapter III. The Adaptations of the human body to varying thermal conditions.
Chapter IV. The Thermal Protective Influence of clothing.
Chapter V. The Objectives of air conditioning.
Chapter VI. Methods of air conditioning.
Chapter VII. The Influence of climate and season upon health.

94. Yoshimura, H., et al

Heat production and environmental temperature.

(Japanese with English summ.). JOUR. PHYSIOL.

SOC. JAPAN v. 20, p. 1015-1023, 1958.

To estimate the extent to which the skeletal muscles contribute to basal metabolism, the effect which ligating of limbs with a rubber band had on total oxygen consumption of the body, was measured under basal conditions. The metabolism decreased by only about 6.4%; the contribution of skeletal muscles to heat production in basal condition is, therefore, not so great as was previously believed. At moderate temperatures, (25 to 30°C), metabolism is at its lowest, this environment belongs in the metabolically indifferent zone. Metabolism rises at lower temperatures, because of the heat produced by the muscles; the metabolic rise almost disappears on ligature of the limbs. Exposure to higher temperatures also brought about a metabolic rise, due mainly to the increased metabolism of internal organs and the central nervous system; ligature of the limbs did not abolish this rise.

95. Zaynullina, G.N.

Body temperature of animals in relation

to metabolic processes. TR. TOMSKOGO

UNIV. n. 143, p. 15-20, 1956. (In Russian)

Body temperatures were lowered and elevated in dogs, rabbits and frogs. Blood values of residual N, urea (1) and total creatinine (II), and the urine values of total N, I and II, were determined in the dogs. In the frogs, residual blood N and urinary total N were determined. Blood gases (CO_2,O_2) were determined in the dogs and rabbits. In the dogs, elevation and lowering

95. (Cont'd)

of body T increased the concentration of N materials in the blood; the rate of their excretion decreased with elevation of T and increased with lowering of body T. No relationship was found in frogs between the residual N values in the blood and the body T, but the elimination of N paralleled changes of body T. During elevation of body T the O_2 saturation of blood and its elimination increased. In lowering of body T the CO_2 blood content and CO_2 elimination increased.

96. Zherebchenko, P.G.

Some characteristics of the central nervous system activity in warmblooded animals under conditions of general chilling. FIZIOL. ZHUR. USSR v. 2, n. 2, p. 21-24, 1956.

Dogs were chilled when wrapped in a rubber blanket equipped for water to flow through it. They were then subjected to stimulations by electric currents which irritated the central end of the left vagus nerve, transected at the level of the lower edge of the thyroid cartilage. The usual inhibitory effects of this nerve upon respiration were barely noticeable during the initial stages of chilling. When deeper cooled the inhibitory effect of the vagus impulses on the animals' respiration was not only restored, but was even stronger in many cases than before chilling. During the chilling period, the animals' extremities were observed to display movements which coincided with the respiratory rhythm, as well as with the undulating fluctuations of blood pressure. Their highest magnitude (40-50 mm) was attained at body temperatures of 25-30°C. As the animals were warmed, the respiratory movements of the extremities and the respiratory undulations of the blood pressure became much less pronounced. The author is of the opinion that these blood pressure changes are effects upon the radiation of respiratory impulses into the area of vasomotor centers.

PART II

METABOLISM

97. Boothby, W.M., Berkson, J. and Dunn, H.L.
Studies of the energy of metabolism of normal individuals: a standard for basal metabolism, with a nomogram for clinical application. AMERICAN JOURNAL OF PHYSIOLOGY v. 116, p. 468-484, 1936.

This study is based on the determination of the energy of metabolism, under standard conditions of 639 male and 828 female human subjects selected as normal individuals from a series of determinations made on more than 80,000 individuals.

98. Cannon, P. and Keatinge, W.R.
The metabolic rate and heat loss of fat and thin men in heat balance in cold and warm water. JOUR. PHYSIOL. v. 154, p. 329-344, 1960.

The metabolic rate of both fat and thin young men in heat balance in water rose when the bath temperature was lowered below 33° C., although the fat men did not achieve their maximal tissue insulation until the water temperature was much lower. The commonly used concept of "critical temperature" was therefore not valid in the case of the fat men and alternative terms are proposed. The metabolic rate rose less in fat than in thin men when the bath temperature was lowered below 33° C.; the stable rectal temperature of the thin men was lower in cold than in warm water, while that of the fattest men was not. It is concluded that the fat men's small metabolic response to cold was due to reflexes from the skin, while in the thin men these were reinforced by a fall in deep temperature and stimulation of deep temperature receptors. The fat men achieved a higher maximal tissue insulation than thin men and could stabilize their body temperature in water down to 10-12° C. In colder water heat loss from their fingers rose in a cyclical manner, their tissue insulation fell by about 50% and their rectal temperatures fell. Work accelerated the fall in rectal temperature of both fat and thin men in water just too cold for them to stabilize their rectal temperature when still.

99. Consolazio, C.F., et al

Energy requirements of men in extreme heat.

JOUR. NUTRITION v. 73, p. 126-134, 1961.

The effects of solar radiation and extreme heat on the energy requirements of eight healthy young men performing a constant daily activity were studied under the following conditions: (1) ten days in direct sunlight from 7 A.M. to 5 P.M., with temperatures averaging 40.5° C.; (2) ten days in the hot shade from 7 A.M. to 5 P.M., with temperatures averaging 40.3° C., and (3) ten days in an air-conditioned room at 26.0° C. The data suggest that there is an increased caloric requirement for men working and living in extreme heat. Significant increases were observed in food consumption and the actual caloric requirements were even greater because of changes in the body composition of the men. The differences in energy cost of the various resting and exercise activities, when comparing the hot-sun or hot-shade to the cool-shade phase were significant. Energy requirements averaged 55.5, 56.4, and 36.6 Cal. per kg. of body weight, respectively, for conditions (1), (2), and (3), when corrected for body composition changes. These increased requirements are probably due to the increased heat load imposed on the body by solar radiation and extreme heat. The increased requirements are, in all likelihood, a combination of increased-action of the blood in heat transport, increased action of the sweat glands, plus the increased total metabolic rate due to the elevation in body temperature.

100. DuBois, E.F.

BASAL METABOLISM IN HEALTH AND DISEASE.

Philadelphia. Lea and Febiger. 1936.

494p.

101. DuBois, E.F.

Mechanism of heat loss in health and disease. ASSOCIATION OF AMERICAN PHYSICIANS. TRANSACTIONS v. 51, p. 252-259, 1936.

102. Henneman, D.H., Bunker, J.P. and Brewster, W.R., Sr.
Immediate metabolic response to hypothermia in man. J. APPL. PHYSIOL. v. 12, p. 164-168, 1958.

103. Lewis, H.E., Masterson, J.P. and Rosenbaum, S.
Stability of basal metabolic rate on a polar expedition. J. APPL. PHYSIOL. v. 16, p. 397-400, 1961.

104. Rennie, D.W.
Energy metabolism in cold. In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE, MAR. 1957. New York, Josiah Macy, Jr., Foundation. p. 253-290, 1958.

105. Swift, R., et al
The effect of high versus low protein equicaloric diets on the heat production of human subjects. J. NUTRITION v. 65, p. 89-102, 1958.

Using the respiration calorimeter, the 24-hour metabolism of two pairs of male college students was measured at intervals during a period of 63 days throughout which time the daily intake of energy and protein remained constant. The two diets were equicaloric but differed markedly in protein. At the end of 63 days the assignment of the diets to the two pairs of subjects was reversed and the experiment continued for 38 days with further measurements of the 24-hour metabolism by direct and by indirect calorimetry. With one pair of subjects, the average daily heat production from the diet high in protein (128.6 gm per subject per day) was about 5.0% greater than that obtained from the equicaloric diet of low protein content (38.0 gm per subject per day). With the second pair of subjects, no difference in daily heat

105. (Cont'd)

productions was found. This finding emphasizes the insignificant dynamic effects of high protein diets in contrast to that of meals composed entirely of protein. Under the conditions of the experiment, it appears that a given diet is as correctly represented by the heat production measured at the end of a few days as when measured after several weeks. The percentage of the total heat which was eliminated by the evaporation of water was approximately 31% and was inappreciably affected by the composition of the diets.

106. Wilson, O.

Adoption of the basal metabolic rate of man to climate. A review. METABOLISM v. 5, p. 531-542, 1956.

107. Wilson, O.

Basal metabolic rate in the antarctic. METABOLISM v. 5, p. 543-554, 1956.

PART III

THERMAL PROPERTIES OF TISSUES.

108. Aschoff, J. and Wever, R.
Anesotropy of the skin for heat transfer.
PFLUEGER ARCH GES. PHYSIOL. v. 269,
p. 130-4, 1959. (In German)

109. Benjamin, F.B.
THE EFFECT OF SKIN TEXTURE ON THE HEATING
OF THE HUMAN SKIN BY THERMAL RADIATION.
Naval Air Development Center. Rept. No.
NADC-MA-5515, 1955.

110. Boehm, G.
Regarding the thermal conductivity anisotropy
in animal tissues. ACTA ANAT. v. 30, p. 95-127,
1957.

111. Bordier, H.
On comparative measurement of the thermal
conductivity of organic tissues. ARCHIVES
DE PHYSIOLOGIE, PARIS SER. 5 v. 10, p. 17-27,
1898.

112. Buettner, K.

Effects of extreme heat and cold on human skin. II. Surface temperature, pain, and heat conductivity in experiments with radiant heat. JOURNAL OF APPLIED PHYSIOLOGY v. 3, p. 703-713, 1951.

The surface temperature of human skin, irradiated with strong infrared radiant heat, was observed. The skin reaches its pain point within 2 to 60 seconds, depending on radiation intensity and on the initial skin temperature. Peripheral blood flow and wetness of the skin do not influence the temperature or the pre-pain time for higher radiation intensities. The pain threshold temperature and the depth of pain receivers in the skin are 44.8°C and 0.1 mm. respectively. From our data the heat conductivity of the upper skin can be derived. This conductivity does not depend on blood flow, except for acral parts, such as finger tips. Additional experiments concern heat burns and effects of extremely cold air on bare skin. Pre-cooling the skin seems to offer an effective protection against overheating.

113. Cooper, T., Randall, W.C. and Hertzman, A.B.

Vascular convection of heat from active muscle to overlying skin. JOUR. APPL. PHYSIOL. v. 14, p. 207-211, 1959.

Both thermocouple and radiometer measurements revealed marked elevations in temperature of skin immediately over actively working muscles of the forearm and leg. Such localized increases in the surface temperature were confined to skin overlying rhythmically contracting muscle. They were attributed to a direct vertical vascular convection of heat from the muscle to the overlying skin because they were prevented by blocking perfusion or by surgical severance of skin from underlying tissue and because of the character of the temperature gradient in the intervening tissue. The argument for a venous rather than an arterial convection was based on (a) the effects of compression of the superficial veins on the temperature changes, (b) the absence of effect on the latter by electrophoresis of adrenaline into the skin, which greatly reduced arterial perfusion of the skin, (c) the absence of evidence of arterial dilation in the skin and (d) the lack of relation of the location of arterial twigs to the topography of the temperature rise.

114. Hardy, J.D.

Cutaneous pain and tissue damage produced by thermal radiation. PROC. NATL. BIOPHYS. CONF. v. 1, p. 577-592, 1959.

A method of stimulating cutaneous pain and producing skin damage is described. When measured under controlled conditions, the pain threshold as determined by the thermal radiation method has been observed to be uniform in subjects differing in sex, age, race, and cultural background. The thermal pain threshold is reached when the skin temperature has been raised to $45 \pm 1.7^{\circ}C$. At this skin temperature, spinal reflexes in man and animals (nociception) are also elicited. It is pointed out that this temperature is also the threshold temperature for burning the skin. The close association of thermal pain and nociception to the rate of thermal inactivation of cutaneous cellular proteins is pointed out in terms of (a) coincidence of threshold temperature, and (b) the increase of pain intensity with skin temperature in proportion to the logarithm of the protein inactivation rate. An application of the theory relating nociception to the rate of tissue damage by heat is described in terms of inhibition of burn development by cold exposure.

115. Hardy, J.D.

SUMMARY REVIEW OF THE INFLUENCE OF THERMAL RADIATION ON HUMAN SKIN. Naval Air Development Center. Rept. no. NADC-MA-5415, 10 Nov 54, 49p. ASTIA AD-49 309.

Discusses the following aspects of thermal radiation effects: Introduction (spectral distribution of solar and low-temperature radiation); Optical characteristics of skin. (spectroscopic measurement of reflectance from the skin; spectral distribution of skin transmittance); Thermal characteristics of skin (density and thermal capacity of the living skin); Stimulating effects of thermal radiation (warm and cold sensation, threshold of warm sensation and pain); Heat loss by radiation (thermal radiation exchange between man and his environment in New York City and in the Arctic, tested with the aid of panradiometer).

116. Hardy, J.D.

Thresholds of pain and reflex contraction as related to noxious stimulation.

JOURNAL OF APPLIED PHYSIOLOGY v. 5, p. 725-39, 1953.

Using the thermal radiation method of simulation, the effect of duration of stimulus upon stimulus intensity has been studied for: (a) the pain threshold in man, (b) the flexor reflex threshold in man (c) the reflex threshold for contraction of the cutaneous maximus muscle of the guinea pig, and (d) the reflex threshold for the tail flick of the rat. The threshold stimulus measured in millicalories per second per square centimeter of thermal radiation is the same for pain sensation and for the reflexes studied. The duration of exposure to the thermal radiation affects the threshold stimulus for pain and the reflexes in an identical manner. As the skin temperature of roughly 45°C is critical both for thermal skin damage and for eliciting pain and reflex responses, it is inferred that the same process underlies them. This process, in the case of heat, is thought to involve thermal inactivation of tissue proteins, probably of the pain fiber endings. As pain and associated reflex reactions depend only upon temperature and not on the duration of exposure to an elevated temperature, it is suggested that the thermal noxious stimulation is characterized by the rate of certain reactions, probably involving protein inactivation, rather than upon the amount of tissue damage caused by the thermal stimulus. The threshold of pain and reflex responses to noxious stimulation by heating is determined by the lowest rate of inactivation of tissue proteins which will cause tissue damage if the thermal stimulation is sufficiently prolonged.

117. Hatfield, H.S., Strafford, H. and Pugh, L.G.C.

Thermal conductivity of human fat and muscle.

NATURE, LONDON v. 168, p. 918-919, 1951.

118. Hendler, E., Crosbie, R. and Hardy, J.D.

Measurement of heating of the skin during exposure to infrared radiation. J. APPL. PHYSIOL. v. 12, p. 177-185, 1958.

119. Lipkin, M. and Hardy, J.D.

Measurement of some thermal properties of human tissues. JOUR. APPLIED PHYSIOL. v. 7, p. 212-217, 1954.

With the use of a high-speed radiometer, measurements of the rapidly changing surface temperature of living human skin and excised human tissues have been made, when exposed to measured intensities of non-penetrating thermal radiation. From these data, the product of the thermal conductivity (k), the density (p), and the thermal capacity (c) was estimated for the tissues studied. This product, kpc, has the significance of an inertia, and was termed the "inertia for surface heating". Values of kpc were determined for living skin, excised human fat, skin, muscle, and bone. The value of kpc for the intact human skin increases several fold under slow heating. Evidence is presented which indicates that this increase in kpc is the result of local passive dilatation of peripheral vessels in the skin area being heated.

120. Randall, W.C., Peiss, C.N. and Hertzman, A.B.

STUDIES ON CUTANEOUS HEAT LOSSES. PART 14. AN ANALYSIS OF THE DESICCATING CAPSULE TECHNIQUE IN THE MEASUREMENT OF REGIONAL WATER LOSSES FROM THE SKIN. St. Louis U. School of Medicine. USAF Technical Rept. no. 6680, Part 14, Dec 53.

121. Stoll, A.M. and Greene, L.C.

Relationship between pain and tissue damage due to thermal radiation. JOURNAL OF APPLIED PHYSIOLOGY v. 14, p. 373-382, 1959.

Sites on the volar surfaces of the forearms of human subjects were blackened with India ink and exposed to thermal irradiances of from 50 to 400 mcal/cm^2 sec. The exposure time and skin temperature at which threshold pain occurred, and which produced minimal blistering within 24 hours, were noted. The thermal inertia (k c) of the skin was shown to vary directly with the level of irradiance. The receptors effective in mediating the pain sensation were

121. (Cont'd)

calculated to be at a depth of approximately 200 microns and to have a threshold of approximately 43.2°C. Tissue damage rates with respect to temperature were derived empirically so that damage integrated over the time for which skin temperature was elevated over the pain threshold was equated to unity. The substitution of the ratio of these rates with respect to temperature for the stimulus ratio, in the prediction of the observed discriminable steps in pain sensation intensity, yielded faithful reproduction of the just noticeable differences observed for pain through the range of this sensation.

PART IV

COMFORT CRITERIA

122. Billingham, J. and Kerslake, D.M.
SPECIFICATION FOR THERMAL COMFORT IN AIRCRAFT CABINS PROPOSED AS A BASIS FOR AN OFFICIAL SPECIFICATION. Flying Personnel Research Committee (Gt. Brit.) FPRC Memo. no. 133, June 60, 24p.

New specifications are proposed to replace thermally inadequate existing requirements for cabin conditioning and air-ventilated suit air-supply requirements in the newer types of high performance aircraft. Although further experiments are needed to verify the theory, the proposals are offered at this time because they are more precise in predicting the requirements for thermal comfort in aircraft. The existing specifications could render aircraft cabins dangerously hot if applied unmodified to some future high-performance military aircraft. Any modifications subsequent to experimental examination of the theory are expected to be small and should not affect the procedure for calculating conditioning requirements.

123. Fahnestock, M.K. and Werden, J.E.
Environment, comfort, health and people. REFRIGERATING ENGINEERING v. 64, n. 2, p. 43-49, 1956.

124. Grieve, J.I.
Thermal stress in a single storey factory. ERGONOMICS v. 3, p. 297-306, 1960.

125. Jassen, J.E.

THERMAL COMFORT IN SPACE VEHICLES.

ASME Paper 59-A-207 for meeting 29 Nov-

4 Dec 59. 8p.

Equations based on existing calorimetric data on human body heat loss separate thermal radiation and convective effects; new forced convection, heat loss term is derived to make Earthbound comfort equation valid for space vehicle cabin; results indicate that thermal radiation is considerably more important comfort variable in space ship than in Earthbound environment.

126. Jennings, B.H.

Research on human comfort and environment.

HEATING, PIPING AND AIR CONDITIONING v. 30,

n. 3, p. 111-114, 1958.

Research into human comfort in the air environment of the body has proceeded rapidly in recent years. The mechanism by which the body adjusts its heat output to achieve comfort is reasonably well established and is conveniently divided into zones. Various indexes of comfort are in existence. All are useful but limited in scope. The Effective Temperature Index established by society research appears to contain uncertainties and to cover a range which might well be extended. Consequently a research facility has been constructed in the Society Laboratory where studies have been started recently aimed at a reevaluation of the index and an extension of its range.

127. Koch, W., Jennings, B.H. and Humphreys, C.M.

Is humidity important in the temperature

comfort range? ASHRAE JOURNAL v. 2, n. 4,

p. 63-68, 1960.

This article covers results of the research program at the ASHRAE Laboratory to determine the thermal responses of subjects under various environmental conditions after extended occupancy of approximately three hours. The subjects wore normal summer clothing, and were at rest. Air motion in the test room was minimal, and room surfaces were maintained at approximately the dry-bulb temperature. Tests were conducted at dry-bulb temperatures from 68 to 94°F, with relative humidities from 20 to 90%. It is shown that the line of optimum comfort is a straight line on a dry- and wet-bulb temperature

127. (Cont'd)

plane and the effect of relative humidity change is small. Respective points on the optimum comfort line at 77.6°F dry bulb and 30% relative humidity and 76.5°F at 85% relative humidity show that the effect of relative humidity through this 55% range is only 1.1°F. It should be recognized that increased activity, and impressions felt immediately on entering the room would, of course, show deviations from this. Decrease in weight of winter clothing with the passage of time since the 1920 decade may account for the fact that in winter, at 50% relative humidity, a 4°F higher dry-bulb temperature is now desired for optimum comfort whereas there is little change in the summer comfort temperature at this humidity.

128. Kreider, M.B. and Buskirk, E.R.

Supplemental feeding and thermal comfort during sleep in the cold. J. APPL. PHYSIOL. v. 11, p. 339-343, 1951.

129. Winslow, C.E.A., Herrington, L.P. and Gagge, A.P.

Relations between atmospheric conditions, physiological reactions and sensations of pleasantness. AMERICAN JOURNAL OF HYGIENE v. 26, p. 103-114, 1937.

The results here reviewed indicate that expressions, on a five-point scale, of subjective sensations with regard to the pleasantness or unpleasantness of the atmospheric environment are sufficiently reliable to yield concordant and significant results. Such sensations are closely correlated with skin temperature and, in hot environments, are even more closely correlated with sweat secretion. For unclothed subjects at rest in a semi-reclining position, there is a middle zone where mean skin temperature is between 88° and 92° (with the warmer regions of the body perhaps 2° higher, and lower extremities perhaps 3° lower). Here, storage (cooling of the body) and "wetted area" (our measure of discharge of sweat) are both generally low and conditions are reported as pleasant. On the cold side, skin temperature falls, storage increases, and the sense of unpleasantness rises sharply, showing a correlation with skin temperature 2° of -.64X6 ±.09. Similarly, on the hot side, where skin temperature rises above 92°, and wetted area increases, the sense of unpleasantness also becomes marked - in spite of the fact that thermal balance is maintained by increased secretion of sweat. Here the sense of unpleasantness shows a correlation of +.50 ±.08 with skin temperature, and a correlation of +.65 ±.06 with wetted area.

PART V

THERMAL INDICES AND UNITS

130. Bedford, T.
ENVIRONMENTAL WARMTH AND ITS MEASUREMENT.
Great Britain. Medical Research Council.
War Memorandum no. 17, 1946, 40p.

131. Belding, H.S. and Hatch, T.F.
Index for evaluating heat stress in terms of resulting physiological strain. HEATING, PIPING AND AIR CONDITIONING v. 27, n. 8, p. 129-136, 1955.

System for assigning index values of human endurance, based on reactions of "standard man" under various indoor or outdoor conditions of heat and strain.

132. Brown, J.R., Crowden, G.P. and Taylor, P.F.
Circulatory responses to change from recumbent to erect posture as an index of heat stress. ERGONOMICS v. 2, p. 262 - 273, 1959.

Experiments are described in which Crampton Index values, derived from measurements of blood pressure and pulse rate following postural change, were related to conditions of environmental heat and to the thermal sensations of resting and working men. Experimental evidence is presented which indicates that changes in the Crampton Index may be of value in defining individual reactions to increasing environmental heat.

133. Bruner, H. and Klein, K.E.
EFFECTS OF HIGH-TEMPERATURES AND ACCLIMATIZATION ON THE EFFICIENCY OF PILOTS. (Deutsche Versuchsanstalt für Luftfahrt) Rept. no. 125, p. 21-31, June 60. (In English and German)

A method is proposed for the evaluation of environmental heat stress by reference to a physical index of effective temperature (heat, humidity, and air speed) in combination with a physiologic stress index of pulse rate and body temperature. A rectal temperature of 38.3° C. and a pulse rate of 115/minute have been found to be the "characteristic value" for the physiologic tolerance limit to heat. Studies of the predictive value of the indices under various environmental conditions have shown that heat tolerance is dependent on the interrelation of rectal temperature and pulse rate, and that acclimatization to heat increases tolerance by 5-6° C. air temperature.

134. Burton, A.C. and Bazett, H.C.
A study of the average temperature of the tissues and of the exchanges of heat transfer and vasomotor responses in man by means of a bath calorimeter. AM. J. PHYSIOL. v. 117, p. 36-54, 1936.

135. Gagge, A.P., Burton, A.C. and Bazett, H.C.
A practical system of units for the description of the heat exchange of man with his environment. SCIENCE v. 94, p. 428-430, 1941.

136. Gold, J.

A NEW THEORETICAL HEAT STRESS INDEX.

Presented at, 44th. Annual Meeting of Federation of American Societies for Esperimental Biology, Chicago, Illinois, 11-15 Apr 60.

A new index, based on heart rate alone, has been devised for the evaluation of physiological strain incurred as a result of heat stress. The index takes into account (a) the beginning and ending heart rates, (b) the same increase in heart rate at different beginning heart rates, and (c) the fact that increase in heart rate cannot exceed a definite value without ensuring physiological deterioration. Results were correlated with body heat storage (q_s) in a series of seventy-five experiments with a resulting overall correlation coefficient of 0.88. Because of this, from heart rate alone it was possible to predict the body heat storage (q_s'), so that the established definitive index was the ratio of predicted over actually measured, body heat storage (q_s'/q_s). Corroborative results were obtained in the Mercury Astronaut Selection Program.

137. Gold, J.

A unified system for evaluation and selection of heat stress candidates. JOUR. APPLIED PHYSIOL. v. 16, p. 144-152, 1961.

A system for the evaluation and selection of heat stress candidates has been developed that is concerned not only with the extent to which an individual is capable of dissipating heat, but also the price he must pay for so doing. The former is dealt with through the concept of effective body heat storage (q_e); the latter, through a newly developed index of strain (I_G). Effective body heat storage is defined as that amount of storage obtained if a subject were able to go into a heat chamber already fully equilibrated with it and with all heat-dissipating mechanisms fully operating. The index attempts to express a new concept, accumulative circulatory strain, in terms of heart rate alone. The best subjects (usually in the young age groups) show a low q_e and low I_G; the worst (usually in the older age groups) show a high q_e and low I_G. All subjects were maintained at rest during heat exposure.

138. Hall, J.F. and Polte, J.W.

Physiological index of strain and body heat storage in hyperthermia. JOUR. APPLIED PHYSIOL. v. 15, p. 1027-1030, 1960.

The inter- and intra-individual variability of a modified Craig index of physiological strain, and the relation between the index and body heat storage over an extensive thermal exposure range (38^{o}-71^{o} C.) were determined in male subjects wearing one clo of body insulation. Measurements were made of heart rate, sweat rate, rate of rectal temperature change, and initial and terminal skin temperatures. Individual variation from the main index of strain was found to be considerable and apparently random at each thermal stress level. Data for body heat storage showed a progressive increase in standard deviation as the intensity of the thermal stress was increased. A statistically significant correlation between strain index and body heat storage was observed.

139. Hirsch, F.G.

Temperature measuring techniques for aviation physiological research. AVIATION MED. SELECTED REVS. AGARD. v. 25, p. 113-124, 1958.

Remarks relevant to the relationship between man and his temperature environment are presented as background information illustrating the utilization which has been made of temperature measuring techniques in aviation biology; i.e. monitoring the environmental temperature exchange as a function of time, the accompanying biological heat storage and loss as a function of time, the design of personal equipment and clothing to protect men against high and low temperatures and the importance of understanding the general principles utilized in thermal sensing instruments. Thermocouples, resistance thermometers, including the relatively new thermistors, calorimetry, telemetering and miscellaneous techniques (temperature tapes and temperature sensitive paints), are briefly discussed.

140. Lind, A.R. and Hellon, R.F.

Assessment of physiological severity of hot climates. J. APPL. PHYSIOL. v. 11, p. 35-40, 1957.

141. Minard, D., Kingston, J.R. and Van Liew, H.D.

HEAT STRESS IN WORKING SPACES OF AN AIRCRAFT CARRIER. Naval Medical Research Inst. Rept. no.3, 12p. ASTIA AD-252 503.

A survey was conducted in which a medical team would measure physiological effects of heat in men standing watch in machinery spaces at the same time that an engineering team evaluated the thermal environment. The experimental protocol was modified to include heat stress measurements on laundry room workers. The physiological findings of the medical team are correlated with the engineering measurements of environmental heat.

142. Smith, F.E.

EFFECTIVE TEMPERATURE AS AN INDEX OF PHYSIOLOGICAL STRESS. Med. Res. Council, Great Britain. R.N.P. 52/728, H.S. 371, Dec 52, 24p.

Conclusions: 1 The rate at which a man sweats in a hot environment can be predicted from effective temperature provided that the rate at which he is working is known. The rate of sweating can be predicted rather more accurately from the P.4.S.R. scale of warmth than from the effective temperature scale. The possible error in predicting individual sweat rate is substantial in each instance. 2. Certain anomalies exist in the effective temperature scale and if these can be eliminated by suitable adjustment the accuracy of predicting sweat rate should be much improved. More data will be necessary before the effective temperature scale can be so adjusted. 3. The rate at which a man works can be taken into account in the effective temperature scale by the addition of a simple supplementary nomogram or by the use of a series of graphs.

143. Snellen, J.W.

Some observations on the usefulness of the method of Hatch and Haines in computing the thermal balance in industrial work. ACTA PHYSIOL et PHARMACOL. NEERLAND v. 5, p. 169-174, 1956.

144. Stoll, A.M.

THE MEASUREMENT OF BIOCLIMATOLOGICAL HEAT EXCHANGE. Naval Air Development Center. Rept. no. NADC-MA-6108, 19 Apr 61, 24p. ASTIA AD-259 074.

Investigation was undertaken to measure heat exchange between man and his environment. The radiant temperatures of both man and his surroundings and of any incident solar radiation were observed. The most recent instruments developed specifically to meet these needs are the wide range Thermistor Radiometer and the Panradiometer. The Thermistor Radiometer measures a wide range of environmental radiant temperature in extremes of normal occurring ambient temperature as well as skin temperature. The instrument is capable of an accuracy of + or - 0.05°C and has been used in ambients of -50°C to +30°C for the measurement of radiant temperatures within + or - 135°C of the ambient. The Panradiometer is constructed to measure the net heat exchange between man and his environment together with a description of the environment in terms of solar radiation, average radiant temperature of the surroundings in sun and in shade, and wind temperature and velocity, all in absolute physical units suitable for computations of the heat load on the individual. The design of this instrument is advantageous in that about 99% of the solar radiation lies at wavelengths less than 3 microns and about the same proportion of the radiation from man to his surroundings at wave-lengths longer than 4 microns.

145. Teichner, W.H.

Assessment of mean body surface temperature. J. APPL. PHYSIOL. v. 12, p. 169-176, 1958.

146. Yaglou, C.P.

A method for improving the effective temperature index. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 53, p. 307-326, 1947.

Effective temperature is shown to overestimate greatly the influence of humidity in the range of temperatures met with in comfort heating and cooling. The disability is attributed to adsorption and adaptation phenomena, which had been overlooked in the development of this index. A rational method is proposed for correcting the index on the basis of mean skin temperature, which is now known to be the best objective index of comfort.

PART VI

COMPENSABLE ZONE-HIGH TEMPERATURE

147. Adolph, E.F., et al

PHYSIOLOGY OF MAN IN THE DESERT.

New York, Interscience, 1947, 357p.

This book outlines the problem of keeping cool which man faces in the desert. Man keeps cool chiefly by evaporating sweat which is mostly water. The water needs of man in the desert and measures by which man may economize his body's use of water are presented. Finally what happens to a man without water is described.

148. Archibald, E.R., et al

CHIMPANZEE TEMPERATURE-HUMIDITY TOLERANCE

TEST NO. 1. USAF, Missile Devel. Center,

Holloman AFB, TN 60-11, July 60, 37p.

Discussion of the effects of a temperature humidity test on a restrained chimpanzee in an environmental test chamber. Duration of the test is eight hours. The subject is exposed to an environment of 85°F. and 80% relative humidity for this period. Pulse rate, respiration rate, electrocardiogram, rectal temperature, galvanic skin resistance (basal), environmental oxygen depletion, and carbon dioxide accumulation are monitored continuously during the test. Instrumentation procedures, general test techniques, and experimental design are described.

149. Bartlett, R.G., Jr., et al

Core to surface thermal gradients in the

rat at several environmental temperatures.

AMER. J. PHYSIOL. v. 193, p. 541-546, 1958.

150. Bartlett, D.J. and Gronow, D.G.C.

THE EFFECTS OF HEAT STRESS ON MENTAL PERFORMANCE. Flying Personnel Research Committee, (Gt. Brit.). Report no. FPRC 846, Aug 53, 16p. ASTIA AD-30 748.

The possible effects of different kinds of heat stress upon anticipatory perception and judgment were investigated. Several displays given to subjects represented aircraft which were to be perceived as moving, according to assigned rules, from square on a card. In some instances these moves would result in aircraft collision. Subjects were required to decide (1) how many, if any, such collisions would occur on any given card; (2) which aircraft would be effected; and (3) where the collision would occur. The climatic conditions experienced were room temperature (60°- 70°F.), 80°/70° F. dry/wet bulb, 90°/80° F. dry/wet bulb, and 100°/90° F. dry/wet bulb. Each of 24 subjects was exposed to the hot conditions for ½ hour before testing and during the ½-hour tests. Results indicated that while performance was significantly affected by increase in the number of aircraft presented and by the card display size, no important effect was caused by heat level or the assigned rate of extent of movement of aircraft.

151. Boguszewska, M., et al

Investigation of certain phenomena relating to loss of heat during physical exercise performed by soldiers. (In Polish) POSTEPY HIG. I MED. DOSWIADCZALNEJ v. 13, p. 787-803, 1959.

Using soldiers to operate a bicycle-ergometer, the authors investigated the relationship of quantity of work to ambient temperature and to the temperature of various parts of the body, both exposed and covered. Within limits the quantity of work increases as ambient temperature decreases and skin temperature increases with amount of work done. The increase in amount of work done was greater for soldiers clothed in cotton overalls than for those in suit-type uniforms (60% wool). The latter clearly is superior from the point of view of maintaining body temperature in the field.

152. Brebner, D.F., Kerslake, D.M. and Waddell, J.L.

The relation between the coefficients for heat exchange by convection and by evaporation in man. JOUR. PHYSIOL. v. 141, p. 164-168, 1958.

Determinations of the coefficients for heat exchange by evaporation and by convection and radiation were made at 4 air speeds on 2 human subjects at rest. It is concluded that over the physiological range of vapor pressures and for air temperatures between 35-48°C, the evaporation coefficient may be taken as twice the convection coefficient, when mm Hg and °C, respectively, are used to define the gradients.

153. Carter, E.T.

Heat protection for space crews. SPACE AERONAUTICS v. 32, n. 1, p. 61-64, 1959.

The basic theory of human heat balance, and the effects of blood circulation and evaporative, radiant, convective, and conductive cooling, as they influence design problems of manned space flight, are discussed. Human performance limits as set by hyperthermia and skin temperature limits are graphically illustrated.

154. Chiles, W.D.

Effects of elevated temperatures on performance of a complex mental task. ERGONOMICS v. 2, p. 89-96, 1958.

It was attempted to determine heat tolerance limits of human subjects, to ensure adequate performance by crew members of an aircraft operating at supersonic speeds or in space vehicles during re-entry. Eleven subjects were tested on a complex mental task during one-hour exposures to four different dry bulb/wet bulb temperature conditions: 85°/75°, 90°/80°, 95°/85°, and 100°/90° F. In a second experiment, ten subjects were tested at 85°/75°, 90°/80°, 110°/90°, and 120°/90° F. In both experiments, differences in performance at the various temperatures were small and not significant. However, the results obtained in the second experiment at 120°/105° F. suggest that this may be near the upper temperature limit for adequate performance by an unprotected subject.

155. Dutkiewicz, J.S., et al
The changes of the body-weight, temperature, blood circulation and respiration in persons resting in dry heat. (In Polish) BULL. ACAD. POLONAISE SCI. CL. II v. 4, p. 29-33, 1956.

156. Dutkiewicz, J.S., et al
Further studies on the changes induced in human organism by dry heat. (In Polish) BULL. ACAD. POLONAISE SCI. CL. II. v. 4, p. 89-93, 1956.

157. Eichna, L., et al
The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments. JOURNAL OF INDUSTRIAL HYGIENE AND TOXICOLOGY v. 27, n. 3, p. 59-84, 1945.

Results of an investigation to determine the effects of excessive heat on men working under controlled conditions of environment and work in a laboratory hot room. Specifically the study was concerned with (1) the upper limits of environmental heat and humidity in which men can still work effectively and efficiently, (2) the role and relative importance of the several components of the environment in determining the ability of men to work in excessively hot surroundings and (3) the relationship between the physiologic responses of man and the physical characteristics of his environment. Only environments at, or close to, the upper environmental limits are here considered.

158. Eichna, L.W., et al

Performance in relation to environmental temperature- reactions of normal young men to hot, humid (simulated jungle) environment. JOHNS HOPKINS HOSPITAL. BULLETIN v. 76, p. 25-58, 1945.

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. The acclimatized man works with a lower heart rate, lower skin and rectal temperature, more stable block pressure and less discomfort than when unacclimatized. 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. Resting in humid heat induces but little acclimatization. Physically fit men acclimatize more rapidly than unfit men and when acclimatized are capable of more efficient work. Acclimatization develops most rapidly when the original environment is warm (summer) and is retained longest when the return is into a warm climate. 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. There is a measure of cross acclimatization, between hot-dry and hot-humid environments. The performance of acclimatized men in humid heat is impaired most seriously by lack of adequate water intake and lack of physical fitness. 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. Sweating in humid heat is profuse, grossly inefficient, wastes water and salt and is independent of the fluid intake. Replacement of the lost water and salt is essential to efficient performance, Thirst is a lagging guide to these needs.

159. Ferguson, I.D., et al

FACTORS IN, VARIABILITY IN AND PREDICTION OF REGIONAL SWEATING RATES OF HUMANS. St. Louis U. School of Medicine. WADC Tech. Rept. 56-312, Dec 56, 37p. ASTIA AD-118 055.

Two factors affecting regional sweating rates were isolated. These factors vary in their amount of contribution to sweating rates of different regions on the body surface, and also in their amount of contribution to sweating

159. (Cont'd)

rates of different individuals. Factors affecting magnitudes of sweating are probably not the same as those affecting variability. Individualistic patterns of sweating may be clearly identificable only on the forehead, abdomen and lower extremity. Prediction of regional sweating rates from two regions to others on the body surface is both possible and practical, through the use of weighted magnitudes of regional sweating rates, the weightings being conditions would be required, either to represent adequately one individual's normal regional sweating variations on different days, or to represent adequately normal regional sweating variations among individuals. The reported results, especially in regard to factors affecting regional sweating rates and a practical method of predicting regional sweating rates, may have important applications in the optimal design and use of ventilated clothing.

160. Ferres, H.M.

The effect of pressure on sweating. J. PHYSIOL. v. 151, n. 3, p. 591-597, 1960.

161. Frankel, H.M.

Tolerance to high temperature in small mammals. Ph.D. Thesis, State University of Iowa. 1958, 128p.

162. Gold, J.

Caloric neutralization during thermal stress. AEROSPACE MEDICINE v. 31, p. 933-940, 1960.

Investigation of the possibility of neutralizing some of the calories absorbed during thermal stress by the administration of cold fluids to the subject. The benefit of the method is that the body must expend 37 kcal. on a liter of ice water and that it provides additional fluid that can be used for sweating.

163. Hasan, J., Laamanen, A. and Niemi, M.

Effect of thermal stress and muscular exercise, with and without insulin hypoglycaemia, on the body temperature, perspiration rate, and electrolyte and lactate content of sweat. ACTA PHYSIOLOGICA SCANDINAVICA v. 31, p. 131-136, 1954. (In English)

The effects of thermal stress (Finnish Sauna bath) and muscular exercise (on treadmill) on the rise in body temperature, on the sweating rate, and on the electrolyte and lactate content of sweat were studied. In one half of the experiments, hypoglycemia was induced by intravenous injections of insulin. There were no significant differences in the rate of sweating and in the composition of sweat during insulin hypoglycemia and during euglycemia. There was some tendency to increased values with decreased blood sugar concentrations in the lactate content of sweat. The rise in body temperature under insulin hypoglycemia was significantly lower than in experiments without insulin injection. The reason for this observation is briefly discussed.

164. Hertig, B.A.

EFFECTS OF IMMERSION IN WATER ON THERMAL SWEATING. University of Pittsburgh, 1960. (Thesis)

Studies on human volunteers immersed to the neck have revealed that sweating in a bath is influenced by time of immersion as well as by level of thermal stress. When stress was maintained at a constant level, sweating declined markedly from the peak rate reached in the first hour of exposure. Numerous three- and four-hour exposures showed that this characteristic time-course of response occurred irrespective of state of acclimatizati n, level of bath temperature, activity, or changes in body temperature. When sweat rate was plotted as a function of time on semi-logarithmic coordinates the data suggested a two component system: thermal stimulation of sweat according to the function: $S = C(1-e^{-kt})$ upon which was superimposed the decline, $S = S_o e^{-kt}$. The time constant k was an order of magnitude larger than k'. Presoaking in thermally neutral water proved that the decline was independent of prior activity of the sweat glands; i.e., the rate of sweating was suppressed equally at a given point in time of the exposure whether the first hours of

164. (Cont'd)

the exposure were in thermally neutral water (sweat glands inactive) or in hot water (sweat glands active). These findings are inconsistent with the concept of "sweat gland fatigue" in which decline of sweating is attributed to inability of the glands to maintain a high secretory rate over a prolonged period. Addition of salt to the bath water in increasing amount decreased the extent to which sweating declined. When the concentration was 15 per cent NaCl (by weight) sweating did not decline at all. Inasmuch as this concentration has been shown by others to prevent inward diffusion of water, several mechanisms by which water absorption could affect sweating were considered. The data indicated that a total of about 30 to 50 grams were absorbed by the corneum and all in the first half hour of exposure. Calculations utilizing published values for the diffusivity of human skin showed the inward diffusion to the deep skin to be on the order of 10 to 15 b/hr. Mechanical occlusion of the sweat duct by swelling of the horny layer did not appear to offer an acceptable explanation for the decline of sweating. The time-course of absorption by the corneum did not agree with the time-course of decline. Further, no miliaria was observed, contraindicating retention of sweat. Considering (1) that glandular fatigue, changes in body temperature and mechanical suppression failed satisfactorily to account for the observed decline, and (2) that decline was apparently associated with pressure for diffusion, it was concluded that the small amounts of water diffused into the deep skin progressively altered the thermal or biochemical properties of the tissues, reducing or inhibiting stimulation of the sweat glands. The results of this study offer an attractive explanation for the observation by several authors that sweating declines more in hot-humid than in hot-dry environments. In the former, excess sweat provides ample opportunity for soaking of the skin. It is suggested that the extra decline in hot-humid air environments may be better ascribed to skin wetness than to glandular fatigue.

165. Hertzman, A.B.

Individual differences in regional sweating.

J. APPL. PHYSIOL. v. 10, p. 242-248, 1957.

166. Hertzman, A.B., et al

STUDIES ON CUTANEOUS HEAT LOSSES. PART 2.

THE REGIONAL RATES OF EVAPORATION FROM THE

SKIN AT VARIOUS ENVIRONMENTAL TEMPERATURES.

St. Louis U. School of Medicine. USAF Tech.

Rept. 6680, Part 2, Nov 51, 12p. ASTIA AD-149 311.

The rates of evaporation of water from the skin of the face, hand, foot, arm, leg and trunk were separately measured by the desiccating capsule technique,

166. (Cont'd)

in resting nude subjects who were exposed to environmental temperatures in the range of 24° to 38°C. At temperatures below the sweating thesholds, insensible perspiration proceeded at a fairly uniform rate (6-10 gm/M^2/hr) from the skin of the arm, leg and trunk. Palmar, plantar, and facial rates were higher (up to 110 gm/M^2/hr. for the palm). The onset of sweating occurred in the various skin regions at different environmental temperature, thus implying a recruitment of sweating which ascended from the distal portion of the extremities to the higher levels of the body as the evaporative demands increased. The possible mechanisms of this phenomenon are discussed. The regional fractions of the total cutaneous evaporation demonstrated domination of evaporative regulation by the legs at temperatures lightly above the sweating thresholds. At temperatures above 34°C., increases in sweating were linear with the rise in temperature and about equal over the body surface. The continued domination of evaporative heat losses by the leg and trunk resulted from the mass effect of their extensive surfaces.

167. Hertzman, A.B., et al

STUDIES ON CUTANEOUS HEAT LOSSES. PART 4.

THE REGIONAL RATES OF CUTANEOUS HEAT LOSS

IN THE ENVIRONMENTAL TEMPERATURE RANGE:

24° - 38°. St. Louis School of Medicine.

USAF Tech. Rept. 6680, Part 4, Dec 51, 13p.

ASTIA ATI-164 232.

The regional rates of heat loss were determined on nude resting subects by a method of partitional calorimetry which was described in a previous AF technical report. The subjects were exposed for three to four hours to environmental temperatures of 24° to 38° C. The following areas were observed; forehead, cheek, arm, forearm, chest, abdomen, thigh, calf, palm and sole. The total cutaneous heat loss as calculated from the weighted regional rates decreased slightly as air temperatures rose from 24° to 32°C. The minimum rate occurred at 32°C. The regional fractions of the total cutaneous heat loss were approximately constant in all skin areas, excepting the palm and sole, in this same temperature range. At air temperatures above 30° to 32°C, the rates of heat loss from the palm, sole, arm, and forearm decreased with rising temperature, while that of the calf increased. These regional differences were related directly to the sudomotor patterns since the decrements in radiation and convection were equal in all skin areas as air temperatures rose above 30°C. In the zone of vasomotor regulation (below 28°C), the changes in radiation and convection were most marked in the palm and sole and fairly uniform in the other skin areas. The relatively large changes in the rates of heat loss from the palm and sole in the temperature range of these experiments, amounting to 100% or more, were nevertheless of minor

167. (Cont'd)

significance in the total thermal economy. In contrast, the relatively stabilized rates of heat loss from the trunk, head and thigh dominated the total cutaneous heat loss and maintained the later relatively constant. Therefore, conclusions concerning the operation of the mechanisms of temperature regulation cannot be drawn safely from observations made on the hands and feet.

168. Hertzman, A.B., et al

STUDIES ON CUTANEOUS HEAT LOSSES. PART 6. THE CUTANEOUS VASCULAR RESPONSES TO RISING ENVIRONMENTAL TEMPERATURE. St. Louis U. School of Medicine. USAF Tech. Rept. 6680, Part 6, Dec 51, 29p. ASTIA ATI-163 920.

The vascular mechanisms available for the convection of heat to the skin surface are reviewed. Anatomical data indicate that this convection of heat could occur via both arterial and venous pathways. The thermal data available at the present time do not permit the separate quantitation of total vascular convection, arterial convection and venous convection of heat, although arterial perfusion of the skin may be estimated.

169. Hertzman, A.B. and Randall, W.C.

STUDIES ON CUTANEOUS HEAT LOSSES. PART 8. SHIFTING PATTERNS OF EVAPORATION FROM THE SKIN SURFACE DURING EXPOSURE TO VARIOUS THERMAL STRESSES. St. Louis U. School of Medicine. USAF Tech. Rept. 6680, Part 8, Feb 52, 9p. ASTIA ATI-164 221.

Long and short cycles in sweating and in evaporation from the various skin areas were studied by continuous and simultaneous observation of the individual areas by the desiccating capsule an d starch-paper-iodine techniques. An ascending successive recruitment of sweating on the chest, arm and face may be parelleled by decreasing sweating on the lower extremity. This phenomenon suggests (in some subjects), a transfer of the evaporative load to the upper parts of the body as the thermal stress mounts. Brief cycles (2-3 minutes) of sweating may be superimposed on longer cycles (10 minutes or longer). Both the longer and the shorter cycles may appear synchronously or asynchronously

169. (Cont'd)

in the various skin areas. The tendency towards synchronicity is most marked in closely adjacent skin areas (some sympathetic dermatomes?).

170. Hertzman, A.B., Randall, W.C. and Peiss, C.N.

STUDIES ON CUTANEOUS HEAT LOSSES. PART II.

THE EFFECT OF AMBIENT TEMPERATURE AND AIR

HUMIDITY ON THE REGIONAL RATES OF SWEATING.

St. Louis U. School of Medicine. USAF Tech.

Rept. 6680, Part 11, Jan 53, 69p. ASTIA AD-12 719.

The regional sweating responses of resting nude young males were recorded by the desiccating capsule and iodine-starch paper techniques when the subjects were exposed to the following environmental conditions: (a) a rising ambient temperature, initially about 26°-33°C, increasing at a rate of about 0.1°C per minute to about 41°C, with humidity rising also to either "high" or "moderate" levels; (b) a relatively constant ambient temperature, about 39° to 42°C, with humidity either "high" or "low". Sweating was recorded continuously from as many as twenty different areas of the body surface during experimental periods of two to three hours. The total sweat output of the subject was estimated from weighting of the regional sweat rates and from weight losses. These two estimates agreed well at high rates.

171. Hertzman, A.B., et al

STUDIES ON CUTANEOUS HEAT LOSSES. PART 12.

FACTORS INFLUENCING THE SIGNIFICANCE OF

LOCAL SWEATING RESPONSES. St. Louis U.

School of Medicine. USAF Tech. Rept. 6680,

Part 12, Dec 53, 20p. ASTIA AD-27 729.

The dessicating capsule and sweat print techniques of measuring local sweating responses were used separately and together in the study of cycling in sweat gland activity and together in the measurement of the mean rate of secretion per individual gland.

172. Hertzman, A.B., et al
STUDIES ON CUTANEOUS HEAT LOSSES. PART 13. CUTANEOUS THERMOSENSORY RECRUITMENT OF SWEATING. St. Louis U. School of Medicine. USAF Tech. Rept. 6680, Part 13, Dec 53.

173. Hertzman, A.B.
STUDIES ON CUTANEOUS HEAT LOSSES. PART 15. THE INDIVIDUALISTIC CHARACTER OF THE RELATION OF REGIONAL SWEATING RATES TO TOTAL WEIGHT LOSS IN NORMAL SUBJECTS. USAF Tech. Rept. 6680, Part 15, Dec 43, 32p. ASTIA AD-63 266.

That each individual exhibits a topographical sweating pattern which is consistently characteristic of that individual and which differs from that of another person, was demonstrated in an intensive study on five young normal male adults. Total sweating rates and those on twenty different loci on the chest, abdomen, thigh, calf and dorsum of the foot were measured after the subjects had come into approximate thermal equilibrium with various chamber climates in the range of 35° to 48°C.

174. Houghten, F.C.
Heat and moisture losses from the human body and their relation to air conditioning problems. AMER. SOC. HEAT. VENT. ENGINEERS TRANS. v. 35, p. 245-268, 1929.

175. Houghten, F.C.
Thermal exchanges between the human body and its atmospheric environment.

175. (Cont'd)

AMERICAN JOURNAL OF PHYSIOLOGY

v. 88, p. 386-406, 1929.

A series of 267 tests were made on seven normal male subjects at effective temperatures of from 6.7 to 37.8°C., humidities of 20, 45, 70 and 95% and in still air and air velocities of 1.19 and 1.96 meters per second (235 and 385 ft. per minute.) The subjects had previously partaken of their regular diet, were normally clothed and seated a great part of the time, but were not restrained from normal movements of limbs and body. A minimum of 53.4 calories per square meter per hour was found for the temperature range 19.3 to 28.7°C, a value in close agreement with results of other investigators for men under like conditions of activity and diet. For higher and lower temperatures there is an increase in the metabolic rate. The human body maintains temperature equilibrium in atmospheres of varying temperature and humidity by controlling heat production at low atmospheric temperatures and by controlling evaporation by control of available perspiration at high temperatures.

176. Houghten, F.C., <u>et al</u>

Heat and moisture losses from men at work

and application to air conditioning problems.

AMER. SOC. HEAT. VENT. ENGINEERS. TRANS.

v. 37, p. 541-570, 1931.

This report contains data in the form of curves giving the rate of total heat loss, heat loss by radiation and convection and heat loss by evaporation for men working at three constant rates in still air at various temperatures and two humidities. Corresponding curves for these losses with subjects seated at rest are also given. A table showing the metabolic rate for different kinds of activity is given and the application to practical problems is shown. Total energy production, energy loss and heat loss are shown to be functions of effective temperature. Sensible and latent heat loss are shown to be functions of dry-bulb temperature and only slightly affected by relative humidity except at extreme temperatures. Sensible heat loss for men working increases but little over this loss for men at rest. Latent heat loss increases rapidly with physical activity and is depended upon almost solely by the body for maintaining a constant body temperature with varying rates of heat production. The comfort zone for men normally clothed and working at 33,075 ft-lb per hour is given as 46 to 64°F effective temperature and the comfort line as 53°. The degree of perspiration experienced by men working at 33,075 ft-lb per hour is given for various temperatures and humidities.

177. Houghton, F.C., et al

Thermal exchanges between the bodies of men working and the atmospheric environment. AMERICAN JOURNAL OF HYGIENE. v. 13, p. 415-431, 1931.

A series of work tests were made on four normal male subjects at effective temperatures of -2.0 to 32.6°C and relative humidities of 20 and 95%. All the subjects were normally clothed and had previously partaken of their regular diet. The work was performed on a special work machine and in the majority of the tests the rate was 4578 kgm. per hour. However, a few tests were made at half, and a few at double this rate. A special test is reported showing the increase in metabolic rates for different states of activity. The efficiency of the human body as an engine is shown to vary from 11 to 20% in performing this type of work. Metabolic processes as measured by gaseous exchange reach equilibrium very quickly after changes in state of activity.

178. Humphreys, C.M., Imalis, O. and Gutberlet, C.

Physiological response of subjects exposed to high effective temperatures and elevated mean radiant temperatures. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 52, p. 153-166, 1946.

Within the range of conditions considered in this study, all variables in a man's environment which affect his physiological reactions may be expressed in terms of Effective Temperature and Mean Radiant Temperature elevation. When physiological reactions are plotted against effective temperature, the results are practically the same for various values of relative humidity. The effect of an increase in MRT elevation on physiological reactions is dependent upon the values of ET and MRT elevation. The effect of radiant heat on physiological reactions decreases as the Effective Temperature increases and becomes surprisingly small as the upper limits of endurability are reached. By repeated exposure to hot environments for periods of 4 hours or less each day, a person can acquire a considerable degree of adclimitization. The acclimitization process may require a period of two weeks or longer.

179. Inouye, T., et al

A comparison of physiological adjustments of clothed women and men to sudden changes in environment. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 59, p. 35-48, 1953.

Women adjust as readily as do men to sudden entrance into a hot humid environment. Their skin temperatures rise promptly, even faster than is observed for men. Sweat is slower to appear than in the case of the men. As women leave a hot humid room and enter one which is normally comfortable, they feel cool, stop sweating promptly, and rapidly adjust their skin temperatures much as do men. This adjustment is controlled by: (1) sweat accumulated in their clothing and available for evaporative heat loss; (2) relative humidity; and (3) clothing.

180. Inouye, T., et al

Effect of relative humidity on heat loss of men exposed to environments of 80, 76 and 72°F. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 59, p. 329-346, 1953.

Non-fasting men, lightly clad in union suits, showed greater heat loss by evaporation in environments maintained at 80, 76, or 72°F with a 30% than with an 80% relative humidity. The effects attributed to relative humidity appeared more readily at the higher environmental temperatures. These men reported that the environments maintained at 76 or 72°F with a 30% relative humidity felt thermally the same as one with an 80% relative humidity. At the time of entrance into the environment having similar temperatures, they felt warmer in one with an 80% than in one with the 30% relative humidity. When the limits of thermal comfort were set between the sensations of very slightly warm and very slightly cool, the resting, lightly clad men were thermally comfortable for a period of 3 hours in environments having temperatures 76 to 72°F and with 30 to 80% relative humidity. The men and women generally showed similar adjustments to environments maintained at 80 or 76°F. When exposed to environments with temperatures of 72°F, the women showed adjustments which were most plausibly explained by their higher body fat.

181. Kerslake, D.M. and Waddell, J.L.

The heat exchanges of wet skin. JOUR.

PHYSIOL. v. 141, p. 156-163, 1958.

The skin temperature was measured in resting men under conditions where the skin was completely wet with sweat. Analysis of the data was limited because the steady state was not reached. The equations of Machle and Hatch (Physiol. Rev. 27:200-227, 1947.), with certain modifications, were found to provide a satisfactory description of the changes in skin temperature. Their prediction of the final steady skin temperature is indirectly supported by the data reported.

182. Kuno, Yas

HUMAN PERSPIRATION. Springfield, Illinois,

Charles C. Thomas, 1956, 416p.

Chap. I Insensible perspiration
Chap. II The sweat apparatus
Chap. III Outline of human sweating
Chap. IV The development of the human sweat apparatus and of their functions
Chap. V Perspiration of the palms and soles and the effect of mental stress on the perspiration in general
Chap. VI Sweating of the Axilla
Chap. VII Sweating on the general body surface- Thermal sweating
Chap. VIII Chemistry of sweat
Chap. IX The loss of water and salt by sweating, their replenishing and changes in the blood
Chap. X The mechanism of sweating
Chap. XI The acclimatization of the human sweat apparatus to heat
Chap. XII The significance of sweating
Chap. XIII Notes on anhidrosis and hyperhidrosis

183. Iampietro, P.F. and Buskirk, E.R.

Effects of high and low humidity on heat

exchanges of lightly clothed men. JOUR.

APPL. PHYSIOL. v. 15, p. 212-214, 1960.

Six healthy young men were exposed, lightly clothed, to various combinations of wind (1 and 10 mph), temperature (40° and 50° F) and relative humidity (30 and 100%). Skin and rectal temperatures and oxygen consumption were recorded. The results show that relative humidity had no effect on the

183. (Cont'd)

physiological responses measured, whereas wind and dry bulb temperature had marked effects. This follows the pattern seen when men were exposed without clothing and indicates that, under chamber conditions, there is little interaction between clothing and humidity that could account for cold-wet "chill." The importance of considering radiation in any comparison of cold-wet and cold-dry environments is discussed.

184. McCutchan, J.W. and Taylor, C.L.

A QUANTITATIVE STUDY OF EVAPORATION FROM THE HUMAN BODY DURING SHORT EXPOSURES TO VARIOUS TEMPERATURES, HUMIDITIES, PRESSURES, AND MASS VELOCITIES. California U. WADC Tech. Note 55-522, June 55, 41p. ASTIA AD-98 216.

This report provides an example of an economical design of a physiological experiment using the Latin Squares technique. Variations in human perspiration, evaporation from the skin, and skin and rectal temperatures are expressed as functions of the environmental variables of air temperature, water vapor pressure, pressure, and mass velocity over the specified ranges. The beneficial effect of reduced pressure on body temperature and heart rate is striking and correlates with the subjective reports. The hypothesis is offered that variations in barometric pressure affect only the diffusional component of skin water loss while body temperature controls the sweat gland component. Computations favorable to that view have been made although direct experimentation is necessary to establish the validity of the hypothesis.

185. Mefferd, R.B., Jr.

Adaptive changes to moderate seasonal heat in human subjects. JOUR. APPL. PHYSIOL. v. 14, p. 995-996, 1959.

The excretion patterns of 29 members (including children) of 7 south Texas Caucasian families of verying economic status were determined each November (neutral-cool, averaging 68.7°F) and May (warm, averaging 81.6°F) for 3 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

185. (Cont'd)

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.

186. Morton, G.M. and Dennis, J.P.

THE EFFECT OF ENVIRONMENTAL HEAT ON PERFORMANCE, MEASURED UNDER LABORATORY CONDITIONS. Great Britain Clothing & Stores Exper. Estb. Rept. no. 99, Mar 60.

ASTIA AD-239 571.

187. Nelson, N.A., et al

The influence of clothing work, and air movement on the thermal exchanges of acclimatized men in various hot environments. JOURNAL OF CLINICAL INVESTIGATION v. 27, p. 209-215, 1948.

Partitional calorimetric data and their physiologic correlates have been presented to show the thermal exchanges and responses of three acclimatized men, nude and clothed, while standing and walking in a series of seven hot environments (90° to 120°F.). In each of the environments the effects of varying the wind velocity between 30 and 600 feet per minute were determined. Convective and radiant heat gain and the compensatory evaporative heat loss showed a progressive increase with increasing air movement.

188. Peiss, C.N. and Hertzman, A.B.

STUDIES ON CUTANEOUS HEAT LOSSES. PART 5. KINETICS OF EVAPORATIVE WATER LOSS FROM

188. (Cont'd)

THE SKIN. St. Louis U. School of Medicine. USAF Technical Rept. 6680, Part 5, Dec 51, 36p. ASTIA ATI-162 415.

An equation has been developed from the diffusion equation which permits calculation of the relative humidity of the skin from experimental data. Calculated values of the relative humidity of the skin are shown to compare closely with previously reported values using different techniques. Determination of skin humidity permits the analysis of evaporative data on the basis of water pressure gradients. Sweating and nonsweating evaporative rates from a large series of subjects over a wide range of air temperatures have been analysed according to the concept of relative humidity of the skin. These data are shown to follow the physical principle that evaporative rate is a function of the vapor pressure gradient. This implies that evaporative heat losses are regulated primarily by the level of skin temperature and skin hydration. The roles of blood flow, skin temperature and skin relative humidity in the control of cutaneous evaporative heat losses under sweating and nonsweating environmental conditions are discussed.

189. Peiss, C.N., Randall, W.C. and Hertzman, A.B. STUDIES OF CUTANEOUS HEAT LOSSES. PART 10. RELATIONS OF HYDRATION OF THE SKIN TO THE REPENETRATION OF WATER, SWEATING, AND EVAPORATION. St. Louis U. School of Medicine. USAF Technical Report 6680, Part 10, Dec 52, 13p. ASTIA AD-6 897.

This report is a preliminary study of the processes of hydration of the skin (palm, sole and forearem) and of the relations obtaining between water uptake, sweating and evaporation. The uptake of water by the skin was studied in immersion experiments (water and salt solutions of various concentrations) and also by the use of specially designed capsules. The data demonstrate that the water uptake follows a curvilinear time course, having its highest rate at the beginning of contact with the solution, and falling off progressively to a very low value. It is argued that the uptake of water is due almost exclusively to absorption by the epithelium and that the removal of water by the vascular system must be slight. The rate and amount of water uptake was much greater on the palm and sole than on forearm skin. It appears that the water uptake bears a direct relation to the cornification of the skin. The evaporation of water subsequent to hydration of the skin followed a time course which was very nearly a replica of the process of hydration. Accompanying

189. (Cont'd)

effects on sweating did not appear to influence the evaporative process, at least during the initial phase following hydration. Sweating, as induced by various sudomotor reflexes, was inhibited on the palm and sole by hydration of the skin; the amount of inhibition was related to the degree of hydration; recovery from the inhibition proceeded with dehydration. Similar effects were observed on forearm skin but the inhibitory effects were very much less than on the palm and sole.

190. Pepler, R.D.

Extreme warmth and sensorimotor

coordination. JOUR. APPL. PHYSIOL. v. 14,

p. 383-386, 1959.

Six subjects were exposed for 30 minutes on three occasions at 48-hour intervals to a very warm, humid climate with a wet bulb temperature of 105°F (41°C). During the second and third exposures the subjects worked continuously to keep a pointer aligned with a target mark, as it moved erratically from side to side. Accuracy of alignment was normal at first, but deteriorated rapidly and progressively. Movement of the pointer was greater than usual right from the start and changed little thereafter. Rectal temperature rose steadily during the exposures. Failures to correct progressively greater misalignments of the pointer were thought to indicate a growing inattentiveness to the task and a general deterioration in the organization of performance.

191. Randall, W.C. and Hertzman, A.B.

STUDIES ON CUTANEOUS HEAT LOSSES. PART 3.

THE DERMATOMAL RECRUITMENT OF SWEATING IN

RESPONSE TO GENERALIZED RADIANT HEATING.

St. Louis U. School of Medicine. USAF

Technical Report 6680, Part 3, Nov 51, 18p.

ASTIA ATI-149 310.

A series of experiments was designed to study the sweating responses on the various body surfaces to a gradually rising environmental temperature. Sweating records were taken by means of the iodine-starch-paper technique on fourteen to seventeen different body regions which were selected to provide observations on as many different sensory dermatomes as possible. The neural control of sweating and the progressive recruitment with increasing environmental temperature is discussed. The concept of sympathetic dermatomes as compared with and differentiated from sensory dermatomes is discussed in relation to the recruitment of sweating.

192. Randall, W.C., Peiss, C.N. and Rowson, R.O.
Simultaneous recruitment of sweating and perception of warmth in man. JOUR. APPL. PHYSIOL. v. 12, p. 385-389, 1958.

193. Stopps, G.J., _et al_
THE REDUCTION IN HEAT STRESS RESULTING FROM REST PERIODS SPENT IN A COOL ENVIRONMENT. Presented at the 44th. Annual Meeting of the Federation of American Societies for Experimental Biology, Chicago, Illinois, 11-15 Apr 60.

194. Wyndham, C.H., _et al_
Thermal responses of men with high initial temperatures to the stress of heat and work. JOUR. APPLIED PHYSIOL. v. 6, p. 687-690, May 1954.

In connection with a previous larger study, an investigation was made on thirty-seven unacclimatized mining recruits, who reported with mild medical complaints and above-average body temperatures. Under medical supervision these men were subjected to the stress of exercise in cool or hot humid environments. The results were subjected to statistical analysis. It was shown that unacclimatized men with symptoms of mild illness and rectal temperatures above 100°F. readily attain rectal temperatures of 104°F. under conditions of moderate and severe heat stress. Most men were distressed at such rectal temperatures. The conclusion was reached that it is possible, on the basis of initial resting rectal temperatures, to predict which man will develop the highest rectal temperatures during work in hot conditions.

195. Young, D.R., et al

Body temperature and heat exchange during treadmill running in dogs. JOUR. APPL. PHYSIOL. v. 14, p. 839-843, 1959.

Body temperature during treadmill running was studied in six dogs at seven different grades from 0-22 degrees of inclination. The replicate variability in the work rectal, skin and fur temperature was ± 0.5°F, ± 1.4°F and ± 1.3°F, respectively. At grades up to 12 degrees of inclination there is a prolonged steady state in the rectal temperature. At higher grades there is a progressive increase in rectal temperature with running time. Body surface temperatures show little affect at the lower grades. At higher work intensities there is an increase in skin and fur temperature. Maximum heat storage varied from 21.3-41.3 Cal during short term exhaustive work. This type of calculation is discussed critically. The relationship between rate of rise in rectal temperature and maximum performance time was studied. Without regard to work load a product-moment correlation coefficient of +0.991 was found.

PART VII

COMPENSABLE ZONE-LOW TEMPERATURE

196. Iampietro, P.F., Bass, D.F. and Buskick, E.R.
Diurnal oxygen consumption and rectal temperature of man during continuous cold exposure. J. APPL. PHYSIOL. v. 10, p. 398-400, 1957.

197. Iampietro, P.F., Bass, D.E. and Buskirk, K.R.
Heat exchanges of nude men in the cold. Effect of humidity, temperature and windspeed. J. APPL. PHYSIOL. v. 12, p. 351-356, 1958.

198. Iampietro, P.F., <u>et al</u>
Heat production from shivering. JOUR. APPL. PHYSIOL. v. 15, p. 632-634, 1960.

Healthy young men were exposed, nearly nude, fro 2 hours or less to various environmental conditions (dry-bulb temperature, 90°-20° F; windspeed, $<$ 1, 5, 10 mph). Oxygen consumption was recorded at intervals during exposure. The results show that even under conditions where no visible shivering was observed, there was an increase in heat production. Exposure to very low temperatures (20°F) with low winds did not evoke the largest increases in heat production. The greatest mean heat production (370 Cal/hr.) was associated with the highest windspeed (10 mph), and this value approached the maximum heat production which can be attained by shivering (mean value about 425 Cal/hr.). Thus, increasing the windspeed had a relatively greater impact on heat production than decreasing the dry-bulb temperature. The relationships between heat production and windspeed and heat production and dry-bulb temperature were nonlinear.

199. Iampietro, P.F.

Prediction of skin temperature of men in the cold. J. APPL. PHYSIOL. v. 16, p. 405-408, 1961.

200. Iampietro, P.F., et al

Response of negro and white males to cold. JOUR. APPL. PHYSIOL. v. 14, p. 798-800, 1959.

Heat production and body temperatures were measured in matched groups of U.S. Negro and white soldiers during whole body cooling, and finger temperatures were measured when only the digits were cooled. Whole body cooling was accomplished by having the subjects, clad only in shorts, sit for 2 hours in a chamber at 50° F with a 5-mph wind. Digital cooling was accomplished by having the subjects immerse the fingers in a water bath at 32° F for 45 minutes. During whole body cooling there were no group differences with respect to the following: heat production, skin and rectal temperatures. During digital cooling white subjects had higher finger temperatures and the "hunting" reaction was more pronounced than for Negroes. In addition, the white subjects required a shorter period for the onset of the first "rewarming" of the fingers. The implications of these findings with reference to the reported higher incidence of cold injury amoung Negro soldiers are discussed.

201. Irving, L.

Animal adaptation to cold. In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE MAR 1957. New York. Josiah Macy, Jr. Foundation. p. 11-60, 1958.

202. Thompson, R.H., *et al*

CONTINUOUS MEASUREMENT OF METABOLIC RATE IN HUMAN SUBJECTS EXPOSED TO COLD 10° C. Presented at 44th. Annual Meeting of the Federation of American Societies for Experimental Biology, Chicago, Illinois 11-15 Apr 60.

PART VIII

HYPERTHERMIC ZONE-NON-COMPENSABLE

203. Adams, T.

ENVIRONMENTAL FACTORS INFLUENCING

THERMAL EXCHANGE. Arctic Aeromedical Lab.

Rept. no. AAL TR 59-22, 54p.

ASTIA AD-251 856.

The existence of a thermodynamic steady state depends not only on a critical adjustment of the several physiological mechanisms involved in temperature regulation, but more importantly on the characteristics and the multifaceted nature of the environment to which the animal is exposed. It is this steady state that allows the homeotherm to maintain a relatively stable internal body temperature. This paper attempts to present a first-order description of the physical phenomena that are ultimately involved in heat fluxes and the so-called avenues of thermal exchange; that is, conduction, convection, radiation, and evaporation. Some degree of understanding of these basic principles is required for even a partial appreciation of the physiological mechanisms involved in temperature regulation. The paper should be regarded perhaps as a primer rather than a comprehensive treatise.

204. Agersborg, H.P.K., Jr., Barlow, G. and Overman, R.R.

Transcapillary exchange rates in acute and

intermittent hyperthermia. J. APPL. PHYSIOL.

v. 14, p. 781-784, 1959.

205. Ajalat, M.P.

Recovery from heat prostration and body

temperature of 109° F. CALIF. MED.

v. 92, p. 350, May 1960.

A patient with heat prostration, the body temperature reaching at least 109°F., recovered in a few days and had no residual abnormality.

206. Allen, E., Jr.

EFFECT OF DRUGS AND WATER BALANCE ON PERFORMANCE UNDER HEAT AND EXERCISE STRESS.

Pennsylvania State University. (Thesis)

108p. 1960.

The purpose of this study was to determine the effect of caffeine, dexedrine, dehydration, and superhydration on man's capacity to withstand heat and exercise stress as measured by heat gain, heart rate, sweat loss, and mental, psychomotor, and strength tests. A total of 90 different experiments were performed on 15 male subjects. Heat stress was provided in a hot room at 110°F. with a humidity of 25 to 30 per cent and an air velocity of 3 to 5 miles per hour. Exercise stress was provided by a motor-driven treadmill, moving at 4 miles per hour at zero grade. The subjects each reported for 3, one-hour acclimatization periods and 6, three-hour experimental periods. The 6 experimental periods were scheduled for all subjects in the following order: (1) Control, (2) Superhydration (1 liter of saline and 1 liter of water), (3) Dexedrine (5 milligrams), (4) Caffeine (324 milligrams), (5) Placebo, and (6) Dehydration (3 per cent). For the administration of the drugs, a double-blind was used. During the three-hour experimental periods, the subjects followed the procedure of alternate 30 minute periods of walking on the treadmill and resting in a seated position. Under the experimental conditions heat gain, heart rate, and sweat loss measurements were obtained by standard laboratory techniques; psychomotor performance was measured by tests of hand and arm steadiness, two-hand coordination, reaction time to light stimulation, transfer of pegs, inversion of pegs, and tapping; mental performance was tested by the addition of two-digit numbers; and strength was determined by hand, leg, and back dynamometers. For purposes of comparison, determinations were made of per cent body fat and physical fitness. From comparisons with the control condition, significant results were found at the one per cent level of confidence under caffeine for increased heart rate and impairment in rate of addition, under dexedrine for impairment in rate of inversion of pegs, under dehydration for increased heart rate, impairment in rate of addition, and impairment in rate of inversion of pegs, and under placebo for impairment in rate of addition and impairment in rate of inversion of pegs. At the five per cent level, results were significant under caffeine for impairment in rate of inversion of pegs, under dexedrine for increased heart rate and improvement in strength, under superhydration for impairment in rate of inversion of pegs and impairment in rate of addition, and under dehydration for impairment in rate of transfer of pegs. Other improvements and impairments were indicated, but not at significant levels.

207. Armstrong, R.C., and Wu, W.L.S.

MEASURES OF PILOT RESPONSE TO A CHANGING THERMAL LOAD UNDER PROTECTED AND UNPROTECTED CONDITIONS. Convair, San Diego. Rept. no. ZR-658-051, 8 May 59, 43p.

A series of test exposures of pilot subjects to the simulated thermal environment of a very high performance aircraft cockpit are reported herein. The effectiveness of a current ventilated, full-pressure suit (Goodrich Mark III), was tested in terms of its capability for successfully protecting the pilot subjects from the experimental temperature profile. Detailed physiological and performance data for the subjects under both test and control conditions are presented, as is a description of the numerous instrumentation problems posed by the dynamic simulation of cockpit thermal conditions. The tests were restricted to a rather small sample of subjects, but there are indications that some peculiar physiological reactions to changing temperature profile may set a different level of tolerance than that shown for steady temperature states. Further research is needed to test this, and such will shortly be inderway. With vent-suit protection, the environment tested was quite tolerable to three pilot subjects, though certain design changes and needed developments in protective clothing are indicated.

208. Bianca, W.

The relation between respiratory rate and heart rate in the calf subjected to severe heat stress. JOUR. AGRIC. SCI. v. 51, p. 321-324, 1958.

In calves subjected to severe heat stress, the breath frequency at first rose from 88 to a maximum of 218 respirations/min. and then fell to 167 respirations/min., while the breathing at first became shallower and than deeper. During the phase in which breathing became faster and shallower (panting), the heart rate rose by a mean of 13 beats/min. for each degree C increase in rectal temperature. During the phase in which breathing became slower and deeper the mean rise in heart rate was 50 beats/min. for each degree C rise in rectal temperature. Changes in respiratory rate and in heart rate occurred at mean rectal temperatures of 40.6 and 41.0° C respectively, and on an average, the change in respiratory rate preceded that in heart rate by 8 min. The steep rise in heart rate has been attributed to the slower and deeper breathing.

209. Blockley, W.V., et al
Human tolerance for high temperature aircraft environments. JOURNAL OF AVIATION MEDICINE v. 25, p. 515-522, 1954.

210. Blockley, W.V. and Lyman, J.
STUDIES OF HUMAN TOLERANCE FOR EXTREME HEAT. IV. PSYCHOMOTOR PERFORMANCE OF PILOTS AS INDICATED BY A TASK SIMULATING AIRCRAFT INSTRUMENT FLIGHT. WADC USAF Tech. Rept. 6521, May 51, 45p.

A total of fourteen exposures of four experienced pilots to three high temperature environments are described in terms of the time course of performance on a complex psychomotor task simulating instrument flying. Experiments were conducted at 160°, 200° and 235°F, with humidity approximately 0.8 in. Hg vapor pressure, using a comfortable environment in the neighborhood of 80°F as a control. Subjects were trained in advance of these experiments in the operation of the test apparatus, which consisted of a portable simulated cockpit with standard Link Trainer controls and instruments, and given an initial one-hour practice period on the experimental flight pattern before the first heat exposure. The task consisted of continuous repetitions of this flight pattern, which was four minutes in duration and included four turns combined variously with climbs, dives and level flight. Though differing in level of competency or skill in the task, no subjects showed a change in proficiency within 80 minutes of flight in the comfortable environments, but under heat exposure showed marked deterioration of performance in the terminal stages, commencing from four to thirteen minutes prior to the termination of exposure. Heat exposures were terminated in accordance with the criteria of tolerance which have been defined in previous reports and used in all series of experiments in these heat tolerance studies. The amount of deterioration, i.e., the increase in error per four minute cycle of the flight pattern, was greater in the high temperature exposures than at 160° F. At 200° and 235° F the deterioration was markedly greater and began sooner for the two less competent subjects. Hypotheses are developed from the results, and certain evidence from reports of other workers are cited in support of these. Numerous comparisons are possible between these results and those obtained with the same subjects in similar environments performing simple addition and number-checking exercises; several such comparisons are reported.

211. Blockley, W.V., McCutchan, J.W. and Taylor, C.
PREDICTION OF HUMAN TOLERANCE FOR HEAT
IN AIRCRAFT: A DESIGN GUIDE. Wright
Air Development Center. WADC-TR-53-346.
May 1954.

212. Blockley, W.V. and Taylor, C.L.
STUDIES IN TOLERANCE FOR EXTREME HEAT II.
California U. Second summary report. USAF
Technical Report 5831, July 49, 84p.
ASTIA ATI-73 854.

Progress in an investigation of human heat tolerance is reported. Two aspects of the program were studied, namely, responses of a group of subject to sub-tolerance exposures, with all experiments being carried to tolerance. The latter requirements were designed to investigate the effects of humidity in measurements at successive time points throughout the experimental range were plotted together with mean-response time curves. Charts for predicting tolerance time for each man from air temperature and vapor pressure are appended. As to the second study, no specific effect of humidity as such on body and tolerance has been determined, increased in humidity being equivalent to a definite increase in temperature.

213. Blockley, W.V. and Taylor, C.L.
STUDIES OF HUMAN TOLERANCE FOR EXTREME
HEAT I. California U. First summary
report. AMC Memorandum Report
MCREXD-696-113A, 1 Nov 48, 204p.
ASTIA ATI-114 848.

Results of investigations conducted in 1947 and 1948 on the general problem of human response to high levels of environmental temperature are presented and discussed in relation to the tolerable limits of heat exposure. Some 50 individual experiments have been completed involving four average college students and the authors as subjects consisting of multiple exposures to air

213. (Cont'd)

temperature levels of 100, 140, 160, 180, 200, 220, 240 and one exposure at 250°F. Humidity of the experimental environments was determined by the atmospheric humidity existing at the time of each exposure, as modified by the moisture production of the subject. The average humidity during heat exposure ranged from 0.25 to 0.9 in. Hg. vapor pressure, but in most experiments was of the order of 0.8 in. Hg. Wall temperatures approximated air temperature to within 5 to 10°F in all experiments.

214. Buettner, K.J.K.

Thermal stresses in the modern aircraft.

In HABER, H. PROCEEDINGS OF A SYMPOSIUM ON FRONTIERS OF MAN-CONTROLLED FLIGHT. University of California. Institute of Transportation and Traffic Engineering, Los Angeles, p. 7-13, 1953.

A table showing temperature classifications according to human tolerances is given. The criteria investigated are tolerance time, warning symptoms, body adjustment, changes of skin and core (rectal) temperatures, and essential properties of protective clothing. It has been found that the thermal characteristics of the body are dependent upon body tolerance and adjustment. In emergencies, shivering and sweating complement normal temperature control mechanisms. Vasodilatation and blood convection raise the resistance of the body. An unpublished mathematical analysis by the author of transient conditions in man (in a hot environment) indicates that blood flow is controlled by internal temperature; the work load on the circulatory system seems to be a limiting factor in heat tolerance. Proposals are advanced for the prevention of thermal injuries by proper adjustments in the aircraft and in clothing as well as in man himself.

215. Carlson, L.D.

HUMAN PERFORMANCE UNDER DIFFERENT THERMAL LOADS. School of Aviation Medicine. Rept. no. 61-43, Mar 61, 13p. ASTIA AD-254 374

This report outlines a hypothesis concerned with the interaction of physiologic inputs from environmental temperature and low oxygen tension, and psychologic inputs from a vigilance test. Blood flow, pulse rate, rectal temperature, GSR, and vigilance were measured in a normal and in a hot environment

215. (Cont'd)

(between 20 and 50 C with less than 20% RH). There were marked individual differences in response, some of which appear to be related to physical fitness. Vigilance was impaired in the hot environment at higher levels of input.

216. Crocker, J.F. and Waitz, C.R.

A HEAT PULSE OVEN FOR STUDY OF HUMAN THERMAL TOLERANCE. Wright Air Development Div. WADD TR 60-733, Dec 60, 8p. ASTIA AD-253 531.

A 4 foot cubic chamber with thin aluminum walls has been built to simulate the thermal surroundings of the crew of a hypersonic vehicle reentering the earth's atmosphere. The walls are heated with quartz tube infra-red lamps mounted on reflectors 5 inches from the chamber's external surfaces. The temperature of each wall is controlled independently with manually operated relays. Wall temperatures may be programmed to rise as rapidly as 100°F per minute. Air temperature within the chamber rises passively as a result of natural convection induced by the chamber walls. Preliminary investigations of tolerance to peak wall temperatures as high as 430°F are summarized, and a more detailed investigation of human physiological and psychological performance during a 400°F peak exposure is described. Results of the latter indicate that rather large changes in cabin temperature of limited length may have small enough effect on pilot performance that they may be included in design of air and space vehicles, particularly in cases where significant savings in weight may be achieved.

217. Dorodnitsyna, A.A. and Shepeley, E.R.

Heat exchange in man under conditions of high temperatures. FIZIOLOGICHESKII ZHURNAL SSSR (LENINGRAD) v. 46, p. 607-612, 1960. (In Russian, with English summary).

The heat exchange of man in a state of relative rest was studied under conditions of varying ambient temperatures (40, 50, 70, and 75° C.). The measurements included determination of values for heat production, heat emission, and heat accumulation in the organism, as well as registration of the pulse rate and the body temperature. The data allowed an estimate of the

217. (Cont'd)

heat load imposed on man in various temperatures and the calculation of the time span for which the studied heat loads may be endured relative to the speed of heat storage and the limiting permissible values of heat accumulated by the organism.

218. Gladoshchuk, G.V., Aksenov, M.D. and Kozhin, A.M.

The effects of high air temperatures on the functional condition of the cerebral cortex. MILITARY MED. J. p. 99-103, 1959.

Eight healthy male subjects were exposed to heat stress in a hermetically sealed chamber. The length of stay was varied, as follows: at 50°C., 85 to 110 minutes; at 60°C., 55 to 60 minutes; and at 70°C., 30 to 45 minutes. The functional condition of the cerebral cortex was determined by the degree of excitability as measured by changes in muscular strength of the hands in response to a momentary and a sustained stress by the speed of sensorimotor reaction to sound and light stimuli, by the frequency and amplitude of tremor of the right arm, and on the basis of subjective reports. In all cases hyperthermia resulted, as indicated by physiologic indices: body temperature ranging from 38.3° to 38.6°C; pulse frequency, 120 to 130 per minute; systolic blood pressure, 120 to 132 mm.; diastolic blood pressure, 40 to 56 mm.; and respiratory volume, 10.5 to 12.5 l. per minute. Muscular strength in response to both momentary and sustained stress decreased, the former by 6 to 8 per cent and latter by 25.8 to 47.3 per cent. The reduction was proportional to the duration of the heat stress. The sensorimotor reaction times were increased, and so were the frequency and amplitude of the hand tremor. The subjective feeling of well-being deteriorated markedly toward the end of heat experiment. It is concluded that a prefominance of inhibitory processes takes place in the cerebral cortex in response to high temperatures. The sensitivity of the analysors exhibits a corresponding decrease.

219. Haber, F.

Space medicine of the next decade as viewed by the engineer. UNITED STATES ARMED FORCES MEDICAL JOURNAL v. 10, p. 426-440, 1959.

Methods of controlling the problems of deceleration and aerodynamic heating during re-entry as related to manned space travel are discussed.

220. Hendler, E. and Santa Maria, L.J.

Response to subjects to some conditions of a simulated orbital flight pattern. AEROSPACE MEDICINE v. 32, p. 126-133, 1961.

Some of the physiological responses of subjects wearing ventilated full pressure suits and exposed to pressure and thermal profiles characteristic of extreme conditions of orbital flight patterns were presented. No significant physiological stress was evidenced in subjects exposed to a modified thermal profile, except for the sweating response of one subject. Exposure of experienced subjects to long duration thermal loads simulating relatively severe post-landing and full thermal profiles resulted in premature test termination when ventilating air temperature was more than a few degrees above initial mean skin temperature.

221. Iwabuchi, T.

Experimental studies on the central hyperthermia. TOHOKU JOUR. EXPTL. MED. v. 71, p. 273-290, 1960.

Generally speaking, mammals cool when restrained and fixed, especially marked when they are fixed with trunk and limbs fully extended, the environmental temperature is low or surgical interference is applied in the fixed position. Unconstrained positions were used as far as possible. The fluctuation of body temperature differs widely among species. Rabbits are often subject to high fever following very slight stimulation. Cats, however, were found fairly stable in their temperature, and the author used 269 mongrel cats. The different parts of the hypothalamus and the tuber cinereum were stimulated or damaged by a variety of methods, but hyperthermia of above 40°C could not be induced except in 2 of the 85 cases tested. In these 2 cases, a rather large hematoma was found in and around the 3d ventricle. It was inferred that a surgical stress to a small area in this part is not sufficient to produce hyperthermia. When autogeneous blood or stimulating substances were directly introduced into the 3d ventricle, or mechanical stimulation was applied to the wall of the third ventricle, hyperthermia was induced in 52 of the 61 cases (86%), 7 of them died (11%) and only 2 survived free of hyperthermia (3%). When the medial side of the grey matter around the ventricle was subjected to the infusion, hyperthermia was induced without exception, but when it was the lateral side, no hyperthermia appeared subsequently. The above findings seem to show that the nuclei around the 3d ventricle, in particular, those on the medial side of the ventricle, cause hyperthermia under stress by joint action. Hyperthermia also followed injection of 50°C physiological saline through the carotid artery. This is perhaps due to the brain edema thereby affecting the nuclei around the 3d ventricle and causing fever. The efficacy of autonomic blocking media and hydrocortisone against experimental central hyperthermia was also studied.

222. Kaurman, W.C., Davis, H.T. and Swan, A.G.

SKIN TEMPERATURE RESPONSES TO SIMULATED NUCLEAR FLASH. Paper Presented at 1961 Meeting of Aerospace Medical Assoc. Chicago, 24-27 April.

Skin temperatures and irradiance levels were measured on a subject seated in a tactical aircraft exposed to thermal radiation characteristic of nuclear weapons. Thermal energy was supplied by 1032 lamps at power levels up to 4000 kw. Standard flight clothing was worn. Cockpit airflow was less than 50 cfm at 70°F. Subject tolerance was attained in a 2.3 second pulse of 3.5 cal/cm^2 at canopy exterior and 1.5 cal/cm^2 at head level measured by calorimeter with 90° acceptance angle. This pulse charred paint on fuselage and headrest and seared the subject's glove. Bare forehead skin temperature reached 126° F. and insulated knee temperature reached 104° F. Subject feelings were of distinct pain. Physiological responses and heat transfer mechanisms in extreme thermal energy pulses are discussed.

223. Malmejac, J., Cruck, S. and Neverre, G.

Role of cutaneous hyperthermia in the production of general disturbances due to high temperatures: Mechanisms involved. MÉDECINE AÉRONAUTIQUE v. 7, p. 441-447, 1952. (In French)

Experiments were made on a flap of skin of an anesthetized dog exposed to high temperatures (60-70°C.) while the animal was breathing cold air. When the temperature of the flap rose to 40-41°C., its blood supply was greatly increased, but decreased again at 42-43°C. The efferent blood of the hypothermic skin flap contained histamine and its protein balance was disturbed (increase of beta globulins). - The authors conclude that hypothermia of the skin may be responsible for various (probably hepatic) reactions which affect the general circulation and may lead to circulatory collapse.

224. Moss, A.J. and Bradley, B.E.

Ballistocardiographic response to

224. (Cont'd)

hyperthermia. JOUR. APPL. PHYSIOL.

v. 15, p. 445-448, 1960.

The body temperature of five normal subjects was raised to levels above 100.°F through the use of a rubberized anti-exposure suit. The induced hyperkinetic cardiovascular state was studied on an ultra-low-frequency force ballisto-cardiograph. The ejection deflection (HI wave) consistently increased in amplitude and became more vertical during the hyperthermic state. The time duration from the onset of ventricular ejection to the J wave peak generally was shortened. These changes were interpreted in terms of the known cardiovascular response to the hyperkinetic state. Diminished peripheral resistance and its sequelae seemed to play a major role in the ballisto-cardiographic changes seen with hyperthermia.

225. Neisser, U.

Temperature thresholds for cutaneous pain.

JOURNAL OF APPLIED PHYSIOLOGY v. 14,

p. 368-372, 1959.

Thresholds for pricking pain, as well as withdrawal points and endurance limens, were measured in 40 untrained subjects. The measurements were made in terms of the instantaneous temperature of the skin during thermal irradiation. The thresholds were lower and more variable for these subjects than for highly trained ones. They varied with the region of skin stimulated, ranging from 40.8°C on the palm to 42.2°C on the forehead, and were about 1°C higher on skin blackened with India ink than on normal skin. Adaptation to pain occurred regularly, sensitivity being decreased in repeated measurements. Implications for pain threshold measurements in general are discussed.

226. Payne, R.B.

Tracking proficiency as a function of thermal

balance. JOUR. APPL. PHYSIOL. v. 14,

p. 387-389, 1959.

An experiment was conducted for the purpose of learning a) whether or not performance decrement in monitoring and controlling a complex visual display is related to body heat loss and b) whether or not such an impairment can be forestalled by glycine administration. Following extensive training on the experimental task, 72 subjects were independently and randomly assigned to the 9 combinations of 3 ambient temperature conditions (70°, 55° and 40°F) and 3 glycine treatments (0, 20 and 40 gm), then required to execute a

226. (Cont'd)

performance sequence lasting 3 hours and 20 minutes. Statistical analyses established that the mathematical function relating performance to temperature was a parabola having a maximum near 55°. No significant glycine effects were observed.

227. Selowry, O. and Kraus, G.E.

Reaction of dogs to hyperthermia and fever.

J. APPL. PHYSIOL. v. 13(2), p. 231-236, 1958.

228. Taylor, C.L.

Human tolerance for temperature extremes.

In PHYSICS AND MEDICINE OF THE UPPER

ATMOSPHERE, A STUDY OF THE AEROPAUSE.

White, C.S. and Benson, O.O., Jr., ed.

University of New Mexico Press, p. 548-561,

1952.

Pressurization and air conditioning of airplane cabins have, within the present range of operations, limited the problems concerning human tolerance of extreme temperatures to incidences of cabin failure. In ultrasonic flight, however, air friction of the fuselage produces surface temperatures which surpass human tolerance (thus, the temperature in a plane flying at a speed of 800 m.p.h., at an outside temperature of 37.7°C. and at a low altitude, would reach 101.5° C.). Waist gunners of the U. S. Air Force wearing heavy clothing with supplementary electrical heating, have withstood environmental air temperatures of -40° C. A pilot provided with heavy clothing is able to withstand temperatures up to -5° C. in his normal resting position, and up to -40° C. when doing work equivalent to walking at a speed of 2.5 m.p.h. The author reviews briefly the basic principles involved in body heat exchange, body evaporation, time tolerance at extreme heat and cold exposures, and the effects of exercise.

229. Taylor, C.L.

Description and prediction of human

response to aircraft thermal environments.

ASME TRANS. v. 79, n. 5, p. 1024-28, 1957.

230. Thauer, R., Mendelson, E.S. and Hays, E.L.

THERMAL ENVIRONMENTS IN AIRCRAFT

PHYSIOLOGICAL LIMITATIONS - PHYSIOLOGICAL

LIMITATIONS TO THERMAL STRESS IN AIRCRAFT.

Naval Air Material Center. Rept. no.

NAM AE 509016, 1v. Dec 49. ASTIA AD-128 954

This article presents a summary of all known data regarding human tolerance to hot environments, and reviews it from the aspect of aircraft air conditioning. The presentation and analysis demonstrate the insufficiency of present knowledge for a clear understanding of physiological limitations to heat and for proper validation of air conditioning practices. The authors propose that systematic efforts be made to obtain the large but necessary amount of information required to evaluate human tolerance to thermal stress. As a first step, they suggest that uniformity of basic procedures and of arbitrary conventionalisms be adopted voluntarily by interested scientists and technicians.

231. Veghte, J.M. and Webb, P.

Body cooling and response to heat. J. APPL.

PHYSIOL. v. 16, p. 235-238, 1961.

Prior body cooling with cold air or water immersion increased human tolerance to a high level of heat stress. The lower the body temperature at the onset of the heat exposure, the greater the increase in tolerance times over the control values. Mean body temperature was the only discriminating criterion which successfully correlated with tolerance time in these experiments. Sudomotor activity in heat was inhibited by prior body cooling. It is postulated that the onset of sweating is due to a gradient effect, not to either peripheral or central control.

232. Veghte, J.H. and Webb, P.

EXTENDING HUMAN TOLERANCE TO HEAT BY

PRIOR BODY COOLING. WADC Technical

Report No. 58-412, Sep 58, 16p.

ASTIA AD-205 544

A preliminary study has been completed to determine the effect of prior body cooling on tolerance to a high level of heat stress. Subjects were exposed

232. (Cont'd)

to three levels of pre-cooling (30-, 60-, and 90- minute exposures in a 60°F. water bath) prior to entering the heat chamber of 160° F. As the time of precooling increases, the average tolerance time in heat is correspondingly greater. At tolerance, a narrow spread of terminal rectal temperatures is observed. Recruitment of sweating in heat is inhibited by prior body cooling. The causative factors for this phenomenon are discussed.

233. Veghte, J.H. and Webb, P.

INFLUENCE OF PRIOR BODY COOLING WITH AIR ON HUMAN HEAT TOLERANCE. Wright Air Develpm. Cent. Tech. Rept. 59-350, 1959, 13p.

This study was conducted with 3 experienced subjects to determine the feasibility of using a ventilating suit as a vehicle for body cooling prior to heat exposures. Various ventilating air temperatures, flows, and time durations were explored. The results confirm the applicability of this approach for prior body cooling and extension of tolerance times to a heat stress. Optimal air temperature for air cooling in terms of subjective comfort appears to be approximately 45° F for 60 minutes or longer. Maximum airflow rate recommended with the ventilating garment is 25 c.f.m. Heavy insulation should be worn over the ventilating garment while cooling and may be worn throughout the heat or flight situation with no tolerance impairment.

234. Watanabe, K.

Experimental studies on the changes of various organs in rabbits exposed to high temperatures. IGAKU KENKYU v. 29, p. 4540-4559, 1959. (In Japanese)

235. Webb, P.

Aerodynamic heating. MECHANICAL ENG. v. 82, n. 6, p. 60-62, 1960.

Studies were made in experimental heat chambers to determine man's tolerance to slow heat pulses, both nude and while wearing protective clothing. Exposure to slow heat pulses with slopes ranging from 15° F. per minute to

235. (Cont'd)

100° F. per minute with nude subjects resulted in intolerable pain at temperatures between 325° F. and 400° F. The faster the rate of temperature rise, the higher the temperature which could be tolerated. Discomfort in breathing was found to be closely related to air temperature, rather than to wall temperature at a level of 260° F. air temperature, most subjects voluntarily changed from nasal breathing to mouth breathing, and at 300° F. air temperature, mouth breathing also became uncomfortable. Among clothed subjects, higher tolerances were realized when more numerous layers or greater thicknesses were worn. The best protection was given by a heavy coverall which had an aluminized outer surface, worn with protective boots, gloves, and helmet.

236. Webb, P.

EXPOSURE TO AERODYNAMIC HEATING TRANSIENTS.

American Society of Mechanical Engineers.

Paper no. 59-A-211.

This paper presents experimentally determined tolerance times for men with varying protection exposed to radiant wall temperatures as high as 550°F, where the temperature increased to maximum in 3 to 15 min.

237. Webb, P.

Protection of man against transient exposure to high heat loads. ADVANCES IN ASTRONAUTICAL SCIENCES v. 4, p. 418-419, 1959.

238. Webb, P.

Temperature stresses. In AEROSPACE MEDICINE. H. G. Armstrong, ed. Williams & Wilkins Co. p. 324-344, 1961.

239. Webb, P.

WHOLE BODY EXPOSURE TO TEMPERATURES ABOVE 250°F. Presented at 44th Annual Meeting of Federation of American Societies for Experimental Biology, Chicago, Illinois, 11-15 Apr 60.

240. Webb, P., Garlington, L.N. and Schwarz, M.S.
Insensible weight loss at high skin temperatures. J. APPL. PHYSIOL. v. 11, p. 41-44, 1957.

241. White, C.S.
TEMPERATURE AND HUMIDITY. Lovelace Foundation for Medical Education and Research, 29 Apr 54, 1v. ASTIA AD-158-985

Data concerning human tolerances are summarized. With clothing insulation values of 1, 2, 3, and 4 clo, 2 hr are tolerable at 58°, 30°, 8°, and -20°F, respectively; 6 hr are tolerable at 64°, 44°, 25°, and 7°F, respectively; 12 hr are tolerable at 65°, 48°, 29°, and 13°F, respectively; and an indefinite period is tolerable at 67°, 51°, 36°, and 20°F, respectively. High temperatures are more critical on human beings than low temperatures. Men wearing shorts tolerated 235°, 200°, and 160°F for 20 to 30, 30 to 45, and 40 to 90 min, respectively. Men wearing 1.0 to 0.5 clo over periods of 0.5, 1.0, 2, 4, and 12 (estimated) hr tolerated 144°, 137°, 128°, 117°, and 107°F effective temperature, respectively, at 10% Rh and 94°, 91°, 96°, 91°, and 86°F effective temperature, respectively, at 90% RH.

242. White, C.S.
TEMPERATURE AND HUMIDITY. ADDENDUM. Lovelace Foundation for Medical Education and Research. 30 Apr 54, 9p.
ASTIA AD-158 986

PART IX

HYPOTHERMIC ZONE NON-COMPENSABLE

243. Adams, T. and Heberling, E.J.
Human physiological responses to a standardized cold stress as modified by physical fitness. JOUR. APPL. PHYSIOL. v. 13, p. 226-230, 1958.

The effects of a standardized cold stress were measured on five adult, male Caucasian volunteers before and after an extended physical training program designed to increase the levels of physical fitness. Rectal, average skin and extremity temperatures and whole body metabolic rates were determined at 5-minute intervals throughout a 1-hour exposure of the nude subjects to an ambient temperature of 50°F (10°C). Physical fitness scores were measured, using a treadmill to ascertain the efficacy of a 3-week physical training program between the cold room exposures. After the physical training program, during which physical fitness levels were significantly increased, average levels of heat production were 15 $Cal/hr/m^2$ higher, mean rectal temperatures were 0.5°C lower, average skin temperatures 1.0°C higher and foot and toe temperatures 3.0 and 4.0°C higher, respectively, with no significant differences in average body temperatures throughout the cold room exposures. These data indicate that many of the currently accepted indices of cold acclimatization may be produced by changing levels of physical fitness alone.

244. Adolph, E.F.
BASIC QUANTITATIVE STUDIES OF SEVERE HYPOTHERMIA. Rochester U. School of Medicine and Dentistry. 1 June 61, 16p. (Contract DA 49-007-md-155). ASTIA AD-257 482.

Small mammals, especially rats, were exposed to cold air or to surface cooling. Adaptation was induced by significant cooling, and four criteria of adaptation were employed to investigate its onset and decay. Hypothermia of 2 to 10°C could be endured for about 1 hr and at higher temperatures up to 25°C for progressively longer times, even 72 hours. In each instance survival after

244. (Cont'd)

rewarming was required as criterion of endurance. Oxygen supply to tissues was especially investigated; oxygen was transported by the blood as long as the circulation continued, the heart usually reversibly ceased to heat at 7°C. But the oxygen was found not to reach all tissues, as was seen in the cessation of blood flow at 10, -15°C in some minute vessels, and in the frequent failure of a tissue oxygen electrode to vary its apparent oxygen tension when the lungs were filled with oxygen or with nitrogen. Several processes were affected disproportionately by cooling so that distortion among them resulted.

245. Adolph, E.F., et al

A STUDY OF TEMPERATURE REGULATION, HEAT EXCHANGE, AND TOLERANCE OF MAN AND WARM BLOODED ANIMALS ON EXPOSURE TO COLD.

AMC Memorandum rept. MCREXD-696-113C, 3 Nov 48.

In four parts:

1. Effects of cold on infant rats: body temperature, oxygen consumption, electrocardiogram.
2. Tolerance to cold and anoxia in infant rats.
3. Lethal limits of cold immersion in adult rats.
4. Acute hypothermia in guinea pigs.

246. Angelakos, E.T.

Distribution of terminal temperatures in hypothermic dogs. PROC. SOC. EXPTL. BIOL. AND MED. v. 97, p. 107-108, 1958.

247. Baker, P.T. and Farrington, D., Jr.

Relationship between skinfold thickness and body cooling for two hours at 0.5 C. J. APPL. PHYSIOL. v. 8, p. 409-416, 1956.

248. Barnett, S.A., Coleman, E.M. and Manly, B.M.

Oxygen consumption and body fat of mice living at -3°C. QUART. JOUR. EXPTL. PHYSIOL. v. 44, p. 43-51, 1959.

Mice of strain A2G, living and breeding in an environment at -3°C., have a resting metabolic rate about four times that of controls at 21°C. The corresponding figure for mice of strain C57BL is more than three times that of the controls. In the warm environment C57BL mice have a higher metabolic rate than A2G mice, but in the cold the A2G mice have the higher rate. Abdominal adipose tissue per unit body weight is much lower in the cold in strains A2G and A, but not in strain C57BL. Total body fat in strain A2G is much lower in the cold than in the warm, but is not significantly different in strain C57BL. Strain differences in fat content parallel differences in growth: C57BL mice are lighter than A2G and A mice in the warm but not in the cold; A2G and A mice are lighter in the cold than in the warm, while C57BL mice show no significant difference in the two temperatures. In adipose tissue and body fat, mice of strains A2G and A, but not C57BL, are more variable in the warm than in the cold. A hypothesis is advanced to account for this.

249. Bartlett, R.C., Jr.

Stress adaptation and inhibition of restraint induced (emotional) hypothermia. J. APPL. PHYSIOL. v. 8, p. 661-663, 1956.

250. Battista, A.F.

Deep hypothermia in the cat. AMER. J. PHYSIOL. v. 196, n. 2, p. 354-356, 1959.

251. Beaton, J.R. and Hunter, J.

Therapy of acute hypothermia with special reference to urea. A preliminary report.

251. (Cont'd)

BIOCHEMISTRY AND PHYSIOLOGY v. 38,

p. 305-309, 1960.

As part of a long-term study on hypothermia in this laboratory, the comparative efficacies of acetazoleamide, THAM, and urea as therapeutic agents which might offer a measure of control in attaining recovery and survival from acute hypothermia were investigated. With regard to urea, we have observed in a separate study that the levels of endogenous blood urea prior to cooling and when the rectal temperature had reached 13 C were 22 ± 3 mg% (10 rats) and 22 ± 2 mg% (10 rats) respectively, i.e., no change in blood urea level resulted from this cooling. The apparent effectiveness of urea and acetazolemide in preventing development of hind limb paralysis in rats rendered hypothermic and rewarmed is of considerable interest although a precise explanation is not yet available. The present study is preliminary and a great deal of investigation is required to elucidate the best dose of these substances for administration, the time schedule for administration, and, most important, the mechanisms through which these substances bring about their beneficial effects in acute hypothermia.

252. Beavers, W.R.

The use of glycine in hypothermia. In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE, MAR. 1957. New York. Josiah Macy, Jr., Foundation, p. 161-175, 1958.

253. Bering, E.A., Jr., et al

Studies on hypothermia in monkeys. The effect of hypothermia on the general physiology and cerebral metabolism of monkeys in the hyperthermic state. SURG., GYNECOL. & OBSTET. v. 102, p. 134-138, 1956.

254. Berne, R.M.

Cardiodynamics and the coronary circulation in hypothermia. ANN. N.Y. ACAD. SCI. v. 80, n. 2, p. 365-383.

255. Blair, E.

Summary of panel discussion on physiology of hypothermia in the human. ANN. N.Y. ACAD. SCI. v. 80, p. 547-9, 1959.

256. Blumer, W.F.C. and Cole, J.

Various degrees of hypothermia in mice. J. APPL. PHYSIOL. v. 14, p. 987-989, 1959.

Some mice were cooled to a deep body temperature of 15° C; others in ice for an additional twenty minutes to 1° C., still others in ice for forty-five minutes to 1° C. The first group showed no impairment for central nervous system function; the second produced equivocal results; in the third group, transitory impairment occurred in skilled mice; and in others, slowness in acquiring skill. The third group also showed a decrease in weight gain and a mortality rate, especially among the heavier mice. It is inferred that duration as well as intensity of hypothermia is significant, and that a critical point is reached after twenty minutes in ice. Histological examination revealed no central nervous system damage.

257. Boba, A.

HYPOTHERMIA FOR THE NEUROSURGICAL PATIENT. Springfield, Charles C. Thomas, 1960, 124p.

The general concepts, the practical applications, and the technical details of inducing hypothermia are discussed in three chapters. The first chapter deals with the mechanisms of cooling and of heat transfer from the core to the shell of the body. Consideration is given to the effects of hypothermia upon (1) the general metabolism, (2) the cardiovascular system (heart rate, blood pressure, cardiac output, electrocardiogram, and myocardial dynamics), (3) the respiratory system (ventilatory mechanics and oxygen transfer), and (4) the central nervous system (brain volume, cerebro-spinal fluid pressure,

257. (Cont'd)

venous pressure, and inflammatory and reparative response patterns to standard injuries). With these general concepts as guides, the second chapter presents a practical basis for inducing hypothermia and gives consideration to the following: the effect of anesthetic agents on the mechanism of cooling; the importance of the interrelationship of body mass, cardiac output, and skin circulation on the determination of rate and depth of body temperature changes; the predictability of body temperature changes and the degree of reproducibility; the detection of shivering; the detection of metabolic or respiratory acidosis and fluid imbalance; and the hazards of hypothermia. In the third chapter, a hypothetical case of hypothermia is followed from preliminary preparations to the rewarming and recovery stage.

258. Bok, S.T. and Schade, J.P.

Hypothermia and cerebral activity. ACTA PHYSIOL ET PHARMACOL. NEERLAND v. 6, p. 775-794, 1957.

Recordings of electro-corticograms in rats showed that between 37-31° C there is a decrease in the number of vibrations per second and an increase of their amplitude (hyper-active state). Around 31°C there is a difference in the ratio between number of vibrations and their amplitude (hypo-active state) and between 31 and 18°C both frequency and amplitude decrease (inactive state). The findings are recorded on a so-called iso-ohm graph. With a cerebral ischemia of 1 minute at 30°C the recovery time is the shortest. Some points of difference and similarity between effects of anesthetics and of hypothermia are indicated, and it is suggested that the iso-ohm graph could be a significant aid to the surgeon making use of hypothermia.

259. Brooks, C.M.

Functional processes in the heart and the possible effects of hypothermia. ANN. N.Y. ACAD. SCI. v. 80, n. 2, p. 332-335, 1959.

260. Bryce-Smith, R., Epstein, H.G. and Glees, P.

Physiological studies during hypothermia in

260. (Cont'd)

monkeys. J. APPL. PHYSIOL. v. 15, p. 440-444, 1960.

Rhesus monkeys were subjected to hypothermia (20° C.) after initial, light anesthesia. Heart rate, EEG and minute volumes during spontaneous respiration were recorded. With cooling there was a progressive fall in heart rate, respiratory rate and minute volume unrelated to the type of anesthetic agent (quantitatively administered ether or i.v. pentobarbitone). Spontaneous EEG waves disappeared at 23° C. following initial anesthesia with pentobarbitone, but persisted to 19° C. after ether anesthesia. Bemegride injected into the hypothermic monkeys caused activation of the EEG. It is concluded that similar procedures could be applied with safety to human subjects for psychiatric purposes.

261. Cardi, L.

Functional changes of the heart during hypothermia. ANGIOLOGY v. 7, p. 171-178, 1956.

262. Carlson, L.D., et al

Immersion in cold water and body tissue insulation. J. AVIATION MED. v. 29, p. 145-152, 1958.

263. Colizzi, Cesare, and Baglioni, A.

Experimental investigation on the physiopathology of the arterial circulation in hypothermia. RIV. BIOL. (PERUGIA) v. 51, p. 169-181, 1959. (In Italian)

Maximal arterial pressures were recorded in response to a number of sympathomimetic drugs given to anesthetized dogs before and during experimental hypothermia. The animals reacted normally to all drugs tested, including nor-adrenalin while in deep hypothermia (rectal temperature of 23°C). However, a consistent lag was noted before drug response, and the intensity and duration of the drug response were increased in the cold-treated dogs. Stimulation of

263. (Cont'd)

the hypertensive reflex by occlusion of the carotid, anoxia or vagal stimulation caused no pressure changes in hypothermic dogs. These last observations agree well with theories of central paralysis following deep hypothermia. The unexpected responsiveness to drugs may be explained by increased sensitivity of the vascular walls to the drugs following more general cardio-circulatory modifications, while duration of the response may be due to a decreased rate of enzymic oxidation.

264. Cooper, K.E.

The circulation in hypothermia. (In HYPOTHERMIA AND THE EFFECTS OF COLD.) BRIT. MED. BULL. v. 17, p. 48-51, 1961.

General circulatory considerations cardiac output, coronary blood flow, retional blood flow changes and cardiac arrhythmias in hypothermia are reviewed.

265. Covino, G.

Some observations on ventricular fibrillation in acute hypothermia. In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE, MAR 1957. New York, Josiah Macy, Jr., Foundation p. 135-159, 1958.

266. Covino, B.G. and Hegnauer, A.H.

Ventricular excitability during hypothermia and rewarming in the dog. PROC. SOC. EXPTL. BIOL. AND MED. v. 89, p. 659-662, 1955.

267. D'Amato, H.E., Kronheim, S. and Covino, B.G.

Cardiovascular functions in the dog rewarmed

267. (Cont'd)

rapidly and slowly from deep hypothermia.

AMER. JOUR. PHYSIOL. v. 198, p. 333-335, 1960.

Heart rate, blood pressure, cardiac output and cardiac minute work were measured in pentobarbitalized dogs prior to induction of hypothermia, at rectal temperatures of 25°C or 20°C, and following rapid rewarming in warm water or slow rewarming by wrapping in heated sheeting. During rapid rewarming from either 25°C or 20°C no consistent failure in recovery of normal cardiovascular function was observed although 1 out of 10 dogs did suffer cardiovascular collapse during rapid rewarming. Slow rewarming from 25° and 20°C resulted in consistent failure of some or all of these functions to recover to prehypothermic levels. Moreover, 5 out of 15 slowly rewarmed dogs suffered cardiovascular collapse during the rewarming process. In five dogs slowly rewarmed from 20°C, saline was infused into the superior vena cava. This procedure resulted in moderate increases in blood pressure butdramatic increases in cardiac output and minute work (200% and 270%, respectively), thereby negating myocardial failure as the primary cause of the occasionally observed cardiovascular failure.

268. Eckenhoff, J.E.

The physiology of hypothermia. BULL. N.Y. ACAD. MED. v. 34, n. 5, p. 297-302, 1958.

269. Fairley, H.B.

Metabolism in hypothermia. (In HYPOTHERMIA AND THE EFFECTS OF COLD). BRIT. MED. BULL. v. 17, p. 52-55, 1961.

The material covered in this review article includes the following: I. Oxygen consumption in relation to requirement, II. Oxygen requirements of individual organs, III. CO and acid-base balance in hypothermia and IV. The effects of circulatory occlusion.

270. Farrand, R.L. and Horvath, S.M.

Body fluid shifts in the dog during hypothermia.

AMER. J. PHYSIOL. v. 197, p. 499-501, 1959.

The rectal temperature of dogs was reduced to 27° C. and stabilized at this level for a period of at least 3 hours. The heart rate, blood pressure,

270. (Cont'd)

respiration rate, blood volumes, extracellular volume (thiocyanate space), and total body water (antipyrine space) were recorded during the reduction in temperature and the period of stable body temperature. No change was observed in the mean arterial pressure during any period of hypothermia; the heart rate decreased exponentially during the reduction in body temperature but remained constant during the stable period. Blood volume increased during the initial stages of hypothermia (33°C to 36°C.) and remained at this level. Hematocrit and erythrocyte volume followed the same pattern as total blood volume, with no alteration in the plasma volume. There were no shifts in the extra-cellular or intracellular volumes at any time during the hypothermic state.

271. Ferrer, I.M.

Cold injury. In TRANSACTIONS OF THE 4TH CONFERENCE NOV 7,8,9, 1955. N.Y. Josiah Macy Jr. Foundation, 1957, 371p.

272. Freezing experiments. In TRIALS OF WAR CRIMINALS BEFORE THE NUERNBERG MILITARY TRIBUNALS, VOL I, THE MEDICAL CASE. U.S. Government Printing Office, p. 198-278, 1949.

Testimony and documents introduced at the Nuremberg War Crimes Trial concerning the freezing experiments conducted on inmates at the Dachau concentration camp from 1941 to 1943. These experiments had the avowed purpose of developing equipment to aid in survival of downed pilots in the North Atlantic. Detailed data was collected on body temperatures and skin temperatures of subjects exposed in both near freezing water and winter air. Time between exposure and unconsciousness or death was measured with a gruesome precision. Experiments on rewarming techniques including some rather novel ones are also reported.

273. Fruehan, A.E.

Accidental hypothermia. Report of 8 cases of subnormal body temperature due to exposure. AMA ARCH. INTERN. MED. v. 106, p. 218-229, 1960.

274. Hamilton, C.A.

PERIPHERAL CIRCULATORY RESPONSES TO

INDUCED HYPOTHERMIA IN DOG AND MAN.

Ph.D. Thesis. Univ. of Nebraska. 1958.

275. Hammel, H.T., Wyndham, C.H. and Hardy, J.D.

Heat production and heat loss in the dog

at 8-36°C environmental temperature.

AMER. JOUR. PHYSIOL. v. 194, p. 99-108,

1958.

Metabolic and thermal responses of three dogs were made in a rapid responding calorimeter at temperatures ranging from 8°C to 36°C. These dogs were acclimatized to a kennel temperature of 27°C and had critical temperatures between 23°C and 25°C. The only physiological responses to low environmental temperatures were a moderate decrease in total heat content and an increase in heat production. The tissue conductance and the cooling constant of the fur did not effectively decrease below the levels obtaining throughout the neutral zone. In a hot environment heat loss from the respiratory tract was greatly increased. Although there was a great increase in the tissue conductance in the hot environment, conductance of heat through the tissue became decreasinly important as the air temperature approached body temperature so that panting became increasingly important for maintaining thermal balance. It is concluded that the vasomotor response of the peripheral vascular system is primarily a mechanism for dissipating excess heat produced during exercise; it is practically unimportant as a heat conserving mechanism. Effective changes in the total insulation of the fur can only be achieved by changing the surface area of the body, particularly those areas which are thinly furred, and not by any important change in the fur thickness through pilomotor activity.

276. Haterius, H.O.

EXPERIMENTAL HYPOTHERMIA AND REWARMING

IN THE DOG: RECOVERY AFTER SEVERE

REDUCTION IN BODY TEMPERATURE. AMC

Memorandum Report MCREXD-696-113,

5 Feb 48.

277. Hegnauer, A., II.
THE INFLUENCE OF IMMERSION HYPOTHERMIA ON THE CARDIOVASCULAR SYSTEM AND ON WATER DISTRIBUTION AND BLOOD VOLUME IN THE DOG.
USAF Technical Report 6567, Feb 52.

278. Hegnauer, A.H.
Lethal hypothermic temperatures for dog and man. ANN. NEW YORK ACAD. SC. v. 80, p. 315-319, 1959.

The mean lethal temperature for the anesthetized dog subjected to cold-water immersion hypothermia is approximately 17° C.; for unanesthetized man it is approximately 27° C. A somewhat lower value is obtained for man exposed to cold air. The nature of death in unanesthetized man appears to be caused by ventricular fibrillation, whereas in the anesthetized dog it may be caused either by ventricular fibrillation at any temperature below 25° C., or asystole in the range of 18° to 14° C.

279. Hegnauer, A.H.
VENTRICULAR FIBRILLATION IN THE HYPOTHERMIC DOG: A STUDY OF UNDERLYING CAUSES AND MEANS OF CONTROL. WADC Tech. Rept. 55-79, Feb 55.

280. Hercus, V., Cohen, D. and Bowring, A.C.
Temperature gradients during hypothermia. BRIT. MED. JOUR. v. 5135, p. 1439-1441, 1959.

Simultaneous temperature records were taken in rectum, lower third of esophagus, nasopharynx, right atrium and cerebral cortex of sheep during hypothermia and re-warming. The esophageal temperature most closely parallels that in the cerebral cortex while the rectal temperature is often considerably lower.

281. Hoffman, B.F.
Hypothermia and vulnerability. ANN. N.Y. ACAD. SCI. v. 80, n. 2, p. 348-350.

282. Kalikhman, A.A.
Changes of conditioned reflexes in rats in cases of general hypothermia. ZHURNAL VYSSHEI NERVNOI DEIATEL'NOSTI (MOSKVA) v. 9, p. 291-295, 1959. (In Russian, with English summary)

This experiment studied the changes in the conditioned motor reflexes (food) of white rats under general hypothermia. A momentary drop of body temperature to 27° C. did not cause a major disturbance of the conditioned reflexes. A drop to 22° C. eliminated some conditioned reflexes and reduced the magnitude of the others. A further drop in the body temperature below 22-20° C. was accompanied by a complete disappearance of the conditioned reflexes.

283. Kao, F.I. and Schleg, B.B.
Impairment of gas transport and gas exchange in dogs during acute hypothermia. J. APPL. PHYSIOL. v. 9, p. 387-94, 1956.

284. Kaufman, N., Gavan, T.L. and Hill, R.W.
The effects of prolonged hypothermia on the rat. ARCH. PATHOL. v. 66, p. 96-99, 1958.

In rats whose body temperature was maintained between 18°-20°C for periods varying from 2-23 hr., no significant alterations occurred in succinic dehydrogenase, cytochrome oxidase and alkaline phosphatase activities in heart, liver or kidneys compared with the activities of these enzymes in warm animals. No alterations were noted in fat content of adrenals, kidneys or liver. A loss of liver glycogen and an increase in myocardial glycogen were the only positive findings that could be demonstrated histochemically in hypothermic animals.

285. Keatinge, W.R.

The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water.

JOUR. PHYSIOL. v. 153, p. 166-178, 1960.

The fall in rectal temperature of ten young men immersed motionless for 30 minutes in stirred water at 15°C. varied little in successive immersions and was closely related to the man's subcutaneous fat thickness. The falls bore relatively little relation to finger blood flow, which was always low during immersions, but both were slightly greater when the men were hot rather than cool at the time of immersion. Metabolic rates during immersion were substantially lowered by a small increase in body temperature at the time of immersion, and increased by exposure to cold air, though not by moderate exercise several hours before immersion. In the first 10 minutes of immersion the metabolic rates of thin men were slightly higher than those of fat men, with a number of substantial and consistent individual differences not related to fat thickness or fall in rectal temperature. In the last 20 minutes of immersion the metabolic rates of thin men increased but those of fat men did not.

286. Keatinge, W.R. and Evans, M.

Effect of food, alcohol, and hyoscine on body-temperature and reflex responses of men immersed in cold water. LANCET (LONDON) v. 2, p. 176-178, 1960.

Administration of 75 ml. alcohol, a heavy meal, or hyoscine to men 45 minutes before immersion for 30 minutes in water at 15° C. had no significant effect on the rate of fall of rectal temperature during immersion. Finger blood flow fell rapidly to low levels in the water, but fell significantly less rapidly after alcohol. The occurrence of ventricular extrasystoles was increased after hyoscine or a heavy meal; no extrasystoles were observed after alcohol. Both metabolic rate and the increase in heart rate during immersion were reduced by alcohol or hyoscine. Alcohol greatly reduced discomfort and sensation of cold in the water.

287. Kreider, M.B.

Death from cold. Body temperature

and physiological change in man during

fatal exposure to non-freezing cold.

APPALACHIA v. 33, n. 1, p. 1-3, 1960.

The ability of man to live in the cold depends largely on his ability to decrease the rate of heat lost from his body through radiation, conduction, convection, and evaporation. Physiological adjustments, such as vaso-construction, shivering, and muscular exercise contribute to his survival to a lesser degree. When heat is lost from the body faster than it can be produced, body temperature must drop. This may occur at temperatures considerably above freezing and will depend largely on the amount of insulation and wind involved. The body can tolerate changes in core temperatures of only a few degrees below 99°F, without noticeable physiological and functional deterioration. Below a core temperature of 86°F psychological contact with the world around is lost. Below 80°F many functions cease and death is imminent. Rewarming should be either very fast or very slow. However, fast rewarming will remain impossible in a field situation until a method is developed.

288. Lewis, F.J.

PROLONGED HYPOTHERMIA. School of

Aviation Medicine. Rept. no. 61-45,

Apr 61, 5p. ASTIA AD-257 291

An automatic control system was used to maintain the body temperature of dogs below 25°C. for 20 hr. Once this low temperature was reached no anesthesia other than hypothermia was required. Blood pressure and pulse rate remained low throughout the cooling periods and as time passed the hematocrit rose, plasma volume fell, pH fell, and venous oxygen saturation fell. Of the 98 dogs cooled in this fashion, 31 survived rewarming. A number of agents and medications have been used in trying to increase the survival rate. Best results were achieved with the most recent technic which features a number of small changes such as deeper anesthesia during induction of hypothermia. Reserpine also may have contributed to a higher survival rate.

289. Love, A.H. and Wormsley, R.A.

Accidental hypothermia. ULESTER MED.

J. v. 28, p. 193-6, 1959.

A case of accidential hypothermia is reported. The diagnosis may be over-looked unless a low-reading thermometer is used. Certain precipitating

289. (Cont'd)

causes are usually evident and a social history may be informative. In the treatment, slow rewarming is indicated if the period of hypothermia is longer than a few hours. Supportive measures to combat hypoglycaemia and adrenal failure are indicated. It is probable that the condition is commoner than is generally recognized.

290. Lovelock, J.E. and Smith, A.U.
Heat transfer from and to animals in experimental hypothermia and freezing.
ANN. N.Y. ACAD. SCI. v. 80, p. 487-99, 1959.

291. Marchand, P. and Allan, J.C.
An experimental study of the effect of hypothermia on the heart and brain.
S. AFRICAN JOUR. MED. SCI. v. 3, p. 127-141, 1956.

292. Marion, P., et al
Hemodynamic, thermodynamic and hematological data in deep hypothermia.
MEM. ACAD. CHIR. v. 86, p. 462-8, 1960.
(In French)

293. Metelitsa, V.I., Kaminskaya, L.R. and Chelukhova, Ye.M.
Investigation of gaseous exchange during hypothermia. EKSPERIM. KHIRURGIIA
p. 24-31, 1956. (In Russian)

During physical and combined cooling of 20 dogs to 35°-27° and lower, gaseous exchange dropped with the drop in temperature. Ventilation of the lungs fell faster than the O_2 requirement. Warming usually led to a sharp increase

293. (Cont'd)

of gaseous exchange. Below 35° fibrillary twitchings appeared in voluntary and smooth musculature. With the beginning of warming the trembling disappeared. Gaseious exchange and ventilation subsequently increased with the trembling and dropped sharply during its cessation. Considering the trembling to indicate absence of sufficient inhibition of the CNS, the authors deny the onset of the "cold narcosis" at a body temperature of 28°. The delays of the fall of the body temperature noted in stages of cooling were accompanied by temporary rise of the O2 requirement. Proteins and fats are used mainly with hypothermia under narcosis. Loss of weight by the animals at the end of the experiment, maximally 3.1%, is not only due to the loss of moisture but also due to energy waste during hypothermia.

294. Mills, A.W.

Finger numbness and skin temperature.

J. APPL. PHYSIOL. v. 9, p. 447-450, 1956.

295. Morton, R. and Provins, K.A.

Finger numbness after acute local exposure to cold. J. APPL. PHYSIOL. v. 15, p. 149-154, 1960.

The index finger of twenty subjects was exposed to air at -22° C, and a wind speed of 300 feet/min. until the indicated skin temperature fell to -5° C. The finger was then returned to room temperature conditions (19° C.) and the subject tested on each of two tasks involving tactile discrimination (two-edge discrimination and reproduction of finger pressure) until the finger had fully recovered. The degree of impairment on both sensorimotor tasks at a given skin temperature varied appreciably from subject to subject, although most subjects showed little impairment above about 8° C. Suddenness of recovery of two-edge discrimination in those subjects experiencing a marked impairment of tactile discrimination with cold exposure was suggested by the L-shaped curve of the relationship between numbness index and skin temperature. The evidence suggests that while finger numbness as measured by Mackworth's V-test may indicate a corresponding impairment of performance in accuracy of pressure reproduction, testing subjects on either task at normal skin temperature will have little predictive value for their relative performance after cold exposure in the present situation.

296. Nardone, Mario, R. and Caravaggio, L.L.

Relation between lethal cold temperature and respiration of excised tissues. J. EXP. ZOOL. v. 131, p. 163-172, 1956.

297. Ogata, K., et al

Oxygen consumption in relation to thermal sensation on cold exposure.

JAPANESE JOUR. PHYSIOL. v. 8, p. 193-205, 1958.

A lepromatous patient with a widespread dermal lesion in which thermal sensations were extensively affected was exposed to cold. The patient complained little, unlike a healthy control, of the cold for the 1st several minutes. The body temperature of the patient was steadily falling and after about 15 minutes when the fall of the temperature exceeded 1 deg. C, the patient began to suffer a chill and oxygen consumption showed a marked increase. When the rectal temperature of a healthy man was lowered with a cold water bath the threshold of warmth on the flexor surface of the forearm suffered no change as long as the skin temperature was maintained at the same level, while the threshold of hot pain became higher and the threshold of cold pain became lower. For comparison, reactions in each stage of cold exposure leading to death was observed in an unanesthetized rabbit. (A) EEGs of the post-central cortex, subcortex and thalamus showed very similar patterns though taken from different levels of the brain. The electrical activity of the brain was considered in relation to EMG and heat production, and a momentous change was highly conceivable at the rectal temperature level of 28-26°C. (B) Sensory EEG arousal response revealed that the ascending reticular system was hyperresponsive in a rectal temperature zone of 34-30°C and below it the system reacted less. (C) The frequency of EEG from the sympathetic zone began to increase below the rectal temperature level of 37 or 36° C. A peak which was reached at 33-30° C was followed by a progressive decrease. The frequency of the parasympathetic pattern did not increase until the rectal temperature fell down below 33-31°C. A peak of increased frequency at 28-27°C was followed by a gradual decrease. A transient rise was observed on both EEGs in the excitation stage before death.

298. Popovic, V.

Survival time of hypothermic white rats (15°C.) and ground squirrels (10°C.).

AMER. JOUR. PHYSIOL. v. 199, p. 463-466, 1960.

The "biological survival time" in which rewarming from a stable body temperature of 15° C could be successfully accomplished was found to be 5.5 hours in adult rats. Biological survival time was unaffected by the rate of rewarming or by the time required (from 15 minutes to 6 hours) for cooling to 15° C. by Giaja's

298. (Cont'd)

confinement technique by submersion in ice water, or by cooling in cold air or by confinement after administration of insulin or chlorpromazine. Survival time was shortened by starvation for 2 or more days before cooling, by administration of sodium pentobarbital, and by decreases in body temperature below 15° C. The biological survival time of your 40-g. rats at 15° C. was 19 hours, and their oxygen consumption by weight was two and one-half times that of adult rats.

299. Provins, K.A. and Morton, R.

Tactile discrimination and skin temperature.

J. APPL. PHYSIOL. v. 15, p. 155-160, 1960.

The index finger of ten subjects was immersed in water at 0.75° C. for 40 minutes. Two-edge threshold discrimination was tested during cooling of the finger and subsequent spontaneous rewarming due to cold vasodilation. There was a marked deterioration of tactile discrimination at finger skin temperatures below about 8° C., although the curve showing the mean decrease of numbness with increasing skin temperature was displaced relative to the curve showing the mean increase of numbness with decreasing skin temperature. Tactile discrimination was also tested on five subjects at each of six water bath temperatures (2°, 4°, 6°, 8°, 15° and 30° C.). At each temperature the finger was immersed for 20 minutes and the finger circulation arrested after the first 5 minutes. There was little impairment of two-edge discrimination after 15-20 minutes immersion of the finger at temperatures of 6° C. or higher. At 4° C. there was marked impairment, and at 2° C. all subjects experienced complete numbness at the test site. It is suggested that the possibly differential effect of cold on sensory nerve endings in human skin may permit impulse conduction until the block is almost complete, at which point the sudden impairment of tactile discrimination noted is precipitated.

300. Roe, Benson, B. and Weirich, W.L.

Total and regional hypothermia with extra-corporeal circulation. CIRCULATION v. 22 (4 pt. 2) p. 800, 1960.

301. Sarajas, H.S., Nyholm, P. and Suomalamen, P.

Stress in hypothermia. NATURE v. 181, p. 612-613, 1958.

302. Severinghaus, J.W.
Temperature gradients during hypothermia.
ANN. N.Y. ACAD. SCI. v. 80, p. 515-21, 1959.

303. Spurr, G.B., et al
Shivering, oxygen consumption and body temperatures in acute exposure of man to two different cold environments.
J. APPL. PHYSIOL. v. 11, p. 58-64, 1957.

304. Starkov, P.M., (ed)
THE PROBLEM OF ACUTE HYPOTHERMIA.
(Trans. from Russian) Pergamon Press.
319p.

305. Suda, I., Kozumi, K. and Brooks, C.M.
Analysis of effects of hypothermia on central nervous system responses.
AMER. J. PHYSIOL. v. 189, p. 373-380, 1957.

306. Saburo, U.
Experimental studies on the hypothermic narcosis. Part I. On the normal process.
SHIKOKU ACTA MED. v. 10, p. 464-470. 1957. (In Japanese with English summ.)

Interference with the introduction of hypothermia is principally due, in the initial stage to the occurrence of shivering and in the terminal stage to

306. (Cont'd)

the insufficiency of both respiratory and circulatory systems. Shivering in rewarming is more intense than that caused by the introduction of hypothermia. Pulse rate in the initial stage of hypothermia increases, then decreases. In rewarming, at about 35°C rectal temperature, various reflexes reappear and among these the most acute one is the response to sound stimulus.

307. Saburo, U.

Experimental studies on the hypothermic narcosis. Part 2. On the gaseous exchange.

SHIKOKU ACTA MED. v. 10, p. 471-477, 1957.

(In Japanese with English summ.)

O_2 consumption decreases, rectal temperature 32-33° C being the point of inflexion. CO_2 production decreases considerably at the time of onset of narcosis. Due to the refrigeration and autonomic block, respiratory quotient decreases to 0.6-0.7.

308. Saburo. U.

Experimental studies on the hypothermic narcosis. Part 3. Dynamic aspects of blood gas. SHIKOKU ACTA MED. v. 10, p. 478-484, 1957. (In Japanese with English summ.)

In artificial low temperatures the respiratory as well as circulatory organs are interfered with so that anoxia as well as hypercapnia become grave. Blood gases of dogs subjected to hypothermia of about 28°C through the Autonomic Block method showed decrease of arterial O_2 content and of arterial O_2 saturation. This phenomenon is presumed to be caused by ventilatory decrease of gaseous exchange. The difference of O_2 content in the artery and in the vein decreases as the temperature lowers, and with the appearance of shivering it reverses. In the low temperature, arterial CO_2 content increases. Artificial respiration and O_2 inhalation prevent these changes.

309. Saburo, U.

Experimental studies on the hypothermic narcosis. Part 4. On the anticipation and prevention of the appearance of shivering. SHIKOKU ACTA MED. v. 10, p. 485-491, 1957. (In Japanese with English summ.)

To prevent shivering the author gives a venous injection of 45 mg/kg of Omropansoda to adult dogs (7.5-16.5 kg), which were left in room temperature D. B. T. 9.0-12-5°C. Correlations between the distributions of temperature in the skin of head, breast, paw as well as rectum and liver were made during awaking from anesthesia and the appearance of shivering. Rates cooling were: ear > paw > head > breast > rectum. Of the skin temperatures of various parts of the body, those in ear and in paw show large fluctuations. The fluctuations $\Delta(T_R - T_E)$ observed as hourly differences between rectum and ear, are always present before the appearance of shivering.

310. Ware, G.W.

Hypothermia. MED. ANN. DIST. COLUMBIA v. 24, p. 333-344, 1955.

PART X

HEAT AND/OR COLD RESISTANT CLOTHING INCLUDING VENTILATED PRESSURE SUITS

311. Burton, A.C.

Clothing and heat exchanges. FED.

PROC. v. 3, p. 344-351, 1946.

A survey of the thermal insulation (clothing) requirements of man for performance in hot or cold environments.

312. Comfort, E.

EFFECTIVE DEAD SPACE IN THE MA-3 HELMET.

Wright Air Development Division.

WADC-TR-60-362, May 60, 4p.

The respiratory response of a group of subjects wearing the MA-3 full-head helmet was compared with the response to known dead space volumes. Comparison of these data showed that the average effective dead space or volume of rebreathed air was approximately 235 cc. when the Ma-3 helmet was supplied with oxygen at 3 to 4 inches of water positive pressure from a standard pressure suit regulator. The concentration of inspired CO_2 was calculated to be o.8 percent.

313. Edwards, M. and Burton, A.C.

Temperature distribution over the

human head, especially in the cold.

JOUR. APPL. PHYSIOL. v. 15, p. 209-211,

1960.

Two separate practical problems are the reduction of the total heat loss of the head, as by insulated helmets, and protection from frostbite, as by face masks. Solution of both problems benefits from knowledge of the distribution of skin temperature. Temperatures were measured with thermo-

313. (Cont'd)

couples at several points on three subjects, in the steady state, at environmental temperature of 0 °C. Topographical differences were similar for the three subjects. Temperatures at a large number of points were measured in a single subject, and isothermal maps were drawn from the results. They show that the areas needing most protection from frostbite are the nose, the rim of the ears, the chin and the cheekbones. The areas of highest temperature (greatest heat loss) are those covered by the conventional insulated helmets. A face mask need not cover the area round the mouth where tactile sensitivity may make it uncomfortable. The isothermal map is correlated with the anatomical distribution of arterial blood supply.

314. Equipping man for a flight to the moon.

ENGINEERING, (LONDON) p. 634-635, 1960.

A general discussion of the problems of man in space with particular emphasis on methods of protecting man against the extremes of hot and cold.

315. Goodrich, B.F., Aviation Products.

LIGHT WEIGHT FULL PRESSURE SUIT, MARK IV - FITTING, DONNING, OPERATION AND MAINTENANCE INSTRUCTIONS. Rept. no. GPS-59-1, Mar 59, 43p.

The suit system is designed to provide an atmosphere compatible with human existence under several distinct conditions that might be encountered in normal flight or an emergency situation.

316. Hall, J.F., Jr., et al

Body cooling in wet and dry clothing.

J. APPL. PHYSIOLOGY v. 13, p. 121-128, 1958.

Skin, rectal and extremity temperatures of clothing subjects were measured. The subjects were immersed in extremely cold water (0°C) for very brief periods of time, then exposed, while occuping a life raft, to ambient air temperatures ranging from +4.4° to -28.9°C. Amount and partitioning of the water absorbed by the clothing and effects of water immersion upon metabolic level were determined. Total water absorbed during an immersion period of from 15 seconds to 2 minutes amounted to 9-10 pounds. Mean metabolic increase due to wearing wet clothing was 54.7%. Total body heat storage loss was

316. (Cont'd)
measured in both dry and wet clothing exposures and mean body cooling curves plotted. Mean body cooling rates for subjects wearing wet clothing were significantly greater (from 49.3% at -40°C to 22.2% at 10°C) than rates observed with dry-clothed subjects. On the basis of total body heat storage loss, a series of predictive curves for human tolerance is presented for both dry- and wet-clothed subjects exposed in a life raft to various low air temperatures.

317. Hall, J.F., Jr., et al

COOLING OF CLOTHED SUBJECTS IMMERSED IN COLD WATER. WADC Technical Report 53-323, Apr 53, 34p. ASTIA AD-22 232

Average skin and extremity cooling rates of seven human subjects immersed in cold water (32°-39°F) and wearing various amounts of insulation under an outer, water-impermeable, anti-exposure suit were determined in 26 experiments. Reference or control temperature levels were established during a 30 minute pre-immersion exposure to air temperatures ranging from 16° to 40°F. Hand, foot, average skin temperatures and metabolism were measured before and during the immersion period. The subjects were immersed to the neck level (approximately 92% of the body surface) while wearing underlying clothing of 2.3; 3.7; and 4.7 clo insulation respectively. The rates of extremity and average skin cooling were calculated and the results presented in tables and graphs. On a basis of maximum safe exposure time and practical limitation of clothing bulk, the use of a minimum of 3.0-3.5 clo body insulation for cold water immersion protection was indicated. Cooling of the upper extremity, particularly the hands, was extremely rapid and was the chief factor limiting tolerance time during cold-water exposure. In contrast, cooling of the lower extremity, particularly the feet, was neither critical not a limiting factor in this type of cold-water immersion exposure.

318. Hall, J.F., Jr.

HEAT STRESS IMPOSED BY PERMEABLE VERSUS IMPERMEABLE CLOTHING. Technical Note WCRD 52-112, Nov 52, 12p. ASTIA ATI-188 243

319. Hall, J.F. and Polte, J.W.

THERMAL INSULATION OF AIR FORCE CLOTHING.

319. (Cont'd)

A CATALOG AND PART 5 OF A SERIES.

Wright Air Development Div. Rept. no.

WADD TR 60-597, Sep 60, 75p.

ASTIA AD-256 875

Results of the fifth of a series of thermal insulation studies performed with electrically heated hand, foot, head, and entire body models are presented. The experimental data include results obtained with light, medium, and heavy clothing types, as well as with thermal protective items of a specialized nature. A revised catalog listing individually the insulation in clo units of numerous recently developed clothing items is included. These are arranged in order of increasing value in each clothing category (i.e., light, medium, and heavy). Relationship between the measured and calculated thermal insulation of clothing assemblies is shown graphically and correction factors for use with each category of catalogued clothing are graphed. The effect of laundering on thermal insulation of many recent Air Force clothing assemblies is illustrated and discussed.

320. Hanson, H.E. and Dee, T.E., Jr.

THE INFLUENCE OF THERMAL-PROTECTIVE ENSEMBLES ON PHYSIOLOGICAL STRESS IN A DESERT ENVIRONMENT. Quartermaster Research and Engineering Command. Technical rept. no. EP-146, Feb 61, 17p. ASTIA AD-253 202

Sweat production, rectal temperatures, and pulse rates were measured, over a 24 consecutive day period on 9 men while resting or walking in a natural desert summer environment, to assess the heat stress imposed while wearing either a conventional ensemble or thermal-protective ensembles. During rest no significant physiological differences occurred while wearing the various ensembles. During activity (walking) thermal-protective ensembles imposed significantly higher stress levels on the individual than did the conventional ensemble. For example, when the Large Spacer ensemble, with all external vents closed, was worn, rectal temperatures were 101.8 F during the first hour of walking.

321. Hick, F.K., et al

Physiological adjustments of clothed human beings to sudden change in environment-first

321. (Cont'd)

hot moist and later comfortable conditions. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 58, p. 189-198, 1952.

On exposure to a hot humid environment, the subjects perspired freely so that at the end of the first hour the moisture content averaged 490 and 200 grams for the summer clothing and union suit groups, respectively; at the end of the second hour 910 and 390 grams for the respective groups. The rectal and skin temperatures attained slightly higher levels with the added clothing by the end of two hours. On moving from the hot room to the comfortable environment, all subjects felt cool. The skin cooling was less rapid with the added insulation in spite of the greater amount of moisture it contained. The amount of evaporation during the hour was the same regardless of the clothing. The men dressed in standard summer clothing withstood the sudden changes in environment readily and without evidences of strain. The adjustments were made with as much ease as by those men dressed in union suits.

322. Iberall, A.S.

Human body as an inconstant heat source and its relation to determination of clothes insulation: Part I, Descriptive models of the heat source; Part 2, Experimental investigation into dynamics of the source. ASME TRANS 82 D (J. BASIC ENGNG.) v. 1, p. 96-112, 1960.

A precise characterization of the thermal resistance of clothes requires an accurate description of the static and dynamic thermal characteristics of the human-heat source. Experimental measurements on the human have revealed a frequency spectrum of sustained thermal power oscillations that mask theoretical long-time equilibrium adjustments. This points to the number of degrees of freedom that must be involved in the thermoregulation of the human, and the specific nonlinear characteristics of the system. Therefore at best, a resistance model for clothes is possible only as an ohmic relation among time-averaged equilibrium values, and for a specific mode of operation of the system. The validity of this hypothesis, however, has not been proved. Quantitative measurement on the human in the so-called evaporative, vasomotor, and metabolic control regimes has revealed frequency spectrum of sustained

322. (Cont'd)

thermal power oscillations with approximate periods of 2, 7, 35 min. and $3\frac{1}{2}$ hr independent of the regime. Step function adjustments take place with a time constant of about 7 min. It is believed that the $3\frac{1}{2}$ hr cycle represents the shortest equilibrium cycle. The hypothesis that it might be possible to measure the resistance of clothing as an ohmic relation among time-averaged equilibrium values, and for a specific mode of operation of the system has now been put in rational context in the time domain. Two equilibrium modes of the human system were explored. The active mode of operation of the system, to which the resistance concept of clothes is most applicable, is as a feedback system in which the extremities are used as error indicators of deviations from a comfort level set point. In response to deviations, the human feeds back a signal to generate an activity level in which only internal work---immediately degraded into heat---is done to maintain the comfort level. This is referred to as the comfort mode of operation of the system. Another "survival" mode of operation of the system is also described.

323. Iberall, A.S.

Precise measurement of clothes insulation

during controlled operation of the human.

JOURNAL OF BASIC ENGINEERING v. 1,

p. 513-527, 1960.

It has been demonstrated that it is possible to measure the resistance of clothing as an ohmic relation between time-averaged equilibrium values of the flux of power (metabolism) and the potential difference between average skin temperature and ambient temperature. Specifically, this has been demonstrated on the human in what has been referred to as the comfort mode of operation of the human system. In this mode of operation, the metabolic level of activity is changed by signaling command to attempt to maintain a specific control level of the average skin temperature. With control attempted to approximately 0.1°C, sufficient precision has been achieved to resolve 1 or 2 per cent difference in clothes resistance. The dynamic input-output data obtained during clothes measurements are presented.

324. Irvine, T.F. and Cramer, K.R.

THERMAL ANALYSIS OF SPACE SUITS IN ORBIT.

Wright Air Development Division. WADD

Technical Note no. 60-145, May 60, 15p.

ASTIA AD-246 381

The thermal analysis of a model space suit in orbit is presented as a guide for designers and as a basis for more extensive studies for the prediction of a

324. (Cont'd)

suited man's thermal environment in an earth orbit. Calculations show the feasibility of passive suit-temperature control through a wide range of temperatures by the proper choice of materials and surface spectral properties.

325. Little, A.D., Inc.

DEVELOPMENT OF A MEANS TO NEUTRALIZE INTENSE THERMAL RADIATION. Final rept. Jan 58-Sep 60. 31 Oct 60, 104p. (Contract DA 19-129-qm-1087).

ASTIA AD-255 690

An evaluation was made of 5 approaches for neutralizing radiant thermal energy incident upon the outer layer of a clothing system: (1) utilization of foam formation; (2) utilization of heats of reaction; (3) utilization of heats of fusion and vaporization; (4) attenuation of incident radiation through the production of smoke or fog; and (5) utilization of sublimation. Most of the tests were performed in a solar furnace, since the spectral distribution of radiation from the sun closely approximates that from an atomic explosion. A carbon arc was used during instances of adverse weather. Theoretical analyses were made of the laws of transient heat flow to get some indication of the relative importance of endothermy, emissivity, and thermal conductivity in providing protection. Of the 5 approaches, smoke screens had the greatest potential. Materials that sublimed readily to provide dense protective smoke layers included ferrocene and related organo metallics, the metal acetonates, camphor, and the anthraquinone derivatives.

326. McCutchan, J.W.

The prediction of human thermal tolerance when using a ventilating garment with an antiexposure suit. JOUR. HEAT TRANSFER (SER. C) v. 82, n. 3, p. 243-251, 1960.

The physiologic responses of human subjects have been investigated in the thermal environments ranging from 120° to 240° F. while wearing the MA-2 ventilating garment, and MK-IV exposure suit, and other garments comprising 2.15 clo (the unit of thermal resistance for clothing) of thermal resistance. The ventilating garment was given air inputs ranging from 2 to 14 cubic feet per minute in volume, and from 50° to 90° F. in temperature. The thermal responses of the subjects are shown graphically in terms of heat storage, heart rates, sweat rates, and composite indexes of these variables. The

326. (Cont'd)
results of these experiments have been prepared in terms of an equation which is presented as a nomograph. This nomograph predicts the cooling power of the MA-2 ventilating garment and is to be used in conjunction with the tolerance chart. The tolerance data, which were determined on steady exposures in a preheated chamber, are used to predict human tolerance for conditions where the air and wall temperatures are not constant.

327. Santamaria, L.J., Klein, S.J. and Greider, H.R.

The maintenance of thermal comfort in a full pressure suit at simulated altitude. AEROSPACE MED. v. 31, p. 288-295, 1960.

In a factorially designed experiment, three subjects were exposed to different levels of ambient and ventilating temperatures to determine ventilation requirements for comfort maintenance. During experimentation, the subject wore a full pressure suit for two hours at a simulated altitude of 18,000 feet. Additional information was obtained regarding the effects of the experimental conditions on various physiological measures while the subject reported a feeling of comfort. The results indicated that ventilation demands for comfort maintenance increased significantly by an average of 24% (170 LPM) as the ambient temperature was increased from 125 to 150° F. Differences in total weight loss and evaporative weight loss were shown to be affected independently by ambient temperatures, ventilating temperatures and differences between subjects. Interactions for subjects and ambient temperatures and subjects and ventilating temperatures indicated that the effects of the experimental conditions on the total weighted skin temperatures increased significantly by an average of 3.6% (1.25°C) with an increase in ambient temperature from 125 to 150°F.

328. Skilling, D.C., McCutchan, J.W. and Taylor, C.L.

A QUANTITATIVE INVESTIGATION OF THE MA-1 VENTILATING GARMENT WHEN USED WITH A MODIFIED MK-IV ANTI-EXPOSURE SUIT. California U., Los Angeles. WADC Technical rept. no. 56-209, Dec 56, 31p. (Contract AF 33(616)32).

ASTIA AD-110 657

The physiological responses of two human subjects have been investigated in thermal environments ranging from 160° to 240° F while wearing the MA-1 ventilating garment, an MK-IV exposure suit, and other garments comprising

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2.15 clo of thermal resistance. The ventilating garment was given air inputs ranging from 6 to 14 ft^3 per minute in volume, and from 50° to 90°F in temperature. The thermal responses of the subjects are analyzed in terms of heat storage, body temperatures, heart rates, sweat rates and composite indices of these variables. The results of these experiments have been prepared in terms of predictive equations for the physiological responses as dependent variables and the chamber operative temperature, ventilating air volume, and temperature as independent variables. Studies of the mode of protection of the suit, while not definitive, support the view, that protection is a function of both the sensible heat transfer to the ventilating air and the volume of the ventilating air. The protective value of the MA-1 may be rated by comparison to the time tolerance of human subjects in corresponding thermal environments, wearing clothing of conventional thermal resistance; the results indicate a three- to fourfold increase in time tolerance in the thermal transient zone. Tests have also been made of the claim for the MA-1, that thermal protection is afforded up to 165°F ambient temperature, which proves to be justified.

329. Stoll, A.M.

THERMAL PROTECTION CAPACITY OF AVIATOR'S TEXTILES. Naval Air Development Center.

Rept. no. NADC-MA-6120, 22 May 61, 11p.

ASTIA AD-259 076

Since the advent of high-speed aircraft and nuclear warfare, the need for protection of personnel from thermal injury has been greatly emphasized. Among the more immediate aviation needs is that for fire-resistant anti-G clothing. An interim method has been devised for the selection and evaluation of textiles on the basis of their resistance to degradation by thermal irradiation of appropriate intensity and their protective capacity when in contact with living skin. Although field testing is not yet complete, a satisfactory thermally-resistant anti-G suit appears to have been achieved through this effort. This suit is fabricated of DuPont Experimental Fiber HT-1 in a twill weave and double-layer construction. On the basis of percentage of total body burns indicated by fuel flame exposures of clothed dummies, it has proven superior to a double-layer nylon suit and the regulation fire-retarded cotton coverall over the cutaway anti-G suit. The present method is being modified to yield surface temperature measurements during irradiation to provide for the ultimate goal of devising a thermal protection index based on previously established relationships between these temperatures and the tissue damage resulting from thermal irradiation.

330. Turl, T.H.

Clothing for cold conditions.

JOURNAL OF OCCUPATIONAL MEDICINE

v. 2, p. 123-128, 1960.

A discussion of clothing for temperatures below 50° F. Includes information on the mechanisms of body temperature regulation. Two general solutions to the wet-cold clothing problem are given. One is permeable to water vapor on the inside but waterproof on the outside, the other employs the vapor barrier principle.

331. Veghte, J.H. and Webb, P.

CLOTHING AND TOLERANCE TO HEAT. Wright Air Development Center. Rept. no. WADC TR 57-759, Dec 57, 10p. ASTIA AD-142 248

A series of experiments has been conducted to determine the effect of clothing on human tolerance to hot environments (90° to 160° F). Exposures were made in five difference clothing assemblies which were representative of permeable and impermeable, lightweight and heavily insulated AF clothing. The effect of the exposures was measured in terms of physiological strain. These experiments show to what extent impermeable clothing, as compared with permeable clothing, reduces human tolerance to heat, regardless of insulation value. Insulation alone serves a protective function in heat. However, a heavy permeable assembly by addition of several permeable layers proved to be functionally impermeable.

332. Veghte, J.H.

THE MA-2 VENTILATING SUIT AS A PROTECTIVE GARMENT IN COLD. Wright Air Development Center. WADC Technical rept. no. 57-564, Sep 57, 14p. ASTIA AD-131 053

To evaluate the possibility of utilizing the MA-2 ventilating garment, developed by the Aero Medical Laboratory, in heating aircrew members in cold environments, a series of exploratory experiments was undertaken at ambient temperatures of -30°C (-22°F) and -40°C(-40°F). The temperature of the ventilating air was varied from 50°C(122°F) to 60°C(140°F). The volume of the air varied from 290 liters per minute (10 cfm) to 430 liters per minute

332. (Cont'd)
(15 cfm). Two metabolic levels were simulated: a sitting, resting subject representing an aircrew member; and a standing, working subject representing maintenance personnel. Heavy Air Force clothing was worn over the MA-2 garment. The results indicated a person was able to tolerate these cold exposures and remain in thermal balance for three hours while using the ventilating garment as a heating vehicle. All the skin temperature measurements of the body areas with the exception of the feet remained in the comfort zone. The minimum skin temperature of the toes was 5.6°C (42°F) in some of the exposures at the end of three hours. These toe temperatures were not a limiting factor in the experiments.

333. Webb, P. and Klemm, F.K.

DESIGN OF VENTILATED CLOTHING. Wright

Air Development Center. Tech. Rept.

58-608, 1959, 17p.

The purpose of ventilation of clothing is reviewed and the functions of convective and evaporative cooling are described. How to achieve these functions is discussed in detail by describing the principles of proper air distribution, effective evaporation, and full utilization of convective cooling in ventilated clothing assemblies. A description of various ventilating garments is given to illustrate the evolution of principles, and, finally, an "ideal" ventilating system is defined for the difficult problem of ventilated pressure suit assemblies. Tests are described which demonstrate the validity of employing each of the design principles which go into the "ideal" system. The general subjects of low energy ventilating systems and of integration of ventilated clothing assemblies are discussed. Recommendations are made concerning the use and design of ventilation systems for protective clothing.

334. Webb, P.

Human thermal tolerance and protective

clothing. ANNALS NEW YORK ACAD. SCI.

v. 82, p. 714-723, 1959.

Man can well tolerate temperatures of 200°, 300°, 400° C. and perhaps higher for minutes and hours, depending on the heat load and the degree of protection supplied. Excellent protection in the form of clothing is available through the proper use of ventilation, insulation, and reflective coatings. Tolerance can be further extended by cooling off just prior to an expected heat exposure. The result of this knowledge may be that clothing technology will need to advance to meet the special problems of high temperature in the clothing itself. Fabrics and joinings in the outer layers may have to retain strength despite

334. (Cont'd)

a several hundred degree temperature. Gloves for handling hot surfaces, elimination or covering of metal closures and snaps that conduct heat straight to the skin, and special foot-gear with low thermal conductivity are all problems that are already troublesome in our experimental work. The new physiology of man's tolerance to supraclimatic heat poses a new challenge to the clothing industry.

335. Woodward, A.A. and Cummings, E.G.

THE EFFECTS OF HYCAR-TREATED UNDERWEAR ON THE PHYSIOLOGICAL PERFORMANCE OF MEN UNDER HEAT STRESS. Army Chemical Research and Development Labs. Rept. no. CRDLR 3058, Apr 61, 36p. ASTIA AD-255 181

Tests were undertaken to compare an experimental model of absorbent protective underwear with the standard CC2 impregnated underwear, with respect to heat stress when the underwear was worn in a two-layer permeable protective clothing assembly. The performances of men at different rates of exercise in a hot room were studied while they wore each of three different clothing assemblies: (a) a permeable, nonprotective, utility costume; (b) a standard, permeable, impregnated costume; and (c) an experimental, permeable, protective costume using the absorbent underwear. When rates of change of average body temperature and heart rate were used as indices of heat strain, no differences were found among the costumes in the amount of heat strain experienced by human subjects while exercising at low and medium workloads, in a hot room at a temperature of 100°F, and 29% relative humidity. At high workloads, no differences in heat strain were observed between men wearing either of the protective assemblies, but heat was stored only about 75% as rapidly by men wearing utility costumes as compared to those wearing the protective costumes.

336. Yaglou, C.P.

Thermal insulation of clothing. AMER. SOC. HEAT. VENT. ENGINEERS. TRANS. v. 54, p. 291-306, 1948.

This paper discusses the usefulness and limitations of the two principal methods for evaluating the thermal insulation qualities of clothing. The two methods are the heat-loss method and the temperature-gradient method.

PART XI

COMBINED THERMAL AND OTHER STRESSES (HYPOXIA, ACCELERATION, ETC.)

337. Bartlett, R.G. and Altland, P.D.

Relation of body temperature and restraint to altitude tolerance in the rat. J. APPLIED PHYSIOL. v. 14, p. 785-788, 1959.

Adult male and female Sprague-Dawley rats, restrained (by loosely fitted wire mesh cylinders) and unrestrained, were used to study the relationship of body temperature and restraint to altitude tolerance. The effects on survival at high altitude (33,000 feet.) were studied for the following: (1) slow, step-wise ascent to altitude, (2) pre-altitude-induced hypothermia (body temperature regulated to 25° C.), (3) pre-altitude cold exposure of unrestrained rats (3-5° C.) for periods of 2 hours and 2 3/4 hours, respectively, and (4) pre-altitude restraint as compared with unrestrained controls. All exposures to altitude were conducted in a decompression chamber. Animals restrained immediately before altitude exposure with rapid ascent (2,000 feet per minute) died significantly sooner than did nonrestrained animals. Slow, step-wise ascent to altitude increased the altitude tolerance of both restrained and nonrestrained animals, but much more for the restrained animals. When body temperatures were dropped to 25° C. before altitude exposure there were no deaths (up to 6 hours) in any of the experimental animals. A lesser body temperature fall provided less protection. The author suggests that restraint may affect altitude tolerance in two distinct ways: (1) the struggling which accompanies restraint increases the rate of oxygen consumption (should decrease altitude tolerance), and (2) restraint apparently hastens the body temperature fall (should increase altitude tolerance). The exact effect of restraint on altitude tolerance, therefore, should be dependent on the relative magnitudes of these two influences. Rapid ascent to critical altitude permits body temperature fall and consequently altitude tolerance is lowered; however, gradual ascent to critical altitude permits lowering of body temperature, thereby resulting in greater altitude tolerance. Restraint either markedly lowers altitude tolerance or greatly increases it, depending on the experimental procedure. It was observed that female rats often demonstrated a greater increase in altitude tolerance as compared to the males.

338. Braun, T. and Mosinger, B.

Effect of hypothermia on death by starvation.

NATURE v. 181, p. 968, 1958.

339. Bullard, R.W.

THE GASEOUS ENVIRONMENT AND TEMPERATURE REGULATION. Indiana U. School of Medicine. 11p. (Contract DA 49-007-md-047).

ASTIA AD-251 656

Studies were continued on the effects of carbon dioxide and hypoxia on mechanisms involved in temperature regulation. In unanesthetized trained dogs immersed in 30°C. water, inhalation of either 6% carbon dioxide or 10% oxygen brought about depression of oxygen consumption, shivering and colonic temperature. The metabolic, heart rate, and body temperature responses to low oxygen were studied in the hamster, rat and 13 lined ground squirrels. In cold animals marked heart rate, body temperature and metabolic depression were seen but these depressions did not occur in animals exposed at 35°C. In the warm animals heart rate increases occurred. The hypoxic alteration of heart rate appeared to be related to the hypoxic alteration of oxygen consumption. Carbon dioxide (6% to 10%) had less depressive effect then did low oxygen on cold exposed small mammals. A moderate but inconsistent augmentation of sweating was seen with 6% carbon dioxide inhalation in men exposed to mild hear. Ten % oxygen inhibited sweating in men exposed to 38°C. but not in those exposed at 46°C. A method for rapid recording of sweat rates is described.

340. Burgess, B.F.

THE EFFECT OF TEMPERATURE ON TOLERANCE TO POSITIVE ACCELERATION. Naval Air Development Center, Johnsville, Pa. Report No. NADC-MA-5905, May 26, 59, 10p. ASTIA AD-218 957

With the advent of space flight, the problems associated with the physiologic effects of extreme temperatures may become a critical factor relating to pilot performance under conditions of high acceleration. In order to determine the effects of high environmental temperatures on G tolerance, six trained centrifuge subjects were exposed to positive acceleration in the heated gondola of the Johnsville centrifuge. Seven thermocouples were located at strategic places over the body surface in order to obtain an accurate recording of skin temperature. Although humidity was not controlled, it was recorded during all centrifuge runs. The environmental temperatures studied ranged from 75° F. to 160° F. where a decrement to G tolerance of 1 G has been obtained at the upper temperature range.

341. Burgess, B.F., Jr.

The effect of temperature on tolerance to positive acceleration. AEROSPACE MEDICINE v.30, p. 567-571, 1959.

342. Carter, E. T. and Bell, M.W.J.

BIOTHERMAL ASPECTS OF RE-ENTRY FROM EXTRA-ATMOSPHERIC FLIGHT. American Rocket Society. Paper 704-58, 1958.

This paper points out certain biothermal problems that are expected to arise as a result of atmospheric re-entry of a manned vehicle. Some solutions are presented, although the authors admit that they fall far short of being acceptable answers to the problem. It is also pointed out that these methods take into account only the stress of temperature and do not consider the possibility that other stresses such as hypoxia or high g loading are present at the same time. These additional stresses could cause an intolerable situation for the vehicle occupant. More information is needed regarding human performance under the combined stresses of heat and acceleration.

343. Davidovic, J. and Wesley, I.

Tolerance of cooled animals to acute hypoxia during rewarming. AM. J. PHYSIOL. v. 197, p. 1357-1358, 1959.

Rats cooled by the closed vessel technique or immersion in cold water to temperatures of varying degrees were allowed to rewarm at a simulated altitude of 11,500 m. for 30 minutes. The rate of death from hypoxia began at a rewarmed temperature of from 22-28° C. (after the animals were cooled to 20° C. by either method) was 10 to 20 per cent, in contrast to a control death rate of 93.7 per cent. Above 28° the death rate increased rapidly from 20 to 90 per cent. Depth of cooling was also shown to affect resistance. Rats cooled to a temperature of 18° C. by the closed vessel technique, or to 22° C. by immersion, were found to have a higher rate of survival under hypoxia begun at a rectal temperature of 33° than animals cooled to 20° by closed vessel technique, or to 20° and 25° by immersion.

344. Frankel, H.M.

Effects of restraint on rats exposed to high temperature. JOUR. APPL. PHYSIOL. v. 14, p. 997-999, 1959.

Male rats were placed in a cage either 8 in. x 8 in. x 10 in. (free) or 2 in. x 2 in. x 8 in. (restrained) and exposed to ambient temperatures between 40° and 60° C. "Restrained" rats died sooner than "free" animals at all temperatures. There was no significant difference between final rectal temperatures of free and restrained rats at ambient temperatures greater than 40° C; mean for these groups was 44.6° C. At 40°C the final rectal temperature was slightly lower in the restrained group (43.4° vs. 44.6°C). Restraint had no significant effect on the constituents of the blood examined. Serum potassium and specific gravity and blood hematocrits were increased and serum sodium was unchanged in heat-exposed rats compared with controls at 26° C. Serum calcium varied irregularly with exposure temperature.

345. Ghinozzi, G.P.

Behavior of rectal temperature in rabbits exposed to barometric depression. RIV. MED. AERONAUTICA v. 19, p. 669-675, 1956.

Ten rabbits were exposed for 1 hour to a simulated altitude of 7000 m in order to observe rectal temperature changes. A decrease in temperature corresponding to 1.7° C in barometric depression occurred.

346. Grande, F.E., et al

Body temperature responses to exercise in man on restricted food and water intake. JOUR. APPL. PHYSIOL. v. 14, p. 194-198, 1959.

Rectal temperatures (T_R) of 12 clinically healthy soldiers were measured in a room at 25.5°C and 40-45% relative humidity during a 1-hour walk on a motor driven treadmill at 3.5 mph and 10% grade, during control with adequate food intake and water ad libitum, and during a period of food and water restriction. The daily water intake during the water restriction period was 900 ml for six of the men, Low Water group (L. W.), and 1800 ml for the other six, High Water group (H. W.). The restriction of water began at the same time as the

346. (Cont'd)
restriction of food and lasted 5 full days for the L. W. group and 10 full days for the H. W. group. Food was restricted to 1000 calories from carbohydrate, 4.5 gm of NaCl and a multivitamin pill/day for 16 days. Water ad libitum was given throughout the experiment except for the period of water restriction. The L. W. group showed a progressive increase of T_R at the end of the walk during the water restriction period with average T_R 1.51°C, higher at peak dehydration than in control. In the H. W. group the greatest average increase, 0.46°C, was observed on day 5 of restriction. Administration of water ad libitum brought the work T_R back to the control level in the L. W. group, but failed to produce any important change in the H. W. group. The relationship between dehydration, elevation of T_R during work and changes in sweat rate is discussed.

347. Hale, H.B.

HUMAN CARDIOACCELERATIVE RESPONSES TO HYPOXIA IN COMBINATION WITH HEAT.

School of Aviation Medicine. Rept. no. 60-14, Sep 59.

With the advent of hypersonic aircraft, where aerodynamic heating is to be expected, and where there is the ever-present possibility of oxygen equipment failure or inadequacy, hypoxia and heat may be encountered simultaneously. Therefore, experimental examination of the physiologic effects of these two factors should produce some information on re-entry effects on humans. In this report, the effects of high ambient temperature on heart rate responses to moderate reductions in oxygen pressure were determined in healthy human males.

348. Hale, H.B.

Observations on men exposed to hypoxia at different environmental temperatures.

FEDERATION PROCEEDINGS v. 12, p. 59-60, 1953.

Changes in circulatory system, respiratory system, body temperature, and adrenal cortical function were followed in male subjects during standardized exposures to low barometric pressure under 2 different conditions of temperature (80° and 120° F) in an effort to determine the extent to which adjustments to heat interfere with or otherwise modify responses to hypoxia. In 19 subjects, exposed to 18,000 feet simulated altitude for 15 minutes, 12 demonstrated an elevated heart rate when overheated. Seven showed a more rapid heart rate

348. (Cont'd)
when in the comfort range. Any elevation in heart rate, due to heat, occurred before or after the hypoxia phase; a truly "additive" effect was not seen during hypoxia. That time is an important factor was shown by the fact that a second group of subjects, breathing a 10% oxygen-nitrogen mixture, demonstrated a slowing of the heart rate after 15 minutes exposure to hypoxia at 80° F, but at the higher temperatures the heart rates either continued to climb throughout the exposure period or suddenly dropped to subnormal levels.

349. Hall, F.G. and Salzano, J.

RESPIRATORY AND CIRCULATORY RESPONSES OF THE HYPOTHERMIC ANIMAL TO CARBON DIOXIDE STRESS. Wright Air Develpm. Div. Tech. Rept. no. 60-82, 12p. 1960.

Some respiratory and circulatory responses to carbon dioxide stress during ice-water immersion hypothermia were studied in 13 dogs. Stresses were imposed by increasing the carbon dioxide tension of the inspired gas in 8 animals and by intravenous infusion of gaseous carbon dioxide in 5 other animals. It was found that, when compensation is made for the depressed ventilation exhibited at low body temperature, animals responded to the carbon dioxide stresses in essentially the same manner in the hypothermic as in the normothermic state. However, the responses are of a lower order of magnitude.

350. Hertzman, A.B. and Ferguson, I.D.

FAILURE IN TEMPERATURE REGULATION DURING PROGRESSIVE DEHYDRATION. Wright Air Develpm. Cent. Tech. Rept. no. 59-398, 27p, 1959.

During exposure to an ambient temperature at 43.3° C (110° F) without food or water, the body weights of young male subjects decreased at the rate of 0.5 per cent per hour of exposure, their body temperatures rose 0.1° C per hour, but the total sweat production changed little despite the increase in body temperature. Calculations indicated that the latter was due to a slightly inadequate sweating which in turn was attributed to a rising thermal threshold for sweating. Regional sweating rates varied widely during the exposure, particularly on the upper parts of the body. Cutaneous conductances, thermal circulatory indices and the pad pulses in the finger and toe changed very little; there was no evidence of peripheral circulatory failure in these experiments. The theoretical implications are discussed.

351. Ivanov, K.P.

Oxygen consumption and heat regulation in hypoxia. FIZIOL. ZHUR. SSSR (TRANSL.) v. 45, p. 302-308, 1959.

The course of the metabolic changes in rabbits in hypoxia depended on the temperature of the surrounding medium. At temperatures of 13-14° C the oxygen consumption in hypoxia fell with reduction in oxygen content of the inspired air. At temperatures of 20-21° C hypoxia caused an increase of 15-40% in oxygen consumption, over the original level. There was a considerable increase in heat loss in rabbits during hypoxia; and the body temperature decreased.

352. Martin, E.E. and Henry, J.P.

The effects of time and temperature upon tolerance to positive acceleration. JOURNAL OF AVIATION MEDICINE v. 29, p. 754, 1958.

353. Megel, H. and Keating, F.M.

EFFECT OF ELEVATED AMBIENT TEMPERATURE AND VIBRATION UPON THE RECTAL TEMPERATURE OF THE RESTRAINED RAT. Paper presented at 32nd Annual Meeting, Aerospace Medical Association, Chicago, Illinois 24-27 Apr 61.

Restrained male rats (140-160 grams) of a Sprague-Dawley strain were exposed to non-lethal elevated ambient temperatures and to vibration. Ambient temperature, vibrational frequency, and duration of exposure were kept constant. The vibrational amplitudes were varied. Rectal temperature of the animals was measured using a thermistor probe. Restrained animals were subjected to varying vibrational displacements (0.0", 0.100", 0.210", and 0.320" double amplitude) keeping frequency (30 cps) and temperature 110° F. (43.4° C.) constant. The rectal temperatures of the animals following a 20 minutes exposure were +3.1° F., +4.7° F., +6.1° F., and +7.8° F., respectively.

353. (Cont'd)

The incidence of lethality for these animals up to 24 hours following exposure was 0, 10, 25, and 75 per cent, respectively. The experiment was repeated at a different frequency. Varying the vibration displacements (0.0", 0.050", 0.075", and 0.100" double amplitude) and maintaining the frequency (60 cps) and temperature 110° F. (43.4° C.) constant resulted in an increase in rectal temperature of +3.1° F., +6.4° F., +10.5° F., and +14.9° F., respectively. The incidences of lethality up to 24 hours following exposure were 0, 25, 42, and 100 per cent, respectively. At both frequencies, the rise in rectal temperature was correlated with the increase in acceleratory force. In order to determine the mechanism underlying the nature of rectal temperature response to increasing acceleratory forces, animals were sacrificed by exposure to ether anesthesia and immediately vibrated at varying displacements (0.0", 0.050", 0.075", and 0.100" double amplitude) keeping frequency (60 cps) and ambient temperature 110° F. (43.4° C.) constant. This particular set of conditions was chosen because the differential in rectal temperature of the live animals was greater with increasing vibratory amplitudes. Following the 20 minute period of exposure, the rectal temperatures of the dead animals were +2.0° F., +7.9° F., +9.8° F., and +13.7°F., respectively. The rectal temperatures of the dead animals were not significantly different from those of the live animals exposed to the identical stress conditions. Mechanisms by which elevated rectal temperatures result from exposure to increasing acceleratory forces may possibly be that vibratory energy is translated into heat energy and/or vibration facilitates transfer of heat from the environment into the animal. Although the rectal temperatures of the dead animals were not significantly different from those of the live animals exposed to the same environmental conditions, metabolism and heat transfer mechanisms available to the live animals cannot be disregarded.

354. Parr, W.H., <u>et al</u>

A STUDY OF COMBINED THERMAL RADIATION

BURN AND X-IRRADIATION EFFECTS ON MICE.

Army Medical Research Lab. Report no.

94, 4 Sep 52, 8p. ASTIA AD-5 467

Mice exposed to both total body X-irradiation (720 r) and thermal radiation burns (non-lethal) succumb more rapidly than animals receiving X-irradiation only. The mice were burned either immediately before or immediately after irradiation with the over-all result being approximately the same. The possible reasons for the earlier and higher mortality of the mice receiving both X-irradiation and non-lethal burns are discussed.

355. Reeves, E.

THE EFFECT OF ACCLIMATIZATION TO COLD ON THE G TOLERANCE OF RATS. Naval Air Development Center. Rept. no. NADC-MA-6117, 9 June 61, 14p.

ASTIA AD-259 072

Two groups of rats were acclimatized to cold (4 to 6 C) for 37 days and then exposed to acceleration of 20 positive G until the heart rate decreased to 2 beats per second. No statistically significant difference in tolerance to acceleration was found between the cold-acclimatized animals and their controls. Exposure to cold caused loss of weight and increase in adrenal gland size.

356. Stupfel, M.

Action of carbon dioxide gas on thermoregulation of the white rat. I. Effect of different concentrations of CO_2 at different temperatures. JOUR. PHYSIOL. (PARIS) v. 52, n. 3, p. 575-606, 1960. (In French)

357. Weiss, L.

Sensitivity of hypothermic mammals to X irradiation. (In HYPOTHERMIA AND THE EFFECTS OF COLD). BRIT MED. BULL. v. 17, p. 70-73, 1961.

PART XII

ACCLIMATIZATION

358. Adams, T. and Covino, B.G.
Racial variations to a standardized cold stress. J. APPL. PHYSIOL. v. 12, p. 9-12, 1958.

359. Andersen, K., et al
Metabolic and thermal responses to a moderate cold exposure in nomadic Lapps. JOUR. APPL. PHYSIOL. v. 15, p. 649-653, 1960.

A field investigation was conducted at Kautokeino in Finnmark to study the tolerance of the Lapps to cold. Their metabolism and skin and rectal temperatures were determined while they rested and slept naked for a night in a single-blanket sleeping-bag, exposed to a moderate cold stress. As compared with unacclimatized white men they showed a greater ability to endure the cold night. In general the Lapps slept well without visible shivering, whereas the controls were prevented from sleeping by the sensations of cold and vigorous shivering. The metabolic rates of the Lapps were close to their basal level, in contrast to the raised metabolism of the unacclimatized control subjects. Some of the Lapps maintained slightly higher peripheral skin temperatures than the control subjects, but had a much greater fall in their rectal temperatures, indicating a greater loss of stored body heat.

360. Clifford, J.D., Kerslake, McK. and Waddell, J.L.
The effect of wind speed on maximum evaporative

360. (Cont'd)

capacity in man. JOUR. PHYSIOL.

v. 147, p. 253-259, 1959.

Determinations of the coefficient for heat exchange in evaporation, k_e, were made on 3 nude male subjects standing at 4 orientations to a horizontal wind at speeds varying from 115-790 ft./min. Differences between subjects and orientations were negligible. All results together are described by the equation, $k_e = V^{0.63}$, where V is the wind speed.

361. Cottle, W.H. and Carlson, L.D.

Regulation of heat production in cold-

adapted rats. PROC. SOC. EXPTL. BIOL.

AND MED. v. 92, p. 845-849, 1956.

362. Davis, T.R.A.

CHAMBER COLD ACCLIMATIZATION IN MAN.

Army Medical Research Lab. Rept. no.

475, 19 May 61, 8p. ASTIA AD-257 954L

Nude subjects were exposed 8 hrs daily for 31 days to a temperature of 11.8 C during March. Other subjects were acclimatized similarly to a temperature of 13.5 C in September. At intervals during the exposures, measurements were made of shivering, O_2 consumption, rectal and skin temperatures during a 2 hr cold exposure. Shivering decreased significantly in both groups by the 14th day; heat production was unchanged in the winter group, but decreased significantly in the summer group. Basal metabolism rate (BMR) did not change in either group. Rectal temperature in both groups was unchanged for 10 days, but decreased after the 14th day. On the basis of shivering and rectal temperature changes, it was concluded that man can be artificially acclimatized. Failure of cold-elevated metabolism to decrease in the face of significant decrease in shivering indicates the presence of nonshivering thermogenesis in man.

363. Davis, T.R., et al

Regulation of shivering and nonshivering heat production during acclimation of rats. AMER. JOUR. PHYSIOL. v. 198, p. 471-475, 1960.

When cold acclimating rats are treated with diathermy, curare and a combination of both, two main fractions of the increase in cold-induced oxygen consumption can be delineated. First, a fraction which diathermy replaces by virtue of the fact that it, in the intensities used, can raise core temperature without altering the temperature of the skin; therefore this fraction appears to be dependent upon changes in central temperature and is found to persist throughout the period of acclimation investigated. Second, a fraction of cold-induced oxygen consumption which is not replaced by diathermy and which is presumed to be dependent upon changes in skin temperature. By the administration of curare, this second fraction can be separated into two further fractions acting reciprocally depending upon the duration of cold exposure. In the early stages of acclimation, the curare-suppressed fraction of oxygen consumption appears to be entirely due to shivering. As shivering disappears with acclimation, it is replaced by a peripherally regulated non-shivering heat source which eventually takes over all the duties of heat production previously performed by shivering.

364. Deb, C. and Hart, J.S.

Hematological and body fluid adjustments during acclimation to a cold environment. CANADIAN J. BIOCHEM. AND PHYSIOL. v. 34, p. 959-966, 1956.

365. Elsner, R.W., Nelms, J.D. and Irving, L.

Circulation of heat to the hands of Arctic Indians. JOUR. APPL. PHYSIOL. v. 15, p. 662-666, 1960.

Nine Indian men of an arctic village and eight urban white men have been compared in their responses to hand immersion in cold water. Following a 30-minute immersion in warm water (30°C) the hands were placed in cold water in an insulated bath (initially 5°C) for an additional 30 minutes. The rate

365. (Cont'd)
of heat transer to the water, finger skin temperatures and skin temperatures over a wrist vein were measured. All subjects were tested in this manner in two environmental situations: clothed in a warm room and unclothed in a cool room. In another experiment six Indians and five whites immersed their right hands in ice water while sitting comfortably warm. Generally, the Indians showed a markedly superior ability to maintain hands warm in cold water. Their hands transferred more heat to the water whether the subjects were comfortably warm or chilly. In the cool environment hand heat loss was reduced in both groups,but the calculated heat transfer from circulation alone was still about twice as great in the Indians. The skin temperature measurements reflected the general trends of hand cooling and rewarming. The Indians withstood the hand immersion in ice water with quicker rewarming and less pain than the whites. Although their response is not conserving of metabolic heat, the loss is apparently trivial. The warming of the Indians' hands appears therefore to be adaptive in nature.

366. Elsner, R.W., Andersen, K.L. and Hermansen, L.

Thermal and metabolic responses of Arctic Indians to moderate cold exposure at the end of winter. JOUR. APPL. PHYSIOL. v. 15, p. 659-661, 1960.

Oxygen consumption, skin temperature and rectal temperature during nights of cold exposure were measured in eight Indian men from a remote arctic village who had been similarly studied the previous fall. The metabolic response of the Indians to cold exposure was similar in the spring to that observed in the fall studies. All subjects showed a general increase of about 30% in O_2 consumption during the night. In addition, the basal metabolic rate of four subjects measured was slightly above the DuBois standards, as in the fall. A decline in rectal and skin temperatures throughout the night was observed to be similar to that of the same subjects in the fall, with the exception that the surface temperatures of arms and legs were slightly cooler in the spring. It was concluded that, except for a tendency toward heat conservation by cooling of extremities, no metabolic or thermal changes of a seasonal nature had taken place in these subjects during the arctic winter.

367. Fleischner, J.R. and Sargent, F.

Effects of heat and cold on the albino rat: Crossed resistance or crossed

367. (Cont'd)

sensitization? J. APPL. PHYSIOL.

v. 14, p. 789-797, 1959.

Two experiments were carried out to test whether or not cold-acclimatized rats adjust better to heat and heat-acclimatized rats adjust better to cold than rats not previously exposed to either environmental extreme. In both, groups of rats were exposed to 94.5°- 96.5°F. (hot), 33°-40°F. (cold) and 76°-78°F. (control). In the first experiment, forty-five female Holtzman litter mates were used. After fifty days, "hot" rats were abruptly transferred to cold, "cold" rats to heat. Control animals were also placed in each environment. In the second experiment fifty-five identical rats were similarly treated; the cross, however, was made after twenty-nine days. Rats exposed to 95°F. exhibited sustained hypothermia. Rats exposed to 36°F. developed a transient hypothermia which lasted longer in the first experiment than in the second and was accompanied by more severe cold injury. Heat was not a stress in the sense of Selye, but cold was. There was crossed sensitization rather than crossed resistance.

368. Hafez, E.S.E.

Physiological mechanisms of acclimatization.

ACTA PHYSIOL LATINOAMER. v. 6, p. 100-104,

1956.

369. Hale, H.B. and Mefferd, R.B., Jr.

Metabolic responses to thermal stressors

of altitude-acclimated rats. AMER. J. OF

PHYSIOL. v. 195, p. 739-743, 1958.

Fasting 24-hour exposures of altitude-acclimated rats (380 mm. Hg., 18,000 ft. simulated) to ground level pressure (750 mm. Hg.) at either cold (3°C), neutral (24°C), or hot (35°C) temperatures seldom resulted in return of their metabolic functions to preacclimative 'normalcy'. Although the control and altitude-acclimated groups both were accustomed to neutral temperatures (24°C and 26°C), quantitative differences at ground level and altitude occurred in various indices of water, mineral and nitrogen metabolism. Of the 32 physiologic variables studied only 4 (ratio of urine volume/water intake, and urinary excretion of potassium, creatinine and glycine) failed to differentiate the responses of the altitude- and ground- accustomed rats. The temperature response curves of the altitude group tended to parallel the corresponding ones for the control group, but most variables were on higher or lower planes. The difference in plane resulted either from the effects of the return to ground level pressure, or from nonreversible effects of acclimation to altitude per se.

370. Hammel, H.T.
THERMAL AND METABOLIC RESPONSES OF THE ALACALUF INDIANS TO MODERATE COLD EXPOSURE. Rept. no. WADD TR 60-633, Dec 60. 48p.

371. Hart, J.S.
Metabolic alterations during chronic exposure to cold. (In SYMPOSIUM ON METABOLIC ASPECTS OF ADAPTATION OF WARM-BLOOD ANIMALS TO COLD ENVIRONMENT). FEDERATION PROC. v. 17, p. 1045-1054, 1958.

372. Hart, J.S.
Physiological effects of continued cold on animals and man. (In HYPOTHERMIA AND THE EFFECTS OF COLD). BRIT. MED. BULL. v. 17, p. 19-24, 1961.

The acclimation of small animals to constant cold, which approximately doubles heat production, generally leads to development of increased cold resistance through an increased capacity to produce heat. The resulting metabolic alterations are the principle focus of studies on cold acclimation today. The process is calorigenically expensive and perhaps does not lead to a lasting improvement in tolerance to cold. A much greater economy of energy is seen in animals acclimatizing to cold climates in which development of increased fur insulation and insulative cooling of peripheral tissues lead to heat conservation. These processes may be combined with the metabolic type of change seen in cold-conditioned animals. Metabolic alterations comparable with those in cold-conditioned animals have never been observed in man, but the extent and duration of exposure to cold have not been comparable. Field studies have suggested reduction in "core" and greater heating of appendages, coupled with delayed metabolic response. In studies on man, the 2 opposing adjustments, peripheral heating (as seen in Eskimos, Indians, cold-acclimatized Caucasians) and toleration of greater peripheral cooling (as seen in Australian Aborigines and Alaskan students) are also seen

372. (Cont'd)

as natural climatic responses. The racial differences may be partly inherited, partly acquired. From the limited data it appears that the extent of protection of the whole body from cold has an important bearing on the type of peripheral adjustment observed.

373. Heberling, E.J. and Adams, T.
Relation of changing levels of physical fitness to human cold acclimatization. J. APPL. PHYSIOL. v. 16, p. 226-230, 1961.

374. Hellon, R.F., <u>et al</u>
Natural and artificial acclimation to hot environments. J. PHYSIOL. v. 132, p. 559-576, 1956.

375. Irving, L.
Human adaptation to cold. NATURE v. 185, p. 572-574, 1960.

376. Irving, L., <u>et al</u>
Metabolism and temperature of Arctic Indian men during a cold night. JOUR. APPL. PHYSIOL. v. 15, p. 635-644, 1960.

During 7 hours of comfortably warm sleep, average metabolic rates of 11 Indian and 7 white men were alike. Since the Indians were 15% lighter their metabolic rates (MR's) referred to weight were greater. During a night at 0° with insufficient covering, MR's rose to 129% and 132% in the two groups. Cold caused equal myographic records of shivering (15% and 13% of records) and gross muscular movement appeared in 6.5% of the records for each group. Encephalograms showed that Indians slept more (51%) than whites (31%). Shivering was recorded in Indians and white men during encephalographic indications of sleep. Rectal temperatures of Indians declined about 0.5°.

376. (Cont'd)
During cold nights skin on the bodies of all subjects cooled 3°-5° and about 15° on the feet. All subjects were disagreeably cold, but their cold sensations stimulated metabolic heat production only half as much as would be necessary to maintain fairly comfortable warmth.

377. Kandror, I.S., Rapoport, K.A. and Soltyskiy, Ye. I.

Thermo-regulatory displacements in the organism of man in a cold climate and morbidity caused with a factor of cooling.

VOENNO.-MED. ZHUR. v. 1957, p. 61-67, 1957. (In Russian)

Displacements are compared in the chemical and physical thermo-regulation of people in various periods of acclimatization in the extreme North (basic metabolism, metabolism during standard work, vascular reaction to cooling of the skin) with the level of morbidity of those nosological forms, in the etiology of which the known role belongs to the cooling factor; and correlations are established between them. Acclimatization displacements of this type generally develop during the 1st year. After the expiration of this period, the morbidity decreases almost 2.5 times in comparison with the 1st year of acclimatization.

378. Kreider, M.B., et al

Effect of continuous cold exposure on nocturnal body temperatures of man.

JOUR. APPL. PHYSIOL. v. 14, p. 43-45, 1959.

Effects of continuous cold stress on 24-hour patterns of body temperature were studied in five men. Cold stress consisted in living at 15.6°C (60°F) for 14 days wearing only shorts. The cold period was preceded and followed by 2 weeks at 26.7°C (80°F). Activity (minimal) and diet were the same for all periods. One blanket was used at night. Rectal temperatures (T_r) and skin temperature (T_s) were measured. T_r during sleep fell more rapidly and to lower values during cold exposure (35.6°C) than during the control period (36.1°C). T_s during sleep was slightly lower in the cold than in the control period; also, T_s did not exhibit the gradual drop characteristic of sleep in the control period. Comparison of T_r and T_s between early and later cold days revealed the following differences: (a) nocturnal T_r fell to lower levels

378. (Cont'd)
on the later cold days; (b) nocturnal toe temperatures were 15°C (27°F) higher on the later cold days. The arch temperatures followed the same pattern as the toes. No significant differences were found in daytime temperatures between early and later cold days. The data suggest that evidence for acclimatization to cold in terms of altered body temperature responses may be fruitfully sought in responses during rewarming and/or sleep.

379. Le Blanc, J.

Evidence and meaning of acclimatization to cold in man. J. APPL. PHYSIOL. v. 9, p. 395-398, 1956.

380. Mefferd, R.B., Jr. and Hale, H.B.

Effects of thermal conditioning on metabolic responses of rats to altitude. AMER. JOUR. PHYSIOL. v. 195, p. 735-738, 1958.

The metabolic responses of rats acclimated to different temperatures (3°, 24° and 35°C) were compared during a 24-hour fasting exposure to low barometric pressure (380 mm Hg). Determinations included fasting weight loss, water intake, urine volume and urinary excretion of Na, K, Mg, Ca, PO_4, urea, uric acid, creatinine, creatine, taurine, β-alanine, glycine, α-alanine, valine + methionine, serine, threonine, tyrosine, glutamic acid, aspartic acid, lysine, arginine and histidine. Since the altitude tests were made at a neutral temperature (25° C) the altitude responses, per se, were determined by comparing the ground and altitude responses of each acclimated group at neutral temperatures. These comparisons revealed that the acclimated state of the rats exercised a strong influence on the altitude response for most of the variables. There were significant intergroup differences in this response for all variables except phosphate, urea, taurine, valine + methionine, serine, histidine and the Mg/Ca ratio.

381. Milan, F.A., Elsner, R.W. and Rodahl, K.

Thermal and metabolic responses of men in

381. (Cont'd)

the antarctic to a standard cold stress. J. APPL. PHYSIOL. v. 16, p. 401-404, 1961.

Thermal and metabolic responses of eight male subjects exposed nude for 2 hours to a standard cold stress (17+ 1.0°C air temperature) were examined in the Austral fall, winter, and spring at Little America in the Antarctic. Mean body, average skin and foot temperatures increased significantly after 3 months. Neither rectal nor finger temperatures were changed over the year. Although basal metabolic rates were unchanged, there was a significant decrease in the metabolic responses to the standard cold stress after 3 months in the Antarctic. It is suggested that these changes represent physiological adaptations to chronic cold.

382. Molloy, R., et al

Acclimatization to cold: Immediate adrenal response and survival of acclimatized rats exposed to more severe cold. CANADIAN JOUR. BIOCHEM. AND PHYSIOL. v. 37, p. 661-670, 1959.

Further observations are described on the measurement of the incorporation of inorganic phosphate labelled with P^{32} into the inorganic phosphate of the adrenal gland to assess the immediate pituitary--adrenal response when cold acclimatized and non-acclimatized rats are exposed to more severe cold (2 hours at - 5°C). In rats acclimatized to cold by conditioning to 3°C for 4 weeks, this immediate pituitary-adrenal response was considerably less than that in non-acclimatized rats maintained at room temperature (22°C). The reduction in the immediate pituitary-adrenal response took 3 to 4 weeks to develop and persisted for 12 hours, but not for 4 days. Rats that were conditioned to -5°C by exposures for 2 or 6 hours daily for 4 weeks showed no reduction in the immediate pituitary-adrenal response to more severe cold, but there was a significant decrease in this response in rats conditioned for 6 hours daily for 8 weeks. Rats acclimatized to cold by conditioning to 3°C for 4 weeks showed greater survival when exposed to an environmental temperature of --15°C than rats conditioned to 22°C. Rats that were conditioned to --5°C for brief daily periods (2 hours or 6 hours) for 4 weeks or 8 weeks also survived exposure to severe cold (-22°C) better than rats maintained at room temperature. In general, significant increases in adrenal weight were found in those cold-conditioned rats that showed a reduced pituitary-adrenal response. However, it is concluded that the development of increased survival on exposure to severe cold, by a process of conditioning

382. (Cont'd)
to less severe cold, is not necessarily accompanied by a reduction in the immediate pituitary-adrenal response to severe cold, or by an increase in weight of the adrenal glands.

383. Rennie, D.W. and Adams, T.
Comparative thermoregulatory responses of negroes and white persons to acute cold stress. J. APPL. PHYSIOL. v. 11, p. 201-204, 1957.

384. Rodahl, K.
Human acclimatization to cold. In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE, MAR 1957. New York, Josiah Macy, Jr. Foundation, p. 177-252, 1958.

385. Scholander, P.F., et al
Cold adaptation in Australian aborigines. U. Oslo. JOUR. APPL. PHYSIOL. v 13, p. 211-218, 1958.

A field investigation was conducted to study cold acclimation in the Pitjandjara, a desert tribe of Australian aborigines. Oxygen consumption and rectal and skin temperatures were taken every half hour throughout the night (a) while the natives were resting naked on the ground between their camp fires and (b) while they rested naked without fires in a single-blanket sleeping bag, subjected to a moderate, but known, cold stress. The air temperature frequently dropped to $0^{\circ}C$ in the early morning. It was found that the camp fires on windless nights could readily supply enough heat to keep both the natives and whites in heat balance throughout the night and resting under basal conditions. In tests with the subjects in light sleeping bags without fires, the natives underwent a considerable peripheral skin cooling, with their foot temperatures dropping regularly to 12°-$15^{\circ}C$. They slept soundly through the night with normal resting heat production. The white controls cooled almost as much, but unable to rest, they shivered and

385. (Cont'd)

thrashed about all night, with a corresponding elevation of metabolism. The cooling adaptation of the Australian aborigines, which resembles the insulative cooling commonly found in mammals, differs from the metabolic compensation and greater peripheral heating developed in cold-acclimated white man.

386. Scholander, P.F., et al

Critical temperature in Lapps.

J. APPL. PHYSIOL. v. 10, p. 231-234, 1957.

387. Scholander, P.F., et al

Metabolic acclimation to cold in man.

J. APPL. PHYSIOL. v. 12, p. 1-8, 1958.

388. Scholander, P.F.

Studies on man exposed to cold. (In SYMPOSIUM ON METABOLIC ASPECTS OF ADAPTATION OF WARM-BLOOD ANIMALS TO COLD ENVIRONMENT). FEDERATION PROC. v. 17, p. 1054-1057, 1958.

389. South, F.E., Jr.

The effects of hot and cold environments on mammals. PROC. ANIMAL CARE PANEL v. 10, n. 2, p. 51-56, 1960.

Homoiothermy has allowed mammals to cope with extremes of heat and cold in a variety of ways. The responses to such environmental stresses involve the generic physiological processes of acclimation, acclimatization and adaptation. Recent data and current concepts are presented and discussed to illustrate the mechanisms of these responses among the mammals subjected to variations in the thermal environment.

390. Von Mormet, J. and Grandjean, E.
Investigation of the resting metabolism during long continued exposure to cold in the arctic. HELVETIA PHYSIOL. ET PHARMACOL. ACTA v. 13, p. 173-177, 1955.

391. Ward, J.S., Bredell, G.A. and Wenzel, H.G.
Responses of Bushmen and Europeans on exposure to winter night temperatures in the Kalahari. JOUR. APPL. PHYSIOL. v. 15, p. 667-670, 1960.

Eight Bushmen and five Europeans were exposed during winter nights in the Kalahari desert to temperatures ranging from about 27°C to 2°C. Oxygen consumption and skin and rectal temperatures were measured over the period of 1 1/2-2 hours of exposure. Comparison of increased metabolic rate with decreasing air temperatures measured in this study is made with similar data on young Norwegians. Bushmen and Europeans respond in a similar manner metabolically to the degree of cold stress experienced. Skin temperatures of the former tend to be lower and metabolism greater than in Europeans. The lower metabolic rate of Europeans is concluded to be due to the greater insulation afforded by their considerably larger subcutaneous fat deposits. These findings on the cold response of Bushmen contrast with those on Australian aborigines in comparable environmental conditions.

PART XIII

HIBERNATION

392. Adolph, E.F., Klem, E.F.S. and Morrow, L.B.
Reversible cessation of blood circulation in deep hypothermia. J. APPL. PHYSIOL. v. 13, n. 3, p. 397-405, 1958.

393. Adolph, E.F. and Goldstein, J.
Survival of rats and mice without oxygen in deep hypothermia. JOUR. APPLIED PHYSIOL. v. 14, p. 599-604, 1959.

Adult rats and mice that were cooled quickly below 11° C. core temperature usually ceased to breathe. Suspension of breathing and heartbeats was tolerated at 2° C. for one hour, whether artificial breathing was given or not and whether air or nitrogen filled the lungs. At heart temperatures of 10° C., where heart beat was maintained, rats survived artificial ventilation with nitrogen for 0.4. hour; ventilation with air for two hours. Anaerobic survival at 10° C. was not demonstrably shortened by inhibitors of glycolysis (fluoride, iodoacetate). Reanimation of 90 per cent of rats and mice under optimal conditions was accomplished by artificial warming, acccmpanied by artificial ventilation with air under intermittent positive pressure. Each process that becomes suspended at its biological zero apparently has a limited time within which rewarming may restore it. The limitation of times less than 1.5 hours was imposed mostly by anoxia. Properties of animals that were injured by anoxia or by hypothermia seemed to vary, since animals might die even after breathing was restored.

394. Aganiants, E.K. and Novikov, V.F.
Restoration of conditioned reflexes in dogs after hypothermia. ZHURNAL PYSSHEI NERVOI DEIATEL'NOSTI

394. (Cont'd)

(MOSKVA), v. 10, p. 569-574, 1960. (In Russian with English summary.)

Restoration of normal body temperature in four dogs cooled to 24° C. rectal temperature resulted in a full recovery of the secretory alimentary and defensive respiratory conditioned reflexes. The latter returned when the body temperature was within the range of 31 to 35° C., and were fully reestablished on the second day after rewarming. In younger dogs the secretory alimentary reflexes reappeared at a body temperature of 36° C. within 24 hr. after rewarming. In the older dogs these began to function 48 to 72 hr. after rewarming. The recovery process is concluded 4 to 9 days after rewarming. Hypothermia reduced the activity of cortical cells by stimulating their protective inhibition. The process of internal inhibition after hypothermia was considerably weakened and recovered later than the process of excitation.

395. Hock, R.J.

Hibernation. In COLD INJURY, TRANSACTIONS OF THE FIFTH CONFERENCE, MAR 1957. New York, Josiah Macy, Jr. Foundation, p. 61-133, 1958.

396. Hock, R.J.

The potential application of hibernation to space travel. AEROSPACE MED. v. 31, p. 485-489, 1960.

397. Kayser, C.

Mammalian hibernation I. Hibernation versus hypothermia. BULL. MUS. COMP. ZOOL. HARVARD U. v. 124, p. 1-29, 1960.

398. Kayser, C.
Physiological investigations on hypothermia in mammals and in hibernating animals. ARCH-ANAT. HISTOL ET EMBRYOL. v. 37, p. 97-103, 1955.

399. Kenyon, J.R.
Experimental deep hypothermia. (In HYPOTHERMIA AND THE EFFECTS OF COLD). BRIT. MED. BULL. v. 17, p. 43-47, 1961.

The methods described have prevented the danger of irreversible ventricular fibrillation in deep hypothermia, and have also permitted complete circulatory arrest combined with exsanguination in experimental dogs for periods of up to 45 minutes. It is possible that the period of 45 minutes of circulatory arrest may be exceeded, but futher research will be necessary to confirm this. Smith (1957) observed intestinal haemorrhages in hamsters kept at 0°C for 70 minutes or longer, and this paper also notes observations of acute pancreatitis and intestinal haemorrhage in the dog when the total circulatory arrest has exceeded 60 minutes. These methods have already been successfully applied to patients undergoing open-heart surgery and may also assist in the surgical reconstruction of the aortic arch. In the future when the homograft reaction has been solved, they may prove of value in transplantation of major organs.

400. Landau, B.R.
PHYSIOLOGY OF MAMMALIAN HIBERNATION. U. of Wisconsin. Thesis. 1956.

401. Lipp, J.A. and Folk, G.E., Jr.
Cardiac response to cold of two species

401. (Cont'd)

of mammalian hibernators. ECOLOGY

v. 41, p. 377-378, 1960.

This study compared the effects of cooling white rats, hamsters (Mesocricetus auratus) and ground squirrels (Citellus tridecemlineatus). The last 2 animals are hibernators. The animals were restrained and placed in a cold box. ECG records and core temperatures were recorded at regular intervals. The heart rate of the hibernators leveled off at a core temperature of about 10°C while the heart rates of the rats continued to fall with a decrease in core temperature until they died. It was anticipated that since the 13-lined ground squirrels and golden hamsters were not preconditioned to cold, they might not tolerate deep artificial hibernation. Instead they proved resistant to the effects of cold which were fatal to the white rats.

402. Lyman, C.P.

Metabolic adaptations of hibernators.

(In: SYMPOSIUM ON METABOLIC ASPECTS OF ADAPTATION OF WARM-BLOOD ANIMALS TO COLD ENVIRONMENT). FEDERATION PROC.

v. 17, p. 1057-1060, 1958.

403. Markiewicz, L. and Ziemlanski, S.

Investigations on the behavior of venous and arterial blood pressure and heart output in experimental hypothermia.

BULL. ACAD. POLONAISE SCI. SER-SCI. BIOL. v. 6, p. 267-271, 1958.

404. Miller, J.A., Jr. and Miller, F.S.

Factors contributing to the successful reanimation of mice cooled to less than 1°C. AMER. J. PHYSIOL. v. 196, p. 1218-1223, 1959.

405. Negovskii, V.A., et al
Restoration of vital function in monkeys after bleeding to death during hypothermia. BULL. ESKPTL. BIOL. I. MED. v. 48, p. 1338-41, 1959. (In Russian)

406. Niazi, S.A.
PROFOUND HYPOTHERMIA IN NONHIBERNATING ANIMALS. Minnesota U. Thesis. 1956.

407. Niazi, S.A. and Lewis, F.J.
Profound hypothermia in the dog. SURG. GYNECOL. AND OBSTET. v. 102, p. 98-106, 1956.

408. Niazi, S.A. and Lewis, F.J.
Profound hypothermia in the monkey with recovery after long periods of cardiac standstill. J. APPL. PHYSIOL. v. 10, p. 137-138, 1957.

409. Orchard, D.P. and Adolph, E.F.
Effects of local cooling or heating in deeply hypothermic rats. JOUR. APPL. PHYSIOL. v. 15, p. 435-439, 1960.

Rats were cooled to 17°C core temperature, and then either the head or the chest was further cooled by 5-10 deg. C. Thermocouples in the hypothalamus and in the vena cava recorded the differences of temperature; electro-

409. (Cont'd)

cardiograms and breathing were observed. Breathing could cease reversibly when the head was cooled and also after a period of gasping whenever the heart was much cooler than the head. Artificial ventilation of the lungs with air did not modify the result of restricted blood flow. Whenever the brain was cooler than the heart, however, artificial ventilation with air could replace spontaneous breathing; the blood flow was then usually adequate. Artificial ventilation with nitrogen reduced the time within which recovery was possible. In general the warmest tissue (head or chest) determined the time of endurance without adequate delivery of oxygen from lungs and blood. Any local cooling failed to increase the rat's endurance of oxygen lack. The results are interpreted to mean that failures to survive below 14°C for 1 hour are due to inadequate oxygen delivery. However, even oxygen delivery believed to be adequate did not allow indefinite survival; 2 hours remained the mean tolerance time below 14°C.

410. Popovic, V.

Lethargic hypothermia in hibernators and nonhibernators. (In: HYPOTHERMIA). ANN. NEW YORK ACAD. SCI. v. 80, p. 320-331, 1959.

Lethargic hypothermia was induced in a nonhibernator, the rat, and in a hibernator of the same size, the ground squirrel. Both were cooled, and their patterns of cooling as the limits of the limits of the lethargic state were determined. The animals were maintained with constant body temperatures, 15°C and 10°C, for the rat and the ground squirrel, respectively, for hours or days, until death. The breathing and the heart stopped (clinical death) after 9.5 hours in the 15°C rat and after 110 hours in the 10°C ground squirrel, yet those animals biologically could survive only 2/3 of the time they could survive clinically. O_2 consumption, as well as the limits of lethargic hypothermia and the survival times, show that lethargic hypothermia in ground squirrels and rats is similar in nature, but quite different from natural hibernation. Unlike animals in hibernation, nonhibernators and hibernators in prolonged lethargic hypothermia show considerable changes in O_2 consumption and probably in other physiological processes that lead to death.

411. Rey, L.R.

Preservation of life with cold. EXPERIENTIA v. 15, p. 449-455, 1959. (In French)

By the addition of a certain amount of glycerol, it is possible to store living animal tissues in the frozen state over very long periods of time.

411. (Cont'd)

Cooling velocity, storage temperature and rate of thawing are important factors. Under optimal conditions, experiments done on the heart of the chick embryo have shown that complete recovery of the normal physiological activities can be achieved after freezing in liquid nitrogen.

412. Sarajas, H.S.S.
Mammalian hibernation. XVII. On the cardiac response in hibernation and induced hypothermia. Functional, pathologic and metabolic aspects. BULL. MUS. COMP. ZOOL. HARVARD U. v. 124, p. 337-51, 1960.

413. Smith, D.E.
Mammalian hibernation. XXVI. The effects of ionizing radiation in hibernation. BULL. MUS. COMP. ZOOL. HARVARD U. v. 124, p. 493-506, 1960.

414. So, T.
Experimental studies on profound hypothermia. NAGASAKI MED. J. v. 34, n. 5, p. 552-72, 1959. (In Japanese with English summary)

415. South, F.E.
Mammalian hibernation XXV. Some metabolic specializations in tissues of hibernating animals. BULL. MUS. COMP. ZOOL. HARVARD U. v. 124, p. 475-92, 1960.

416. Yefimov, M.I.

The possibility of obtaining continued and safe hibernation in animals not naturally falling into this condition.

TR. KIRG. GOS. MED. INST. v. 1956, p. 164-173, 1956. (In Russian)

Rats kept during 3-4 hours at a body temperature of 15-22°, easily recovered from hypothermia (1st period of hibernation). Sustained artificial cooling in the course of 12-16 hours (repeated cooling) led to the impossibility of spontaneous warming; careful artificial warming caused the deaths of animals after a short period of activation (2nd period of hibernation). Further extension of hypothermia caused the deaths of rats in the process of artificial warming without preliminary increase of their physiological activity (3d period of hibernation). Experiments with the accommodation of cooling to various body temperatures showed that the 1st period of hibernation with repeated temperature fasts can be increased up to 9.7 hours at an environmental temperature of 14-15°. Hibernation in addition was achieved with cooling of the animals to 15-20°. The use of urethane before the cooling increased the limitations of the environmental temperature of the first period of hibernation to 20-30°. The introduction of urethane during hibernation and before warming, exerted a favorable effect which raised the possibility of bringing the animals out of even the 2d period of hibernation (with artificial warming).

417. Yonce, L.R.

HYPOTHERMIA AND BLOOD FLOW THROUGH SKELETAL MUSCLE. North Carolina U. School of Medicine. Progress rept. for 1 Sep 60-31 Aug 61. 25 May 61, 15p. (Contract DA 49-007-md-1002).

ASTIA AD-256 859

The general purpose of this study is to determine the vascular response of an isolated gracilis muscle to hypothermia. Data are presented on three pertinent aspects of this problem: (1) the effect of the rate of lowering the temperature on the bascular response of the isolated gracilis muscle, (2) the effect of hypothermia on the oxygen consumption of the resting isolated muscle, and (3) the effect of hypothermia on the reactivity of the vasculature of the isolated muscle.

PART XIV

THERMAL MODELS OF HUMANS

418. Crosbie, R.J., Fessenden, E. and Hardy, J.D.

ELECTRICAL ANALOG SIMULATION OF TEMPERATURE REGULATION IN MAN. NAVAL Air Development Center. Rept. no. NADC-MA-6130, 21p.

ASTIA AD-259 077

Using the basic equations for heat balance which have been developed to take into account heat losses by radiation, convection and evaporation, an electrical analog has been constructed to simulate the physiological responses to heat and cold in the nude man. As has been previously shown, physiologic temperature regulation involves three of the basic types of control modes, namely, proportional control, rate control and some of the characteristics of on-off control. The rate and proportionality constants have been determined experimentally on the assumption that the regulated temperature is the average body temperature (average body temperature = 80 per cent rectal temperature + 20 per cent skin temperature). Time constants for the various thermal changes can be determined from the thermal constants of tissue and the response times of the physiological variables of sweating, vasomotor activity and change in metabolic rate. The simulator predicts steady state situations of rectal temperature, skin temperature, metabolic rate, vasomotor state and evaporative heat loss under both resting conditions and exercise. Dynamic responses to sudden shifts in environmental temperature, air velocity, relative humidity and metabolic rate can be simulated to a considerable extent using equations based on the controls outlined above.

419. Hardy, J.D. and Soderstrom, G.F.

Heat losses from the nude body and peripheral blood flow at temperatures of $22\text{-}35^{\circ}$ C. J. NUTRITION v. 16, p. 494-510, 1938.

Data obtained on heat loss in the Russell Sage calorimeter have been analyzed as regards the transfer of heat from the interior of the body to the skin and

419. (Cont'd)

from the skin into the environment at temperatures of 22°C to 35°C. The heat loss from a blackened cylinder similar in shape to a man's trunk was studied and a comparison made with the heat loss from the skin.

420. Herrington, L.P.

Full-scale human-body-model thermal exchange compared with equational condensations of human calorimetric data. J. HEAT TRANSFER, (SER. C) v. 81, p. 187-194, 1959.

Calorimetric data on seated, clothed human subjects have been condensed into linear differential equations which permit the bioengineer to quickly approximate the effect of complex air and radiant temperatures on the human element of a man-machine design problem. These equations are descriptive of the range of thermal loads typical of the region from 40 to 80° F., and separately, by reason of different human temperature regulation characteristics, for the range from 80 to 105° F. Static heat exchangers (an electrically heated model of the human body and a hemispherically capped cylinder) have been used to establish an experimental connection between the heat-exchange properties of these inanimate bodies and linear differential equations which generalize the thermal exchanges of the human body as observed in a calorimeter environment.

421. Stoll, A.M.

A COMPUTER SOLUTION FOR DETERMINATION OF THERMAL TISSUE DAMAGE INTEGRALS FROM EXPERIMENTAL DATA. Naval Air Development Center. Rept. no. NADC-MA-6004, 1960. 13p.

A computer method utilizing the IBM 650 and the Bell Telephone programming system was developed for the evaluation of tissue damage due to thermal irradiation. It is presented as an illustration of the possibilities computers offer the biological investigator unversed in their use. The data to be analyzed consisted of temperature-time histories of skin during and following exposure to thermal radiation sufficient to cause blistering. The experimental data were related to tissue damage through the rate of damage

421. (Cont'd)

commensurate with temperature level (a logarithmic function) and the time for which the temperature prevailed. Thus, the total damage was represented by the integral of the pertinent damage rates and the heating and cooling time. Despite the non-linearity of these curves, it was possible to obtain a complete analysis, yielding separate values of damage during heating, damage during cooling, and total damage, within 45 seconds or less, of machine time for each set of data. In contrast, graphical integration by a skilled operator required at least a half-hour for each set. Since hundreds of such analyses may be required in this type of study, the advantages of computer use are obvious. Furthermore, the relative simplicity of the programming system is such that very little training or mathematical skill is required for the biological investigator to be able to prepare his own computer programs and thereby eliminate many tedious and time-consuming graphical procedures.

422. Taylor, C.L.

Heat-transfer applications in the human

body. MECH. ENGNG., N.Y. v. 77,

p. 511-513, 1955.

A brief review of the factors influencing the thermal balance of the human body with its surroundings is presented, with some historical notes on development of the currently available information. An electric analog model is described in principle with which it is hoped the complex heat and mass-flow problems of the transient human-environment relationships can be solved.

423. van Gunst, E.

Physical aspects of the heat exchange

between the human body and its surroundings,

especially by radiation. INGENIEUR v. 72,

p. G.61-G.71, 1960.

The paper gives a survey of the physical principles of the heat exchange of the human body: convection, evaporation, radiation. In several industrial processes the human body has to be protected against comparatively heavy heat radiation from heat sources. Methods for evaluating the heat quantities and their distribution over the human body must be available both in the design of new processes and in existing situations which need correction. For designing purposes there is a need for calculation techniques; for studying situations under working conditions direct measurements can be carried out. These methods have to take into account the configuration factors and the

423. (Cont'd)
temperature distributions over the heat sources. Measurements have to prove the validity of the available methods of calculation. The heat exchange by radiation between two surfaces is given by the Stefan-Boltzmann Law.

$$Q_{12} = (\varepsilon_1 \varepsilon_2)(f_{A_1A_2} A_1)\sigma\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]$$

For purposes of evaluation, information must be available of the emission capacities, the configuration factor and the temperatures of the surfaces. If the two surfaces are irregularly shaped, calculation of the configuration factor from available graphs and tables is highly complicated and time-consuming. A method has been developed for measuring the configuration factor from a point to a surface. From that point a photograph can be taken of the surface. This photograph can be integrated by an integrator with the factor as result.

424. Woodcock, A.H., Thwaites, H.L. and Breckenbridge, J.R.
AN ELECTRICAL ANALOGUE FOR STUDYING
HEAT TRANSFER IN DYNAMIC SITUATIONS.
QM Res. and Engin. Command. TR No.
EP-86, 1958.