7911165

STEPHENS, ROGER LEE
A STUDY OF HEAT ACCLIMATIZATION, ITS DECAY AND REINDUCTION FOR YOUNG FEMALES.

THE UNIVERSITY OF OKLAHOMA, PH.D., 1978

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

A STUDY OF HEAT ACCLIMATIZATION, ITS DECAY AND REINDUCTION FOR YOUNG FEMALES

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

By

ROGER LEE STEPHENS

Norman, Oklahoma

1978

A STUDY OF HEAT ACCLIMATIZATION, ITS DECAY AND

REINDUCTION FOR YOUNG FEMALES

APPROVED BY

LaVerne L Hoag

[illegible]

Jerry L Purswell

Larry K Michaelsen

Ronald A Ratliff

DISSERTATION COMMITTEE

ACKNOWLEDGEMENTS

I would like to express my gratitude to all those who aided me in this research effort. Without the guidance of my committee chairman, Dr. LaVerne Hoag, this work would never have been completed. Thanks are also due Dr. Ron Ratliff for his assistance with equipment and testing and Dr. Al Nicewander for his statistical interpretations and advice. Dr. Larry Michaelsen's contributions were significant to the maintenance of my self-confidence during this exercise; and, Dr. Jerry Purswell deserves a special note of thanks in that without his assistance and advice, I would have never pursued a graduate degree.

A great deal of credit for this research is owed the ladies who participated in this study as subjects: Cheri Ortiz, Diane Arnett, Mary Lowery, Deena Telley, Lynn Ragsdale, and Susan Bryant. The last of these subjects provided support for which I cannot adequately express my appreciation. Thanks are overdue to my parents, Mr. and Mrs. Orville E. Stephens, who assisted in the financing of my education, were always encouraging and optimistic yet never forceful.

A special note of thanks is due my friend Robert Schlegel whose efforts during hardware fabrication and data collection were requisite to the success of this undertaking. Thanks also go to Marty Peters who typed this dissertation from totally illegible notes. Lastly, I wish to express my thanks to Dr. George Carroll and Dr. Dave Cochran who personally demonstrated to me that with enough tenacity, the Ph.D. degree can be acquired. A sincere thank you to all those who have assisted me over the years to this end.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

A STUDY OF HEAT ACCLIMATIZATION, ITS DECAY AND REINDUCTION FOR YOUNG FEMALES

CHAPTER I

INTRODUCTION

The study of females who perform physical work tasks in stressful environments is becoming an area of significant research interest. This study is an attempt to quantify some of the physiological parameters of females who have become heat acclimatized as well as the changes observed in these parameters after periods of inactivity. Furthermore, these parameters and their associated changes are examined for different decay periods that allow for partial losses of the heat acclimatized state. A second objective of this study was the evaluation of the Wet Bulb Globe Temperature Index as a predictor of environmental severity for the female where variations in humidity levels occur.

Consider that there are nearly 37 million women in the American labor force, and that they are a cross section of all women in the country. They are of all ages from 16 to 70 or more and of every race and color. They include the married, the never married, the widowed, divorced, and separated; and they live on farms, in suburbs and in central cities.

The majority of studies to determine individual physical work capacities, physiological costs for various work tasks and the effects of various stressors resulting from numerous environmental parameters have been performed on males. Recently more emphasis has been placed on the study of women and older individuals in an attempt to better define the levels of stress that these individuals can endure without compromising their health or safety as a result of the task-environment constraints. With respect to females employed in manual labor in hot environments, the present philosophy among most work physiologists is that women cannot tolerate hot environments as well as can males. The National Institute for Occupational Safety and Health (NIOSH, 1972) has determined various criteria for recommended standards with respect to occupational exposure to hot environments. The recommended work practices require special procedures if the work environment exceeds 79^{o}F Wet Bulb Globe Temperature (WBGT) for males and 76^{o}F WBGT for females. There is a significant lack of data on the physiological reactions of the female population who may choose to do work at these environmental levels (Jensen and Dukes-DuBos, 1976). The time required for females to acclimatize for various work loads at hot environmental levels as well as the rate of decay of their acclimatization resulting from periods of absence from the hot environment pose significant questions which must be answered in order to safely utilize the female in this traditionally male work environment. Furthermore, Wet Bulb Globe Temperature is suggested by NIOSH as the index for industrial evaluation of temperature to determine hot environments. The WBGT formula incorporates a measure of relative humidity in the environment being described. The question arises as to whether or not, for a fixed value of WBGT, female physiological reactions to work are the same for a high humidity versus a low humidity environment. For example, does a $90^{\circ}F$ WBGT environment with high relative humidity elicit the same physiological responses in the working female as does the low humidity environment for a given work task? Thus, it was the intent of this investigation to examine female physiological responses with respect to acclimatization, its decay, and reinduction in the region of recommended thermal limits for work in hot environments. Furthermore, an attempt was made to evaluate the effect of relative humidity extremes on female physiological reactions for comparable Wet Bulb Globe Temperatures.

Heat stress tolerance of women is a sub-topic in the area of work capacity of women with respect to men. During the early 1970's problems relating to sex discrimination emerged as a major concern for personnel management. The inclusion of sex as a basis of discrimination to be prohibited by Title VII of the Civil Rights Act was an apparent effort to defeat the bill at the time it was passed and its inclusion was even opposed by the Women's Bureau of the U.S. Department of Labor. The interpretation of this provision has proved to be one of the most difficult problems for the Equal Employment Opportunity Commission (EEOC) as it has faced an increasing number of sex discrimination complaints over the years.

One basis for the difficulties in enforcing the ban on sex discrimination in employment is that such discrimination may be permissible where sex is a "bona fide occupational qualification" (BFOQ) necessary to the employer's normal operation. The BFOQ exception also applies to discrimination based on religion or nationality but not to racial discrimination. What constitutes a BFOQ has been subject to different interpretations in various courts, although the EEOC itself maintains this exception should be interpreted narrowly. Jobs may be restricted to one sex for reasons of authenticity, as for example, actresses or models portraying women, or on the basis of community standards of morality, or propriety, as in the case of restroom attendants, but not on the basis of general assumptions of characteristics or stereotypes of men or women in general.

An issue that arose very early under the sex discrimination ban was that of jobs traditionally denied women because of certain physical aspects of the work such as strenuous lifting. In general, the courts have upheld the

EEOC position that such weight lifting requirements do not constitute bona fide occupational qualifications. This problem was confounded by the presence in many states of so-called protective laws, many dating back to the early 1900's limiting the number of hours women could work or the weights they could be required to lift. At first, EEOC evaluated such laws on a case by case basis, on the assumption that the ban on sex discrimination was not intended to disturb state laws that have the effect of protecting women. Finally, the EEOC decided that because these laws treat all women as a group and do not take individual differences into account they cannot be used as a basis for denying jobs to women. As a result many of the protective laws have been ruled by the courts as in conflict with the federal law and thus invalid, and by 1971 only 10 states had retained maximum hour laws unchanged out of the 40 that had such laws before the Civil Rights Act went into affect. In certain states these laws were simply repealed, although there have been proposals that they should be extended to cover men as well as women and there have also been complaints about employers requiring women to work extra long hours once the state protective laws were no longer in force.

In light of EEOC legislation concerning the employment of females, the rapidly expanding female labor force, the cost of disabling injuries and turnover, and the necessity for motivated and qualified workers in the industrial complex, the progressive engineer or personnel manager must be aware of significant male-female differences in order to adequately design jobs as well as organizational structures. Various parameters exist for the quantification of many of these differences which must be reviewed and/or researched further in order to adequately utilize as well as predict levels of success for women who choose to pursue traditionally male work tasks requiring more strenuous exercise in varied work environments. More than ever, significant research into the physical work capacity of the female and comparisons of this capacity with that of males for many tasks is requisite for an efficient utilization of the labor force available.

All individuals possess a physical work capacity. This refers to the physiological mechanisms that underlie a task performance that employs large muscle groups and rhythmical contractions. While machines have taken over much of the heavy work of industrial operations, numerous tasks still require human effort, such as shoveling, pushing or pulling of hand trucks, manual transfer of goods, loading of containers, etc. For such tasks it is often desirable to have a basis for pacing the work, for recommending rest pauses, and for selecting individuals who can be expected to perform the work without undue strain. The metabolic energy cost of performing any job requiring repetitive muscular exertion is a function of the type of exercise required with respect to its intensity, duration and muscles involved, the environment in which the activity is performed, and the capacity of the individual to adapt to the task and environment through training, conditioning and acclimatization.

Classical sex stereotyping has left many employers with the philosophy that females do not possess the physical work capacity necessary to perform many tasks which require a significant physical exertion; this same discriminatory action has been generalized to the aging worker resulting in conclusions that the older worker is not capable of performing similar physical work tasks. Few jobs exist in industry which require more than 50% of a young man's physical capacity over the course of the work day (AIHA, 1971). Indeed, most industrial task design requires significantly less than the 50% of a young man's physical work capacity. Therefore, many tasks exist which can be performed by either the older male or the female with respect to the quantity of energy expended to do the task. These individuals, while having less maximal capacity than the average young male, still possess the capability to perform given work tasks by employing a greater percentage of their physical work capacity than would the young male, yet still operate within the limit of half their maximal capacity.

CHAPTER II

LITERATURE REVIEW

In the simplest analysis, man can be viewed as a heat exchanger reacting with the environment via the mechanisms of convection, evaporation, radiation and conduction. Because of the complex geometry of a man-environment system, the heat transfer equations presented in the following discussion are generalizations. Even these simplified equations are difficult to apply in practice; fortunately, most job design work can be predicated on previous experimental knowledge. However, the basic heat transfer equations can always be used for rough estimates of environmental severity in previously unencountered situations.

Convection can be free or forced. Free or natural convection is unpredictable for clothed people moving about an environment. Forced convection can be approximated at low to moderate air velocities (up to about 10 m/sec) by the equation (Jakob, 1959):

$$H_c = 10\ A\ V\ (T_s - T_a)$$

where H_c is heat transferred to the environment in kilocalories

(Kcal)/hour, V is air velocity in m/sec, A is the area (in m^2) of the unclothed body subjected to the moving air, and T_s and T_a are the body surface and ambient temperatures in ^oC. With air movement greater than about 10 m/sec it becomes difficult to predict a time course for T_s, and convective formulas can only indicate an initial tendency for heat transfer.

Prediction of evaporative heat loss is nearly impossible because the only workable equations require the assumption of a completely wetted skin surface. The estimator equation presented here is useful for some predictive applications where subjects are unclothed and are perspiring over the entire body surface (A.F.S.C., 1977):

$$H_e = 0.58 \ \Delta W_e$$

where H_e is heat transfer to the environment in Kcal for a given time interval, and ΔW_e is grams of sweat evaporated in the same time interval.

The complex shape of the body dictates a practical approach to radiation transfer equations. Considering the environment as an infinite sphere radiating at some average temperature, the equation is (McAdams, 1954):

$$H_r = \sigma \varepsilon_1 \varepsilon_2 \ A(T_s^4 - T_a^4)$$

where H_r is heat transfer to the environment in Kcal/hr, σ is the Stephan-Boltzmann constant (4.93×10^{-8} Kcal/hr-m^2-^oK),

ε_1 and ε_2 are emissivities of the body and environment (both are usually near 1.0 in the infrared thermal region), A is the radiation area of the body in m^2 (this is usually 70-80% of total body surface area), and T_s and T_a are the body surface and environmental temperatures in degrees Kelvin.

Conductive heat transfer occurs only in special circumstances, such as water immersion. The formula is (A.F.S.C., 1977):

$$H_{cd} = k\ A(T_c - T_s)$$

where H_{cd} is the heat lost to an infinite environmental sink, k is the conductivity of the skin in Kcal/m^2-hr-^oC, and T_c and T_s are the temperatures of the body core and skin surfaces in degrees Centigrade. Small conductive components exist in the industrial setting but are usually restricted to the hands, seat and feet.

One may conclude that employment of the above equations to calculate heat gain or heat loss of an individual in an industrial setting would be quite difficult to perform and provide at best results of questionable reliability. Practicality constraints dictate some other approach for studying heat effect beyond basic heat transfer equations, such as the observation of certain human physiological reactions to various heat loads.

Using the four aforementioned modes of heat transfer, humans have the capability to thermoregulate themselves in different environments. The simplest and most accurate way of representing the human thermal regulation is by the core-shell concept. In this view, the body core produces heat which is lost to the environment through the shell (skin). Using sensors in both core and shell for information feedback, the body attempts to maintain the temperature of the core. Its principal mechanisms are the ability to produce or lose extra heat, and to change the conductivity of the shell. When challenged by a hot environment the body uses three methods to maintain core temperature:

1. Vasodilation in the skin causes the blood flow to the skin to increase. This increases the conductivity of the shell and increases the skin temperature, allowing a more rapid heat loss by convection, radiation, and evaporation.
2. Sweating dissipates body heat by evaporation. If the environmental temperature is greater than blood temperature, sweating is the only means by which the body can maintain its heat balance.
3. Behavior adjustments to heat are self-explanatory but often ignored. When a person gets uncomfortably warm, he attempts to move to a cooler environment, reduce his work rate or load, remove clothes, etc.

Conversely, three principal means of cold weather regulation are analogous to those used in the heat:

1. Vasoconstriction--The blood flow to the skin is

reduced, increasing shell insulation and decreasing skin temperature, both of which reduce heat loss to the environment.

2. Thermogenesis--The body produces more heat than necessary for the metabolic requirements of the organs and muscles. The best known form of thermogenesis is shivering, in which heat is produced by the skeletal muscles.
3. Behavior--A cold person attempts to move to a warmer place, put on more clothes, engage in heavier muscular activity, etc.

When a person is engaged in physical labor, his regulatory drives remain much the same, but there are three extra phenomena to consider:

1. The working muscles are producing heat which must be lost.
2. More blood flow is required for the working muscles.
3. The body attempts to regulate at a higher core temperature depending on the workload.

These factors usually work against thermoregulation in the heat, and assist it in the cold.

Though the body can control its rate of heat transfer to the environment, the heat exchange itself is governed by physical laws. The physical state of the environment is therefore important in its effect on transfer. The four environmental factors which influence heat exchange are:

1. Air temperature has a direct influence on convective heat transfer.
2. Humidity has an important effect on evapoaration in that the higher the humidity, the less evaporation possible.
3. Wind velocity is extremely important in both convection and evaporation.
4. Radiation from the sun and other sources, including sunlight reflected from within the work environment, contributes to changes in skin temperature.

The combined effects of air temperature, humidity, wind velocity and radiation upon human heat exchange make it difficult to assess the severity of a given environment. For many years physiologists sought to describe the environment as a single variable, written as a combination of two or more of these four factors, which would be an accurate predictor of human stress. Frequently used environmental indices include:

1. Dry Bulb Temperature (DB)--The air temperature is measured by a common thermometer. Dry bulb temperature is acceptable as a stress measurement only if the air is quite dry, with minimal windspeed and no radiative component. Despite these limitations, the DB is still widely used by laymen to assess many environments. It is the single variable for which most people seem to have a mental reference.
2. Wet/Dry Index (WD)--This is found by the formula

WD = 0.85 WB + 0.15 DB, (A.F.S.C., 1977),

where WB is the unaspirated wet bulb temperature. In the absence of a radiant load and with minimal air movement, it is a good predictor of human stress, especially in environments over 50% relative humidity (RH).

3. Effective Temperature (ET)--There are two indexes of effective temperature, both of which were developed under the sponsorship of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The original effective temperature (ET) scale was developed as an empirical sensory index, combining into a single value the effect of temperature and humidity on thermal sensations, with an adjustment for the effects of air movement. It was developed through a series of studies in which subjects compared the relative thermal sensations of various air conditions in adjoining rooms by passing back and forth from one room to the other. Any given ET was operationally characterized as the thermal sensation produced by a dry-bulb temperature of that same temperature in combination with relative humidity of 100 percent. However, other combinations of dry-bulb temperature and RH that produced the same sensation under the experimental condition used have the same ET. In general terms, the "other"

combinations for any given ET were characterized in terms of higher dry bulb temperatures and lower relative humidity values.

The original ET scale has been demonstrated to overemphasize the effect of humidity in cool conditions and to underemphasize its effect in warm conditions, and it does not account fully for air movement in hot-humid conditions. Further, its use was limited to sedentary conditions. Therefore, the ASHRAE sponsored the development of a new effective temperature scale based in part on consideration of the physiology of heat regulation as it applies to comfort, temperature sensation, and health, especially as heat regulation depends upon evaporative heat loss. The body generally is in a state of thermal neutrality with respect to "regulatory" heat loss when the dry-bulb temperature is about 77°F (25°C) and the relative humidity is 50 percent. Holding relative humidity constant (at 50 percent), higher or lower temperatures alter the evaporative process, thus affecting the ratios of skin "wettedness." The scale is based essentially on these ratios; however, any given level of skin "wettedness" can be produced by other combinations of dry-bulb temperature and relative humidity, and these are represented by the various lines on the associated chart.

4. Predicted Four-Hour Sweat Rate (P4SR)--In a series of investigations McArdle et al. (1947) found that sweat loss was the physiological measurement that correlated best with the severity of experimental environments. They then developed a scale based on sweat produced in four hours by acclimatized young men performing a prescribed amount of work. The index accounts for globe or dry-bulb temperature, wet-bulb temperature, and air speed, with adjustments for energy expenditure and clothing worn, and in effect predicts the sweat rate for the reference group from these environmental factors. MacPherson (1973) noted that it is based on the assumption that the level of environmental heat stress can be expressed as a function of the amount of sweat produced by the individual. Leithead and Lind (1964) expressed the opinion that it is the most accurate scale of heat stress, but it would be applicable only where sweating would continuously occur.

5. Wet Bulb Globe Temperature (WBGT)--This index is derived from ET scales and represents a simplified form developed from the U.S. Army. A globe temperature is determined by placing a thermometer in the center of a sphere 6 inches in diameter. The sphere is constructed of copper and blackened for high

absorptivity over the solar and infrared spectrum. The temperature inside the globe is a physical composite of DB and radiation. The Wet Bulb Temperature is determined by covering the base of a dry bulb thermometer with a length of cotton wick which extends into a 125 ml flask filled with distilled water. One inch of the wetted wick is exposed to the air between the thermometer base and the top of the filled flask and reflects temperature variances attributed to wind velocity and relative humidity of the air. The WBGT becomes a thermal predictor for indoor (minimal solar load) use when the globe temperature is weighted with the wet bulb as follows:

$$\text{WBGT} = .7 \text{ wet bulb} + .3 \text{ globe}$$

This index is inexpensive to determine, and usable over a wide range of indoor conditions.

The WBGT index has been used by the U.S. Marine Corp to reduce the number of heat casualties in training camps as reported by Minard (1961). Jensen and Dukes-Dubos (1976) found that heat exposure based on the WBGT index can be used to predict the heat stress conditions that will result in workers showing signs of heat strain.

In 1971, the American Conference of Governmental Industrial Hygienists published a notice of intent to establish threshold limit values (TLV) for heat stress. These proposed TLV's were based on the assumption that an acclimatized, fully clothed worker whose deep body temperature is maintained at 38°C or less is not subjected to heat stress.

Obviously, it is not practical or economically feasible to monitor every worker's heat stress by measuring his deep body temperature. Thus, investigators turned to the measurement of certain environmental factors which correlate well with physiological response to heat. For many years, scientists have been searching for an environmental heat stress index which was physiologically valid over a wide range of hot environments. An excellent review of this search for a universal heat stress index was prepared by the late Dr. Belding who listed 14 systems for rating heat stress and heat strain, including the aforementioned ones (1972). Many of these systems had obvious limitations which prevented them from gaining widespread usage. Others became popular for a time and then lost their popularity because shortcomings were discovered or because an apparently better index was developed. Several of these indices are in use today, but none achieved a position of universal acceptability because each index appeared to have shortcomings in certain environments.

In order to understand what is meant by a heat stress index, it is important to understand the terms heat stress and heat strain. Heat stress is the total heat load on the individual from both environment and metabolic sources according to Henschel (1963). Heat strain is defined by Henschel as the sum of the biochemical, physiological and psychological adjustments made by the individual in response to the stress. The most common dimensions used to measure heat strain are body temperature, heart rate and sweat rate. Other physiological indices of heat strain are blood volume, total body water, kidney and liver functions, electrolyte concentration in the body fluids, hormone production, blood pressure, work capacity, and behavior.

As the preceding definitions indicate, heat stress is the total of the metabolic and environmental heat load; therefore, in order to assess the heat stress on an individual, it is necessary to determine the heat load due to both metabolism and the environment. The ultimate test of the validity of an environmental heat stress index is the ability to provide an accurate prediction of how people will respond to the environmental conditions being measured. Investigators have conducted studies relating human responses to a variety of environmental heat levels. Unfortunately, these investigators have used several indices to describe the environmental heat levels to which the subjects were exposed. Jensen and Heins (1976) compared several prominent heat stress indices and concluded that the Wet Bulb Globe Temperature (WBGT) provided the best means for temperature evaluation in the majority of industrial environments. Their conclusions supported utilization of WBGT as recommended by Mutchler et al. (1975). Since 1971, two additional developments related to occupational health standards for heat stress have placed the WBGT index in even greater prominence as the index to be used in determining acceptable conditions in the hot work environment. In September, 1972, NIOSH published its Criteria for Recommended Standard for Occupational Exposure to Hot Environments. WBGT was specified as the index to be used in determining requirements for implementation for work practices designed to "reduce the risk of harmful effects due to the interactions between excessive heat and toxic chemicals and physical agents."

In 1974, the Occupational Safety and Health Administration standards advisory committee on heat stress presented its "Recommendations for Standards for Work in Hot Environments," which likewise employed WBGT as the index of heat stress. Still, at the time of this writing, no index has been formally adopted.

When the body is subjected regularly to an environment which imposes a heat stress, certain physiological adjustments occur over a period of one to three weeks. This process is called acclimatization, and the effect is to allow the body to better tolerate the stressful environment.

Heat acclimatization has meaning only when the word heat is taken to mean work in the heat. Only slight acclimatization takes place without work in the heat, and hard work in a cool environment produces only partial acclimatization (A.I.H.A., 1975). The principal body changes are a shunting of blood away from the skin, and an increase in the ability to sweat. In effect, the body learns to cool itself more efficiently by letting extra sweating take the load off the circulatory system. Heat acclimatization extends both useful working time and tolerance time in stress conditions. The major physiological cost is simply the need for more drinking water.

Thus, in environmentally stressful situations, body heat content is changed and thermoregulatory mechanisms are brought into play. If an environment is such that these cannot completely compensate, there exists a tolerance situation. The body is in a transient thermal state, and after a time will reach a core temperature at which it will no longer function usefully. If a thermally comfortable person is placed in a tolerance situation, the time required for him to reach this state of dysfunction is the tolerance time for that particular environment. Tolerance time exists at a core temperature about 2^{o}C above or below the normal 37^{o}C (A.F.S.C., 1977).

Performing light work in a hot tolerance situation results in rising skin temperature, followed by a rising body core temperature. Vasodilation and sweating commence, but cannot completely compensate. As the core temperature continues to rise, the heart rate increases and eventually may reach 70 beats per minute (or more) above normal. As a body continues to store heat, the individual:

(1) begins to lose concentration or focus on a task,

(2) becomes irritable or sick,

(3) loses the desire to drink.

Syncope may occur with sudden postural changes caused by a lack of blood to the brain. If not removed from the environment, the individual will go into heat stroke (complete loss of thermal regulation) after which he will soon die. A person performing heavy or moderate work will develop a higher core temperature before the onset of intolerance symptoms. Occasionally, people hard at work experience almost none of the intolerance warnings, but go directly into syncope, or, in rare instances, directly into heat stroke.

Acclimatization has an important effect on tolerance to hot environments. An environment which produces an intolerance situation in an unacclimatized working person may be indefinitely tolerable to an acclimatized one (A.I.H.A., 1975). Because of extremely high sweating rates, dehydration and accompanying fatigue may occur. In unacclimatized people salt depletion may also occur, resulting in fatigue and the possibility of muscle cramps. Tolerance time limits may be defined in two ways:

(1) maximum allowable internal temperature--This is about 39°C for a resting or lightly working person, but can be almost 40°C for an exceptionally fit and acclimatized person (A.F.S.C., 1977).

(2) maximum allowable heat storage--This is approximately 1.5 Kcal/kg of body weight, or about 75 $Kcal/m^2$ of body surface area. Maximum allowable heat storage is determined physiologically from total body temperature (TBT). Assuming that the specific heat of the body tissues average 0.83, then:

Body Heat Stress (BHS) = 0.83 (TBT - 36) Kcal/kg

where TBT = $1/3\ T_{skin} + 2/3\ T_{core}$ (A.F.S.C., 1977).

If the heat transfer characteristics of the man/environment system are known, the rate of BHS can be calculated physically. However, practicality constraints disallow the calculation of the heat transfer values at most industrial settings.

NIOSH conclusions for work in hot environments state that a deep body temperature of 38°C or less can be termed safe for 95% of the worker population. This maximum allowable temperature is less than some studies have concluded, but it is a value which should adequately protect workers who are at the physiological limits of the worker population; those who are old, obese, female, temporarily unfit or a combination of these factors.

The choice of the maximum allowable deep body temperature is based on the approach developed by Lind (1963) who devised Figure 1. Each point on the graph represents the result of an experiment lasting until the core temperature of the subject attained a steady state.

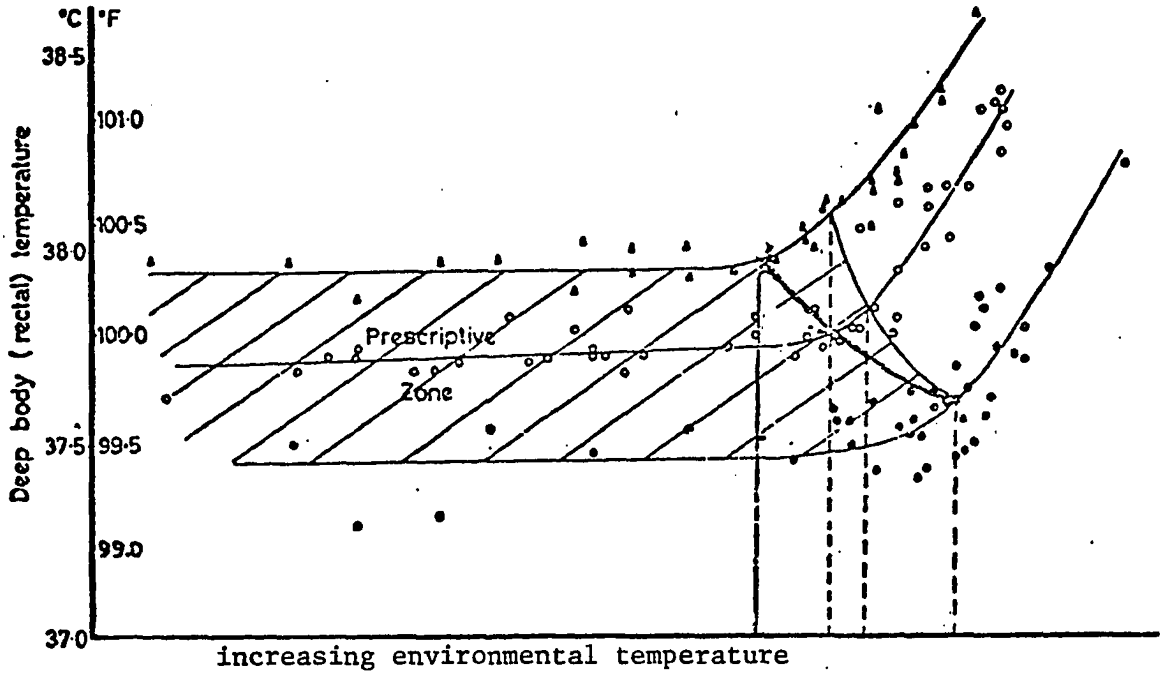

Figure 1. The levels of rectal temperature equilibrium of one subject working at 180 (•), 300 (o), and 420 (▲) Kcal/hr.

This took up to a maximum of one hour to achieve, depending on the intensity of the combined heat and work exposure. One may determine from this figure that up to a certain level of environmental temperature for a given work load, that there is no change in the slope of core temperature.

Notice that the core temperature is higher when the work load is increased but still maintains a steady slope. In this range of environmental heat load, the core temperature is determined by the work load. This range is termed the Prescriptive Zone (PZ).

At some points on the figure, all the curves show a sudden inflection and turn upward indicating that over these environmental temperatures, core temperature increases each time the climatic heat load is increased. This is the range where deep body temperature is sensitive to the environment as well as the work load, and an individual loses his ability to maintain core equilibrium, thus incurring the possibility of heat related disorders. This range of climatic conditions is termed the Environment Driven Zone (EDZ).

The environmental temperatures which border the PZ and EDZ are called the Upper Limits of the Prescriptive Zone (ULPZ). The value of the ULPZ, which varies for different individuals, is higher for acclimatized men than unacclimatized men by about 2°C and is lower the more clothing an individual wears. Tradeoff considerations such as acclimatization state, clothing worn at work, age, physical fitness, etc. all contribute to the development of the ULPZ for the worker population according to Lind (1973). All ULPZ work for various environmental temperatures at fixed work loads has been performed on males. Lind (1976) states:

> Currently there is no information by which we can judge to what extent, if any, the ULPZ would be altered for

women--it may be as with aging in men, no clear differences emerge between men and women in climates within the prescriptive zone but in climates which are hotter than prescriptive, clear evidence of additional physiological strain is evident. The matter remains to be determined.

Lind and Liddell (1963) found a ULPZ for a group of 128 seminude men of average physical fitness in an environment of 27^{o}C performing moderate work at the rate of 300 Kcal/hr. One might assume as previously stated by Lind that this task/environment combination could also yield the ULPZ for women but this has yet to be confirmed. According to Kraning et al. (1966) for unacclimatized workers heavy work loads greater than 350 Kcal/hr require a lowering of the environmental temperature by approximately 1^{o}C from 27^{o}C to attain the ULPZ; light work requires an increase above 27^{o}C of about 1^{o}C to maintain a steady-state core temperature at the ULPZ. These variances as a function of workload are predicated on the hypothesis that heat generated by work metabolism causes about twice as much strain on the cardiovascular system as the same amount of heat taken up from the environment. Thus, 27^{o}C appears to be the ULPZ for the average male working at moderate energy expenditures, and this environmental condition should be examined for the female with respect to seminude activity with moderate workload.

Numerous studies have been performed on males and a few on females with moderate workloads between 25^{o}C and 35^{o}C where subjects attain acclimatized status in 6 to 12 days.

The subjects increased their sweat rates and lowered their heart rates and core temperatures until a steady-state was reached over this time frame. Full acclimatization to the task/environment was defined as the point where no inflection was discernible on the curves describing the physiological indices. Typically acclimatization yields a drop in heart rate of 30-40 beats per minute and a drop in core temperature of about $1^{o}C$ when compared to those values obtained at initial task/environment exposure within the region of the ULPZ (Lind and Bass, 1963). Lind and Bass also noted that a single exposure of 100 minutes per day at a moderate work load yielded more rapid acclimatization than two separate bouts of 50 minutes per day, but that two exposures of 100 minutes per day did not speed acclimatization over the single 100 minutes per day exposure.

A sex difference in the pattern and magnitude of physiological responses to work in heat has been demonstrated. Whether the observed differences in responses reflect real differences in heat tolerance or in work performance is not fully proven (Henschel, 1971; Wyndham et al., 1965; Hertig, 1971; Morimoto et al., 1967; Weinman, 1967).

Hertig and Sargent (1963) demonstrated that women can be acclimatized to heat, manifesting the same physiological adjustments associated with acclimatization in males; reduced heart rate; reduction in body core and skin temperature rise; onset of sweating at a lower skin temperature; and lessened discomfort. One factor was stated which appeared to put the female at a disadvantage in the heat; a lower reserve capacity to move blood to the skin.

Several studies have shown that women sweat less than men under identical task/environment conditions (Hardy et al., 1941; Kawahata, 1960; Hertig and Sargent, 1963; Wyndham et al., 1965; Bartnicki, 1969; Fox et al., 1967). Yet it has been shown that women have a higher density of sweat glands than do men (Kawahata, 1960; Morimoto, 1967; Bar-Or et al., 1968; Knip, 1969). Women have higher skin temperatures than men at the onset of sweating (Kawahata, 1960; Fox et al., 1967; Bittel and Henane, 1975). Most hypothesize that these male-female differences in sweating capacities are a function of differing physical work capacities, physical condition, and degree of acclimatization but no concrete evidence has yet emerged to support these hypotheses.

With respect to core temperature differences, females have been reported to have higher values than males for work in heat (Wyndham et al., 1965; Weinman, 1967). Others have found that there are no differences at rest or during light work in heat (Haslag and Hertzman, 1965; Morimoto et al., 1967). Schwartz and Meyerstein (1970) found no differences in core temperature between sexes to work in heat. After acclimatization, core temperatures and heart rates have been found to be about the same for both sexes for moderate work in the heat but sweat production is half that of males for the females (Wyndham, 1965). Weinman (1967) concluded that there is no real difference in the acclimatization that can be reached in men and women, but that they may achieve equal acclimatization in different ways using different configurations of components of the regulating process.

CHAPTER III

PROBLEM, TASK, AND EQUIPMENT

Statement of the Problem

Although many studies have been performed under conditions of heat stress, relatively few have been performed on women. Those that have been performed on women have dealt primarily with the time required to achieve acclimatization, and comparisons of the various acclimatization mechanisms with those of males. It is well established that, on the average, women have a lower physical work capacity than men, and that women have higher body temperatures and heart rates than men when exposed to identical work in heat (Åstrand, 1960; Hertig, 1970).

NIOSH recommendations for the use of special work practices to reduce the risk associated with physical work in hot environments are predicated on studies of males with adjustments generalized to encompass established female variances. With respect to acclimatization work practices, permissible exposure limits for women are purely estimates according to the author of these recommended practices (Dukes-Dubos, 1976). Dukes-Dubos states in this previously referenced article that there is a need for more evidence with regard to the accuracy of these estimates for women. Indeed several investigators have commented in their findings that more research is needed in the area of female responses to long term and intermittent work in hot environments.

Though some work has been done on acclimatization of females under conditions of heat stress, no studies have been encountered in the literature which report on the decay or loss of heat acclimatization when females cease working in hot environments. Furthermore, there is no information with respect to the reinduction of full acclimatization after periods of time which do not allow for total decay. Thus, the problem yet to be resolved is one of how much decay transpires over time and how much time is required to reinduce the acclimatized state after various periods of decay. This study was undertaken in an attempt to generate data to aid the evaluation of present recommended work practices or allow for adjustments to benefit both the female worker and the industry in which she is employed.

A second question arose with respect to the measure of environmental severity employed to monitor heat stress in the industrial setting. Limit values for work in hot environments are expressed in terms of the Wet Bulb Globe Temperature index. Calculation of the WBGT accounts for moisture in the air or humidity level, but does this index account for extremes of relative humidity adequately when work is performed in the region of the Upper Limits of the

Prescriptive Zone? Perhaps some adjustment may be necessary in the threshold limit values for large variances in humidity.

Thus, this study was performed to provide information on the female with respect to the rate of decay of her acclimatized status for periods of 4, 8 and 12 days, and this was assessed by an evaluation of her residual acclimatization. The time necessary for full reacclimatization following each decay period was ascertained. Finally, for a fixed value of WBGT, the study sought to determine if women performing the acclimatization study in a low humidity environment responded significantly differently than women performing the same task in a higher humidity environment.

The Experimental Task

The task for all subjects over all trials consisted of walking on level treadmills. After subjects had been selected and examined for their aerobic power, body fat content, necessary anthropometric data and general physical health, the physical working capacity of each subject was calculated. Since individuals seldom exceed an average 50% of their physical work capacity during an eight hour industrial work day, this factor was applied to the experimental task to determine the treadmill speed so that the work task should elicit approximately half of each female subject's work capacities. The energy expenditure for this moderate work load was approximately 325 Kcal/hr. (Lehman, 1962), and required a treadmill speed of approximately 3.15 miles per hour (4.8 km/hr.) for each subject.

Subjects performed the experimental task daily by walking 50 minutes, resting seated for 5 minutes, and walking again for 50 minutes. This task was performed until the subjects attained an acclimatized status; that is, there was no significant difference in the levels of physiological indices monitored at the end of the work task for three consecutive days for each subject. This acclimatization process required ten days to complete. All subjects continued to perform the work task daily until every subject was fully acclimatized.

Subjects then refrained from physical activity in hot environments for four days allowing for some decay of their acclimatized state. All subjects began reinduction of acclimatization and performed the work task until it was determined that they had returned to their previously established levels of acclimatization. This decay and reinduction process was repeated for decay periods of eight and twelve days where all subjects followed an identical work days - decay days regimen until the decay-reinduction phase of the experiment was completed. At this point the high humidity or wet environment group performed the work task for one day in the low humidity or dry environment and vice versa. Finally all subjects were again evaluated for changes in aerobic power and body fat content in an effort

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark ✓.

1. Glossy photographs _______
2. Colored illustrations ✓
3. Photographs with dark background _______
4. Illustrations are poor copy _______
5. Print shows through as there is text on both sides of page _______
6. Indistinct, broken or small print on several pages _______ throughout _______
7. Tightly bound copy with print lost in spine _______
8. Computer printout pages with indistinct print _______
9. Page(s) _______ lacking when material received, and not available from school or author _______
10. Page(s) _______ seem to be missing in numbering only as text follows _______
11. Poor carbon copy _______
12. Not original copy, several pages with blurred type _______
13. Appendix pages are poor copy _______
14. Original copy with light type _______
15. Curling and wrinkled pages _______
16. Other ______________________________________

Figure 2. View of the experimental subjects for the dry environment.

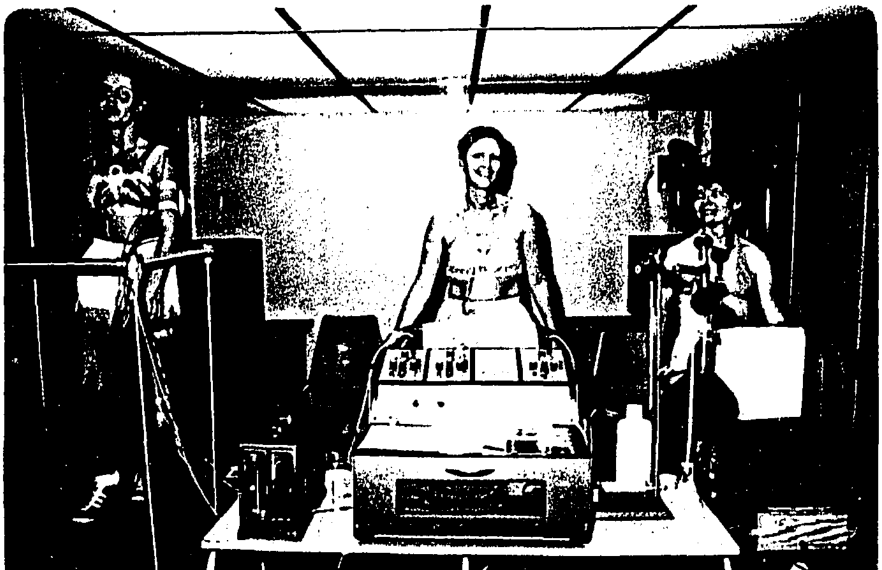

Figure 3. View of the experimental subjects for the wet. environment.

to determine what, if any, significant changes in their physical condition resulted during the experiments. It should be noted that each subject performed her work tasks at the same time each day to minimize the variance effects of Circadian rhythms on body temperature.

Equipment and Measurement

The equipment required for the study can be classified into three groups, the subject evaluation equipment, the environmental control and task apparatus, and the monitoring systems for physiological indices.

Subject Evaluation Equipment

In order to properly select subjects with adequate physical work capacity for the experiment and to determine if those selected significantly enhanced their physical condition during the study, all potential subjects were stress tested employing the Bruce Regimen (Bruce, 1974) to determine their physical work capacity. Body mass and skinfold measurements for subcutaneous body fat were also obtained. In order to gather this data, the following equipment was employed.

1. Treadmill Model 18-54 manufactured by Quinton, Inc.
2. Oxygen analyzer--Beckman Model OM-11
3. CO_2 analyzer--Beckman
4. Chart recorder--PNP-4A by Narco BioSystems, Inc.
5. 2 amplifiers manufactured by Narco Bio-Systems, Inc.

6. 3 silver-chloride chest electrodes from NDM per subject
7. Stethoscope and ausculation cuff
8. Fairbanks double-beam balance scales
9. John Bull Harpenden skin fold calipers

Environmental Control and Task Apparatus

All experimentation occurred in a controlled environment where a constant temperature of $33.5^{o}C \pm 0.5^{o}C$ WBGT was maintained for all trails. Humidity levels were held to 75% ± 4% and 35% ± 4% for wet tests and dry tests, respectively. The work task for all subjects consisted of treadmill walking at 3.15 miles per hour ± 0.05 mph. The equipment required for this phase of the investigation was:

1. Sherer-Dual controlled environment room--11' x 15'
2. Two humidifiers model 707 TW manufactured by Herrmidifier Co., Inc.
3. Two dehumidifiers model 3930 manufactured by Sears, Roebuck and Co. and one dehumidifier model 35 from Westinghouse.
4. Three treadmills manufactured by Quinton, Inc.
5. Wet Bulb Globe Temperature Monitoring System
6. Hygrotherm Humidity Sensor

Monitoring Systems

In order to obtain a record of subject physiological performance during the experimental trials and allow for

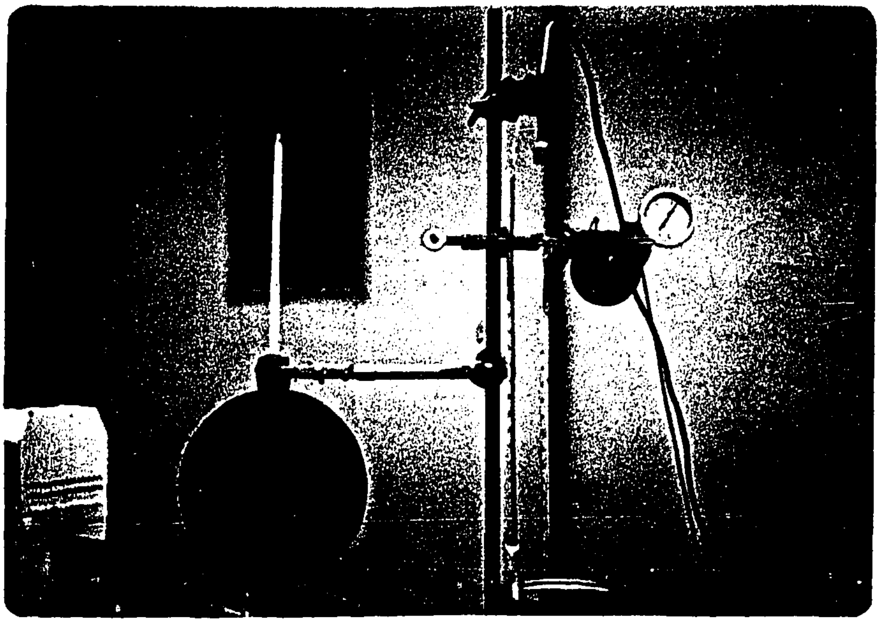

Figure 4. View of wet bulb globe temperature monitoring equipment.

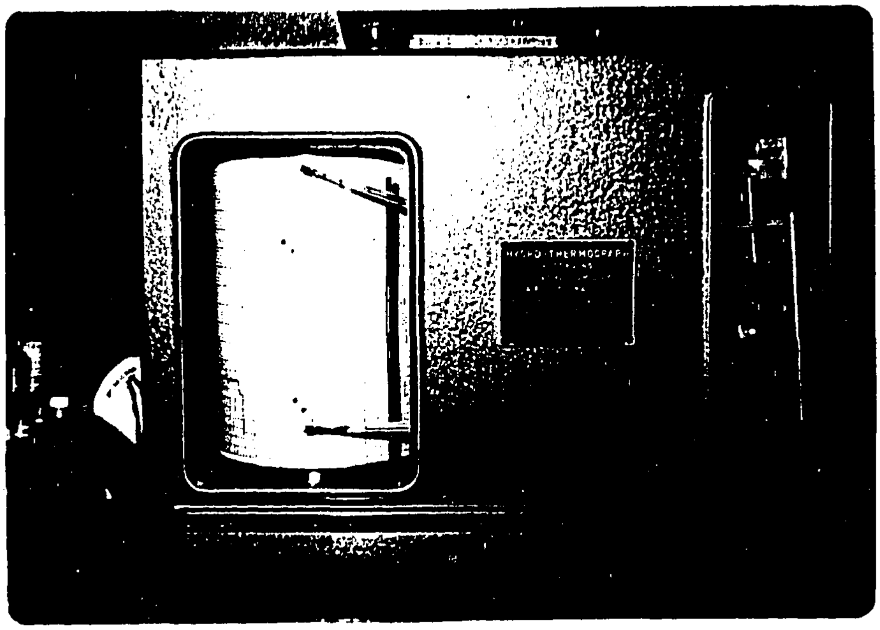

Figure 5. View of the hygrotherm employed to monitor humidity levels.

the continuous monitoring of heart rate and core temperature to assure the safety of the subjects, the following systems were utilized:

1. Fairbanks Double Beam Scales--accurate to $\pm$ ¼ oz.
2. Three NDM chest electrodes per subject per trial
3. Three model 7070 channel amplifiers manufactured by Narco BioSystems, Inc.
4. Three model 7171 Hi-Gain couplers manufactured by Narco BioSystems, Inc.
5. DECLAB 11/03 Minicomputer manufactured by Digital Equipment Corp.
6. Twelve skin thermistors model 409 manufactured by Yellow Springs Instruments, Inc.
7. Six rectal thermistors model 401 manufactured by Yellow Springs Instruments, Inc.
8. Constant current thermistor bridge circuit constructed for eighteen simultaneous inputs/outputs.
9. An 18-signal multiplexer interface outputting six signals.
10. Miscellaneous junction boxes to input subject hardwire and multiconductors to instruments external to the chamber.
11. Miscellaneous items to include adhesive tape, towels, salt, potable saline solution, 36.5 oz. H_2O containers and an intercommunications system into the chamber.

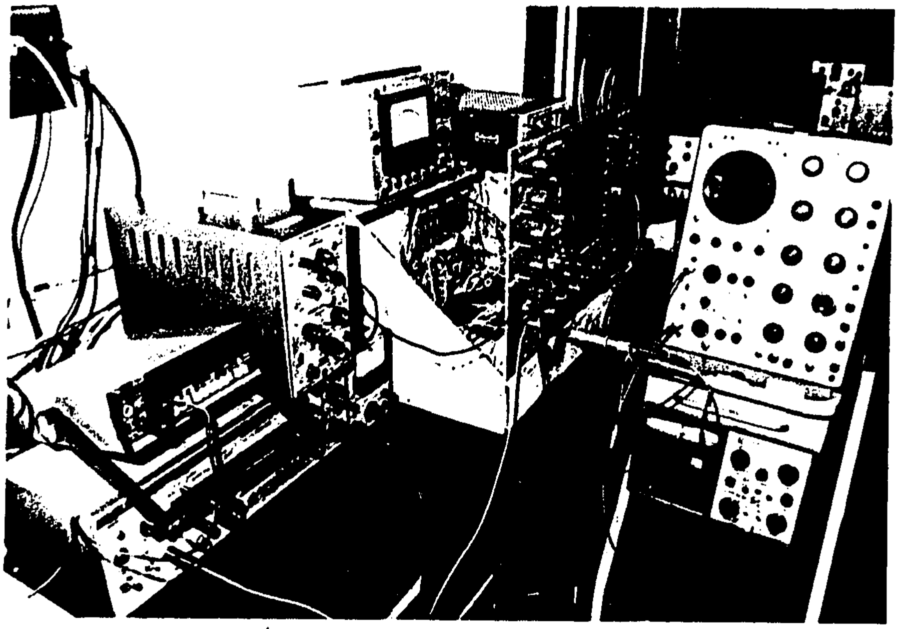

Figure 6. View of experimental monitoring interface.

Figure 7. View of minicomputer utilized to record physiological indices for all subjects.

CHAPTER IV

EXPERIMENTAL METHODOLOGY

Independent Variables

Decay Days

The first variable (D) and perhaps the most important was the time allowed for the decay of the acclimatized state for the female subjects. Only a few studies have been reported on the decay or loss of heat acclimatization when individuals stop working in hot environments (Henschel et al., 1943; Bean and Eichna, 1943; Wyndham and Jacobs, 1957; Adam et al., 1960; Lind and Bass, 1963; Williams et al., 1967). Following a review of those studies, Givoni and Goldman (1973) tentatively suggested that heat acclimatization decays at a rate of loss of one day of acclimatized status for every two days spent without working in the heat. However, the data presented in all the aforementioned studies except that by Williams et al. (1967) are based upon very small samples, incomplete acclimatization or brief decay periods. Also the subjects utilized in those experiments were all males. Pandolf et al. (1977) investigated loss of heat acclimatization in males for decay periods of 3, 6, 12 and 18 days but employed only subjects who were in excellent physical condition that averaged 50 ml/kg/min maximal aerobic capacity. Few females possess the aerobic capacities of those military subjects utilized in the previous study. Adam et al. (1960) have reported that, after 6 days without exposure to heat, "a substantial part of the improved tolerance to heat" was lost by a group of eight subjects and, after 28 days, "the decay in acclimatization was virtually complete." Henschel et al. (1943) looked at the decay of acclimatization of 24 subjects after 1, 2, 3 or 4 weeks out of the heat, but the subjects had not been fully acclimatized since they had only 2 days of initial heat exposure. Bean and Eichna (1943) have reported the loss of acclimatization for decay periods of 1, 2, 3, 5, 6, and 13 weeks, but for only one different individual for each decay period. Lind and Bass (1963) observed the decay process for groups of 2 or 3 subjects after 3, 5, 8 and 17 days without heat exposure; unfortunately, their 8 and 17 day groups were not as fully acclimatized as their 3 and 5 day groups. Wyndham and Jacobs (1957) have reported a significant loss of acclimatization to humid heat in 73 men after a 6 day decay period, but not for other durations.

NIOSH (1972) recommends that:

> For workers in hot environments, regular acclimatized employees who return from nine or more consecutive calendar days of leave, shall undergo a four day acclimatization period. The acclimatization schedule shall begin with 50 percent of the anticipated total

exposure on the first day, followed by daily 20 percent increments building up to 100 percent total exposure on the fourth day. Regular acclimatized employees who return from four consecutive days of illness should have medical permission to return to the job, and should undergo a four day reacclimatization period as defined above.

It appears that NIOSH considers 3 days of reinduction at reduced work loads adequate time to reacclimatize after 9 or more days of decay in healthy employees or 4 or more days of decay for employees who have been ill.

Based on the previous research and observations, and NIOSH recommendations, it was determined that three levels of days of decay should be examined. Those were decay periods of 4, 8, and 12 days which should adequately bracket periods comparable with industrial absences. Nine days or more of decay is recognized at present by NIOSH to necessitate a reacclimatization scheme.

Humidity

Another variable (H) was the degree of relative humidity or the moisture content of the air in the hot working environment. NIOSH (1972) defines a hot environmental condition as "any combination of air temperature, humidity, radiation and wind speed that exceeds a Wet Bulb Globe Temperature (WBGT) of 79°F (26.1°C)." This figure is for men; for women a hot environment is defined as 76°F WBGT (24.4°C) or above. The lower limit for females which necessitates special hot environment work practices and documentation is based on the classical opinion that women cannot tolerate heat as well as men. These work practices are employed when the possibility exists that an employee's core temperature may exceed 100.4°F (38.0°C) and pose a risk to his or her health.

The WBGT index is the only method recommended by NIOSH to determine environmental conditions on which the implementation of special work practices is determined. As stated in the Literature Review, women sweat less than men under identical environmental conditions, and females possess a higher skin temperature at the onset of sweating. The degree of relative humidity has a pronounced effect on heat transfer through the mechanism of sweat evaporation. More moisture content in the air results in a decreasing capacity for the transfer of heat away from a perspiring worker. In view of these findings, the query arose as to whether or not that within the region of the Upper Limits of the Prescriptive Zone, does the WBGT index adequately account for humidity variations with respect to the female worker? To address this problem two levels of humidity were selected for the work environment which resulted in the same comparative WBGT value. Those were 35 percent relative humidity and 75 percent relative humidity, referred to as the dry and wet environments respectively.

Subjects

The last independent variable to be incorporated in the experimental design was subjects. Practicality constraints dictated that six female subjects be selected and groups of three be placed in the two aforementioned levels of the independent variable humidity. A subject pool was selected and six were chosen from it for the experiment based on their capacity to adhere to the experimental controls and meet the time requirements of the test regimen. All subjects were stress tested to determine their aerobic capacities and associated heart rates, as well as weighed and measured in order to determine their percentages of subcutaneous body fat. This data was entered on a table of subject information prior to the pre-experiment acclimatization process. At the conclusion of the decay-reinduction testing, each subject was again reevaluated for the aforementioned parameters, the post test data was tabularized, and any significant changes in physical condition were noted. All subjects were paid for their time and effort when they completed the experiment.

TABLE 1

INDEPENDENT VARIABLE IDENTIFICATION, LEVEL AND RANDOMNESS

Variable	Identification	Level	Randomness
Work day	W_i	4	Fixed
Decay period	D_j	3	Fixed
Humidity	H_k	2	Fixed
Subjects	$S_{l(k)}$	6	Random

Employing analysis of variance, the design of the experimental model was as follows:

$$Y_{ijkl} = \mu + W_i + D_j + H_k + S_{l(k)} + WD_{ij} + WH_{ik} + DH_{jk}$$

where: $i = 1,2,3,4$ at 1,2,3,4 work days
$j = 1,2,3$ at 4,8,12 days for decay
$k = 1,2$ at 35%, 75% relative humidity
$l = 1,2,3,4,5,6$ with 1,2,3 nested under H_1 and 4,5,6 nested under H_2

Dependent Variables

The dependent variables to be monitored were heart rate, sweat loss, mean skin temperature, and body core temperature. Heart rate was measured every 2.5 minutes of the work task for each subject by measuring the time lapses between beats and averaging them to a beats per minute base. Sweat loss was determined by weighing each subject in the nude prior to each trial and upon completion of each trial after toweling off residual moisture. This data was then adjusted for the quantity of water ingested during the course of the experimental trial. Skin temperatures were monitored at the chest, upper arm, thigh, and calf of each subject for five seconds of every 2.5 minutes of the work task. The mean skin temperature was calculated using the formulas derived by Ramanathan (1964) by the computer and recorded. As with mean skin temperature, body core temperature was recorded each 2.5 minutes of testing. A rectal probe inserted approximately ten centimeters provided core temperature status for subjects to data display. Heart rate and core temperatures were outputted to the computer terminal for each subject to provide any information necessary for the cessation of testing in order to insure the safety of the subjects.

Experimental Routine

The protocol required by the University of Oklahoma Human Subject Use Committee was followed. Physical examinations of subjects by a physician prior to experimentation, and statements of informed consent were signed by subjects and were notarized. After these administrative requirements were met, several briefings were held with the six subjects selected to perform the study. The subjects were informed as to the purpose of the experiment, what instrumentation for their bodies was required and its function, as well as how to properly instrument themselves, body weighing techniques, proper clothing and shoes, and instruction, with practice for treadmill walking. Furthermore the rigidity of the trial schedules to be followed and the importance of the pre-trial requirements was discussed. The pretrial requirements were as follows:

1. Do not consume any food or drink except water for at least two hours before each trial.
2. Minimize smoking if you smoke and do not smoke at all for at least one hour before each trial.
3. Get at least seven hours of sleep the night before you are scheduled for a trial.
4. Refrain from any heavy physical exercise or any activity in a hot environment until the experiment is completed.
5. Do not apply any oils or skin creams to your body

on the days you are scheduled for a trial.

6. Report any variance you have encountered with the pre-trial requirements to the experimenter.

All experimental trials were held during July, August, and September, 1978. "Dry" trials were held between 1530 and 1745 hours and "wet" trials between 1745 and 2000 hours with the environmental chamber temperature constant at 33.5°C WBGT. Only one experimental trial per subject was allowed on any day. Dress consisted of a "bikini top," white cotton shorts, sockettes and tennis shoes. Subjects with long hair were required to fashion it into a "pony-tail" style or utilize a headband to minimize insulation effects.

A typical trial was conducted as follows. When a subject arrived at the laboratory, the experimenter asked if she had followed the pre-trial instructions and felt in good health. If the answer was affirmative, she entered the preparation room and prepared for the experiment. Her preparation consisted of a trip to the toilet where she urinated as much as possible, then she completely undressed and weighed herself recording her exact body weight on the proper form, and then she dressed for the experiment. At this point, the subjects instrumented one another with three chest electrodes and four skin thermistors. Each subject then inserted her own rectal probe. The subjects examined one another for proper instrument locations and attachment strengths by following a posted check list. They were then allowed to sit down and rest until they were summoned by the investigator.

During subject preparation, the experimenter switched on the computer and associated interface equipment and performed preliminary system checks. The chamber environment was evaluated for proper WBGT and humidity levels utilizing the appropriate instruments. Any variances from the fixed levels required were compensated for quickly and accurately.

When all subjects were properly dressed and instrumented, monitoring systems ready, and chamber conditions ideal, the three subjects entered the chamber and the time was noted. The subjects stood beside their assigned treadmill and plugged their transducers into the proper junction box. The experimenter examined all mechanical inputs and made corrections as required. He then switched the monitoring system to the record mode and ascertained if all transducer signals were successfully reaching the computer. Minor system adjustments were performed until reliable data was being recorded. The treadmills were then switched on and after three minutes of resting values were obtained, the experimenter told the subjects to commence walking on the treadmills.

The three subjects walked at 3.15 miles per hour for fifty minutes at which point they were given five minutes of seated rest. At the end of the five minutes all subjects returned to the walking task and performed for another fifty minutes. A known quantity of water was available for each subject and they drank as much as they desired at any time during the trials. If at any time during the course of testing any subject attained a deep body temperature of 39°C or a heart rate of 180 beats per minute, her test was to be immediately terminated. Any subject who chose to voluntarily suspend testing would have been allowed to do so. Values for the various physiological indices were continually recorded at the computer for the two hours of testing and observed by the investigator at the computer terminal.

After two hours of testing, the investigator would tell the subjects to cease walking and be seated. During the next few moments the monitoring equipment was switched to the standby mode and the subjects detached their transducers from the appropriate junction boxes. Upon direction from the investigator, the women exited the chamber for the preparation room, removed their transducers, and completely undressed. They then toweled off the moisture on their bodies, weighed themselves and recorded their post trial weight on the appropriate form. They were then debriefed by the investigator, reminded of pre-trial instructions, informed of their next scheduled test, and allowed to leave the laboratory.

At this point, the investigator determined the fluid quantities consumed by each subject to the nearest half-ounce and entered the data along with the weight measures into the Laboratory Record book.

The chamber thermostat was then adjusted, the dehumidifiers switched off and emptied, the humidifiers switched on, water bottles refilled, and treadmills checked for calibration in preparation for the wet test. The experimental regimen for the wet test was identical to the dry test. At the conclusion of the wet trial, the dehumidifiers were switched on, the humidifiers switched off and the thermostat readjusted for the next dry test. This scheme, including periodic checks on environmental indices for the chamber, was followed for all trials.

CHAPTER V

ANALYSIS OF RESULTS AND DISCUSSION

The significant effects of the independent variables on the dependent variables as determined by the statistical method of analysis of variance is presented in this chapter. Also, the results of the fitting of descriptive equations to the variables is presented.

It should be noted that all subjects were examined the day prior to the beginning of the experiment and the day following its conclusion for aerobic power, body weight, and subcutaneous body fat content. The purpose of this effort was to discern if any significant changes occurred to the physical condition of any of the subjects during the course of the experiment which might contribute to erroneous conclusions. These measures as well as others of interest appear in Table 2, the Subject Information Summary. Inspection of pre/post differences indicates that there were only minimal changes in aerobic powers, body weight, and body fat contents for the six subjects during the two months in which the experiment was performed.

TABLE 2

SUBJECT INFORMATION SUMMARY

Parameters	Dry Group Subjects			Wet Group Subjects		
	1	2	3	4	5	6
Age (years)	18	21	22	30	23	26
Height (cm)	165.4	166.4	159.7	156.2	168.9	159.4
Weight pre/post (kg)	55.8/54.5	61.3/60.8	58.9/58.8	47.9/48.8	51.5/51.9	55.3/54.3
Aerobic Power pre/ post (ml/kg/min)	44.3/44.3	35.1/40.8	39.1/37.0	33.8/34.0	39.1/36.2	43.1/37.3
Skinfolds pre/post (mm)						
Arm	12.0/12.0	12.0/11.0	16.0/13.5	14.0/12.0	13.0/14.0	14.0/11.5
Axilla	10.0/ 9.5	14.0/12.5	13.5/14.0	11.5/ 9.0	18.0/16.0	11.0/10.5
Back	10.0/10.5	15.0/16.5	22.0/19.5	9.5/ 9.0	17.0/18.0	16.0/16.5
Thigh	27.0/26.0	21.0/20.5	33.0/30.0	18.0/16.5	26.0/23.0	27.5/27.5
Hip	17.0/14.0	13.0/15.0	20.0/19.5	7.0/ 7.5	16.0/18.5	18.0/17.0
Abdomen	22.0/21.0	19.0/17.0	22.0/19.5	9.0/ 8.5	22.0/23.0	19.5/21.0
Total	98.0/93.0	94.0/92.5	126.5/116.0	69.0/63.5	112.0/112.5	106.0/104.0
Heart Rate (B.P.M.)						
Pretrial Resting H.R. Average	98	93	105	107	88	84
Max Observed:						
Stress Test	205/	192/	204/	188/	205/	186/
Experiment	147	170	164	162	185	150
Resting Blood Pressure Prior to Stress Test (mmhg)	110/70	100/70	108/64	102/66	118/82	108/70
Stress Test Durations (min) pre/post	12.2/12.3	11.2/11.6	10.5/10.1	9.0/9.4	10.3/10.1	10.7/10.2

Analysis of Variance

An IBM 370/158 computer, utilizing the analysis of variance program obtained from the Statistical Analysis Systems (SAS, 1976) program series was used to compute the necessary ANOVA tables for the experimental variables. These tables are presented in the appendix and include the independent variable F-ratios and their appropriate error terms.

Table 3, Composite of Significant Effects, depicts the significant effects and the associated alpha levels found in the ANOVAs. All other effects were found to be insignificant at an alpha of .10.

Table 4, Daily Water Loss in Ounces, shows the average water loss per subject per trial. The average water loss was 41.4 ounces for the wet group and 46.4 ounces for the dry group per subject per work period. ANOVA yielded no significant differences in water loss between the wet and dry groups, between the differing decay periods, or between different days of work. Water loss was not a realistic indicator of stress differences but approximated a constant value for the work task.

End of Work Heart Rate, Table 5, shows the average responses for each group for the course of the experiment. ANOVA yielded three cases of significance where work day values varied significantly at an alpha of .01, decay periods differed with an alpha of .02, and the decay period and group interaction was significant at an alpha of .10.

TABLE 3

COMPOSITE OF SIGNIFICANT EFFECTS*

Source of Variation	End of Work Core Temperature	End of Work Heart Rate	End of Work Mean Skin Temperature	Water Loss
Day (W)	.01	.01	.04	-
Decay Period (D)	-	.02	-	-
Group (H)	-	-	.05	-
Decay x Group (D x H)	.04	.10	-	-
Day x Group (W x H)	.02	-	-	-

*Minimum α level at which effect is significantly different than zero.

TABLE 4

DAILY WATER LOSS IN OUNCES

Work Day Sequence	Dry Group Average	Wet Group Average
1	-	-
2	-	-
3	-	-
4	43.2	47.8
5	47.5	44.2
6	50.0	44.8
7	49.3	41.5
8	47.8	42.5
9	48.3	37.5
10	49.8	39.7
4 Days Decay		
15	45.3	37.5
16	55.5	41.5
17	41.0	42.5
18	45.0	40.8
8 Days Decay		
27	41.5	41.7
28	43.8	42.0
29	43.3	43.0
30	39.3	41.8
12 Days Decay		
43	53.0	37.0
44	50.2	41.5
45	41.7	43.8
46	45.5	40.8
47	43.8	35.8
Reversed Environments		
48	43.8	42.3

TABLE 5

END OF WORK HEART RATE AVERAGE
IN BEATS PER MINUTE

Work Day Sequence	Dry Group Average	Wet Group Average
1		
2		
3		
4	148.7	148.7
5	144.3	146.7
6	141.3	144.3
7	142.7	142.7
8	138.3	138.3
9	136.7	133.3
10	136.0	135.0
4 Days Decay		
15	150.3	145.7
16	144.7	136.3
17	136.3	137.3
18	140.6	135.7
8 Days Decay		
27	156.0	152.0
28	147.0	139.7
29	137.7	139.7
30	133.3	136.3
12 Days Decay		
43	159.7	165.7
44	151.3	157.3
45	143.3	148.3
46	141.3	138.3
47	134.0	134.7
Reversed Environments		
48	142.7	127.7

Figure 8, Averaged Values by Group for End of Work Heart Rate, depicts the phenomena of increasing end of work values after longer decay periods on the first day of returning to work, and a continual decrease in maximal heart rate elicited as the days of work progressed. The significance of the group-decay period interaction suggests that the groups may have lost their degree of acclimatized status at differing rates. However, the experimental design with its small sample size disallows statistical interpretations between groups and decay periods with respect to the differences in rates of decay for each group. Plots of the actual values were employed in an effort to establish any trends but these were of no benefit in that the parameter lines found for each group intersected at more than one point. Thus, conclusions cannot be drawn as to which group gained or lost their acclimatized status more quickly. It should be noted that there was no significant difference between wet and dry group heart rates.

End of Work Core Temperature in ^{o}C, Table 6, depicts the daily deep body temperature averages for each group. The day effect was found to be significant at an alpha level of .01 and this trend of decreasing core temperature as the number of work days increases can be seen in Figure 9, Averaged Values by Group for End of Work Core Temperature. Differing decay periods, however, showed no significant effects as shown by the ANOVA. However, the decay period x

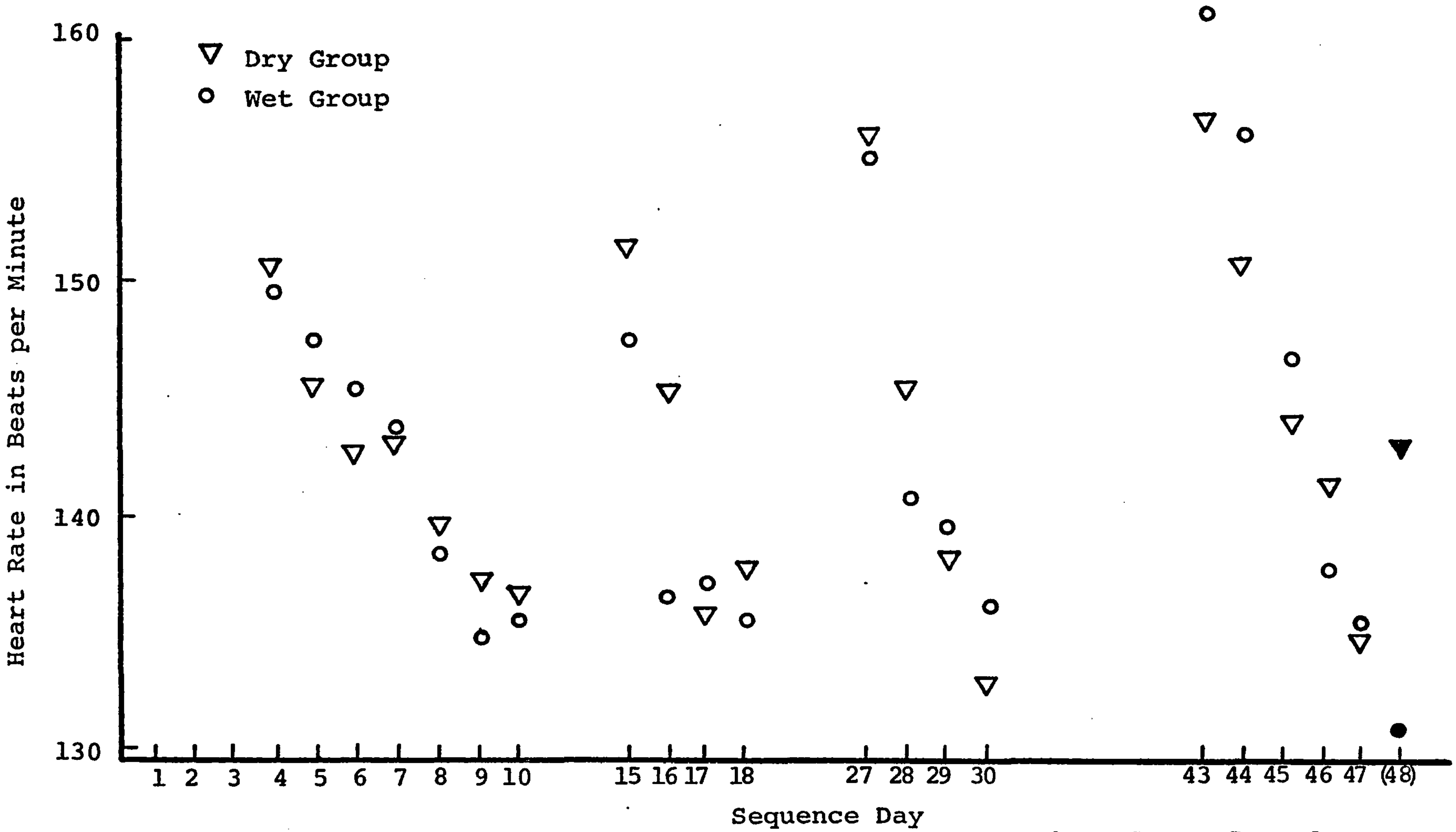

Figure 8. Averaged Values by Group for End of Work Heart Rate, where Decay Days Are Represented by Unnumbered Points on the Sequence Day Axis.

TABLE 6

END OF WORK CORE TEMPERATURE IN ^{o}C

Work Day Sequence	Dry Group Average	Wet Group Average
1		
2		
3		
4	38.38	38.39
5	38.29	38.30
6	38.34	38.45
7	38.18	38.51
8	38.24	38.28
9	38.14	38.04
10	38.18	38.10
4 Days Decay		
15	38.33	38.34
16	38.36	38.21
17	38.22	38.15
18	38.23	38.08
8 Days Decay		
27	38.37	38.36
28	38.17	38.26
29	38.15	38.29
30	38.14	38.12
12 Days Decay		
43	38.41	38.44
44	38.28	38.42
45	38.16	38.23
46	38.14	38.15
47	38.14	38.11
Reversed Environments		
48	38.08	38.09

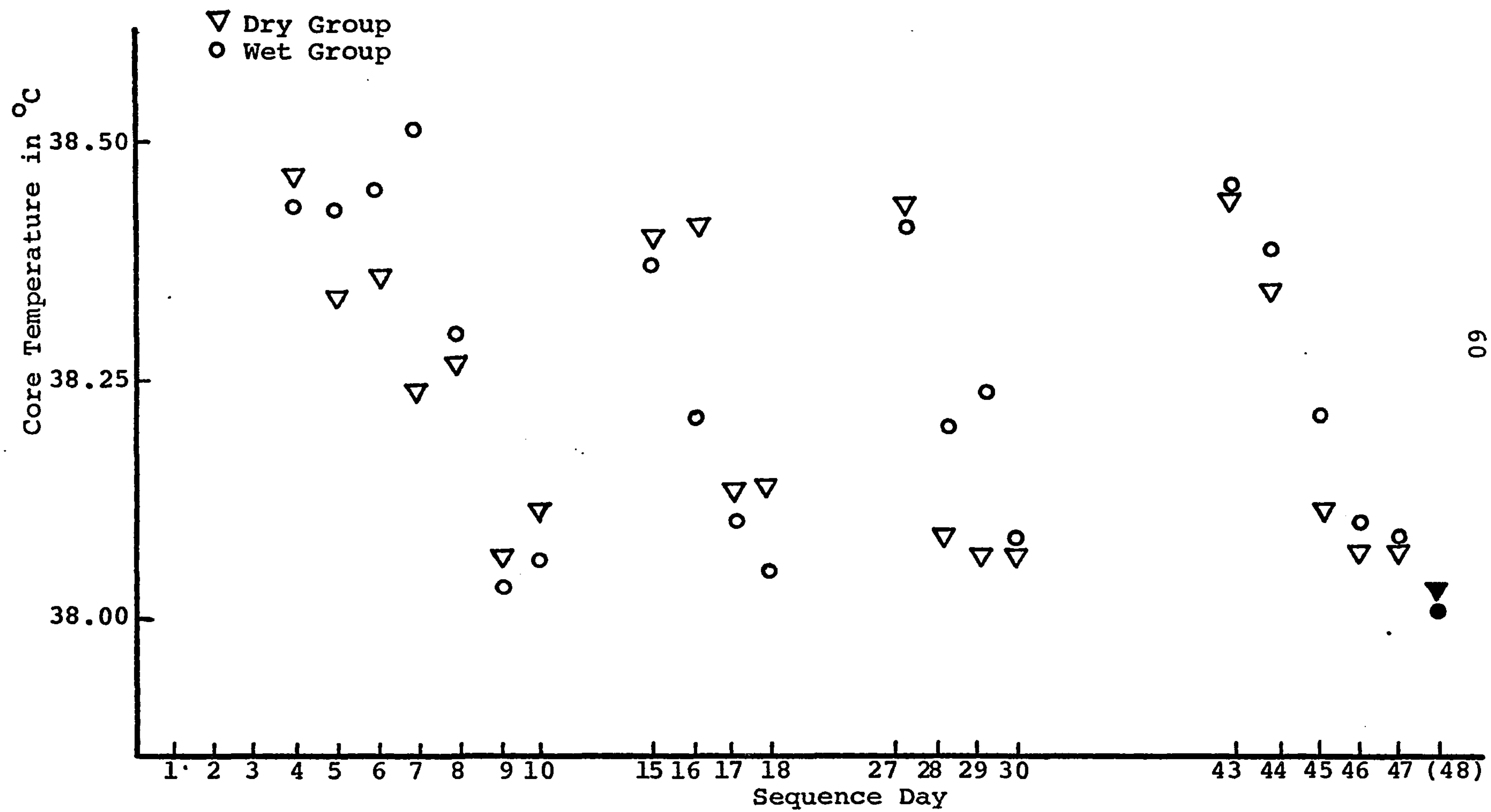

Figure 9. Averaged Values by Group for End of Work Core Temperature, where Decay Days Are Represented by Unnumbered Points on the Sequence Day Axis.

group interaction and the work day x group interaction were found to be significant at alpha levels of .04 and .02, respectively. Again, as with heart rate, these findings support the hypothesis that acclimatization rates vary between groups, but insufficient data disallow quantification or interpretation of this difference. It should be noted that, as with heart rate, there was no significant difference in core temperature found between the wet and dry groups.

Table 7, End of Work Mean Skin Temperature in ^{o}C, shows the responses obtained for the experiment. Work day effects and group effects were found to be significant at alpha levels of .04 and .05, respectively. Figure 10, Averaged Values by Group for End of Work Mean Skin Temperature, depicts the decrease in mean skin temperature as the number of work days increases. The difference between groups can best be explained by the fact that the dry group performed the experiment in an environment possessing a greater dry heat load than did the wet group. No other parameters were found to be significant for this index.

Regression Analysis

A linear and a quadratic regression analysis were performed using the number of decay days and the number of the consecutive return to work days as the independent variables. These predictive equations were formed for the dependent variables of end of work heart rate, core

TABLE 7

END OF WORK MEAN SKIN TEMPERATURE IN ^{o}C

Work Day Sequence	Dry Group Average	Wet Group Average
1		
2		
3		
4	37.51	36.50
5	37.34	36.75
6	37.54	36.71
7	37.07	36.62
8	36.81	36.41
9	36.63	36.13
10	36.43	36.19
4 Days Decay		
15	37.12	36.49
16	36.98	36.34
17	36.39	36.24
18	36.49	36.17
8 Days Decay		
27	37.28	36.56
28	36.86	36.34
29	36.61	36.28
30	36.50	36.18
12 Days Decay		
43	37.19	36.43
44	37.01	36.48
45	36.76	36.43
46	36.90	36.26
47	36.64	36.12
Reversed Environments		
48	36.23	36.67

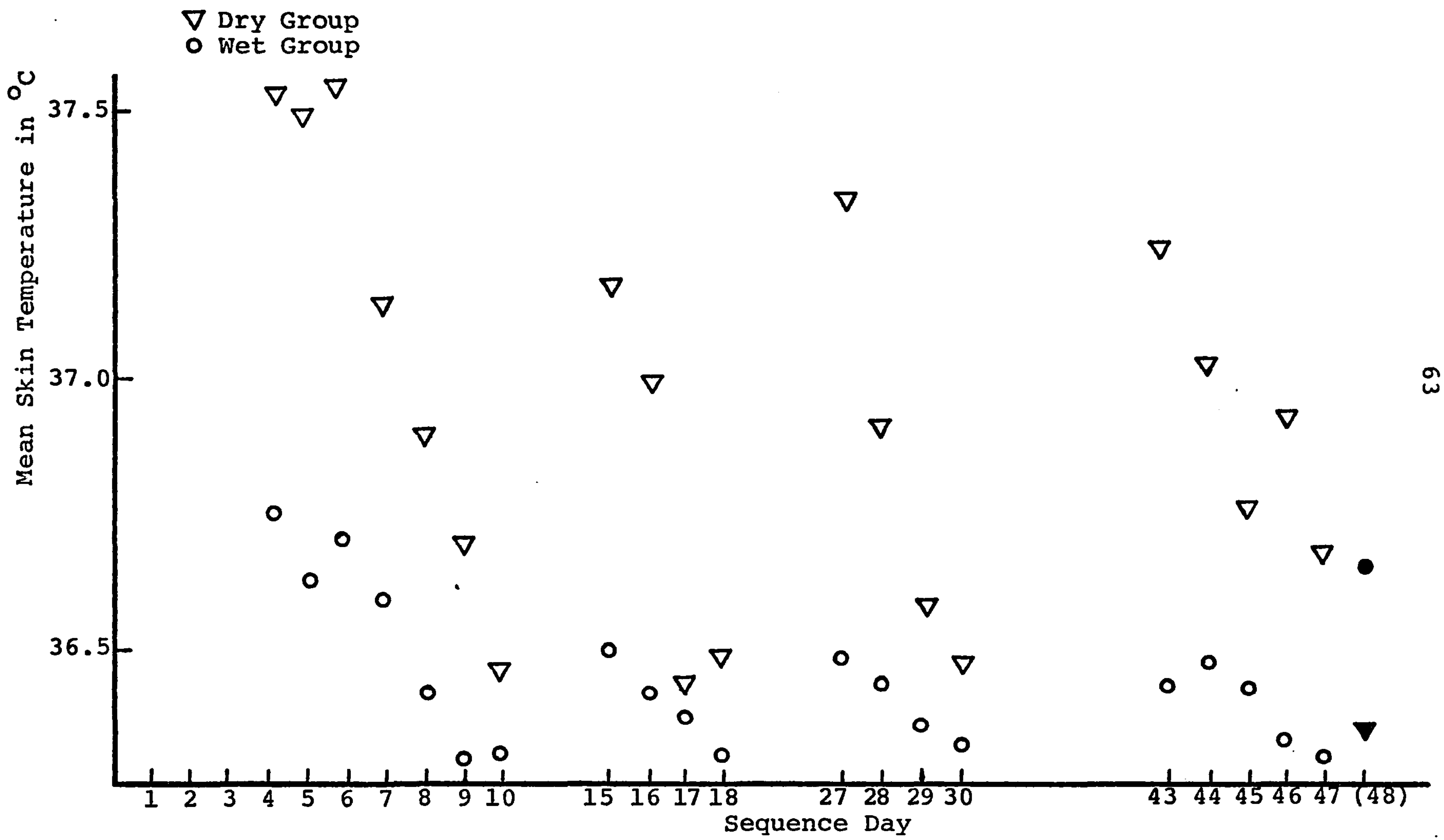

Figure 10. Averaged Values by Group for End of Work Mean Skin Temperature, where Decay Days Are Represented by Unnumbered Points on the Sequence Day Axis.

temperature, and mean skin temperature. Thus, one may predict the level to be attained for each physiological index for female subjects who work at comparable energy expenditures in similar environments. These values may be predicted for decay periods of four through twelve days for the first through the fourth day of returning to work by employing the following equations:

For End of Work Heart Rate--

$$(\text{H.R., b.p.m.}) = 143.70 + 1.57\ (\text{Decay Days}) - 4.53\ (\text{Work Days}) \qquad R = .48$$

For End of Work Core Temperature--

$$(\text{C.T., }^{o}\text{C}) = 38.34 + .006\ (\text{Decay Days}) - .06\ (\text{Work Days}) \qquad R = .38$$

For End of Work Mean Skin Temperature--

For high humidity levels 75%

$$(\text{M.S.T. Wet, }^{o}\text{C}) = 36.50 + .01\ (\text{Decay Days}) - .096\ (\text{Work Days}) \qquad R = .60$$

For low humidity levels 35%

$$(\text{M.S.T. Dry, }^{o}\text{C}) = 37.13 + .03\ (\text{Decay Days}) - .20\ (\text{Work Days}) \qquad R = .65$$

Table 8 depicts heart rate and core temperature confidence intervals for the first and fourth day of work for four through twelve days of decay of acclimatization. It should be noted that quadratic functions were generated as well as the linear functions previously presented. The quadratics did not significantly enhance the predictive

TABLE 8

SELECTED CONFIDENCE INTERVALS FOR END OF WORK HEART RATE AND CORE TEMPERATURE

Number of Decay Days	Day of Work	Heart Rate		Core Temperature	
		Lower 95% C.L.	Upper 95% C.L.	Lower 95% C.L.	Upper 95% C.L.
4	1	140.5	- 150.3	38.23	- 38.38
	4	125.1	- 138.5	38.02	- 38.23
5	1	142.1	- 151.8	38.23	- 38.39
	4	126.6	- 139.8	38.03	- 38.23
6	1	143.7	- 153.5	38.24	- 38.39
	4	128.1	- 141.1	38.05	- 38.23
7	1	145.3	- 155.0	38.24	- 38.40
	4	130.0	- 142.0	38.06	- 38.22
8	1	146.8	- 156.6	38.25	- 38.41
	4	133.4	- 142.8	38.07	- 38.22
9	1	147.9	- 158.6	38.25	- 38.42
	4	135.0	- 144.3	38.07	- 38.23
10	1	149.0	- 160.7	38.25	- 38.43
	4	136.6	- 145.8	38.08	- 38.23
11	1	150.1	- 162.7	38.25	- 38.45
	4	138.2	- 147.6	38.09	- 38.23
12	1	151.3	- 164.7	38.24	- 38.46
	4	139.8	- 148.9	38.09	- 38.24

capacity for the indices studied and it was concluded that the linear estimators provided the best descriptions from a parsimonious approach to the selection of regressions.

Reversed Environments

On the last day of the experiment, the wet group performed the work task in the environment previously utilized for the dry group and the dry group performed in the wet environment. Inspection of data for that day yielded no notable differences in end of work core temperature, heart rate, or water loss. Only mean skin temperature varied as was to be expected. This tends to support W.B.G.T. as an effective index of environments from a physiological cost viewpoint, but this conclusion is not statistically justifiable. Subjective remarks by subjects, however, suggested that the wet environment was more stressful than the dry environment for the dry group, and the dry environment felt less stressful for the wet group than did the wet environment. In fact, two dry group subjects commented that they probably would not have completed the experiment had they had to perform in the wet environment.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This chapter summarizes the results of the Analyses presented in Chapter V as well as recommendations of areas of interest for further research.

Conclusions

Maintenance of an enhanced sweating response when exposed to moderate work in heat appears to be a characteristic of unacclimatized, but physically fit individuals (Gisolfi, 1973). Gisolfi noted that there was no change in sweat rate for six initially fit subjects for eight days of heat acclimatization and this has been supported by Robinson et al. (1943). Piwonka (1965) and Robinson (1969) found no increase in sweat rate during heat acclimatization for physically fit subjects but they did find significant changes in heart rate and core temperature. Gisolfi and Robinson (1969) concluded that physical conditioning "partially preacclimatized subjects for acclimatization to heat." It appears that with physically fit subjects, changes in sweat rate during acclimatization are minimal which tend to support the findings in this investigation with respect to a fairly constant sweat rate for the six female subjects employed.

The data presented in the previous chapter supports the premise that for periods of no exposure to work in the heat, there is a loss of acclimatization to heat stress. Decay periods of four, eight, and twelve days following acclimatization exposures yielded physiological responses of successively greater magnitudes on the first day of return to task/environment exposures. Thus, one can conclude that a substantial part of a person's tolerance to heat is lost during periods of nonexposure, and that this loss increases as the length of the period of nonexposure increases. It must be noted that the rate of decay of acclimatized status varies as a function of the index utilized to ascertain acclimatized status. Heart rate appears from this study to be the most sensitive indicator of heat stress. According to the heart rate data and assuming twelve days of decay as a base for defining specific loss of acclimatized status, 45 percent of this twelve day loss is realized after only four days of decay and 68 percent of the twelve day loss is realized after eight days decay. Core temperature, the more popular of the indices for heat stress, appears much less sensitive than heart rate and yields different percentage losses with respect to the degree of acclimatization. With respect to the twelve day decay base, core temperature indicates that 66 percent of acclimatized status is lost after a four day decay and 77 percent is lost after an eight day decay. Thus, one may conclude that the rate of decay of the acclimatization process cannot be described simply as a function of a single parameter such as heart rate or core temperature, but some combination of those indices, and possibly others, should be developed in order to describe the multiplicity of activities involved in heat acclimatization. It must also be noted that the magnitude of observed differences for the physiological parameters may have been greater had the experiment not occurred during one of the hottest seasons on record which may have had some contribution to the loss of heat acclimatization.

Only a few studies have reported on the decay of heat acclimatization and these were presented in the Literature Review. Givoni and Goldman (1973) reviewed these studies and suggested that heat acclimatization decays at a rate of loss of one day of acclimatized status for every two days spent without working in the heat. Analysis of heart rate data presented in Chapter V demonstrates that a loss of one day of acclimatized status occurred for every three days of nonexposure. Yet, the core temperature trends support a much slower loss of acclimatization at a ratio of one to ten. Pandolf et al. (1977) found heart rate changes proportionately greater over time than core temperature for their decay and reinduction study of fit males. They hypothesized that the high degree of physical fitness of their subjects was the prime factor in their rapid acclimatizations with small decays even after 18 days of non-exposure. Thus, the relationship between loss of days of acclimatized status as a function of periods of nonexposure depends upon the criterion index employed as well as the physical fitness levels of the individuals being described. Minimal data exists with respect to decay and reinduction time relationships for men, and this study was the first to be performed on females.

A review of the significant findings presented in the previous chapter indicates that certain conclusions can be drawn about the adequacy of the W.B.G.T. index as a descriptor of environmental severity. Analysis of variance demonstrated that there were no significant differences in the physiological responses for end of work values of heart rate, core temperature, and water loss for the two environments investigated. Thus, for an environment of 33.5^{o}C W.B.G.T., the Wet Bulb Globe Temperature index compensates well for a variation of 35 percent to 75 percent relative humidity. Only Mean Skin Temperature demonstrated a significant difference between environments and this was to be expected since there was a 4.0^{o}C globe temperature difference between environments. Since the dry environment had a higher heat energy load, the skin temperature for that subject group was correspondingly higher. It must be noted that this conclusion with respect to the adequacy of W.B.G.T.

is valid only for the environment investigated with subjects performing at a moderate work load. Yet, even with the 40 percentage point variation in relative humidity between environments, the W.B.G.T. index compensations for equal temperature allowed for identical average water loss from sweating for each group of .80 ounces per kilogram of body weight. More data in the range of ULPZ values at other work loads must be developed in order to confirm the validity of the W.B.G.T. index.

The experiment confirmed the existence of the process of acclimatization and demonstrated that as more days of decay of acclimatized status occurs, more days of exposure time are required to return subjects to the acclimatized state. Regression equations describing the levels of physiological responses attained for one through four days of work and for four through twelve days of decay have been developed in order to allow for the prediction of time to lose or gain acclimatized status.

Recommendations for Further Research

In order to develop the data necessary for the establishment of protective work practices in an effort to reduce the risk of work related heat disorders, several areas of study seem worthy of further research. Recommendations for reduced work loads and periods of limited exposure for workers in hot environments must be accurate in order to ensure the support of the industrial complex which will utilize them. Any proposed scheme for the initial acclimatization to heat as well as any reinduction regimen for reacclimatization after periods of decay should require a quantitative data base encompassing several parameters. These parameters broadly include the worker, work task, work environment, and time periods allowing for the decay of acclimatized status.

More individuals of both sexes should be evaluated in controlled experiments to determine their physiological responses to work in heat. The level of physical fitness of individuals varies significantly when variables such as somatotype, aerobic power, age, and ethnic origin are considered. Still several male-female differences in reaction to heat stress have yet to be resolved with respect to responses under conditions of heat stress. The human variability among as well as between sexes for heat stress/strain relationships may suggest that work practices which will protect 95% of the population could be unrealistic for the majority of persons who choose to work in hot environments. Perhaps more than one scheme of work practices may be developed and applied to specific populations where the physical work capacities of each population has been ascertained. Therefore, an adequate number of individuals possessing various physiological characteristics should be examined employing research techniques which can provide statistically reliable and repeatable conclusions.

The work tasks utilized in controlled experiments should be constant with respect to work load. A constant work load for experimental trials is necessary to maintain adequate control. Yet most industrial tasks do not require a constant level of effort. Thus, laboratory studies should be performed at constant levels of effort with respect to energy expenditure for both static and dynamic work tasks, and these results made available to investigators who can compare them with observations made at the industrial setting. These observations to be made at the industrial setting appear to be the primary mechanism by which to ascertain the adequacy of work practice recommendations which will be predicated on the laboratory studies. The selection of representative work tasks in industry, as well as the design of monitoring schemes for physiological parameters, are significant undertakings but requisite to the evaluation of any realistic work practices.

Evaluation of responses to various work environments presents problems to investigators similar to those of work task evaluation. Laboratory studies are usually conducted in controlled environments while most industrial environments often precludes on the job studies with a constant heat load. Different levels of environmental severity when combined with tasks of varying metabolic cost that elicit core temperatures in the range of the Upper Limits of the Prescriptive Zone must be investigated in order to adequately quantify both male and female responses. The environments studied should reflect extremes of relative humidity and heat load contributors in an effort to determine what effects these variations have on the processes of heat acclimatization. The W.B.G.T. index should be evaluated at various W.B.G.T. values with variations in the globe temperature and wet bulb temperature combined to yield identical W.B.G.T. values. The quest for another index of environmental severity besides W.B.G.T. should not be abandoned, but these other indices should be ascertained as well as W.B.G.T. in future laboratory studies.

The last parameter of significant research interest is decay periods which reduce the acclimatized status of individuals. Males and females should be examined where the combinations of the aforementioned parameters can be fixed for both sexes. Then decay periods such as those investigated in this study as well as longer periods of decay should be examined and these examinations should be conducted serially for at least a year in order to ascertain the effects of climatic seasonal variations on decay and reinduction of heat acclimatization.

Predictive equations such as those generated in this study could predict the level attained for various physiological indices for workers of defined sex and physical work capacity and for given task-environment constraints with further development. Knowledge of how long an individual has not been exposed to heat stress would allow for the prediction of the stress expected on return to the work environment. Thus, realistic recommendations for special work practices could be developed on a credible base.

It should be noted in closing that the quantification of those areas for further research presents a challenge of considerable magnitude; thus, this knowledge will require several years of dedicated effcrt to reach fruition. It also appears that if no tentative work practices are required of industry, cases of job related heat disorders will continue to occur. Therefore, some work practice constraints should be developed in the near future knowing full well that they should be flexible enough to adjust to new findings and interpretations of existing and future research.

REFERENCES

1. Adams, S.M.; Fox, R.H.; Grinby, G.; and Kidd, D.S. Acclimatization to Heat and Its Rate of Decay in Man. Journal of Physiology 152:26-27, 1960.

2. American Heart Association. Exercise Testing and Training of Apparently Healthy Individuals: A Handbook for Physicians, 1972.

3. A.I.H.A. Ergonomics Guide to Assessment of Metabolic and Cardiac Costs of Physical Work. Journal of the A.I.H.A., August, 1971.

4. A.I.H.A. Heat Exchange and Human Tolerance Limits. Heating and Cooling for Man in Industry, Akron, Ohio, 1975.

5. A.F.S.C., Air Force Systems Command. Design Handbook 1-3, Human Factors Engineering, Dayton, Ohio, 1977.

6. Bar-Or, O.; Lundegren, H.M.; and Busikirk, E.R. Heat Tolerance of Exercising Obese and Lean Women. Journal of Applied Physiology 26:403-409, 1969.

7. Bar-Or, O.; Lundegren, H.M.; Magnosson, L.I.; and Buskirk, E.R. Distribution of Heat Activated Sweat Glands in Obese and Lean Women. Human Biology 40:235-248, 1968.

8. Bartnicki, C.; Esjsmont, W.; and Dubrawski, R. Differences of Some Physiological Reactions in Women and Men Exposed to the Effects of High Environmental Temperatures. Bulletin of the Institute of Marine Medicine in Gdansk 20:45-49, 1969. Cited in Hertig (1971).

9. Bean, W.B., and Eichna, L.W. Performance in Relation to Environmental Temperature. Federation Proceedings 2:144-158, 1943.

10. Belding, H.S. Engineering Approach to Analysis and Control of Heat Exposures. Industrial Environmental Health. New York: Academic Press, 1972.

11. Bittel, J., and Henane, R. Comparison of Thermal Exchange in Men and Women under Neutral and Hot Conditions. Journal of Physiology 250:475-489, 1975.

12. Bruce, R.A. Methods of Exercise Testing. American Journal of Cardiology, Vol. 33, 1974.

13. Fox, R.H.; Goldsmith, R.; Hampton, I.F.G.; and Hunt, T.J. Heat Acclimatization by Controlled Hyperthermia in Hot-Dry and Hot-Wet Climates. Journal of Applied Physiology 35:875-879, 1973.

14. Givoni, B., and Goldman, R.G. Predicting Effects of Heat Acclimatization of Heart Rate and Rectal Temperature. Journal of Applied Physiology 35:875-879, 1973.

15. Hardy, J.D.; Milhorat, A.S.; and DuBois, E.F. Basal Metabolism and Heat Loss of Young Women at Temperatures from 22°C to 35°C. Journal of Nutrition 21:383-404, 1941.

16. Haslag, W.M., and Heartzman, A.B. Temperature Regulation in Young Women. Journal of Applied Physiology 20:1283-1288, 1965.

17. Henschel, A.; Taylor, H.L.; and Keys, A. Persistence of Heat Acclimatization in Man. American Journal of Physiology 140:321-325, 1943.

18. Henschel, A. The Environment and Performance in Physiology of Work Capacity and Fatigue. E. Simonson, Ed., E.G. Thomas, Springfield, Ch. 14, 1971.

19. Henschel, A. From a Lecture Presented at Several NIOSH Courses on Heat Stress. Cited in Jensen and Heins (1976).

20. Hertig, B.A., and Sargent, F. Acclimatization of Women during Work in Hot Environment. Federation Proceedings Vol. 22, p. 180, 1963.

21. Hertig, B.A. Human Physiological Responses to Heat Stress: Males and Females Compared. Journal of Physiology 63:270-273, 1971.

22. Hicks, C.R. Fundamental Concepts in the Design of Experiments. New York: Holt, Rinehart, and Wilson, 1964.

23. Jakob, Max. Heat Transfer. New York: John Wiley and Sons, 1959.

24. Jensen, R.C., and Dukes-Dubos, F. Rationale and Provisions of the Work Practices Standard for Work in Hot Environments as Recommended by NIOSH. Symposium of Standards for Occupational Exposures to Hot Environments. NIOSH, 1976.

25. Jensen, R.C., and Heins, D.A. Relationships between Several Prominent Heat Stress Indices. DHEW (NIOSH) Pub. No. 77-109, Cincinnati, 1976.

26. Kawahata, A. Sex Differences in Sweating. In: Essential Problems in Climatic Physiology. Edited by H. Yoshimura: Nankodo, 1960. Cited in Hertig (1971).

27. Knip, A.S. Measurement and Regional Distribution of Functioning Eccrine Sweat Glands in Male and Female Caucasians. Human Biology 41:380-387, 1969.

28. Kraning, K.K.; Belding, H.S.; and Hertig, B.A. Use of Sweating Rate to Predict Other Physiological Responses to Heat. Journal of Applied Physiology 21:111-117, 1966.

29. Kuhlevneier, K.V., and Miller, J.M. Assessment of Deep Body Temperature of Workers in Hot Jobs, DHEW (NIOSH) Pub. No. 77-110, Cincinnati, 1977.

30. Kuhlemeier, K.V., and Miller, J.M. Assessment of Deep Body Temperature of Women in Hot Jobs, DHEW (NIOSH) Pub. No. 77-215, Cincinnati, 1977.

31. Leithead, C.S., and Lind, A.R. Heat Stress and Heat Disorders. London: Cassell & Co., 1964.

32. Lind, A.R., and Bass, D.E. Optimal Exposure Time for Development of Acclimatization to Heat. Federation Proceedings Vol. 22:704-708, 1963.

33. Lind, A.R., and Liddell, F.D.K. Influence of Individual Variation on the Prescriptive Zone of Climates. London: National Coal Board, 1963.

34. Lind, A.R. A Physiological Criterion for Setting Thermal Environmental Limits for Everday Work. Journal of Applied Physiology 18:51-56, 1963.

35. Lind, A.R. The Prediction of Safe Limits for Prolonged Occupational Exposure to Heat. Federation Proceedings 32:610-613, 1973.

36. Lind, A.R. Limits of Exposure to Work in Hot Climates without a Rise in Body Temperature. Symposium on Standards for Occupational Exposures to Hot Environments. NIOSH, 1976.

37. MacPherson, R.K. Thermal Stress and Thermal Comfort. Ergonomics 16:5, 1973.

38. McAdams, W.H. Heat Transmission. New York: McGraw-Hill, 1954.

39. McArdle, R., et al. The Prediction of Physiological Effects of Warm and Hot Environments. Medical Research Council (Great Britain), H.S. Royal Naval Personnel Research Committee, R.N.P. 47, 391, 1947.

40. Minard, D. Prevention of Heat Casualties in Marine Corps Recruits, 1955-1960, with Comparative Incidence Rates and Climatic Heat Stresses in other Training Categories. Contract #MR 005. 01-0001.01, Nav al Medical Research Institute, Bethesda, 1961.

41. Mitchell, D., and Wyndham, C.H. Comparison of Weighting Formulas for Calculating Mean Skin Temperature. Journal of Applied Physiology 26:616-622, 1969.

42. Morimoto, T.; Slabochova, Z.; Waman, R.K.; and Sargent, F. Sex Differences in Physiological Reactions to Thermal Stress. Journal of Applied Physiology 22:526-532, 1967.

43. Mutchler, J.E.; Malzahn, D.C.; V ecchio, J.L.; and Soule, R.D. An Improved Method for Monitoring Heat Stress Levels in the Workplace. DHEW (NIOSH) Pub. No. 75-161, Cincinnati, 1975.

44. NIOSH. Occupational Exposure to Hot Environments. DHEW Pub. No. HSM72-10269, Washington, D.C., 1972.

45. Occupational Safety and Health Administration, Standards Advisory Committee. Recommendations for a Standard for Work in Hot Environments. Occupational Safety and Health Reports. Draft No. 5:1050-1057, 1974.

46. Pandolf, K.B.; Burse, R.L.; and Goldman, R.F. Role of Physical Fitness in Heat Acclimatization, Decay and Reinduction. Ergonomics 20:399-408, 1977.

47. Physical Agents Committee, Proposed Threshold Limit Values. American Conference of Governmental Industrial Hygienists, Cincinnati, 1971.

48. Ramanthan, N.L. A New Weighting System for Mean Surface Temperature of the Human Body. Journal of Applied Physiology 19:531-533, 1964.

49. Ramanthan, N.L., and Belding, H.S. Physiological Evaluation of the WBGT Index for Occupational Heat Stress. Presented at the AIHA Conference, Boston, Mass., 1973.

50. S.A.S. A User's Guide to SAS·76. Raleigh, N.C.: SAS Institute, Inc., 1976.

51. Schwartz, E., and Meyersen, N. Effect of Heat and Natural Acclimatization to Heat on Tilt Tolerance of Men and Women. Journal of Applied Physiology 28:428-432, 1970.

52. Weinman, K.P.; Slabochova, Z.; Bernader, B.M.; Morimoro, T.; and Sargent, F. Reactions of Men and Women to Repeated Exposures of Humid Heat. Journal of Applied Physiology 22:533-538, 1967.

53. Williams, C.G.; Whydham, C.H.; and Morrison, J.F. Rate of Loss of Acclimatization in Summer and Winter. Journal of Applied Physiology 22:21-26, 1967.

54. Winer, B.J. Statistical Principles in Experimental Design. New York: McGraw-Hill, 1971.

55. Wyndham, C.H., and Jacobs, G.E. Loss of Acclimatization after Six Days of Work in Cool Conditions on the Surface of a Mine. Journal of Applied Physiology 11:197-198, 1957.

56. Wyndham, C.H.; Morrison, J.F.; and Williams, C.G. Heat Reactions of Male and Female Caucasians. Journal of Applied Physiology 20:357-364, 1965.

APPENDIX I

DEVELOPMENT OF TEMPERATURE/RESISTANCE EQUATION FOR YSI SERIES 400 TEMPERATURE PROBES

The following procedure was used to derive an equation for calculating the thermistor temperature directly from the resistance of the probe. The "Instructions for YSI Series 400 Temperature Probes" booklet includes a table which lists the temperature/resistance characteristics for the probes. The data in this table was used to generate an equation relating the temperature in degrees Kelvin to the resistance of the probe in ohms.

Various equations were tried as suggested by Sachse (1975). The equation which provided the best fit was developed by Steinhart and Hart (1968) and rewritten by Trolander, Case and Harruff (1973) in the form

$$T = 1 / [A + B \ln R + C(\ln R)^3]$$

where

T = temperature in degrees Kelvin ($^{o}C + 273$)

R = resistance in ohms

A,B,C = coefficients to be estimated.

The coefficients were estimated using the NLIN procedure of the Statistical Analysis System (SAS), a computer package of statistical programs. The NLIN procedure produces least squares estimates of the coefficients of a non-linear model using a modified Gauss-Newton method.

The data from the YSI table used for the regression included those values from 0 to 50°C (273 to 323°K). The initial estimates provided by SAS accurate to eight decimal places were

$$A = 0.00146703 \qquad B = 0.00023858 \qquad C = 0.00000010 \; .$$

The predicted temperature is very sensitive to the value used for the coefficient C, requiring an estimate which is accurate to more than eight decimal places. An interactive program was written to test the effect of slight changes in the value of C. After several iterations, a refined value of C accurate to thirteen decimal places was determined:

$$C = 0.00000010187802 \; .$$

Thus, the final form of the equation is

$$T = 1 \,/\, [0.00146703 + 0.00023858 \ln R + 0.00000010187802 \, (\ln R)^3]$$

for T in °K

T in ohms.

Using the above equation, the predicted values match all of the tabled values in the range of 0 to 50°C within 0.01°C. The smallest change in resistance which is equivalent to a temperature of 0.1°C is approximately 3 ohms.

TABLE 9

ANALYSIS OF VARIANCE FOR END OF WORK HEART RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratios	Probabilities
Between Groups (H)	1	351.1250	351.1250	0.1096	0.75281
Between Work Days (W)	3	5363.4844	1787.8281	8.8298	0.00265
Work Days x Groups (WxH)	3	704.7070	234.9023	1.1601	0.56577
Between Decay Periods (D)	2	2447.8611	1223.9304	6.9870	0.01760
Decay Periods x Groups (DxH)	2	1117.5833	558.7915	3.1899	0.09517
Work Days x Decay Periods (WxD)	6	565.1389	94.1898	0.4230	0.85668
Work Days x Decay Periods x Groups (WxDxH)	6	1252.7527	208.7921	0.9377	0.51245

TABLE 10

ANALYSIS OF VARIANCE FOR END OF WORK CORE TEMPERATURE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratios	Probabilities
Between Groups (H)	1	0.0131	0.0131	0.0225	0.88233
Between Work Days (W)	3	0.5492	0.1831	31.4361	0.00004
Work Days x Groups (WxH)	3	0.0809	0.0270	4.6299	0.02236
Between Decay Periods (D)	2	0.0032	0.0016	0.1054	0.90056
Decay Period x Groups (DxH)	2	0.1487	0.0744	4.8689	0.04098
Work Days x Decay Periods (WxD)	6	0.0489	0.0081	0.7467	0.61934
Work Days x Decay Periods x Groups (WxDxH)	6	0.1475	0.0246	2.2543	0.07203

TABLE 11

ANALYSIS OF VARIANCE FOR END OF WORK MEAN SKIN TEMPERATURE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratios	Probabilities
Between Groups (H)	1	6.1484	6.1484	7.7985	0.04932
Between Work Days (W)	3	1.3555	0.4518	3.8738	0.03741
Work Days x Groups (WxH)	3	0.5605	0.1868	1.6017	
Between Decay Periods (D)	2	0.4767	0.2383	2.0845	0.18618
Decay Periods x Groups (DxH)	2	0.2982	0.1491	1.3040	0.32390
Work Days x Decay Periods (WxD)	6	0.6612	0.1102	0.6078	0.72326
Work Days x Decay Periods x Groups (WxDxH)	6	0.5752	0.0959	0.5288	0.78213

TABLE 12

ANALYSIS OF VARIANCE FOR END OF WORK WATER LOSS

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratios	Probabilities
Between Groups (H)	1	316.6804	316.6804		
Between Work Days (W)	3	145.3611	48.4537	0.8842	0.52108
Work Days x Groups (WxH)	3	283.0693	94.3564	1.7218	0.21501
Between Decay Periods (D)	2	53.6944	26.8472	0.2731	0.76995
Decay Periods x Groups (DxH)	2	179.1112	89.5556	0.9111	0.55736
Work Days x Decay Periods (WxD)	6	120.7220	20.1203	0.9593	0.52611
Work Days x Decay Periods x Groups (WxDxH)	6	175.6385	29.2731	1.3957	0.25634