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<p>13. ABSTRACT (Maximum 200 words)</p> <p>The military needs to understand how mental performance, psychomotor performance, and subjective responses vary with severity of heat stress. Understanding this relationship is important because heat stress can significantly impair military performance and because psychological changes often precede the onset of critical physiological changes. Establishing well-defined relationships between climatic conditions and psychological performance has been difficult. Thermal stress researchers have attempted to identify psychological breaking points in performance, but the environmental conditions employed to simulate the natural world (combinations of temperature, humidity, wind speed, and exposure time) do not lend themselves to systematic, real-world organization. Therefore, it is difficult to make broad generalizations about the effects of heat stress on psychological performance. Nevertheless, there is general agreement that (1) the upper limit of heat exposure for unimpaired psychomotor performance is 90°F WBGT; (2) the upper limit of heat exposure for unimpaired mental performance is 85°F WBGT if the service member is required to perform the task for 2 hours or longer; at less than 1 hour on the task, individuals can perform proficiently at higher ambient temperatures approaching 109° WBGT; and (3) continuous repetitive tasks with relatively low arousal value tend to be the most affected. Psychological performance during ambient heat exposure is compounded for military personnel because they are often encumbered by mission-essential clothing and equipment, including, for example, chemical protective clothing or medications such as nerve-agent antidotes, or both. Realistic military training in hot environments followed by persistent practice of military tasks in hot environments will attenuate otherwise severe impairments in performance. Humans differ in their predispositions, ranges of capability, motivations, and expectations for success. Although for convenience we tend to conceptualize human performance in terms of averages, military personnel still respond as individuals with different talents, initiatives, and attitudes.</p>					
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Chapter 4

PSYCHOLOGICAL ASPECTS OF MILITARY PERFORMANCE IN HOT ENVIRONMENTS

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INTRODUCTION

The success of military operations as well as survival in combat greatly depends on the ability of military personnel to deal effectively with environmental conditions. Throughout military history, more deaths and injuries in war have been attributed to extreme weather conditions than to battle casualties. By far the most important weather extreme in military operations is heat, because so many strategically important world areas are in hot regions, and because heat exposure can seriously impair human performance in so many ways.

The military needs to understand how cognitive, behavioral, and subjective responses vary with severity of heat stress not only because heat stress can significantly impair military performance but also because psychological changes often precede the onset of critical physiological changes. As a matter of fact, some have argued that a decrement in psychological performance may be considered a precursor to critical physiological change.¹ Establishing well-defined relationships between climatic

conditions and psychological performance has been difficult. During World War II, thermal stress researchers attempted to identify psychological "breaking points" in performance. Unfortunately, the environmental conditions employed to simulate the natural world (combinations of temperature, humidity, wind speed, and exposure time) were not systematically organized, which made it difficult to make broad generalizations about the effects of heat stress on psychological performance.

The physical principles of heat dynamics and the physiology of human thermoregulation during heat exposure are discussed in other chapters of this book. We will address other important issues involved in adjustment to heat exposure that vitally depend on behavioral rather than physical or physiological factors, or both. Although the chapter is primarily organized around the experiences and operational mission requirements of personnel in the US Army and US Marine Corps, the facts and principles apply to all services.

PSYCHOLOGICAL PERFORMANCE IN HOT ENVIRONMENTS

When it is hot, we often hear ourselves or others complain that we cannot do our jobs because we cannot concentrate, that we are tired, lethargic, and just downright uncomfortable. It is a common belief that we need air conditioning, or cool, dry air, to maintain proficient mental performance. We also feel that we need cool, dry air to keep from feeling sticky, or being sweaty, so that we can perform tasks requiring fine manual dexterity; otherwise we lose our grip on tools. In this section, we will discuss human psychological performance in hot environments. We organize psychological performance into behaviors that are mainly intellectual or rational in terms of the task at hand, which we will call *mental*; those that are mainly manual tasks, which we will call *psychomotor*; and those that concern our feelings, moods, and attitudes, which we will call *subjective*.

The performance measures used to assess psychological performance are many and varied. They include those that assess tasks requiring simple and swift reactions to basic changes in the environment. They include sensory tasks, primarily the domains of vision and hearing. They include interpretations of basic changes in the environment, otherwise known as perception, which include the ability to

discriminate friendly from enemy targets. They include the ability to perform complex mental tasks that generally require verbal reasoning, mathematical reasoning, or both, and sometimes require the performance of two or more tasks at the same time, called dual task or concurrent task performance.

Figure 4-1 presents the basic psychological model and the main research variables or factors that research psychologists must consider when investigating the relationship between the hot environment and psychological performance. The conceptual model being presented is one in which behavior (B) is a function of the thermal environment (E), the person (P), the task (T), and the situation (S), or $B = f(E, P, T, S)$. Notice that accompanying the environmental variables (air temperature, radiant temperature, humidity, wind, clothing, and duration of exposure) are a host of other relevant, independent variables that may influence how a person responds to a hot environment, as reflected in the various categories of dependent variables (sensation, perception, cognition, psychomotor, and subjective response). For example, it has been found that some people respond differently as a function of their experience or training, intellect, skill at the relevant task, personality, current mood, motivation, and

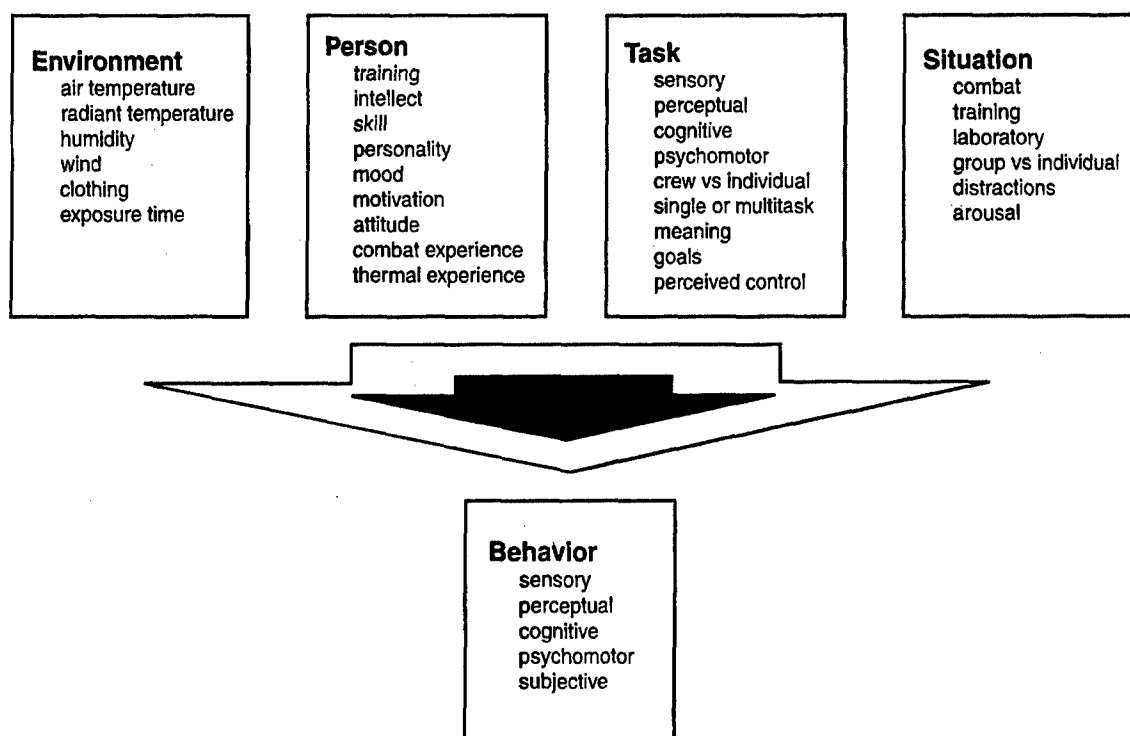


Fig. 4-1. The basic psychological model, in which behavior (the dependent variable) is a function of the environment, the person, the task, and the situation (the independent variables), or $B = f(E,P,T,S)$.

attitude. Military tasks also vary along dimensions such as crew versus individual. And the type of situation in which the task is assessed has been deemed important; for example, the task may vary as a function of whether it is performed in combat, during training, or in a laboratory; whether it is performed in a group setting, whether there are distracting stimuli; and how long the task must be performed before it is considered completed.

Mental Performance

In general, there seems to be agreement that the upper limits of heat exposure for unimpaired mental performance is about 85°F wet bulb globe temperature (WBGT) if the individual is required to perform the task for 2 hours or longer (Figure 4-2). At less than 1 hour on the task, individuals can perform proficiently at higher ambient temperatures approaching 109°F WBGT.² WBGT is an index of the thermal environment used to express the combined effects of heat, humidity, and radiation.³ Continuous, repetitive tasks that are boring tend to be affected most. Interesting tasks requiring frequent and varied responses to the environment are affected less.

Reaction Time

Studies of reaction time traditionally have distinguished between two types of tasks: *simple* reaction time, involving direct response to the onset of a stimulus; and *choice* reaction time, involving a selection of alternative reactions. Simple reaction time is believed to represent mainly neural processing time and is usually shorter than choice reaction time, which involves additional cortical processing. Studies of the effects of ambient heat exposure on both types of reaction time have yielded mixed findings, including increases^{4,5} and decreases,⁶ as well as no change⁶ in reaction time. Acclimation (physiological adjustment to a controlled environment) to prolonged heat exposure has been shown to result in a reduction of initial impairment of simple visual reaction time by heat.⁷ Although it has been reported that men have consistently faster reaction times than women,⁸ heat had only a negligible overall effect. A study of sustained attention in the heat showed reduced accuracy in a choice reaction time task.⁹

Studies of the effects of direct heating of the body on reaction time have given rather contradictory findings. Heating of the entire body¹⁰ was shown

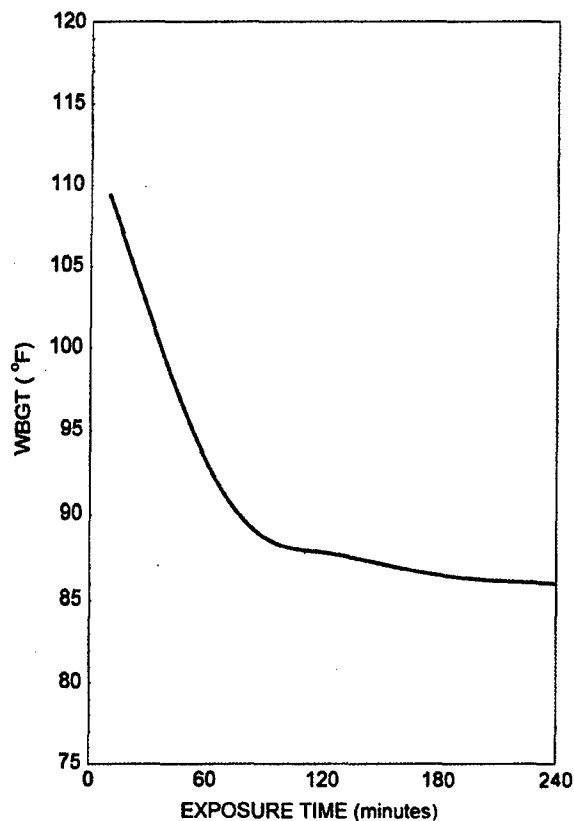


Fig. 4-2. Upper limits of thermal stress (wet bulb globe temperature, WBGT) for unimpaired mental performance as a function of exposure time. Reprinted from National Institute for Occupational Safety and Health. *Criteria for a Recommended Standard—Occupational Exposure to Hot Environments*. Washington, DC: NIOSH; 1972.

to shorten reaction times but to reduce performance accuracy. Warming the head¹¹ with a heated helmet resulted in increased reaction times but reduced error rates. Based on tympanic measurements, the authors ascribed this effect to an increase in cortical temperature.¹¹ Because tympanic temperature is affected by the temperature of nearby skin, however, tympanic temperature measurements do not necessarily indicate that the observed responses were the result of changes in cortical temperature.

The role of heat-induced reaction time changes on overall task performance is suggestive rather than definitive. That is, a review of thermal stress effects on human performance¹² shows that interpretation of the available data is complicated by differences in methodology and definition of the basic stimuli. Thus, we cannot draw definitive conclusions about the effects of heat exposure on reaction time because the testing conditions used in the

available studies vary considerably, and the resulting findings tend to be contradictory.

Sensation

Studies of sensory processes typically have been conducted on the separate sensory modalities, principally vision, audition, olfaction, taste, skin senses (thermal, tactual, vibratory, pressure), motion detection, vestibular orientation, and pain. Considerably less research has been done involving interactive combinations of the separate modalities.

Most research on effects of heat exposure on sensory action has concerned visual functions, probably because of the major role of vision in human performance. Examination of effects of both hot-dry and hot-humid conditions on visual contrast sensitivity, a measure of brightness and contrast discrimination, showed reduced sensitivity for the higher spatial frequencies.¹³ Investigation of hot-dry and hot-humid conditions on visual acuity found diminished acuity at both bright and dim luminance levels.¹⁴

Some studies of heat effects on vision have involved the additional heat stress generated by wearing encapsulating chemical protective clothing systems at high ambient heat and humidity levels. One study¹⁵ tested heat effects on visual acuity, phoria (a measure of ocular muscle balance), stereopsis (a measure of depth discrimination), and contrast sensitivity. All measures were significantly and progressively impaired over a 2-hour exposure period. Another study¹⁶ investigated similar heat effects on visual detection capability for target locations distributed throughout the entire visual field. Conditions of ambient heat while subjects were wearing chemical protective clothing produced significant systematic increases in response time to all signals; the worst performance occurred when subjects wore chemical protective clothing in high temperatures. One study¹⁷ investigating tactile sensitivity at low, moderate, and high ambient temperatures indicated that sensitivity was greatest at a moderate heat level.

Vigilance

Vigilance is a major element in many important military activities and tasks, such as sentry duty, watch keeping, vehicle operation, instrument monitoring, and surveillance. Analysis of vigilance behavior is a complex problem because it consists of several component behaviors such as attention, alertness, cognitive sensitivity, and judgment and

decision making. Because of the role of vigilance in military activities, it is important for all military personnel, but especially commanders, to understand the effects of stressors such as ambient heat exposure. Most studies that have explored the effects of ambient heat on vigilance performance have used visual monitoring tasks.

In an early study, Mackworth¹⁸ found that visual search performance is best at 85°F, 63% relative humidity (rh), but that visual search tasks are impaired above and below that temperature, even in heat-acclimatized subjects. These findings were supported in later studies by Mortagy and Ramsey¹⁹ and by Pepler,²⁰ wherein visual vigilance decrements occurred at 102°F, 24% rh; and also below 90°F, 65% rh. Poulton and Edwards²¹ and Poulton, Edwards, and Colquhoun²² also reported that both visual and auditory vigilance tasks are impaired at 100°F, 74% rh. Thus, the optimum conditions for visual vigilance tasks that have been studied appear to be around 85°F, as Mackworth¹⁸ originally reported.

Complex Mental Performance

There is considerable support for the idea that heat impairs complex mental performance. Complex mental processes can be grouped for practical purposes into three categories: storage and retrieval of information (memory); understanding, reasoning, and evaluation (cognition); and interpreting incoming sensory information in terms of previous experience (perception). It has been proposed²³ that impairment of mental performance by heat is a function of the resulting internal body temperature during heat exposure. This notion may be useful in developing a system for explaining decrements in mental tasks under heat exposure. Hancock²⁴ attempted to validate this view using published findings based on performance of mental and cognitive skills, tracking, and dual task performance under exposure to effective temperatures above 85°F. Effective temperature (ET) is an index of the thermal environment based on the subjective matching by human raters of various experienced combinations of dry bulb temperatures, relative humidities, and air velocities to determine those combinations that produce equivalent feelings of personal comfort.^{25,26} Hancock also suggested that practice on the specific tasks involved may be useful in offsetting such decrements.

Although systematic demonstration of heat effects on complex mental performance has been difficult, some militarily meaningful studies have been

conducted. Fine and Kobrick²⁷ studied the effects of heat on complex cognitive tasks involved in soldiers' performance at an artillery fire direction center. For 7 hours at 90°F, 88% rh, five 6-man groups performed message reception and decoding, arithmetic conversions, and reception and recording of meteorological data. All tasks were significantly and similarly impaired by heat, although the participants differed considerably in the degree and type of their stress response. Errors of omission greatly exceeded errors of commission. These same investigators²⁸ later examined the effects of heat on sustained cognitive performance of soldiers in the heat while clad in chemical protective clothing. After 4 to 5 hours, cognitive performance began to deteriorate markedly, and after 7 hours the percentage of group error on fast-paced tasks ranged from 17% to 23% over control conditions, largely due to errors of omission. Productivity on a slower, self-paced task diminished by 40% from control conditions. Accuracy of map plotting, however, was not markedly affected.

Curley and Hawkins²⁹ assessed cognitive performance during a 10-day heat acclimatization regimen (in a natural environment), using repeated acquisition and time estimation tasks. The participants walked on a treadmill at 90°F dry bulb, 70°F wet bulb temperature for 155 minutes daily. By the 10th day of heat exposure, all participants were heat-acclimatized, but mean performance on the repeated acquisition task and on the time estimation task was still impaired.

Ramsey and associates³⁰ demonstrated that in an industrial workplace situation, ambient temperatures above and below the temperature range preferred by most workers were associated with a higher incidence of unsafe behaviors and potential accidents. Nunneley and associates¹⁰ took the unusual approach of heating the human head directly and studied the derived effect of elevated head temperature on reaction time and cognitive performance. Shortened reaction times and diminished performance accuracy were observed.

Psychomotor Performance

In general, there seems to be agreement that psychomotor tasks (eg, tracking) quickly become impaired above a temperature of 85°F WBGT. The upper limits of heat exposure for unimpaired psychomotor performance is about 90°F WBGT regardless of the length of time the task is required to be performed—out to 4 hours (Figure 4-3). As is the case with mental tasks, continuous repetitive tasks

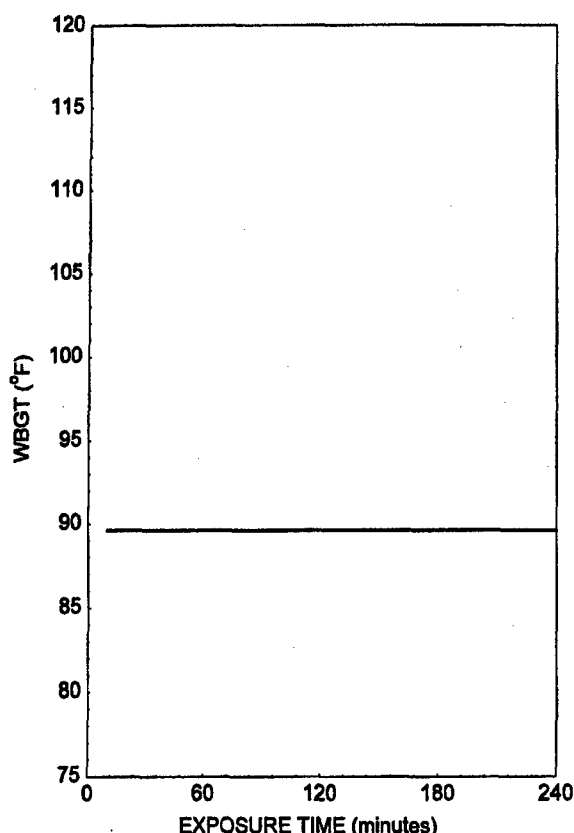


Fig. 4-3. Upper limits of thermal stress (wet bulb globe temperature, WBGT) for unimpaired psychomotor performance, as a function of exposure time.

with relatively low arousal value tend to be affected most. Interesting tasks with high arousal value requiring frequent and varied responses to the environment are less affected.

Dexterity, Steadiness, and Aiming

Military operations require the performance of numerous tasks involving psychomotor components, such as object manipulation, manual dexterity, steadiness, aiming, and rifle marksmanship. Studies that have explored the effects of ambient heat on psychomotor activity have also included the influence of other factors, such as chemical protective clothing, fatigue, and drugs of military interest.

Although heat effects on psychomotor performance have been reported, there are contradictions among the findings. An early study³¹ found that ability to align pointers was poorer at ambient temperatures above 90°F, but a later study⁶ reported better steadiness at high temperature (126°F). A

more recent study by Johnson and Kobrick³² reported poorer steadiness and rifle marksmanship, but better manual dexterity, at high temperature (95°F, 60% rh). Another study involving high heat and humidity (95°F, 60% rh), chemical protective clothing, and drug antidotes (atropine and 2-PAM Cl [2-pyridine aldoxime methyl chloride, also called pralidoxime chloride])³³ reported impairment of several psychomotor tasks (steadiness in aiming, gross and fine manual dexterity, and gross body coordination in rail-walking) at 95°F, 60% rh, regardless of clothing or drug condition. Fine and Kobrick²⁸ found that 6 hours of ambient heat (91°F, 61% rh) exposure led to impairments in plotting, arm and hand steadiness, peripheral vision, and rifle-firing accuracy. Thus, the measured effects of ambient heat on psychomotor tasks show a general overall trend of impairment, but the findings have not been uniformly consistent.

Other studies suggest that heat may interact with gender differences and accompanying personal factors, such as level of comfort. Beshir and Ramsey³⁴ reported that while performing certain perceptual-motor tasks, women were more uncomfortable and reported more fatigue and boredom at higher temperatures than did men. Wyon³⁵ showed that, regardless of gender, typists did more and better work at lower (66°F, 50% rh) than at higher (75°F, 50% rh) air temperatures. Meese and associates³⁶ compared the performance of 1,000 factory workers (men and women, black and white) on simulated factory tasks involving psychomotor performance, which were studied at ambient temperatures of 68°F, 79°F, 90°F, and 100°F with "low humidities" for all exposures. Performance at 90°F improved for all groups but white women, and was best for both white and black men. The performance of white women improved at 68°F and 79°F, was worst at 90°F, and improved again at 100°F. These results suggest complex gender and race differences in the effects of heat on psychomotor performance.

Tracking

Tracking typically involves the manual coordination of devices and controls with targets of various kinds, and is a very common military activity. Visual tracking is probably the most common type, although tracking can also involve the use of other senses.

Studies of the effects of ambient heat on tracking have shown decrements in performance and a general cumulative effect of heat with continued exposure. Pepler^{20,37-40} showed consistent impair-

ment of a tracking task based on pointer alignment, even when the subjects were heat acclimatized. Two later studies also showed impairment of tracking tasks in the heat. Bell⁴¹ showed impairment of a subsidiary task but not of a primary task performed concurrently. Beshir, El Sabagh, and El Nawawi⁴² showed that impaired performance was directly related to task duration. However, Nunneley⁴³ found that a simple tracking task showed some improvement in the heat, but that two more complex tasks showed no change. Neither Russell¹⁷ nor Grether and associates⁴ found any impairment of tracking tasks in the heat.

Based on available data, effects of heat on tracking appear to be interactively related to task complexity, task duration, and operator skill. This position is supported in review articles by Hancock,⁴⁴ and Enander and Hygge,¹² and by the findings of Poulton and Edwards.^{21,45}

Concurrent Tasks

The effects of heat on performance of two or more tasks performed concurrently have received less attention because such studies are more complicated and, therefore, more difficult to conduct and analyze. Studies indicate that heat generally causes decrements in concurrent task performance of various types. Bell⁴⁶ studied the combined performance of a primary pursuit-rotor task and a subsidiary number-processing task under ambient temperatures of 72°F, 84°F, or 95°F (all at 45% rh) and noise levels of either 55 or 95 dB. Performance decrements occurred for both high noise and high temperatures for the subsidiary task, but not for the primary task, and were attributed to overload factors. Mackie and O'Hanlon⁴⁷ found that heat-impaired steering caused more errors in a driving task and reduced sensitivity of brightness discrimination. Iampietro and associates⁴⁸ found that heat impaired a number of aviation flight tasks. Bell⁴⁶ found decrements in one task but no change in performance of other concurrent tasks, the implication being that performance was maintained on a chosen task at the cost of lowered performance on others. Provins and Bell⁴⁹ observed that heat led to initial improvement on one task but not on others, followed later by impaired performance. Dean and McGlothlen⁵⁰ found no change in concurrent tasks due to heat exposure. Two reviewers have concluded that heat stress generates systematic decrements in mental and cognitive skills, tracking and psychomotor performance, and multitask activities. Hancock²⁴ has proposed that such decrements are due not only to

heat but also to task complexity, and that the decrements are correlated with heat stresses that are physiologically uncompensable, so that deep body temperature continues to rise. Enander and Hygge¹² have taken a similar position but pointed out that empirical research is difficult to interpret because of differences in methodologies and operational definitions of the basic stimuli.

Subjective Response

The perception of bodily sensations associated with heat exposure and the accompanying feelings of discomfort are often considered aspects of the hot environment that have to be tolerated. However, in this section we shall see that subjective responses affect behavior (eg, sleep quality and the nature of social interactions) and that accurate perception of our bodily sensations is important in judging the onset of heat injury.

Symptomatology

Studies have shown that 6 or more hours of ambient heat (91°F–95°F, 60% rh) exposure leads to typical symptomatic reactions⁵¹ such as weakness, "rubbery legs," dizziness, restlessness, hyperirritability, feeling hot and sweaty, loss of appetite, vomiting, and nausea. In addition, heat-stressed individuals tend to be unwilling to drink adequate water and make up for salt depletion. (For further discussion of this "voluntary" dehydration, see Montain's chapter, Hydration, in Volume 3 of *Medical Aspects of Harsh Environments*.)

Salt depletion is a major factor in the development of heat symptoms. During the first several days that military personnel are rapidly deployed to the field, their dietary salt consumption is often reduced because salt content in field rations is altered and total ration consumption is generally reduced.⁵² In a jungle, in a desert, or at sea in the tropics, decreased salt consumption becomes particularly problematic because of salt losses associated with sweating.

The minimum salt requirements for acquiring and sustaining heat acclimatization under desert conditions were established in a study using 17 healthy soldiers. After completing 7 days of optimum control conditions, the soldiers underwent 10 days of heat acclimation (106°F, 20% rh) while receiving diets containing low-normal (8 grains [5.2 mg]) or low (4 grains [2.6 mg]) levels of daily salt.^{53,54} The data were analyzed for incidence of heat symptoms using a questionnaire-based index of subjec-

tive heat illness.^{53,55} The analysis disclosed that regardless of diet group, the predominant symptoms during heat acclimation were warmth, sweatiness, weakness, irritability and restlessness, and rapid heart beat. Dizziness and disturbed coordination also occurred, most often during the first 2 days of heat acclimation. It is clear that greater salt intake significantly reduced reports of subjective heat strain (ie, the physiological change produced by a disturbance) during the first 2 days of heat acclimation but not thereafter. This study assumes paramount importance when we consider that a service member's *perception* of heat illness symptoms is the sole basis for judging the onset of heat injury.⁵⁶

Discomfort

Discomfort due to heat is a familiar experience to everyone. However, the range of reactions varies widely among people in both the kind and the severity of symptoms. Although this is commonly understood, it is difficult to measure and systematically classify the symptoms.

In an attempt to measure subjective reactions to environmental stress, including heat discomfort, Sampson and associates⁵⁵ developed a combination inventory and rating scale called the Environmental Symptoms Questionnaire (ESQ). Kobrick and associates⁵¹ employed the ESQ in a study mentioned previously to assess subjective reactions to heat while wearing impermeable chemical protective clothing (mission-oriented protective posture, MOPP 4). The ESQ dramatically reflected the incidence and increase in severity of discomfort reactions in the heat and MOPP 4 condition.

Other approaches have also been used to assess subjective reactions to heat. Beshir and Ramsey³⁴ compared the reactions of men and women to heat as it was judged to affect their performance of perceptual-motor tasks. The participants rated their thermal reactions, drowsiness, boredom, and fatigue while performing the tasks. The study found that men preferred significantly lower temperatures than women did, but women were more uncomfortable at the temperature extremes. Women reported greater drowsiness and boredom overall, but men became more fatigued than women at higher temperatures.

Another study examined subjective discomfort during the process of recovery from heat stress. Shitzer and associates⁵⁷ first exposed men to a standard heat condition, and then allowed them to choose recovery temperatures at will from either (a) a personally preferred temperature, which each participant had individually chosen prior to the

heat exposure condition, or (b) varied schemes starting either nine Fahrenheit degrees above or nine Fahrenheit degrees below the preferred temperature. The recovery conditions with the highest overall temperature were judged the most comfortable, implying that subsequent comfort reactions are biased by previous exposure conditions.

Price and Hennigan⁵⁸ asked each of 24 undergraduate men to estimate the immediate temperature of the heat chamber in which he sat. The researchers found that temperature estimates were closer to the dry bulb air temperature than to either the WBGT or a temperature-humidity index. The participants' everyday experience with dry bulb air temperature as an index of heat was concluded to be the dominant factor in temperature estimation.

In summary, these findings reflect the highly subjective quality of personal discomfort reactions and show that experience is a strong factor in the kinds of discomfort reactions that occur. In effect, previous heat experience can influence later heat tolerability. It also seems clear that people judge discomfort on the basis of familiar indices, primarily dry bulb temperature, which is the most commonly cited everyday index.

Changes in Sleep Behavior

Another common belief is that heat disrupts normal sleep. Restlessness due to discomfort is a familiar reaction at night during a heat wave, and there is considerable research evidence⁵⁹⁻⁶¹ to indicate that hot conditions do seriously disrupt ordinary restful sleep.

Libert and associates⁶² studied the effects of continued heat exposure (5 days and nights at 95°F) on actual sleep during that period using unacclimated participants. The time distribution of sleep stages and recovery effects at subsequent normal temperatures were examined. It was found that effectiveness and quality of sleep were generally reduced at high temperature; also, there were no indications of improvement in sleep with continuing heat exposure, despite increased physiological heat adaptation. Libert and associates⁶³ then examined the effects of heat exposure and hot sleeping conditions combined with traffic noise on sleep activity. Heat was found to be more disruptive to sleep than was noise. Sleep time decreased in the heat, the pattern of sleep stages was disrupted, and time awake increased. In general, the available findings indicate that attempting to sleep in the heat is not only unpleasant, it also affects sleep patterns.

Social Effects

It is a common belief that motivation and activity levels tend to be lower in hot and hot-humid regions, whereas the opposite is believed to be true for aggression. A major problem in studying the influence of climate on social groups is that the effects of heat on behavior are interrelated with other potential causal factors, such as social influence; differences in individual reactivity to heat; crowded living conditions associated with hot, urban areas; cultural beliefs and practices; and seasonal climatic changes.

In a study by Bell and associates,⁸ 64 men and 64 women undergraduates performed an easy or a complex reaction time task, either alone or in pairs (coaction), while exposed to ambient temperatures of either 72°F, 46% rh; or 98°F, 43% rh. Reaction time was faster for men than for women, faster for the easy than for the complex task, and faster for coacting than for individually acting participants. Heat increased reaction time, although its effect was statistically "weak." All of these factors were essentially additive, with task difficulty having the strongest effect.

Bell and Doyle⁶⁴ studied the effects of heat and noise on helping behavior. Ninety-six undergraduates were given an opportunity to aid a confederate both before and after exposure to ambient temperatures of either 73°F, 46% rh; or 95°F, 46% rh; and to noise levels of 55 dB, 95 dB without perceived control, or 95

dB with perceived control. Although heat produced discomfort and led to negative evaluations of the environment, and noise generally increased response to stimuli (arousal), neither heat nor noise influenced any measures of helping behavior.

Megargee⁶⁵ addressed concerns about the influence of overcrowding, cramped space, and uncomfortable temperatures in prisons on inmate misconduct. The relation of population size, amount of personal space, and population density were compared with the incidence of disruptive behavior over a 3-year period in a correctional institution for young male offenders. Population size was significantly correlated with the number but not the rate of disciplinary violations. The total amount of personal space and the index of population density were significantly correlated with both the number and the rate of violations. A post hoc analysis showed that the incidence of uncomfortably hot days had no relation to disruptive behavior.

On the other hand, it is well documented that aggression toward neighbors and family members increases in crowded urban areas during summer heat waves.^{66,67} Although these data have not gone unchallenged, it is clear that heat increases the likelihood of heightened anger and irritability, which in turn, leads to quarreling among neighbors, family members, and coworkers. Analysis of the effects of hot living conditions on overt social behavior is blocked by interactions of heat with crowding, urban problems, and socioeconomic factors.

UNDERLYING MECHANISMS

To explain the effects of the thermal environment on psychological performance, several underlying mechanisms have been proposed. We consider three here: the influence of heightened physiological arousal accompanying heat exposure, the influence of a stable (static) versus a changing (dynamic) deep body temperature, and the influence of emotional reactions to heat exposure.

Arousal

In emergency situations, an organism's responsiveness to external and internal stimuli is heightened. Emotions such as fear and anger motivate us to act. Arousal reactions are accompanied by measurable changes such as an activated electroencephalogram (EEG), increased heart rate, and elevated blood pressure. One theory to explain changes in performance that accompany heat stress centers on an individual's arousal level.^{68,69} In this

theory, exposure to ambient heat is considered a stressor that increases arousal, and the relationship between arousal and performance is seen as an inverted U function (Figure 4-4). Too little or too much arousal may impair performance. The theory states that (1) psychological performance improves as arousal increases above a comfortable resting level (as can be caused by mild heat), and (2) performance degrades when arousal either drops below or rises above this optimal level. Presumably, performance is best when one is fully awake, poorer when one is less than fully awake (just waking up or falling asleep), and poorest (or nonexistent) when one is either asleep or hyperalert. Hyperalertness occurs during panic situations such as those associated with extreme danger or extreme pressure (eg, imminent or actual combat). For poorly learned tasks, performance is best when arousal is low. A beginning marksman, for example, will likely fire more accurately when in a quiet area (low arousal) than

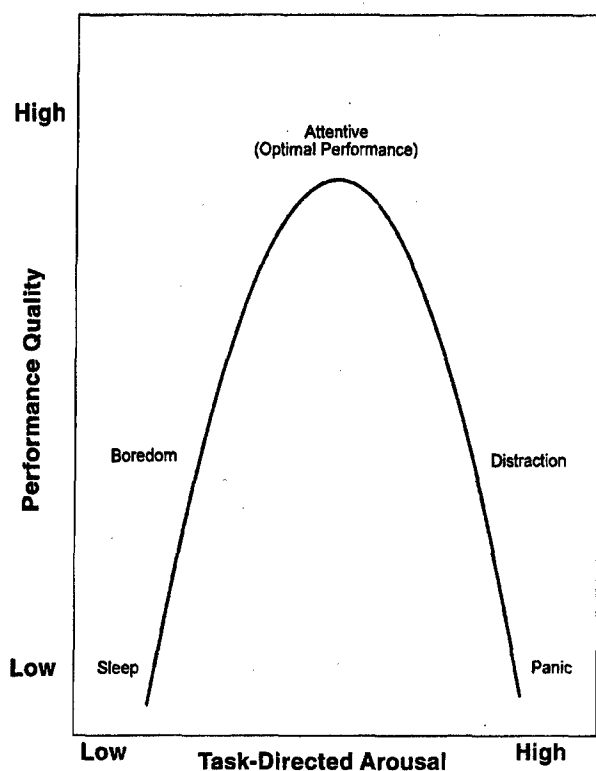


Fig. 4-4. The arousal-performance function for a moderately difficult task.

in an area where an instructor is yelling (high arousal). On the other hand, an excellent marksman is less likely to fire poorly under high arousal conditions. This relationship between performance, arousal, and task difficulty is known as the Yerkes-Dodson Law⁷⁰ and predicts that for highly skilled (trained) individuals, performance deteriorates less rapidly as arousal increases.

If ambient heat is intense enough, it may be perceived as dangerous to health, high arousal will occur, and performance will likely be extremely poor. Grether⁷¹ has suggested that performance is optimal when ambient temperature is 80°F ET, or just above the thermal comfort level. Grether's selection of 80°F ET as the optimal level for psychological performance was based on studies of vigilance and of Morse code operation during ambient heat exposure.^{20,31}

Static Versus Dynamic Deep Body Temperature

In a review of the effects of the thermal environment on vigilance, Hancock¹ has argued that the data in support of the arousal theory interpretation actually contradict the notion that performance is

facilitated in ambient temperatures that exceed a comfortable level. Rather, Hancock argues that performance is degraded as the thermal homeostasis of the individual is disturbed; that is, deep body temperature becomes dynamic. Hancock points out that in the original experiments of Mackworth³¹ and of Pepler,²⁰ two variables—ambient temperature and the "thermal state" of the individual—were confounded. Specifically, in Mackworth's study, the optimal ambient condition, 79°F ET, happened to be the only ambient condition selected for study that did not cause a change in deep body temperature of the individuals being tested; that is, deep body temperature was static. On the other hand, both of Mackworth's heat stress conditions, 87.5°F and 97°F ET, were above the ambient temperature level, 85°F ET, which results in heat stresses that are physiologically uncompensable, so that deep body temperature continues to rise. Hancock argues that a significant breakdown in performance efficiency does not necessarily occur when the ambient temperature is above a certain level, but occurs when deep body temperature is disturbed or changing; in other words, when an individual's deep body temperature is in a dynamic as opposed to a static state.

If Hancock is correct, then performance should remain unaffected as long as deep body temperature is stabilized and is neither rising nor falling. In a study of combinations of ambient heat (up to 93°F ET) and ambient noise (110 dB), Dean and McGlothen⁵⁰ found no change in vigilance performance during a 30-minute exposure to heat and noise. These data support Hancock's contention that it is not the actual ambient temperature that affects performance, but it is a combination of exposure time and ambient temperature sufficient to change deep body temperature that will lead to degradations in performance. Although the ambient condition was high enough to produce an uncompensable rise in deep body temperature, the 30-minute exposure was not long enough to induce a measurable change in body temperature.

Improvement in psychological performance as a result of thermal stress has been found when the individual has been stabilized in a static hyperthermic state. For example, Wilkinson and associates⁷² assessed auditory vigilance in subjects who had been stabilized at either 1.4, 2.5, or 3.6 Fahrenheit degrees above preexposure deep body temperature. This was accomplished by first exposing them to 109.4°F and 100% rh until their body temperature reached one of the target levels. They were then removed from the heat chamber; put into a heated, impermeable suit to maintain body temperature; and tested on

the vigilance performance task. At body temperatures more than 1.4 Fahrenheit degrees above pre-existing levels, vigilance performance improved as measured by speed of response to targets and correctness of target identification. Hancock points out that the difference between this study and the others was the establishment of a static hyperthermic state that lacked the stress associated with the constant rise in body temperature. Thus, the data are in line with the notion that performance degradations resulting from heat exposure are associated with dynamic deep body temperature and not with static deep body temperature.

Emotional Arousal and Experience

Stressful situations, including heat stress, tend to elicit emotional responses that were linked to stressful situations in the past. In high-stress situations, the emotional response (activated EEG, rapid heart rate, elevated blood pressure) is, at a minimum, distracting, and at most, incapacitating (panic reaction). These emotional responses have become associated with stress and now become the dominant responses during stress. Behaviors associated with calmer times are less likely to be remembered and performed. If an appropriate adaptive response is not well practiced, it is extremely difficult to remember it and perform it well while under stress. Research has shown that if a response is practiced so that it becomes automatic, it has a better chance of being expressed during crises.⁷³ Because military personnel are required to respond quickly to changing events during stressful situations, such as those that exist on the battlefield or during heat stress, when arousal is sure to be high, military tasks have to be overlearned if they are to be proficiently performed when needed most. For these reasons, all military tasks, from the most basic to the most complex, need to be practiced during times that are not stressful as well as during times of high stress if

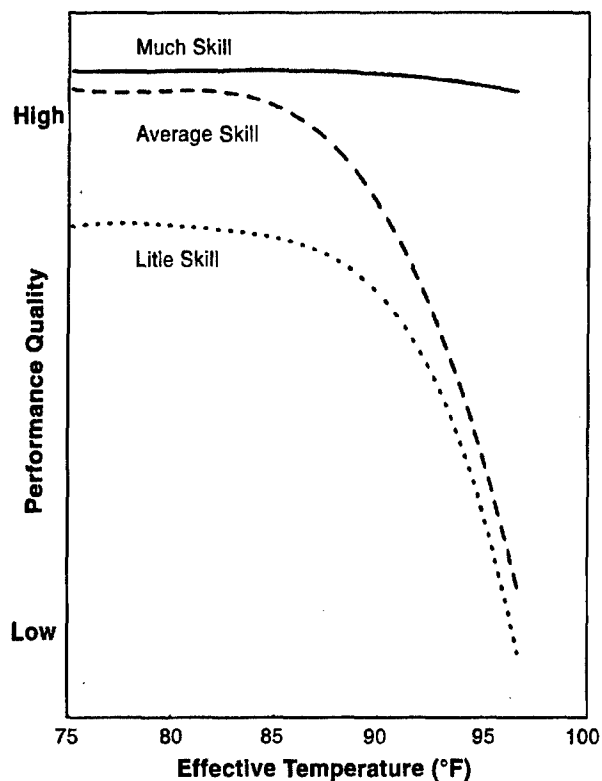


Fig. 4-5. The performance-heat exposure function for different skill or training levels.

they are to have a chance to become the appropriate first response (or at least a not-too-belated second response) in the repertoire of emotional responses. Using data from validated heat stress situations,^{20,31,73} we have constructed Figure 4-5, which illustrates how well tasks are likely to be performed under varying levels of ambient heat. Performance decrements are likely to be minimal when skill level is high, and considerable when skill level is medium or low.

CHANGES IN PERFORMANCE UNIQUE TO THE MILITARY

Some aspects of the military situation uniquely influence psychological performance. Uniforms and equipment, for example, which are designed to protect the soldier from both chemical contamination and ballistic fragments, often impose an added heat load due to impairments in normal evaporative cooling. Medications designed to protect a soldier from nerve agents often impair thermoregulation by inhibiting sweat production. Acclimatization and appropriate training in hot environments may help

to attenuate limitations imposed by clothing, equipment, and medications.

Performance as a Function of Clothing and Equipment

Military clothing and equipment are inherently involved in ambient heat exposure because, on the one hand, shelters, vehicles, and clothing provide environmental protection (eg, shade, wind protec-

tion, and thermal insulation). On the other hand, shelters and vehicles trap heat and retard ventilation, and clothing, especially impermeable encapsulating ensembles, traps body moisture. Also, evaporative cooling is hampered by other devices such as load-carrying systems, which block moisture release.

Most of the research on heat stress involving clothing and personal equipment systems has directly examined the effects on operator performance while wearing various clothing and equipment items and systems in the heat. Major attention has been directed to problems due to wearing chemical protective ensembles, particularly MOPP 4, which, by necessity, is totally encapsulating and impermeable. Kobrick and associates^{51,74} compared performance over a target period of 6 hours on a variety of psychomotor, cognitive, visual, and locomotor tasks; and subjective reactions, while subjects wore the MOPP 4 ensemble and the standard military battle dress uniform (BDU) under hot-humid (91°F, 35% rh) and temperate (70°F, 30% rh) conditions. All participants completed the 6-hour sessions while wearing the BDU ensemble, and showed only minimal performance impairment and few subjective reactions. In contrast, the MOPP 4 heat sessions could not be continued beyond 2 hours, and all tasks were significantly impaired. Subjective reactions were numerous and severe. Kobrick and associates¹⁵ also measured the effects of the same test conditions on several indices of visual performance (acuity, phoria, stereopsis, contrast sensitivity). All indices showed significant impairment under continued heat exposure. Kobrick and Sleeper¹⁶ also studied the effects of the same test conditions on sensitivity for detecting signals distributed at various locations throughout the visual field, and found significant systematic increases in response time to all signals.

Fine and Kobrick²⁸ examined the effects of similar heat conditions on sustained cognitive performance while wearing MOPP 4 chemical protective clothing. Cognitive performance began to deteriorate markedly after 4 to 5 hours in the heat. By the end of 7 hours of exposure to heat, increases in the percentage of group error on investigator-paced tasks ranged from 17% to 23% over control conditions. Most of the decrements were due to increases in errors of omission. The productivity of the group on a self-paced task (map plotting) diminished by approximately 40% from control conditions after 6 hours in the heat in protective clothing; accuracy of plotting was not markedly affected.

Carter and Cammermeyer⁷⁵ observed the task performance of 195 medical unit personnel partici-

pating in a 3-day simulated chemical warfare field training exercise under very hot conditions. A heat injury checklist was used to assess physiological parameters of heat stress. Participants performed under simulated scenarios: (1) conventional warfare, (2) chemical casualties, and (3) hostile and chemical attack. Participants in the second scenario appeared to experience the most stress. Participants became increasingly disorganized in the third scenario. Five real casualties emerged as a result of heavy activity, medical problems, limited food and fluid intake, overweight, or prior difficulty wearing gear.

In a similar type of study approach, White and associates⁷⁶ examined physiological and subjective responses of nine men (aged 21–33 y) who worked while wearing two types of protective ensembles (chemical protective clothing and scuba gear) in each of three thermal environments. Even at a low work intensity, individuals who wore chemical protective clothing in the heat required progressively shorter work periods and more frequent and longer rest periods. Subjective responses indicated that the participants perceived the chemical protective clothing as less acceptable than the scuba gear.

Arad and associates⁷⁷ investigated the effects of pyridostigmine pretreatment; nuclear, biological, and chemical (NBC) protective gear; and heat-exercise exposure on psychomotor performance and subjective sensations in eight healthy, heat-acclimatized men. Exercise in heat enhanced the performance of vertical addition but prolonged reaction time. The effects of pyridostigmine, protective gear, and the interactions between the various stressors were not significant. Cognitive performance was not dependent on body core temperature. Multiple complaints of subjective discomfort arose from wearing the protective garment. Results suggest the existence of significant subjective discomfort but absence of major cognitive decrements.

These studies indicate that heat stress generated by wearing clothing and equipment systems adds to that created by the same ambient environment alone. These effects cause impairment of a wide range of tasks involving sensory, psychomotor, cognitive, and subjective aspects of performance. It should also be noted that there may be additional hampering effects caused by the physical characteristics of the equipment itself (eg, visually restricting face masks, glove liners that ball up when wet with perspiration, restriction of manual dexterity by stiff and thick glove material, and hearing restriction due to encapsulating headgear).

Johnson and Kobrick⁷⁸ evaluated the findings of numerous studies on the effects of wearing chemical protective clothing on rifle marksmanship and on selected sensory and psychomotor tasks. Task performance in the BDU under thermoneutral conditions was used as a standard for comparison based on the percentage of change to evaluate the separate and combined effects of wearing chemical protective clothing, exposure to ambient heat, and test duration. The findings indicated that wearing chemical protective clothing resulted in an early overall impairment of task performance (less than 2 h), but that the magnitudes of impairment did not increase progressively over time (up to 6 h) beyond the initial impairment levels. Although wearing chemical protective clothing in hot conditions led to the development of heat stress (and thus limited test time to less than 2 h), it did not degrade sensory or psychomotor performance beyond that observed under thermoneutral conditions for the same period. Wearing chemical protective clothing during heat exposure did, however, degrade rifle firing accuracy during the first 2 hours (mainly due, however, to the poor compatibility of the face mask with the rifle, which caused poor alignment of the eye with the sights and the target). Tasks involved in simulated sentry duty showed that wearing chemical protective clothing intensified vigilance decrements and degraded rifle marksmanship. (For further information, interested readers can consult Taylor and Orlansky.⁷⁹)

Influence of Operational Requirements: Medications

The effects of drugs and other chemical substances on military performance during heat exposure are of high interest to military unit commanders. Available studies have explored effects of substances either of some pragmatic interest, or of a known relationship to some heat-mediating body function.

Kobrick and associates^{15,51,74} conducted a multi-factorial investigation of the effects of a standard US Army nerve agent antidote (2 mg atropine combined with 600 mg 2-PAM Cl vs a placebo) and heat exposure (95°F, 60% rh vs 70°F, 30% rh) on repeated performance of militarily relevant psychological tasks while wearing the BDU and while wearing chemical protective clothing (MOPP 4). Twenty-three men, aged 18–23 years, volunteered. All BDU sessions (6 h in duration) were completed, but with some task impairments and a few subjective discomfort reactions. MOPP 4 heat sessions could not

be continued beyond 2 hours; all tasks were impaired, and significant subjective reactions were numerous and severe. The combination of atropine and 2-PAM Cl significantly shortened endurance time for heat sessions in MOPP 4. If we assume that heat exposure combined with wearing MOPP 4 chemical protective clothing constitutes a very severe form of heat experience, these investigations indicate a sizable drug-related impairment to several types of behavior, which increases with heat exposure.

In another study, Arad and associates⁷⁷ examined effects of heat exposure combined with pyridostigmine, a nerve agent pretreatment, on varieties of psychomotor performance and subjective reactions. Eight healthy, heat-acclimatized men were tested on addition and reaction time tasks while they exercised in the heat. Performance of addition was enhanced, but reaction time increased. The effects of pyridostigmine, protective gear, and the interactions between the various stressors were not significant. Cognitive performance was not dependent on core body temperature. Multiple complaints of subjective discomfort arose from wearing the protective garment. Results suggest the existence of significant subjective discomfort but an absence of major cognitive decrements in a multiple-stress state of chemical warfare alertness.

One study examined the effects of substances believed to be related to physiological heat-regulation mechanisms. Bakharev⁸⁰ studied the action of the synthetic posterior pituitary hormone, arginine vasopressin (AVP), a neuromodulator of long-term memory, on human tolerance to the short but intensive action of a hot-dry environment, using eight participants who were 29 through 35 years old. No direct effect of AVP on the dynamics of the heat balance of the body could be found. However, AVP improved participants' subjective sensations with respect to most parameters studied.

Acclimatization and Training

The beneficial influence of heat acclimatization on subsequent physical performance in the heat is well documented. It is also generally understood that heat acclimatization is best achieved by exercise during continued heat exposure. However, the available information on heat acclimatization effects pertains mainly to physical activity and allied physiological functions; related factors involving training in the heat also primarily address physical performance. In contrast, knowledge of the effects of heat acclimatization and training on psychologi-

cal and cognitive performance is much more limited and, in fact, considerably speculative.

Mackworth³¹ studied the decoding of Morse code messages by military personnel of varying skill and training levels at ambient heat levels of 79°F, 83°F, 87.5°F, 92°F, and 97°F ET. He found that personnel who were highly skilled in decoding were least affected by the heat, showing fewer than 10 errors per hour regardless of the ambient heat level to which they were exposed. Those with medium and minimal skill levels showed their usual error rates (< 10 and < 40 errors per hour) at 79°F and 83°F; at 92°F, they began to show increased errors over the lower temperature conditions; and at 97°F both groups showed dramatic impairments in performance (80 and 90 errors per hour, respectively). Skill and training levels are obviously an important factor in determining the extent to which performance is impaired by ambient heat exposure.

Razmjou and Kjellberg⁹ studied the effects of heat (104°F dry bulb, 77°F wet bulb) on sustained attention and serial response in a simple reaction time task and a serial four-choice reaction time task. They found that in unacclimatized subjects, simple reaction time performance as well as accuracy in the serial choice reaction time task deteriorated significantly in heat. In a study of performance during heat acclimatization, Shvartz and associates⁷ found that simple reaction times to a visual stimulus obtained over 10 consecutive days during exercise in heat decreased, so that they were only 10% higher than resting reaction times on the last heat stress day, and were the same as resting reaction times on the last (room temperature) day. In other studies, Curley and Hawkins²⁹ and Curley and associates⁸¹ assessed cognitive performance during a 10-day heat-acclimatization regimen using repeated acquisition tasks. On the first day of exposure, performance on the repeated acquisition tasks yielded slight decrements compared with preacclimatization baseline values recorded at moderate tem-

peratures. By the 10th day of heat exposure, all participants demonstrated significant heat acclimatization. However, mean performance on the repeated acquisition task was still impaired. Results suggest that tasks requiring the acquisition of new behaviors may be difficult to perform in a hot environment, even by partially acclimatized individuals. Thus, the available studies have produced somewhat conflicting results, which have not dealt experimentally with the influence of training level and skill of the participants. In a review article, Hancock⁸² reflected this concern, noting that individuals who are skillful at a task may be better able to withstand the detrimental effect of the stress exposure than their unskilled counterparts.

The potential effects of experience with heat exposure are considered in three other studies of effects of heat adaptation on perceptual reactions. Khudaiberdiev and associates^{83,84} and Khudaiberdiev and Pokormyakha⁸⁵ used psychophysical scaling to assess temperature judgments of individuals during summer and winter seasons, and found sensitivity to smaller temperature increments in summer than in winter. They concluded that temperature judgment sensitivity becomes reorganized during prolonged exposure to higher seasonal temperature; however, the authors did not propose a causal mechanism for the change in sensitivity. Two reviews from a similar aspect consider the heat adaptation effects of sauna bathing on perception and performance^{86,87} and note that the psychological effects of the sauna have rarely been studied. Nevertheless, they speculate that users undergo (1) autonomic changes and build up resistance to the temperature extremes, as well as (2) subjective adaptation to the experience. Sulanov and Freink⁸⁸ argue that to adapt to arid heat, humans adopt an avoidance strategy that incorporates specific work and rest patterns, use of shade, air conditioning, and clothing that screens the body from the sun's radiation.

MILITARY APPLICATIONS AND CONSIDERATIONS

We now have considerable knowledge about human reactions to heat exposure and can make some useful recommendations about military performance in the heat, based on available research findings and our own practical experience. This section is intended to provide concise recommendations for dealing with heat effects (Exhibit 4-1). The guidelines are organized according to the behavior categories that we have used above, and in

the context of military operations wherever possible.

Mental Performance

In the military, mental performance includes the performance of those tasks that are mainly intellectual, from the most basic decision (whether or not to react to the sudden appearance of a target), to

EXHIBIT 4-1

GUIDELINES: PSYCHOLOGICAL EFFECTS OF HEAT ON MILITARY PERFORMANCE

These useful conclusions are intended to help military personnel address psychological effects on performance of military tasks due to heat exposure:

1. Simple reactions can be performed as quickly in the heat as under normal conditions. More complicated reactions involving compound actions or some form of judgmental choice will take longer and show more variability as heat increases.
2. Although vision is not directly affected by heat, seeing clearly is impaired by secondary factors such as sweat running into the eyes and moisture obscuring optics and lens surfaces.
3. Visual distortions due to heat, such as mirages, optical illusions, shimmer and glare, reduce accuracy in performing visual tasks such as rifle aiming and distance judgment.
4. Equipment controls properly designed for use under optimum conditions can interfere with efficient manual operation when they become too hot to handle comfortably.
5. Sweating causes headgear and headphones to become unstable and slide on the head, interfering with hearing, vision, and the performance of other tasks.
6. Tasks requiring sustained attention, such as sentry duty, watch keeping, and instrument monitoring, usually deteriorate after 90 minutes, even under normal conditions. Heat exposure will shorten effective performance time to about 30 minutes. However, attention losses can be significantly counteracted by using various forms of caffeine and by taking intermittent breaks to reduce boredom.
7. Complex mental tasks, such as mathematical reasoning and decoding of messages, deteriorate in heat above 90°F after about 3 hours. Acclimatization to the heat and training in the heat reduce such decrements by increasing tolerable heat level and extending endurance time.
8. Protective handwear worn in the heat can cause increased sweating, as well as swelling of the hands themselves. These lead to slipperiness of gloves on the hands, bunching up of glove liners, and impairment of dexterity and tactility.
9. Continuing heat exposure causes progressive motor instability, leading to impaired steadiness and reduced rifle firing accuracy due to increased variability.
10. Target tracking, in which the operator must judge differences in continuous target alignment, deteriorates under hot conditions.
11. Simple tasks are less affected by heat than are highly complex tasks. Moderately complex tasks tend to be the most resistant to heat effects because they tend to sustain attention while placing only moderate demands on the operator's overall performance.
12. Multiple tasks (ie, two or more tasks being performed concurrently) are more affected by heat than any of the same tasks performed individually.
13. Discomfort reactions are widely different among individuals, and heat acclimatization and experience greatly influence degrees of discomfort. People are typically most uncomfortable and most distracted from their military tasks during conditions of heat and high humidity.
14. Symptoms of heat illness seriously degrade soldier performance, and symptom intensity varies widely among individuals. Military personnel should not be returned to duty prematurely because residual effects, although not directly obvious, can still affect military performance.
15. Crowded conditions commonly aggravate the effects of heat exposure, leading to increased aggression and irritability among groups in settings such as confined crew compartments and crowded troop transports.

(Exhibit 4- 1 continues)

Exhibit 4-1 continued

16. Typical disruptions of sleep patterns during military operations are further aggravated by hot conditions. The resulting sleep deprivation leads to difficulty in concentrating, thinking clearly, and reacting quickly and appropriately.
17. Although chemical protective clothing temporarily shields the body from direct (mainly radiant) heat, it also creates a microenvironment around the body that inhibits dissipation of heat and humidity generated by the wearer. In effect, a servicemember wearing chemical protective clothing in the desert may really be suffering instead from the effects of wet, jungle-like heat conditions. Mandatory requirements for encapsulation unavoidably intensify heat loads.
18. Wearing chemical protective clothing in the heat can be expected to cause almost immediate moderate impairment in military performance but with no additional significant increase for up to 6 hours thereafter. The decrements apparently are due mainly to the physical encumbrance of the clothing itself rather than to the heat effects per se.
19. The main effects of the nerve agent antidote, atropine, are slowed reaction time and photophobia. At the same time, heat causes reduced steadiness. These separate effects of drug and heat combine to impair tasks such as rifle firing, which require motor stability, quick reaction, and clear vision under bright conditions.
20. Commanders should take every opportunity to train their troops under hot conditions to avoid the disrupting effects of experiencing heat for the first time in the field. In other words, tasks to be performed in the heat should be learned and practiced in the heat. The beneficial effects of heat acclimatization and training can act to reduce the performance impairments, which would otherwise occur without such heat experience.

the maintenance of vigilance through determination (sentry duty), to the complex (map plotting, decoding of messages).

Reaction Time

During brief heat exposure, tasks involving simple reactions, such as straightforward target detection, are largely unaffected. In fact, reaction time in general seems to be quite durable during heat exposure; even choice reaction time is relatively unaffected. The severity of heat (dry bulb temperature $\geq 120^{\circ}\text{F}$) seems to be the driving factor rather than the duration of exposure. Nevertheless, complicated reactions can be expected to deteriorate sooner than simpler ones during heat exposure.

Despite the length of heat exposure, simple military tasks such as the operation of toggles will be performed with minimal delay. However, when choices are required, such as discriminating friend from foe, some lag will occur, but not to an important degree. This general relationship will hold throughout the tolerable temperature range, but deterioration will increase as temperature rises to the point of heat incapacitation. Personnel will also become more variable in their reaction speeds at

higher temperatures and when performing more complicated tasks. Heat acclimatization, however, will still act to mitigate these heat effects.

Sensation

Vision is clearly the most important human sense because it provides the most information for guiding overall behavior. Therefore, factors that affect vision, either directly or indirectly, are crucial considerations for efficient military performance. The available data seem to indicate that heat does not affect the visual process directly. However, heat exposure can indirectly interfere with normal visual function by causing disruptive conditions, such as condensation collecting on eyeglass or mask lenses, and sweat that runs into the eyes and causes headgear and headphones to become unstable and slide around on the head.⁸⁹

Service members can be expected to have visual problems whenever severe sweating occurs. Sweat that runs into the eyes is especially troublesome when encapsulating clothing is worn because the sweat cannot be wiped away without breaking the seal of the protective mask. Collection of moisture on the eye-pieces of the mask is a further problem because it

obscures the visual field. We have seen soldiers dressed in the MOPP 4 ensemble trying to look through trickle patterns in the condensed moisture on the eye ports—their only means of seeing clearly. Whether or not encapsulating clothing is involved, sweat in the eyes can cause excessive tearing, leading to reduced acuity. Thus, even though heat exposure does not directly affect vision, it can produce other major problems that lead to impaired sight.

Heat also can interfere with other normal sensory actions and, as a result, can cause sensations that are quite different from those experienced under cool conditions. Such effects are often mistakenly judged to be artifacts, but can be the immediate cause of performance decrements. For example, hot environments can cause mirages, visual distortions, and optical illusions due to atmospheric shimmer and glare, all of which result in reduced or inaccurate performance of visual tasks. Because these phenomena are common, it is strongly recommended that military personnel be given direct experience with them, by being trained in hot conditions where they occur. Similarly, it is important that the training be conducted in an environment most like the actual operational conditions (eg, on terrain similar to what will be encountered during real operations) so that personnel will become familiar with the possible visual effects.

Vigilance

Whether on land, in the air, or at sea, military operations invariably require continual surveillance and attention to current conditions. Therefore, vigilance and alertness are critical military factors, and the effects of heat on them are of serious concern. In tasks involving sustained attention, alertness, or both (eg, sentry duty, vehicle operation, instrument monitoring), vision appears to be the main process affected by heat. However, there is evidence that auditory vigilance tasks are also affected by heat. Interpretation of the findings is complicated by both visual and auditory vigilance studies' having been based on several different temperature indices (eg, dry bulb, WBGT, ET). Nevertheless, deterioration of vigilance seems to begin at around 85°F and higher.

Various studies using watch-keeping tasks have shown that aspects of vigilance significantly deteriorate after 90 to 120 minutes of sustained performance. Heat exposure likely will further shorten effective performance time, but this also will depend on the demand level of the task. Low-demand, boring tasks, such as watch keeping, with little chal-

lenge to the operator, can be expected to be the most vulnerable to heat effects, and the reduction in effective performance time can be as much as 60 to 90 minutes.⁷⁹ This means that the reliability of watch keeping in the heat will drop after 30 minutes, and that personnel should be relieved as often as possible to maintain effective surveillance. Vigilance can also be maintained fairly effectively by using caffeine in the form of coffee, tea, cola, chocolate, and even over-the-counter stimulants, usually in dosages of 200 mg. Familiar experience suggests that brief interruptions or breaks such as getting "a breath of fresh air," stretching, and walking around seem to help reduce boredom. There are also some data showing that experience, training, and motivation are positive factors in reducing the negative effects of heat on vigilance.

Complex Mental Performance

Virtually every military task requires service members to be able to process information rapidly and accurately, and to remember and use this information effectively. Therefore, the effects of heat on the complex mental processes involved are important considerations. Heat has been shown to affect short-term memory, mathematical reasoning, map plotting, and the coding or decoding of messages, typically after 3 hours at or above 90°F.^{27,28,32,33} Acclimatization can be an effective means of reducing the decrements that develop, both by increasing the tolerable heat load and by extending the length of endurable heat exposure. In like manner, training tends to offset the effect of heat by reducing errors and serving to maintain the quality of performance for longer periods.

Every effort should be made to acclimatize military personnel to the prospective temperature conditions they may encounter, and to provide as much training as possible in the specific operational tasks required to accomplish a mission. Overtraining is better in all respects than merely adequate training to accomplish the task in temperate conditions. Even better is training conducted in the actual heat conditions that are expected to be encountered in the field.

Psychomotor Performance

Psychomotor performance includes those tasks that are largely manual. It includes manual dexterity (with and without protective handwear), steadiness, aiming, and visual tracking (the firing of small

arms requires proficiency in this area). Complex tasks often require the concurrent performance of two or more psychomotor tasks, such as in the operation of vehicles, tanks, and helicopters.

Dexterity, Steadiness, and Aiming

Modern mechanized warfare involves many manual operations, such as manipulation of controls, assembly of weapons, and mechanical maintenance. Therefore, the effects of heat exposure on dexterity and psychomotor performance can seriously influence military operations. As with vigilance and perceptual performance, heat levels of 90°F to 95°F in laboratory studies have shown impairments that warrant serious concern for practical operations. High heat levels also raise the surface temperature of devices that personnel operate, rendering them uncomfortable, or even painful, to handle.⁹⁰ Many controls that are well-designed for operation under cool conditions cannot be operated when they heat up in the sun, and can even cause thermal burns to the skin.⁹⁰ Thus, heat by itself can block the performance of many operational tasks for physical reasons that are entirely unrelated to the physiological effects of heat.

Although gloves will protect the hands from contact burns, they create other problems that result from overheating the hands. The main problem is sweat that is generated and then trapped inside the gloves. The result is slipperiness between the hands and gloves, causing the gloves to slide on the hands, and at the same time causing sensory impairment because of the interference of the glove material. Glove liners invariably become soaked, leading to their bunching up at finger joints, slipping down the hands, or wadding up in clumps.

Finally, hands and feet often become edematous, causing gloves to fit too tightly. This, in turn, leads to reduced joint motility and reduced manual dexterity due to stiffness.

External ambient temperatures of 90°F to 95°F translate to much higher levels inside cramped spaces such as closed metal crew compartments and in encapsulating uniforms. Whenever heat entrapment occurs, heat exposure and its consequent effects can be expected to be much more severe than might otherwise be the case.

As shown in laboratory studies, another issue for serious concern is the impairment of steadiness caused by ambient heat. Unsteadiness can influence many military tasks, rifle marksmanship among others. Such effects lead to loss of accuracy and increased variability of rifle firing accuracy. Applied

to military units rather than just one marksman, such effects could be devastating for the outcome of military combat operations.

Tracking

Military tasks involving alignment of weapons or control systems to track moving target positions (eg, machine gun firing; control of tube-launched, optically tracked, wire-guided [TOW] weapons), manipulation of joy-stick controls, and even complex tasks such as piloting aircraft, have been shown to deteriorate in the heat ($\geq 90^\circ\text{F}$). Tracking is a complex skill involving complex coordination, steadiness, and focused attention. Impaired tracking is directly related to reduced steadiness, which also deteriorates under hot conditions, as noted previously. This causes interference with the ability to track targets reliably, particularly in compensatory tracking, when an operator must continuously make up the difference between control position and target position. Beyond the direct expedient of simply keeping the operator cool, some compensation for heat effects may be obtainable by building in more reluctance into control systems (ie, making controls stiffer to operate, thus tending to cancel out deviations due to the operator's unsteadiness and tremor). However, in the field, commanders will still have to cope with the effects of very hot conditions like those encountered in the desert, which will seriously influence the performance of crucial tasks such as operating guidance systems in fully closed tanks, where interior heat levels become nearly unendurable. Although there has been progress in the development of air-conditioned vehicles and practical, microclimate-controlled clothing, older equipment still will be used in combat. As a result, commanders must understand and make allowances for increased variability and unreliability of troop performance in the heat.

Concurrent Tasks

Many military tasks are routinely performed individually in some situations, but at other times may be performed with other tasks. The effects of heat on task performance may be quite different for the component tasks when performed singly or in combination. We must therefore consider the effects of heat on task interactions. The main factors that influence performance where these interactions are involved seem to be the complexity level of each individual task, the combined complexity of the combination of tasks, the skill and experience of the

operator, and the heat load accompanying the situation. Tasks that are performed concurrently are usually prioritized by the operator based on the demands of the mission, the requirements of the separate tasks, and the environmental conditions. It is important to understand the basic principle in such task interactions: that performance of individual tasks in the heat is usually best under moderate levels of heat load and task demand. Conversely, poorest performance will occur with highly complex task combinations under very hot conditions, although degraded performance will be somewhat offset by the motivation of the operator and the perceived importance of the mission. Commanders may be able to preserve the overall efficiency of their units in hot weather conditions by delegating task assignments so that the stress load is shared by all.

Subjective Response

A commander's awareness of the subjective response of the soldier is important to proficient accomplishment of the mission. Discomfort and distraction owing to heat symptoms can be a serious matter for the soldier and impair the completion of minor tasks. Discomfort may also lead to poor unit cohesion when social interactions become strained.

Symptomatology

In addition to physiological reactions to heat, there are characteristic symptomatic reactions that can seriously affect capability. In practical terms, a service member who feels ill is less apt to be an effective warrior. Reactions are highly individual but still can be grouped into common categories that occur frequently. The predominant symptoms include weakness, dizziness, hyperirritability, discomfort from feeling hot and sweaty, loss of appetite, and vomiting and nausea. These symptoms may not be intense enough to require medical attention, but they can be serious enough to interfere directly with military performance, or indirectly by influencing morale and motivation and by distracting the individual from the tasks to be performed. Although the tendency might be to return military personnel to duty when the physical signs of heat illness have diminished, there may still be residual symptoms that are not obvious but need to be taken into account. Commanders and medical personnel should therefore be warned about returning service members to duty too soon after they have suffered heat injuries.

Discomfort

Discomfort due to the heat can have a strong effect on individual capability. In combat situations and emergencies, discomfort may be ignored by the service member, but otherwise it can become severe enough to actually incapacitate. Heat combined with high humidity intensifies discomfort for most people. Nevertheless, discomfort is a highly individual subjective reaction; one person's idea of intolerable heat may be considerably different from another's. We can speculate that soldiers who grew up in hot regions should be more accustomed to hot conditions and will probably endure heat somewhat better, overall, than those who grew up in colder parts of the world. Acclimatization and experience with heat will help to remedy such differences by accustoming troops to heat exposure. Nevertheless, military leaders must realize that the urgency of discomfort during severe heat exposure can be a major factor in the willingness and motivation of individuals to perform their assignments. Military personnel who are trained in the heat should be able to endure higher heat conditions for longer periods than those with the same military task experience but who were trained under more comfortable conditions.

A considerable amount of research data⁵⁹⁻⁶¹ shows clearly that heat exposure seriously disrupts normal sleep. Sleep deprivation leads to disturbances of logical reasoning and creative ability, inability to concentrate effectively and react quickly, and weariness and irritability, all of which are clearly impediments to military performance. Service members who are exposed to hot conditions, particularly for prolonged periods when sleep deprivation can build up, should be expected to show impaired performance of many military activities involving the above factors. They may be at risk when driving vehicles, and may show lapses of performance during monitoring and surveillance assignments, and while performing mental activities ranging from simple substitution tasks, such as decoding messages, to complex planning of tactical operations. It may not be possible to counteract such effects, but military commanders and medical officers need to know about such impairments, and to expect them to be potential hazards during hot-weather operations.

Social Effects

Although there is considerable literature on both individual and group subjective reactions to heat

exposure, specific or quantitative conclusions about such reactions cannot yet be made from available research findings. Still, there is a common belief that heat, humidity, and crowding affect human behavior, probably as much from discomfort as from reducing physical capability in the heat. The common expression, "It's not only the heat, it's the humidity," conveys its own meaning and, for the most part, is probably true. However, the transition from this truism to practical recommendations for military operations in the heat is hard to make based on our knowledge of how people react to hot, humid, and crowded conditions. Common sense tells us to provide shelter from the sun, make sure that adequate cool water is available and that soldiers drink required amounts, and to attempt to ease crowded conditions. It may also be necessary to inform military leaders that the old idea of water discipline

education (ie, that personnel can be trained to get along on less water by denying it to them), is dangerous and wrong. Another equally dangerous misconception is the idea that "sucking pebbles" to stimulate salivation somehow reduces thirst.

There is a solid database on the effects of heat and its relationship to violence and aggression in crowded situations. This research has clear implications for military team situations. Commanders should expect that personnel will be more argumentative and irritable during hot weather, and especially in crowded conditions, such as on troop ships, and in confined areas, such as tanks and foxholes. However, it may be possible to avoid or reduce such reactions by informing troops that they are natural and typical results of heat and overcrowding, to expect them to happen, and to try to keep them under control.

SUMMARY

The military needs to understand how mental performance, psychomotor performance, and subjective responses vary with severity of heat stress. Understanding this relationship is important because heat stress can significantly impair military performance and because psychological changes often precede the onset of critical physiological changes. Establishing well-defined relationships between climatic conditions and psychological performance has been difficult. Thermal stress researchers have attempted to identify psychological breaking points in performance, but the environmental conditions employed to simulate the natural world (combinations of temperature, humidity, wind speed, and exposure time) do not lend themselves to systematic, real-world organization. Therefore, it is difficult to make broad generalizations about the effects of heat stress on psychological performance. Nevertheless, there is general agreement that

- the upper limit of heat exposure for unimpaired psychomotor performance is 90°F WBGT;
- the upper limit of heat exposure for unim-

paired mental performance is 85°F WBGT if the service member is required to perform the task for 2 hours or longer; at less than 1 hour on the task, individuals can perform proficiently at higher ambient temperatures approaching 109°F WBGT; and

- continuous repetitive tasks with relatively low arousal value tend to be the most affected.

Psychological performance during ambient heat exposure is compounded for military personnel because they are often encumbered by mission-essential clothing and equipment, including, for example, chemical protective clothing or medications such as nerve-agent antidotes, or both. Realistic military training in hot environments followed by persistent practice of military tasks in hot environments will attenuate otherwise severe impairments in performance. Humans differ in their predispositions, ranges of capability, motivations, and expectations for success. Although for convenience we tend to conceptualize human performance in terms of averages, military personnel still respond as individuals with different talents, initiatives, and attitudes.

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