Chapter 6

PREVENTION OF HEAT ILLNESS

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INTRODUCTION

Heat stress is a significant factor in many military activities, and heat casualties have posed a problem throughout the history of warfare. Egyptian failure to implement adequate precautions against heat stress contributed to the quick Israeli victory in the 1967 conflict in the Sinai desert.[1] Heat casualties among US military trainees were a major concern during World War II[2] and continue as a problem to this day.[3,4] Both desert (hot, dry) and tropical (warm, wet) climates pose hazards; the current requirement that US forces stand ready to deploy on short notice anywhere in the world means that all four US military services must be prepared to operate under hot conditions to which personnel are unaccustomed. Relevant research programs are conducted at a number of military laboratories, including the US Army Research Institute of Environmental Medicine (USARIEM), Natick, Massachusetts, and the Naval Health Research Center, San Diego, California.

Heat has a broad spectrum of effects. Heatstroke is equivalent to a major wound: each case is a potential fatality, and survivors are lost to service for prolonged periods. In contrast, heat exhaustion and related syndromes are only temporarily incapacitating, are generally treated in the field, and often go unreported; they can nevertheless significantly affect mission accomplishment.[5] There is also a growing body of evidence that heat stress that is physiologically tolerable can impair human ability to accomplish complex tasks of military importance.

The implementation of relatively simple preventive measures can have a dramatic effect on heat illness rates in military settings,[5,6] yet the necessary preparations are readily overlooked during contingency planning. Medical personnel must be prepared to advise commanders on the potential adverse effects of heat and to propose practical options for control of heat stress under difficult circumstances. The development of credible medical guidance requires a thorough understanding of the material in the Hot Environments section of this textbook, including knowledge of normal human responses to heat (Chapter 2, Human Adaptation to Hot Environments, and Chapter 3, Physical Exercise in Hot Climates: Physiology, Performance, and Biomedical Issues), its psychological effects (Chapter 4, Psychological Aspects of Military Performance in Hot Environments), the nature of heat illness (Chapter 5, Pathophysiology of Heatstroke), and its treatment (Chapter 7, Clinical Diagnosis, Management, and Surveillance of Exertional Heat Illness). This chapter summarizes this material as it relates to the prevention of heat-induced errors, performance decrements, and casualties.

Complexity of the Threat

Heat casualties occur when the stresses imposed by some combination of environment, work, and clothing combine to exceed individual tolerance limits (Figure 6-1). Personnel may encounter high environmental heat loads while working outdoors on paved surfaces, muddy trails, or desert sand; during road marches; and while carrying litters or servicing aircraft. Enclosed spaces can be extremely hot owing to the heat generated by internal sources as well as the environmental heat load; examples include poorly ventilated vehicles, maintenance facilities, and ship compartments. Hot working conditions are often made more dangerous by military

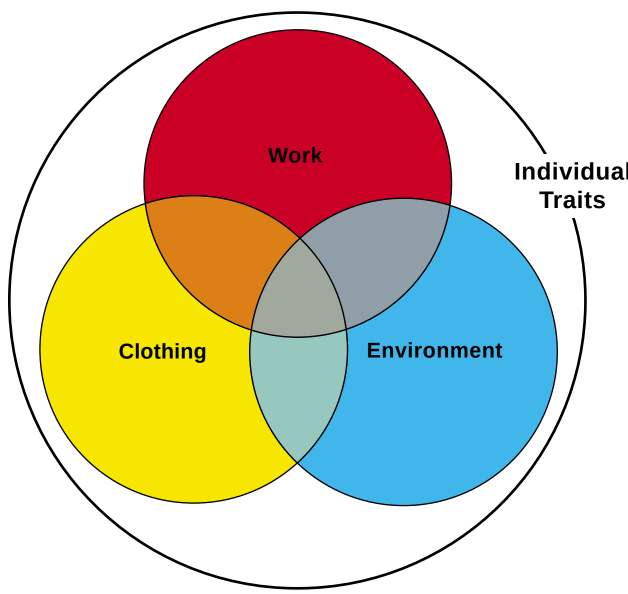

Fig. 6-1. Venn diagram of the three factors that determine heat stress: work, the environment, and clothing. Single factors represent a lesser risk of heat stress, two overlapping factors represent intermediate risks, and the area where all three factors overlap represents a heightened risk of heat stress. The response to a given level of heat stress also depends on a variety of individual traits, which interact with the three factors and may vary from one day to the next. Adapted with permission from Nunneley SA. Design and evaluation of clothing from protection from heat stress. In: Mekjavic I, Banister E, Morrison J, eds. *Environmental Ergonomics.* London, England: Taylor & Francis; 1987: 88.

demands for prolonged exertion. In addition, heavy or impermeable protective clothing may cause heat illness in otherwise temperate conditions. The picture is further complicated by the multiplicity of interacting variables that determine the normal range of individual heat tolerance.[7]

The level of heat stress and consequent risk that are acceptable can vary widely depending on the military situation. The goal for troops on a road march may be simply to go the distance without incurring frank casualties. On the other hand, a fighter pilot requires substantial protection from heat and dehydration to support the stress of aerial combat. Low-level missions in all types of aircraft expose crews to hot ambient conditions that are linked to performance decrements.[8,9] Helicopter crews face special problems in performing highly skilled flying tasks alternating with physical work to prepare the aircraft for the next flight; in addition, they often sleep in tents and thus fail to obtain the level of comfort and recovery afforded to aircrews in fixed-base and carrier operations.

Although most knowledge of heat stress is based on studies of healthy young men, military deployment now involves men and women, regular troops, reservists, and contractors, over a wide range of ages. Some of these personnel may have preexisting medical conditions and take prescription medications. Such a mixed population will produce a broader range of responses to heat stress and may develop medical problems not seen in younger populations.

Heat Stress in Military Settings

Preventive strategies cannot be expected to eliminate heat stress but should minimize its impact on the mission while preserving the health of personnel to the fullest extent possible. Techniques for primary prevention in both civilian and military settings include administrative plans and procedures, engineering control of the environment, appropriate use of equipment, and continuous medical surveillance to screen out vulnerable individuals. Supply officers preparing for deployment should be made aware of the need to stock hats, sunglasses, sunscreen, lip balm, and skin-care items, while individuals should ensure that their own deployment kits contain an initial supply of these items.

Flexibility and practicality are critical in providing medical support to commanders who face difficult decisions. Military working conditions often limit the effectiveness of natural thermoregulatory mechanisms and constrain normal behavioral defenses. Common civilian strategies to ameliorate environmental conditions, reduce workload, or lighten clothing may be unacceptable because they interfere with military objectives. Furthermore, exposure to heat in military settings is not limited to a conventional work shift but may continue without relief for prolonged periods, especially for troops living in tents or structures that are subject to solar load and lack air conditioning. Therefore, programs to control heat stress among deployed troops must often be extended beyond the working environment to cover conditions for feeding, rest, and recreation.

Military medical personnel who must work in hot conditions should recognize that they are themselves subject to deterioration in performance and possible heat illness. Health maintenance is particularly important in this group because healthcare involves a combination of physical effort, skill, and judgment that affects the welfare of their patients. Medical facilities in buildings and tents should be actively cooled in hot climates because high indoor temperatures cause difficulties with equipment and deterioration of supplies and are detrimental to the welfare of patients and staff. In the presence of heat stress, performance of critical tasks should routinely be double-checked for errors of omission and commission.

IMPROVING HEAT TOLERANCE

Human capacity to work in hot conditions can be maximized through preparatory physical conditioning and attention to details on deployment. Careful attention must be paid to physical fitness and heat acclimatization, living conditions, personal hygiene, and replacement of fluid and electrolytes.

Physical Fitness and Acclimatization

Human tolerance for work in heat is substantially affected by an individual's recent history of exposure to such stress. Acclimatization (ie, physiological adaptation to repeated stress, in nature) to heat produces complex physiological changes that improve heat transport from the body's core to its surface, and then dissipation of the heat to the environment.[10] Any exercise program that builds and maintains a high level of aerobic fitness will also confer at least partial adaptation to heat stress.[11,12] In addition, highly fit individuals will achieve complete acclimatization more quickly and with less discomfort than is the case for sedentary persons.[13,14]

An exception to this linkage between aerobic capacity and heat tolerance is fitness that is developed primarily through swimming in water cool enough to limit the usual exercise-induced rise in core temperature.[15] It should also be noted that high levels of fitness and acclimatization offer little improvement to work in heat with protective clothing.[12]

Military units preparing for deployment to a hot climate should intensify their physical training and use it to gradually increase their state of heat acclimatization. Personnel who cannot prepare in advance must be allowed a period for acclimatization on arrival at the deployment site. In either case, acclimatization is most quickly accomplished through daily exercise bouts that last a minimum of 1 to 2 hours per day and are sufficiently strenuous to produce a rise in core temperature and profuse sweating. Although complete acclimatization requires about 10 days, substantial changes take place in the first 2 to 3 days. Exposure to heat stress every second or third day will also produce acclimatization, although such intermittent exposure greatly prolongs the total period required to achieve complete adaptation.[16] If the unit is located in a cool climate, acclimatization can be improved by wearing heavy clothing during exercise, cautious use of a vapor-barrier layer in the clothing, or indoor exercise. Passive exposure to heat (as in a sauna) does little to improve capacity to work in heat.

Both physical fitness and heat acclimatization are subject to decay if conditioning is discontinued for long. Therefore, unless military operations themselves provide a high level of activity, appropriate physical training should be resumed soon after arrival at the deployment site. However, maintaining fitness in the field requires careful planning.[17] Outdoor training may have to be scheduled at unusual hours; local climate and weather conditions should be analyzed to select the best possible times to allow adequate exertional stress without undue risk of heat casualties. Vigorous exercise such as running can produce heat illness at any time of day if the combination of heat and humidity produces a wet bulb globe temperature (WBGT) of 18°C (65°F) or higher,[4] or at lower WBGTs if the participants are loaded with protective clothing and equipment. Furthermore, exercise in hot weather requires that personnel have suitable lightweight clothing, sufficient water and soap to wash themselves and their garments, and space to dry clothing and towels. Laundry requirements can be reduced if exercise equipment is set up in an air-conditioned building or tent, but this limits the stimulus to maintain heat acclimatization, one of the purposes of the exercise.

While acclimatization is critical to maximizing heat tolerance, it does not confer immunity, and fully adapted personnel can still be overwhelmed by a stressful combination of work, environmental heat load, and protective clothing. In addition, the benefits of acclimatization can be nullified by other stresses associated with deployment, including sleep deprivation, illness, dehydration, missed meals, or use of drugs and alcohol. Heat strain also reduces the physiological resources available for defense against other environmental stressors and makes it difficult for individuals to assess their own reserves. Examples include the occurrence of parade-ground syncope and unexpected acceleration-induced loss of consciousness in flight.

Although early studies of women seemed to indicate that they had a relatively low tolerance for work in heat, later experiments showed that finding to be an artifact related to fitness and other factors that differed systematically between the study groups of men and women.[18] Later experimental protocols that used matched subjects or otherwise made allowance for differences in physical characteristics found that men and women responded similarly to heat stress.[19–22] Closely controlled laboratory studies show small, consistent changes in thermoregulation over the menstrual cycle, but this has no practical effect on women's heat tolerance.[21,23]

Living Conditions and Personal Hygiene

Heat stress and sleep loss tend to form a positive feedback loop. It is therefore important to develop and enforce adequate work/rest schedules and sleep discipline among troops, not forgetting those in leadership positions. Special provision must be made for individuals who work at night because they often have difficulty getting adequate sleep during the day, particularly on deployment to hot climates. Every effort must be made to provide such personnel with cool, dark, quiet sleeping accommodations that are located as far as possible from noise sources such as roads, aircraft landing zones, maintenance shops, and recreational areas. Because windows must be covered or tent sides rolled down to shut out daylight, active cooling must be provided in the form of evaporative cooling or refrigerated air conditioning, supplemented by appropriate use of fans. Cooling systems also provide low-level background sound, which helps to mask outside noise. Ear plugs and sleep masks should be available for those who find them helpful. Short-acting hypnotics may also be considered under special circumstances.

Maintaining safe supplies of food and water in hot weather requires especially strict enforcement of sanitation and hygiene. Use of local supplies and handling of food and water by indigenous personnel introduce potential sources of infection. Seemingly minor lapses in cleanliness and refrigeration can produce immediate, disastrous consequences. Precautions must also be taken to prevent the proliferation of pests and the transmission of endemic diseases caused by bacterial, viral, and parasitic agents. Gastroenteritis constitutes a serious threat to people who work in hot conditions because emesis and diarrhea lead to dehydration and electrolyte disturbances, which can then impair heat tolerance.

Care of the skin and eyes is especially important in hot climates. Whenever possible, lightweight garments should be used to prevent sunburn while allowing free movement of air over the body. In addition, sunblock should be used generously on exposed skin to prevent acute sunburn and decrease the lifetime risk of skin cancer (a serious problem for military members, who may accumulate many years of exposure to solar ultraviolet radiation). Personnel should be encouraged to wear gloves and appropriate hats; hats with brims all around are preferable to baseball-style caps, which fail to protect the neck and ears.[24] Routine use of sunglasses or goggles is advisable, especially in windy conditions and around aircraft. Protective eyewear keeps sand and other foreign material out of the eyes, and prevents acute solar keratoconjunctivitis as well as lowers the incidence of pterygium. Eye protection also reduces the long-term effects of ultraviolet exposure with associated cataract formation.

Fungal and bacterial skin infections are a serious problem in hot weather; in desert environments the threat arises primarily from grit and irritation in crevices and areas of friction, while in humid conditions the problems are related to continuous exposure to sweat and moist clothing. It is therefore important to provide adequate facilities for bathing and laundry and to encourage their regular use by all personnel. Undergarments, socks, and shoe liners should be changed frequently, washed with disinfectant detergents or additives, and kept as dry as possible between uses.

Metal and other materials that have been sitting in the sun can be hot enough to blister skin on contact.[25] Personnel should be forewarned and wear gloves if they must handle materials under such conditions. Because swelling of the hands is a common problem during the first several days of heat exposure, personnel should be advised to remove rings in advance and string them onto their dog-tag chains. Body-piercing ornaments present special hygienic difficulties in hot climates and, like rings, present hazards of physical trauma and burns under wartime conditions.

Fluid and Electrolyte Balance

Unimpaired mental performance and physical work in the heat can be sustained only with adequate intake of water, electrolytes, and energy substrates; of those three, it is water that must be replaced on an hourly basis. Even mild dehydration leads to early fatigue and may also be associated with increased incidence of nonthermal illness and injury.[26] Dehydration is associated with a progressive rise in core temperature, reduced plasma volume, and tachycardia,[27] leading to clinical effects ranging from syncope to heatstroke.[28]

Deployment produces a variety of associated stresses such as frantic schedules, cumulative fatigue, infectious illness, and anxiety, which often cause people to ignore thirst or forgo meals. Individual trouble signs include weight loss and dark (concentrated) urine. In addition, troops in the field (especially women) may deliberately limit drinking to delay the need to urinate; this self-imposed dehydration is dangerous and must be counteracted through education and by providing the best possible latrines, which are both reasonably convenient and sufficiently private. Supervisors may need to institute a system of urine-color checks as a simple means to monitor hydration.

Desert air may be so dry that sweat evaporates instantly; under such conditions, personnel who are sweating profusely may develop severe dehydration without becoming aware of it.[29] During hard work in either hot–dry or warm–humid conditions, sweat output can exceed the rate at which water can be consumed, emptied from the stomach, and absorbed from the gut, a maximum of about 1.5 L/h in men.[30] When water intake and absorption fail to keep pace with loss, progressive dehydration is the inevitable result. The options for avoiding trouble are either

- to work until some physiological limit is reached and then take the substantial time required for complete recovery, or
- to take frequent rest breaks that lower time-averaged metabolic heat production and permit catch-up rehydration.

Attempts to drink more water than the gut can absorb will lead to abdominal distress and possibly to vomiting.[31,32]

Water Intake

Early investigators found that troops in the desert lost 1% to 3% of their body weight before voluntarily beginning to drink and then drank less water than they were losing through sweat; the resulting water deficit was not reversed until the evening meal.[29] Adolph and associates named this condition "voluntary dehydration"[29]; its magnitude depends on a variety of factors, including overall stress level and psychosocial factors as well as physiological control mechanisms.[33] Much of the current knowledge in this area derives from sports medicine. Distance runners on average consume water at the rate of only about 500 mL/h during a race and frequently lose 5% to 6% of their body weight before reaching the finish line.[34] Such dehydration alters the distribution of water through the various body compartments, contributes to cardiovascular drift, and can lead to premature exhaustion.[27,35]

Statements of requirements for water and electrolytes may be found in the chapter by Montain, Hydration, in Volume 2 of *Medical Aspects of Harsh Environments*, and elsewhere.[36–38] Contrary to popular belief, acclimatization does not decrease the need for water but rather *increases* it through earlier onset and higher rates of sweating.[39] Requirements for drinking water range from about 2 L/d for a sedentary person in a temperate climate to 15 L/d or more for someone performing hard work under the hottest desert conditions (Figure 6-2).[29] The same database was also used to estimate the water needs of sailors aboard lifeboats in hot climates.[29]

For troops on deployment, rehydration after a workday (or night) is an important aspect of preparation for the next work bout. Complete rehydration is best accomplished at meals, which should be accompanied by generous supplies of cool water and flavored drinks served in large cups. Personnel should take a generous drink before going to sleep and again on arising because this routine allows the kidneys to produce a normal state of fluid and electrolyte balance before the next exposure to stress. The possible benefits of prehydration or deliberate water loading just before the onset of heat stress are a matter of debate.[35]

Voluntary dehydration can be reduced through training and active encouragement of drinking in amounts equaling at least 80% of water lost as sweat.[40] Frequent intake of moderate volumes is generally better than large drinks at longer intervals.[31,32] Leadership must implement a system for delivering water on a prescribed schedule to both fixed work sites and troops on the move, and should implement a simple system for monitoring individual consumption. For example, soldiers on a road march may be instructed to carry two canteens and to consume their contents during a 1-hour interval, at the end of which there is a rest break and every canteen is refilled under supervision from unit supplies. At air bases and other fixed locations, water must be readily available at each work site, in vehicles, and in sleeping quarters. Drinking cups or free-flowing containers should be provided to facilitate rapid consumption of large volumes. In this spirit, normal US Air Force rules forbidding loose objects on the flight line were waived during the Persian Gulf War to allow aircraft mechanics to keep water bottles in their work areas.[41]

For purposes of rehydration, plain or pleasantly flavored water is preferable to beverages that are carbonated, heavily sugared, or contain caffeine (which is a diuretic).[42] Any drink that decreases thirst may inhibit intake before full rehydration is accomplished. So-called sports drinks and other flavored beverages may enhance consumption by some individuals but should be used with caution (discussed later and in Chapter 5, Pathophysiology of Heatstroke), and plain water must always be available to be drunk alone or mixed with other beverages. Commercial flavorings neutralize chlorine or other water purification agents and should therefore be added just before use, while drinks con-

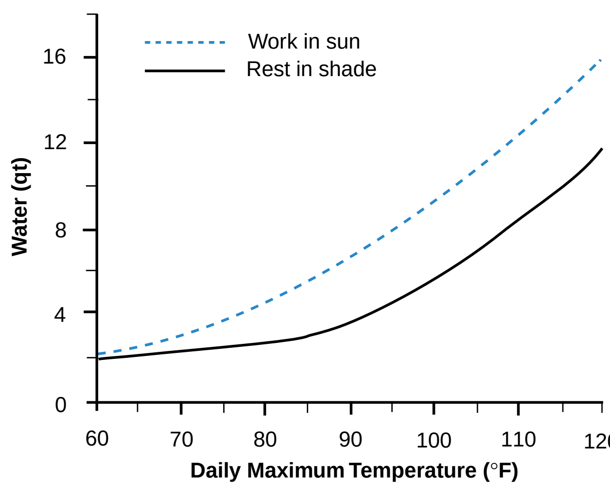

Fig. 6-2. Daily water intake requirements for men in the desert. Adapted with permission from Adolph EF, Associates. *Physiology of Man in the Desert.* New York, NY: Haffner Publishing (1969 facsimile of the 1947 edition); 1947: 121.

taining nutrients must be handled in the same manner as foodstuffs.

Drinking will be maximized if fluids are cool but not ice cold.[42–44] A simple cooling technique in the field is to store water in semiporous containers, where external evaporation lowers the temperature of the contents. This works best in arid environments, where low humidity assures efficient evaporation. Cooling by refrigeration or ice requires access to sophisticated machinery and power supplies. In addition, ice is a common medium for the spread of gastroenteritis, a lesson that has been relearned in every major deployment, including the Persian Gulf War. Ice may be made from an unsafe water supply or be contaminated in handling, and it cannot be disinfected. If there is any doubt of its purity, the ice should be used only for external cooling of drink containers without allowing either the ice or its meltwater to mix with drinks. In addition, nonpotable water and ice can be used to wet skin and clothing in the hope that such external cooling might lower the sweat rate and thus reduce dehydration.

Electrolyte Requirements and Nutrition

Secreted sweat is a markedly hypotonic solution containing sodium chloride, a small amount of potassium, and traces of other minerals and organic compounds.[45] Acclimatization to heat enhances reabsorption of electrolytes from the sweat ducts and thus improves electrolyte conservation; however, total salt loss may increase due to high sweat volume. Under normal conditions, the diet contains sufficient sodium and electrolytes to replace daily losses in the sweat of acclimatized persons.[37] However, it is possible for sodium depletion to develop in persons who are sweating profusely and either not fully acclimatized or not consuming normal amounts of dietary sodium. Adequate sodium is required to support the acclimatization process[46]; unfortunately, both loss of salt in sweat and failure to replace it through eating are likely to be worst early in deployment.

However, overzealous water intake over prolonged periods can increase total body water and produce dilutional hyponatremia (water intoxication).[47] Although the kidneys ordinarily can excrete a free water load, their capacity to do so may be reduced by various physiological and pathophysiological influences, including intense exercise. If the surplus water is not excreted, the fluid volume of the extracellular space increases, thus producing dilutional hyponatremia. Hyponatremia can develop fairly rapidly, and may be accompanied by cerebral edema, a potentially life-threatening complication.

Depressed appetite and gradual weight loss are common occurrences among troops deployed to hot climates.[48] Personnel should be actively encouraged to eat all scheduled rations to replenish calories and nutrients. Personnel must be taught neither to skip meals nor to replace them with candy bars, snack foods, or sugary drinks, items that may be convenient and pleasurable but lack important nutritional components. Military units should make every effort to provide at least one cooked, communal meal per day as the most effective means of encouraging adequate nutrition, complete rehydration, and reduction in stress through the opportunity to interact with others. Those responsible for planning meals should monitor dining areas to see which foods go uneaten and use that information to improve consumption.

Electrolyte and carbohydrate supplementation in drinks is not ordinarily necessary but may become an issue when logistical problems or military contingencies impede delivery of meals, and when illness, anxiety, and heat stress itself interfere with individual ability to eat. If troops are missing meals or are subjected to prolonged hard work in heat, small quantities of table salt may be added to the drinking water to improve intake and retention.[49] Carbohydrates (usually glucose) may also be added to provide energy and reduce fatigue but cannot be expected to alter thermoregulatory capacity.[50] (USARIEM recommends the following as a "homemade" rehydration drink: 6 g salt and 40 g sugar per quart of potable water.[51])

A carbohydrate concentration of 4% to 8% in drinks is recommended for endurance athletes.[40] The lower end of that range might be appropriate for military personnel, for whom heat stress is likely to originate more from environmental sources and less from extreme exertion. Concentrations greater than 8% improve carbohydrate delivery but slow gastric emptying, and therefore impair water replacement.[52] Commercial sports drinks are potentially useful for electrolyte supplementation, although brands that are hypertonic owing to their very high sugar content should be mixed with 1 to 2 times their volume of water to prevent nausea and vomiting. Salt tablets are not necessary and their use should be actively discouraged because they are readily abused. Although it is difficult to drink too much water, excess salt intake is a real hazard, leading to increased water requirements, greater urinary output, nausea, and increased susceptibility to heat illness.

MEDICAL SCREENING FOR RISK

Certain physical characteristics and a number of medical conditions are associated with increased risk of heat illness (Exhibit 6-1). The factors fall generally into two categories, transient and chronic, and include situational, personal, and medical conditions. Medical officers and other military personnel should keep in mind that casualties may be unable to thermoregulate when rashes, sunburn, or occlusive dressings cover large areas of their skin.

Transient Conditions

Recent arrivals at the deployment site are especially susceptible to heat injury and illness. Contributing factors include travel fatigue, jet lag, nutritional deficit, and sleep loss. Other problems may include recent immunizations or exposure to viral illnesses in transit. New personnel coming from cooler regions are unlikely to be fully acclimatized to work in heat and will have to learn local routines for self-care and prevention of heat illness. There is also evidence that heat stress on one day may increase vulnerability to heat illness on the next (see Figure 7-4 in Chapter 7, Clinical Diagnosis, Management, and Surveillance of Exertional Heat Illness).[4]

Heat tolerance is reduced by many common illnesses, including colds and other conditions that cause fever, vomiting, diarrhea, or failure to eat and drink normally. Extensive sunburn, miliaria rubra (prickly heat), and other rashes can seriously impair thermoregulatory capacity by altering cutaneous perfusion and inhibiting secretion of sweat over the injured area. All personnel should understand that those recovering from illness or skin problems require protection from heat stress for several days following apparent recovery to ensure full return of thermoregulatory capacity.

EXHIBIT 6-1

FACTORS THAT REDUCE TOLERANCE FOR WORK IN HEAT

Transient Conditions

- Situational
  - Travel fatigue, jet lag, or both
  - Sleep deprivation
  - Failure to eat or drink
  - Alcohol
  - Lack of acclimatization
- Medical
  - Recent immunization
  - Febrile illness
  - Gastroenteritis (emesis, diarrhea)
  - Skin conditions
  - Self-medication

Chronic or Permanent Conditions

- Personal
  - Small size
  - Low aerobic capacity
  - Age > 40 years
  - Overweight or obesity
- Medical
  - History of heat illness
  - Cardiovascular disease
  - Metabolic abnormalities
  - Prescription medications
  - Pregnancy

Chronic Conditions

Small size (ie, low muscle mass) and lack of physical fitness are risk factors in both men and women who must perform physical work at a fixed pace because the set work load uses a relatively high percentage of their strength and aerobic capacity. Aging is another risk factor because thermoregulatory competence tends to diminish with age,[53] although this trend is attenuated in persons who maintain a high level of fitness and avoid gaining weight.[53,54]

Overweight does not directly interfere with heat-dissipation mechanisms (vasodilation and sweating) but is usually associated with low aerobic capacity and lack of acclimatization, while the excess weight also increases the physical cost of any task involving locomotion. The combination of relatively low fitness and high body mass index (weight ÷ height^2, often used as an index of obesity) in military trainees significantly increases the risk of heat illness.[55]

Persons who have suffered previous heatstroke are at increased risk of recurrence,[56] although the mechanism is a matter of debate.[57,58] In addition, a small percentage of apparently normal individuals prove unable to adapt to heat. Such persons generally abhor heat stress and have learned to avoid it in their daily lives, a behavioral defense that deployment disrupts. For this reason, medical screening for hot work should include specific questions regarding past experience with heat stress. Disqualification should be considered for anyone with a history of two incidents of heat intolerance or a single occurrence of unexplained heat illness with persistent sequelae or difficulty in readapting to heat. A few individuals may require referral for a heat tolerance test.[57]

Deployment now includes significant numbers of women and therefore requires consideration of gynecological conditions and pregnancy in relation to environmental stress. Pregnancy involves altered hormone levels, changes in fluid balance, and increased circulatory demands. In addition, morning sickness can cause problems with nutrition, electrolyte balance, and hydration. The result may be increased susceptibility to syncope and diminished tolerance for dehydration. Although severe maternal hyperthermia due to febrile illness increases the incidence of fetal malformation, heat stress in the physiological range appears to pose little risk.

Chronic medical conditions that cause difficulty in hot climates include diabetes mellitus, thyroid disorders, renal disease, and cardiovascular disease. Any process that limits cardiac pumping or venous return can cause problems when heat-induced increases in cutaneous blood flow are added to the circulatory demands of working muscle.[59]

EXHIBIT 6-2

PHARMACOLOGICAL AGENTS THAT MAY REDUCE HEAT TOLERANCE

Drugs of abuse (eg, cocaine, ethanol)

Anesthetic agents

Anticholinergics

Antidepressants

Antihistamines

Antihypertensives (sympatholytics)

ß-blockers

Diuretics

Lithium

Monoamine-oxidase inhibitors

Phenothiazines

Salicylates

Stimulants

Sympathomimetics

Thyroid hormone

Medications and Drugs of Abuse

Several classes of prescription medications diminish heat tolerance by increasing metabolic heat production, suppressing body cooling, reducing cardiac reserve, or altering renal capacity to defend fluid and electrolyte balance (Exhibit 6-2). Problems with pharmaceutical agents are especially likely to arise from new prescriptions or changes in dosage. Self-medication with over-the-counter agents can also cause difficulties.

Aspirin and other nonsteroidal antiinflammatory agents should be used with caution because they may reduce renal blood flow and thus predispose heat-stressed users to acute renal dysfunction. Although hyperthermia due to heat stress alone does not respond to antipyretics, use of these medications in febrile illnesses may be justified on the grounds that fever itself significantly increases the risk of heat illness.

Sedatives and narcotic analgesics affect mental status and may thereby suppress beneficial thermoregulatory behaviors. Alcohol is a common and serious problem because it impairs intake of food and water, acts as a diuretic, and disturbs judgment. The adverse effects of alcohol extend many hours beyond the time of intake, especially if the person has vomited.

REDUCING HEAT STRESS

When the thermal load exceeds the coping ability of fully trained, well-led, well-supported troops, the prevention of casualties requires the modification of work conditions. *This is also the only safe and effective means of reducing water requirements when supplies are limited.* Selection of optimal stress-reduction methods requires a dialogue between medical staff members and military leadership to develop a trade-off analysis of possible modifications to the three components of heat stress: work, the environment, and clothing (see Figure 6-1).

Environmental Heat Load

External heat load is a function of air temperature, humidity, wind, and solar load. Whenever possible, advance planning should include study of mean and extreme climatic conditions at the deployment site as described in atlases and in long-term weather records such as those maintained by the US Air Force Meteorological Center at Scott Air Force Base, Illinois. On arrival at the new site, staffs should establish communications links to obtain regular real-time weather data and predictions, because short-term weather phenomena may increase the risk of heat casualties or provide windows of opportunity for critical military operations.

Engineering techniques should be employed wherever possible to improve environmental conditions at work sites. Buildings and other enclosed spaces should be actively cooled by means of evaporative systems or refrigerated air conditioning. Conditions for outdoor work can be improved by using misting to lower air temperature, fans to increase air movement, and portable structures to provide shade. If the worksite cannot be improved, an alternative is to provide an air-conditioned space nearby for use during rest breaks. Arduous work that must be conducted in the open should be performed during the cooler hours and may have to be scheduled at night. Planners should consider the 24-hour pattern of temperature and humidity for the deployment site, as well as the times of sunrise and sunset. Note that effective thermoregulation depends on ambient water vapor pressure rather than relative humidity, as it is the skin-to-air difference in vapor pressure that allows the evaporation of sweat. Conversion among relative humidity, water vapor pressure, wet bulb temperature, and dew point can be accomplished using a psychrometric chart (which is discussed in the chapter by Santee and Matthew, Evaluation of Environmental Factors, in Volume 3 of *Medical Aspects of Harsh Environments*), provided that input values of temperature and humidity are simultaneous measurements and not averages representing differing times of day.

Trucks, tanks, and aircraft that have been parked in the open present thermal hazards because solar heating can produce extreme internal air temperatures and make surfaces hot enough to blister skin.[25] Such machines should be parked in shade whenever possible; the simple act of covering transparencies (eg, windows, portholes, and aircraft canopies) also provides substantial protection. High-performance jet aircraft present a special problem owing to the need to protect their crews from severe heat stress (Exhibit 6-3).[60,61]

Metabolic Heat Production

When military priorities dictate that neither environmental conditions nor protective clothing can be modified, the only remaining option for thermal control is to lower individual work load. In some cases, mechanical aids can be deployed to reduce human effort. For instance, dollies can be used to move equipment and supplies that could otherwise be carried by hand, and troops can be provided with mechanized transport. A second line of defense is to spread out the work over time. When the military situation allows prolongation of a task, the time-averaged level of effort can be reduced by adopting a work/rest schedule either developed on an ad hoc basis or calculated from a predictive model (see the section on predictive models later in this chapter); as much time as possible should be spent in shade. For time-critical tasks, work-load reduction can be accomplished by dividing the task among a greater number of personnel laboring simultaneously or in alternating teams.

A major influence on work/rest planning is the fact that recovery from hyperthermia is an inherently slow process. Although air conditioning or a cool shower provides symptomatic relief by lowering skin temperature, substantial reduction of core temperature requires 30 minutes under the best of conditions and much longer in a hot environment. It is difficult to monitor recovery; humans cannot directly sense their own core temperature, and its measurement in the field is usually impractical. Use of fixed rest intervals is one way to get around this problem. Alternatively, resting (unstressed) heart rate can be used as an indication of return toward baseline core temperature; a common technique is to count the pulse at 10-minute intervals after cessation of physical work.

Use of predetermined work/rest intervals has major disadvantages. Because of the wide variation in individual response to heat stress, fixed schedules waste potential work capacity of more resistant personnel while continuing to pose some risk of casualties among the most vulnerable. Self-pacing may be a practical alternative for workers who have previous experience under similar conditions. Recent advances in electronic instrumentation also make it possible to measure individual temperatures and heart rate for real-time display on a body-mounted unit or telemetry to a central monitoring station. Commercial versions of such systems are now available, but most use an algorithm to set work limits that may be unsuitable for military applications.

EXHIBIT 6-3

PROTECTING PILOTS FROM UNDUE HEAT STRESS

Crews of high-performance aircraft require effective protection from heat and dehydration in order to maintain both physiological resistance to inflight stress and ability to operate a complex weapons system under dynamic conditions. Specifically, aerial combat entails sequences of aerobatic maneuvers with levels of acceleration (G-stress), which challenge human tolerance limits, and heat stress lowers the threshold at which the crew may lose consciousness. Although fighter crews experience only limited physical work loads in the cockpit, flight clothing imposes a significant thermal burden for hot-weather operations. The multilayered, protective clothing includes cotton underwear, fire-retardant coveralls, antigravity suit, parachute harness, boots, gloves, and helmet. A chemical defense layer may be added as underwear or incorporated into the coverall. The process of dressing in this ensemble, walking to the aircraft, and conducting preflight inspection on a hot ramp significantly raises core temperature. Thus, it is an already warm crew that enters the cockpit of a heat-soaked aircraft and goes through the sequences required for engine start. Although modern fighter aircraft can cool the cockpit during ground operations (standby and taxi), the thick clothing and impermeable layers of the antigravity suit mean that the occupants receive only limited benefit. Typically, heat removal occurs so slowly that the aircraft is in combat or returning to base before cooling is complete. In wartime, crews are expected to fly two, three, or more missions in quick succession with little chance to achieve full recovery in terms of body temperature and hydration. The following procedures are designed to minimize heat stress impact under such conditions:

- keep the sun out of transparencies by using rolling roofs or fabric covers;
- precool cockpits by means of air-conditioning the ground carts;
- transport crew members directly to the aircraft;
- assign alternate crew members to perform preflight aircraft inspection;
- encourage crews to drink water before cockpit entry, during standby, and in flight;
- limit the permitted duration of in-cockpit standby;
- in cases of mechanical delay, allow only one change of aircraft before requiring return to Ready Room;
- optimize conditions for cooling and rehydration between flights; and
- support self-assessment and empower crews to stand down when they judge that further flights would be unsafe.

Protective Clothing

Thermal Costs of Protection

Protective clothing amplifies heat stress in many settings.[62,63] The military services face serious problems due to increasing requirements for use of chemical–biological defense garments (ie, mission-oriented protective posture [MOPP] gear, either with or without headgear).[64,65] Other items that contribute to heat stress include helmets, flack jackets, aircrew clothing, and special protective clothing that is worn when handling hazardous material. Such clothing impedes convective and evaporative dissipation of body heat to the environment and may also significantly increase the metabolic cost of movement by adding weight and hobbling movement.[64,66] The only thermal advantage of heavy clothing is its tendency to damp transient pulses of external heat, an important function of firefighter bunkers (ie, firefighter clothing that combines reflective and insulative protection).

Protective helmets and masks create special discomfort because they absorb solar heat and retain sweat. White or reflective helmet surfaces can reduce the radiant heating, but their high visibility makes them unacceptable for military use. Helmets fitted with a suspension harness allow some air movement over the scalp. However, holes in a close-fitting shell have little effect until the openings occupy a significant proportion of the surface, as in bicycle helmets. The use of face masks is often troublesome because the combination of heat stress with respiratory resistance and anxiety often produces hyperventilation.[67,68] Although aircrew members are accustomed to wearing visors and oronasal masks, ground troops must undergo thorough training to develop confidence in their ability to work while wearing respiratory protection. Use of chemical–biological protective facemasks in hot weather creates an additional problem: wearers cannot wipe their faces, so sweat runs into their eyes and causes pain with potentially disabling blepharospasm.

Interaction With Work Load and the Environment

Because heavy clothing isolates the body from the environment, ambient humidity is less important to those wearing heavy clothing, and the level of physical activity becomes a dominant factor in heat stress.[69,70] In addition, clothing diminishes or eliminates the advantages conferred by high levels of physical fitness and heat acclimatization, because it prevents evaporation of sweat from the skin.[12] Furthermore, the high sweat rates associated with acclimatization lead to wet clothing and rapid dehydration.

Continuous wear of chemical–biological protective clothing in moderate to hot weather requires major revision of work/rest schedules.[71] For this reason, the use of WBGT with a fixed "add-on" as a guide to work in heavy clothing[72] is not only simplistic but also can be misleading; more sophisticated models are required to provide valid predictions of tolerance.[12,69] To avoid the need for prescribed rest breaks, the US Army has developed modified clothing configurations for its MOPP levels to lower heat stress while maintaining appropriate levels of protection in the presence of low-to-moderate chemical and biological threats. (For a more complete discussion, see the chapter by Musa, Bandaret, and Cadarette, Protective Uniforms for Chemical and Biological Warfare, in Volume 2 of *Medical Aspects of Harsh Environments.)*

The thermal burden imposed by a particular clothing ensemble depends on its effective thermal insulation and resistance to transfer of water vapor.[73] A small role is played by absorption of solar radiation in the visible and infrared spectra, in which color is a minor factor. The addition of external items such as body armor and backpacks can significantly alter the thermal situation by adding weight, inhibiting air movement within the clothing, and obstructing the evaporation of sweat.

The thermal insulation of clothing is proportional to its thickness and depends primarily on the volume of air trapped within and between layers rather than the fiber from which the item is made.[73] Membranes that prevent liquid penetration impose very little insulation but drastically curtail air movement and the evaporation of sweat. Only limited improvement is offered by use of specialized semipermeable membranes. Although such high-technology materials increase water vapor transfer compared with impermeable materials such as polyvinyl chloride, semipermeable membranes still form a barrier to evaporation on the scale required for work in the heat.[74]

Heavy clothing has profound effects on the prescription of work/rest schedules.[70,75] For instance, performing very hard work while wearing chemical–biological protective clothing can induce such a rapid rise in core temperature that a safe schedule dictates very short bouts of work alternating with prolonged rest; because few tasks can be accomplished on such a schedule, it may be more practical to use a single work session of 30 to 40

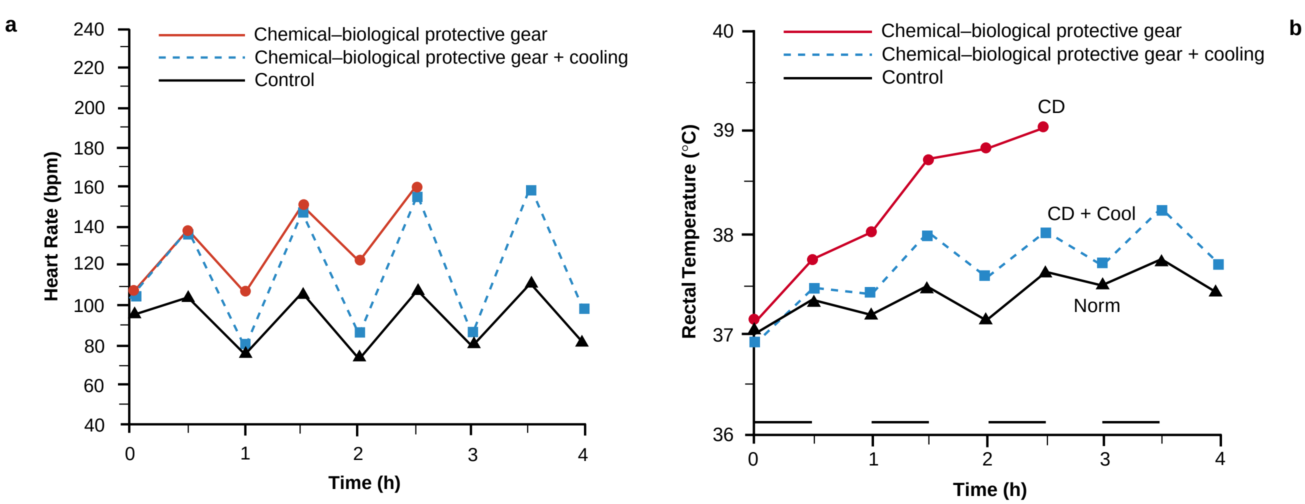

Fig. 6-3. An example of the effects of intermittent cooling in extending tolerance time for work in heat. Panels show (**a**) heart rate and (**b**) core temperature of subjects (n = 8) performing simulated work/rest cycles of ground crews. Bars indicate work intervals. Ambient conditions were T_{db} = 38°C, T_{wb} = 26°C, and T_{bg} = 43°C (db: dry bulb; wb: wet bulb; bg: black globe). Adapted with permission from Constable SH, Bishop PA, Nunneley SA, Chen A. Intermittent microclimate cooling during rest increases work capacity and reduces heat stress. *Ergonomics*. 1994;37(2):280.

minutes, followed by immediate retreat to collective protection for recovery. When personnel must continue to wear chemical–biological protective clothing after hard work, their rectal temperatures continue to rise for the first several minutes of rest, and subsequent cooling may be extremely slow. Under these conditions, personnel are acutely aware of their discomfort and may hyperventilate or become syncopal while resting. This phenomenon is a potential source of casualties among troops waiting to process into collective chemical–biological defense shelters at the end of work.

Gaining experience with heavy clothing in hot environments presents a special problem, because troops must achieve and maintain proficiency in their work while at the same time trying to avoid becoming heat casualties. Because the primary impediment to performance derives from the limitations to vision, communication, and manual dexterity, one response is to train wearing the headgear and gloves while substituting lightweight clothing for the heavy layers, thus eliminating the primary source of risk.

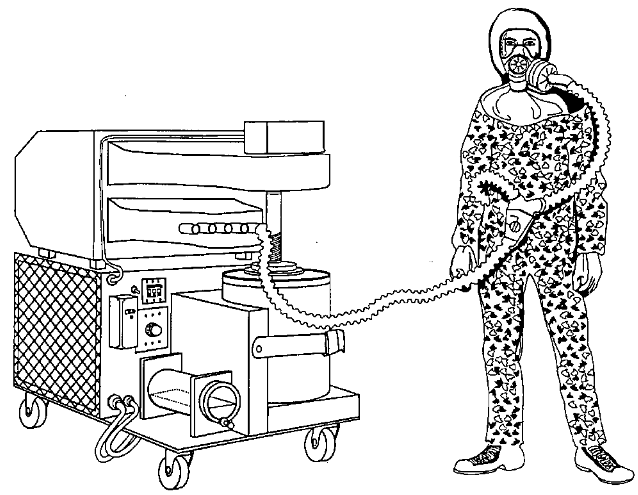

Fig. 6-4. The US Air Force developed a deployable system for air-cooling groundcrews during rest breaks with continuous wear of chemical defense clothing (otherwise known as chemical–biological protective gear or mission-oriented protective posture [MOPP] gear). Personnel wore an air vest under their garments and attached themselves to the cooling system while awaiting the arrival of the next aircraft. Cool, filtered air was provided by a device attached to a standard aircraft air conditioning cart.

Personal Cooling Systems

In an ideal world, personal cooling could be used to eliminate heat stress as a risk factor in military operations. Both air- and liquid-cooled garments have been studied for military applications.[76–78] In practice, technological limitations and the logistical costs of system support have limited their applicability. Individuals who can move freely with body-mounted cooling systems receive limited benefit because the added weight of the equipment increases the work load enough to offset most of the cooling. Practical applications are therefore limited to personnel who work in and around machinery, or at fixed locations where they can either be tethered to a mechanical heat sink or have frequent access to ice cartridges. To date, specific military applications of personal cooling systems include ice vests for personnel in ship engine rooms[79]; liquid-cooled garments for helicopter crews[80]; air vests for tank crews[81,82]; and air- and liquid-cooled garments for fighter pilots.[77] Certain tasks may require freedom during work but allow tethered cooling during rest breaks (eg, crews who rearm and refuel aircraft during surge operations). Laboratory experiments confirmed that intermittent cooling can substantially extend work capacity for subjects wearing chemical–biological protective ensembles (Figure 6-3),[83] and the US Air Force deployed an air-vest cooling system during the Persian Gulf War (Figure 6-4).

TOOLS FOR PREVENTION

Advance planning is critical to prevention of heat casualties. Fortunately, several tools are available to aid in this endeavor, among them training, predictive models, and surveillance.

Training

Medical staff members play key roles in providing education and supporting the realistic training exercises that underlie effective control of heat stress and prevention of heat casualties in hot climates.[5,84] Whenever possible, all deployable personnel should attend lectures and receive appropriate written materials well in advance of departure. Personnel arriving on site without such preparation should be briefed at once on issues related to heat stress. Commanders and unit leaders must be made aware of possible heat stress effects on performance and general health, as well as the potential tactical impact of heat casualties. They should also clearly understand that casualties are most likely when troops first arrive at their deployment site and during time-

EXHIBIT 6-4

MYTHS ABOUT HEAT STRESS

- Real men don't drink water.
- Don't drink unless you're thirsty.
- You can get a lot of cooling from a damp cloth on forehead, neck, or wrists.
- Training decreases the need for water.
- Sports drinks are better than water.
- Salt tablets counteract dehydration.
- Women are more vulnerable to heat than men.
- Baseball caps are good protection against the sun.

critical military contingencies.

Successful programs of prevention require universal education on sources and control of heat stress, normal responses, practical measures to maximize heat tolerance, signs of impending trouble in oneself and others, and appropriate corrective actions. Key points should be reinforced with relevant case reports or afteraction summaries to enhance individual and group resourcefulness and efficacy in dealing with heat stress. Education must also aim to stamp out common myths and erroneous assumptions that imperil health, because they induce inappropriate behaviors in the presence of heat stress (Exhibit 6-4). A dangerous example is the persistent belief that troops can somehow be trained or toughened to get along on reduced water rations, a concept that is incompatible with human physiology; military leaders *must* understand that water requirements can be reduced only by decreasing the need to sweat.

Predictive Models

It is often desirable to predict the effects of heat stress or recommend safe work/rest schedules under hot conditions. Various tables, equations, and computer programs have been developed to aid these processes. All of these can be called "models" in the sense that they use data and inference to develop a numerical description of human response to a given set of conditions (see also the chapter by Reardan and Pandolf, Modeling the Effects of Exposure, in Volume 3 of *Medical Aspects of Harsh Environments*). A computer program developed at USARIEM has been widely applied to US Army scenarios,[85] the US Navy uses an index developed in-house for shipboard operations,[86] and the US Air Force has its own specific guidance for operation of fighter aircraft in hot weather.[87]

A flag system is used to prevent heat casualties at US Department of Defense training installations (Table 6-1). Its development was prompted by the occurrence of heat casualties and deaths in US military training camps during World War II. Researchers developed the WBGT, a simple but effective index of environmental heat stress, to serve as a basis for modifying training activities in accordance with prevailing weather conditions.[2] A colored flag (green, yellow, red, or black) is displayed to indicate the current level of risk, and associated directives prescribe appropriate reductions in outdoor activity, differentiating between new trainees and fully acclimatized troops. An immediate and dramatic reduction in the incidence of heatstroke followed the implementation of the WBGT system.[6] WBGT has also been adopted as the basis for industrial work/rest schedules, where different boundaries may be used.[63,88]

More recently, computer-based mathematical models of heat stress have been developed in a number of laboratories. Their purposes range from the theoretical study of human thermoregulation[73,89,90] to empirical prediction of temperature rise and water requirements.[85,91,92] All such models require the input of multiple variables to describe work rate and clothing characteristics as well as heat, humidity, and other aspects of the environment. Simplified computer programs and derivative tables necessarily involve a number of assumptions, the details of which are often lost in the process of disseminating the information. Those who use such materials should carefully review the underlying assumptions and limitations to confirm that the model is applicable to their situation. Because small changes to input variables can have a major effect on output, users may wish to examine a variety of related scenarios to understand the effect of seemingly small variations (eg, an unexpected change in the weather, or the rescheduling of a task to a different time of day).

In any model designed to set safe schedules, the prescribed duration of work is set according to one of two criteria:

1. a single work bout, which is expected to produce the maximum safe core temperature, and following which the worker must return to base for recovery; and
2. a shorter work interval with a limited temperature rise, which can be repeated after a suitable rest interval.

TABLE 6-1

ACTIVITY RESTRICTIONS FOR OUTDOOR TRAINING OR PHYSICAL CONDITIONING IN HOT WEATHER

WBGT* °C (°F)	Flag Color	Guidance† for nonacclimatized personnel in boldface *Guidance for fully acclimatized personnel in italics*
25°C–26.9°C (78°F–81.9°F)	No flag	**Extreme exertion may precipitate heat illness** *Normal activity*
27°C–28.9°C (82°F–84.9°F)	**Green**	**Use discretion in planning intense physical activity** *Normal activity*
29°C–30.9°C (85°F–87.9°F)	**Yellow**	**Cancel intense physical activity; curtail other outside work** *Use discretion in planning intense physical activity*
31°C–31.9°C (88°F–89.9°F)	**Red**	**Stop work details and physical conditioning** *Curtail strenuous exertion, limit outdoor work to 6 hours*
= 32°C (= 90°F)	**Black**	**Cancel all outdoor work requiring physical exertion** *Cancel all outdoor work involving physical exertion*

*WBGT: wet bulb globe temperature
Calculation of WBGT: 0.7 T_{wb} + 0.2 T_{bg} + 0.1 T_{db}, where T_{wb}: wet bulb temperature; T_{bg}: black globe temperature; T_{db}: dry bulb temperature
†Guidelines assume that personnel are wearing summer-weight clothing; all activities require constant supervision to assure early detection of problems.
Adapted from HQ AETC/SGPB. *Prevention of Heat Stress Disorders.* San Antonio, Tex: Air Education and Training Command, Randolf Air Force Base; 17 Oct 1994. AETCI 48-101.

It should be noted, however, that neither body temperature nor hydration are likely to return to baseline during the prescribed rest breaks because complete recovery requires 30 minutes or more under cool conditions.

Heat-stress models generally express work and rest as subdivisions of 60 minutes. Although the work period cannot be safely lengthened beyond the prescription, the schedule can be divided into shorter intervals as long as the ratio between work and rest is preserved. For example, when a chart suggests 40 minutes of work alternating with 20 minutes of rest, a 20:10 schedule could also be used if better suited to a particular task.

Models are largely based on data from experiments on fit, young men and make no allowance for individual variation in physiological response. Although the more complex models allow adjustment for body size and fat content,[89] simpler empirical models do not.[85] Furthermore, models can safely predict the effect of conditions only within their envelope of experimental validation, when a valid model should produce satisfactory predictions in the hands of someone other than its developer.[70] Unfortunately, extrapolation from predicted core temperature to incidence of heat casualties remains largely speculative because it has not been possible to collect adequate experimental data on this relationship.

Surveillance

Surveillance and detection of signal events are important aspects of prevention requiring careful implementation (Exhibit 6-5). Leaders must be aware that heat casualties can occur suddenly and in large numbers. Therefore, seemingly minor complaints or signs of impaired performance among troops call for immediate corrective action to minimize deterioration in psychomotor performance as well as to prevent epidemic heat illness; stragglers or staggerers on a road march may indicate that the entire group is on the edge of serious trouble (Exhibit 6-6). Readers should keep in mind, however, that as currently defined, surveillance counts only casualties who have entered the medical treatment system and does not include those whose injury is too minor to require medical intervention.

In addition, the signs and symptoms of heat illness are not unique. Because desert and tropical climates also involve exposure to unfamiliar agents of disease as well as heat, medical personnel must always be aware of the need to exclude other potential diagnoses before settling on heat stress as the sole cause of a problem.

EXHIBIT 6-5

CURRENT APPROACH TO HEAT INJURY SURVEILLANCE

In recent years, the US Department of Defense (DOD) has significantly increased the emphasis on preventing disease and injury associated with military service. Under the general heading of Force Health Protection, a variety of preventive measures have been mandated, including disease and nonbattle injury (DNBI) surveillance on deployments. DNBI surveillance focuses on monitoring and controlling problems that could have a significant impact on a military force, including heat injuries.

The key elements of surveillance are systematic collection of health data, rapid analysis to identify problems, and corrective action based on the data. DNBI surveillance is essentially unit-based, and is conducted at every facility or unit that provides care for a deployed population. The diagnosis of every patient seen is recorded in a logbook. At the end of each week, each diagnosis is placed in a defined category, and the total number is counted. A weekly rate (expressed as percent per week [%/wk]) is then calculated for each category, based on the total population being cared for by the medical facility. Analysis consists of comparing this weekly rate to a standard reference rate. If the rate is higher than expected, further investigation and analysis is done to identify potential problems, and corrective action is then initiated.

The DOD DNBI surveillance category of heat injury includes the specific diagnoses of heatstroke, heat exhaustion, heat cramps, and dehydration. The heat injury category is designed to capture even the relatively mild cases that require treatment, because such cases may indicate breakdowns in the command's preventive efforts. A reference rate of 0.1%/wk is provided for comparison. If a unit's rate is appreciably higher than 0.1%/wk, then causative factors should be sought and corrected. Such factors might include lack of acclimatization, inadequate access to water, or failure to follow established guidelines for the ambient conditions. Immediate feedback should be given to unit commanders on the elevated rates and the probable causative factors. Commanders (rather than medical personnel) are usually in the best position to correct the problems that are causing heat casualties. In many cases, action can be taken immediately after recognizing that an abnormal number of heat injuries has occurred, without waiting to calculate weekly rates.

Although DNBI surveillance is currently mandated only for deployments, it is a useful tool for military units in any environment, including in garrison. This is especially true for heat injuries, which are a significant threat to units doing routine training during the warmer months. The heat injury rate is a very useful outcome measure for how well a unit is protecting its personnel.

Exhibit prepared for this textbook by Kevin Hanson, MD, MPH, Captain, Medical Corps, US Navy; Director, General Preventive Medicine Residency, Uniformed Services University of the Health Sciences, Bethesda, Maryland 20814-4799

SUMMARY

Heat casualties can impose significant penalties on military operations in hot climates, including both desert and tropical areas of the world. The spectrum of effects runs from subtle psychomotor impairment to discomfort, disability, and death. Medical officers should be prepared to assist commanders with planning and tradeoff analyses of practical alternatives, to minimize the impact of heat stress on the mission while preserving the health of personnel to the fullest extent possible.

Heat stress results from the combined effects of three factors: (1) environmental heat load, (2) metabolic heat production, and (3) protective clothing. Individual response to a given stress varies with age, physical conditioning, and the presence of additional factors such as sleep deprivation or intercurrent illness. While most studies of thermal stress have been conducted on healthy young men, deployed personnel may include both genders, a range of ages, and some persons using prescription medications that affect thermoregulation.

Human heat tolerance can be optimized through medical screening to disqualify unusually vulnerable individuals, systematic physical conditioning, and gradual acclimatization to work in heat. Special attention must be paid to living arrangements at the deployment site, including arrangements for personal hygiene, laundering of clothes, and appropriate sleeping arrangements. Sanitary handling and storage of food and water assume critical importance under hot conditions, where gastroenteri-

EXHIBIT 6-6

MARINE CAPTAIN COURT-MARTIALED AFTER RECRUIT'S HEATSTROKE DEATH

On 8 April 2000, a Marine captain was found guilty of dereliction of duty in the heatstroke death of a reservist under his command. The captain was court-martialed after the Marine collapsed and died following a conditioning hike. The 180-man Marine company, all carrying weapons and packs, made an 8-mile night march at Camp Lejeune, North Carolina, on a July night with an ambient temperature of 80°F. The Marine who died was a 21-year-old college student. He was seen vomiting at the first rest stop and later was heard telling a noncommissioned officer that he "couldn't make it," but was nevertheless pressed back into the formation. After the hike, he was seen to be lethargic with slurred speech; he wandered off and his body was found 2 hours later.

Testimony at the court-martial indicated that the march was conducted at a fast pace with few breaks, and that the captain appeared to be in a hurry to complete the march and go home. It was reported that many Marines became overheated or ill and straggled out of the captain's sight. Three Marines who were checked for hyperthermia had body temperatures exceeding 103°F.

The prosecution charged that the captain did not "follow established procedures for training marches, normally conducted at a slightly slower pace and with more rest stops than hikes for seasoned marines"[1(pA8)]; and that the captain "violated standing operating procedures for conditioning hikes and that he showed a careless disregard for his men."[2(pA4)]

This case exemplifies the risk of heat exhaustion and heatstroke during sustained exertion—even at night—if both temperature and humidity are high. In addition, the commander failed to make due allowance for green troops or to heed the signal events when numbers of trainees fell out during the march.

(1)Associated Press. Marine captain goes on trial for reservist's death. *The Washington Post.* 4 April 2000: A8. (2) Associated Press. Captain is convicted in death of Marine: Judge finds neglect of duty on fatal hike. *The Washington Post.* 9 April 2000: A4.

tis—a constant threat—can turn tolerable heat stress into life-threatening dehydration.

Frequent water intake is required to replace secreted sweat and prevent development of a significant water deficit. Under some conditions, sweat rate may exceed the maximum rate at which the human gut can absorb water (1.5 L/h); under such conditions, work load must be reduced or breaks provided to avoid progressive dehydration. The limited quantity of electrolytes lost in sweat can generally be replaced in meals, so that electrolyte drinks are required only for troops who are unable to eat regularly or for seriously dehydrated individuals.

Techniques for reduction of heat stress include (1) scheduling work for cooler times of day or night; (2) moving activities to cooled or shaded sites; and (3) reducing metabolic heat load through use of mechanical devices, spreading the work among more personnel, or instituting planned rest intervals.

Military contingencies may require wearing protective clothing such as MOPP ensembles, which interfere with convective and evaporative cooling of the skin; such clothing nullifies the thermoregulatory advantages of physical fitness and heat acclimatization. Clothing made with semipermeable membranes offers negligible relief under these extreme conditions. However, pilots and others working with machinery may be able to use air- or liquid-based personal cooling garments to improve comfort and performance of complex tasks.

Effective advance planning is the key to prevention of heat casualties on deployment. Useful tools include training of all personnel, use of models to predict and control heat stress levels, and surveillance and detection of signal events before casualties reach elevated levels.

REFERENCES

1. Hubbard RW. Water as a tactical weapon: A doctrine for preventing heat casualties. *Army Science Conference;* 1982: 125–139.

2. Yaglou CP, Minard D. Control of heat casualties at military training camps. *Arch Ind Health.* 1957;16:302–316.

3. Reardon MJ. *Heat Stress Illness in a Mechanized Infantry Brigade During Simulated Combat at Fort Irwin*. Natick, Mass: US Army Research Institute of Environmental Medicine: 1994. Technical Report 94-14.

4. Kark JA, Burr PQ, Wenger CB, Gastaldo E, Gardner JW. Exertional heat illness in Marine Corps recruit training. *Aviat Space Environ Med.* 1996;67:354–360.

5. Kerstein M, Hubbard R, Mager M, Connely J. Heat-related problems in the desert: The environment can be an enemy. *Mil Med.* 1984;149:650–656.

6. Minard D. Studies and recent advances in military problems of heat acclimatization. *Mil Med.* 1967;132:306–315.

7. Havenith G, van Middendorp H. Relative influence of physical fitness, acclimatization state, anthropometric measures and gender on individual reactions to heat stress. *Eur J Appl Physiol.* 1990;61:419–427.

8. Bollinger RR, Carwell GR. Biomedical cost of low-level flight in a hot environment. *Aviat Space Environ Med.* 1975;46:1221–1226.

9. Froom P, Caine Y, Shochat I, Ribak J. Heat stress and helicopter errors. *J Occup Med.* 1993;35:720–724.

10. Nielsen B. Heat stress and acclimation. *Ergonomics*. 1994;37:49–58.

11. Gisolfi CV, Cohen JS. Relationships among training, heat acclimation and heat tolerance in men and women: The controversy revisited. *Med Sci Sports Exerc.* 1979;11:56–59.

12. Aoyagi Y, McLellan TM, Shephard RJ. Effects of training and acclimation on heat tolerance in exercising men wearing protective clothing. *Eur J Appl Physiol.* 1994;68:234–245.

13. Pandolf KB, Burse RL, Goldman RL. Role of physical fitness in heat acclimatization decay and reinduction. *Ergonomics*. 1977;20:399–408.

14. Armstrong LE, Maresh CM. Induction and decay of heat acclimatization in trained athletes. *Sports Med.* 1991;12:302–312.

15. Avellini BA, Shapiro Y, Fortney SM, Wenger CB, Pandolf KB. Effects of heat tolerance of physical training in water and on land. *J Appl Physiol.* 1982;53:1291–1298.

16. Fein JT, Haymes EM, Buskirk ER. Effects of daily and intermittent exposures on heat acclimation of women. *Int J Biometeorol.* 1975;19:41–52.

17. Patton JF, Vogel JA, Damokosch AI, Mills RP. Effects of continuous military operations on physical fitness capacity and physical performance. *Work and Stress.* 1989;3:69–77.

18. Nunneley SA. Physiological responses of women to thermal stress: A review. *Med Sci Sports Exerc.* 1978;10:250–255.

19. Avellini BA, Kamon E, Krajewski JT. Physiological responses of physically fit men and women to acclimation to humid heat. *J Appl Physiol.* 1980;49:254–261.

20. Frye AJ, Kamon E, Webb E. Responses of menstrual women, amenorrheal women and men to exercise in a hot, dry environment. *Eur J Appl Physiol.* 1982;48:279–288.

21. Kenney WL. Review of comparative responses of men and women to heat stress. *Environ Res.* 1985;337:1–11.

22. Carpenter AJ, Nunneley SA. Endogenous hormones subtly alter women's response to heat stress. *J Appl Physiol.* 1988;65:2313–2317.

23. Stephenson LA, Kolka MA. Thermoregulation in women. In: Holloszy J, ed. *Exerc Sport Sci Rev.* 1993;21:231–262.

24. Keeling JH, Kraus EW, Pthak M, Sober AJ. Hats: Design and protection from ultraviolet radiation. *Mil Med.* 1989;154:250–255.

25. Stoll AM, Chianta MA, Piergallini JR. Prediction of threshold pain skin temperature from thermal properties of materials in contact. *Aviat Space Environ Med.* 1982;53:1220–1223.

26. Henry CD. Heat stress and its effects on illness and injury rates. *Mil Med.* 1985;150:326–329.

27. Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol.* 1992;73:1340–1350.

28. Sutton JR. Clinical implications of fluid imbalance. In: Gisolfi C, Lamb D, eds. *Perspectives in Exercise Science and Sports Medicine. Vol 3: Fluid Homeostasis During Exercise.* Carmel, Ind (now in Traverse City, Mich): Benchmark Press; 1990.

29. Adolph EF, Associates. *Physiology of Man in the Desert.* New York, NY: Haffner Publishing; facsimile of the 1947 edition; 1969.

30. Costill DL. Gastric emptying of fluids during exercise. In: Gisolfi C, Lamb D, eds. *Perspectives in Exercise Science and Sports Medicine. Vol 3: Fluid Homeostasis During Exercise.* Carmel, Ind (now in Traverse City, Mich): Benchmark Press; 1990:97–128.

31. Mitchell JB, Voss KW. Influence of volume of fluid ingested on gastric emptying and fluid balance during prolonged exercise. *Med Sci Sports Exerc.* 1991;23:314–319.

32. Noakes TD, Rehrer NJ, Maughan RJ. Importance of volume in regulating gastric emptying. *Med Sci Sports Exerc.* 1991;23:307–313.

33. Greenleaf JE. Problem: Thirst, drinking behavior, and involuntary dehydration. *Med Sci Sports Exerc.* 1992;24:645–656.

34. Noakes TD. Fluid replacement during exercise. *Exerc Sports Sci Rev.* 1993;21:297–330.

35. American College of Sports Medicine. Exercise and fluid replacement (ACSM Position Stand). *Med Sci Sports Exerc.* 1996;28:i–vii.

36. Mack GW, Nadel ER. Body fluid balance during heat stress in humans. In: Fregly MJ, Blatteis CM, eds. *Handbook of Physiology*, Section 4, Vol 1: *Environmental Physiology.* New York, NY: Oxford University Press; 1996: 187–214.

37. Marriott BM, ed. *Nutritional Needs in Hot Environments: Application for Military Personnel in Field Operations.* Washington, DC: National Academy Press; 1993.

38. Marriott BM, ed. *Fluid Replacement and Heat Stress.* Washington, DC: National Academy Press; 1994.

39. Davies CRT. Effect of acclimatization to heat on the regulation of sweating during moderate and severe exercise. *J Appl Physiol.* 1981;50:741–746.

40. Coyle EF, Montain SJ. Benefits of fluid replacement with carbohydrate during exercise. *Med Sci Sports Exerc.* 1992;24:S324–S330.

41. Cornum K. Deployment operations in the heat: A Desert Shield experience: Support of Air Operations Under Extreme Hot and Cold Weather Conditions. Victoria, BC, Canada: Advisory Group for Aerospace Research and Development (NATO); 1993.

42. Szlyk PC, Sils IV, Francesconi RP, Hubbard RW, Armstrong LE. Effects of water temperature and flavoring on voluntary dehydration in men. *Physiol Behav.* 1989;45:639–647.

43. Hubbard RW, Sandick BL, Matthew WT, et al. Voluntary dehydration and alliesthesia for water. *J Appl Physiol.* 1984;57:868–875.

44. Szlyk PL, Sils IV, Francesconi RP, Hubbard RW. Patterns of human drinking: Effects of exercise, water temperature and food consumption. *Aviat Space Environ Med.* 1990;61:43–48.

45. Robinson S, Robinson AH. Chemical composition of sweat. *Physiol Rev.* 1954;34:202.

46. Armstrong LE, Costill DL, Fink WJ. Changes in body water and electrolytes during heat acclimation: Effects of dietary sodium. *Aviat Space Environ Med.* 1987;58:143–148.

47. Noakes TD, Goodwin N, Rayner BL, Taylor RKN. Water intoxication: A possible complication during endurance exercise. *Med Sci Sports Exerc.* 1985;17:370–375.

48. Thomas CD, Baker-Fulco CJ, Jones TE, et al. *Nutritional Guidance for Military Field Operations in Temperate and Extreme Environments*. Natick, Mass: US Army Research Institute of Environmental Medicine; 1993. Technical Note 93-8.

49. Nose H, Mack GW, Shi X, Nadel ER. Role of osmolality and plasma volume during rehydration in humans. *J Appl Physiol.* 1988;65:325–331.

50. Levine L, Rose MS, Francesconi RP, Neufer PD, Sawka MN. Fluid replacement during sustained activity in the heat: Nutrient solution vs. water. *Aviat Space Environ Med.* 1991;62:559–564.

51. Glenn JF, Burr RE, Hubbard RW, Mays MZ, Moore RJ. *Sustaining Health and Performance in the Desert: Environmental Medical Guidance for Operations in South West Asia.* Natick, Mass: US Army Research Institute of Environmental Medicine; 1990. Technical Note 91-1.

52. Mitchell JB, Costill DL, Houmard JA, Fink WJ, Robergs R, Davis J. Gastric emptying: Influence of prolonged exercise and carbohydrate concentration. *Med Sci Sports Exerc.* 1989;21:269–274.

53. Kenney WL, Hodgson JL. Heat tolerance, thermoregulation and aging. *Sports Med.* 1987;4:446–456.

54. Havenith G, Inoue Y, Luttikholt VGM, Kenney WL. Age predicts cardiovascular but not thermoregulatory responses to humid heat stress. *Eur J Appl Physiol.* 1995;70:88–97.

55. Gardner JW, Kark JA, Karnei K, et al. Risk factors predicting exertional heat illness in male Marine Corps recruits. *Med Sci Sports Exerc.* 1996;28:939–944.

56. Armstrong LE, De Luca JP, Hubbard RW. Time course of recovery and heat acclimation ability of prior exertional heatstroke patients. *Med Sci Sports Exerc.* 1990;22:36–48.

57. Epstein Y. Heat intolerance: Predisposing factor or residual injury? *Med Sci Sports Exerc.* 1990;22:29–35.

58. Royburt M, Epstein Y, Solomon Z, Shemer J. Long-term psychological and physiological effects of heat stroke. *Physiol Behav.* 1993;54:265–267.

59. Johnson JM, Proppe DW. Cardiovascular adjustments to heat stress. In: Fregly MJ, Blatteis CM, eds. *Handbook of Physiology. Vol 1, Sec 4.* New York, NY: Oxford University Press; 1996: 215–243.

60. Nunneley SA, Myhre LG. Physiological effects of solar heat load in a fighter cockpit. *Aviat Space Environ Med.* 1976;47:969–973.

61. Nunneley SA, Stribley RF. Heat and acute dehydration effects on acceleration response in man. *J Appl Physiol.* 1979;47:197–200.

62. Electric Power Research Institute. Heat stress—management program for nuclear power plants. Palo Alto, Calif: EPRI; 1986.

63. American Conference of Governmental Industrial Hygienists. *Threshold Limit Values and Biological Exposure Indices for 1992–93.* Cincinnati, Ohio: ACGIH; 1992.

64. Patton JF, Bidwell TE, Murphy MM, Mello RP, Harp M. Energy cost of wearing chemical protective clothing during progressive treadmill walking. *Aviat Space Environ Med.* 1995;66:238–242.

65. Taylor HL, Orlansky J. Effects of wearing protective chemical warfare combat clothing on human performance. *Aviat Space Environ Med.* 1993;64:A1–A41.

66. Nunneley SA. Heat stress in protective clothing: Interactions among physical and physiological factors. *Scand J Work Environ Health.* 1989;15:52–57.

67. Morgan WP. Psychological problems associated with the wearing of industrial respirators: A review. *Am Ind Hyg Assoc J.* 1983;44:671–676.

68. Louhevaara VA. Physiological effects associated with the use of respiratory protective devices. *Scand J Work Environ Health.* 1984;10:275–281.

69. Antuñano MJ, Nunneley SA. Heat stress in protective clothing: Validation of a computer model and the heat humidity index (HHI). *Aviat Space Environ Med.* 1992;63:1087–1092.

70. McLellan TM, Jacobs I, Bain JB. Influence of temperature and metabolic rate on work performance with Canadian forces NBC clothing. *Aviat Space Environ Med.* 1993;64:587–594.

71. Kraning KK, Gonzalez RR. Physiological consequences of intermittent exercise during compensable and uncompensable heat stress. *J Appl Physiol.* 1991;71:2138–2145.

72. Departments of the Army, Navy and Air Force. *Occupational and Environmental Health.* Washington, DC: DA, DN, DAF; 1980. TB MED 507, NAVMED P-5052-5, AFP 160-1.

73. Lotens WA, Havenith G. Calculation of clothing insulation and vapour resistance. *Ergonomics.* 1991;34:233–254.

74. Havenith G, Lotens WA. What, actually, is the advantage of semi-permeable over impermeable rainwear? Soesterberg, The Netherlands: TNO Institute for Perception; 1984: IZF 1984–6.

75. McLellan TM, Jacobs I, Bain JB. Continuous vs. intermittent work with Canadian Forces NBC clothing. *Aviat Space Environ Med.* 1993;64:595–598.

76. Shapiro Y, Pandolf KB, Sawka MN, Toner MM, Winsmann FR, Goldman RF. Auxiliary cooling: Comparison of air-cooled vs. water-cooled vests in hot-dry and hot-wet environments. *Aviat Space Environ Med.* 1982;53:785–789.

77. Allan JR. The development of personal conditioning in military aviation. *Ergonomics.* 1988;31:1031–1040.

78. Neal W Jr, Pimental NA. A review: US Navy (NCTRF) evaluations of microclimate cooling systems. In: Pandolf K, ed. *Perspectives on Microclimate Cooling/Conditioning of Protective Clothing in the Heat.* Vol 1. Washington, DC: The Technical Cooperation Program: Subcommittee on Non-Atomic Military Research and Development; 1995: 81–126.

79. Frim J, Glass KC. Alleviation of thermal strain in engineering space personnel aboard CF ships with the Exotemp personal cooling system. Downsview, Ontario, Canada: DCIEM; 1991. DCIEM 91-62.

80. Frim J, Bossi LL, Glass KC, Ballantyne MJ. Alleviation of thermal strain in the CF: "Keeping our cool" during the Gulf conflict. Support of Air Operations Under Extreme Hot and Cold Weather Conditions. Victoria, BC, Canada: Advisory Group for Aerospace Research and Development (NATO); 1993.

81. Toner MM, Drolet LL, Levell CA, et al. *Comparison of Air Shower and Vest Auxiliary Cooling During Simulated Tank Operations in the Heat.* Natick, Mass: US Army Research Institute of Environmental Medicine; 1983. T2/83.

82. Cadarette BS, Pimental NA, Levell CA, Bogart JE, Sawka MN. *Thermal Responses of Tank Crewmen Operating With Microclimate Cooling Under Simulated NBC Conditions in the Desert and Tropics*. Natick, Mass: US Army Research Institute of Environmental Medicine; 1986. T7/86.

83. Bishop PA, Nunneley SA, Constable SH. Comparisons of air and liquid personal cooling for intermittent heavy work in moderate temperatures. *Am Ind Hyg Assoc J.* 1991;52:393–397.

84. Kerstein MD, Wright D, Connelly J, Hubbard R. Heat illness in hot/humid environment. *Mil Med.* 1986;151:308–311.

85. Pandolf KB, Stroschein LA, Drolet LL, Gonzalez RR, Sawka MN. Prediction modeling of physiological responses and human performance in the heat. *Comput Biol Med.* 1986;16:319–329.

86. Dasler A. Heat stress, work function and physiological heat exposure limits in man. In: Mangum B, Hill J, eds. *Thermal Analysis—Human Comfort—Indoor Environments.* Gaithersburg, Md: National Bureau of Standards; 1977: 65–92.

87. Nunneley SA, Stribley RF. Fighter index of thermal stress (FITS): Guidance for hot-weather aircraft operations. *Aviat Space Environ Med.* 1979;50:639–642.

88. American College of Sports Medicine. Heat and cold illnesses during distance running (ACSM Position Stand). *Med Sci Sports Exerc.* 1996;28: i–x.

89. Wissler EH. Mathematical model of the human thermal system. *Bull Math Biophys.* 1964;26:147–166.

90. Werner J, Buse M, Foegen A. Lumped versus distributed thermoregulatory control: Results from a three-dimensional dynamic model. *Biol Cybern.* 1989;62:63–73.

91. Shapiro Y, Pandolf KB, Goldman RF. Predicting sweat loss response to exercise, environment and clothing. *Eur J Appl Physiol.* 1982;48:83–96.

92. Moran D, Shapiro Y, Epstein Y, Burstein R, Stroschein L, Pandolf K. Validation and adjustments of the mathematical prediction model for human rectal temperature responses to outdoor environmental conditions. *Ergonomics.* 1995;38:1011–1018.