Section II

The Physical Work Environment

6

HOT ENVIRONMENTS

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Exposure to high ambient temperatures while working in hot indoor environments or while working outdoors in hot weather is a common and potentially fatal occupational hazard. Normally, the human body functions within a very narrow range of core body temperature. In the occupational setting, heat stress, from the combined effects of environmental heat, metabolic heat, and often the use of impervious clothing, can strain the body's ability to maintain heat balance, and the body's core temperature may begin to rise. Workplace heat exposure, in addition to causing heat-related illness, has been found to decrease productivity and to increase job-related accidents.[1]

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OCCUPATIONAL SETTING

No recent estimate of the number of workers exposed to hot environments has been published. In 1986, the National Institute for Occupational Safety and Health (NIOSH) estimated that 5–10 million Americans worked in jobs where heat stress was an occupational health hazard, and this range is probably still a reasonable estimate.[2] Table 6.1 lists some common work sites where workers are exposed to heat or to hot, humid environments.[3] Heat-related deaths are common in the USA, and the Centers for Disease Control and Prevention (CDC) reported an average of 371 deaths annually attributable to "excessive heat exposure".[4] Most of the heat-related deaths reported by the CDC were in non-working populations. Occupational- or exertional-related heat death, while known to occur, is infrequently reported in the medical literature. On the other hand, occupational heat-related illness is relatively common. A recent case series of heat-related casualties in the mining

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Table 6.1 Work sites with heat exposure.[3]

Iron and steel foundries
Non-ferrous foundries
Brick-firing and ceramics plants
Glass products facilities
Rubber products factories
Electrical utilities
Bakeries
Confectioneries
Commercial kitchens
Laundries
Food canneries
Chemical plants
Mining sites
Smelters
Steam tunnels
Fires (firefighting)
Outdoor operations
Surface mines
Agriculture sites
Construction sites
Merchant marine ships
Hazardous waste sites
Military training sites
Athletic competitions

industry reported the incidence of heat exhaustion in the summer months as 43 cases/million man-hours worked.[5] Military personnel, who are often required to achieve very high levels of work output in thermally extreme environments, have a long history of high risk for heat stress.[6] Reports from the military continue to provide information on the occurrence of heat injury in healthy, young individuals.[7,8]

In any heat hazard environment, whether indoors or outdoors, high humidity or heavy manual labor increases the workers' risk for heat strain. Specific occupational groups, such as firefighters are at exceptionally high risk for heat stress. Not only are they exposed to extremely high temperatures while fighting fires, but they also must perform demanding physical tasks while wearing fire-resistant protective clothing that diminishes the elimination of body heat. The hazardous waste clean-up industry is also a field where heat is a potentially significant occupational hazard. Workers are required to wear respiratory protection and full protective clothing. These requirements limit the use of conventional heat stress monitoring guidelines and place an additional strain on the hazardous waste clean-up worker.

MEASUREMENT ISSUES

Environmental heat

Ambient or environmental heat affecting the worker and the worker's ability to transfer body-generated heat to the environment is determined by four environmental factors: (1) air temperature, (2) air humidity, (3) air movement or velocity, and (4) radiant heat (solar and infrared). Microwave radiation may also be a source of environmental heat in some work situations (Chapter 15). Various measures of ambient heat load, reflecting the factors influencing heat transfer, are available for use in the industrial setting. The most commonly used measures of external heat are dry bulb temperature, wet bulb temperature, and wet globe temperature–are described in Table 6.2.

Metabolic heat

Heat production in the body is the by-product of normal basal metabolism, and averages approximately 1.5 kilocalorie (kcal) per min.[2] Under resting conditions, most heat production occurs in the liver, brain, heart, and skeletal muscles. During exercise or work, skeletal muscle activity greatly increases the production of metabolic heat. A measurement of metabolic heat production or, at least, an estimate of metabolic heat is essential in determining a worker's total heat stress and in calculating workplace heat exposure limits. Direct or indirect measurement of each worker's level of work and the kilocalories of heat produced in the occupational setting is not practical. Therefore, tables of the workload or energy cost of various tasks have been developed and are used to estimate metabolic heat (Table 6.3).

Table 6.2 Measures of external heat.[2]

Measure	Device	Comments
Dry bulb	Liquid-in-glass thermometer; thermocouple; resistance thermometer	Measures ambient air temperature and is temperature useful in determining comfort zone for lightly clothed sedentary workers. Does not measure effect of humidity, radiant heat or air movement on temperature
Wet bulb	Thermometer bulb or sensor covered by a wet cotton wick that is exposed to air movement	Measures effect of humidity on evaporation temperature and effect of air movement on ambient temperature. Natural wet bulb temperature is the term used if the wet bulb is exposed to prevailing natural air movement; may be a useful guide in preventing heat stress in hot, humid, still environments where radiant heat does not contribute to heat load, such as underground mines
Globe temperature	Black globe—temperature sensor in the center of a 15-cm hollow copper sphere painted flat black Wet globe—temperature sensor in the center of a 3-in copper sphere covered by a wet black cloth	Measures effect of radiant heat. Wet globe thermometer (Botsball) also reflects the effect of humidity and supposedly exchanges heat with the environment similarly to a nude man with totally wet skin

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Table 6.3 Examples of activities with metabolic rate categories.

Categories	Example activities
Resting	Sitting quietly Sitting with moderate arm movements
Light	Sitting with moderate arm and leg movements Standing with light work at machine or bench while using mostly arms Using a table saw Standing with light or moderate work at machine or bench and some walking about
Moderate	Scrubbing in a standing position Walking about with moderate lifting or pushing Walking on level at 6 km/hour while carrying 3-kg weight load
Heavy	Carpenter sawing by hand Shoveling dry sand Heavy assembly work on a non-continuous basis Intermittent heavy lifting with pushing and pulling (e.g. pick-and-shovel work)
Very heavy	Shoveling wet sand

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EXPOSURE GUIDELINES

Heat stress indexes

The guidelines currently used for worker exposure to heat stress are based on indexes developed through subjective and objective testing of workers or from combinations of external heat measurements. Today, the most commonly used index is the Wet Globe Bulb Temperature Index. An historically widely used heat stress index is the Effective Temperature (ET) Index.[2] Developed in the early 1920s, it was derived from studies on the subjective impressions of comfort and heat effects in sedentary subjects exposed to differing combinations of air temperature, humidity, and air motion. A third index, the Heat Stress Index (HSI), was developed by Belding and Hatch in the 1950s. Derived from the heat balance equation, it combines the total heat gain from radiation, convection and metabolism in terms of the required sweat evaporation necessary to maintain heat balance. The required component measurements make this index difficult to use, although these same measurements may be valuable in identifying the sources of the heat stress.[9]

Wet Globe Bulb Temperature Index

The Wet Globe Bulb Temperature (WGBT) Index is a commonly used heat stress index in the USA. It is recommended by the Occupational Safety and Health Agency (OSHA), NIOSH, and the American Conference of Governmental Industrial Hygienists (ACGIH), and required by the US armed forces.[10,11]

The WGBT Index is calculated from measurements of the natural wet bulb (NWB), the black globe (GT), and the dry bulb (TA) temperatures.

For outdoor environments with a solar heat source, the WBGT formula is:

$$\mathrm{WBGT} = 0.7\mathrm{NWB} + 0.2\mathrm{GT} + 0.1\mathrm{TA}$$

For indoor use or for outdoor settings without a solar load, the formula is:

$$\mathrm{WBGT} = 0.7\mathrm{NWB} + 0.3\mathrm{GT}$$

The necessary measurements require relatively simple instrumentation and can be easily obtained in an industrial environment. Heat stress monitors that measure all three temperatures and calculate the WBGT Index temperature are also available. An example of an automated WBGT monitor is shown in Figure 6.1. The WBGT Index was developed for men exercising outdoors in military fatigues. Therefore, if different types of clothing are worn, correction factors are required. This index is not applicable in settings where sweat-impermeable clothing is required and may not be as effective as other indices in preventing heat casualties in extreme heat stress conditions. Much of the original work on the WBGT index was performed by the military in an effort to decrease heat-related casualties during training and war-time operations.[6,12]

Heat strain indicators

In addition to the heat stress indexes based upon external heat measurements, measures of heat strain, or the physiologic responses to environmental heat stress, have also been used to evaluate worker tolerance to heat exposure. The four main heat strain indicators are heart rate, body temperature, skin temperature, and hydration status. Historically, the cumbersome nature of monitoring equipment and its lack of durability have limited our ability to make real-time measurements of a workers' core temperature or heart rate. As technology improves and durable, convenient monitors and sensors become available, the physiologic measures of heat strain may take on increasing importance, especially for workers in heavy protective clothing.

Of all the physiologic measures, heart rate is the most easily measured. It is a reliable indicator of overall heat strain, rising with both increasing workload and increasing core temperature. Utilizing this physiologic response to heat, a method of measuring oral temperature, post-work heart rate, and recovery heart rate to monitor for heat strain has been developed. Heat stress is assumed not to cause progressive deterioration of the pulse if:

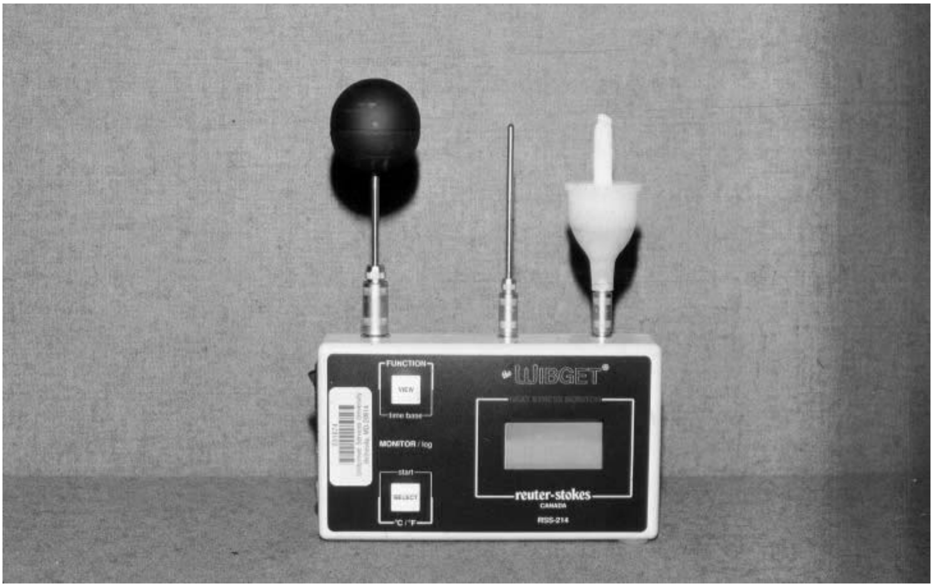

Figure 6.1 Automated WBGT monitor. From American Conference of Governmental Industrial Hygienists (ACGIH®), 2000 Threshold Limit Values (TLVs®) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs®). Reprinted with permission.

(1) the oral temperature does not exceed 37.5°C (99.5°F) and if the heart rate at 30–60 s into rest is <110, or (2) the heart rate difference from the initial 30–60 s into rest and the heart rate 2.5–3 minutes into rest is >10 beats per min.[2] The availability of inexpensive electronic pulse monitors and timers has made this method easier, and it can be a valuable indicator of heat strain in certain settings.

Of all the measures of heat strain, core body temperature appears to be the most reliable indicator. The World Health Organization recommends that deep body temperature should not, under circumstances of prolonged daily work and heat, be permitted to exceed 38°C (100.4°F) rectally or 37.5°C (99.5°F) orally.[2] Though this heat strain index may seem ideal, monitoring internal or core body temperature with rectal or esophageal probes is not acceptable to many workers. Oral temperatures, while easy to obtain, may be inaccurate measures of core temperatures because of mouth breathing, drinking hot or cold liquids immediately before using a thermometer, or improper use or storage of the oral thermometer. An ingestible capsule containing a temperature sensor and a device producing a telemetry signal is available to monitor real-time internal temperatures as the capsule passes through the gastrointestinal tract. This type of temperature monitoring in the work setting may be an important advance; however, one study of experimental subjects found a difference between the sensor-measured internal temperature and commonly measured rectal temperature.[13] Therefore, additional research is needed before telemetry internal temperature monitoring can be advocated for heat-exposed workers. Tympanic membrane temperature monitors also provide an acceptable measurement of core temperature, but use of these monitors is uncommon because of ear discomfort and the need for a good seal in the ear canal.

Estimation of fluid loss or hydration status by regular weight measurements prior to work and throughout the day has also been proposed as an indicator of heat strain. Based upon weight measurements (assuming that the worker was fully hydrated before beginning work), the heat-exposed worker can be encouraged to drink liquids to maintain hydration and constant body weight throughout the day. Urine-specific gravity measurements before, during and after work have also been used to assess hydration status in workers.

EXPOSURE GUIDELINES

In the USA, the ACGIH guidelines are frequently used by industry to determine acceptable heat exposure for employees. These guidelines or threshold limit values (TLVs) permit working conditions "that nearly all adequately hydrated, unmedicated, healthy workers may be repeatedly exposed without adverse health effects."[10]

A recent revision of the ACGIH heat stress guidelines includes a decision tree for the

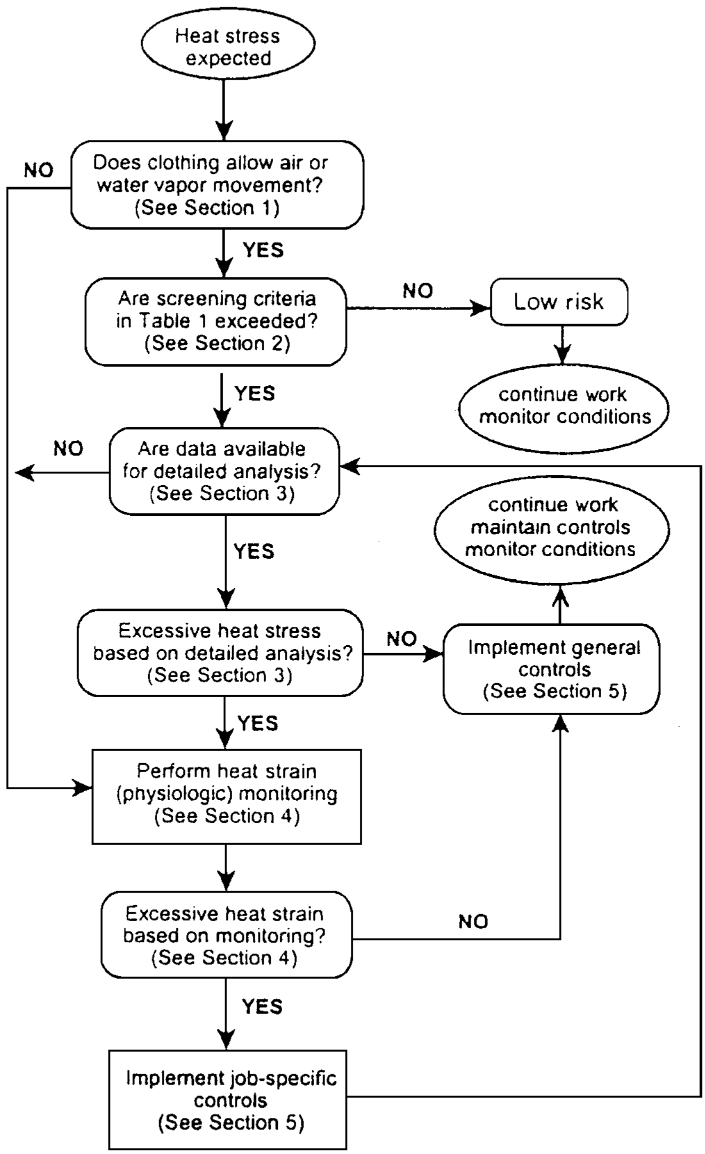

Figure 6.2 Heat stress decision tree. From American Conference of Governmental Industrial Hygienists (ACGIH®), 2000 Threshold Limit Values (TLVs®) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs®). Reprinted with permission.

assessment of a worker's risk of heat stress (Figure 6.2). The previous ACGIH guidelines were similar to the NIOSH guidelines and recommended that workers in hot environments rest for a portion of each hour, with the amount of rest based upon WBGT Index, level of activity, and acclimation status of the worker. The current ACGIH recommendations still use a "work–rest regimen" but expand the guidelines for work situations where heat stress conditions (e.g. use of encapsulating clothing) exceed the typical work–rest cycle recommendations.

In general, the ACGIH decision tree incorporates an assessment of the type of clothing worn by the worker, the level of environmental heat or WBGT Index, an estimate of the worker's level of physical activity, an analysis of the work and work site, and if necessary, physiologic monitoring of the worker. After the initial assessment of clothing requirements, Table 6.4 provides work–rest cycles based upon worksite WBGT Index, work demand level and worker acclimation status. If the temperature index or work exceeds that outlined in Table 6.4, a detailed analysis of the heat stress potential of the work site is required. If the detailed analysis reveals excessive heat stress, physiologic monitoring of the workers is needed. The reader should consult an experienced health professional and review the specific guideline documentation before attempting to implement these guidelines in the workplace.[10]

NIOSH also has heat exposure guidelines published in the 1986 "Criteria for a Recommended Standard Occupational Exposure to Hot Environments."[2] In this document, the agency proposed a system of work–rest cycles, similar to the ACGIH guidelines in Table 6.4, to prevent heat-related illnesses. Work–rest time curves based upon WBGT Index measurements and metabolic heat estimates were developed for heat-unacclimatized and heat-acclimatized workers; they are called Recommended Alert Limits (RALs) and

Table 6.4 Examples of permissible heat exposure threshold limit values: Screening Criteria for Heat Stress Exposure (WBGT values in °C).

	Acclimatized				Unacclimatized			
Work demands	Light	Moderate	Heavy	Very heavy	Light	Moderate	Heavy	Very heavy
100% work	29.5	27.5	26		27.5	25	22.5	
75% work 25% rest	30.5	28.5	27.5		29	26.5	24.5	
50% work 50% rest	31.5	29.5	28.5	27.5	30	28	26.5	25
25% work 75% work	32.5	31	30	29.5	31	29	28	26.5

See Table 6.3 and the Documentation for work demand categories.

WBGT values are expressed in °C and represent thresholds near the upper limit of the metabolic rate category.

If work and rest environments are different, hourly time-weighted averages (TWA) should be calculated and used. TWAs for work rates should also be used when the work demands vary within the hour.

Values in the table are applied by reference to the "Work–Rest Regimen" section of the *Documentation* and assume 8-hour workdays in a 5-day workweek with conventional breaks, as discussed in the *Documentation*. When workdays are extended, consult the "Application of the TLV" section of the *Documentation*.

Because of the physiologic strain associated with heavy work among less fit workers regardless of WBGT, criteria values are not provided for continuous work and for up to 25% rest in an hour. The screening criteria are not recommended, and a detailed analysis and/or physiologic monitoring should be used.

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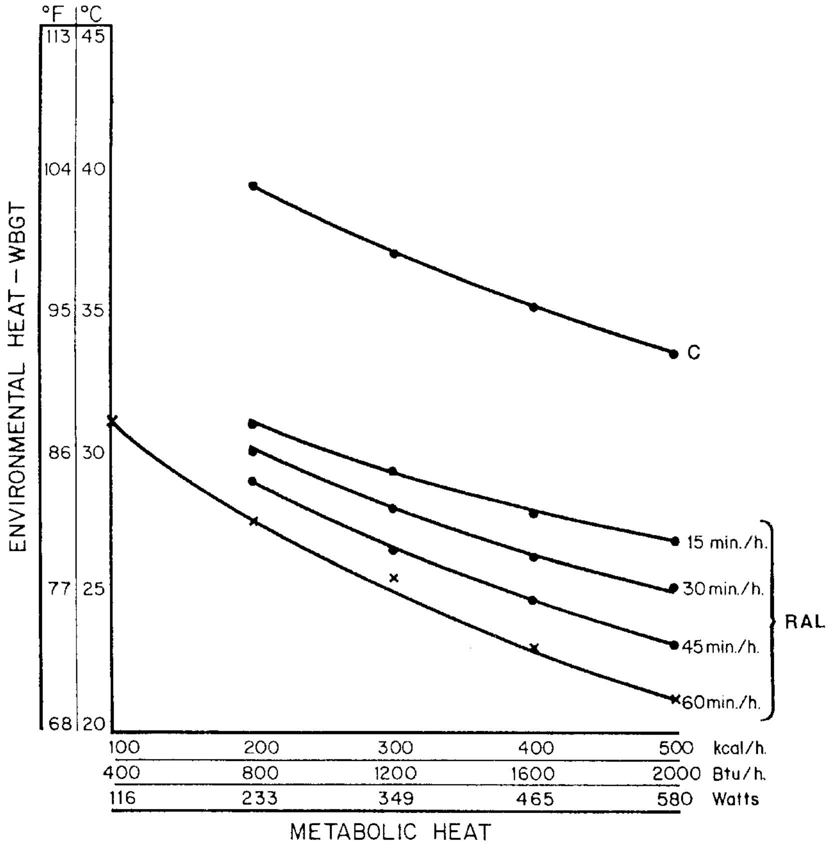

Figure 6.3 Recommended heat stress alert limits for heat-unacclimatized workers. C = ceiling limit; RAL = Recommended Alert Limit. Calculations are for a standard worker of 70 kg (154 lb) body weight and 1.8 m^2 (19.4 ft^2) body surface. Reproduced from National Institute for Occupational Safety and Health. Criteria for a recommended standard. Occupational exposure to hot environments. Revised criteria. DHHS (NIOSH) publication no. 86-113. Washington, DC: US Government Printing Office, 1986.

Recommended Exposure Limits (RELs), respectively (Figures 6.3 and 6.4). The NIOSH RALs and RELs were developed for healthy workers who are physically and medically fit for their level of activity and who are wearing customary work clothes (i.e. a long-sleeved shirt and trousers).

NORMAL PHYSIOLOGY

The normal human body maintains a narrow core body temperature range of 36.7–37°C (98–98.6°F) by oral measurement and 37.3–37.6°C (99–99.6°F) by rectal measurement. This narrow range of temperature control is maintained through the production and conservation of metabolic heat in cold ambient conditions or the transference of metabolic heat to the environment in hot ambient conditions. Under heat strain conditions, a series of physiologic mechanisms is initiated to bring internal heat to the body surface and to cool the body surface through the evaporation of sweat. In humans, the hypothalamus serves as the primary temperature regulator. Neurons in the preoptic area of the anterior hypothalamus, along with deep body temperature sensors, have the ability to detect small changes in blood temperature. As the blood temperature rises, sensing neurons in the hypothalamus

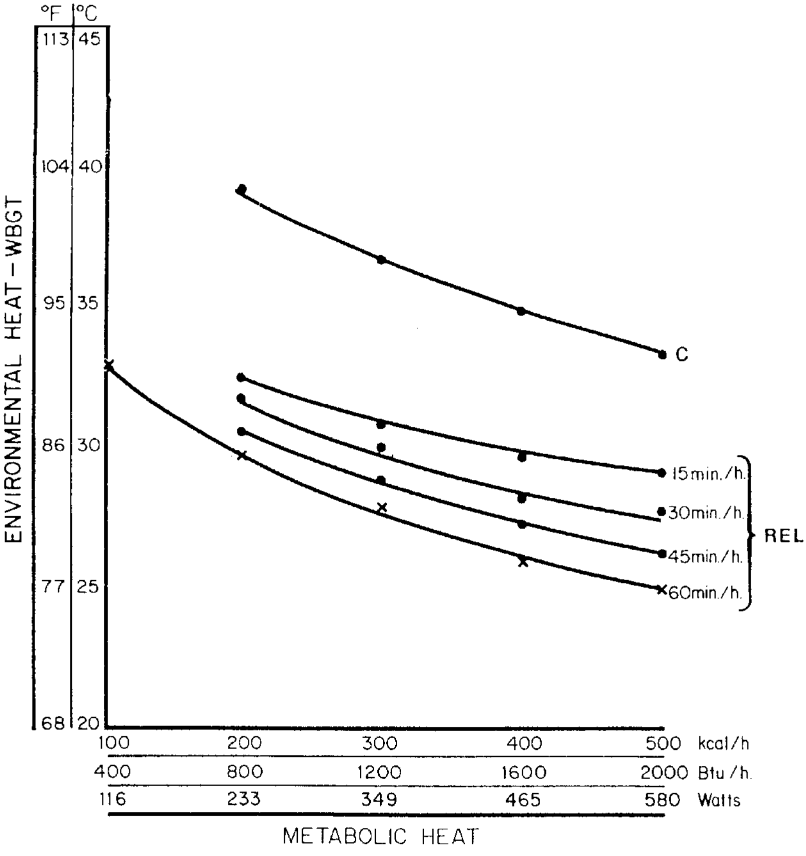

Figure 6.4. Recommended heat stress exposure limit for heat-acclimatized workers. C = ceiling limit; REL = Recommended Exposure Limit. Calculations are for a standard worker of 70 kg (154 lb) body weight and 1.8 m^2 (19.4 ft^2) body surface. Reproduced from National Institute for Occupational Safety and Health. Criteria for a recommended standard. Occupational exposure to hot environments. Revised criteria. DHHS (NIOSH) publication no. 86-113. Washington, DC: US Government Printing Office, 1986.

activate the autonomic nervous system, which in turn triggers changes in the circulatory, endocrine, and eccrine, or sweat gland, systems to rid the body of excess heat.

Heat stress places demands on many body systems. Proper functioning of the cardiac, pulmonary, renal, endocrine and autonomic nervous systems, the sweat glands, and the central nervous system thermoregulatory mechanism, are all necessary for toleration of heat exposure. The cardiovascular system plays a prominent role in heat dissipation. As internal body temperature rises, neuro-regulatory mechanisms increase cardiac output, through increases in stroke volume and heart rate, and dilate cutaneous blood vessels. Bloodflow is shunted from internal organs to the dilated blood vessels in the skin, where the heated blood can lose heat to the surroundings. To maintain blood pressure and bloodflow to exercising muscles and vital organs while blood is being shunted to the skin, adequate hydration is essential. The functioning of the sweat gland system is also essential in the dissipation of heat. Sweat evaporation is the body's primary method of heat loss. For each gram of water or sweat that evaporates from the skin, 0.58 kcal of heat is lost.[14] Under heat strain conditions, the sweat glands can be stimulated to produce up to 2 liters per hour (l/hour) in an acclimatized individual, and sweat rates of 1 l/hour would not be unusual in industrial workers.[2] Sweat rates this high cause significant losses of body water. Sweat also contains sodium, chloride and potassium and can account for measurable losses of these electrolytes from the body.[15]

After repeated exposures to heat, the human body gradually develops physiologic mechanisms that improve heat dissipation and tolerance. This adaptation to heat stress, or heat acclimatization, occurs over 5–14 days with daily exercise in hot ambient conditions and of sufficient duration and level of exertion to raise body temperature.[14] Once acclimatized, a worker exposed to the same levels of heat will have a lower core temperature, a lower heart rate, and an increased volume of sweat that contains a lower concentration of sodium. The reduced sweat sodium concentration is the result of aldosterone-mediated reabsorption of sodium and chloride ions in the sweat glands. With acclimatization, sweat rates can increase from 0.6 l/hour to 2 l/hour, and sodium chloride loss can decrease from 15–30 grams per day (g/day) to 3–5 g/day.[14] Overall, the sodium loss is reduced to <5 g/day after acclimatization. The average American diet provides 8–14 g of salt each day, which is adequate for the acclimatized worker. Before acclimatization, salt deficits may occur in heavily sweating workers.[2] However, except for increasing dietary salt during the period of acclimatization, salt supplementation is rarely required.

Generally, physically fit workers are better able to tolerate heat, and they achieve acclimatization more rapidly than non-physically fit workers. Physical training not only makes the muscles more efficient, so that they produce less heat per unit work, but also enhances the body's ability to sweat and dissipate heat. The adaptations of heat acclimatization are rapidly lost when the worker leaves the heat stress environment. Workers who return to hot environments after more than a few days away from the job—especially those who return after an illness—should be allowed to reacclimatize to the hot environment before resuming full-time work.

Heat exchange

Heat exchange between the body and the environment is influenced by air temperature and humidity, skin temperature, air velocity, evaporation of sweat, radiant temperature, and the clothing worn.[2] The heat balance equation incorporates the major modes of heat exchange or loss by the body (Table 6.5).

An additional mode of heat exchange, conductive heat exchange, where there is direct transfer of heat to air or objects in contact with the body, is rarely an important source of heat gain or loss in clothed workers in most occupational settings. Conductive heat exchange may be an important mode of heat transfer for workers, such as divers, working in hot or cold water. Since the human body requires evaporative and convective heat exchange to dissipate most excess internal heat, factors that diminish these modes of heat transfer will cause the body temperature to rise, resulting in hyperthermia. High ambient humidity and clothing are the primary factors in diminishing heat transfer for workers. Humidity decreases sweat evaporation, and

Table 6.5 Heat balance equation.

$$S = (M - W) + C + R - E$$

where:

S = amount of heat gained or lost by the body
$(M - W)$ = total metabolism − external work performed
C = convective heat exchange or heat transferred to or from the skin by the ambient air
R = heat gain from radiative heat exchange or heat transfer by electromagnetic radiation, such as heat from the sun or furnace, and heat lost by radiation from the body
E = evaporative heat loss as sweat evaporates from the surface of the skin

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clothing insulates the body and skin from the surrounding air, impedes convective heat loss and interferes with the evaporation of sweat from the skin. Protective clothing, especially sweat-impermeable clothing, which effectively eliminates any body cooling from sweat evaporation, places workers at significant risk for heat strain and heat-related illnesses.

Numerous acute and chronic medical conditions, medications and individual characteristics may diminish the body's ability to cope with heat stress and dissipate internal heat (Table 6.6). Dehydration from any cause, whether due to increased sweating or associated with underlying illness, fever, vomiting or diarrhea, increases the risk of hyperthermia. Many medications, especially anti-hypertensive or cardiac medications that affect the cardiovascular or renovascular systems or medications with anticholinergic effects on sweat glands, may alter a worker's physiologic responses to heat and therefore increase the risk of heat strain. Previous heat-related illness, especially heat stroke, has historically been considered an indicator of both heat intolerance and a possible underlying defect in the individual's thermoregulatory system. One investigation of 10 individuals with previous exertional heat stroke found that nine of them readily acclimatized to heat while one displayed evidence of persistent heat intolerance for almost 1 year following heat stroke. The investigators concluded that a small percentage of individuals with previous heat stroke may be heat-intolerant.[16]

Table 6.6 Risk factors predisposing to heat disorders.

Individual factors
Increased age
Obesity
Lack of acclimatization
Use of water-impermeable/heavy clothing
Fatigue/sleep deprivation
Underlying medical conditions/states
Dehydration
Infection/fever/recent immunization
Overuse of ethanol
Diseases
Cardiovascular disease
Renal disease
Hyperthyroidism
Diabetes mellitus
Parkinson's disease
Skin conditions limiting sweating, including sunburn
Previous heat disorder
Pesticide poisoning
Drugs
Medications with anticholinergic effects
Antispasmodics
Tricyclic antidepressants
Psychotropics
Antihistamines
Anti-hypertensive medications
Diuretics
Stimulants (decongestants, amphetamine, cocaine)

PATHOPHYSIOLOGY OF ILLNESS AND TREATMENT

The spectrum of heat-related disorders ranges from relatively harmless pruritus due to heat rash or miliaria to fatal heat stroke. In between these extremes are several other conditions caused by exposure to heat.

Heat-related skin conditions

Heat rash, or miliaria, is caused by sweat duct obstruction and resultant sweat retention within the sweat gland. Obstruction of the sweat duct leads to duct rupture within the skin and an inflammatory reaction surrounding the duct. Because the rupture of the sweat ducts may occur within different layers of the skin, three forms of miliaria—crystalline, rubra, and profunda—are described.[17]

Miliaria crystallina is a mild, asymptomatic skin condition consisting of small, clear vesicles resulting from sweat duct rupture within the surface layers of skin. Small erythematous macules resulting from sweat duct rupture within middle layers of the skin and associated with burning and itching is known as miliaria rubra, or "prickly heat". Miliaria rubra commonly affects the skin of the trunk and intertriginous areas of the body. Extensive cases of miliaria rubra involving large numbers of sweat glands can impede body heat dissipation and contribute to more severe heat-related illness. Miliaria profunda results from sweat duct rupture deep within the skin. The lesions, which usually appear only after prolonged periods of miliaria rubra, are small, white to flesh-colored papules and occur most commonly on the trunk. Sunburned skin and occlusive clothing that precludes the free evaporation of sweat increase the risk of all forms of miliaria. Treatment involves reducing sweating in the affected individual and keeping the skin cool and dry. In workers whose jobs require sweat-impermeable protective clothing, the treatment of miliaria may include a temporary transfer to a job not requiring protective clothing or into an air-conditioned workspace. Miliaria rubra usually resolves within a week. Complete resolution of miliaria profunda may take several weeks in a cool environment.

Heat edema

Heat edema is often not considered a true heat-related disorder. It is a rather common condition in which the extremities swell during the first 7–10 days of exposure to higher temperatures. Typically it is found in unacclimatized individuals, often women, who stand or sit for long periods during hot weather and is not associated with cardiac or renal impairment. The etiology of heat edema is uncertain, but it may involve local vasomotor changes or be associated with changes in aldosterone activity.[15] It is sometimes prominent in pregnancy, when heat can aggravate the underlying condition of pregnancy-associated edema. Heat edema usually resolves spontaneously within a few days as the individual acclimatizes. Diuretic therapy is thought not to provide significant relief and is not indicated. Symptomatic treatment—elevation of the legs, compression stockings, and gradual exposure to heat—is generally all that is required.

Heat cramps

Heat cramps are painful muscle spasms that occur during or following intense physical exercise in hot environments. The affected individual is usually acclimatized to heat and gives a history of heavy exertion in the heat, profuse sweating, drinking large quantities of water, and minimal salt or electrolyte replacement. Inadequate electrolyte replacement is probably associated with the underlying mechanism responsible for the muscle spasm.[15]

The muscles involved in the spasm are usually the same muscles used during the preceding exercise, such as the abdominal muscles or the large muscles of the thigh. Heat cramps may be heralded by fasciculations, and while multiple muscle spasms may occur simultaneously, usually only a small section of the muscle is involved. Individual heat-induced muscle spasms last less than a minute; but if untreated, attacks of intermittent heat cramps may last for 4–8 hours.[18]

Heat cramps respond to rest in a cool place and ingestion of 0.1% saline solution (1 teaspoon of salt in a quart of water) or fluids containing electrolytes.[19] Salt tablets should not be given. If nausea and vomiting preclude oral solutions, intravenous electrolyte solutions may be necessary. Heat cramps can be prevented by ensuring that workers, especially acclimatized workers, maintain adequate dietary salt intake in addition to adequate fluid replacement.

Heat syncope

Heat syncope occurs in individuals who stand for prolonged periods, who make sudden postural changes, or who exercise strenuously in the heat. The underlying mechanism of heat syncope is similar to that of orthostatic syncope. Because venous return to the heart is reduced by pooling of blood in dependent extremities or in dilated peripheral vessels, cardiac output is inadequate to maintain cerebral circulation and consciousness. Heat syncope is not associated with elevated body temperature, and the syncope victim may remember a typical prodrome of nausea, sweating and dimming of vision before loss of consciousness. Following syncope and falling to a recumbent position, consciousness returns rapidly. Heat syncope is generally a benign "faint". The primary health concern is the potential for falling and injury, especially for workers on roofs and scaffolding.

Following an episode of heat syncope, the worker should be allowed to recover in a cool area. To ensure that he or she has not been injured by the fall, a medical examination should be performed. The employer should make sure that the victim is hydrated and acclimatized before returning to a job that requires heavy exertion or standing in a hot environment.

Heat exhaustion

Heat exhaustion is a complex of symptoms of fatigue, nausea, headache and giddiness associated with findings of moist, clammy skin, rapid heart rate, low to normal recumbent blood pressures that may fall upon standing, and usually normal to slightly elevated rectal temperature (37.5–38.5°C or 99.5–101.3°F). Since the symptoms of heat exhaustion are similar to those of early heat stroke, all heat exhaustion victims must be evaluated to eliminate the diagnosis of heat stroke. Therefore, careful assessment of core or rectal temperature is essential, and the thermometer used must be capable of accurately recording temperatures above 40°C (104°F). Heat exhaustion occurs more commonly in workers who are unacclimatized to heat and who are without adequate water and salt replacement.[19] Although most types of heat exhaustion are of mixed etiology, two types of heat exhaustion—water-depletion heat exhaustion and salt-depletion heat exhaustion—are described. Water-depletion heat exhaustion occurs when water replacement is inadequate to compensate for the water lost in sweat. Dehydration is present and thirst may be a prominent symptom. Hypernatremia may be present and urine volume will be small. Salt-depletion heat exhaustion occurs when sweat fluid losses are replaced with water but salt intake is inadequate to replace sodium and chloride losses. Dehydration is usually not present and urine volume is normal.

Treatment of heat exhaustion must be individualized based upon the severity of the presenting symptoms and the underlying cause. Mild heat exhaustion may be treated by having the victim rest in a cool area and providing oral fluid and salt replacement. Severe cases of heat exhaustion—especially severe water-depletion type requiring intravenous fluids—need to be referred to an emergency room for careful replacement of body water. Timing of return to work after heat exhaustion has not been fully studied, but it seems prudent to allow at least 24–72 hours for full rehydration and correction of electrolyte abnormalities before the individual returns to work.

Heat Stroke

Heat stroke is a life-threatening medical condition. Symptoms include altered mental status and rectal temperatures >40°C (104°F) and often >42°C(107.6°F).[20] When the body's mechanisms to dissipate heat are overwhelmed by internal or external heat load, body temperature begins to rise. Continued increase in body temperature is associated with partial or complete collapse of the body's thermoregulatory mechanism, and heat stroke occurs.

Heat stroke is a medical emergency requiring immediate cooling of the affected individual. Classic heat stroke occurs during summer heat waves, predominantly in infants or elderly individuals. The condition is most common in poor, elderly individuals who take medications for underlying medical conditions and live in poorly ventilated housing.[21] After days of hot, humid environmental conditions, their ability to maintain body heat balance fails and heat stroke occurs. A second form of heat stroke, exertional heat stroke, occurs in workers, athletes or military recruits who perform vigorous exercise in hot, humid conditions. The symptoms and physical findings of both forms of heat stroke are similar, except that an exertional heat stroke victim may be able to sweat. Mental status changes are the predominant initial presenting symptom. Heat stroke victims may present with any form of mental status change, ranging from irrational behavior, poor judgment and confusion to delirium, seizures, and coma. The skin is usually flushed and hot. Sweating, characteristically absent in classic heat stroke, may be present in exertional heat stroke. The rectal temperature is >40°C (104°F) and may be much higher; the pulse is elevated; the blood pressure is normal or low; and hyperventilation is common. Nausea, vomiting and diarrhea may be present.

Initial laboratory findings often include proteinuria with red blood cells and granular casts also present in the urine, an elevated white blood cell count, and decreased platelet count. Serum electrolyte levels will vary with level of hydration, acid–base status, and underlying tissue damage. Serum enzymes—lactate dehydrogenase, creatinine phosphokinase, aspartate aminotransferase, and alanine aminotransferase—released from damaged muscle and liver cells are characteristically elevated. With hyperventilation, respiratory alkalosis may be present; but in exertional heat stroke, lactic acidosis may be the presenting acid–base abnormality. Abnormalities of blood clotting consistent with disseminated intravascular coagulation—including decreased fibrinogen, prolonged prothrombin time and partial thromboplastin time, and elevated levels of fibrin split products—may be present on initial evaluation.[15]

The treatment for all heat stroke victims is immediate initiation of cooling and appropriate resuscitation. The method of cooling used in military settings is immersion of the victim in ice water and massage of the skin of the extremities. Even though this type of cooling will cause cutaneous vasoconstriction and shivering, thereby decreasing conductive heat loss and increasing metabolic heat formation, it is still probably the most effective method of cooling outside of a healthcare facility.[22] Other rapid cooling methods used for heat stroke include packing the individual in ice or applying ice packs, and wrapping the victim in wet sheets or spraying with cold water and then vigorously fanning with cool, dry air. Specialized body-cooling units that use water spray to enhance evaporative heat loss are also effective in the treatment of heat stroke.[20] Once cooling has been initiated, the victim should be transferred immediately to a hospital for continuous monitoring of core temperature and definitive care. To decrease the possibly of over-cooling, cooling should be discontinued once the rectal temperature decreases to 39°C (102.2°F).[23] Endotracheal intubation and invasive cardiovascular monitoring are often needed during resuscitation and follow-up care.

The severity of sequelae and mortality in heat stroke is determined by the degree and duration of the elevated temperature. After initial resuscitation of an individual with heat stroke, failure or disruption of the function of multiple organ systems is common and should be expected. Frequent sequelae to heat stroke include liver function abnormalities, disseminated intravascular coagulation, rhabdomyolysis, and acute renal failure.[15] Other reported complications of heat stroke include pancreatitis, pulmonary edema, myocardial infarction, and central and peripheral nervous system damage.

MEDICAL SURVEILLANCE

Medical surveillance of heat-exposed workers is one aspect of the overall prevention of heat-related illness. Preplacement and periodic medical examinations of heat-exposed workers should ensure that they can meet the total demands and stresses of the hot job environment without putting their safety and health/or that of fellow workers in jeopardy.[2] The components of the preplacement and periodic medical examinations recommended by the NIOSH are provided in Table 6.7. There are no strict guidelines to identify which heat-exposed workers require medical surveillance. An initial medical history may be taken on all heat-exposed workers to identify those at risk for heat stress. The initial history should elicit information about underlying medical conditions, use of prescription and over-the-counter medications, and previous episodes of heat-related illness. Workers may not require regular medical surveillance if they (1) do not have medical conditions that increase their risk of heat injury, (2) are not exposed to heat above recommended guidelines, and (3) are properly trained in the prevention of heat-related illness. Special categories of workers likely to be exposed to extreme heat stress conditions, such as hazardous waste site workers who wear heavy protective clothing and respirators, should be screened carefully before placement and should receive periodic medical surveillance. One method for predicting heat tolerance has been tested in nuclear power workers.[24] Subjects pedal a bicycle ergometer against a fixed load (or bench-step at the same work rate) in a vapor barrier suit; then their heart rate is compared to a standard. Though this test is readily available, it has not found much use, possibly because of the time, equipment and supervision required to conduct the test.

HEAT EXPOSURE AND REPRODUCTION

Physiologic and hormonal changes during early pregnancy are associated with a slight increase in maternal resting core temperature; however, there is no evidence that the pregnant woman's ability to eliminate excess heat is diminished. In fact, physiologic adaptations during pregnancy—increase in blood volume, increase in cardiac output and resting pulse rate, and increase in cutaneous bloodflow—appear to offset the increased metabolic heat load associated with pregnancy.[25,26] In one study, physically fit, pregnant women appeared to maintain thermoregulation during exercise throughout their pregnancy at least as well as non-pregnant women.[27] During the late 3rd trimester of pregnancy, decreased venous return, due to the size of the uterus, may compromise cardiac output in the pregnant worker and impair heat tolerance.

In experimental animal studies on a variety of species, hyperthermia has been found to be teratogenic.[2] Early in the gestation, excessive heat exposure in animals is associated with structural defects, predominantly of the central nervous system and skeleton, and embryo death. Heat stress in animals later in gestation has been associated with retarded fetal growth and postnatal neurobehavioral defects. Studies of the effect of hyperthermia on the developing human fetus have been primarily concerned with the effect of illness-related fever during pregnancy. The results of these studies have

Table 6.7 NIOSH recommended medical surveillance for heat-exposed workers.

Preplacement medical evaluation		Periodic medical evaluation	
Component	Special emphasis on	Component	Special emphasis on
History		History	
Occupational	Previous heat exposure jobs Use of personal protective equipment	Occupational	Changes in job or personal protective equipment
Medical	Diseases of the following systems: cardiovascular, respiratory, endocrine, gastrointestinal, dermatologic, renal, neurologic, hematologic, reproductive	Medical	Change in health status Symptoms of heat strain
Personal habits	Alcohol and drug use	Personal habits	Update
Medications	Prescription and over the counter	Medications	Update
Characteristics	Height, weight gender, age	Characteristics	Update
Direct evaluation		Direct evaluation	
Physical examination	Cardiovascular, respiratory, nervous and musculoskeletal systems Skin	Physical examination	Systems emphasized in preplacement examination
Blood pressure		Blood pressure	
Clinical chemistry tests	Fasting blood glucose Blood urea Serum creatinine Serum electrolytes Hemoglobin Urinary sugar and protein	Clinical chemistry tests	Fasting blood glucose Blood urea Serum creatinine Serum electrolytes Hemoglobin Urinary sugar and protein
Mental status	Assessment of worker's ability to understand heat, communicate and respond to emergencies	Mental status	Reassessment of ability to understand heat
Detailed medical evaluation	Cardiovascular disease Pulmonary disease Medication use which might interfere with heat tolerance or acclimatization Hypertension Need to use respiratory protection History of skin disease that may impair sweating Obesity Women with childbearing potential	Detailed medical evaluation	Based upon changes in health

Table 6.8 Heat strain/heat-related illness prevention.[2]

Engineering controls
- Decrease convection heat gain by worker
- Cool air temperature to below mean skin temperature
- Increase air movement (if ambient temperature is below skin temperature)
- Decrease radiant heat gain by worker
- Insulate hot surfaces
- Use shielding between worker and heat source
- Increase evaporative heat loss by worker
- Eliminate humidity sources (steam leaks, standing water)
- Decrease air humidity (ambient water vapor pressure)

Administrative and work practices controls
- Limit workers' exposure to hot working environment
- Use appropriate environmental monitoring
- Work during cool parts of day or in the shade
- Schedule hot work for cool seasons
- Provide cool rest areas
- Increase the number of workers for a given job
- Use recommended work/rest regimens
- Decrease the metabolic heat load
- Mechanize heavy work when possible
- Rotate heavy work over entire workforce or increase workforce
- Decrease shift time; allow liberal work breaks; restrict overtime
- Enhance tolerance to heat
- Encourage physical fitness in workers
- Require minimum level of fitness in certain jobs
- Use heat acclimatization program for new workers or workers returning from vacations, layoffs, or illness
- Encourage regular fluid and salt replacement
- Health and safety training for supervisors and workers
- Recognize signs and symptoms of heat intolerance
- Emphasize acclimatization, fluid and salt replacement
- Avoid conditions increasing risk of heat strain
- Use control methods to prevent heat strain
- Use protective clothing
- Use buddy system, if applicable
- Medical screening of workers with heat intolerance
- Establish heat alert program
- Establish heat alert committee
- Reverse plant winterization measures
- Ensure water sources, fans and air conditioners are working
- Ensure that medical department is prepared to treat heat casualties
- Establish criteria for heat alerts
- Take all appropriate preventive measures during heat alerts
- Post signs identifying heat hazard areas

Protective clothing and auxiliary body cooling
- Water-cooled garments
- Air-cooled garments
- Ice-packet vests
- Wetted overgarments
- Aluminized overgarments

been inconsistent. Some investigators have reported an association between maternal fevers of 38.9°C (102°F) and abnormal fetal development, whereas others found no association between maternal hyperthermia and adverse pregnancy outcomes.[28] Heat exposure, in addition to its possible effects on female reproduction, is associated with decreases in sperm count and motility in male workers.[29] Considering the potential for reproductive effects due to heat in both females and males, preventive measures to limit excessive heat exposures are essential for all workers.

PREVENTION

The prevention of heat-related illnesses and conditions of unacceptable heat stress can be categorized into four basic areas of control: (1) engineering controls, (2) administrative controls, (3) work practices controls, and (4) protective clothing and devices.[2] Table 6.8 summarizes these prevention measures. Engineering controls, such as shielding and increased air movement, are the most desirable preventive measures. However, they are not effective in many outdoor work sites or work sites requiring full protective clothing. In these cases, administrative and work practices controls—such as reducing heat exposure, reducing work rates, enhancing fitness and heat tolerance, and offering special heat safety training—should be utilized to the fullest extent possible. Adequate fluid replacement in the heat-exposed worker is critical. The sensation of thirst has been proven to be inadequate to prevent hypohydration in heavily sweating individuals.[14] Therefore, workers need to be encouraged to drink adequate amounts of liquid to replace sweat losses. Any water or beverage provided for workers should be cool (10–15°C or 50–59°F), and it should be consumed in small volumes. The use of ice-cold water is not recommended. In the acclimatized worker, sweat rates of 1 l/hour are possible, and fluid replacement with approximately 5–7 oz every 15–20 minutes approximates fluid losses. Maximum gastric emptying in exercising individuals is 1–1.5 l/hour; therefore, larger volumes of fluid are not effective.[30] Overhydration and resultant hyponatremia, while rare, have been reported in marathon runners.[31] Numerous carbohydrate and electrolyte solutions are marketed for fluid replacement in athletes and workers. Studies have shown that the addition of carbohydrates and electrolytes to fluids may be beneficial for athletes who exercise strenuously for long periods.[30] For acclimatized workers whose diet includes sufficient calories and salt, water alone should provide adequate fluid replacement. Because of their diuretic effect, caffeinated beverages should be discouraged as a primary source of fluid replacement.

Personal protective equipment can be very effective in prolonging intervals of heat exposure. Ice-packet vests are the least cumbersome items to wear because they require no umbilical to provide cooling air or water. At work sites where radiant heat sources are the primary source of exposure, aluminized suits are a good choice.

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