14 Understanding the Impacts of Heat

Brenda Jacklitsch and W. Jon Williams

14.1 INTRODUCTION

Heat is often a major concern in response activities, due not only to environmental heat but also to the combined heat burden of metabolic heat from physical exertion during tasks and the clothing and personal protective equipment (PPE) that is worn, which can trap heat or increase physical exertion. In a study that surveyed 119 first responders (i.e., law enforcement, firefighting, explosive ordnance disposal [EOD], and hazardous materials [HAZMAT] technicians), 99% reported heat stress and heat-related illnesses (HRIs) (e.g., heat rash, heat cramps, heat exhaustion, and heat stroke) and injuries (e.g., incidents from sweaty palms or slipping on a sweat puddle on the floor, visual impairment from fogged-up safety glasses, and touching hot equipment that could result in burns) to be a risk to employee safety during occupational duties, and 47% reported having had at least one employee experience a HRI during operations in the previous year (Bach et al. 2018). For example, heat stress is an ongoing issue among responders in large-scale oil spills. The Deepwater Horizon oil spill response had 47,000 workers, including responders, at the height of the response and 978 documented heat stress incidents (Michaels and Howard 2012). During these large-scale emergencies, responders often find themselves in stressful situations where there is a great demand for tasks to be completed quickly. The tasks are physically strenuous, the shifts are long, and there is the need to wear PPE – all leading to a higher risk for HRIs and injuries (NIOSH 2016).

14.2 HEAT IMPACTS WITH OCCUPATIONAL SAFETY AND HEALTH IMPLICATIONS

14.2.1 Environmental Heat Impacts

Many workers spend their entire work shift in a variety of hot environments that may become hotter because of rising ambient temperatures, increases in extreme heat events, or shifting and expanding hot seasons (CDC 2008; Stocker 2014; Schulte et al. 2016; Dahl et al. 2019a, 2019b). Overall, occupational exposures to heat and humidity may be more hazardous than community exposures because workers generally have less control over the exposures in their response activities. Another health issue of growing concern related to rising temperatures is chronic kidney disease of

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unknown etiology (CKDu). CKDu first started to draw attention when it was discovered in sugar cane workers in Central and South America, with over 20,000 documented deaths noted by 2013 (Chicas et al. 2019; Pundee et al. 2020). CKDu has been most often associated with chronic or repeated dehydration and heat stress from physical work in a hot environment (Chapman et al. 2021; Chicas et al. 2019; Glaser et al. 2016; Pundee et al. 2020; Shih 2023), while most cases of traditional chronic kidney disease (CKD) are caused by hypertension and diabetes (NIH 2024). Cases of chronic kidney disease have also been seen increasingly in various work populations (e.g., other agricultural workers, construction workers, and miners) and are of increasing concern as more workers labor for longer periods in higher temperatures (Glaser et al. 2016; Shih 2023; Pundee et al. 2020; Pradhan et al. 2019).

With hotter temperatures, workers may be less likely to wear appropriate clothing and PPE, reducing the protective layers over their skin that shield them from ultraviolet (UV) radiation. Overexposure to UV radiation can result in skin cancer, eye damage, and even potential immune suppression (McCarty and Taylor 2002; Jaggernath et al. 2013; Barnes et al. 2019; Parker 2021).

Extreme weather (e.g., storms, floods, droughts, and wildfires) is a hazard to many workers and results in hazardous conditions for emergency responders during and after these events (Pinkerton et al. 2019; Vaisala 2022). Many of these worker and responder populations will experience physical fatigue from long work hours, such as during post-disaster rescue or cleanup phases, as well as resulting mental health issues (Dodgen et al. 2016; Wang et al. 2016; Daghagh Yazd et al. 2019; Howard et al. 2020; Metregiste et al. 2020). As many extreme weather events occur in warmer months, these responders will also be at increased risk for HRIs and injuries (de Almeida et al. 2012).

Temperature extremes, along with precipitation and moisture levels, can affect the seasonality and distribution of vector-borne diseases, including mosquito-borne and tick-borne diseases. Vector habitats are expanding, resulting in the wider spread of ticks and mosquitoes, which may transmit diseases like Lyme disease, West Nile, and Zika (Levi et al. 2018; Caminade et al. 2019; Fouque and Reeder 2019). Poisonous plants (e.g., poison ivy, poison oak, and poison sumac) and venomous snakes may spread through expanding habitats when temperatures become more conducive to sustaining the species' populations (Klimaszyk et al. 2014; Schulte et al. 2016; Schindler et al. 2018). Increases in certain fauna and flora species may also lead to increased usage of pesticides and herbicides, resulting in the potential for additional human chemical exposures, such as particulates being spread during fires and floods of areas that were chemically treated (Gatto et al. 2016).

14.2.2 Mental Health Impacts

Responders facing post-disaster rescue and cleanup efforts from extreme weather events, including high temperatures, may face mental health disorders, as they may be more likely to suffer from new or worsened post-traumatic stress disorder (PTSD) and depression (Lowe et al. 2016; Wang et al. 2016; Orui et al. 2018). For example, during the multiday 2021 Heat Dome that affected western Canada, there was a massive increase in 911 calls for ambulance, police, and fire services to respond to hundreds of community members succumbing to the heat (Tetzlaff et al. 2024). According to the study, these responders experienced stressful job demands, consisting of work overload (e.g., the surge in call volume, firefighters responding to medical emergencies), emotional demands (e.g., severe medical emergencies, sudden deaths, unresponsive patients, distraught family members), and physical demands (e.g., resuscitation while wearing PPE, HRIs, and injuries). The study also noted that work overload is a significant factor that contributes to worker burnout (Tetzlaff et al. 2024).

14.2.3 Occupational Health Equity Impacts

Occupational health equity is an issue, particularly as increasing temperatures disproportionately impact certain workers who are already at higher risk for injury, illness, and fatality (Levy and Patz 2015; US EPA 2021a). The outdoor environments where emergencies occur may include numerous hazards, and controlling for exposures and hazards is often challenging and not always feasible due to the nature of the work (Kjellström et al. 2019; Orlov et al. 2019; NOAA NCEI 2022). As emergency response and economic situations evolve, more migrant or immigrant worker populations are participating in disaster response cleanup efforts, which may offer better pay or other incentives. A combination of factors makes these workers more susceptible to heat and other hazards, such as a lack of knowledge and safety training, poverty, seasonality of the work, extreme work conditions, cultural differences, and language barriers (Flynn et al. 2014; O'Connor et al. 2014; Spector and Sheffield 2014; Levy and Patz 2015; Kiefer et al. 2016; Fan and Qian 2017; Ellis and Stam 2018; US EPA 2021a).

When compared to larger businesses, small businesses participating in responses, including those being contracted for cleanup efforts, often face a lack of resources for safety and health practices, greater time demands on managers, and fewer employees to engage in activities such as safety committees (Lentz and Wenzl 2006; Mendeloff 2006; Buckley et al. 2008; Sinclair and Cunningham 2014). As safety and health may require additional resources, they may not always take priority. Therefore, small businesses are often burdened with higher injury and fatality rates (De Kok 2005; Hasle and Limborg 2006; Lentz and Wenzl 2006; Donato et al. 2007; Parker et al. 2007; Delp et al. 2009; Sinclair and Cunningham 2014).

14.3 BASICS OF PHYSIOLOGY AND HEAT

14.3.1 How the Body Cools

Humans have the capacity to maintain a nearly constant core (internal) body temperature. A constant core body temperature is possible because of the ability to transfer body heat (produced by the metabolism of food) to the environment (Parsons 2003). In moderate environmental temperatures (i.e., below the average skin temperature of 82.4°F–91.4°F [28°C–33.8°C]), there is a temperature difference between the environment and skin. The laws of thermodynamics dictate that energy (heat) flows from a hotter region to a cooler region to achieve thermal equilibrium (Taylor et al. 2008). Therefore, body heat will flow from warm skin to the cooler environment. When core body temperature warms the blood, which is circulated to the skin, heat is transferred to the environment through *dry heat transfer*. Dry heat transfer occurs through three primary methods: (1) convection (movement of air across the skin, taking heat away from the body), (2) conduction (direct heat transfer from the skin to a colder surface), and (3) radiation (direct heat transfer from the body to cooler objects in the environment through infrared radiation). However, when the temperature of the objects in the environment is greater than skin temperature, heat flows from the objects in the environment to the body, increasing core body temperature. For example, firefighters are exposed to fires where the heat of the flames is transferred to the firefighter (cooler object) through radiation (electromagnetic radiation in the infrared spectrum) and the firefighter gains heat (Parsons 2003; NIOSH 2016).

14.3.2 What Happens When a Body Gets Too Hot

When core body temperature increases, the cardiovascular system responds by rerouting warm blood from the deep body tissues to the blood vessels in the skin. This warm blood heats up the skin, creating a larger temperature difference between the skin and the environment. This facilitates the transfer of body heat to the environment by dry heat mechanisms (i.e., convection, conduction, radiation) and helps the body maintain a stable core body temperature (McArdle et al. 2010; Williams 2013; NIOSH 2016; Williams 2018).

When in a hot environment or when engaging in physical exertion, the body activates the sweating mechanism. When the core body temperature increases above a certain level, water is transferred to the sweat glands and is excreted onto the skin as sweat, where it evaporates. When sweat evaporates, it can remove a significant amount of heat. Each liter (L) of sweat evaporated transfers 580 kilocalories of heat from the body to the environment. A problem with this mechanism arises when the relative humidity increases and the atmosphere can no longer accept any additional moisture. In hot and humid environments, sweat does not evaporate; it remains on the skin and does not contribute to the transfer of heat to the environment. The addition of heat to the core body temperature due to increased metabolism from physical exertion adds to the heat contribution from the environment and increases the risk of an HRI or injury (Taylor et al. 2008).

14.3.3 Heat-Related Illnesses and Injuries

Heat-related illnesses and injuries lie on a continuum ranging from mild to severe (including death). If proper intervention is initiated immediately, HRIs are treatable, and those with mild to moderate HRIs generally recover completely. However, as the severity of an HRI increases, the affected individual may progress from heat exhaustion to heat stroke in a matter of minutes (Leon and Bouchama 2011; NIOSH 2016; Kenny et al. 2018). It is therefore vitally important to identify and treat HRIs rapidly (Leon and Bouchama 2011; NIOSH 2016). Heat tolerance is widely variable and depends to a large degree on an individual's prior acclimatization, physical fitness, hydration status, cardiovascular function, prescription/recreational drug use (including diuretics, alcohol, amphetamines, others), history of heat illness, and age (Taylor, Kondo, and Kenney 2008; NIOSH 2016). The following sections describe the various types of HRI and injuries, from mild to severe.

14.3.3.1 Heat Rash

Heat rash (miliaria rubra or prickly heat) appears as red papules in areas where clothing is restrictive and where the skin is continuously wet due to unevaporated sweat. This condition is caused by the reabsorption of sweat by keratinous layers of the skin, which results in regional swelling. The regional swelling causes an obstruction of the sweat ducts, which, if untreated, may develop staphylococcal infections (NIOSH 2016; Danzig et al. 2024). Miliaria crystallina, a similar skin disorder, generally occurs during the onset of sweating in areas of damaged skin (e.g., sunburn) when the damage prevents the release of sweat. Sweat becomes trapped in clear skin bumps, which resolve when sweating stops (NIOSH 2016; Palaniappan et al. 2023). Finally, a third type of heat rash known as miliaria profunda occurs when sweat ducts are blocked below the surface of the skin, usually following damage to the skin (e.g., sunburn). However, cases of miliaria profunda have been reported in the absence of any obvious injury to the skin. In contrast to miliaria rubra (prickly heat), miliaria profunda manifests as discrete pale skin bumps like gooseflesh (NIOSH 2016; Danzig, Raunig, and Acholonu 2024).

In nearly all cases, heat rashes resolve with a return to a cooler environment and with the cessation of sweating. When exposure to heat is limited and the skin is allowed to dry, the incidence of recurrence of heat rashes diminishes. Heat rashes are not by themselves dangerous but can result in a reduction of sweating and a decrease in evaporative heat loss. Generally, the skin recovers from heat rashes within a few weeks (NIOSH 2016; Danzig, Raunig, and Acholonu 2024).

14.3.3.2 Heat Cramps

Heat cramps may be associated with a continued loss of salt in sweat, accompanied by a copious intake of water without appropriate replacement of salt (NIOSH 2016). Low salt levels in the muscles can cause these painful cramps, which often occur in the abdomen, arms, or legs. If someone is experiencing heat cramps, they need to rest in a cool area, drink water, and eat some salty snacks or drink a sports drink. A worker with heat cramps will need to wait a few hours before returning to heavy work. If they have heart problems, are on a low-sodium diet, or if cramps do not subside within one hour, then additional medical care may be necessary. Salt tablets should not be taken since they are generally not necessary and can have some unexpected effects (NIOSH 2016). Each salt tablet contains about 400 mg of sodium and, if taken without water, can result in stomach irritation. Moreover, salt tablets are poorly absorbed in the stomach, but once they are absorbed they can result in significant strain on the kidneys. The kidneys will register that the body has absorbed too much salt and will excrete the excess salt in the urine while also excreting a significant amount of fluid in the process. Therefore, consumption of salt tablets may actually result in dehydration rather than increased hydration (Coyle 2004). The average diet in the United States contains more sodium than the minimum daily requirement, and sodium lost from sweating will often be replaced from dietary sources (Montain and Cheuvront 2008).

14.3.3.3 Heat Exhaustion

Heat exhaustion is the result of excessive exposure to heat coupled with reduced fluid intake (Kenny et al. 2018; Périard et al. 2021). Without adequate fluid intake, especially during increased sweating, a reduction in blood plasma volume occurs, which results in cardiovascular strain (Taylor et al. 2008; NIOSH 2016). The reduction in plasma volume may be worsened by the vomiting that is often observed in those suffering from heat exhaustion (Leon 2007; Leon and Bouchama 2011). This leads to an inability to sustain cardiac output (the amount of blood pumped by the heart per minute). Heat-related cardiovascular strain results in an increased heart rate (greater than expected due to physical activity alone) to maintain cardiac output in the presence of a decreased stroke volume (the amount of blood pumped by the heart per beat) (Lucas et al. 2018).

A reduction in cardiac output decreases the oxygen supply to cells and organ systems, compromises muscular function, and reduces the flow of blood to the skin for heat transfer (Kenny et al. 2018). Frequently, the inability of the cardiovascular system to compensate for excessive heat leads to a drop in blood pressure (due to a decrease in peripheral vascular resistance), resulting in symptoms such as lightheadedness, dizziness, or fainting (Kenny et al. 2018). If the person experiencing early levels of heat exhaustion is removed from the source of heat to rest and consume water, they will recover completely with adequate care if they continue to rest and drink water (Gauer and Meyers 2019). However, it is important to note that heat exhaustion may progress rapidly to heat stroke unless rapid cooling is applied immediately (Leon 2007; Leon and Bouchama 2011).

14.3.3.4 Heat Stroke

Heat stroke is the most severe form of HRI and is a life-threatening emergency. There are two types of heat stroke: (1) “classical” heat stroke and (2) “exertional” heat stroke.

Classical heat stroke generally occurs most frequently in the elderly or in young children and is not generally associated with physical activity (Leon and Bouchama 2011). The incidence of classical heat stroke is usually associated with exposure to prolonged environmental heat (e.g., heat waves). *Exertional heat stroke* occurs in the young, fit population engaging in physical activity, often during periods of moderate to high environmental heat (Leon and Bouchama 2011).

In general, heat stroke is diagnosed as a core body temperature of ≥104°F (40°C) in combination with symptoms of neurological dysfunction, such as exhibited by delirium (e.g., acute, reversible state of disorientation and confusion), coma, and seizures (Leon and Bouchama 2011). Importantly, regardless of the type of heat stroke (classical or exertional), the presence of neurological symptoms (e.g., confusion, dizziness, headache, syncope, seizures) is critical to the diagnosis of heat stroke.

The physiological injuries resulting from heat stroke often progress to organ system damage and often multi-organ failure, leading to death. Long-term disability from heat stroke is well documented (Leon and Bouchama 2011). Although the use of rapid cooling may restore normal core body temperature, approximately 30% of the victims of heat stroke experience poorly controlled core temperature, alterations in the level of consciousness, disseminated intravascular coagulation (DIC), acute respiratory distress syndrome (ARDS), organ system dysfunction often leading to multi-organ failure and inflammatory effects (Leon and Bouchama 2011). Although the victim survives the acute phase of heat stroke, they may suffer multi-organ system damage (e.g., liver, kidney, muscle dysfunction), neurological damage, reduced exercise capacity, heat intolerance that may last for months to years, and death may ensue at a later date due to these ongoing issues (Leon 2007; Leon and Bouchama 2011; DeGroot et al. 2022).

14.3.3.5 First Aid

It is important to learn the symptoms of heat-related illnesses and the associated first aid. First aid is important even when help (e.g., emergency medical services) is on the way, as cooling the victim quickly may prevent long-term health effects and death. Additional information is provided in Table 14.1 (adapted from NIOSH 2016).

14.3.3.6 Heat-Related Injuries

Along with HRIs, heat can also cause physical injuries such as incidents from sweaty palms or slipping on a sweat puddle on the floor, visual impairment from fogged-up safety glasses may be a concern, and touching hot equipment, which could result in burns (NIOSH 2016). Dizziness and other symptoms may also cause workers to neglect or forget safety protocols, resulting in potential traumatic injuries to themselves or others, such as experiencing falls from elevations or mishandling heavy equipment (Spector et al. 2019). In conditions of extreme heat, workers may also be more likely to loosen or remove PPE, which may lead to additional hazardous exposures.

14.4 RISK FACTORS FOR HEAT-RELATED ILLNESS

14.4.1 Environmental versus Individual Factors

Many factors can increase the risk of HRI, including environmental and individual factors. Environmental factors may include direct sun exposure, high temperatures, humidity, lack of breeze or ventilation, and radiant heat sources (e.g., equipment generating heat) (NIOSH 2016). Individual factors may include the level of acclimatization, clothing and PPE, level of physical exertion, level of hydration, physical condition, medications, advanced age, pregnancy, and having experienced a previous HRI (NIOSH 2016).

TABLE 14.1
Heat-Related Illnesses and First Aid

Type of Heat-Related Illness	First Aid
Heat Rash *Symptoms:* • Clusters of red bumps on the skin, often appearing on the neck, upper chest, groin, under the breasts, and in elbow creases	• Try to work in a cooler, less humid environment when possible. • Keep the affected area dry. • Powder may be applied to increase comfort. • Do not use ointment or creams.
Heat Cramps *Symptoms:* • Muscle pain or spasms, usually in the abdomen, arms, or legs	• Rest in a shady, cool area. • Drink water and have snacks and/or sports drinks every 15–20 minutes. • Do not use salt tablets. • Wait a few hours before returning to heavy work. • Seek medical care if the worker has heart problems, is on a low-sodium diet, or if cramps do not subside within one hour.
Heat Exhaustion *Symptoms:* • Headache • Dizziness • Heavy sweating • Nausea • Weakness • Elevated temperature • Irritability • Thirst • Decreased urine output	• Stay with the worker until help arrives. • Move to a cool area and give liquids. • Encourage frequent sips of liquids. • Remove unnecessary clothing. • Cool body with cold compresses or wash their head, face, and neck with cold water. • If the condition continues to worsen despite hydration and cooling efforts, take to an emergency room for medical evaluation or call 911!
Heat Stroke *Symptoms:* • Confusion, altered mental status, slurred speech • Loss of consciousness • Red, hot, dry skin or profuse sweating • Seizures • Very high body temperature	• MEDICAL EMERGENCY: Call 911! • Stay the with worker until help arrives. • Remove outer clothing. • Cool quickly with a cold water or ice bath; wet the skin, or soak clothing in cool water. • Place cold, wet cloths or ice on the head, neck, armpits, and groin. • Fan air around the worker.

14.4.2 Acclimatization

Workers lacking recent exposure to heat in the work environment are considered unacclimatized. Unacclimatized workers readily show signs of heat stress and have trouble replacing all the water lost in sweat (NIOSH 2016). Published studies have shown that unacclimatized workers are at a significantly higher risk of HRI, including dying from heat stroke in the first week on a new job (Day and Grimshaw 2005;

Jackson and Rosenberg 2010; Arbury et al. 2014; Spector et al. 2014; Park et al. 2017; Tustin et al. 2018; Heinzerling et al. 2020).

When a person is acclimatized to a hot environment, their body is better prepared for the heat, and the resulting adaptations make it less likely they will experience an HRI. The physiological adaptations that occur include increased sweating efficiency (which includes earlier onset of sweating, greater sweat production, and reduced electrolyte loss in sweat), stabilization of circulation, and the ability to perform work with a lower core body temperature and heart rate (NIOSH 2016). An acclimatized worker will also experience increased skin blood flow at a given core temperature, providing additional relief as heat is released back into the environment. For proper acclimatization, a worker needs to gradually be exposed to hot conditions over 7–14 days (NIOSH 2016). While both new and returning workers (i.e., those that have been away for a week or more) will need time to acclimatize, a new worker will likely need more time to acclimatize than a worker who was away (e.g., brief illness, time off).

14.4.3 Clothing and PPE

The use of PPE occupationally represents the last line of defense against external hazards (e.g., chemical, biological, and particulate exposures). In other words, PPE is used only after other control options (substitution of hazard for non-hazard, administrative controls, or engineering controls) are deemed impractical or ineffective given the occupational setting.

While PPE is crucial for protection against external hazards (e.g., chemical, biological, and particulate exposures), its use may present another set of hazards to the wearer (McLellan et al. 2013; Williams 2013). This is particularly true when the responder is wearing completely, or nearly completely, encapsulating PPE (e.g., firefighter turnout clothing, HAZMAT gear) that is potentially able to trap body heat (Havenith 1999; McLellan et al. 2013; Williams 2013). In addition, the PPE may encumber the wearer such that body motion is limited and additional physical exertion is required to move while wearing the PPE (McLellan et al. 2013).

The degree to which PPE (or clothing) traps body heat depends on the design of the PPE, which is dependent upon the nature of the hazards to which the worker will be exposed. For example, firefighter turnout ensembles are constructed of multiple layers (including the outer shell, the moisture barrier, and the insulating thermal liner) and may have various degrees of water vapor and air permeability that contribute to the heat stress imposed by the garment (Morel et al. 2014). In addition, the multiple layers add to the weight of the garment, which results in greater effort required by the wearer. This effort is accompanied by an increased metabolic rate (heat generation) that contributes to the thermal stress imposed on the wearer (McLellan et al. 2013). Unlike firefighter turnout gear with its limited moisture and air permeability, HAZMAT gear has essentially zero permeability because it is designed to completely isolate the wearer from a hazardous external environment (McLellan et al.

2013, Williams 2013). Because of this impermeability, heat cannot be transferred to the environment through any of the body's mechanisms (e.g., sweat evaporation).

14.4.4 Physical Exertion

The level of physical exertion is also a risk factor. Even when at rest, muscles produce about 20%–25% of the body's total heat (Rowell 1993). Heat produced by muscles during physical exertion will be much higher. For those experiencing high levels of physical exertion, metabolic heat will continue to increase, contributing to overall heat stress.

14.4.5 Level of Hydration

The hydration status of the worker is a balance between fluid intake and loss. During exposure to hot environments and during exercise, sweating can easily increase to 1.5–2.0 L per hour. This can result in a significant loss of body water that causes a reduction in blood volume. This contraction reduces the ability of the cardiovascular system to provide blood to the skin for heat transfer and oxygenated blood to vital organs and muscles (Taylor et al., 2008). The sweating response is normally initiated when the core body temperature increases 0.36°F–0.9°F (0.2°C–0.5°C) above the mean body temperature (98.6°F [~37°C]) (Taylor et al. 2008). If the exercise level increases, sweating will increase proportionately.

A well-acclimatized person may produce 0.3–3 L per hour or more of sweat during hard work in a hot environment (Leon and Bouchama 2011; Périard et al. 2021). Therefore, it is imperative that the supply of fluid lost to sweating be replaced by drinking the right fluids (water in the short term and balanced electrolyte/carbohydrate fluids in the longer term) (ACSM 2018; Périard et al. 2021). A guideline for rehydration involves measuring changes in body weight. Every 0.45 kg (15 fluid oz) decrease in body weight represents 450 mL of body water lost to sweating, which must be replaced with the ingestion of the same amount of fluid. A rehydration strategy during exposure to heat and physical exertion will allow for the appropriate replenishment of body water, which will allow for the continuation of the sweating response that is crucial to thermoregulation (e.g., one cup of water every 15–20 minutes or sports drinks with balanced electrolytes when sweating for several hours) (NIOSH 2016).

In addition, sweat contains some sodium, and profuse sweating over a couple of hours may result in significant sodium loss (Sawka and Montain 2000; ACSM 2018; Périard et al. 2021). Low sodium in blood plasma results in the rapid movement of fluid into the brain, leading to the development of symptoms ranging from mild (headache, confusion, malaise, nausea) to severe (seizures, coma, pulmonary edema, cardiac arrest, and death) (McArdle et al. 2010).

Generally, a person can lose approximately 2.7 kg (2.7 liters or 91.3 fluid oz) of body weight in sweat and replenish the lost electrolytes with a small amount of salt in food (Sawka and Montain 2000; ACSM 2018). A loss of 2.7 kg of body weight is equivalent to a loss of 2.7 L of sweat. This amount of sweat could be lost by an acclimatized person in an hour of intense physical exertion (although this amount may be affected by individual body weight). However, producing a greater volume of sweat over more than two hours could result in a significant loss of sodium, which could lead to hyponatremia (Sawka and Montain 2000; ACSM 2018; Périard et al. 2021). The hyponatremia would be worsened with the continued consumption of plain drinking water during this time due to the further dilution of sodium in the blood plasma. Hyponatremia may be avoided by increasing dietary sodium intake after bouts of sweating and/or the use of balanced electrolyte/carbohydrate-containing "sports" drinks during bouts of intense sweating over a period of hours (Sawka and Montain 2000; ACSM 2018; Périard et al. 2021). Given that the daily average sodium intake in the US diet is 2-4 grams (National Research Council 1989), simply eating a normal meal contains enough sodium to adequately replenish the sodium lost during sweating.

14.4.6 Physical Condition and Health Problems

A person's physical condition may influence susceptibility or resistance to heat stress. Acute illness (vomiting, diarrhea) may cause sufficient loss of body water to leave the person significantly dehydrated. The discomfort of these illnesses may cause the victim to be disinclined to rehydrate immediately, thus leaving them more vulnerable to heat illness.

Another physical condition to consider is the responder's degree of physical fitness, as frequent physical exercise provides at least partial acclimatization to heat exposure. Physical exercise results in elevated metabolic heat production from muscle activity. This metabolically produced heat must be exchanged with the environment using the physiological mechanisms discussed previously. Regular exercise induces several physiological adaptations to transfer heat more efficiently from the body to the environment. This may involve increased sweat production, induction of sweating at a lower body temperature, increased blood flow to the skin for heat exchange, reduction of blood flow to the viscera, and conservation of body electrolytes to prevent sodium depletion. All of these adaptations (acclimatization) help increase heat transfer to the environment to prevent an increase in body core temperature and reduce the possibility of HRI or injury. Conversely, a physically unfit person will be more vulnerable to HRI because these physiological adaptations to increased metabolic heat production have not been induced (Parsons 2003; McArdle et al. 2010; NIOSH 2016).

A responder's physical condition may also affect their risk for an HRI. For an overweight or obese worker, carrying extra body weight requires greater physical exertion to perform a given task (Kenny et al. 2010). The body's surface-to-body-weight ratio is also less favorable for heat dissipation, and the increased fat layers provide insulation and slow heat loss (NIOSH 2016). There may be other conditions associated with obesity that affect risk, such as lower physical fitness, decreased maximum work capacity, and decreased cardiovascular capacity.

Other health conditions that may increase the risk for an HRI include cardiovascular disease, diabetes, or any diseases in which gastrointestinal permeability is compromised (NIOSH 2016). Even seemingly more minor health concerns, like experiencing a common cold, febrile illness, and sleep deprivation or fatigue, may increase risk (Westwood et al. 2021).

14.4.7 Medications

Medications can contribute to heat sensitivity in many ways, such as reduced thirst sensation, interference with central thermoregulation, impaired sweating, hypotension, reduced cardiac output, reduced kidney blood flow, reduced blood vessel dilation, drug toxicity from reduced clearance of medications, and electrolyte imbalance (CDC 2024). In addition, heat exposure may damage medication delivery devices and may degrade medications. For example, inhalers can burst in hot environments, and EpiPens may malfunction or deliver less epinephrine when exposed to heat. Insulin may become less effective if left in the heat instead of being stored in a refrigerator.

This list of medications in Table 14.2 (adapted from CDC 2024), which increase the vulnerability to heat, is intended to augment other existing documents that describe the physical, physiological, and general health aspects of heat stress and response to heat stress. The medications in Table 14.2 are largely prescribed for the appropriate treatment of medical conditions. Workers can consult their healthcare providers to have a medication plan in place with consideration for working in the heat and to avoid abruptly stopping any medications.

14.4.8 Advanced Age (Workers 65 Years and Older)

Older workers (within this heat stress context, older workers are defined as those ≥65 years of age) have increased vulnerabilities to HRIs and injuries not generally associated with physical exertion (Leon and Bouchama 2011). The incidence of heat injury in this group usually is associated with exposure to prolonged environmental heat (most notably during severe heat waves). The increased vulnerability that older workers have to heat is associated with a greater incidence of cardiovascular disease (Leon and Bouchama 2011); a reduced sweat gland response; decreased skin blood flow; use of medications (e.g., diuretics, β-blockers, calcium channel blockers, laxatives) which reduce tolerance to heat and may compromise a number of the physiological mechanisms needed for heat transfer from the body to the environment; chronic illness; and a sedentary lifestyle (Leon and Bouchama 2011; NIOSH 2016).

14.4.9 Pregnancy

Pregnant people may also be at higher risk when working in the heat because as the pregnancy progresses, heat tolerance decreases (NIOSH 2016; Rekha et al. 2024).

TABLE 14.2
Medications That May Increase Risk of Heat-related Illness

Medication Type	Drug Class	Examples	Mechanisms
Cardiovascular medications (Antihypertensives)	• Diuretics	• Furosemide • Hydrochlorothiazide • Acetazolamide	• Electrolyte imbalance • Volume depletion, dehydration, and increased risk of fainting and falls • Reduced thirst sensation
	• β-blockers	• Atenolol • Metoprolol • Propranolol	• Reduced superficial vasodilation • Decreased sweating • Reduced blood pressure, increased risk of fainting and falls
	• Calcium channel blocker	• Amlodipine • Felodipine • Nifedipine	• Decreased blood pressure, increased risk of fainting and falls • Electrolyte imbalance
	• Angiotensin Converting Enzyme Inhibitor (ACEi) • Angiotensin II Receptor blockers (ARBs)	• ACEi: Enalapril, Lisinopril, Ramipril	• Decreased blood pressure, increased risk of fainting and falls • Reduced thirst sensation
	• Angiotensin Receptor-Neprilysin Inhibitors (ARNIs), combination drugs including ARB	• ARB: Valsartan, Losartan • Sacubitril/Valsartan	• Decreased blood pressure, increased risk of fainting and falls • Reduced thirst sensation
Cardiovascular medications (Anti-platelet medications)		• Clopidogrel • Aspirin	• Reduced superficial vasodilation

(*Continued*)

TABLE 14.2 (CONTINUED)
Medications That May Increase Risk of Heat-related Illness

Medication Type	Drug Class	Examples	Mechanisms
Cardiovascular medications (Antianginals)	• Nitrates	• Glyceryl Trinitrate • Isosorbide mononitrate	• Worsened hypotension
Psychiatric medications	• Mood stabilizer	• Lithium	• Diabetes insipidus-induced water loss and risk for fainting, falls • Electrolyte imbalance • Risk for toxicity in setting of dehydration because of narrow therapeutic index
	• Antipsychotics	• Haloperidol • Olanzapine • Quetiapine • Risperidone	• Impaired sweating • Impaired temperature
	• Selective Serotonin Reuptake Inhibitors (SSRI) • Serotonin and Norepinephrine Reuptake Inhibitors (SNRI) • Tricyclic antidepressants (TCAs)	• SSRI: Fluoxetine, Sertraline • SNRI: Duloxatine, Venlafaxine • Amitriptyline • Clomipramine	• Increased sweating • Decreased sweating
Antiseizure medications		• Topiramate • Oxcarbazepine • Carbamazepine	• Decreased sweating • Increased sweating • Increased urination • Dizziness and weakness, especially after an increased dose
Antihistamines with anticholinergic properties		• Promethazine • Doxylamine • Diphenhydramine	• Decreased sweating • Impaired thermoregulation

(Continued)

TABLE 14.2 (CONTINUED)
Medications That May Increase Risk of Heat-related Illness

Medication Type	Drug Class	Examples	Mechanisms
Analgesics	• Nonsteroidal anti-inflammatory drugs (NSAIDs) • Aspirin • Acetaminophen	• Ibuprofen • Naproxen	• Kidney injury with dehydration • Increased heat production with overdose • Kidney injury with dehydration • Heat-related liver injury, increased risk for acetaminophen hepatoxicity
Antibiotics	• Sulfonamides	• Sulfamethoxazole/ trimethoprim	• Kidney injury risk with dehydration
Antiretrovirals	• Protease inhibitors	• Indinavir	• Kidney injury risk with dehydration
Thyroid replacement		• Levothyroxine	• Excessive sweating
Stimulants		• Cocaine	• Reduced sweating • Reduced dilation of skin blood vessels • Impaired heat perception
		• Amphetamine • Methylphenidate	• Increased body temperature
Hallucinogens		• Methylenedioxy-methamphetamine (MDMA) (and alternatives)	• Reduced sweating • Reduced skin blood vessel dilation • Impaired heat perception
Alcohol			• Increased sweating • Increased urination • Impaired heat perception

Those who are pregnant will also need to take additional time to cool down and rehydrate more often. Normally, a pregnant person's circulation helps protect the fetus. In very hot work environments, however, a pregnant person's core body temperature may rise, and in some cases, this has been linked to birth defects and other reproductive problems (Ravanelli et al. 2019; Syed et al. 2022).

14.4.10 Previous Heat-Related Illness

Responders who have experienced a previous HRI are more likely to experience one again as they may be less tolerant to the heat (Armstrong et al. 1990; Day and Grimshaw 2005). For responders returning to hot activities after an HRI, additional precautions are needed, such as time to acclimatize and adjusting their schedule to reduce time in the heat or physical exertion. These responders may also need additional monitoring throughout the shift to ensure they are not showing symptoms of an HRI.

14.5 HEAT STRESS AND TOXICOLOGY

Exposure to heat can affect how chemicals are absorbed into the body. Previously published animal studies have shown that exposure to heat exacerbates chemical absorption and toxicity (Leon 2008). Changes to the body's core temperature can alter the absorption, distribution, metabolism, and excretion of toxicants (Leon 2008). Additionally, increases in respiration can lead to further toxicant exposure through inhalation, whereas increases in sweat and skin blood flow can lead to more efficient transcutaneous absorption of some toxicants (Gordon 2003; Leon 2008).

Studies have suggested that heat stress, with or without physical exertion, will activate skin blood flow, sweating, and respiration, which may then accelerate chemical absorption (Gordon and Leon 2005). The hazard associated with some pesticides or other chemicals increases with increased temperatures. High temperatures accelerate the dispersion of the chemicals and increase the density of airborne particles. Additionally, some workers may remove or loosen their PPE due to discomfort in the heat, and this may increase their exposure to these hazards (Gordon 2003).

Most of what is known about toxicants is derived from animal studies in which the animals were often kept in comfortable temperatures. Therefore, a better understanding of the mechanisms involved between heat exposure and toxicants in humans is needed (Gordon 2003; Gordon and Leon 2005; Leon 2008).

14.6 TRAINING AND EDUCATIONAL NEEDS

Worksite training programs should be implemented for all responders and supervisors when there is a likelihood of HRI (NIOSH 2016). Training should include heat hazards, risk factors, symptoms, and first aid. Heat stroke is an important topic to discuss because the characteristics of the individual, type of activity, and symptoms vary between the classic and exertional classifications, and the end result, if not treated emergently, is often death (DOD 2003; NIOSH 2016). Medications, alcohol, and caffeine that may reduce heat tolerance and increase risk should also be presented in training (NIOSH 2016). Refresher training may also be warranted, especially regarding symptoms, as some of the common public health messaging focuses on classic heat stroke, and those working in the heat are at higher risk for exertional heat stroke (DOD 2003, Armstrong et al. 2007; Navy Environmental Health Center 2007). In addition, there may need to be discussions about cultural attitudes toward heat stress. For example, some individuals might incorrectly believe that they can be "hardened" against the requirement for fluids by deliberately and regularly becoming dehydrated before work. This type of misinformation can be addressed (NIOSH 2016; Schwarz et al. 2016).

14.6.1 Controlling Heat Stress

Finally, considerations for how to reduce heat stress by implementing the hierarchy of controls, including engineering controls or work practice controls, can be shared, particularly during supervisor training.

These considerations should be written in a heat management plan and might include those that aim to increase air cooling, provide heat barriers, limit time in the heat or increase recovery time in a cool area, reduce the metabolic demands, institute a heat acclimatization plan, implement a buddy system and/or heat alert program, provide and encourage hydration breaks, and, in certain situations, require workers to conduct self-monitoring (NIOSH 2016). Also, as many responders find themselves experiencing significant heat strain from the environment, tasks, and PPE worn, consider implementing auxiliary cooling systems (e.g., water-cooled garments, air-cooled garments, cooling vests, and wetted overgarments) (NIOSH 2020). Auxiliary cooling may be used before (pre-cooling), during (concurrent cooling), or between operations (recovery cooling during breaks or after shift completion). Additional considerations include barriers to the use of auxiliary cooling, such as availability, cost, logistics, and knowledge (Bach et al. 2018).

14.6.2 Delivering Training and Education

Consider the most effective mechanisms for delivering heat stress education and training with the responder audience in mind. A heat-related training needs assessment on oil spill cleanup responders found that the most common training delivery methods and education received included just-in-time training and printed materials (Jacklitsch et al. 2018). However, this study also reported that the most desirable future training delivery methods and education products were smartphone or tablet applications, printed materials, and online training. Taking time to seek out various options may help identify the best tools available that will resonate with responders and provide accurate and timely information.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

REFERENCES

ACSM. 2018. "Environmental considerations for exercise prescription." In *IACSM's Guidelines for Exercise Testing and Prescription*, 10th ed., edited by D. Riebe, J. E. Ehrman, G. Liguori, and M. Magal, 217–9. Philadelphia, PA: Wolters Kluwer.

Arbury, S., B. Jacklitsch, O. Farquah, M. Hodgson, G. Lamson, H. Martin, and A. Profitt. 2014. "Heat illness and death among workers—United States, 2012–2013." *Morbidity and Mortality Weekly Report* 63, no. 31: 661–5.

Armstrong, L. E., D. J. Casa, M. Millard-Stafford, D. S. Moran, S. W. Pyne, and W. O. Roberts. 2007. "American College of Sports Medicine Position Stand. Exertional heat illness during training and competition." *Medicine and Science in Sports and Exercise* 39, no. 3: 556–72.

Armstrong, L. E., J. P. De Luca, and R. W. Hubbard. 1990. "Time course of recovery and heat acclimation ability of prior exertional heatstroke patients." *Medicine and Science in Sports and Exercise* 22, no. 1: 36–48.

Bach, A. J. E., M. J. Maley, G. M. Minett, and I. B. Stewart. 2018. Occupational cooling practices of emergency first responders in the United States: A survey. *Temperature* 5, no. 4: 348–58. https://doi.org/10.1080/23328940.2018.1493907.

Barnes, P. W., C. E. Williamson, R. M. Lucas, S. A. Robinson, S. Madronich, N. D. Paul, J. F. Bornman, A. F. Bais, B. Sulzberger, and S. R. Wilson. 2019. "Ozone depletion, ultraviolet radiation, climate change and prospects for a sustainable future." *Nature Sustainability* 2, no. 7: 569–79.

Buckley, J. P., J. P. Sestito, and K. L. Hunting. 2008. "Fatalities in the landscape and horticultural services industry, 1992–2001." *American Journal of Industrial Medicine* 51, no. 9: 701–13.

Caminade, C., K. M. McIntyre, and A. E. Jones. 2019. "Impact of recent and future climate change on vector-borne diseases." *Annals of the New York Academy of Sciences* 1436, no. 1: 157–73.

CDC. 2008. "Heat-related deaths among crop workers—United States, 1992–2006." *Morbidity and Mortality Weekly Report* 57, no. 24: 649–53.

CDC. 2024. "Heat and medications—Guidance for clinicians." https://www.cdc.gov/heat-health/hcp/heat-and-medications-guidance-for-clinicians.html.

Chapman, C. L., H. W. Hess, R. A. Lucas, J. Glaser, R. Saran, J. Bragg-Gresham, ... & Z. J. Schlader. 2021. Occupational heat exposure and the risk of chronic kidney disease of nontraditional origin in the United States. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 321, no. 2: R141–51.

Chicas, R., J. Mix, V. Mac, J. Flocks, N. E. Dickman, V. Hertzberg, and L. McCauley. 2019. Chronic kidney disease among workers: A review of the literature. *Workplace Health & Safety* 67, no. 9: 481–90.

Coyle, E. F. 2004. Fluid and fuel intake during exercise. *Journal of Sports Sciences* 22: 39–55.

Daghagh Yazd, S., S. A. Wheeler, and A. Zuo. 2019. "Key risk factors affecting farmers' mental health: A systematic review." *International Journal of Environmental Research and Public Health* 16, no. 23: 4849.

Dahl, K., R. Licker, J. T. Abatzoglou, and J. Declet-Barreto. 2019a. “Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century.” *Environmental Research Communications* 1, no. 7: 075002.

Dahl, K., E. Spanger-Siegfried, R. Licker, A. Caldas, J. Abatzoglou, N. Mailloux, R. Cleetus, S. Udvardy, J. Declet-Barreto, and P. Worth. 2019b. *Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days*. Union of Concerned Scientists. https://www.jstor.org/stable/resrep24062.

Danzig, R. M., J. M. Raunig, and C. J. Acholonu. 2024. “Exertional heat illness—From identifying heat rash to treating heat stroke.” *Pediatric Annals* 53, no. 1: e17–21.

Day, T. K. and D. Grimshaw. 2005. “An observational study on the spectrum of heat-related illness, with a proposal on classification.” *Journal of the Royal Army Medical Corps* 151, no. 1: 11–8.

DeGroot, D. W., F. G. O’Connor, and W. O. Roberts. 2022. “Exertional heat stroke: an evidence based approach to clinical assessment and management.” *Experimental Physiology* 107, no. 10: 1172–83.

de Almeida, R. A. C. D. S., M. M. Veiga, F. J. de Castro Moura Duarte, L. A. Meirelles, and L. B. E. Veiga. 2012. Thermal comfort and personal protective equipment (PPE). *Work* 41(Supplement 1): 4979–82.

De Kok, J. M. 2005. “Precautionary actions within small and medium-sized enterprises.” *Journal of Small Business Management* 43, no. 4: 498–516.

Delp, L., L. Podolsky, and T. Aguilar. 2009. “Risk amid recovery: occupational health and safety of Latino day laborers in the aftermath of the Gulf Coast hurricanes.” *Organization & Environment* 22, no. 4: 479–90.

DOD. 2003. *Technical Bulletin: Heat Stress Control and Heat Casualty Management (TBMED 507/AFPAM 48-152 (I))*. Washington, DC: Department of Defense. https://apps.dtic.mil/sti/tr/pdf/ADA433236.pdf.

Dodgen, D., D. Donato, N. Kelly, A. La Greca, J. Morganstein, J. Reser, J. Ruzek, S. Schweitzer, M. Shimamoto, and K. T. Tart. 2016. “Mental health and well-being.” In *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, 217–46. Washington, DC: U.S. Global Change Research Program. https://health2016.globalchange.gov/low/ClimateHealth2016_08_Mental_Health_small.pdf.

Donato, K. M., N. Trujillo-Pagan, C. L. Bankston III, and A. Singer. 2007. “Reconstructing New Orleans after Katrina: the emergence of an immigrant labor market.” In *The Sociology of Katrina: Perspectives on a Modern Catastrophe*, edited by D. L. Brunsma, D. Overfelt, and J. S. Picou, 217–34. Lanham, MD: Rowman & Littlefield Publishers.

Ellis, B. D. and H. J. Stam. 2018. “Cycles of deportability: Threats, fears, and the agency of ‘irregular’ migrants in Canada.” *Migration Studies* 6, no. 3: 321–44.

Fan, W. and Y. Qian. 2017. “Native-immigrant occupational segregation and worker health in the United States, 2004–2014.” *Social Science & Medicine* 183: 130–41.

Flynn, M. A., T. Carreón, D. E. Eggerth, and A. I. Johnson. 2014. “Immigration, work, and health: A literature review of immigration between Mexico and the United States.” *Revista de trabajo social* 6: 129.

Fouque, F. and J. C. Reeder. 2019. “Impact of past and on-going changes on climate and weather on vector-borne diseases transmission: A look at the evidence.” *Infectious Diseases of Poverty* 8, no. 3: 1–9.

Gatto, M. P., R. Cabella, and M. Gherardi. 2016. “Climate change: the potential impact on occupational exposure to pesticides.” *Annali dell’Istituto superiore di sanita* 52, no. 3: 374–85.

Gauer, R. and B. K. Meyers. 2019. “Heat-related illnesses.” *American Family Physician* 99, no. 8: 482–9.

Glaser, J., J. Lemery, B. Rajagopalan, H. F. Diaz, R. García-Trabanino, G. Taduri, M. Madero, M. Amarasinghe, G. Abraham, and S. Anutrakulchai. 2016. "Climate change and the emergent epidemic of CKD from heat stress in rural communities: The case for heat stress nephropathy." *Clinical Journal of the American Society of Nephrology* 11, no. 8: 1472–83.

Gordon, C. J. 2003. "Role of environmental stress in the physiological response to chemical toxicants." *Environmental Research* 92, no. 1: 1–7.

Gordon, C. J. and L. R. Leon. 2005. "Thermal stress and the physiological response to environmental toxicants." *Reviews on Environmental Health* 20, no. 4: 235–64.

Hasle, P. and H. J. Limborg. 2006. "A Review of the literature on preventive occupational health and safety activities in small enterprises." *Industrial Health* 44, no. 1: 6–12.

Havenith, G. 1999. "Heat balance when wearing protective clothing." *Annals of Occupational Hygiene* 43, no. 5: 289–96.

Heinzerling, A., R. L. Laws, M. Frederick, R. Jackson, G. Windham, B. Materna, and R. Harrison. 2020. "Risk factors for occupational heat-related illness among California workers, 2000–2017." *American Journal of Industrial Medicine* 63, no. 12: 1145–54.

Howard, M., S. Ahmed, P. Lachapelle, and M. B. Schure. 2020. "Farmer and rancher perceptions of climate change and their relationships with mental health." *Journal of Rural Mental Health* 44, no. 2: 87.

Jacklitsch, B. L., K. A. King, R. A. Vidourek and A. L. Merianos. 2018. "Heat-related training and educational material needs among oil spill cleanup responders." *Environmental Health Insights* 12:1178630218802295.

Jackson, L. L. and H. R. Rosenberg. 2010. "Preventing heat-related illness among agricultural workers." *Journal of Agromedicine* 15, no. 3: 200–15.

Jaggernath, J., D. Haslam, and K. S. Naidoo. 2013. "Climate change: Impact of increased ultraviolet radiation and water changes on eye health." *Health* 5: 921–30.

Kenny, G. P., T. E. Wilson, A. D. Flouris, and N. Fujii. 2018. "Heat exhaustion." *Handbook of Clinical Neurology* 157: 505–29.

Kenny, G. P., J. Yardley, C. Brown, R. J. Sigal, and O. Jay. 2010. "Heat stress in older individuals and patients with common chronic diseases." *CMAJ* 182, no. 10: 1053–60.

Kiefer, M., J. Rodríguez-Guzmán, J. Watson, B. van Wendel de Joode, D. Mergler, and A. S. da Silva. 2016. "Worker health and safety and climate change in the Americas: issues and research needs." *Revista Panamericana de Salud Pública* 40: 192–7.

Kjellström, T., N. Maître, C. Saget, M. Otto, and T. Karimova. 2019. *Working on a Warmer Planet: The Impact of Heat Stress on Labour Productivity and Decent Work*. International Labour Organization, Geneva.

Klimaszyk, P., D. Klimaszyk, M. Piotrowiak, and A. Popiołek. 2014. "Unusual complications after occupational exposure to giant hogweed (Heracleum mantegazzianum): A case report." *International Journal of Occupational Medicine and Environmental Health* 27: 141–4.

Lentz, T. and T. Wenzl. 2006. "Surveillance: small businesses with high fatality rates: assessment of hazards and their prevention." *Journal of Occupational and Environmental Hygiene* 3, no. 2: D8–14.

Leon, L. R. 2007. "Heat stroke and cytokines." *Progress in Brain Research* 162: 481–524.

Leon, L. R. 2008. "Thermoregulatory responses to environmental toxicants: The interaction of thermal stress and toxicant exposure." *Toxicology and Applied Pharmacology* 233, no. 1: 146–61.

Leon, L. R. and A. Bouchama. 2011. "Heat stroke." *Comprehensive Physiology* 5, no. 2: 611–47.

Levi, M., T. Kjellstrom, and A. Baldasseroni. 2018. "Impact of climate change on occupational health and productivity: a systematic literature review focusing on workplace heat." *La Medicina del lavoro* 109, no. 3: 163.

Levy, B. S. and J. A. Patz. 2015. "Climate change, human rights, and social justice." *Annals of Global Health* 81, no. 3: 310–22.

Lowe, S. R., R. K. Kwok, J. Payne, L. S. Engel, S. Galea, and D. P. Sandler. 2016. "Why does disaster recovery work influence mental health?: Pathways through physical health and household income." *American Journal of Community Psychology* 58, no. 3–4: 354–64.

Lucas, R. A., L. C. Wilson, P. N. Ainslie, J.-L. Fan, K. N. Thomas, and J. D. Cotter. 2018. "Independent and interactive effects of incremental heat strain, orthostatic stress, and mild hypohydration on cerebral perfusion." *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 314, no. 3: R415–26.

McArdle, W., F. Katch, and V. Katch. 2010. *Exercise Physiology: Nutrition, Energy, and Human Performance*. Philadelphia, PA: Wolters Kluwer Lippincott Williams & Wilkins. .

McCarty, C. A. and H. R. Taylor. 2002. "A review of the epidemiologic evidence linking ultraviolet radiation and cataracts." *Developments in Ophthalmology* 35: 21–31.

McLellan, T. M., H. A. Daanen, and S. S. Cheung. 2013. "Encapsulated environment." *Comprehensive Physiology* 3, no. 3: 1363–91.

Mendeloff, J. M. 2006. *Small Businesses and Workplace Fatality Risk: An Exploratory Analysis*. RAND Corporation.

Metregiste, D., D. Boucaud-Maitre, L. Aubert, L. Noubou, and L. Jehel. 2020. "Explanatory factors of post-traumatic distress and burnout among hospital staff 6 months after Hurricane Irma in Saint-Martin and Saint-Barthelemy." *PLoS One* 15, no. 3: e0229246.

Michaels, D. and J. Howard. 2012. "Review of the OSHA-NIOSH response to the Deepwater Horizon oil spill: protecting the health and safety of cleanup workers." *PLoS Currents* 18(4):e4fa83b7576b6e.

Morel, A., G. Bedek, F. Salaün, and D. Dupont. 2014. "A review of heat transfer phenomena and the impact of moisture on firefighters' clothing and protection." *Ergonomics* 57, no. 7: 1078–89.

Montain, S. J. and S. N. Cheuvront. 2008. Fluid, electrolyte and carbohydrate requirements for exercise. In *Physiological Basis of Human Performance during Work and Exercise*, edited by N. A. S. Taylor and H. Groeller, 563–73. Churchill: Livingstone; Edinburgh: Elsevier.

National Research Council. 1989. *Recommended Daily Allowances*, 10th ed. Washington, DC: National Academies Press .

Navy Environmental Health Center. 2007. Prevention and treatment of heat and cold stress injuries. https://www.med.navy.mil/sites/nmcphc/Documents/policy-and-instruction/oem-prevention-and-treatment-of-heat-and-cold-stressinjuries.pdf.

National Institutes of Health (NIH). 2024. Causes of chronic kidney disease. https://www.niddk.nih.gov/health-information/kidney-disease/chronic-kidney-disease-ckd/causes.

NIOSH. 2016. *Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments*. B. Jacklitsch, W. J. Williams, K. Musolin, A. Coca, J.-H. Kim, and N. Turner, eds. Cincinnati, OH: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf?id=10.26616/NIOSHPUB2016106.

NIOSH. 2020. *Limiting Heat Burden While Wearing Personal Protective Equipment (PPE).* https://www.cdc.gov/niosh/topics/heatstress/heat_burden.html.

NOAA, NCEI. 2022. "Billion-dollar weather and climate disasters." https://www.ncdc.noaa.gov/billions/overview.

O'Connor, T., M. Flynn, D. Weinstock, and J. Zanoni. 2014. "Occupational safety and health education and training for underserved populations." *New Solutions: A Journal of Environmental and Occupational Health Policy* 24, no. 1: 83–106.

Orlov, A., J. Sillmann, A. Aaheim, K. Aunan, and K. De Bruin. 2019. "Economic losses of heat-induced reductions in outdoor worker productivity: A case study of Europe." *Economics of Disasters and Climate Change* 3, no. 3: 191–211.

Orui, M., Y. Suzuki, A. Goto and S. Yasumura. 2018. "Factors associated with maintaining the mental health of employees after the Fukushima Nuclear Disaster: Findings from companies located in the evacuation area." *International Journal of Environmental Research and Public Health* 15, no. 1: 53.

Palaniappan, V., A. Sadhasivamohan, J. Sankarapandian, and K. Karthikeyan. 2023. "Miliaria crystallina." *Clinical and Experimental Dermatology* 48, no. 5: 462–67.

Park, J., Y. Kim, and I. Oh. 2017. "Factors affecting heat-related diseases in outdoor workers exposed to extreme heat." *Annals of Occupational and Environmental Medicine* 29, no. 1: 30.

Parker, D., L. Brosseau, Y. Samant, P. Pan, Wei, M. Xi, and D. Haugan. 2007. "A comparison of the perceptions and beliefs of workers and owners with regard to workplace safety in small metal fabrication businesses." *American Journal of Industrial Medicine* 50, no. 12: 999–1009.

Parker, E. R. 2021. "The influence of climate change on skin cancer incidence – A review of the evidence." *International Journal of Women's Dermatology* 7, no. 1: 17–27.

Parsons, K. 2003. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort and Performance*. London: Taylor & Francis.

Périard, J. D., T. M. Eijsvogels, and H. A. Daanen. 2021. "Exercise under heat stress: Thermoregulation, hydration, performance implications, and mitigation strategies." *Physiological Reviews* 101, no. 4: 1873–79. https://doi.org/10.1152/physrev.00038.2020.

Pinkerton, K. E., E. Felt, and H. E. Riden. 2019. "Extreme weather resulting from global warming is an emerging threat to farmworker health and safety." *Journal of Agricultural Safety and Health* 25, no. 4: 189–90.

Pradhan, B., T. Kjellstrom, D. Atar, P. Sharma, B. Kayastha, G. Bhandari, and P. K. Pradhan. 2019. Heat stress impacts on cardiac mortality in Nepali migrant workers in Qatar. *Cardiology* 143, no. 1–2: 37–48.

Pundee, R., P. Kongtip, N. Nankongnab, S. Anutrakulchai, M. G. Robson, and S. Woskie. 2020. "Cross-shift change of acute kidney injury biomarkers in sugarcane farmers and cutters." *Human and Ecological Risk Assessment: An International Journal* 27, no. 5: 1170–87.

Ravanelli, N., W. Casasola, T. English, K. M. Edwards, and O. Jay. 2019. "Heat stress and fetal risk. Environmental limits for exercise and passive heat stress during pregnancy: A systematic review with best evidence synthesis." *British Journal of Sports Medicine* 53, no. 13: 799–805.

Rekha, S., S. J. Nalini, S. Bhuvana, S. Kanmani, J. E. Hirst, and V. Venugopal. 2024. "Heat stress and adverse pregnancy outcome: Prospective cohort study." *BJOG: An International Journal of Obstetrics & Gynaecology* 131, no. 5: 612–22.

Rowell, L. R. 1993. *Human Cardiovascular Control*. New York: Oxford University Press.

Sawka, M. N. and S. J. Montain. 2000. "Fluid and electrolyte supplementation for exercise heat stress." *The American Journal of Clinical Nutrition* 72, no. 2: 564S–72S.

Schindler, S., W. Rabitsch, F. Essl, P. Wallner, K. Lemmerer, S. Follak, and H.-P. Hutter. 2018. "Alien species and human health: Austrian stakeholder perspective on challenges and solutions." *International Journal of Environmental Research and Public Health* 15, no. 11: 2527.

Schulte, P., A. Bhattacharya, C. Butler, H. Chun, B. Jacklitsch, T. Jacobs, M. Kiefer, J. Lincoln, S. Pendergrass, and J. Shire. 2016. "Advancing the framework for considering the effects of climate change on worker safety and health." *Journal of Occupational and Environmental Hygiene* 13, no. 11: 847–65.

Schwarz, N., E. Newman and W. Leach. 2016. "Making the truth stick & the myths fade: Lessons from cognitive psychology." *Behavioral Science & Policy* 2, no. 1: 85–95.

Shih, G. 2023. "The world's torrid future is etched in the crippled kidneys of Nepali workers." *The Washington Post*.

Sinclair, R. C. and T. R. Cunningham. 2014. "Safety activities in small businesses." *Safety Science* 64: 32–8.

Spector, J. T., J. Krenz, E. Rauser, and D. K. Bonauto. 2014. "Heat-related illness in Washington State agriculture and forestry sectors." *American Journal of Industrial Medicine* 57, no. 8: 881–95.

Spector, J. T., Y. J. Masuda, N. H. Wolff, et al. 2019. "Heat exposure and occupational injuries: Review of the literature and implications." *Current Environmental Health Reports* 6: 286–96.

Spector, J. T. and P. E. Sheffield. 2014. "Re-evaluating occupational heat stress in a changing climate." *Annals of Occupational Hygiene* 58, no. 8: 936–42.

Stocker, T. 2014. *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Syed, S., T. L. O'Sullivan, and K. P. Phillips. 2022. "Extreme heat and pregnancy outcomes: A scoping review of the epidemiological evidence." *International Journal of Environmental Research and Public Health* 19, no. 4: 2412.

Taylor, N., N. Kondo, and W. L. Kenney. 2008. "The physiology of acute heat exposure, with implications for human performance in the heat." In *Physiological Bases of Human Performance during Work and Exercise*, edited by N. A. Taylor and H. Groeller, 341–58. Edinburgh: Elsevier.

Tetzlaff, E. J., C. Cassan, N. Goulet, M. Gorman, B. Hogya, and G. P. Kenny. "Breaking down in tears, soaked in sweat, and sick from the heat": Media-based composite narratives of first responders working during the 2021 Heat Dome. *American Journal of Industrial Medicine* 67: 442–52. https://doi.org/10.1002/ajim.23576.

Tustin, A. W., D. L. Cannon, S. B. Arbury, R. J. Thomas, and M. J. Hodgson. 2018. "Risk factors for heat-related illness in U.S. workers: An OSHA case series." *Journal of Occupational and Environmental Medicine* 60, no. 8: e383–9.

US EPA. 2021a. *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*. EPA 430-R-21-003. Washington, DC: U.S. Environmental Protection Agency.

Vaisala. 2022. "Total lightning statistics: 2021 annual lightning report." Vantaa. https://www.vaisala.com/sites/default/files/documents/WEA-MET-2021-Annual-Lightning-Report-B212465EN-A.pdf.

Wang, X. L., P. S. Yip, and C. L. Chan. 2016. "Suicide prevention for local public and volunteer relief workers in disaster-affected areas." *Journal of Public Health Management and Practice* 22, no. 3: E39–46.

Westwood, C. S., J. L. Fallowfield, S. K. Delves, M. Nunns, H. B. Ogden, and J. D. Layden. 2021. Individual risk factors associated with exertional heat illness: A systematic review. *Experimental Physiology* 106, no. 1: 191–9.

Williams, W. 2013. "Physiological impact of flame resistant clothing: managing heat stress." In *Handbook of Fire Resistant Textiles*, edited by F. S. Kilinc, 434–55. Amsterdam: Elsevier.

Williams, W. 2018. "Behavioral and technological adaptation." In *Human Health and Physical Activity During Heat Exposure*, edited by Y. Hosokawa, 85–9. Springer Briefs in Medical Earth Sciences. Cham: Springer.

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LeeAnn Racz is a Supervising Engineer at ToxStrategies LLC in Fort Walton Beach, FL. Prior to this initiative, she was President and Founder of ClearView Environmental Engineering and Consulting, and she served for 23 years as a bioenvironmental engineer and civil engineer in the US Air Force. Dr Racz is a licensed professional engineer, certified industrial hygienist, and board-certified environmental engineer. She earned a BS in Environmental Engineering from California Polytechnic State University, San Luis Obispo, an MS in Biological and Agricultural Engineering from the University of Idaho, and a PhD in Civil and Environmental Engineering from the University of Utah. She has authored dozens of refereed journal articles, conference proceedings, magazine articles, and presentations, and edited six handbooks. Dr Racz is a member of several professional organizations and honor societies and has received numerous prestigious teaching and research awards.

Adedeji B. Badiru is Dean Emeritus and a retired Professor of Systems Engineering at the Air Force Institute of Technology (AFIT). He is a registered professional engineer and a fellow of the Institute of Industrial Engineers, as well as a fellow of the Nigerian Academy of Engineering. He has a BS degree in Industrial Engineering, an MS in Mathematics and an MS in Industrial Engineering from Tennessee University, and a PhD in Industrial Engineering from the University of Central Florida. He is the author of several books and technical journal articles and has received several awards and recognitions for his accomplishments. His special skills, experience, and interests center on research mentoring of faculty and graduate students.

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