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Farmworker Vulnerability to Heat Hazards: A Conceptual Framework

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Abstract

Purpose: To review factors that impact the effect of hot environments on the human body in order to develop a conceptual model of human biological response.

Methods: The organizing concept for the model development was the multilevel integration of three major factors, exposure to heat, sensitivity and adaptive capacity, and the heat stress response. Exposure of a vulnerable occupational group was used to illustrate the components of the model.

Findings: Components of this framework include the hazard (environmental heat stress), vulnerability factors (workplace exposure, sensitivity and adaptive capacity), and the heat stress response. The combination of the vulnerability factors of workplace exposure (work intensity, duration), sensitivity (age, gender, etc.), and adaptive capacity (hydration, clothing, work hygiene) mediate a worker's heat stress response to the hazard. A worker's heat stress response can be classified as progressing towards two outcomes: physiologic equilibrium or physiologic disequilibrium.

Conclusions: This framework provides a starting point for the design and development of studies of heat-related illness (HRI) in farmworker and other vulnerable populations exposed to rising global temperatures.

Clinical Relevance: Identification of vulnerability factors to HRI, informs research designs which will lead to the development of public health interventions.

Now and in the future, global climate change will continue to be a persistent public health threat affecting all living spaces, including those where we live and work. Escalating trends in global warming place vulnerable worker populations at increased risk for heat-related illness (HRI; Lundgren, Kuklane, Chuansi, & Holmer, 2013; Roelofs & Wegman, 2014). HRI occurs when the body's innate compensatory mechanisms for combating heat stress are overpowered, leading to thermoregulatory imbalance. Agricultural workers are highly susceptible to heat stress and HRI, given routine occupational exposure to hot, humid, environments in which they have little opportunity to protect themselves. Every year agricultural workers continue to experience heat-related deaths. In 2016, Jean Francais Alcime of Immokalee, Florida, after exhibiting signs of HRI since earlier that day, died on the 2-hr return bus ride from the fields, the usual mode of transportation for crop workers for the farms in Collier County (Perez, 2016). During the years between 2000 and 2009, an examination of observed annual record high maximum and record low minimum daily temperatures across the United States indicated that there were nearly twice as many daily record high temperatures as daily record low temperatures, and temperature models predict increasing ratios of record highs to record lows (Meehl, Tebaldi, Walton, Easterling, & McDaniel, 2009).

Several decades of research have examined physiologic responses to nonfatal heat strain in the general public (Schaffer, Muscatello, Broome, Corbett, & Smith, 2012; Semenza et al., 1996), athletes (Webborn, Price, Castle, & Goosey-Tolfrey, 2005), firefighters (McLellan & Selkirk, 2006), and military personnel (Sawka et al., 2001; Sawka,

Table 1. Heat stress response components defined

Key definitions
Heat-related Illness (HRI) Symptoms – The clinical manifestations of heat-related illness that occur along a cascade from mild to critical that may include excessive sweating, cramps, headache, edema, fatigue, dizziness, fainting, nausea and vomiting (Becker & Stewart, 2011; Glazer, 2005; Jackson & Rosenberg, 2010).
Core body temperature (T_c) – The dynamic temperature of the vital organs in the body considered to be most accurate in the pulmonary artery (Brengelmann, 1987), but most accurately measured in field-based settings via the gastrointestinal tract (Byrne & Lim, 2007).
Physiological Strain Index (PSI) – The degree to which the body is unable to maintain core temperature prescribed by the hypothalamus described on a universal scale of 0–10 based upon heart rate and rectal temperature (T_{re}) (Moran, Shitzer, & Pandolf, 1998).

Young, Francesconi, Muza, & Pandolf, 1985; Sawka et al., 1992). Despite the history of research centered on other groups, heat stress remains an understudied but important occupational hazard for agricultural workers (Flocks et al., 2013). Recently work has begun to characterize HRI in farmworkers utilizing surveys (Bethel & Harger, 2014; Fleischer et al., 2013; Mirabelli et al., 2010; Spector, Krenz, & Blank, 2015), analyses of a longitudinal database of visit records from community and migrant health centers (C/MHCs; Cooper et al., 2014; Zhang, Arauz, Chen, & Cooper, 2016), and field-based continuous biomonitoring (Hertzberg et al., 2017; Mac et al., 2017). Research exploring the relationship between personal physiologic factors and outdoor work in agricultural settings has the potential to advance the state of the science for climate adaptation, specifically human physiologic responses to environmental heat.

Given the complexity of the response of the human body to the exogenous factor of increasing environmental heat, models are needed to promote our understanding of the vulnerability and physiologic response. In this article, we propose a framework that can serve as a guide for nurses engaging in research, policy, and action in this vital area of public health. We first identify the inputs, mediators, and resulting outputs of this delicate system (**Table 1**), followed by an exploration of exemplars, and conclude with a discussion examining the dynamic functioning and application of this framework.

Framework Components

A framework describing the factors surrounding heat stress in farmworkers needs to conceptualize the physiologic processes occurring internally via the body's attempt to maintain equilibrium in relation to heat stress sources

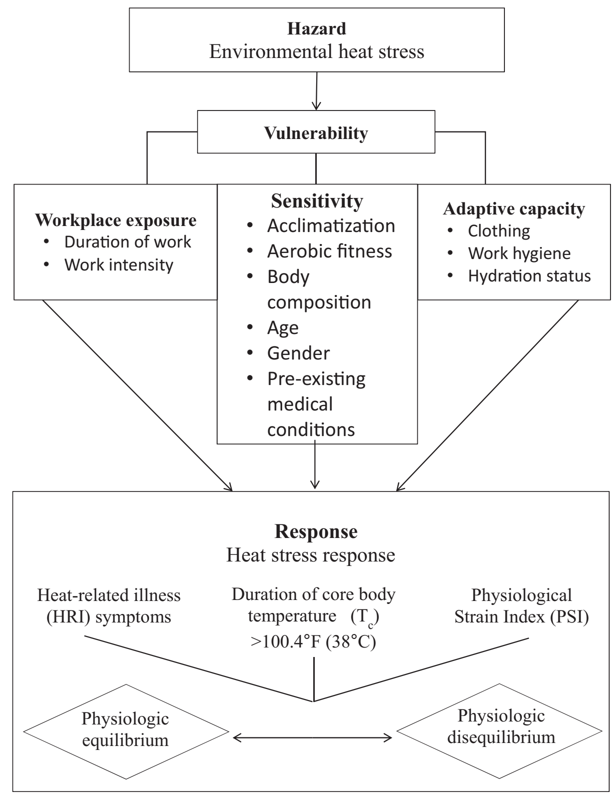

Figure 1. Farmworker Vulnerability to Heat Hazards Framework

and moderating factors. Romero-Lankao and Qin, building on others' earlier work (Ionescu, Klein, Hinkle, Kavi Kumar, & Klein, 2009, p. 4, fig. 1; McCarthy, Canziani, Leary, Dokken, & White, 2001), proposed a conceptual model relating climate change to the health of urban environments (Romero-Lankao & Qin, 2011, p. 143, fig. 1). Their framework proposed vulnerability to climate change in terms of relationships among five key concepts: "hazard," "exposure," "sensitivity," "adaptive capacity," and "response." In their framework, Romero-Lankao and Qin present vulnerability in the context of climate change resilience of cities as resulting from a dynamic interaction between the hazard itself and three separate but interrelated vulnerability factors (exposure, sensitivity, and adaptive capacity) rather than simply as a propensity to be harmed based solely upon the magnitude of the oncoming hazard. These macrolevel frameworks (Ionescu et al., 2009; McCarthy et al., 2001; Romero-Lankao & Qin, 2011) form the platform for our translation of ideas into one that can capture the dynamic circumstances surroundings an individual's physiologic response to heat stress (**Figure 1**). Following, we discuss the individual components of our proposed framework.

Hazard

There are a variety of strategies for operationalizing and measuring the basic hazard in the model, environmental heat stress. Wet-bulb globe temperature (WBGT), comprising natural wet bulb temperature (T_{nwb}), dry-bulb temperature (T_{db}), and black globe temperature (T_{bg}), is a primary index that describes heat stress in a given environment and that serves as a measurement of the hazard in this framework (Budd, 2008). WBGT can be measured in indoor environments and confined spaces as well as in outdoor environments. Ideally, microclimate WBGT measurements can be acquired at the worksite using standardized instrumentation and calibrated temperature equipment, but in lieu of on-site monitoring, estimating WBGT from local meteorological data is an option since these readings are widely accessible from local or regional weather services (Bernard & Barrow, 2013; Patel, Mullen, & Santee, 2013). With WBGT estimations, outdoor workers can be advised of acceptable work and rest cycles according to the level of environmental heat stress and the level of individual workload (light, moderate, or heavy), defined by the number of watts expended per hour (American Conference of Governmental Industrial Hygienists [ACGIH], 2014). For example, when the WBGT reaches 29°C, a worker engaging in a moderate workload, classified as an energy expenditure of 235 to 360 W/hr, should spend 25% of every hour in recovery to decrease the risk for developing HRI (ACGIH, 2014). If agricultural workers are employed in operations in which portions of the work take place inside partially enclosed, non-temperature-controlled areas like packing houses, greenhouses, or inside packing and loading trailers, WBGT from meteorological data may underestimate the actual conditions. In these cases, direct WBGT at the worksite is preferred to more accurately measure the level of environmental heat stress to guide the choice of the appropriate work–rest cycle.

Although, WBGT is the standard occupational environment temperature assessment, the National Weather Service calculates the heat index (Steadman, 1979a, 1979b) from meteorological data, specifically relative humidity and ambient temperature, to guide the issuance of heat warnings for communities that stratify the risk for HRI (National Institute for Occupational Safety and Health [NIOSH], 2016). This is a possible alternative to WBGT for capturing the degree of heat hazard.

The State of California has instated heat illness prevention regulations (CCR, section 8 §3395. Heat Illness Prevention) based upon guidance from the Occupational Health and Safety Administration (OSHA) to protect farmworkers. These regulations mandate employers to be aware of daily ambient temperatures and to follow situation-based recommendations based upon these readings on a given day. Specific actions include the provision of shade when ambient temperatures reach 80°F and mandatory rest breaks of 10 min in length every 2 hr when the environmental temperature exceeds 95°C. Community- and regionally-based weather monitoring can provide accurate and accessible information from which public health surveillance and situation-based recommendations can be developed in other regions of the country.

Vulnerability

An individual's vulnerability incorporates three interrelated factors: workplace exposure, sensitivity, and adaptive capacity. Workplace exposure represents the extent to which an individual (i.e., agricultural worker) quantitatively experiences a hazard (environmental heat stress). Of importance is the nature of the work that the individual is engaged in, the duration of the work, and the physical demands involved. Farmworkers may work long hours (Flocks et al., 2013); agricultural work is among the most demanding of all occupational classes (Hansen & Donohoe, 2003). In the Farmworker Vulnerability to Heat Hazards Framework, workplace exposure is the measure of the duration of work and the intensity of work. Of note, there are two sources of heat stress, including environmental heat stress (the hazard) and internal heat stress generated from the movement required to perform physical tasks. For this framework, internal heat stress is captured under workplace exposure because its magnitude is entirely dependent upon the amount of time working and the intensity of work. Environmental heat stress (the hazard) exists independently of workplace exposure, and the dose of the hazard is titrated by the degree of workplace exposure, which is why workplace exposure is a component of vulnerability in this framework.

The second component of vulnerability is sensitivity. Sensitivity consists of modifying factors that can have a positive or negative impact on an individual's vulnerability to heat hazards, including those defined in **Table 2**. In the context of this framework, sensitivity includes factors of acclimatization (Cheung, McLellan, & Tenaglia, 2000; Semenza et al., 1996), aerobic fitness (McLellan, Cheung, Selkirk, & Wright, 2012), body composition (Selkirk & McLellan, 2001; Yokota, Berglund, & Bathalon, 2012), age (Åström, Bertil, & Joacim, 2011), gender (Shapiro, Pandolf, Avellini, Pimental, & Goldman, 1980), pre-existing medical conditions and certain medications (Binkley, Beckett, Casa, Kleiner, & Plummer, 2002; Glazer, 2005; Howe & Boden, 2007; Kravchenko, Abernethy, Fawzy, & Lyerly, 2013), as well as other

Table 2. Sensitivity components defined

Key definitions
Aerobic Fitness – The level to which an individual can perform physically at a high level for an extended period of time which is dependent upon the degree of efficiency that the cardio-respiratory system can oxygenate the blood, transport that oxygenated blood to the muscles being used, and how efficiently the involved muscle cells can uptake and utilize that oxygen to create an output of power (Jones & Carter, 2000).
Acclimatization – The process by which individuals undergo physiologic adaptations to improve their ability to withstand strain placed on the body by heat stress. Acclimatization may include a decrease in heart rate, perceived exertion, increased plasma volume and decreased core temperature (Armstrong & Maresh, 1991).

sociodemographic factors, such as housing (Quandt, Wiggins, Chen, Bischoff, & Arcury, 2013).

Adaptive capacity, the primary modifiable component of vulnerability, refers to the availability of resources to counteract heat stress. These components vary and may be beyond the control of the worker, including workplace hygiene (e.g., availability of water and toileting facilities, and ability to take regular breaks; Bethel & Harger, 2014; Fleischer et al., 2013; Flocks et al., 2013). HRI prevention knowledge and practices, including the training of crew leaders, supervisors, and employers in HRI prevention and early action algorithms, could also be included as an adaptive capacity component as an aspect of workplace hygiene.

More research regarding heat stress experienced by agricultural workers will further illuminate components of sensitivity and adaptive capacity. Recent work examining grower-provided farmworker housing in North Carolina showed that workers often face high levels of heat and humidity even after leaving the worksite, during sleeping hours (Quandt et al., 2013). Quandt et al. (2013) cite the known detrimental impact of elevated heat and humidity in sleep environments on wakefulness, rapid-eye-movement sleep, and slow-wave sleep via a higher thermal load that inhibits the normal decreases in body temperature during sleep (Okamoto-Mizuno & Mizuno, 2012). This risk for impaired nighttime cooling and recovery could potentially affect an individual's response to heat at the worksite. Further research characterizing the physiologic effects of the documented high heat and humidity indices in grower-provided farmworker housing can elucidate the predicted health effects.

An individual's vulnerability to the hazard of environmental heat stress, expressed as the synergy among workplace exposure, sensitivity, and adaptive capacity, mediates that individual's response to the hazard (heat stress response). If the combination of workplace exposure and sensitivity exceeds an individual's adaptive capacity, then the heat stress response is in disequilibrium, leading to HRI. If an individual's adaptive capacity is high enough to offset his or her combination of sensitivity and exposure to the hazard, then the compensatory heat stress response leads to physiologic equilibrium. In theory, vulnerability and adaptation can be fluid, with individuals oscillating between degrees of vulnerability related to changing adaptive capacity, workplace exposure, or sensitivity resulting in an oscillation between physiologic equilibrium and disequilibrium during the growing season or a single workday.

Heat Stress Response

An individual's heat stress response can be quantified using three metrics: (a) core body temperature; (b) the Physiological Strain Index (PSI); and (c) HRI symptoms. The ACGIH has set a physiologic limit for core body temperature at 38°C (100.4°F). This means that workers of unknown medical fitness for their specific work task are advised to cease work when their core body temperature exceeds this cap to avoid adverse effects from repeated or extended exposure. If multiple workers exceed the recommended limit, workplaces need to take steps to attenuate heat exposure (ACGIH, 2014). These recommendations are made to curtail HRI and injury in worker populations facing high heat exposure. In 2016, OSHA revised its NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments (NIOSH, 2016); this document supports the use of the physiologic limits set by the ACGIH. These criteria also state that there may be exceptions to the 38°C (100.4°F) limit, noting that some workers may be safe to work as long as their core body temperature does not exceed 38.5°C (101.3°F). However, these individuals must be medically cleared, remain under medical supervision, and be acclimatized, directly supervised, and adequately hydrated (NIOSH, 2016).

The PSI utilizes simultaneous measurements of heart rate and core body temperature to quantify heat strain experienced by an individual; PSI employs a scaled value between 0 and 10, with a value of 10 indicating a physiologic state that is very strenuous (Moran, Shitzer, & Pandolf, 1998). Its inclusion as a component of an individual's heat stress response provides a more robust picture of what is occurring physiologically by capturing the cardiovascular and thermoregulatory response to heat stress (Moran et al., 1998). Lastly, including actual HRI symptoms experienced by an individual extends the characterization of the heat stress response beyond physiologic measurements of heart rate and core body temperature. HRI symptoms may not be tied to a specific core body temperature, and capturing these symptoms at earlier stages of the heat stress response can aid in the prevention of HRI progression (Becker & Stewart, 2011; Glazer, 2005; Howe & Boden, 2007).

Conceptual Framework Exemplars

Exemplar 1: Physiologic Equilibrium

A 28-year-old healthy farmworker with no chronic conditions who has been working in the tomato field since 6:30 a.m. is wearing a long sleeve white t-shirt and notices that she is beginning to feel disoriented and dizzy, indicating a shift towards physiologic disequilibrium in her heat stress response. It is a clear day in June with a WBGT of 28°C, and she has been making a moderate energy expenditure. She notifies her crew leader, who sends her to take a 20-min rest and water break, accompanied by another worker, the worker's designated "buddy." During this break, the affected farmworker sits down under the shade of a canopy cloth, refills her water bottle with cool water and adds an electrolyte replacement pill to her water. She also wets a bandana with cool water to place around her neck while resting. The "buddy" keeps talking to her throughout her rest break, asking how she is feeling. At the end of the break, the worker is feeling better and the dizziness and disorientation have subsided; the worker walks back with the buddy to the tomato row where the crew is now working and resumes picking.

In this example, the worker was young and did not have any chronic conditions that could have increased her sensitivity. Fortunately, she was also wearing single-layered, light-colored clothing and sought out water and an electrolyte supplementation, all of which bolster adaptive capacity. By taking a break she was able to temporarily decrease her work intensity, resulting in a temporary decrease in her workplace exposure. This combination of factors related to the actions she took to slow the HRI cascade, her personal characteristics, and clothing choices resulted in a decrease in her vulnerability, allowing her heat stress response to shift back towards equilibrium.

Exemplar 2: Physiologic Disequilibrium

In this scenario, a 36-year-old farmworker is picking watermelons in the month of June in Immokalee, Florida, and loading them into the truck as he and the other crew members follow the loading truck down the row. Even though he has worked in agriculture for decades, he is new to this crew and crop and he has been out of work for the last month. Six hours into the workday he is keeping up with the pace of the loading truck and is feeling fine overall, except for some muscle cramps that he attributes to not being accustomed to lifting the watermelons and a headache that he believes is from not sleeping well the night before. He has been drinking water that is stored on the loading truck when the crew stops for breaks decided upon by the crew leader. The WBGT is 29°C, but the crew leader is unaware of the environmental heat readings and bases the break schedule on the schedule he has always used, despite the current heat wave. Towards the last hour of work, the worker begins to feel nauseated and lightheaded but knows that the day is almost over and does not want to stop early because he is new and does not want to lose productivity.

When the workday ends, he is feeling so nauseated that he does not want to drink much water and he does not have a sports drink or a low-sugar electrolyte beverage to drink. Because he is new to the crew, he does not have a co-worker who knows him or what he looks like when he is not feeling well. He walks back to the bus that transported all the crews to the fields that morning and will be the sole option for the 30-min ride back to the town center. Pulling himself onto the bus, he steadies himself, placing his hands on the tops of the seats at each row, as he walks down the aisle towards the empty seats in the middle of the bus. He sits down by himself, hoping that the dizziness will subside if he just closes his eyes. One of the other workers on the bus asks him if he is alright, and he replies that he is feeling dizzy and just needs to close his eyes for a few minutes next to the open window. When the bus arrives at the town center, the workers begin to unload off the bus, but he does not get up. One of the other workers notices him and tries to wake him up, but he is unresponsive. Then 911 is called and the other worker stays with him until the ambulance arrives.

These circumstances increased this worker's vulnerability to environmental heat stress. Not being acclimatized to the current work environment increased his sensitivity to heat stress, and the performance pressure he felt as a new crew member increased his workplace exposure to it. He began to decompensate early in the day when he experienced HRI symptoms of muscle cramps and headache; not identifying these as symptoms of HRI marked his progression down the HRI cascade. When the worker's HRI symptoms got worse and he began to feel nauseated, he pushed through, leading to further disequilibrium. His vulnerability to environmental heat stress was further increased because his adaptive capacity was further jeopardized because he was not able to take enough work breaks to attenuate his HRI symptoms, he had inadequate access to appropriate fluid replacement, and the workplace lacked established practices and early action plans for worker symptom surveillance that might have detected his progression down the HRI cascade before severe HRI occurred.

Discussion

This framework is particularly useful for conceptualizing future directions that can prevent HRI, decrease vulnerability to heat, and promote physiologic equilibrium. The framework can aid in the systematic identification of time points when interventions to promote health and prevent HRI could occur in vulnerable populations. The basic input, heat hazard, is not necessarily modifiable. However, the modifiable components of the framework lie in the combination of factors that constitute vulnerability—exposure, sensitivity, and adaptive capacity—which present valuable opportunities for intervention.

Sensitivity is the component of vulnerability that is the least modifiable since these factors are mainly physiologic or social, but improvements in upstream interventions, like regular and pre-employment medical examinations, might reveal pre-existing conditions or medications that place a person at greater risk. Modifications to workplace exposure are multifaceted and usually beyond the control of the workers without supervisor and employer support. With the support of employers and supervisors, modifications to workplace exposure include work systems that promote self-pacing and alterations of work schedules to avoid high heat periods of the day. Regulations could help, such as those that mandate specific work–rest algorithms based upon environmental conditions and regular and accessible provision of water, shade, and proper work clothing. Interventions to strengthen adaptive capacity could include on-site action plans to quickly identify workers suffering from the early stages of HRI and ensure that actions to halt HRI progression and promote recovery are implemented swiftly by workers, crew leaders, and managers.

The Farmworker Vulnerability of Heat Hazards Framework acknowledges that the three components of vulnerability stand in delicate balance with one another; at any given time, one factor can significantly alter vulnerability and affect the heat stress response. Thus, even if only one aspect is altered, such as duration of exposure time through working earlier hours, this action could have meaningful effects if its impact is large enough to decrease vulnerability and tip the scales towards physiologic equilibrium rather than disequilibrium.

This model provides a useful framework to aid nurses in the design of research to increase our understanding of the complexity of the human response to increasing environmental heat and to inform effective public health policies to diminish HRI risk, particularly among vulnerable working populations. The next step for this model will be to test its value in the study of farmworkers, as well as other climate-vulnerable worker groups, including first responders, military personnel, and aging workers. Further research may expand the model by identifying additional factors, including relationships or interactions between model components that may contribute to increased risks to human health associated with climate change.

Conclusions

The Farmworker Vulnerability to Heat Hazards Framework provides a useful inventory of the factors related to the occurrence of heat injury and HRI in response to heat stress. This model also portrays the concept of vulnerability as a dynamic and changeable mediator of heat stress based upon the presence and magnitude of the factors of vulnerability, including workplace exposure, sensitivity, and adaptive capacity. Finally, the heat stress response of equilibrium or disequilibrium acknowledges the true symptomatic and physiologic responses that can occur in response to heat hazards rather than merely relying on a body temperature reading that does not fully explain what is occurring at the level of the individual. Therefore, the Farmworker Vulnerability to Heat Hazards Framework aids in operationalizing and characterizing heat stress in farmworkers and other climate-vulnerable populations in planning further studies.

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Clinical Resources

- American Academy of Family Physicians. Heat-related illnesses. http://www.aafp.org/afp/1998/0901/p749.html
- Migrant Clinicians Network. Clinician guides for farmworker health and safety regulations.

http://www.migrantclinician.org/toolsource/resource/clinician-guides-farmworker-health-and-safety-regulations.html
- Migrant Clinicians Network. Heat-related illness. http://www.migrantclinician.org/issues/heat-stress.html
- Occupational Health and Safety Administration. Heat illness index of educational resources, using the heat index, training, and online toolkit. https://www.osha.gov/SLTC/heatillness/index.html
- Occupational Health and Safety Administration. Occupational heat exposure: Heat-related illnesses and first aid. https://www.osha.gov/SLTC/heatstress/heat_illnesses.html
- Occupational Health and Safety Administration. Occupational heat exposure: Industry-specific resources. https://www.osha.gov/SLTC/heatstress/industry_resources.html
- Occupational Health and Safety Administration. Occupational heat exposure: Prevention. https://www.osha.gov/SLTC/heatstress/prevention.html

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