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Editorial

Occupational Heat Stress In USA: Whither We Go?

Introduction

Occupational heat stress is defined by its contributing factors of work demands, environmental conditions, and clothing requirements. Work demands are an indicator of internal heat generation and heat stress is fundamentally a problem of dissipating internally generated heat to the environment. Among the environmental factors, the amount of water vapor in the air (humidity) is a major influence because the water vapor pressure gradient between the skin and the environment drives evaporative cooling. Air temperature and speed are other contributors to overall heat exchange as well as radiant heat. Finally, clothing modifies the rate of heat exchange with the greatest impact on evaporative cooling. Ideally, there is a balance between heat generation (and gains from the environment) and losses to the environment from evaporative cooling (and convection and radiation).

Heat stress on an individual drives a broad spectrum of acute and chronic physiological responses. The acute heat strain is most simply described by heart rate (the physiological outcome that is a surrogate for the movement of internal heat to the surface for dissipation to the environment), sweating (the physiological outcome that facilitates the dissipation), and core temperature (the physiological outcome the marks heat storage). The chronic physiological response is acclimatization, which helps reduce acute heat strain.

If thermal equilibrium can be established, then the heat strain is relatively stable. That is, the physiological responses are sufficient to support thermal balance in the context of the work demands, environmental conditions, and the clothing requirements. In practice, the heat stress (external conditions or job factors) are assessed and used to predict if thermal equilibrium can be established for most workers. That is, the heat stress exposure allows for sustained work over the course of a day.

Where We've Been

For occupational heat stress exposures, the Belding-Hatch Heat Stress Index[1)] was an early model of heat exchange between a person and the environment. It still is used to present a simple model to articulate the three contributors to heat stress. In practice, the Heat Stress Index was used to determine if the heat stress exposure was sustainable (preferably with HSI<0.7). Soon afterwards, Lind proposed the Upper Limit of the Prescriptive Zone as an upper bound on a sustainable level of heat stress[2)]. By the early 1970s, the US National Institute for Occupational Safety and Health (NIOSH)[3)] and the ACGIH® adapted Lind's studies to an occupational exposure limit for a healthy worker wearing a standard work uniform. The exposure limit used wet bulb globe temperature (WBGT) index as the metric for the environment and the environmental limit was adjusted for different metabolic rates.

The exposure limits in the United States were essentially set with the publication of the revised NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments in 1986[4)] and the similar thresholds published by the ACGIH® earlier. US Occupational Safety and Health Administration (OSHA) uses the same limits in its technical manual (there is no specific OSHA standard)[5)].

In summary, the exposure assessment was based a sustainable exposure (assumed minimal risk of excessive core temperature) for healthy workers wearing ordinary work clothes. The NIOSH criteria document[4)] also promoted many components of what can be described as a heat stress management program.

The WBGT exposure assessment method is widely accepted by occupational safety and health professionals in the United States. Its acceptance is helped by the fact that an exposure limit that is sustainable for a day is also consistent with most chemical and other physical agent exposure limits.

Where We Are

By the 1990s, the ACGIH® Physical Agents Committee decided to address two issues. The first was that many workplaces were moving away from the standard cotton work uniform and that different clothing requirements needed to be addressed. Second, some guidance was necessary for indeterminate exposures or exposures above the sustainable threshold.

To address the issue of clothing, the ACGIH® opted for clothing adjustment factors to account for the heat stress burden of some protective clothing ensembles[6]. The clothing adjustment factors were quantified at a point near the sustainable exposure limit and are not sensitive to metabolic rate[7]. For woven clothing and some non-woven clothing with low to moderate evaporative resistance, the clothing adjustments are not sensitive to the water vapor pressure. With high evaporative resistance, the computed adjustment changes with water vapor pressure[8]. In this case, the ACGIH chose protective values. The current version of the TLV® for heat stress and strain lists clothing adjustment factors for six ensembles[6]. Other values are available in the literature and open sources.

When the heat stress exposure is above the occupational exposure limit, the ACGIH® recommends an exposure method that accounts for higher (unsustainable) exposures over shorter periods of time[6]. Specifically mentioned is Predicted Heat Strain[9], which is an ISO standard (ISO 7933)[10].

Sometimes, the exposures are indeterminate, above the exposure limit using WBGT, Predicted Heat Strain, etc., or simply stipulated as being high without an exposure assessment. In these cases, the ACGIH® recommends that physiological (heat strain) monitoring be used to demonstrate adequate control[6]. Criteria for heart rate and body temperature are offered, not to the exclusion of other methods or thresholds.

Outside of the ACGIH® framework, some states and employers use prevailing ambient conditions to set trigger points. These can be based on empirical relationships between ambient conditions and previous exposure assessment[11] or on models of heat stress exposure[12, 13]. This allows for real-time assessment and adjustments in work practices[11].

Both the ACGIH® and NIOSH describe elements of a heat stress management program. These are intended for health and safety professionals to help design an appropriate program in the context of their workplace.

Both the WBGT-based exposure limits and the Predicted Heat Strain implicitly assume that the metabolic rate does not decrease with increasing levels of heat stress. In many circumstances, this is unlikely to be true, but it is protective. The Thermal Work Limit[14] is an alternative heat stress evaluation scheme that describes a metabolic rate limit rather than an environmental limit, which allows self-paced workers some guidance on how to reduce their work demands.

Where We May Go

There are many aspects of occupational exposures to hot environments that would benefit from further activity. Exposure limits are largely based on laboratory studies and the risk of heat stroke based on predicted increases in body core temperature[4, 9]. There is little epidemiological evidence of heat stress exposures and health outcomes that can be used to critically evaluate the exposure assessment methods currently used.

While the WBGT-based method is basically set, a good method to translate the thermal characteristics of clothing (e.g., manikin tests) to clothing adjustment factors (or a better method to account for clothing) would expand the applicability of the WBGT method. In similar fashion, the Predicted Heat Strain would be more broadly applicable by validating an expanded range of clothing characteristics[15]. The use of smart clothing that changes thermal properties dynamically will be a greater challenge.

Physiological monitoring to demonstrate adequate heat stress management has been used for 50 years[16, 17] and real-time monitoring to limit individual exposures has greater potential for the future[18, 19]. Physiological monitoring has relied on heart rate and a surrogate measure of core temperature such as oral temperature. There are commercial systems to measure core temperature directly and that measure heart rate and skin temperature. These systems make the assessments in real time and can report the results to a remote central station. While the costs remain high for the direct assessment of core temperature, this approach can be feasible for demonstrating adequate management and for high-risk operations. There is evidence that skin temperature and heart rate can be used together to inform decisions about the degree of heat strain. Validation of less expensive systems based on heart rate and skin temperature is timely.

Associated with the validation of personal monitoring is the analysis framework. Usually, validity is established by showing a linear relationship between the personal monitoring metric and a gold standard for heat strain (e.g., skin temperature vr. core temperature). There are methods that account for the repeated measures nature of personal monitoring and do not require a linear relationship to a gold standard[20]. These should be considered in future validation studies.

Heat stress management programs are based on traditional occupational health and safety program elements and the science behind risk factors and the exposure mechanisms. The ACGIH® outline[6] is simply an example where the general controls address the common risks to health associated with all heat stress exposures. These include training programs, heat stress hygiene practices and environmental and medical surveillance. The job specific controls follow guidance over the past 50 years and are framed in the traditional hierarchy of engineering controls to eliminate or reduce the hazard, administrative controls to manage the exposure to the hazard, and personal protection to provide a micro-environment that better supports heat loss. An open issue is how well individual components of heat stress management programs work and their relative influence on risk reduction. This is especially true for training programs, heat stress hygiene activities, and administrative controls that require individual judgment (e.g., self-pacing).

Another feature of heat stress exposures is the demonstrated increase in unsafe behaviors[21] and acute injuries[22, 23] as well as the loss of productivity[24] and the possible effects on product quality. This calls for epidemiological studies focused on all heat-related disorders as well as other outcomes like acute injury, and effects on productivity and quality metrics. With these data, the exposure assessment can be revisited with all outcomes considered. A further consideration is the evaluation of personal monitoring and relevant thresholds.

Summary

The methods for exposure assessment that include the job risk factors of work demands and environment are fairly mature. There are basic approaches to accounting for clothing that show promise.

Future efforts would be well spent (1) validating easy and economical methods of personal monitoring, (2) evaluating the effectiveness of heat stress management programs, and (3) performing epidemiological studies that consider a range of outcomes that include heat-related disorders, acute injuries, personal monitoring metrics, and productivity and quality metrics.

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