Understanding Heat Stress for Workers in the Electric Power Industry

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EPRI Project Manager

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ABSTRACT

Electric utility field workers are regularly exposed to thermal challenges in their work environments that can negatively impact their health and safety, according to recent research by the Electric Power Research Institute (EPRI). For example, many electric utility field workers may experience occupational heat stress that can cause serious, even fatal health consequences in extreme situations. Due to their simplicity and relative ease of use, the Threshold Limit Values (TLVs®) for Heat Stress and Strain published by the American Conference of Governmental and Industrial Hygienists (ACGIH®) have become the most widely recommended heat exposure guidelines. The TLVs aim to prevent a worker's core temperature from rising above a predefined threshold of 38.0 degrees Celsius (°C) or 100.4 degrees Fahrenheit (°F).

In the present research, two studies found that while the TLVs® may provide an effective strategy to manage the level of thermal strain experienced by workers in hot environments, adjustments that consider the unique manner in which work is performed in the electric utility industry should be considered. This includes special consideration of all factors that contribute to heat stress (i.e. protective clothing, hydration status, worker age, others).

Keywords
Heat stress
Utility workers
Work exposure guidelines
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Thermometry
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KEY RESEARCH QUESTION

Given that electric utility field workers perform physically demanding tasks while exposed to hot environments in both the power delivery and generation sectors, do currently accepted guidelines for heat stress management -Threshold Limit Values (TLVs®) published by the American Conference of Governmental and Industrial Hygienists (ACGIH®) – provide an effective heat management strategy to mitigate increases in core temperature during physically demand work in the heat?

RESEARCH OVERVIEW

In a series of research trials, physiological responses were assessed using the TLV-prescribed work exposure limits for moderate-to-heavy intensity work (semi-recumbent cycling) at different WBGTs (Wet Bulb Globe Temperatures) in younger (Study 1) and older (Study 2) workers. The first work protocol performed by both younger and older workers was 2 hours (120 minutes) of continuous work at 28°C WBGT (CON[28.0°C]). The younger workers also performed three 2-hour protocols consisting of intermittent work bouts (15 minutes in duration) adjusted for increases in WBGT. These protocols were equivalent to total work durations of 90, 60, and 30 minutes, respectively. Due to the higher level of physiological strain experienced by older workers relative to their younger counterparts, the older workers performed only the first two intermittent protocols.

KEY FINDINGS

- Many of electric utility field workers are subject to occupational heat stress. Over the course of a work shift, employees may experience substantial fluid loss due to elevated sweat rates. These conditions could place workers at higher risk for serious heat-related injuries, especially when working consecutive shifts.
- Furthermore, since electric utility field workers face physically demanding work conditions but (a) may work in a dehydrated state, and (b) may have difficulty pacing their work output, these individuals may be at an elevated risk of experiencing potentially dangerous levels of physiological strain.
- Because of their simplicity and relative ease of use, the ACGIH TLVs have become the most widely recommended guidelines for managing heat stress in workers who must labor in hot environments. However, based on the present research conducted by the University of Ottawa, relying on the current TLVs do not consider the unique manner in which work is performed in the electric utility industry and therefore may not provide adequate protection against heat stress and significant health effects especially in more extreme heat conditions.
- Since workers evaluated in this study were healthy, physically active men who were well-hydrated and heat-acclimated by their physical training, it is likely that physiological strain would be greater in individuals who are not heat-acclimated, less fit, poorly hydrated, and/or experiencing chronic health conditions (*e.g.*, obesity, type 2 diabetes, hypertension, others) known to impair the body's ability to dissipate heat.

WHY THIS MATTERS

The key findings from EPRI research underscore the potentially negative physiological consequences of heat stress for worker health and safety. It is an appropriate next step to apply these findings—combined with an advanced understanding of heat stress monitoring technologies—and to inform management options and strategies that electric utility professionals can use to protect the workforce at their companies.

HOW TO APPLY RESULTS

Results suggest there is a need to inform appropriate adjustments in work exposure limits to better protect workers during work in the heat that considers the influence of the manner in which work is uniquely performed in the power delivery and generation sectors. Further, the results highlight the need to encourage hydration before, during, and after work shifts, as well as basic physiological monitoring (*e.g.*, hydration status, perceived level of physical exertion, thermal comfort, and heart rate). Before heat stress management strategies and monitoring insights are developed in planned future EPRI research utility managers may want to consider these key findings while implementing existing programs.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- *2016 Heat Stress Supplemental Study Phase II Research Results: Heat Stress Experienced During Electrical Utilities Work Over Consecutive Work Shifts.* EPRI, Palo Alto, CA: 2016. 3002009459.
- *2016 Heat Stress Supplemental Study Phase I Research Results: Effects of Work Uniforms on Whole-Body Heat Dissipation during Exercise in the Heat.* EPRI, Palo Alto, CA: 2016. 3002009496.
- *An Evaluation of the Physiological Strain Experienced by Electrical Utility Workers in North America.* EPRI, Palo Alto, CA: 2015. .3002006900.
- R. D. Meade, M. P. Poirier, A. D. Flouris, S. G. Hardcastle, and G. P. Kenny, "Do the Threshold Limit Values for Work in Hot Conditions Adequately Protect Workers?" Medicine & Science in Sports & Exercise. Vol. 48, No. 6, pp. 1187–1196 (2016).
- Follow-on work to develop heat stress management strategies and options is planned for 2017–2021 under the sponsorship of Program 62, Occupational Health and Safety. Also, an EPRI Technology Innovation-funded heat stress monitors/sensors project is under way (2017), and a second phase will include field testing and efficacy evaluation, as part of the overall heat stress management strategies and options project. Taken together, this heat stress work is relevant to all sectors within EPRI.

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PROGRAM: Occupational Health and Safety, Program 62

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LIST OF TERMS

ACGIH®	American Conference of Governmental and Industrial Hygienists
BL	Baseline
CDC	Centers for Disease Control and Prevention
CON	Continuous
°C	degrees Celsius
°C/min	degrees Celsius per minute
°F	degrees Fahrenheit
EPRI	Electric Power Research Institute
ISO	International Organization for Standardization
min	Minute
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
pbm	beats per minute
TLV®	Threshold Limit Value
WBGT	wet-bulb globe temperature
WR	work-to-rest (ratio)
Δ	Change
ΔTre	change in rectal temperature

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INTRODUCTION

Recent research by the Electric Power Research Institute (EPRI) has shown that electric utility workers are regularly exposed to thermal challenges in their work environments that can negatively impact their health and safety [1–3]. For example, many electric utility fieldworkers are subjected to occupational heat stress.[1] Over the course of a work shift, most of these employees also experience substantial fluid loss due to elevated sweat rates. These conditions place workers at higher risk for serious heat-related injuries [1–3], especially when working consecutive shifts. Employees in a recent study [3] experienced marked heat and cardiovascular strain during a second shift relative to a first shift—despite decreasing work output. This result suggests that consecutive work shifts may place workers at greater risk for heat- and/or work-related injury.

Occupational Safety and Health Administration (OSHA) requires employers to provide workplaces free of known safety hazards. Moreover, OSHA mandates that an employer of workers exposed to high temperatures must establish a complete heat illness prevention program. Although OSHA issues citations in cases of heat illness or death, it offers limited guidance in how best to implement a heat illness prevention program. Therefore, industry must rely on available heat exposure guidelines and management solutions to protect workers. Due to their simplicity and relative ease of use, the Threshold Limit Values (TLVs®) for Heat Stress and Strain published by the American Conference of Governmental and Industrial Hygienists (ACGIH®) [4] have become the most widely recommended heat exposure guidelines. The TLVs are endorsed by OSHA, the Centers for Disease Control and Prevention (CDC), the National Institute for Occupational Safety and Health (NIOSH), and others. Although the TLVs are the most widely used guidelines for managing heat stress in workers who must perform tasks in hot environments, limited information is available regarding their applicability to the electric power industry workforce.

Studies show a high degree of variability in the type, duration, and intensity of work performed within and between various occupations [1,2,5,6]. This variability is paralleled by marked differences in time-dependent changes in a worker's body core temperature (core temperature). The TLVs aim to prevent a worker's core temperature from rising above a predefined threshold of 38.0 degrees Celsius (°C) or 100.4 degrees Fahrenheit (°F).

The TLVs consist of work-rest allocations considering two key factors that influence body heat exchange—environmental conditions and work intensity. Environmental conditions are expressed as wet-bulb globe temperature (WBGT), while work intensity is estimated as light, moderate, heavy, or very heavy. The TLVs are designed to limit heat strain for workers by allowing their bodies to achieve heat balance. Heat balance occurs when the rate of

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[1] Occupational heat stress is the net load to which a worker is exposed from the combined contributions of metabolic heat production, environmental factors, and clothing worn. This net load causes an increase in body heat storage and therefore, body core temperature. Heat stress can result in heat-related illnesses, such as heat rashes, heat cramps, heat exhaustion, or heat stroke.

environmental and/or metabolic heat gain is matched by the rate of total heat loss from the body, resulting in a stable core temperature that does not exceed 38.0˚C (100.4°F) for extended periods [4].

Recent research, conducted at the University of Ottawa under EPRI sponsorship, showed that North American electric utility workers who regularly work under hot ambient conditions, had highly elevated levels of heat and cardiovascular strain during work in the heat [1,2]. The majority of monitored workers (75%) had core temperatures equal to or greater than 38.0˚C (100.4°F) [1,2]. Moreover, this research showed that some workers had core temperatures above 39.0°C (102.2°F), while others had temperatures exceeding 39.5°C (103.1°F) [1] (Figure 1-1).

Despite the fact that the proportion of the work shift spent at rest tended to increase over consecutive days of work, peak core temperatures also increased over the same period [3].

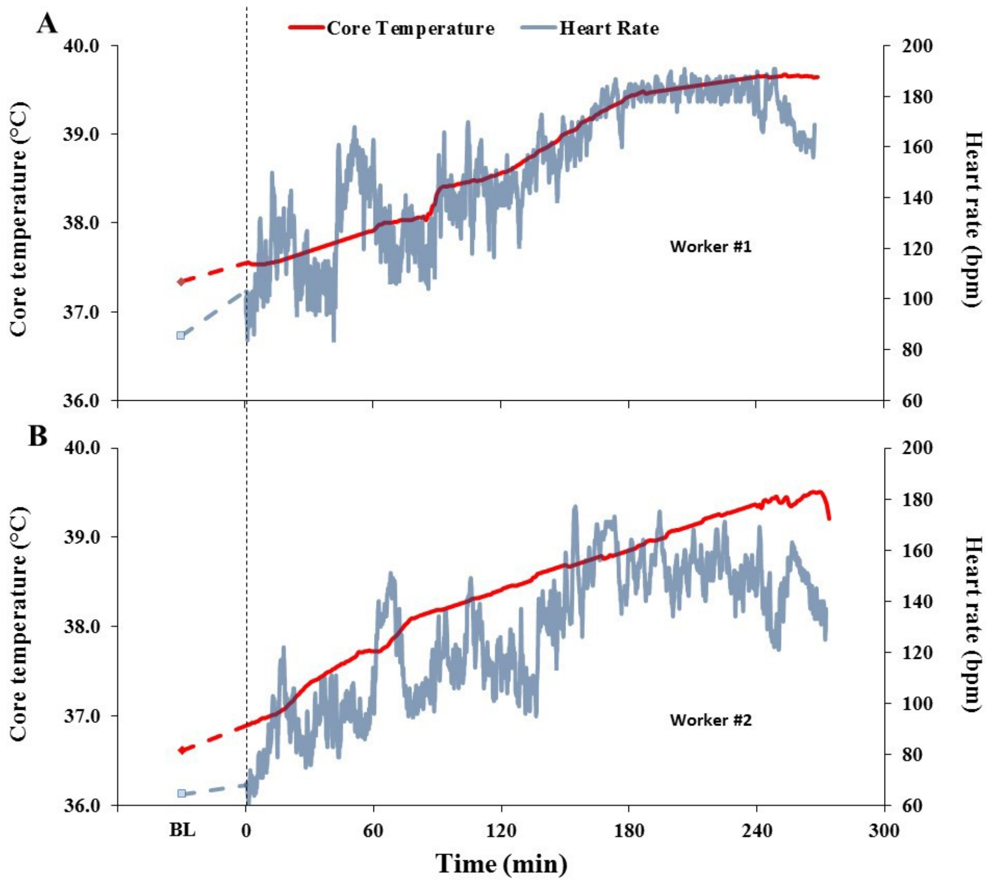

Figure 1-1
Isolated cases of severe heat stress in electric utility workers during work in hot ambient conditions

Both workers spent more than half of the work period at a core temperature above 38.5°C (101.3°F). However, their thermal sensation and perceived exertion scores were comparable to those measured in other workers tested during the same exposure. Both workers reported to work dehydrated and remained dehydrated at the end of their work shift. BL = baseline resting; bpm = beats per minute.

Observations of an elevated and sustained level of heat strain experienced by electric utility workers is particularly concerning, given the fact that more than 70% of the work activities conducted during the work shift were considered to require very light (rest) to light levels of physical effort [1,2] (Figure 1-2).

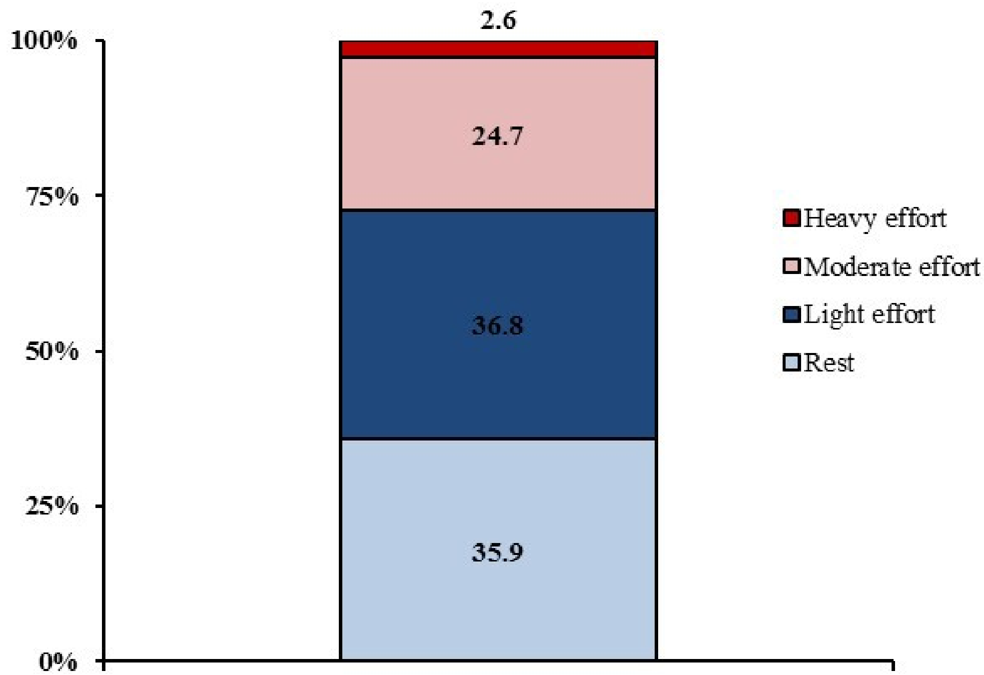

Figure 1-2
Mean proportion of time spent by electric utility workers at different levels of physical effort during an entire work shift

The classification of physical effort is defined by International Standards Organization (ISO) 7243; Light blue = rest, Dark blue = light effort, Light red = moderate effort, Dark red = heavy effort.

Despite this relatively light level of physical effort, workers experienced hyperthermia. Of the thirty-two electric utility workers assessed, 75% exceeded a core temperature of 38.0°C (100.4°F), while more than 20% exceeded a core temperature of 38.5°C (101.3°F) [1]. In fact, 50% of all workers performing manual pole work experienced some of the largest increases in core temperature. In parallel with the elevated state of hyperthermia experienced by many workers over the course of their shift, all workers experienced significant cardiovascular strain that was worsened by a progressively greater state of dehydration [1]. For all workers, peak heart rates (as defined by 220 minus age) were attained (and in many cases sustained) over the work period [1].

Taken together, these findings suggest that electric utility field workers face physically demanding work conditions. This information—combined with previous research that workers (a) are likely to work in a dehydrated state [1,2], and (b) have difficulty in pacing their work output [2]— indicates that these individuals may be at an elevated risk of experiencing potentially dangerous increases in core temperature paralleled by elevated levels of physiological strain (*i.e.,* elevated heart rates, general fatigue, *etc.*).

2
STUDY OBJECTIVE

The present study examined the physiological strain experienced by electric utility workers as they performed moderate-to-heavy work in a controlled laboratory setting. Workers typically perform at this level of effort over about 30% of their work shift [1]. The objective of the study was to determine whether application of the TLVs, as recommended by regulatory bodies such as OSHA, is an effective heat management strategy to mitigate potentially dangerous increases in core temperature during work requiring major effort.

Responses were examined in younger (21 ± 3 years of age) and older (58 ± 5 years of age) workers to best represent the age demographics of electric utility workers. Natural aging has been shown to impair the body's ability to dissipate heat, even in physically active adults as young as 40 years of age [7]. As a consequence, middle-aged and older workers can experience greater levels of physiological strain during work, especially in the heat [8]. The ultimate goal of this research is to understand the physiological responses of electric utility workers, as shown by applying the TLVs, in order to inform appropriate adjustments in work exposure limits that help prevent potentially dangerous increases in core temperature during job performance.

In a series of research trials, physiological responses were assessed using the TLV-prescribed work exposure limits for moderate-to-heavy intensity work (semi-recumbent cycling) at different WBGTs in younger (Study 1) and older (Study 2) workers. The first work protocol performed by both younger and older workers was 2 hours (120 minutes) of *continuous* work at 28°C WBGT (CON[28.0°C]). The younger workers also performed three 2-hour protocols consisting of *intermittent* work bouts (15 minutes in duration) adjusted for increases in WBGT:

1. Work-to-rest (WR) ratio of 3:1 at 29°C (WR3:1[29.0°C]);
2. WR ratio of 1:1 at 30°C (WR1:1[30.0°C]); and
3. WR ratio of 1:3 at 31.5°C (WR1:3[31.5°C]).

These protocols were equivalent to total work durations of 90, 60 and 30 minutes, respectively. Due to the higher level of physiological strain experienced by older workers relative to their younger counterparts, the older workers performed only the first two protocols (listed as 1 and 2 above).

Detailed descriptions of these studies are available in the published literature at:

- Study 1 (younger workers) *Medicine & Science in Sports & Exercise* [9] http://dx.doi.org/10.1249/MSS.0000000000000886
- Study 2 (older workers) *Journal of Occupational and Environmental Hygiene* [10] http://dx.doi.org/10.1080/15459624.2017.1321844

Section 3 provides a brief overview of the findings for each of the two studies.

3
RESULTS

Study 1—Younger Workers

In this research, heat balance (and therefore, stable core temperature) was not achieved when the TLVs were applied to younger workers performing short-duration (2-hour) moderate-to-heavy intensity work—the level of effort typically exerted by electric utility field workers over about 30% of their work shift [1,2] in a hot environment [9]. Specifically, while average rectal temperature in younger workers did not exceed 38.0˚C (100.4˚F), heat balance was not achieved during exercise in any work conditions—*i.e.*, the rate of change in rectal temperature was greater than 0°C per minute in all conditions, signaling that the body was continuously gaining heat (Figure 3-1). Based on this finding, if the work period is projected to 4 hours, younger workers might experience increases in core temperature that could exceed safe work limits (*i.e.*, > 38.0°C, [100.4˚F]) (Figure 3-2). Taken together, these findings show that in the absence of adjustments in work exposure and/or work effort, younger workers may experience unsafe increases in core temperature if the TLVs were applied during work in hot conditions.

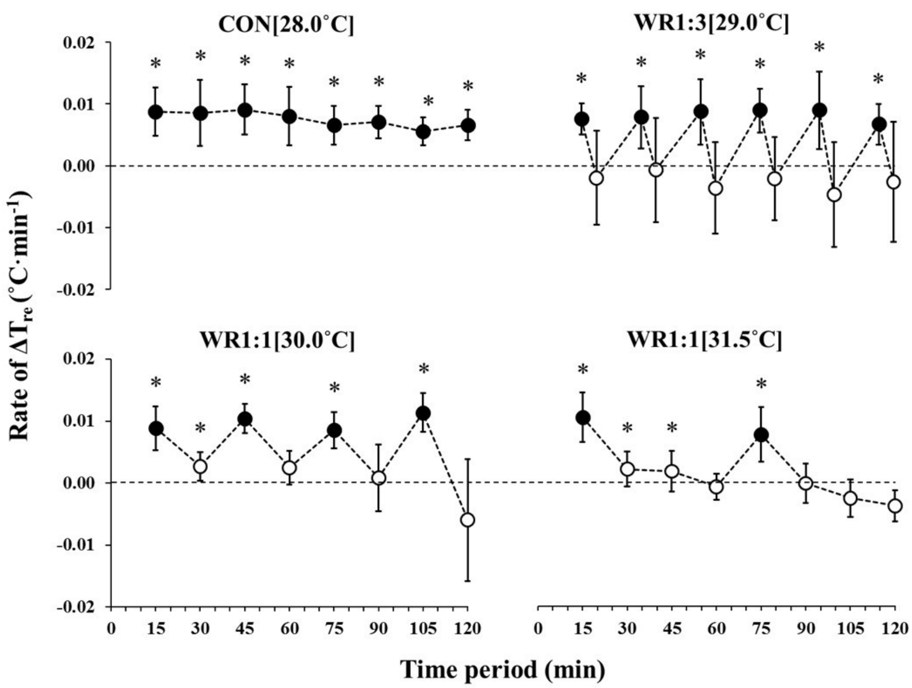

Figure 3-1
Rate of change in rectal temperature (rate of ∆Tre; °C/min) for younger workers during work (filled circles) and recovery (open circles) in each 2-hour work protocol

*Values represent the average rate of ∆Tre calculated over the preceding 5-minute interval. Data are presented at 15-minute intervals for CON[28°C], WR1:1[30.0°C] and WR1:3[31.5°C], whereas for WR3:1[29.0°C], data are provided at the end of each 15-minute work bout and 5-minute recovery period. Horizontal dashed lines indicate no change in rectal temperature. * = significant rate of ∆Tre. Reprinted from Medicine & Science in Sports & Exercise.*

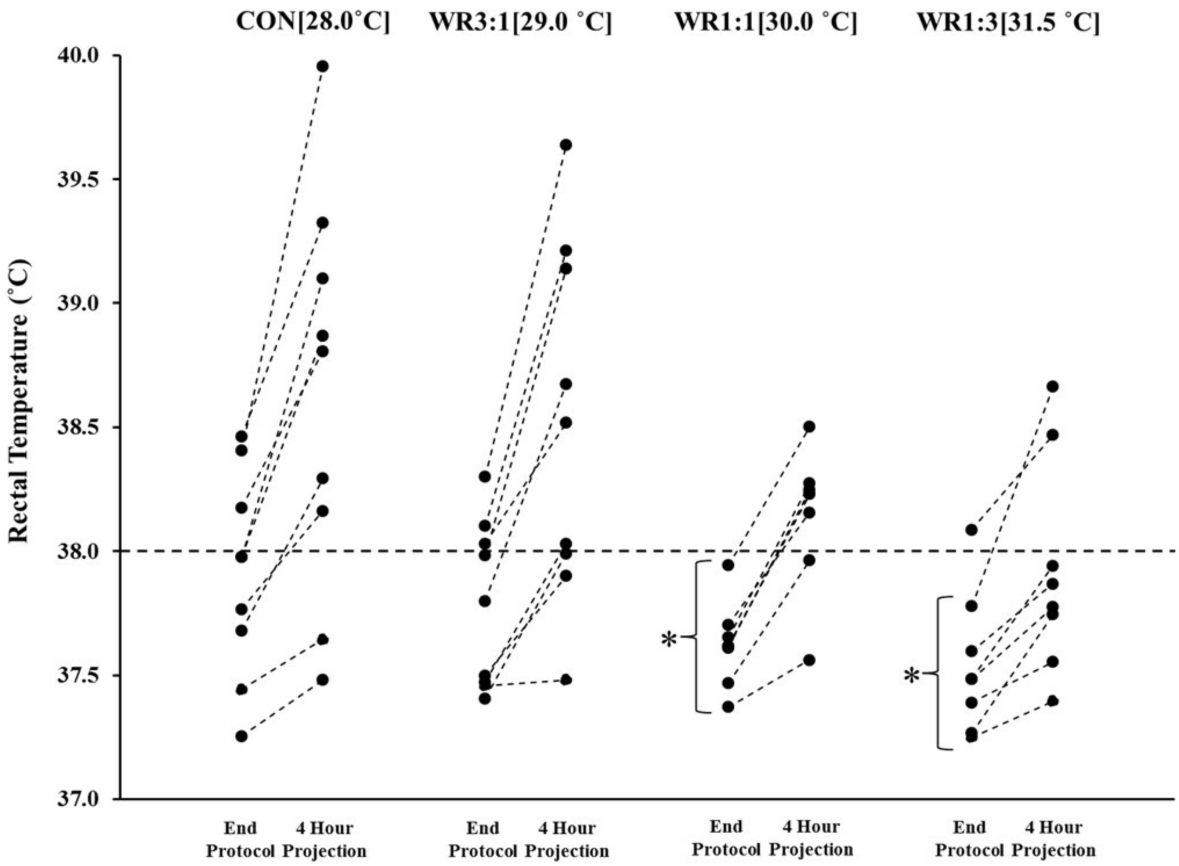

Figure 3-2
Rectal temperature at the end of the 2-hour work protocol and at the projected 4-hour time point

The 4-hour time point is calculated based on the average rectal temperature increase recorded over the last hour of each work protocol. Horizontal dashed lines indicate the TLV upper limit core temperature threshold of 38.0°C (100.4˚F). Reprinted from Medicine & Science in Sports & Exercise.

A secondary, but key finding was the observed difference in the level of heat stress shown by direct calorimetry (measurement of body heat storage) compared with that shown by thermometry (measurement of rectal temperature). Specifically, while the amounts of heat stored in the body measured in each of the four work protocols (performed under increasing WBGT) were similar, a greater change in mean body temperature was observed with direct calorimetry compared with thermometry in all three intermittent work protocols (Figure 3-3).

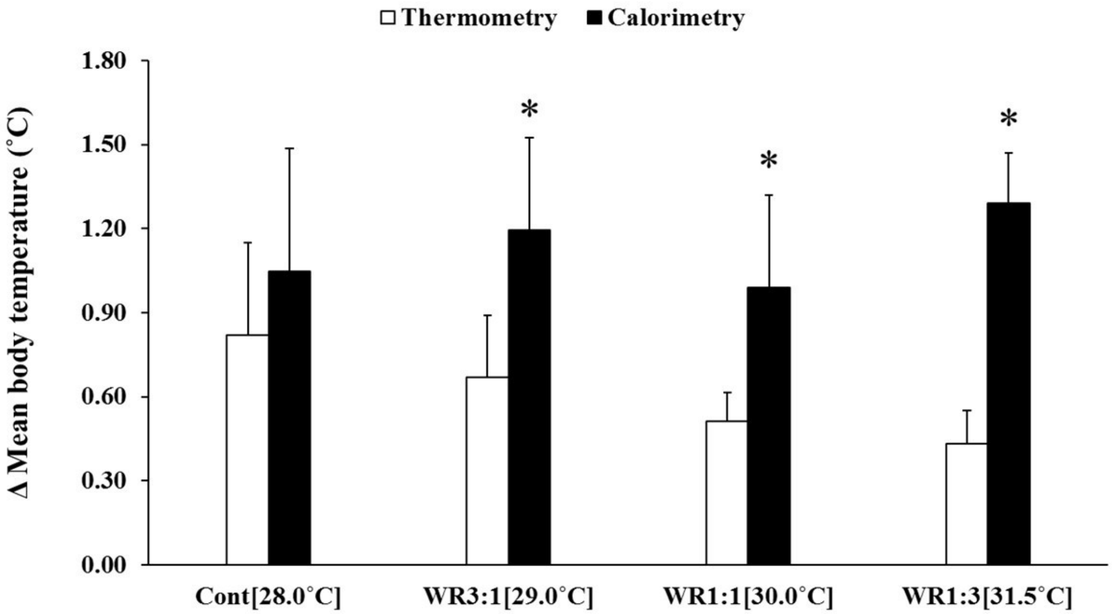

Figure 3-3
The change (Δ) in mean body temperature (℃) at the end of each work protocol calculated *via* thermometry (white bars) and direct calorimetry (black bars)

** Significant difference versus thermometry. Reprinted from Medicine & Science in Sports & Exercise.*

Why is this information important? When applying a criterion core temperature—such as that used in the TLVs—to define exposure limits for work in the heat, it is important to understand whether this value represents an accurate measure of heat strain experienced by the worker.

Measurement of body heat storage by direct calorimetry shows precisely how much heat is stored in the body. In a theoretical example, if (a) 100 specialized telemetric microspheres[2] were infused into the circulatory system (blood) of the body and (b) these microspheres were detected by using a receiver located in a calorimeter and also by using core temperature sensors inserted into the rectum and the esophagus, the calorimeter would determine that there are 100 microspheres in the body. In contrast, the core temperature sensors in the rectum and esophagus would detect only those microspheres that were in close proximity to them. While the core temperature sensors might track only the 15 microspheres close to the rectum and the 21 microspheres close to the esophagus for example, they would neglect the remaining microspheres distributed throughout the body. It is important to note that the calorimeter can determine that there are a total of 100 microspheres in the body, but it is unable to provide information about their specific locations.

By combining measurements derived from thermometry and direct calorimetry, the present study demonstrates, for the first time, that the TLVs affect heat exchange (i.e., heat distribution) differently during different work scenarios—leading to different core temperatures, albeit similar levels of body heat storage and similar levels of hyperthermia. This finding suggests that only

[2] A microsphere is a tiny (micron-diameter) spherical shell made of biodegradable or resorbable plastic polymer. In this example, the presence of a specialized microsphere could be sensed by remote (telemetric) detection.

measuring workers' core temperature may under-estimate the worker's state of hyperthermia. In this context, it is likely that the level of heat strain previously measured in the electric utility workers under field conditions may in fact, be greater than previously thought.

Study 2—Older Workers

A key limitation of the TLVs is the assumption that the guidelines are generalizable to all workers irrespective of age and other factors, such state of health, fitness, *etc*. For example, the TLVs do not consider age-related impairments in the body's ability to dissipate heat. In recently completed trials discussed above [10], middle-aged adults performed the same work protocols as their younger counterparts, except they did not complete the WR ratio of 1:3 at 31.5°C (which had previously been shown to result in the lowest level of heat strain). When the TLVs were applied under the same conditions for middle-aged workers (about 45 to 55 years old, an age range similar to that of a cohort of electric utility workers previously assessed in the field), heat balance was not achieved during exercise in any work conditions. As for the younger workers, the rate of change in rectal temperature was greater than 0°C per minute, signaling that the body was continuously gaining heat. Consequently, mean rectal temperature exceeded 38.0°C (100.4˚F), and the time needed for rectal temperature to exceed 38.0°C decreased as total work duration increased.

For a large proportion of the older workers, core temperature exceeded 38.5°C (101.3˚F), the upper limit permitted for brief periods in heat-acclimated workers (Figure 3-4). In some participants, core temperature peaked at or above 39.0°C (102.2˚F) [10,11] after only a 2-hour work period. Finally, core temperatures were estimated to exceed 39.5°C (103.1˚F) over a 4-hour work period (*i.e.*, exposure typical of pre- and post-lunch break work periods). These results are consistent with recent field observations [1] in which measurements showed dangerous, sustained increases in core temperatures of nearly 40°C (104.0˚F) in some middle-aged electric utility workers over a 4-hour monitoring period (see Figure 1-1). Taken together, these findings suggest that age-dependent adjustments in work-rest allocations are required to ensure that workers do not experience unsafe increases in their level of thermal strain.

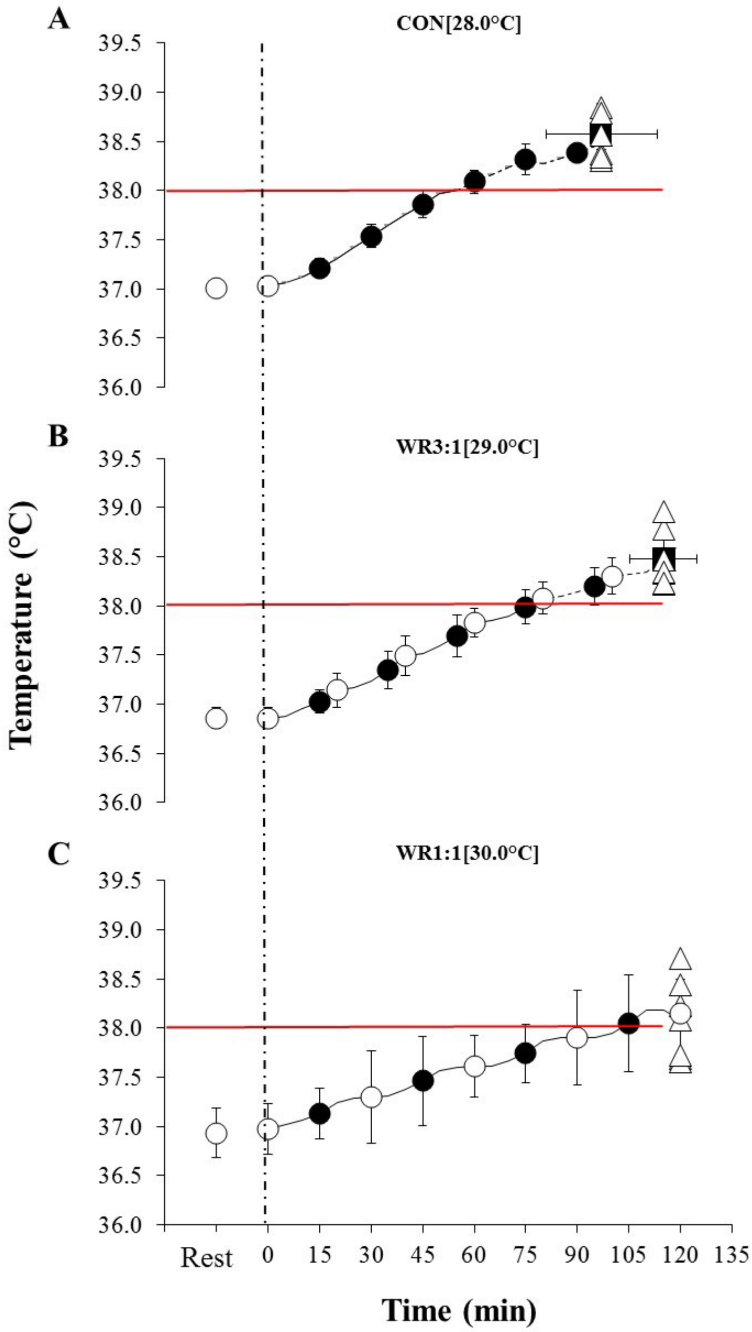

Figure 3-4
Rate of change in rectal temperature (rate of ∆Tre; °C/min) for older workers during work (filled circles) and recovery (open circles) in each 2-hour work protocol

Values represent the average rate of ∆Tre calculated over the preceding 5-minute interval. Data are presented at 15-minute intervals for CON[28°C], WR1:1[30.0C] and WR1:3[31.5°C]. Vertically stacked open triangles represent individual rectal temperatures at the end of the work protocol. Horizontal red lines indicate the TLV upper limit core temperature threshold of 38.0°C (100.4˚F).

4
CONCLUSIONS

While multiple heat exposure guidelines are available to industry, by far the most widely used guidelines in North America are the ACGIH TLVs for Heat Stress and Strain, recommended by OSHA, CDC, NIOSH, and others. However, results from EPRI-sponsored laboratory studies show that both younger and older (middle-aged) workers can experience sustained increases in core temperature that far exceed the TLV-defined safe limit of 38.0°C (100.4˚F) while performing moderate-to-heavy intensity work in the heat under work-rest allocations specified in the TLVs [10,11]. This response pattern was also observed in electric utility workers performing their regular duties under field conditions [1].

Observations in the laboratory also show that middle-aged workers generally experience core temperature increases that are about 0.5–1.0°C higher than those of their younger counterparts. This heightened response places middle-aged workers at an elevated risk of a heat-related injury (*e.g*. heat exhaustion, heat stroke) while performing the same work.

Taken together, these findings suggest the need to consider new approaches and guidelines at least with respect to electric utility workers who perform their duties in hot environments. In the context of applying the TLVs, this will require research to inform the adjustments in work-rest allocations needed to ensure that core temperature does not exceed safe limits, except for very brief periods (*e.g*., when physically demanding work must be performed for only a few minutes). While the correct assessment of work rate and environmental conditions is critical to defining safe work durations, the present research demonstrates that worker age is an equally important factor to consider.

In the present research, the level of heat strain indicated by the highly accurate technique of direct calorimetry (which measures the amount of heat stored in the body) differs from that indicated by thermometry (which uses esophageal and rectal measurements to estimate core temperature). Given this disparity, future studies are needed to determine how changes in core temperature should be interpreted when the TLVs are applied for different ambient conditions and work intensities.

Using the TLVs, the present findings suggest that the majority of electric utility field workers may experience hyperthermia while performing their duties in very high-temperature and high-humidity environments, or when wearing protective clothing that restricts the body's ability to dissipate internal heat [12]. Other peer-reviewed research has shown heat stress is an underlying cause for many workplace accidents and injuries. Heat stress impairs mental function, dexterity and coordination, physical performance [14,15], and productivity [16]. Furthermore, the physical discomfort associated with elevated core temperature promotes irritability, anger, and other emotional states—often causing individuals to overlook safety procedures or become distracted while performing their duties [17]. Additionally, working continuously under heat stress can lead to a decline in health, reduced physical capacity, and increased psychological distress [18]. Thus, the potential for accidents and injuries to occur as a result of heat-induced disorders can represent a greater health and safety risk than the disorders themselves. Therefore, there can be multiple benefits from improvements in heat stress management strategies and options to better protect electric utility workers from experiencing potentially dangerous increases in core temperature during work in the heat.

5 RECOMMENDATIONS

The electric power industry faces important challenges in protecting the health and safety of its workers. Many electric utility field workers experience occupational heat stress associated with an elevated risk of heat-related injury or death. Even in cool and temperate environments, the high physical demands of field work combined with heat loss restrictions of protective clothing may cause some workers to experience dangerous increases in core temperature that severely compromise their performance [1,2]. OSHA requires employers to provide workplaces free of known safety hazards. Compliance with the law includes providing a heat-illness prevention program [19] for workers exposed to high temperatures. However, as shown above, application of the TLVs recommended by OSHA for the management of heat stress do not consider all factors of heat stress and may not protect workers from potentially dangerous increases in core temperature, or hyperthermia [9]. This is especially true for the most vulnerable workers—those 40 years of age and older [10,11]. The TLVs do not consider personal factors such as sex, fitness, hydration, and health status (i.e., presence of chronic disease) which are known to affect an individual's ability to dissipate body heat [20]. Other factors, such as work shift frequency and duration—which have been shown to influence the physiological strain experienced by electric utility workers performing tasks in the heat [3]—are also not considered.

Given these insights, the electric power industry might consider taking steps to:

- define effective management strategies for workplace heat stress; and
- identify technologies and protocols for monitoring physiological strain during work, especially in the heat.

Informing Management Strategies

Further work is recommended to inform the current TLVs in order to define appropriate work exposure limits that protect all electric utility field workers. This can be achieved by building on EPRI's leading-edge research to improve knowledge of the relationships among occupational risk factors, the incidence of occupational heat stress, and underlying heat stress mechanisms.

Occupational risk factors to be addressed by preventive and reactive measures include:

- demographics—age, physical fitness, health status, level of worker experience;
- shift schedules—work duration, break intervals, rest between work shifts;
- weather events—heat waves, high humidity;
- clothing—personal protective gear that provides maximal heat transfer; and
- physiology—acclimation status, fluid intake verified by hydration monitoring, *etc*.

The important research steps recommended here could support improved management of occupational heat stress.

To ensure maximum impact, protective information about occupational heat stress management gained from this research can be transferred through EPRI-sponsored workshops and on-site training sessions tailored to the needs of interested electric utility companies. Further, this information can be used to develop a “heat stress management information card”—a pocket-sized card carried by workers as a quick reference guide to best practices for avoiding the detrimental effects of occupational heat stress.

Monitoring Physiological Strain

As noted above, the TLVs may not take into account individual variation in the heat stress response, which is known to be influenced by many factors such as physical fitness, age, body composition, health status, etc. [20]. Furthermore, these exposure guidelines are based on a core temperature limit of 38.0°C (100.4°C)—which itself is problematic because core temperature varies greatly among individuals and may not reflect the true thermal state of a worker’s body [20]. To prevent potentially catastrophic hyperthermia, it is important to manage thermal exposures, not only in relation to extreme environmental conditions but also in relation to the variability associated with heat stress responses of individual workers.

Physiological monitoring of body temperature and heart rate during work and recovery in workers exposed to hot environments was first recommended by NIOSH in 1986 as a practical simple approach to protecting workers from heat-related illnesses or injuries.

Monitoring of a worker’s physiologic responses to heat stress provides a quantitative basis for assessing the risk of heat-related injury faced by that individual. This approach takes into account individual variation in those factors (listed above) known to affect heat tolerance, thus permitting researchers to track the actual strain experienced by each individual [20–24].

Physiological monitoring offers quantitative data that supports a greater level of confidence in the assessment of individual responses to heat stress in the workplace. Moreover, physiological monitoring takes the impact of personal protective clothing and equipment into account.

Ultimately, the design and implementation of a physiological monitoring program may help minimize the risk to workers’ health and safety from heat hazards in the workplace.

As a first step in such a program, it will be important to identify appropriate technologies for monitoring the effects of heat stress on physiological strain experienced by personnel in power generation and delivery working environments. This will require the development, prototyping, and testing of a system suitable for use in the electric power industry to monitor workers under different work conditions (*e.g.*, pole work, nuclear plant operations, coal pulverizer operation, *etc*.).

The monitoring program also will require research on how best to interpret physiological responses, especially in the most vulnerable, heat-intolerant workers. While it is important to identify and select appropriate technologies for physiological monitoring of individuals in high-risk work environments, it is equally important to correctly interpret the physiological responses observed and to define acceptable limits for increases in those responses to heat stress.

EPRI’s on-going research in this area will address both monitoring technology and the interpretation of the data they provide, along with their role in overall heat stress management strategies and options relevant to the electric utility industry.

6
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