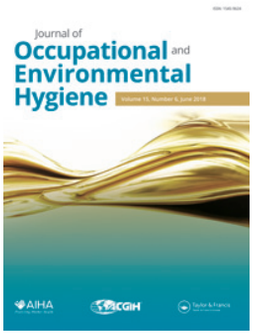

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SHORT REPORT

Evaluation of heat stress and heat strain among employees working outdoors in an extremely hot environment

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ABSTRACT

A heat stress evaluation was conducted among employees engaged in strenuous work in an extremely hot outdoor environment. Environmental conditions that contribute to heat stress along with various physiological indicators of heat strain were monitored on a task-basis for nine employees daily across four workdays. Employees performed moderate to heavy tasks in elevated environmental conditions for longer periods of time than recommended by various heat stress exposure limits. Seven of nine employees showed evidence of excessive heat strain according to criteria yet all employees were able to self-regulate task duration and intensity to avoid heat-related illness.

KEYWORDS
Heat strain; heat stress; heat-related illness; rhabdomyolysis

Introduction

Heat stress is the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment (environmental heat) minus the heat lost from the body to the environment.[1] Many bodily responses to heat stress are desirable and beneficial. However, at some stage of heat stress, the body cannot compensate resulting in internal body temperatures rising too high for normal functioning.

The body's response to heat stress is called heat strain. Heat strain manifests as a spectrum of signs and symptoms referred to as heat-related illness (HRI). HRI includes heat exhaustion, heat rash, heat cramps, and heat stroke (exertional and classical/non-exertional). In addition, engaging in strenuous physical activities in these environments increases the potential for inducing heat strain. Heat strain is highly individualized and the form of HRI it may manifest as cannot be predicted on the basis of environmental heat stress measurements alone. HRI is a leading cause of work-related fatalities. Heat stroke experienced in occupational settings is typically exertional in nature. In a 15-year period (1992–2006), it was the cause of 423 workplace fatalities nationwide.[2] Heat stroke, whether it be exertional or classical, is the most severe form of HRI and is a medical emergency that can quickly become fatal. Heat stroke results in a change of mental status while in a hot environment and can manifest as confusion, bizarre behavior, or seizures. As a result, there may be an increased risk of accidents related to impaired mental status if employees with early, unrecognized heat stroke continue working in a hot environment.

The National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) in response to employer concerns about HRI among employees engaged in strenuous work outdoors in an extremely hot environment.[3] The primary objective of the evaluation was to measure the heat stress conditions and indicators of heat strain among park employees engaged in strenuous work. In this report, we summarize the results of this HHE which took place at a national park in North America that covers 3.4 million acres with elevations ranging from 282 ft below sea level to 11,049 ft above sea level. The lower areas of the park are approximately 20° Fahrenheit (°F) (7°C) warmer than higher elevations. The HHE was conducted in July when normal average daily temperatures ranged from 88°F–116°F (31°C–47°C). This park is a very dry environment with daytime humidity peaking at 10% during summer months.[4] The park employed approximately 100 people.

Methods

While measuring heat stress conditions, we assessed employees' heat strain through core body temperature (CBT) as measured via an ingestible thermistor, and heart rate (HR) measurements. These measurements were made over the standard 4-day workweek of Monday–Thursday. Heat strain measurements were compared to

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the ACGIH® guidelines.[5] According to these guidelines, an individual's heat stress exposure should be discontinued when any one of the following heat strain indicators occur:

- sustained (over several minutes) HR that exceeds 180 bpm minus the individual's age in years for those with normal cardiac performance;
- recovery HR at 1 min after a peak work effort exceeds 110 bpm;
- CBT is greater than 101.3°F (38.5°C) for medically selected, acclimatized personnel, or greater than 100.4°F (38°C) in unselected personnel whose acclimatization status is unknown; and
- presence of symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

We modified the ACGIH criteria used to define excessive heat strain among the employees for our evaluation. For the first criterion, we defined "several minutes" to mean at least 3 min. Second, we did not use the recovery HR criterion due to the episodic nature of the tasks. Third, we surveyed employees at the end of each work shift to determine if they experienced any of the symptoms in the guidelines. Fourth, we also considered a cross-shift body weight loss >1.5% as an additional criterion indicating excessive heat strain.

All nine employees were considered acclimatized because they had worked in this hot environment during the 2 weeks prior to our evaluation. Also, they lived in housing inside the park or in towns just outside of the park borders with a similar climate.

Heat stress/heat strain assessment

A Quest Technologies QUESTemp°36 instrument was used to measure the wet bulb globe temperature (WBGT) at each work location and in cooling recovery areas. The WBGT measurements were logged at 1-min intervals during the entire workday. NIOSH staff observed all tasks (Table 1) and manually recorded the start and stop times for each task on a daily activity log sheet so task-specific average WBGT values could be calculated. This daily activity log was also used to describe each work task, its duration, the estimated metabolic load (exertion level) required to perform the task, and rest breaks. The metabolic loads were classified as rest, light, moderate, heavy, and very heavy on the basis of NIOSH and ACGIH heat stress criteria, which are the same.[1,5]

Each employee's work tasks and the estimated metabolic load for each task were grouped into approximately 1-hr time periods over 1 day. From these data groupings, a time-weighted average (TWA) exposure using the duration of each task and the average estimated metabolic load were calculated and compared to work and rest schedules recommended by NIOSH and ACGIH for acclimatized employees. All employees wore cotton work uniforms, so no clothing adjustment to the WBGT was necessary.[5]

Table 1. List of tasks evaluated.

Number of employees	Activities	Equipment used and work description
5	Removing asphalt from parking lot and preparing the lot for repaving.	About 10,000 ft^2 of asphalt removed. Equipment used included a grader, skid-steer loader, backhoe, shovels, and rakes.
2	Landscaping, property clean-up, and interior renovation of a housing unit.	Used rakes and shovels to cleanup property. Remodeled and repaired interior spaces of housing units. The housing units were not air-conditioned.
1	Mixing mortar and installing bricks.	Exterior bricklaying on a kiosk.
1	Assessing new construction locations and surveying archaeological sites.	Archaeological surveys were often off-road and remote. Occasionally the employee walked several miles through sand dunes to access the survey site. The park required the archaeologist to provide an impact assessment prior to allowing any new construction within the park.

Core body temperature (CBT)

A Philips Respironics Equivital biomonitoring system was used to measure CBT in the nine employees. The system uses an ingestible single use thermistor that takes temperature measurements as it passes through the digestive system before exiting the body with a bowel movement. After being swallowed, the thermistor transmits the CBT measurements to a receiver that is worn outside the body. The thermistor is about the size of a multivitamin and is biologically inert. Using a CBT thermistor is considered an accurate way to measure internal body temperature.[6–8]

Each CBT thermistor transmitted data every 15 sec. Employees swallowed a new CBT thermistor before starting work each morning. Each employee drank about 16 oz of water and ate 5–10 saltine crackers to help move the thermistor from the stomach into the small intestine where the most accurate CBTs are measured. At the end of each workday, the CBT data was downloaded and stored.

Heart rate (HR)

An Equivital LifeMonitor EQ02 physiological monitoring system was used to measure and store employee HR data every 15 sec throughout the workday. This system uses a chest strap sensor that contacts the skin and measures HR. The HR data were transmitted and stored on the same receiver worn by the employee to collect the CBT data.

Table 2. Employees meeting our evaluation criteria for excessive heat strain.

Heat strain criterion	Employees who met criteria at any time during testing (n = 9)
Heart rate > 180 minus age in years for three or more minutes	5
CBT > 101.3°F (38.5°C)	1
Symptoms of sudden and severe fatigue, nausea, headache, dizziness, rash, feeling faint or lightheadedness	3
Weight loss over a shift > 1.5% of body weight	1

Results

Nine employees (8 male and 1 female) participated in the evaluation. Their average age was 46 years (range: 28–59 years). The average duration of employment at this location was 8 years (range: 2–23 years). None of the 9 employees followed a set work/rest cycle (e.g., work 45 min then rest 15 min) on the basis of environmental conditions noted in the NIOSH heat stress guidelines.[1]

Work tasks/park policy

We observed employees shoveling rocks, laying brick, trimming trees, and raking debris regardless of the hour of the day or the environmental conditions. All employees took rest breaks and drank fluids at their own discretion. Vehicles were not left running with the air conditioning on which is a park policy so employees would have access to a cool environment to rest and recover when working in remote areas.

NIOSH staff observed several work practices that could increase the risk for HRI. First, we observed an inconsistent use of the buddy system. We noticed poor communication between employees and the park safety officer regarding employee work locations. Effectiveness of radio communications was limited as employees were often observed leaving their handheld radios out of earshot instead of carrying them as they moved between work locations at a single site (i.e., employees remodeling housing units would leave the radios in the kitchen as they worked on different spaces inside and outside the house). Finally, we did not observe any radio welfare checks between employees and the safety officer or their supervisor when working alone.

Quantitative test results

Seven of the 9 employees met 1 or more of our criteria for excessive heat strain at least once during the 4 days of testing. Five of the 9 employees met the criteria on the basis of the sustained HR criterion (Table 2). One employee had a CBT > 101.3°F (38.5°C), 1 had a cross-shift body weight loss of more than 1.5%, and 3 reported heat symptoms.

Given the large amount of monitoring data collected for this group of nine employees across four workdays, we decided to present the heat stress and strain data for three scenarios:

- CBT and HR above the excessive heat strain criteria;
- HR above the excessive heat strain criteria; and
- no CBT or HR above the excessive heat strain criteria.

The average WBGT, estimated metabolic load, CBT, and maximum sustained HR for three or more minutes for these 3 employees are shown in Tables 3–5. The task-based average WBGT measurements ranged from 68°F (20°C) (driving in an air-conditioned vehicle) to 94°F (34.4°C) (raking debris). Some tasks were performed

Table 3. Heat stress and strain by task* for archaeologist, day 1.

		Average		Exceed (Yes/No)		
Description of task	Duration (minutes)	Metabolic rate† (watts)	WBGT °F (°C)	Max CBT‡	Max HR§	Recommended 1-hr work/rest schedule (minutes)
Drive to work site with AC on, walk to work site	50	197	79 (26)	No	No	60/0
Walk around work site, walk to second work site	**60**¶	228	87 (31)	No	No	**45/15**¶
Break; walk to work site, walk back to vehicle	**55**¶	253	92 (33)	Yes	Yes	**15/45**¶
Drive to third work site with AC on, walk to work site, walk around work site	78	171	88 (31)	No	No	60/0
Lunch in AC, drive to fourth work site, walk to/from work site	80	230	86 (30)	Yes	Yes	60/0
Drive back to staging area with AC on	50	109	68 (20)	No	No	60/0

AC = Air-conditioning.
*Individual tasks were grouped into approximately 1-hr periods.
†Metabolic rate adjusted by the weight of the employee.
‡101.3°F (38.5°C).
§Sustained heart rate for three or more minutes during task > 180 minus age in years.
¶Bolded values indicate tasks that were performed longer than the NIOSH REL guidelines for working and resting over a 1-hr period (Figure 1).

Table 4. Heat stress and strain by task* for maintenance/landscaper, day 1.

Description of task	Duration (minutes)	Average		Exceed (Yes/No)		Recommended 1-hr work/rest schedule (minutes)
		Metabolic rate† (watts)	WBGT °F (°C)	Max CBT‡	Max HR§	
Drive to work site with AC on, walk to work site	24	174	79 (26)	No	No	60/0
Raking, trimming brush/trees	**60**¶	453	85 (29)	No	Yes	**30/30**¶
Take break outdoors, rake, trim brush/trees	**70**¶	293	90 (32)	No	Yes	**15/45**¶
Take break outdoors, rake, trim brush/trees	**30**¶	221	94 (34)	No	Yes	**15/45**¶
Take break outdoors, rake, trim brush/trees	**60**¶	290	91 (33)	No	Yes	**15/45**¶
Lunch outdoors	**60**¶	174	92 (33)	No	No	**15/45**¶
Rake, trim brush/trees, take break outdoors	**65**¶	421	90 (32)	No	Yes	**15/45**¶
Take break outdoors	75	174	85 (29)	No	No	60/0
Drive to staging area with AC on	20	174	68 (20)	No	No	60/0

*Individual tasks were grouped into approximately 1-hr periods.
†Metabolic rate adjusted by the weight of the employee.
‡101.3°F (38.5°C).
§Sustained heart rate for three or more minutes during task > 180 minus age in years.
¶Bolded values indicate tasks that were performed longer than the NIOSH REL guidelines for working and resting over a 1-hr period (Figure 1).

longer than the NIOSH recommended exposure limit (REL) work/rest schedule shown in Figure 1. Working longer than recommended resulted in only 1 exceedance of the CBT (Table 3), but 5 exceedances of the HR criterion (Table 4). However, 1 employee did not exceed either the CBT or HR criteria despite working longer than recommended by the NIOSH REL (Table 5). In 2016, NIOSH revised its criteria document on occupational exposure to hot environments.[1] This update eliminated the ceiling REL for acclimatized workers.

Discussion

Seven of the nine employees met our criteria for excessive heat strain. The employees performed moderate to heavy tasks in elevated WBGT conditions for longer periods of time than are recommended by NIOSH (Figure 1). However, despite working in a hot environment, none had complications or were substantially dehydrated. Several factors may have played a role in this finding. The first is that these employees were well acclimatized to the environment and to their work tasks. All lived within the park in staff housing or in nearby towns. These employees were adept at pacing their work effort and taking breaks as needed to regulate their level of exertion. They were diligent about consuming enough water to stay hydrated in this extremely hot environment. However, given this unique work environment, these results cannot be extrapolated to other workplaces with newer and/or unacclimatized employees, mandatory work/rest cycles, or other types of tasks.

Table 5. Heat stress and strain by task* for bricklayer, day 1.

Description of task	Duration (minutes)	Average		Exceed (Yes/No)		Recommended 1-hr work/rest schedule (minutes)
		Metabolic rate† (watts)	WBGT °F (°C)	Max CBT‡	Max HR§	
Drive to work site with AC on, move equipment, mix mortar, lay bricks	**60**¶	401	86 (30)	No	No	**30/30**¶
Take break indoors with AC on, mix mortar, lay bricks	**75**¶	392	87 (31)	No	No	**30/30**¶
Take break indoors with AC on, mix mortar, lay bricks	**70**¶	392	89 (32)	No	No	**15/45**¶
Lay brick, light shoveling, move brick, lunch indoors with AC on	60	220	82 (28)	No	No	60/0
Lay brick, cut brick, take break indoors with AC on	**145**¶	428	87 (31)	No	No	**15/45**¶
Lay brick, move equipment, drive to staging area with AC on	**70**¶	408	87 (31)	No	No	**30/30**¶

*Individual tasks were grouped into approximately 1-hr periods.
†Metabolic rate adjusted by the weight of the employee.
‡101.3°F (38.5°C).
§Sustained heart rate for three or more minutes during task > 180 minus age in years.
¶Bolded values indicate tasks that were performed longer than the NIOSH REL guidelines forworking and resting over a 1-hr period (Figure 1).

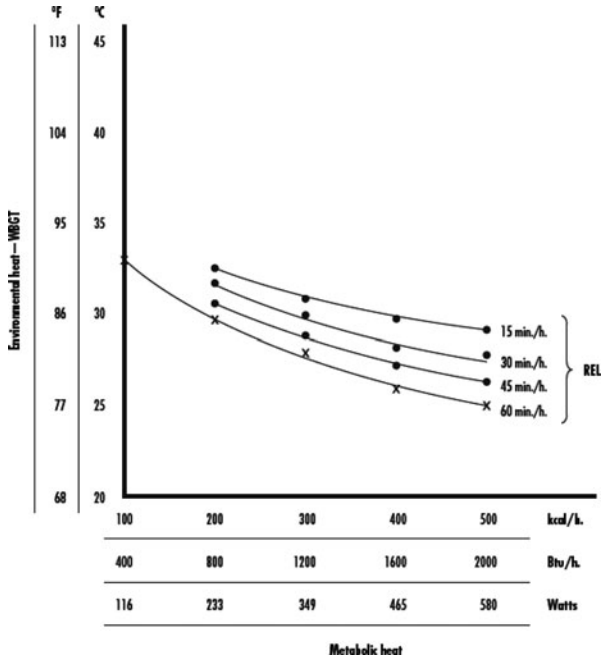

Figure 1. NIOSH-recommended heat stress exposure limits for acclimatized workers.

Observations of employee work practices revealed deficiencies in the park's health and safety program, such as instances of employees working alone. The buddy system is important in extreme heat environments so that a lesser affected employee may recognize HRI symptoms in their co-worker, thus allowing them to start basic first aid and call for help. Additionally, working alone without a radio and not notifying the park safety officer about changes in work locations or conducting periodic welfare checks could place employees at risk for becoming incapacitated and hamper rescue efforts. Finally, radios left out of hearing distance could result in a call for assistance being missed.

As evident from this survey involving nine employees, there are logistical challenges in conducting a comprehensive heat stress and heat strain evaluation. WBGT measuring instruments are simple to use and provide information on the heat contribution from the environment but these instruments do not factor in the heat contribution from the employees' physical exertion. Therefore, any comprehensive evaluation of heat stress must include worker observations and estimates of metabolic workloads because they are critical when interpreting and comparing the WGBT data to recommended guidelines. However, documenting employee work tasks and estimating changing metabolic workloads throughout a workday can be manually intensive and time-consuming, especially when employees are performing episodic work concurrently in multiple locations, are mobile, or are spread out over a wide geographical area. All of these conditions existed during this evaluation.

With respect to the physiologic responses and the impact they have on heat strain measurements, the data collected during this evaluation show that the sustained HR measurement appears to be a sensitive but less specific indicator of excessive heat strain and physical exertion. This finding may be due to the way the criterion is computed and the influence age has on the calculated value. As an example, results showed that a 60-year-old employee, whose maximum allowable HR is 120 beats per minute, repeatedly exceeded the HR guideline but not the CBT limit. The reason for this appears to be related to the amount of time necessary to change HR versus CBT (HR can change faster than CBT). Other factors that may influence HR include the physical condition of the individual, use of prescription and over-the-counter medications that affect HR, caffeine intake, and hydration status.[1]

This evaluation had the following limitations. Only nine employees were assessed over 4 days of work, and not all park job titles were evaluated. Therefore, these findings may not be generalizable to all park employees. In addition, the nine employees evaluated did not work under worst-case environmental conditions in this location on two of the four testing days because of cooler temperatures following a storm. Finally, HRI is a spectrum whose clinical presentation may be highly variable and, therefore, use of different case definition criteria or requiring two or more to be met could change these results.

Conclusions

Employees performed moderate to heavy tasks in elevated WBGT conditions for longer periods of time than recommended by the NIOSH heat stress REL.[1] Seven of nine employees showed evidence of excessive heat strain according to our criteria. All employees were able to self-regulate task duration and intensity to avoid HRI complications and significant dehydration. Preventing excessive heat strain and HRI will require a combination of risk management approaches and administrative controls outlined below.

Recommendations

1. Provide WBGT measuring instruments to employees working outdoors in extreme heat. Employees should be trained on the instrument operation and the interpretation of results. The instruments should operate continuously during the work shift and be checked hourly. The safety

manager should observe work practices and create a list of estimates of metabolic load for each task so employees can use this information, along with the WBGT data to determine appropriate work/rest regimens as outlined in the NIOSH heat stress criteria document (Figure 1).[1] Overall, reduce the duration of work, and enforce mandatory rest breaks if moderate to heavy work under extreme WBGT conditions must be performed.

2. Develop a workgroup of employees, the safety manager, and a medical advisor to decide among options and develop standard operating procedures for self-monitoring during periods of extreme heat. Several options are available which may improve compliance and accuracy, each with their own strengths and limitations. Measuring one's pulse periodically (e.g., every 15–30 min during exertion in extreme heat) is the simplest and easiest method of determining an individuals' HR. Wearing heart rate monitors (such as those worn on the wrist by runners) may be feasible but these instruments can be susceptible to motion artifacts during heavy physical exertion. Using oral or tympanic thermometers to monitor body temperatures during exertion may be considered alternatives to the ingestible sensor but their accuracy and precision need to be validated. Measuring pre- and post-shift body weight is another option to consider.
3. Schedule strenuous outdoor work such as road repair/replacement, bricklaying, and tree-trimming for cooler months. If these activities must occur during the summer, then they should be performed at night or early in the morning.
4. If possible, stop work outdoors and inside buildings without air-conditioning during extreme heat advisories and apply this policy consistently to all park employees.
5. Continue to train employees to recognize early signs and symptoms of HRI in themselves and their coworkers. Instruct employees to tell their supervisor immediately if they develop any symptoms or if they notice any signs or symptoms in their coworkers.
6. Continue to allow employees to take rest breaks and fluid intake as needed.
7. Provide a nearby cooling area for employees working outdoors.
8. Supply additional water to employees so they can wet their work clothes during the workday when temperatures are high. Wetting clothing aids evaporative cooling and should be done frequently in low relative humidity environments.
9. Establish a procedure for communication between the safety manager and employees or work crew supervisors so that work locations are known. If changes are made, the safety manager should be notified so that she or he can make an informed decision regarding potential work stoppages.
10. Use the buddy system. If solitary work is unavoidable, ensure employees have a radio with them at all times, submit their work schedule/locations to their supervisor and safety manager, and arrange for periodic welfare checks over the radio. All employees should keep radios within hearing distance so that a call for assistance can be heard and responded to without delay.

Disclaimer

The findings and conclusions in this manuscript are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company or product does not constitute endorsement by NIOSH.

References

[1] **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Criteria for a Recommended Standard: Occupational Exposure to Hot Environments*. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2016–106. Available at https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf (accessed April 7, 2017).

[2] **CDC (Centers for Disease Control and Prevention):** Heat-Related Deaths among Crop Workers—United States, 1992–2006. *MMWR 57*(24):649–653 (2008). Available at https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5724a1.htm (accessed April 7, 2017).

[3] **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation Report: Evaluation of Heat Stress, Heat Strain, and Rhabdomyolysis in National Park Employees*, by J. Eisenberg and M. Methner. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report No. 2013-0109-3214. Available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2013-0109-3214.pdf (accessed April 7, 2017).

[4] **Wagner, T.:** "The Weather and Climate in Death Valley, California." Available at http://traveltips.usatoday.com/weather-climate-death-valley-california-59328.html (accessed April 7, 2017).

[5] **American Conference of Governmental Industrial Hygienists (ACGIH):** *2017 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

[6] **Sawka, M.N., and K.B. Pandolf:** Physical Exercise in Hot Climates: Physiology, Performance, and Biomedical Issues. In: *Medical Aspects of Harsh Environments*, vol. 1. pp. 89–90. Washington, DC: Office of the Surgeon General at Textbooks of Military Medicine Publications, 2001.

[7] **McKenzie, J.E., and D.W. Osgood:** Validation of a new telemetric core temperature monitor. *J. Therm. Biol. 29*(7):605–611 (2004).

[8] **Byrne, C., and C.L. Lim:** The ingestible telemetric body core temperature sensor: A review of validity and exercise applications. *Br. J. Sports Med. 41*(3):126–133 (2007).