Factors Associated With Heat Strain Among Workers at an Aluminum Smelter in Texas

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Objectives: To determine the prevalence of heat strain and factors associated with heat strain among workers at an aluminum smelter in Texas. **Methods:** Continuous core body temperature (T_c), heart rate, and pre- and postshift serum electrolytes, and urine specific gravity were measured, and symptom questionnaires were administered. **Results:** Most participants (54%) had 1 or more signs of heat strain. Unacclimatized participants were significantly more likely to exceed the American Conference of Governmental Industrial Hygienists–recommended T_c than acclimatized participants (88% vs 20%; $P < 0.01$). Participants who exceeded the T_c for their acclimatization status and/or exceeded the recommended sustained peak HR had a significantly lower body mass index than those who did not (27.6 vs 31.8 and 28.4 vs 32.4, respectively; $P = 0.01$). **Conclusions:** Employees and management need to strictly adhere to a heat stress management program to minimize heat stress and strain.

Aluminum potroom workers engage in rigorous physical tasks near smelters where operating temperatures to reduce alumina to pure aluminum can reach 1,800°F.[1] Many workers exposed to such extreme heat conditions are at risk of developing heat strain. Furthermore, potroom workers who work outdoors in areas with high ambient temperature and humidity (eg, Texas during the summer months) may be at increased risk of developing heat strain.

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends ceasing exposure to heat stress if an individual demonstrates signs of excessive heat strain or symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.[2] Signs of excessive heat strain include (1) a core body temperature (T_c) greater than 100.4°F for unselected, unacclimatized personnel and greater than 101.3°F for medically fit, heat-acclimatized personnel; (2) sustained (over several minutes) heart rate (HR) exceeding 180 beats per minute (BPM) minus the individual's age in years (180 BPM − age) for those with normal cardiac performance; or (3) recovery HR at 1 minute after a peak work effort exceeding 120 BPM. The ACGIH also notes that another practical and useful approach to using HR as a sign of heat strain is that daily average HR should not exceed 115 BPM. Exceeding these physiologic limits can result in various heat-related illnesses, including heat syncope, heat exhaustion, and heat stroke. Heat syncope is an early warning sign of excessive heat strain. It is characterized by an abrupt drop in blood pressure due to peripheral vasodilation.[2] Core body temperature is normal or mildly elevated, and patients recover quickly with treatment. Heat exhaustion is characterized by an inability to maintain adequate cardiac output and T_c is usually elevated (101°F to 104°F). Symptoms include lightheadedness, fatigue, nausea, reduced psychomotor skills, and lessened work ability.[2] Heat stroke results from failure of the thermoregulatory system and is a medical emergency with high morbidity and mortality. Characteristics include an elevated T_c (often exceeding 105°F), central nervous system dysfunction (ie, change in mental status and seizures), and multiorgan failure.

The National Institute for Occupational Safety and Health (NIOSH) received a request to evaluate work-related heat exposure in an aluminum smelter in Texas. From March to August of that year, the medical department at the smelter logged 158 episodes of heat disorders (mostly "hot and tired," muscle cramps, or both) and three episodes of heat-related illnesses. Because of concerns of heat-related illnesses during the summer months, NIOSH investigators conducted an evaluation of potroom workers at the aluminum smelter to determine (1) the prevalence of excessive heat strain and (2) risk factors for excessive heat strain.[2]

METHODS

Study Population

We conducted a pre- and posttest evaluation of aluminum potroom workers at a smelting facility in Texas, over a 4-day period in July. The study population was based on a nonrandomized convenience sample. Inclusion criteria included aluminum potroom workers identified by the employer and union as working in the hottest jobs, and who worked during the first or second shift (8 AM to 4 PM or 4 PM to 12 AM). An attempt was made to select an equal number of employees working 8-hour and 16-hour shifts, and those who worked in the same crew (to facilitate observation of employee activities). Participation was voluntary, and written informed consent was obtained from all participants. This evaluation was conducted under a blanket institutional review board approval for the NIOSH Health Hazard Evaluation program. In general, Health Hazard Evaluations are considered workplace evaluations and not research.

Questionnaire

Participants completed a questionnaire about their medical history, work history, and symptoms experienced and amount of fluids consumed during the shift on which they were monitored. Symptoms of interest included muscle cramps, headache, lightheadedness or dizziness, nausea or vomiting, racing heartbeat or palpitations, unsteady walk, and confusion or disorientation. These symptoms were selected on the basis of the extant literature and common clinical presentations of heat-related illnesses. Participants were considered unacclimatized if they had been off work or worked completely outside the potrooms for 4 or more consecutive days in the past 2 weeks.[2]

Biologic Monitoring

Urine specific gravity and blood electrolytes were measured in the field immediately after collection before and after each

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participant's shift. The i-STAT 1 handheld analyzer and i-STAT 8+ cartridges (Abbott Point of Care, Inc, East Windsor, NJ) were used to measure serum electrolytes. Two to three drops of whole blood was collected via finger prick and placed in the well of the cartridge before inserting the cartridge in the analyzer. The Atago Uricon-Ne Refractometer (Atago USA, Inc, Bellevue, WA) was used to measure urine specific gravity. The refractometer measures specific gravity from 1.000 to 1.050 and is accurate to 0.001. Urine was collected in sterile urine collection cups.

Physiologic Monitoring

Shortly before their shift, participants swallowed a VitalSense (Mini-Mitter Company, Inc, Bend, OR) temperature sensor pill, and a data logger was attached to the participant waist belt. The VitalSense monitoring system continuously measured T_c at 1-minute intervals to ±0.2°F. At the end of shift, data loggers were removed, and T_c data were downloaded. Core body temperature data were included in analysis once T_c readings stabilized (ie, readings no longer affected by the intake of fluids and food). Continuous HR was measured at 1-minute intervals throughout a work shift, using an ActiHeart HR monitor (Mini-Mitter Company, Inc). The HR monitors were attached to participants before their shift and removed after their shift.

Heat-Exposure Monitoring

Wet bulb globe temperatures (WBGTs) were monitored at several locations throughout the potrooms, simulating the locations where employees normally worked, using QUESTemp°36 and QUESTemp°34 instruments (Quest Technologies, Inc, Oconomowoc, WI). These instruments measure temperatures from 23°F to 212°F and are accurate to ±0.9°F. These instruments were allowed to equilibrate for a minimum of 15 minutes before data were collected, unless otherwise noted.

Weather Conditions

Outdoor weather conditions, including temperature, relative humidity, and wind speed, at the plant were measured using a HOBO® weather station (Onset Computer Corporation, Bourne, MA). The weather station was set up near the entrance to the plant and allowed to continually monitor conditions throughout the study.

Definition of Heat Strain

In this evaluation, signs of excessive heat strain include (1) a T_c greater than 100.4°F for unselected, unacclimatized personnel and greater than 101.3°F for medically fit, heat-acclimatized personnel; (2) sustained (greater than 5 minutes) HR exceeding 180 BPM minus the individual's age in years (180 BPM − age) for those with normal cardiac performance; or (3) daily average HR exceeding 115 BPM. This HR criteria was used in this evaluation instead of recovery HR because the nature of the job did not permit assessment of recovery HR.

Statistical Analysis

Statistical analysis was carried out with SAS version 9.1.3 software (SAS Institute, Cary, NC). A $P \leq 0.05$ was considered statistically significant. Paired *t* tests were used to compare pre- and postshift blood and urine laboratory means. When the data were normally distributed, the *t* test was used to compare body mass index and changes in pre- and postshift laboratory values between employees who did and did not have signs of heat strain. In cases where the data were not normally distributed, the nonparametric Wilcoxon test was used to compare differences in pre- and postshift laboratory values between employees who did and did not have signs of heat strain. The *t* test was also used to compare average T_c, peak T_c, and average HR between employees who were and were not acclimatized. The Fisher exact test was used to compare differences in the percentages of employees having each sign of heat strain in employees who were and were not acclimatized. *t* tests or Wilcoxon tests were used to compare average T_c, peak T_c, and average HR between employees with and without work-related symptoms.

RESULTS

Facility and Process Description

At the time, this facility produced up to 1.67 million pounds of aluminum per day. Products included sheet ingots, primary ingots, and aluminum powder. The smelter had six smelting lines. Aluminum production used two pot styles: (1) older T-51 pots containing 20 carbon anodes; and (2) newer, larger P-100 pots containing 26 carbon anodes. Each T-51 potroom housed 72 pots, while the P-100 potrooms housed 80 pots per room. Each crew oversaw 12 T-51 pots or 13 P-100 pots per shift.

Approximately 600 employees worked in the potrooms over three 8-hour shifts. Volunteers were solicited from the prior shift to work an additional 8-hour shift if there was a shortage of employees. If too few employees volunteered, mandatory overtime was enforced. No employee was allowed to work more than 64 hours per week.

Workers in the potrooms performed various tasks. Tapper carbon changers removed molten aluminum and replaced carbon anodes from the pots. Overhead crane operators helped replace carbon anodes, transported and added alumina via portable bins, and moved all pot tapping equipment. Pot tenders periodically broke the insulating crust that formed at the surface of the bath mixture, added aluminum ore, and aligned the anodes. They used wooden probes to break up air gaps in the molten material. Potroom helpers added ore and other materials to the pots and performed miscellaneous tasks. Heat-stress carbon setters were added to potroom crews during the warmer summer months. They performed the same duties as the tapper carbon changers, pot tenders, and potroom helpers.

Study Population

Sixty-one potroom workers agreed to participate in the study, and 60 were included in the analysis. One employee completed the questionnaire but was excluded from analysis because that individual worked only 30 minutes. Personal characteristics of the participants are summarized in Table 1. Six of the 60 participants worked an overtime shift. Three participants performed equally hot job duties

TABLE 1. Personal Characteristics of Study Participants ($n = 60$)

Average age (range), yr	32 (19–50)
Men, *n* (%)	57 (95)
Average years working in a potroom at the facility (range)	1.2 (0.1–6.0)
Average body mass index (range),* kg/m^2	30.5 (19.4–47.3)
Average hours slept before starting work (range)	6.6 (3.0–10.0)
Unacclimatized, *n* (%)	8 (13)
Comorbid conditions, *n* (%)	
Diabetes	1 (2)
Heart disease	0
High blood pressure	3 (5)
Kidney disease	0
Thyroid disease	1 (2)
Other†	4 (7)

*Body mass index was calculated using self-reported height and weight.
†Arthritis, asthma, depression, and sarcoidosis.

during their overtime shift as during their regular shift. Two worked as a tapper carbon changer (one of the hottest jobs) for two 8-hour shifts in a row, and one worked as a head tapper carbon changer during the first shift and then as a tapper carbon changer/crane operator for 2 overtime hours.

Heat-Related Symptoms

The most common symptoms during the work shift were racing heartbeat or palpitations (30%), headache (20%), muscle cramps (13%), and lightheadedness or dizziness (13%). Less common symptoms included confusion or disorientation (8%), unsteady walk (5%), and nausea or vomiting (2%). The only participant who reported nausea or vomiting had the highest peak T_c value of 102.83°F.

Biologic Monitoring

Study participants' pre- and postshift changes in serum and urine measurements are shown in Table 2. Serum sodium was corrected for participants with glucose concentrations greater than 200 mg/dL.[3] This applied to one participant who had a preshift glucose concentration of 263 mg/dL. Three participants showed marked increases in pre- to postshift blood creatinine measurements. Their pre- and postshift blood urea nitrogen to creatinine ratios were 14.0/1.1 to 20.0/2.3, 11.0/1.3 to 13.0/2.4, and 12.0/1.0 to 15.0/2.6. These participants were advised to drink plenty of fluids and have their blood urea nitrogen and creatinine levels rechecked the following day. One of these participants returned the following day, and the creatinine had dropped from 2.3 to 1.4 mg/dL.

The average amount of fluids consumed during the shift was 180 ± 102 ounces. Electrolyte packets, provided by the employer to replace electrolytes lost from excessive sweating, contained 40 mg potassium chloride, 18 mg calcium phosphate, and 9 mg magnesium carbonate. Among those reporting consumption of the electrolyte packets during their shifts (12 of 60), the average number of packets used was 3.1. Participants who reported drinking alcoholic beverages during the 24 hours before starting work (11 of 60) consumed an average of 3.5 alcoholic beverages.

TABLE 2. Comparison of Mean Pre- and Postshift Blood and Urine Values (Mean ± SD)

	Preshift (n = 60)	Postshift (n = 60)	P*
Blood			
Sodium (corrected)†	138.01 ± 1.84	138.37 ± 2.44	0.26
Potassium	4.45 ± 0.46	4.28 ± 0.42	0.03
Chloride	108.67 ± 2.04	108.23 ± 2.94	0.21
Bicarbonate	23.03 ± 1.47	23.52 ± 1.88	0.02
BUN	14.47 ± 3.98	16.23 ± 4.31	<0.01
Creatinine	1.06 ± 0.18	1.34 ± 0.32	<0.01
BUN/creatinine ratio	14.04 ± 4.56	12.61 ± 4.09	<0.01
Glucose	110.20 ± 29.80	107.12 ± 21.44	0.43
Osmolality	287.31 ± 3.97	288.48 ± 5.35	0.07
Urine			
Specific gravity‡	1.023 ± 0.01	1.028 ± 0.01	<0.01

*Paired t test.
†Sodium is corrected for participants with glucose concentrations greater than 200 mg/dL, using the formula: corrected sodium = measured sodium + 0.016 (glucose − 100).
‡Data were missing for one participant in the preshift group.
BUN, blood urea nitrogen.

Weather Conditions

The mean ambient temperature for the 5 days of our evaluation was 78°F. The mean temperature for July for that geographic area from 1971 to 2000 was 85°F.[4]

Heat-Exposure Monitoring

Thirty-one WBGT measurements were collected in areas where employees performed routine job tasks. These included a T-51 and a P-100 pot, a pot with side covers removed, a tapping crucible next to a T-51 and a P-100 pot, an aisle with no spent anodes and one with spent anodes, and the operator's enclosure on the overhead crane. Protective clothing worn by employees in the potrooms included a flame-resistant long sleeve shirt and pants, long sleeve cotton t-shirt, steel toe boots, and a hard hat.

The WBGT measurements ranged from 83°F to 120°F, with dry bulb air temperatures reaching 134°F and radiant temperatures reaching 188°F. The highest WBGT measurement in the potroom was taken between a T-51 pot and a tapping crucible during tapping. The second-highest WBGT measurement was taken on the center of the catwalk between pots with one side open. This measurement may have underestimated the actual temperature, because the WBGT monitor was not fully equilibrated because the high radiant heat load was starting to melt the monitor's tripod.

Radiant heat (globe bulb temperature) measured at all except one location inside the potrooms equaled or exceeded 96°F. At these temperatures, employees absorb rather than radiate heat unless proper shielding is provided. The highest globe bulb temperature was measured on the catwalk in the center of two pots with the side shields removed on one pot. The second-highest globe bulb temperature was measured between a T-51 pot and a crucible during tapping.

A clothing adjustment factor was estimated at 5°F for the clothing worn by employees in the potrooms. Metabolic rates for employees in the potrooms were estimated to be in the moderate to light category, ranging from 115 to 360 W. Clothing adjustment factor and metabolic heat production rates were estimated using the NIOSH method.[5] When compared with the WBGT measurements taken in the potrooms, portions of all tasks, except for the crane operator, exceeded the ACGIH threshold limit value and NIOSH ceiling limit for working in a hot environment.[2,5]

Physiologic Monitoring

The number of participants showing signs of heat strain is shown in Table 3. Most participants (54%) had at least one sign of

TABLE 3. Participants With Signs of Heat Strain*

ACGIH Heat Strain Criteria	n (%)
Core body temperature greater than recommended maximum†	17 (29)
Sustained‡ heart rate greater than (180 − age) BPM	24 (43)
Average heart rate greater than 115 BPM	11 (20)
Number of signs of heat strain	
0	26 (46)
1	12 (21)
2	15 (27)
3	3 (5)

*n = 56–58. Core body temperature data were missing for two participants. Heart rate data were missing for four participants.
†T_c greater than 101.3°F for acclimatized employees or greater than 100.4°F for unacclimatized employees.
‡Values sustained for greater than or equal to 5 continuous minutes.
ACGIH, American Conference of Governmental Industrial Hygienists; BPM, beats per minute.

TABLE 4. Differences in Pre- and Postshift Blood and Urine Values of Participants by Maximum Recommended Core Body Temperature

	T_c Exceeds Maximum Recommended*				
	Yes ($n = 17$)		No ($n = 41$)		
	Preshift Mean	Postshift Mean	Preshift Mean	Postshift Mean	P†
Blood					
Sodium (corrected)‡	137.82	137.82	138.09	138.56	0.34
Potassium	4.49	4.36	4.42	4.22	0.76
Chloride	108.82	108.18	108.56	108.24	0.66
CO_2	22.41	22.65	23.27	23.78	0.66
BUN	15.35	16.29	14.15	16.32	0.11
Creatinine	0.95	1.28	1.11	1.37	<0.05§
BUN/creatinine ratio	16.65	13.44	12.91	12.35	<0.01§
Glucose	112.76	106.65	107.29	107.37	0.46
Osmolality	287.39	287.39	287.19	288.91	0.23
Urine					
Specific gravity	1.023	1.026	1.023‖	1.029	0.59

*T_c greater than 101.3°F for acclimatized employees or greater than 100.4°F for unacclimatized employees.
†Wilcoxon test; P values when comparing the difference in pre- and postshift blood and urine values between participants with maximum T_c that do and do not exceed the American Conference of Governmental Industrial Hygienists heat strain criteria.
‡Sodium is corrected for participants with glucose concentrations greater than 200 mg/dL using the formula: corrected sodium = measured sodium + 0.016 (glucose − 100).
§$P \leq 0.05$ was considered statistically significant.
‖$n = 40$.
BUN, blood urea nitrogen; T_c, core body temperature.

TABLE 5. Differences in Pre- and Postshift Blood and Urine Values of Participants by Sustained and Average Heart Rate

	Sustained* Heart Rate > (180 − age)					Average Heart Rate > 115				
	Yes ($n = 24$)		No ($n = 32$)			Yes ($n = 11$)		No ($n = 45$)		
	Preshift Mean	Postshift Mean	Preshift Mean	Postshift Mean	P†	Preshift Mean	Postshift Mean	Preshift Mean	Postshift Mean	P‡
Blood										
Sodium, corrected§	138.0	137.3	137.9	139.1	<0.01‖	138.4	138.4	137.8	138.3	0.66
Potassium	4.5	4.2	4.4	4.2	0.51	4.6	4.4	4.4	4.2	0.94
Chloride	109.0	107.9	108.3	108.5	0.07	109.0	109.0	108.5	108.1	0.92
CO_2	22.7	22.7	23.3	24.0	0.17	23.1	22.6	23.0	23.6	0.07
BUN	15.1	16.9	14.2	16.0	0.95	17.0	18.7	14.0	15.8	0.66
Creatinine	1.0	1.3	1.1	1.3	0.24	1.0	1.4	1.1	1.3	0.07
BUN/creatinine ratio	15.6	13.5	13.0	12.3	0.03‖	16.6	14.0	13.5	12.6	0.04‖
Glucose	114.0	112.2	105.5	102.7	0.90	106.0	103.7	109.9	107.5	0.99
Osmolality	287.7	286.9	286.7	289.6	<0.01‖	288.7	289.4	286.8	288.2	0.66
Urine										
Specific gravity	1.022	1.026	1.024¶	1.029	0.93	1.026	1.031	1.022¶	1.027	0.82

*Values sustained for greater than or equal to 5 continuous minutes.
†Paired t test when comparing the difference in pre- and postshift blood and urine values between participants with and without a sustained heart rate greater than (180 − age).
‡Paired t test when comparing the difference in pre- and postshift blood and urine values between participants with and without an average heart rate greater than 115.
§Sodium is corrected for participants with glucose concentrations greater than 200 mg/dL, using the formula: corrected sodium = measured sodium + 0.016 (glucose − 100).
‖$P \leq 0.05$ was considered statistically significant.
¶Data were missing for one participant in the preshift group.
BUN, blood urea nitrogen.

TABLE 6. Heat Strain Measurements in Acclimatized and Unacclimatized Employees

	Acclimatized (n = 48–50)	Unacclimatized (n = 8)	P
T_c, average, °F	99.6	99.7	0.68
Peak T_c, average (range), °F	100.7 (99.0–102.8)	101.0 (99.5–102.4)	0.34
HR, average (range), BPM	107 (84–127)	118 (105–134)	<0.01
T_c > criterion,* n (%)	10 (20)	7 (88)	<0.01
Minutes above criterion, median (range)	28 (6–112)	46 (11–597)	
Period monitored above criterion, average, %	9	22	
Sustained† HR > (180 − age), n (%)	19 (40)	5 (63)	0.27
Minutes above criterion, average	53	53	
Period monitored above criterion, average, %	13	12	
Average HR > 115, n (%)	8 (17)	3 (38)	0.18

*American Conference of Governmental Industrial Hygienists heat strain criteria: T_c greater than 101.3°F for acclimatized employees or greater than 100.4°F for unacclimatized employees.
†Values sustained for greater than or equal to 5 continuous minutes.
BPM, beats per minute; HR, heart rate; T_c, core body temperature.

heat strain, and 17 participants (29%) exceeded the T_c criterion for their acclimatization status.

Relationship Between Symptoms and Biologic Parameters With Heat Strain

Comparisons of the differences in pre- and postshift laboratory values for participants who did and did not have signs of heat strain are shown in Tables 4 (T_c) and 5 (sustained peak HR and average HR). Participants who exceeded the T_c for their acclimatization status also had, on average, a significantly higher increase in blood creatinine.

Unacclimatized participants ($n = 8$) were significantly more likely to exceed the recommended maximum T_c, as shown in Table 6. Among unacclimatized participants, 88% (7 of 8) exceeded their ACGIH heat strain criterion for T_c compared with 20% (10 of 50) of acclimatized participants ($P < 0.01$). Among participants who exceeded ACGIH T_c criteria, the average percentage of the period of time monitored above criteria was 22% for unacclimatized employees and 9% for acclimatized employees. In addition, participants who exceeded the T_c for their acclimatization status and/or exceeded the sustained peak HR criterion had a significantly lower average body mass index than those who did not exceed those ACGIH criteria (27.6 vs 31.8 [$P = 0.01$] and 28.4 vs 32.4 [$P = 0.01$], respectively). Unacclimatized potroom participants also had a significantly higher average HR than the acclimatized participants (118 vs 107 BPM; $P < 0.01$).

DISCUSSION

In this study of 60 aluminum potroom workers, most had at least one sign of excessive heat strain. All jobs except the crane operator exceeded the ACGIH threshold limit value and NIOSH ceiling limit for working in a hot environment. These findings call attention to the extreme heat conditions in which aluminum potroom workers work. It also highlights opportunities for minimizing factors that increase the risk of developing excessive heat strain.

Data from this study are consistent with other studies identifying lack of acclimitazation and volume depletion as factors associated with excessive heat strain.[6,7] The significant increase in postshift blood bicarbonate, blood urea nitrogen, creatinine, and urine specific gravity is consistent with volume depletion. These laboratory values suggest that many participants did not drink enough fluids to keep up with the amount of water and salt lost through excessive sweating. In addition, this study identified a lower body mass index as a potential risk factor for excessive heat strain in aluminum potroom workers.

This evaluation has several methodologic strengths. The major strength is the use of continuous T_c measurements rather than skin temperature. In addition, pre- and postshift blood and urine measurements assessed volume depletion. Limitations of this evaluation include the inability to compare differences in physiologic markers for heat stress and strain in potroom employees working 8-hour shifts and those working an additional overtime shift because of the small number of employees who worked overtime during our evaluation. In addition, the outdoor temperatures on the days of monitoring were cooler than expected during the summertime in Texas, and the heat strain and symptom data may have underestimated what potroom employees might experience during extreme heat.

CONCLUSIONS

This evaluation highlights the importance of strictly adhering to a heat stress management program to minimize the incidence of heat stress and strain among aluminum potroom workers. It also provides insight into modifiable factors related to heat stress and strain, such as ensuring proper acclimitazation and adequate hydration.

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