Heat Strain and Hydration Status of Surface Mine Blast Crew Workers

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Objective: Dehydration and symptoms of heat illness are common among the surface mining workforce. This investigation aimed to determine whether heat strain and hydration status exceeded recommended limits. **Methods:** Fifteen blast crew personnel operating in the tropics were monitored across a 12-hour shift. Heart rate, core body temperature, and urine-specific gravity were continuously recorded. Participants self-reported fluid consumption and completed a heat illness symptom inventory. **Results:** Core body temperature averaged 37.46 ± 0.13°C, with the group maximum 37.98 ± 0.19°C. Mean urine-specific gravity was 1.024 ± 0.007, with 78.6% of samples 1.020 or more. Seventy-three percent of workers reported at least one symptom of heat illness during the shift. **Conclusions:** Core body temperature remained within the recommended limits; however, more than 80% of workers were dehydrated before commencing the shift, and tended to remain so for the duration.

Many industrial workplaces and surface mine sites expose workers to outdoor environmental conditions. In Northern Australia, it is commonly hot and humid, particularly in summer, where wet-bulb globe temperature (WBGT), an index of heat stress, can exceed 30°C.[1,2] In such conditions, the International Organization for Standardization recommends that even light-intensity work is ceased[3] to avoid the deleterious effects of excessive heat strain as well as the potential to develop heat illnesses such as heat exhaustion and heat stroke.

Recent reports have shown many surface mine workers routinely experience symptoms of heat illness, including fatigue, headache, and muscle cramp.[4] Symptoms of heat illness were associated with hydration status, such that those who self-reported greater levels of dehydration (estimated from urine color) were at increased risk of moderate symptoms of heat illness. Although self-reported urine color is a subjective indicator, other studies also report dehydration (urine-specific gravity [USG] >1.020) to be common among the workforce.[1,5,6] This level of dehydration generally coincides with a body mass loss of approximately 3%,[7] a level that is known to increase physiological heat strain[8–11] and be associated with the development of heat illness.[12–17]

Even though reports of dehydration and symptoms of heat illness are becoming increasingly common among the surface mining workforce, the physiological heat strain experienced by surface mine workers has received little attention. Body temperatures of 36.5 to 37.6°C have been reported among surface mine workers.[2,6] Although core body temperature in this range is within the recommended limits for occupational settings—core body temperature of 38.0°C for unacclimatized workers or 38.5°C for acclimatized workers—[18,19] cautious interpretation is warranted. In these studies, body temperature was measured only at three discreet time points (before shift, on break, and after shift). Continuous monitoring of underground miners found core body temperature to increase by as much as 0.5°C in 10 minutes, or 0.9°C in 60 minutes.[20] Recording temperature during work breaks, possibly at a distance from the work site (allowing time for cooling), may not reveal the peaks in core body temperature experienced by this workforce. As such, the core body temperature elevation during surface mine work remains largely unknown. In light of the commonality of dehydration and mild-to-moderate symptoms of heat illness, further research is required to evaluate worker heat strain. Therefore, the aim of this investigation was to determine whether heat strain and hydration status of blast crew members, an industry identified at risk population of surface miners, when measured continuously for longer periods exceeded recommended limits.

METHODS

Blast crew personnel (age, 36.7 ± 9.7 years; height, 1.8 ± 0.1 m; body mass, 100.9 ± 14.3 kg; sex, 14 male and 1 female) at a surface mine in a tropical region (latitude 22.025° South) volunteered to participate in this study. All were informed of the study requirements and had any questions answered to their satisfaction before giving their written consent to participate. This study received ethical approval from the Queensland University of Technology Human Research Ethics Committee.

Over 4 days, participants were monitored for a single 12-hour shift commencing at 6 AM. Physiological measures recorded during work included core body temperature, heart rate, and USG. Core body temperature (intestinal) was monitored by an ingestible temperature sensor and a data logger carried in a hip or chest pocket (CorTemp, HQ Inc, Palmetto, FL), recording at 1-minute intervals. Sensors were calibrated using a water bath at 34, 36, 38, and 40°C.[21] No sensor differed from mean temperature values more than 0.09°C. Linear corrections for discrepancies were applied to the raw data. Participants ingested the sensors before retiring the night before the work shift. Heart rate data were recorded at 1-minute intervals (Polar S625x, Polar, Kempele, Finland). Work intensity was estimated from heart rate using the heart rate reserve:

$$\%HRR = \left[\frac{(WHR - RHR)}{(APMHR - RHR)}\right] \times 100$$

where *WHR* is heart rate during work, *RHR* is resting heart rate, and *APMHR* is age-predicted maximum heart rate (220 − age).

Before, during, and at the completion of the work shift, participants provided a midstream sample of urine from each void. Samples were stored in an insulated but unchilled container until analysis, in duplicate, for specific gravity using a digital refractometer (PAL-10s, ATAGO, Tokyo, Japan).[22] Storage in this manner has previously been shown to maintain the validity of the urine samples for 24 hours when assessed for specific gravity.[23]

Before commencing the work shift, participants reported their alcohol consumption for the previous night, and caffeinated beverage consumption for the previous 3 hours. At the completion of the shift, participants returned a logbook in which they recorded the type and volume of fluids consumed throughout the shift. In addition,

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participants completed the heat illness symptom index.[24] The index asks the worker to rate the severity of 11 symptoms on a scale of 0 to 10, anchored at 0, 3, 5, 7, and 10 by "no symptom," "mild symptoms that did not interfere with work," "moderate symptoms," "severe symptoms requiring a break from work," and "had to stop work," respectively.

Air temperature and humidity were measured every 30 minutes with a digital weather meter (Kestrel 4000, Kestrel Weather Australia, Australia) and were used to estimate WBGT.[22] It should be noted that this method does not account for radiant temperature or wind speed and may underestimate heat stress in conditions of clear full sun and low humidity, conditions observed in this study.

Data are summarized as mean and standard deviation (unless otherwise stated). A core body temperature in excess of 38.5°C was chosen as the safe limit on the basis of the Australian Institute of Occupational Hygienists (AIOH) recommendation[18] and a USG of 1.020 or more was set as the indicator of dehydration.[7,25] Pearson correlation analysis assessed the relationship between the heat illness symptom score and potential risk factors including age, height, body mass, USG, body temperature, and WBGT. Paired and independent samples t-tests were used to assess the difference in USG between the first and last samples of the shift and between consumers and nonconsumers of alcohol and caffeine, respectively. Repeated measures analysis of variance was used to assess the differences in physiological variables and ambient temperature and relative humidity between 6 AM and 10 AM, 10 AM and 2 PM, and 2 PM and 6 PM time points. Statistical significance was set at $P < 0.05$.

RESULTS

Core body temperature and heart rate for a representative worker are presented in Fig. 1. Means were calculated for heart rate, heart rate reserve, and core body temperature for each participant over the 12-hour shift. Average mean heart rate, heart rate reserve, and core temperature were 86.0 ± 14.5 beats per minute, 19.5 ± 6.2%, and 37.46 ± 0.13°C, respectively. Average maximum heart rate, heart rate reserve, and core temperature were 126.9 ± 19.8 beats per minute, 53.7 ± 12.5%, and 37.98 ± 0.19°C, respectively. The maximum core body temperature experienced during the shift exceeded 38°C for 47% of participants, with the maximum recorded core body temperature across all participants being 38.44°C. The physiological responses over the three portions of the shift are summarized in Table 1.

The USG analysis is summarized in Table 2. Mean USG was calculated for each participant across all urine samples. The group average mean USG was 1.024 ± 0.007. Mean USG was 1.020 or more for 78.6% of participants. Pre- and postshift urine samples were not significantly different (preshift, 1.023 ± 0.007; postshift, 1.025 ± 0.007; $P = 0.068$). Preshift USG was significantly lower for those who consumed alcohol the previous night—alcohol ($n = 8$), 1.019 ± 0.007; no alcohol ($n = 7$), 1.027 ± 0.004 ($P = 0.030$). Similarly, mean USG (over the whole shift) was lower for those who consumed alcohol the previous night—alcohol, 1.021 ± 0.007; no alcohol, 1.028 ± 0.004 ($P = 0.022$). Caffeine consumption before the shift was not associated with a significant difference in preshift USG—caffeine ($n = 6$), 1.023 ± 0.008; no caffeine ($n = 9$), 1.023 ± 0.007 ($P = 0.983$)—or mean USG over the whole shift—caffeine, 1.026 ± 0.006; no caffeine, 1.023 ± 0.008 ($P = 0.526$). The mean volume of fluids consumed during the shift was 4.4 ± 2.1 L. All workers reported consuming water, with several indicating they also consumed an electrolyte beverage, soft drink, energy drinks, tea, or coffee. The volume of fluid consumed during the shift was not significantly different between consumers and nonconsumers of alcohol—alcohol, 4.8 ± 2.5 L; no alcohol, 3.8 ± 1.5 L ($P = 0.433$).

Seventy-three percent of personnel reported at least one symptom of heat illness during the shift. The incidence and severity of symptoms experienced are presented in Table 3. The sum of the symptom severity score was not significantly correlated with age ($r = -0.267$; $P = 0.402$), body mass index ($r = -0.174$; $P = 0.589$), average mean USG ($r = 0.468$; $P = 0.125$), average mean core body temperature ($r = -0.005$; $P = 0.987$), average maximum core body temperature ($r = -0.328$; $P = 0.298$), mean WBGT ($r = 0.229$; $P = 0.473$), or maximum WBGT ($r = 0.168$; $P = 0.602$). The ambient conditions in the outdoor work environment are summarized in Table 4.

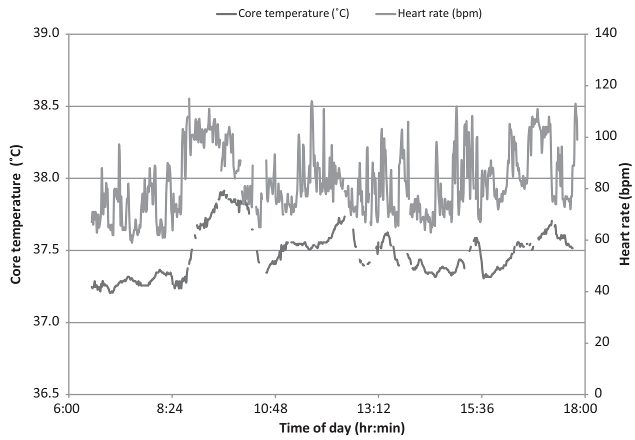

FIGURE 1. A representative example of heart rate and core body temperature throughout the shift.

TABLE 1. Heart Rate, Heart Rate Reserve, and Core Body Temperature Across the Three Periods of the Work Shift

	6 AM to 10 AM	10 AM to 2 PM	2 PM to 6 PM	*P*
Mean				
Heart rate, bpm	84.8 ± 14.3	85.8 ± 15.5	87.1 ± 14.5	0.355
Heart rate reserve, %	18.6 ± 6.4	19.3 ± 7.2	20.5 ± 6.5	0.340
Core body temperature, °C	37.37 ± 0.13	37.41 ± 0.17	37.57 ± 0.19*,†	0.001
Maximum				
Heart rate, bpm	117.8 ± 19.0	120.4 ± 21.5	121.5 ± 20.9	0.566
Heart rate reserve, %	46.1 ± 12.2	48.0 ± 13.1	49.3 ± 13.9	0.561
Core body temperature, °C	37.74 ± 0.21	37.79 ± 0.21	37.94 ± 0.25*,†	0.030

*Significantly different from 10 AM to 2 PM.
†Significantly different from 6 AM to 10 AM.
bpm, beats per minute.

TABLE 2. Urine-Specific Gravity Before, During, and After the Work Shift

	Preshift	6 AM to 10 AM	10 AM to 2 PM	2 PM to 6 PM	Postshift
Mean ± SD	1.023 ± 0.007	1.017 ± 0.008	1.023 ± 0.007	1.025 ± 0.008	1.024 ± 0.007
Number of samples	12	4	8	11	8
≥1.020, %	83.3	50	87.5	72.7	87.5

SD, standard deviation.

TABLE 3. Heat Illness Symptoms and Severity Rating

Symptom	Participants Reporting *n* (%)	Severity Rating Median (Range)
Feeling tired	10 (67)	3 (1–6)
Cramps	3 (20)	4 (1–6)
Nausea	3 (20)	1 (1–3)
Dizziness	2 (13)	1.5 (1–2)
Thirst	11 (73)	5 (1–7)
Vomiting	3 (20)	2 (1–2)
Confusion	5 (33)	1 (1–6)
Muscle weakness	5 (33)	3 (1–6)
Heat sensations	9 (60)	3 (1–8)
Chills	2 (13)	2.5 (2–3)
Feeling light-headed	4 (27)	2 (1–4)
Overall	11 (73)	12* (4–50)

*The severity of each symptom was summed for each participant and the median is reported here.

Severity scale: 0, no symptom; 3, mild symptoms that did not interfere with work; 5, moderate symptoms; 7, severe symptoms requiring a break from work; 10, had to stop work.

DISCUSSION

The aim of this investigation was to determine whether the heat strain and hydration status of surface mine workers exceeded the recommended limits across extended periods. The results indicate that, although the climatic conditions and work intensity were sufficient to cause a challenge to thermoregulation (elevated core body temperature), heat strain (core temperature and heart rate) remained within the recommended limits. In contrast, more than 80% of workers were dehydrated before commencing the shift, and tended to remain so for the duration. Furthermore, more than 70% of workers reported symptoms of heat illness of mild-to-moderate severity.

Heat Strain

This study reveals that surface mine workers were under much greater heat strain than previously reported in the scientific literature, although it was not in excess of the recommended limits. The AIOH recommends that an individual's exposure to heat stress be discontinued if core body temperature is 38.5°C or more for acclimatized personnel.[18] Although no workers experienced excessive heat strain in this study, it was apparent from the fluctuations in core body temperature observed during the shift that the heat stress workers were exposed to was sufficient to challenge thermoregulation.

Core body temperature reached its highest mean and maximum between 2 PM and 6 PM (Table 1), and this reflects the contribution of the diurnal variation that peaks between 4 PM and 6 PM.[26] Acute fluctuations in the core temperature response (Fig. 1) are determined firstly by work intensity, and secondly by climatic heat stress above a certain level.[27,28] Heart rate indicated that workers spent the majority of the shift at a light work intensity (heart rate reserve of approximately 20%), with short periods of moderate-intensity activities (average maximum heart rate reserve of approximately 50%) (Table 1). It is recognized that the measurement of heart rate to estimate work intensity is subject to an error when the worker is exposed to heat stress. For a given work intensity, heart rate will be elevated when in a hot, compared with a cool climate.[29] Using heart rate reserve may have slightly overestimated the work intensity of blast crews. In conjunction, the work environment provided a moderate-to-high degree of heat stress (Table 4). Figure 1 shows that performing these tasks in the prevailing climatic conditions was sufficient to cause a challenge to thermoregulation, with core temperature rising approximately 0.6°C over a 1-hour period.

Another important point to consider in relation to the core body temperature experienced by surface mine workers is that almost 50% of workers exceeded 38.0°C during their shift. This finding is far greater than previously identified (22%) in a similar workforce.[6] The core temperature of 38.0°C is the limit value recommended by the AIOH for unacclimatized personnel.[18,19] These individuals who are unaccustomed to work in a hot environment are initially at greater risk of experiencing high levels of heat strain because they have not yet gained the beneficial effects of acclimatization. If new or inexperienced workers were to be introduced to this work, or if employees were returning from an extended period away from work, this finding highlights that they may be at risk of excessively high heat strain, as their body has not yet adapted to improve their heat tolerance.[30] Allowing new, inexperienced, or returning workers a period of acclimatization, involving shortened work rest cycles,

TABLE 4. Climatic Conditions

	6 AM to 10 AM	10 AM to 2 PM	2 PM to 6 PM	*P*
Ambient temperature, °C	28.6 ± 1.5	33.9 ± 1.7*	35.5 ± 1.3*	<0.001
Relative humidity, %	52.1 ± 8.5	28.3 ± 5.7*	24.0 ± 6.3*,†	<0.001
WBGT, °C	28.1 ± 2.3	29.1 ± 2.4	29.5 ± 1.9	0.071

†Significantly different from 10 AM to 2 PM.
*Significantly different from 6 AM to 10 AM.
WBGT, wet-bulb globe temperature.

should be implemented to gradually build up their tolerance to their work tasks in the heat.[31]

The present findings provide greater detail and insights into the core body temperature response to surface mine work. Other researchers have shown body temperature to range between 36.5 and 37.6°C for outdoor workers before, during (lunch break), and after a work shift.[2,6] These values are much lower than maximum core body temperatures found in this study, which can mainly be attributed to the continuous measurement of core body temperature, revealing the true peaks experienced by the workers. Although this study has shown that the combination of climatic conditions and work load is sufficient to cause a challenge to thermoregulation and that heat strain is much higher for surface mine workers than previously observed,[2,6] it remains within the limits recommended by the AIOH.

Hydration Status

The most concerning finding of the present investigation was that USG was 1.020 or more in more than 80% of workers on commencing their shift. These findings support previous research associated with surface mining and extend the issue of dehydration in the industrial workforce to surface mine workers in Queensland. Surface mines in Western Australia report USG to range between 1.019 and 1.029 before, during, and after a shift,[1,5,6] with 65% to 80% of the samples above 1.020.[1] Underground miners have also shown mean USG to be 1.025 before, during, and after a shift.[32] These data suggest that although many industrial workers are dehydrated, they are able to maintain a consistent level of dehydration throughout their shift.

Workers tended to maintain this level of inadequate hydration throughout the shift. An exception was a temporary improvement between 6 AM and 10 AM (Table 2). Two possible explanations can be put forward to explain this observation. First, the number of workers providing a urine sample at this time was less than all other time points. Workers who are better hydrated are likely to produce more urine samples; therefore, they may be overrepresenting the study sample at this time. Second, it could be that workers consumed a large amount of fluid on commencing their shift possibly because they were aware that their hydration status was being monitored. This can produce a lower USG value if the fluid passes through the body with little being absorbed. At least 50% of workers who provided urine samples showed a USG of 1.020 or more at all other time points.

The observation that workers are able to maintain a consistent level of dehydration is contradictory to the phenomenon of "voluntary dehydration," which stipulates that individuals will tend to replace only 60% to 70% of fluids lost through sweating, contributing to an overall loss in body mass.[33] A recent study investigated the influence of initial hydration status on voluntary fluid consumption during exercise.[34] Comparing well-hydrated and dehydrated (3.7% of body mass loss) groups, it was observed that the dehydrated group consumed sufficient fluid during exercise to maintain their initial body mass. In contrast, the hydrated group lost 1.4% of their body mass during 90 minutes of treadmill walking in the heat. The difference in fluid consumption was attributed to the rating of thirst experienced by the groups, and it was concluded that increased thirst-driven drinking (in those initially dehydrated) could attenuate the loss in body mass during exercise in the heat. The observed USG values in both this study and others reported previously suggest that it is likely that workers are maintaining a body mass deficit of approximately 3% throughout their shift. Because thirst is generally not experienced until a loss of 2% in body mass is incurred, it would appear that miners are drinking to the dictates of the thirst mechanism, similar to the dehydrated group in the above study. This is supported by the finding that the majority of workers reported experiencing thirst during their shift in this study (Table 3).

The volume of fluids consumed by workers in this study was higher than[6] or similar to that observed in surface mine workers in Western Australia,[1] but is much lower than 8.9 L consumed per shift by construction workers.[1] Over a 12-hour shift, these values (this study) equate to approximately 0.36 L/hr. This is lower than reported among petroleum workers in North West Australia (0.46 L/hr[35]) or underground miners (0.46 to 0.80 L/hr).[32,36] As body mass loss progresses above 2%, research has reported increased perceived effort,[37–39] reduced physical[37,40–44] and cognitive[45,46] performance, elevated heat strain,[8–11] and increased risk of heat illness.[12–17] Therefore, the hydration status of this workforce is a health and safety concern that needs to be addressed.

Another important finding of this study is the association between alcohol consumption the night before and hydration status. Contrary to what might be expected, it was observed that those who consumed alcohol the night before had significantly lower USG, suggesting improved hydration status. Others have also reported lower USG in workers consuming alcohol in the hours preceding work, although the difference was not significant.[5] There is some evidence that this is due to the volume of other fluids consumed. In this study, those who drank alcohol tended to also consume more fluid during their shift, although the difference did not reach statistical significance. It has also been reported that those who consume alcohol consume a greater volume of other fluids when off duty.[5] These studies suggest that the consumption of alcohol at night, which is common among this workforce, does not necessarily deteriorate hydration status, provided that the consumption of other fluids is concomitantly increased. Nevertheless, it should be noted that alcohol has a diuretic effect, allowing more water into the urine, hence lowering USG. Therefore, hydration among alcohol consumers may be poorer than indicated by USG.

Heat Illness

In the present investigation, more than 70% of workers reported experiencing at least one symptom of heat illness. Thirst was the most commonly reported symptom and was generally moderate in severity. The symptom "feeling tired" was also common, although tended to be mild in nature. Muscle cramps and weakness of a mild-to-moderate severity were experienced by 20% to 30% of workers. Two factors add to the importance of this finding. First, workers were only monitored for a single shift, which suggests that heat illness symptoms are a common experience among these workers. Second, many workers anecdotally reported that climatic conditions and work tasks on the days monitored were not the most demanding they may be exposed to. Therefore, there is a potential for more severe symptoms of heat illness to be experienced by surface mine workers than were captured by this study.

The present findings add to a growing body of evidence showing symptoms of heat illness to be common among surface mine workers, and the broader mining industry. Recent reports have shown that many surface mine workers routinely experience symptoms of heat illness.[4] A similar frequency of symptoms was reported in underground mines in the United Kingdom where medical personnel estimate a heat-related incident occurring every day, ranging from heat rash to loss of consciousness.[47] Similar to this study, the heat strain in underground miners did not identify any cases of heat illness requiring medical attention during the periods monitored.[20,48] Nevertheless, these findings raise a health and safety concern for surface mine workers and the broader industry, as mild symptoms can quickly progress to more serious or life-threatening situations if appropriate control measures are not in place.[49–51]

Heat illness has traditionally been labeled as either "present" or absent" according to defined conditions, such as heat cramps, heat exhaustion, and heat stroke. Although this classification may be useful for clinical diagnosis, it may be disadvantageous when studying the development of these conditions. Instead, heat illness should be considered as falling along a continuum of ailments resulting from an accumulation of the effects of heat in the body.[24] Continuing this approach of monitoring symptoms may be more useful in industrial settings and aid in the early identification of heat illnesses before progression to serious conditions.

In this study, none of the known risk factors for heat illness (including body mass index, age, core body temperature, climate, and hydration status) were found to be associated with the experience of heat illness symptoms. The most likely reason for this was a small sample size combined with inadequate variation in the study population. Although the sample monitored in this study represents approximately 75% of workers in these job categories for the contractor at this mine site, the number of workers is quite small. Because there are several factors thought to contribute to heat illness symptoms, the bivariate correlations with individual factors tend to have low r^2 values. This makes it more difficult to establish statistical significance with a small sample size as it is likely that each of the risk factors is influencing the symptoms experienced to some degree. In addition, there may not have been sufficient variation in the population or the environmental conditions to provide a complete view of each factor's influence. The majority of workers were overweight (body mass index $\geq$25) and dehydrated (USG $\geq$1.020); therefore, there may not have been sufficient numbers of healthy weight, and well-hydrated individuals to bring out these relationships statistically.

CONCLUSIONS

Many of the surface mine workers in this study were dehydrated on commencing work and tended to remain so for the duration of the shift. The work performed and prevailing climatic conditions were sufficient to cause thermoregulatory challenge, but workers did not experience excessive levels of heat strain and reported only minor symptoms of heat illness. Because heat illness occurs along a continuum and can easily progress into more serious cases, these findings highlight the necessity to maintain appropriate vigilance and control measures around known risk factors.

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