

The risk of heat exhaustion at a deep underground metalliferous mine in relation to surface temperatures

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The risk of heat exhaustion at a deep underground metalliferous mine was assessed in relation to thermal conditions prevailing on the surface. For each day of a 1-year prospective case series of heat exhaustion, surface 24-h mean wet and dry bulb temperatures were recorded. From this data, 24-h mean wet bulb globe temperatures were derived using certain assumptions. The three surface temperature variables were significantly higher on those days on which heat exhaustion occurred, compared to those days on which it did not occur ($P < 0.001$). The relative risk of heat exhaustion on days when the 24-h mean wet bulb globe temperature was in the range 26.0–28.0°C was 4.82 (95% confidence interval 2.12–10.96). Surface temperature data could be used at this mine to warn miners about the risk of heat exhaustion.

Key words: Heat; heat exhaustion; mine; miners; mining; risk; thermal; tropical; underground; ventilation.

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INTRODUCTION

Thermal conditions in underground mines are the result of thermal conditions on the surface, sources of heat and humidity underground, and ventilation/refrigeration.^{1,2} A recent paper reported a 1-year prospective series of 106 cases of heat exhaustion in a deep underground metalliferous mine.³ The present paper aims to assess the risk of heat exhaustion, in relation to surface thermal conditions occurring at the same mine, in order to determine whether surface temperature data could be used to warn miners going underground about this risk. To the best of our knowledge such an analysis has not been undertaken before.

METHODS

The response data for the study came from a 1-year prospective case series of acute heat exhaustion cases.³ This was undertaken from 1 October 1997 to 30 September 1998 at a deep (1800 m maximum depth) underground metalliferous mine in tropical arid Australia. Entry criteria required a history of significant heat exposure, the presence of one or more symptoms of heat exhaustion commencing after starting work (headache, dizziness, fatigue, nausea, vomiting, transient loss of consciousness) and the reasonable clinical exclusion of alternative diagnoses. Details of the case series and underground thermal conditions have already been reported.³ The mine operates 24 hours per day, 365 days per year. Twelve-hour shifts are worked, with 2 day shifts followed by 2 night shifts followed by 4 days off. Approximately the same numbers of miners are underground at any time.

For every day of the 1-year study period, surface temperatures were obtained from the mine's meteorologist. These were computer recorded as 24-h mean wet bulb temperatures (24WBT) and 24-h mean dry bulb temperatures (24DBT). The 24-h sampling period

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commenced at midnight. From this data, 24-h mean wet bulb globe temperatures (24WBGT) were derived using the formula $(0.7(24WBT)) + (0.3(24DBT))$. Dry bulb temperature was substituted for globe temperature in the standard equation.⁴ The reason for this was that we were interested in the character of air entering the mine's ventilation intakes and this is not influenced by radiant heat.

Two groups of temperature data were generated. These represented the days on which heat exhaustion did and did not occur.

Curtin University's Human Research Ethics Committee approved the study.

Statistical analysis

Mean, standard deviation, median and range values were determined for each of the surface temperature variables on days on which heat exhaustion did and did not occur (Microsoft Excel). Box plots were generated for the surface temperature variables on days on which heat exhaustion did and did not occur (SPSS). The significance of differences between the surface temperatures on days on which heat exhaustion did and did not occur, were determined using the Mann-Whitney *U* test (SPSS). Relative risks and their 95% confidence intervals were calculated for the risk of heat exhaustion occurring in several ranges of each surface temperature variable (Epi-Info).

RESULTS

One hundred and six of 118 cases (90%) of heat exhaustion were studied. The miners with heat exhaustion had worked underground for a mean period of 7.1 years (SD 6.6, median 4.0, range 0.01–30.0). Only 12.3% had worked underground for less than 1 year. Only one miner had been outside the tropics in the 2 weeks before presentation.

Surface temperatures were collected for every day of the 1-year study period. The descriptive statistics are presented in Table 1. The results of the Mann-Whitney *U* tests for differences between the surface temperatures on days on which heat exhaustion did and did not occur are also listed in Table 1. Box plots of the data are presented in Figure 1.

The numbers of days on which heat exhaustion did and did not occur are listed for several ranges of each surface temperature variable in Table 2. Relative risks of heat exhaustion and their 95% confidence intervals are given for each surface temperature range in Table 2, taking the rate for the lowest stated temperature range as the 'unexposed' comparison rate.

DISCUSSION

The three surface temperature variables were significantly higher on those days on which heat exhaustion occurred compared to those days on which it did not

Table 1. 24WBT, 24DBT and 24WBGT for days on which heat exhaustion did and did not occur

Data for surface temperature	No HE	HE	P
24WBT			
<i>n</i>	284	81	<0.001
Mean	16.8	19.9	
Standard deviation	4.4	4.2	
Median	17.0	21.1	
Range	5.4–25.8	7.6–24.4	
24DBT			
<i>n</i>	284	81	<0.001
Mean	25.1	27.5	
Standard deviation	5.3	4.9	
Median	25.9	29.1	
Range	10.7–35.9	14.6–35.2	
24WBGT			
<i>n</i>	284	81	<0.001
Mean	19.3	22.2	
Standard deviation	4.4	4.1	
Median	19.8	23.9	
Range	7.0–27.5	9.8–27.6	

No HE, number of days on which no cases of heat exhaustion occurred.

HE, number of days on which cases of heat exhaustion occurred.

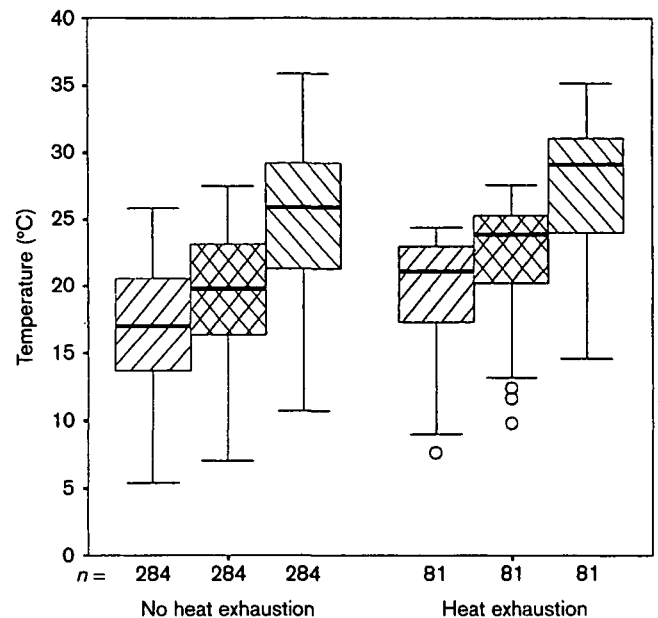
24WBT, the 24-h mean wet bulb temperature (°C).

24DBT, the 24-h mean dry bulb temperature (°C).

24WBGT, the 24-h mean wet bulb globe temperature (°C).

P, *P* value for the difference between No HE and HE thermal values.

Figure 1. Surface temperatures on days on which heat exhaustion did and did not occur. (▨) 24WBT, 24-h mean wet bulb temperature; (▩) 24WBGT, 24-h mean wet bulb globe temperature; (▧) 24DBT, 24-h mean dry bulb temperature.



occur. In addition, the relative risk of heat exhaustion increased with increasing temperature for each of the thermal variables. These observations indicate the presence of an exposure-response relationship between surface temperatures and the occurrence of heat exhaustion. This is consistent with the observation that the incidence of heat exhaustion increases in summer.³

Table 2. Number of days on which heat exhaustion did and did not occur, stratified by thermal values. Relative risk of heat exhaustion stratified by thermal values

Range*	No HE	HE	RR	95% CI
24WBT				
16–18	43	9	1.00	
18–20	37	6	0.81	0.31–2.09
20–22	47	19	1.66	0.82–3.37
22–24	33	27	2.60	1.35–5.01
24–26	4	6	3.47	1.59–7.57
24DBT				
21–24	53	9	1.00	
24–27	38	11	1.55	0.70–3.43
27–30	78	15	1.11	0.52–2.38
30–33	46	26	2.49	1.26–4.90
33–36	6	9	4.13	1.99–8.59
24WBGT				
18–20	46	7	1.00	
20–22	42	10	1.46	0.60–3.53
22–24	51	12	1.44	0.61–3.40
24–26	38	32	3.46	1.66–7.22
26–28	4	7	4.82	2.12–10.96

No HE, number of days on which no cases of heat exhaustion occurred.

HE, number of days on which cases of heat exhaustion occurred.

RR, relative risk.

95% CI, the 95% confidence interval for the relative risk.

24WBT, the 24-h mean wet bulb temperature (°C).

24DBT, the 24-h mean dry bulb temperature (°C).

24WBGT, the 24-h mean wet bulb globe temperature (°C).

*Range of days for each surface temperature variable.

It is unlikely that the increased incidence of heat exhaustion in summer is due to recruitment of inexperienced or unacclimatized workers. Only 12.3% of the cases had been underground for less than a year and only one case had been outside the tropics in the 2 weeks before presentation.

Surface temperature data could be used at this mine to warn miners going underground about the risk of heat exhaustion. When the 24-h mean wet bulb globe temperature was within the range 24.0–26.0°C (RR 3.46, 95%CI 1.66–7.22), a warning sign could be displayed at the sub-brace, where miners enter the cage to go underground, indicating an elevated risk of heat exhaustion and the need for conscientious fluid intake and careful self-pacing of the work rate. When the 24-h mean wet bulb globe temperature exceeded 26.0°C (RR 4.82, 95% CI 2.12–10.96), a very high-risk warning could be displayed. These temperature ranges would be reached on 70 and 11 days of the year, respectively, based on the study year experience. It is therefore unlikely that the warning signs would be ignored through overuse. An electronic display board could be used for the warning signs, driven by computer algorithm using

real-time computer recorded 24-h mean temperatures. Management could also increase the frequency of underground thermal measurements on these high-risk days in order to detect withdrawal conditions more effectively.

Although this approach could be adopted elsewhere, the relative risks would need to be calculated locally because variations in climate, the geothermal gradient, mine depth, heat production from machinery, control of groundwater/mine-water, and ventilation/refrigeration practices would modify the risk. At remote mine sites the warning display could be placed in miners' living quarters. This would allow more time for rehydration prior to starting work. This would not be possible at the mine that was studied as the miners live in their own homes in a nearby city.

Clearly this is a supplementary control method and does not replace the need for several other controls in the management of heat stress underground,^{1–3} such as:

- selection of energy efficient machinery,
- control of groundwater/mine-water,
- appropriate ventilation and refrigeration,
- measurement of underground thermal conditions,
- use of withdrawal underground thermal limits,
- education to promote hydration before, during and after the shift,
- education to promote self-pacing of the work-rate.

Several factors influencing the occurrence of heat exhaustion, including underground thermal conditions, mine depth, state of hydration, work rate, body mass index, and maximal oxygen uptake are examined in two related papers.^{3,5}

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