Evaluation of heat-acclimatization procedures at wet-bulb temperatures below 31,7 °C

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SYNOPSIS

Three groups of unacclimatized men were subjected to five-day climatic-room procedures at wet-bulb temperatures of 29, 30, and 31 °C respectively. The findings indicated that individuals reach a satisfactory level of heat acclimatization for work in environmental temperatures conforming to those at which they were acclimatized. It is, therefore, superfluous to acclimatize men at wet-bulb temperatures that exceed those at which they are destined to work. These methods of acclimatization can be linked advantageously to heat-tolerance testing at mines with suitable underground temperatures.

SAMEVATTING

Drie groepe ongeakklimatiseerde proefpersone het 'n vyf-dag akklimatisasieprogram voltooi by natboltemperature van 29, 30 en 31 °C, onderskeidelik. Die resultate toon dat 'n aanvaarbare vlak van akklimatisasie verwerf word vir fisieke werk in omgewingstoestande wat ooreenstem met dié waarby akklimatisasie plaasgevind het. Dit is derhalwe onnodig om akklimatisasie uit te voer by temperature hoër as die waarby individue verwag sal word om te werk. Hierdie metodes van akklimatisasie kan op voordelige wyse gekoppel word aan hittetoleransietoetse by myne met toepaslike ondergrondse toestande.

Introduction

The acclimatization of men to working in heat forms an integral part of the South African gold-mining industry, and, on the average, formal acclimatization in a climatic room requires 4,7 shifts per man. Heat acclimatization becomes necessary whenever men are required to work in underground environments in which the temperatures are higher than 27,5 °C wet-bulb[1], and at present workers are acclimatized for three ranges of wet-bulb temperature: 27,5 to 29,0 °C, 29,1 to 29,9 °C, and 30 to 32,8 °C. This is achieved by varying the number of days spent on acclimatization for the respective target underground temperatures, rather than by varying the thermal conditions, which are kept constant at 31,7 °C wet-bulb and 33,3 °C dry-bulb in all acclimatization centres[2].

Recent advances in the control of environmental temperatures in gold mines[3] will eventually result in relatively cooler working places underground. The question now arises as to whether it is necessary or scientifically tenable to acclimatize men in temperature conditions exceeding those in which they are destined to work. As no relevant information on the subject is available, a study was undertaken to ascertain whether men will reach a satisfactory level of heat acclimatization if they are acclimatized at the environmental temperatures corresponding to those at which they will ultimately be required to work underground.

Experimental Procedures

Three groups of 20 or more unacclimatized men were used as subjects, their physical characteristics being as given in Table I. All three groups were subjected to a five-day acclimatization procedure at wet-bulb temperatures of 29, 30, and 31,7 °C (respectively Groups 1, 2 and 3) and dry-bulb temperatures chosen to provide a relative humidity of approximately 90 per cent. The daily exposure times, work rates (block-stepping), and procedures followed during these acclimatization regimes were identical to the standard five-day procedure used in the mining industry[2].

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS

Experimental Group	*n*	Mass kg	Height m	Age
Group 1	20	60,27±5,51	1,69±0,05	24,6±5,2
Control 1	10	60,57±6,71	1,68±0,05	27,1±6,2
Group 2	20	60,41±5,91	1,67±0,06	26,2±5,9
Control 2	20	62,00±4,74	1,68±0,04	26,9±5,2
Group 3	30	62,19±5,79	1,69±0,05	25,3±3,1
Control 3	20	61,52±6,92	1,68±0,05	26,0±4,1
Control 4	44	61,71±6,99	1,68±0,05	25,7±3,8

So that the extent of heat acclimatization achieved by the different groups could be assessed, the respective acclimatization procedures were followed by two consecutive test days conducted under the conditions outlined in Table II.

The activity of the first test day was performed under thermal conditions identical to those prevailing during the respective acclimatization regimes, while identical conditions (31,7 °C wet-bulb and 33,3 °C dry-bulb temperatures) were chosen for the second test day. Measurements of heart rate and rectal temperature were obtained at rest and hourly during heat exposure. Sweat rates were calculated from hourly differences in mass, taking into account the water ingested and the urine voided. The total sweat rate was calculated from the total sweat loss after 4 hours of work in the climatic room. During all the stepping procedures, only athletic shorts were worn and, during the course of exposure in heat, subjects were allowed to drink water *ad lib.* at half-hourly intervals.

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TABLE II

TEST CONDITIONS USED TO DETERMINE DEGREE OF HEAT ACCLIMATIZATION ACHIEVED AT VARIOUS WET-BULB TEMPERATURES

Group	Test conditions					
	Day 1			Day 2		
	Work rate W	Wet-bulb temperature °C	Exposure time h	Work rate W	Wet-bulb temperature °C	Exposure time h
1	54	29,0	4	54	31,7	4
2	54	30,0	4	54	31,7	4
3	54	31,0	4	54	31,7	4

The results obtained on the respective test days were compared with those of four different control groups subjected to identical heat-stress conditions. These control groups consisted of men acclimatized by the standard climatic room procedure[2] for work in environmental temperatures of 29, 30, and 31,7 °C wet-bulb. Their physical characteristics are also given in Table I.

Results

The heart rates and rectal temperatures of the subjects at rest and after each hour of work in heat on the first test day are given in Table III. The hourly sweat rates are also included in this table. No significant differences could be demonstrated between the respective experimental and control groups with respect to fourth-hour heart rate, rectal temperature, and hourly sweat rate on the first test day.

Fourth-hour rectal temperatures on the respective test days, which are a measure of the degree of acclimatization achieved, are presented in Table IV.

From these results it is clear that the mean fourth-hour rectal temperatures of Groups 1, 2, and 3 on the first test day compare favourably with their respective controls. Although the responses of the experimental group manifest a superior degree of heat acclimatization, thus suggesting a generally superior heat-acclimatization regime, the differences are statistically insignificant (Student t-test: $p > 0,05$ in all three cases). Moreover, the respective standard deviations obtained for the three groups are also of the same order of magnitude as those of the corresponding control groups on the first test day, indicating similarity also in the range of individual responses. It is also evident that the maximum fourth-hour rectal temperatures recorded for the experimental groups did not exceed those of their respective controls.

On the basis of normal distribution theory, the risk of obtaining fourth-hour rectal temperatures in excess of 40 °C under the various test conditions was calculated for the three groups (Table V).

The risk of developing fourth-hour rectal temperatures in excess of 40 °C was less than 1 in a million under conditions of the first test day for all three groups. However, the risk increased considerably under conditions of an elevated wet-bulb temperature as experienced on the second test day: 5000 per million men in Groups 1 and 2, and 500 per million men in Group 3. The inability of the experimental groups to maintain thermal equilibrium relative to the responses exhibited by the control group is clearly shown in Fig. 1.

It is also evident that the experimental groups were at a disadvantage despite exhibiting higher sweat rates than those of the control group (Fig. 2).

TABLE III

HEART RATE, RECTAL TEMPERATURE, AND SWEAT RATE DURING THE FIRST HEAT-STRESS TEST

Variable	Hour	Test temperature 29,0 °C wet-bulb				Test temperature 30,0 °C wet-bulb				Test temperature 31,0 °C wet-bulb			
		Test (n = 20)		Control (n=10)		Test (n = 20)		Control (n=20)		Test (n = 20)		Control (n=20)	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Heart rate, beat·min^{-1}	R	72,5	10,9	82,8	9,0	74,6	10,4	78,9	8,0	75,6	9,6	76,6	7,7
	1	109,5	10,3	122,0	16,7	105,9	13,0	113,0	7,2	119,9	11,5	119,0	10,6
	2	111,8	11,0	121,4	19,2	109,7	10,2	113,0	7,6	119,7	10,2	121,8	14,5
	3	116,4	9,7	122,0	18,8	111,7	10,6	116,9	6,8	123,9	11,7	127,6	15,6
	4	119,1	8,4	125,6	18,4	119,3	12,4	122,2	11,4	127,7	12,1	128,9	16,9
Rectal temperature, °C	R	36,95	0,22	37,36	0,28	36,91	0,20	37,18	0,23	36,98	0,18	37,15	0,29
	1	37,72	0,22	37,89	0,29	37,77	0,26	37,98	0,22	37,94	0,28	38,04	0,27
	2	37,80	0,24	37,94	0,34	37,81	0,25	38,03	0,17	38,09	0,31	38,17	0,26
	3	37,87	0,20	37,95	0,35	37,88	0,27	38,07	0,20	38,20	0,29	38,34	0,34
	4	37,93	0,29	38,02	0,29	38,07	0,24	38,15	0,26	38,36	0,33	38,54	0,40
Sweat rate, l·h^{-1}	1	0,54	0,19	0,62	0,16	0,63	0,21	0,75	0,18	0,60	0,17	0,67	0,14
	2	0,60	0,20	0,69	0,16	0,75	0,25	0,74	0,15	0,74	0,15	0,72	0,17
	3	0,50	0,16	0,53	0,15	0,54	0,16	0,57	0,14	0,62	0,14	0,58	0,16
	4	0,45	0,11	0,50	0,14	0,49	0,11	0,49	0,11	0,52	0,12	0,51	0,14

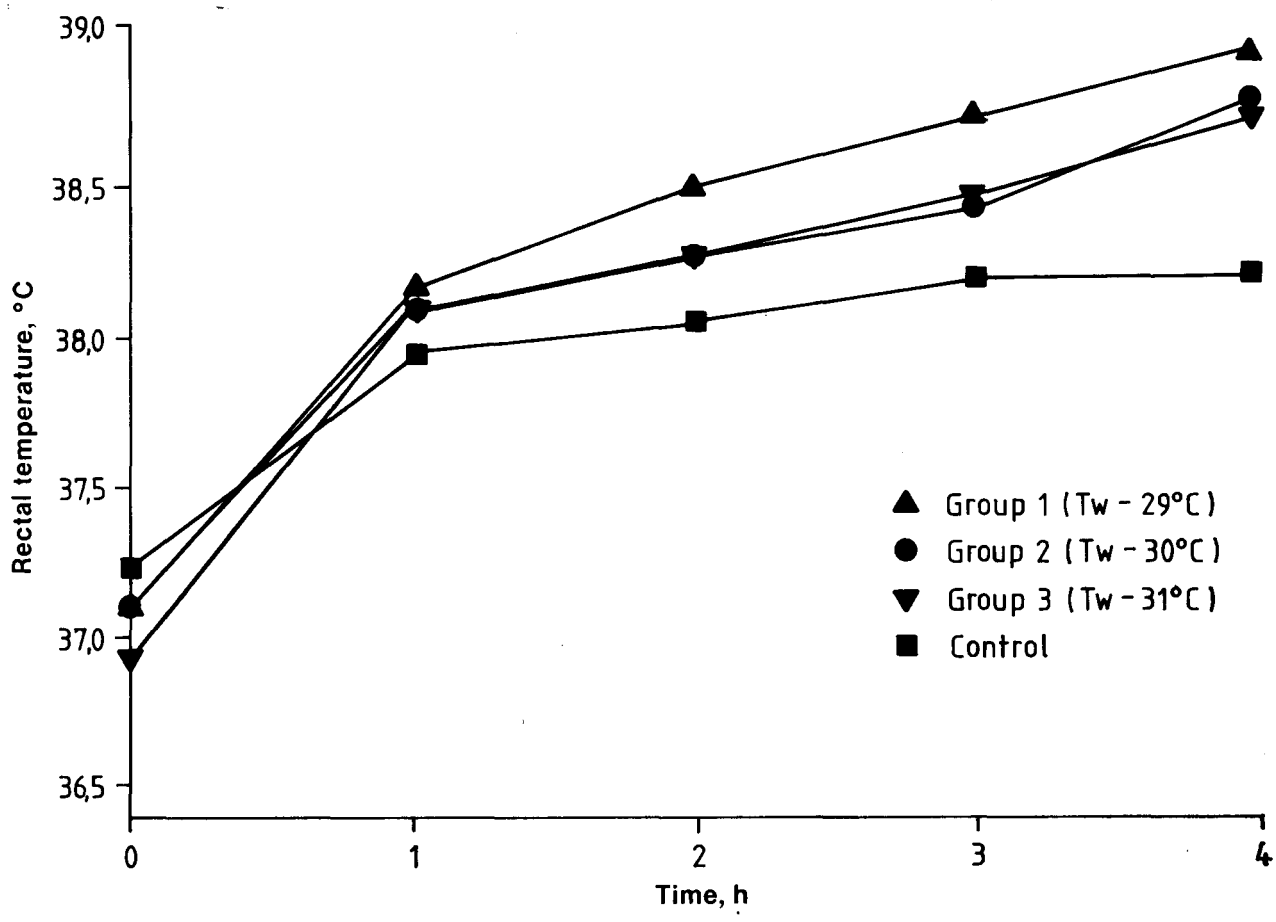

Fig. 1—Mean hourly rectal temperatures of experimental groups on test day 2.

Discussion

Of practical relevance is whether 'over-acclimatization' confers any special physiological benefit that would make it mandatory for men to be acclimatized under conditions more severe than those they are destined to encounter. In terms of the parameters assessed, no such benefit could be demonstrated. Thus, men acclimatized at wet-bulb temperatures of 29,0, 30,0, and 31,0 °C were as well equipped to cope with these levels of stress, respectively, as were men acclimatized at 31,7 °C, i.e. 'over-acclimatized' men.

Conversely, acclimatization achieved at levels of stress lower than those expected increased the risk of hyperthermia considerably. For example, an increase in wet-bulb temperature from 31,0 to 31,7 °C (i.e. only 0,7 °C) was associated with more than a 500-fold increase in the risk of exceeding a rectal temperature of 40,0 °C. These findings underline the specificity of heat acclimatization.

TABLE IV

FOURTH-HOUR RECTAL TEMPERATURES (TR_4) ON TEST DAYS

Experimental group	*n*	Target wet-bulb temperature °C	Test day — TR_4 values		
			1		2
			Maximum °C	Mean ± SD °C	Mean ± SD °C
Group 1	20	29	38,5	37,93 ± 0,29	38,92 ± 0,42
Control 1	10	29	38,5	38,02 ± 0,29	
Group 2	20	30	38,4	38,07 ± 0,24	38,78 ± 0,47
Control 2	20	30	38,6	38,15 ± 0,26	
Group 3	30	31	39,0	38,36 ± 0,33	38,75 ± 0,38
Control 3	20	31	39,2	38,54 ± 0,40	
Control 4	44	31,7	—	—	38,31 ± 0,34

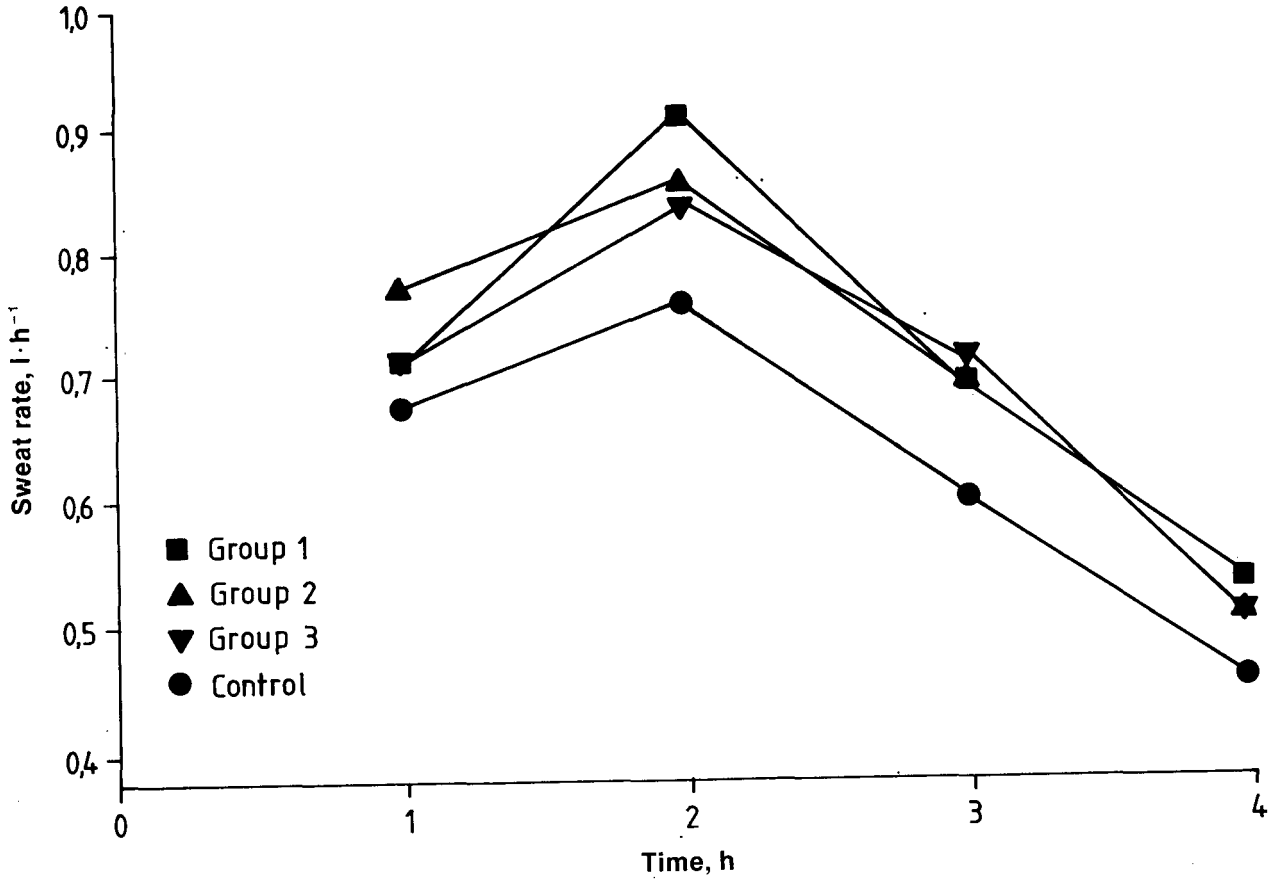

Fig. 2—Mean hourly sweat rates of the experimental groups on test day 2

Previous studies[2] indicated that returnees (i.e. men who had been heat-acclimatized successfully on former contracts) show better tolerance to heat and require less acclimatization than men new to the industry (novices). The present study confirms these views: returnees were able to complete the fifth day of their respective acclimatization regimes, which consisted of four hours of work at a rate of 70 W, without developing dangerously high body temperatures. Average fourth-hour rectal temperatures recorded on that day ranged from 38,5 °C (Group 1) to 38,6 °C (Groups 2 and 3), and the probability that the fourth-hour rectal temperatures would exceed 40,0 °C amounted to less than one in a million for all three wet-bulb temperatures. It would therefore appear that four days of heat acclimatization are sufficient for returnees to reach full acclimatization at these temperatures.

The results of this study suggest further that it would be feasible to introduce a modification of current procedures at mines with maximum underground temperatures of between 30,0 and 31,0 °C wet-bulb. Mines falling within these limits are at present subjecting their workers to a five-day acclimatization regime at 31,7 °C wet-bulb, and, since such men are destined to work at lower wet-bulb temperatures (between 30,0 and 31,0 °C), some energy and cost savings can probably be achieved by lowering the temperature of the climatic room. Moreover, the number of men who are incapable of achieving heat acclimatization under climatic room conditions of 31,7 °C wet-bulb, but who may nevertheless show normal acclimatization responses at lower wet-bulb temperatures, is likely to diminish with the modified procedure. This would mean a reduction in the number of unproductive shifts and the number of extra days spent in the climatic chamber.

TABLE V

PROBABILITY OF DEVELOPING FOURTH-HOUR RECTAL TEMPERATURES EQUAL TO OR HIGHER THAN 40,0 °C ON THE RESPECTIVE TEST DAYS

Group	Test day 1 men per million	Test day 2 men per million
1	< 1	5000
2	< 1	5000
3	< 1	500

Since heat tolerance is a function of wet-bulb temperature, heat acclimatization accomplished at temperatures of 29, 30, and 31 °C wet-bulb could be linked advantageously to heat-tolerance tests[4]. Thus, men who fail the heat-tolerance test would revert to conventional heat-acclimatization procedures without the need for changes in the environmental conditions. The disadvantage of a longer acclimatization period at 29 °C wet-bulb (one to two days longer than the method used at present) would be offset by the greater proportion of men (approximately 72 per cent)[4] who are likely to be classified as hyper-heat-tolerant. Only a relatively small

number of men would require conventional acclimatization in a climatic room. The extra time spent on acclimatization would therefore be insignificant compared with the time saved on acclimatization by the hyper-heat-tolerants.

Conclusions

The findings of this study underline the specificity of heat acclimatization and, inasmuch as over-acclimatization confers no additional physiological benefit at relatively low levels of heat stress, an option is provided whereby sufficient heat acclimatization can be achieved at temperatures lower than the present levels recommended for climatic rooms (31,7 °C wet-bulb and 33,3 °C dry-bulb). The advantage is related primarily to the saving of unproductive shifts through a decrease in the number of men who are likely to be deemed heat-intolerant during conventional acclimatization and, on mines where the heat tolerance test is applied, through an increase in the number of hyper-heat-tolerant men.

References

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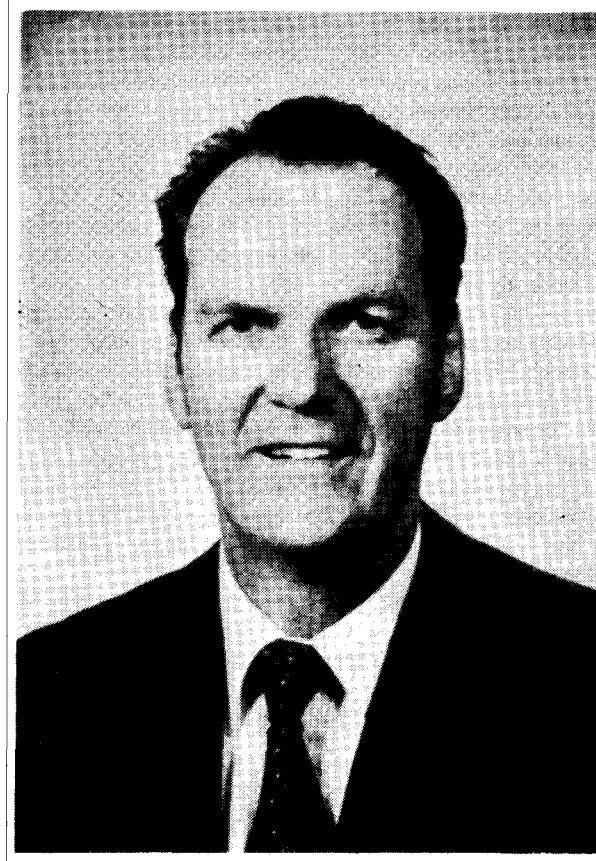
Geological award

Dr Douglas R. Piteau of Piteau & Associates in Vancouver (Canada) and Mr Lionel Peckover, Consultant, Vaudreuil (Canada) were named 1982 recipients of the E. B. Burwell, Jr. Award given by the Geological Society of America for their paper 'Engineering of Rock Slopes'. The paper is Chapter 9 in a book entitled *Landslides: Analysis and Control*, published by the Transportation Research Board, National Academy of Sciences.

This award is made annually for a published work of distinction in engineering geology or rock mechanics in which the role of geology is emphasized.

Dr Piteau, while working with the De Beers/Anglo American group, completed his Ph.D. at the University of the Witwatersrand. He worked closely with the late Professor J. E. Jennings.



Dr Douglas R. Piteau