The performance of the improved microclimate suit

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SYNOPSIS

An assessment has been made of a new improved microclimate jacket when worn by men working for four hours in a hot environment (wet-bulb temperature of 33,9°C and an air speed of 0,4 m/s) and at work rates of 35 W and 70 W.

At the lower rate of work in heat, the use of microclimate suits maintained the rectal temperatures of the men at almost the same level as when they worked without that protection at normal room temperature (20°C).

At the greater rate of work without protection, the men's rectal temperatures rose to 40°C within two to three hours, so that they could not complete four hours of work. When they wore microclimate suits, they easily completed four hours of work, and their rectal temperatures were lower than when they worked at the lower rate without protection.

SAMEVATTING

Die nuwe verbeterde mikroklimaatbaadjies was getoets vir doeltreffendheid om persone wat teen twee verskillende tempos in 'n warm omgewing werk, te beskerm. Vyf geakklimatiseerde Bantoe proefpersone moes werk verrig teen tempos van 35 en 30 W vir vier ure in 'n omgewing van 33,8°C natbol-temperatuur en 'n windsnelheid van 0,4 m/s.

Om vergelykende redes het hulle teen dieselfde werkladings by normale kamertemperature gewerk (± 20°C natbol). By die lae werklading het die mikroklimaatbaadjies rektaaltemperature by amper dieselfde waardes gehou as toe die persone by kamertemperature gewerk het.

Sonder die beskerming van die baadjies was dit nie moontlik om die vier ure van harde werk te voltooi nie omdat hul liggaamstemperature tot 40°C binne twee tot drie ure gestyg het. Toe hulle die mikroklimaatbaadjies gedra het terwyl hulle hard gewerk het in hitte kon hul die vier ure van werk met gemak voltooi en was hul liggaamstemperature laer as toe hulle by die lae werklading sonder beskerming gewerk het.

INTRODUCTION

The results reported by Van Rensburg *et al.*[1] on the performance of microclimate suits were obtained on the first crude prototype jackets constructed at the Human Sciences Laboratory. These results indicated the advantages to be gained in the physiological well-being of labourers from the wearing of microclimate suits in hot environments. Consequently, a new type of microclimate suit, consisting of a pre-frozen waistcoat and an insulating over-jacket, was designed and manufactured by Mine Safety Appliances Ltd[2]. The results of two series of underground tests on the practical application of these pre-frozen suits[3] confirmed the results obtained by Van Rensburg *et al.*, and led to marked improvements in the design and manufacture of the suits so that the present article bears little resemblance to the prototype suit used by Van Rensburg *et al.* The performance characteristics of the new microclimate suit cannot therefore be evaluated on Van Rensburg's results. In the study reported here, the performance of the present suit was investigated by the experimental procedures used by Van Rensburg *et al.* The subjects worked at two work rates, 35 W and 70 W, and at a wet-bulb temperature of 33,9 °C.

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METHODS

Five men having the physical characteristics shown in Table I volunteered for the tests. After being tested on the treadmill for maximum oxygen intake, they underwent the usual eight-day climatic-room acclimatization procedure[4] at temperatures of 31,7 °C wet-bulb and 33,3 °C dry-bulb, and an air speed of 0,4 m/s. As a precaution, the procedure for the eighth day was repeated to ensure full acclimatization[5]. The subjects thereafter daily carried out four hours of work at rates controlled at 35 W or 70 W (i.e., stepping on and off blocks at pre-set heights at either 12 or 24 steps per minute) in a hot environment and finally at room temperature. The men were always re-acclimatized on Mondays so as to eliminate the 'Monday effect'. The tests were done according to the following schedule:

Day	Work rate	D.B. temp.	W.B. temp.	With or without jackets
	W	°C	°C	
1	70	35,6	33,9	Without
2	70	35,6	33,9	With
3	70	33,3	31,7	*
*	70	33,3	31,7	*
4	70	35,6	35,6	Without
5	35	35,6	35,6	Without
6	35	35,6	35,6	Without
7	70	35,6	35,6	With
8	35	33,6	35,6	With
*	70	33,3	31,7	*
9	35	35,6	33,9	With
10	70	22,0	15,0	Without
11	70	22,0	15,0	Without
12	35	22,0	15,0	Without
13	35	22,0	15,0	Without

* = Re-acclimatization

The air speed remained the same (i.e., 0,4 m/s) for all hot experimental conditions, while there was no measurable air flow at room-temperature conditions. Each experiment lasted four hours, except when subjects developed body temperatures higher than 39,8 °C or stopped owing to fatigue or danger of collapse. Observations of heart rate and rectal temperature were made hourly by means of an Erbepuls 200 heart-rate counter and clinical thermometers. On those days on which jackets were worn, the men started off with pre-frozen waistcoats and were issued with hard frozen waistcoats after two hours of work. The microclimate suits used, i.e., water waistcoat plus insulation jacket, were of the latest design available from the manufacturers.

In addition to the above tests, observations were made of the energy cost of stepping at the two work loads when the subjects were without the jackets, when they were wearing the jackets but were compensated by a reduction in stepping height, and when they were wearing the jackets without such compensation.

RESULTS

The data are represented in Figs. 1 and 2, and are summarized in Tables II and III. Each point on the curves in the diagrams represents the average of the responses of each of the five subjects to two test runs on different days.

Low Work Rate (35 W)

The rectal temperatures of the men during stepping in cool conditions increased from resting values and levelled off at 37,5 °C at the low work rate. In the hot environment (33,8 °C wet-bulb), when the men were not wearing the ice-jackets, the average rectal temperatures of the acclimatized subjects rose steadily from 38,2 °C at the first hour to 39,0 °C at the fourth hour. A two-way analysis of variance indicated that the differences between these two sets of observations were highly significant, as indicated in Table II. The reason for the significant difference between the body temperatures of the men at rest must be sought in the difference in the temperatures of the two environments in which the men rested.

When the men were wearing the microclimate suits during the same heat exposure and work rate, their temperatures levelled off at 37,7 °C, i.e., only 0,2 °C higher than when they were working under room-temperature conditions. No significant differences could be detected between the temperature responses under these two conditions, except that, during the last hour of the tests at room temperature, their rectal temperatures decreased and could be shown to be significantly different at the 5 per cent level from those observed when ice-jackets were worn under the hot conditions.

The heart rates of the men under the three conditions of cool, protected in heat, and unprotected in heat, levelled off at 90, 105, and 135 beats per minute respectively, and were found to differ highly significantly from one another. However, the advantage of wearing the suit remains evident.

The average total sweat rates when the subjects stepped for four hours at 33,8 °C were 3,027 litres when they were unprotected, 1,789 litres when they were protected, and only 0,476 litres when they stepped at room temperature.

Hard Work (70 W)

Doubling the work rate from 35 to 70 W resulted in a rise of 0,2 °C in rectal temperature when the men worked at room temperature. When unprotected, two of the subjects failed to complete more than two hours of work, and another withdrew after the third hour. This reduction in numbers made statistically valid comparisons of the physiological reactions during the third and fourth hours impossible. The two men who completed the test had rectal temperatures of 40 °C at the end of the test. The rectal temperatures of the protected men during the first two hours were significantly lower (at the 1 per cent level) than those of the unprotected men, and all the protected men were able to complete the four hours of exposure. In fact, while they were protected, their temperatures were lower than those observed when they were unprotected and worked at only half the rate.

Heart rates of the men protected by cool suits were also significantly lower than those of the men who worked without the protection of the cool suit. No true equilibrium in heart rate was reached under any of the three conditions.

Sweat rates again differed significantly, but the differences between those of the protected and those of the unprotected men were not as large as they were when the men worked at the lower rate.

Energy Costs

The energy costs, expressed as

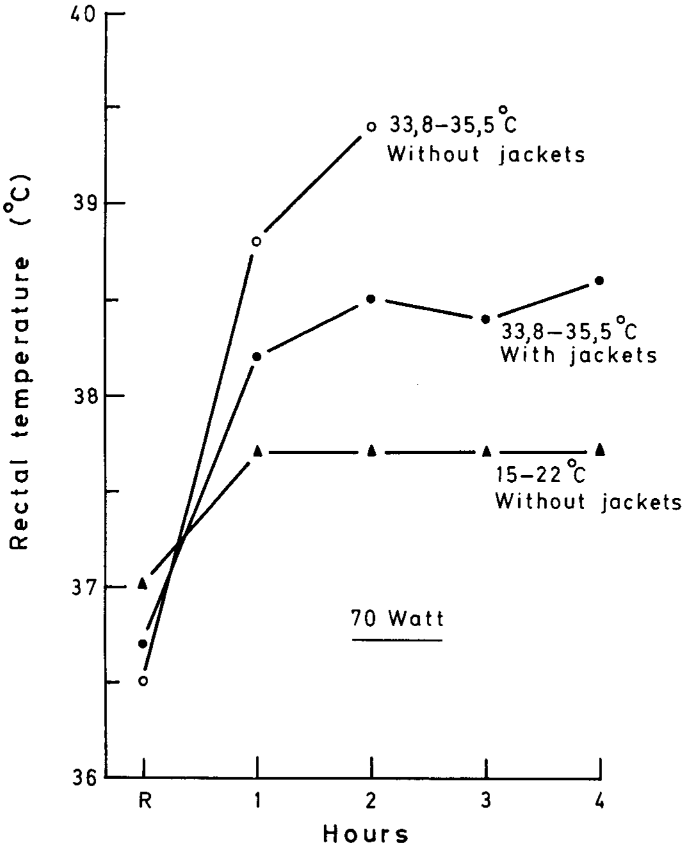

Fig. 1—Hourly rectal temperatures of subjects working with and without ice-jackets at various wet-bulb temperature

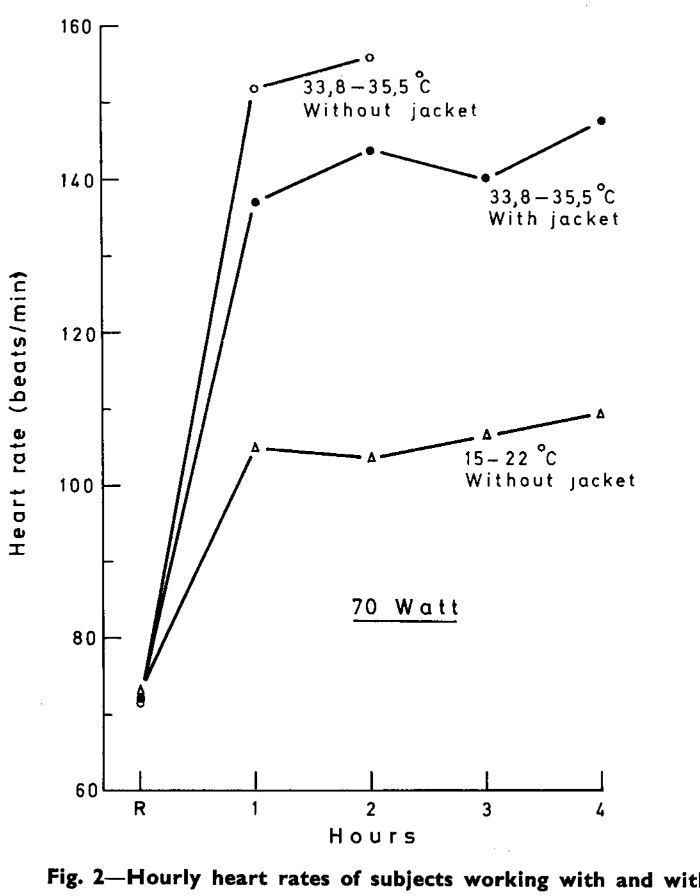

Fig. 2—Hourly heart rates of subjects working with and without ice-jackets at various wet-bulb temperatures

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS

No.	Age	Tribe	Weight	Height	Max. heart rate	VO_2 max	ml/kg.min
	y		kg	cm	beat/min	l/min	
86	21	Shangaan	57,20	162,6	181	2,802	49,5
32	25	Shangaan	59,30	165,4	173	2,813	47,8
83	22	Malawi	57,35	172,5	197	3,144	55,3
75	20	Malawi	52,50	162,2	182	2,423	46,2
36	28	Malawi	55,80	168,9	196	3,197	53,7

TABLE II

MEANS, DIFFERENCES, AND LEVELS OF SIGNIFICANCE FOR OBSERVATIONS AT VARIOUS ENVIRONMENTS AND 35 W

Parameter	Time	Conditions 1 Without	2 With	3 Cool Without	Differences 1 — 2 (N = 10/10)	2 — 3 (N = 10/10)	P 1 — 2	2 — 3
Heart rate (beat/min)	R	70,4	68,4	75,2	2,0	—6,8	> 0,05	> 70,05
	1	133,4	106,0	90,6	27,4	15,4	< 0,01	< 0,01
	2	134,8	105,2	89,5	29,6	15,7	< 0,01	< 0,01
	3	133,4	103,0	89,1	30,4	13,9	< 0,01	< 0,01
	4	135,6	105,8	87,8	29,8	18,0	< 0,01	< 0,01
Rectal temp. (°C)	R	36,69	36,63	36,99	0,06	—0,36	> 0,05	< 0,01
	1	38,22	37,52	37,45	0,70	0,07	< 0,01	> 0,05
	2	38,60	37,66	37,46	0,94	0,02	< 0,01	> 0,05
	3	38,64	37,66	37,48	0,98	0,18	< 0,01	> 0,05
	4	38,79	37,66	37,44	1,13	0,22	< 0,01	< 0,05
Sweat rate (ml/h)	—	3026,5	1788,5	475,5	1238	1313	< 0,05	< 0,01

TABLE III

MEANS, DIFFERENCES, AND LEVELS OF SIGNIFICANCE FOR OBSERVATIONS AT VARIOUS ENVIRONMENTS AND 70 W

Parameter	Time	Conditions 1 Without	2 With	3 Cool Without	Differences 1 — 2 (N = 10/10)	2 — 3 (N = 10/10)	P 1 — 2	2 — 3
Heart rate (beat/min)	R	71,3	72,2	73,0	—0,9	—0,8	> 0,05	> 0,05
	1	151,6	136,8	105,0	14,8	31,8	< 0,01	< 0,01
	2	155,8(9)*	143,4	103,4	12,4	40,0	> 0,05	< 0,01
	3	160,0(6)	140,0	106,4	—	33,6	—	< 0,01
	4	145,0(2)	147,2	109,2	—	38,0	—	< 0,01
Rectal temp. (°C)	R	36,54	36,68	36,96	—0,14	—0,28	> 0,05	< 0,05
	1	38,83	38,21	37,74	0,62	0,47	< 0,01	< 0,05
	2	39,42(9)	38,48	37,65	0,94	0,83	< 0,01	< 0,01
	3	39,53(6)	38,40	37,73	—	0,67	—	< 0,01
	4	39,86(4)	38,64	37,69	—	0,95	—	< 0,01
Sweat rate (ml/h)	—	3160,0(3)	2968,0	1048,5	—	1919,5	—	< 0,01

*(9) = number of men still in experiment

TABLE IV

MEAN OXYGEN INTAKES, DIFFERENCES, AND SIGNIFICANCE FOR TWO WORK RATES AND THREE COMBINATIONS

Work rate W	a Without	b Compensated	c Uncompensated	Differences and Significance a—b	P	a—c	P	b—c	P
35	0,8448	0,8778	0,9760	—0,033	> 0,50	—0,131	> 0,10	—0,098	< 0,01
70	1,3089	1,3140	0,4050	—0,005	> 0,70	—0,096	< 0,001	—0,091	< 0,001

litres of oxygen consumed at the two work rates used, are summarized in Table IV. When the stepping height was reduced to compensate for the additional weight of the ice-jacket (5,0 kg), the oxygen intake during stepping at 12 or at 24 steps per minute was the same as when the men were not wearing jackets but stepping the usual heights set for 35 and 70 W. When no compensation was made for the additional weight carried, small but significant increases in oxygen intake were observed.

DISCUSSION

The results obtained again underline the significant advantages to be gained from the use of microclimate suits in hot underground environments. These results are in general agreement with those reported by Van Rensburg *et al.*[1] Even though valid comparisons between the two sets of data are not possible, it seems that the present jacket is more effective than the original one. This assessment is supported by the fact that equilibrium levels in heart rates and body temperatures were not obtained by Van Rensburg *et al.* even at a work rate of 35 W (see their Fig. 9), as was the case in these tests. Furthermore, although the subjects used in this study weighed less and had smaller surface areas than those used by Van Rensburg, their fourth-hour heart rates and rectal temperatures were lower than those of Van Rensburg's subjects.

At the low work rate (35 W) in heat, the use of microclimate suits maintained the rectal temperatures of the subjects at a value almost equal to those when they were working at the same rate at room temperature. There was no significant difference between the rectal temperatures of men working under the two temperature conditions, and the men were able to reach equilibrium at temperatures of 37,5 to 37,7 °C, i.e., at least 1,0 °C less than the rectal temperatures observed when the men were not protected.

When the men worked in heat at 70 W with microclimate protection, their rectal temperatures were lower than those of unprotected men working at only half that rate.

The additional weight of the ice-jacket presents no real problem. Under the test conditions, the increase in energy cost due to the weight of the suit (Table IV), although significant, was small. Men working in stopes are not always required to raise their body mass continually against gravity and, even if they do, their pace will normally be slower than when they step at 70 W in the laboratory. In practice, the energy cost of wearing the suits will be even less than that found in the tests. The protection provided by the microclimate suit will enable men to work without the risk of hyperpyrexia, thus compensating for the disadvantage of the additional weight.

The high sweat rate of men wearing the microclimate suit and working in heat at a rate of 70 W is an interesting phenomenon in that the secretion of sweat does not occur underneath the cold jacket. Exposed skin areas must therefore compensate with higher sweat rates. This observation demonstrates that the intake of water during hard work in heat cannot be reduced substantially by the introduction of microclimate suits, and that a high degree of heat-acclimatization may still be necessary even when these suits are being used extensively. The unacclimatized individual is not capable of sweating at such a high rate. However, further studies need to be made in order to assess what acclimatization is required when microclimate suits are worn.

The foregoing findings suggest that the use of microclimate suits may be of great importance to production, particularly if microclimate suits are also made available to supervisors. Production depends to a large extent on physiological well-being[6] and on good supervision. Bell and Provins[7] have shown that mental performance decreases and fatigue increases with a rise in body temperature. A supervisor who is mentally, psychologically, and physically fatigued because of heat stress will not be efficient, nor will he be able to get the same work out of his labourers as one who is kept cool by a microclimate suit. The psychological improvements observed in men wearing these suits have been discussed by Van Rensburg *et al*[1].

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