

Safety in Mines Research Advisory Committee

Final Report

A pilot study to assess the heat tolerance of female miners

PC Schutte, AJ Kielblock, DB de Villiers and B Dias

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Executive Summary

The consequences of high environmental heat loads can be expressed in terms of impaired work capacity, errors of judgment with obvious implications for safety, and the occurrence of heat disorders, especially heat stroke which is often associated with severe and irreversible tissue damage and high mortality rates. It follows that overall fitness to undertake physical work in hot environments is a prerequisite and should conform to certain minimum standards. However, depending on circumstances, different sets of standards may be applied.

In the South African mining industry, female mineworkers are now also employed in occupations and environments conducive to the development of heat stroke. They may, therefore, be required to undergo heat tolerance screening (HTS). Initial attempts to screen female mineworkers for heat tolerance suggested that they had difficulty in passing the standard HTS test employed in the South African mining industry.

It is generally believed that, under conditions of high ambient temperature, thermoregulation in women is 'less efficient' than in men. Furthermore, individual characteristics of males and females can have a significant influence on the responses to physical work at high environmental thermal loads. A fundamental question that remains is whether any of the differences in thermoregulatory capacity are of a magnitude that would justify discrimination on the basis of gender. The current pilot study was commissioned by SIMRAC in order to respond to this question.

The heat tolerance of a group of 27 female mineworkers and a group of 17 male mineworkers, who acted as controls, was assessed by means of the HTS. The analysis of the data was aimed at comparing the physical characteristics and oral temperature responses of the female mineworkers who had passed the HTS with those of the female mineworkers who had failed the test, as well as with those of the male control group. Regression analysis was used to examine the relationship between the oral temperature responses during the HTS and variables consisting of the physical and physiological features measured prior to the HTS.

The body temperature responses of a group of female mineworkers using the standard block-stepping routine during the HTS were compared with their corresponding responses while using stationary bicycle ergometers during the HTS. In the comparison of these exercise modes, the hypothesis that there was no statistically significant difference between the oral temperature responses of subjects using block stepping and those of subjects using the bicycle was tested.

Information from HTS centres participating in the pilot study indicated that the failure rate of female mineworkers is not as high as initial test results had suggested. Based on current statistics, approximately 4% of the females tested failed the HTS. The corresponding figure for male mineworkers ranges between 0,5% and 4%.

The results obtained in the present study highlighted the importance of individual anthropometric characteristics in the human response to heat stress. Factors such as body mass, BMI, body surface area and body surface area to mass ratio played an important role in the outcome of heat tolerance screening procedures. All of these factors are interlinked. Physical work capacity (aerobic capacity) has also been identified as a key factor in determining individual heat tolerance.

In terms of existing recommendations and standards (Department of Minerals and Energy), all employees who work under “conditions conducive to heat stroke” should be screened for gross or permanent heat intolerance by means of the HTS procedure. Based on the findings of the present study, there is no fundamental reason why such a requirement should not be extended to female mineworkers destined to work under similar conditions. Current recommendations regarding the assessment of overall fitness for work in heat should be followed without exception, especially those dealing with individuals who fail the heat tolerance screening test.

Within the context of recruiting a labour force to undertake physically demanding work in hot environments, gender matching is irrelevant. The reason is that health risk is defined irrespective of gender. Concessions for gender or any other physical or physiological feature, for example age, work capacity or BMI, are therefore entirely inappropriate: to make allowances, especially for gender, by imposing less stringent

HTS to achieve better pass rates would simply reduce the health risk assessment to a meaningless level.

The introduction of a screening procedure to determine physical work capacity (aerobic capacity) should be considered as part of the assessment of overall fitness for work in heat. Information obtained during such a procedure could form part of a “risk profile” for any employee destined to enter “hot” working environments in the execution of his or her duties and responsibilities. The above information could, in turn, be used to devise proactive risk management strategies.

In view of their smaller physical work capacity (aerobic capacity) and physical strength, female mineworkers may experience undue physiological strain when performing “strenuous” tasks while working underground. Since no information is currently available on the physiological strain experienced by female mineworkers, it is recommended that this aspect be investigated and the results obtained be compared to those obtained for male mineworkers involved in similar tasks. In addition, if the recruitment of female labour is regarded as important, the development of realistic work-hardening programmes seems to be a logical, if not crucial, subject for further research.

The results obtained from the comparison of the two modes of exercise employed to provide the physical work component during the HTS procedure showed that the mean increase in body temperature does not differ significantly for the two modes, although there seems to be a greater tendency for the increase to be higher for block stepping than for cycling. This will, however, need to be further investigated as it may be purely due to chance in view of the small sample size used.

In view of the above, it is recommended that the block stepping routine currently used remain part of the HTS and that bicycle ergometers be used only in exceptional cases, and only when recommended by a medical practitioner. Individuals using the latter mode of exercise during the HTS should be closely monitored on an individual basis to ensure that the required work rate is maintained for the full duration of the HTS.

In order to assist employers to fulfil their duties and responsibilities in terms of the Basic Conditions of Employment Act, 1997, female mineworkers should be encouraged to

inform their employers when they are pregnant and should then be required to work under the heat stress conditions as outlined in the *Code of Good Practice on the Protection of Employees during Pregnancy and after the Birth of a Child*.

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1 Introduction

Humans are homeothermic creatures and regulate their body temperatures within a narrow range over the entire course of their lives. When an individual is capable of maintaining thermal equilibrium in the face of thermoregulatory challenge, that individual is said to be experiencing compensable heat stress. A thermal environment of compensable heat stress can become one of uncompensable heat stress by wearing clothing that restricts evaporative heat loss and/or by increasing the ambient temperature or water vapour pressure (Gonzalez, 1988). During uncompensable heat stress, the body's evaporative cooling requirement exceeds the maximum cooling capacity of the environment. As a result, individuals are unable to achieve thermal balance and will continue to store heat until exhaustion occurs (Mountain et al., 1994).

The consequences of high environmental heat loads can be expressed in terms of impaired work capacity, errors of judgement with obvious implications for safety, and the occurrence of heat disorders, especially heat stroke which is often associated with severe and irreversible tissue damage and high mortality rates (Gardner et al., 1996; Kielblock, 1992). It follows that overall fitness to undertake physical work in hot environments is a prerequisite for safeguarding workers exposed to occupational heat stress.

The determination of fitness for work in heat forms an integral part of the heat stress management programmes used by South African mines. An appraisal of overall fitness for work in hot environments will depend on the outcomes of a purpose-developed general medical examination, a specific physical evaluation and an assessment of heat tolerance. The latter assessment is based on the outcome of a Heat Tolerance Screening (HTS) procedure (Kielblock and Schutte, 1998).

The primary objective of the HTS is to identify individuals with gross or inherent heat intolerance (i.e. individuals with an unacceptable risk of developing excessively high levels of hyperthermia during work in heat). The criterion currently used during the HTS to categorise employees, as well as to determine current heat stress limits, is based

exclusively on the physiological responses of male mineworkers. In other words, only the physiological responses of males were used to assess risk during the development of the HTS and the determination of heat stress limits.

It is generally believed that, under conditions of high ambient temperature and low humidity, thermoregulation in women is 'less efficient' than in men (Grucza, 1999). In men, sweating appears faster, the intensity of sweating is greater and the increases in body temperatures are lower than in women (Bittel and Henane, 1975; Grucza et al. 1985). On the other hand, under hot humid conditions the lower sweating response enables women to control thermal balance at a lower level of physiological strain than men (Candas et al., 1982). Shapiro and co-workers (1980) concluded that females and males react in a physiologically similar manner under comfortable environmental conditions, females tolerate hot-wet climates better than males, and males better tolerate hot-dry conditions.

The specific thermoregulatory responses in women are often attributed to their anthropometry or morphology (Anderson, 1999), their lower aerobic capacity (Havenith and van Middendorp, 1990) and a difference in the endocrine milieu compared with men (Horvath and Drinkwater, 1982). However, when some physical characteristics of men and women are matched, most of the gender-related thermoregulatory differences disappear, except for the intensity of sweating which is still lower in women (Anderson et al., 1995; Havenith et al., 1995).

Female mineworkers are now also employed in occupations and environments conducive to the development of heat stroke. They may, therefore, be required to undergo the HTS procedure. Initial attempts to screen female mineworkers for heat tolerance suggested that they had difficulty in passing the standard HTS used in the mining industry. In view of the above, SIMRAC commissioned a pilot study to investigate the situation with regard to the heat tolerance of female mineworkers.

2 Objectives of pilot study

The objectives of the pilot study were to assess the current levels of heat tolerance of female mineworkers and to identify those physiological and anthropometrical factors that could potentially contribute to gross heat intolerance. As part of the study, two modes of exercise that were employed to provide the physical work component during the HTS procedure were also compared.

3 Methods

The study consisted of two phases. In the first phase, the heat tolerances of a group of female mineworkers (experimental group) and a group of male mineworkers (control group) were assessed. The second phase focused on a comparison of the two modes of exercise employed to provide the physical work component during the HTS procedure.

3.1 Assessment of heat tolerance

The heat tolerances of a group of 27 female mineworkers and a group of 17 male mineworkers, who acted as controls, were assessed by means of the standard HTS procedure employed in the South African mining industry (Kielblock and Schutte, 1998). All the participating mineworkers had been declared medically fit after undergoing a purpose-developed general medical examination (including specific physical evaluations) which forms part of the standard procedures on mines to determine overall fitness for work in heat.

The HTS consisted of bench-stepping for 30 minutes in a climatic chamber at an external work rate of approximately 80 W (positive component) in an environment with a dry-bulb temperature of 29,5 °C and a wet-bulb temperature of 28,0 °C. The air movement in the climatic chamber was controlled within the range of 0,3 to 0,5 m.s⁻¹. The assessment of relative heat tolerance was based on oral temperature recorded at the end of the 30-minute bench-stepping exercise. (The use of oral temperature was

necessitated by the subjects' resistance to more accurate indicators of thermoregulatory strain, such as rectal temperature and heart rate.)

The subjects were requested to perform a ten-minute step procedure at a sub-maximal work rate to predict their maximum aerobic capacity approximately 90 minutes prior to the HTS. The Physical Selection Test (PST), an indirect test of aerobic capacity specifically developed for the South African mining industry, was used for this purpose (Strydom et al., 1980). This test basically consists of bench-stepping for 10 minutes at an external work rate of 54 W (positive component) at room temperature. The heart rate recorded at the end of the test period is used to predict aerobic capacity. In order to get an indication of their fitness level, subjects were also asked to perform the Harvard step test.

During the HTS and PST procedures, the standard control and supervisory measures, as well as the required first aid facilities, were in place at the heat tolerance centres used.

3.2 Comparison of exercise modes

The body temperature responses of a group of female mineworkers while using a block-stepping routine (external work rate of 80 W, positive component) during the standard HTS (Kielblock and Schutte, 1998) were compared with their corresponding responses while using stationary bicycle ergometers (external work rate of 80 W) during the same HTS. On completion of the exercise modes, the subjects were questioned on their perceived level of exertion (using the Borg scale) to complete the respective HTS procedures.

During the HTS procedures, the standard control and supervisory measures, as well as the required first aid facilities, were in place at the climatic chambers used.

3.3 Measurements

The age, mass and stature of the subjects were recorded. Mass and stature values were used to calculate Body Mass Index (BMI), body surface area and body surface area to mass ratio. Percentage body fat was estimated by means of bioelectrical impedance analysis. Oral temperatures were taken before subjects entered the climatic chamber and on completion of the HTS.

During the heat tolerance assessment phase of the study, it became clear that the sample of female mineworkers who failed the test ($n = 5$) was too small for any meaningful analyses in terms of physical characteristics. In view of this, as well as the fact that it was very difficult to find any “new” female mineworkers, it was decided to increase the sample size of the “failed” group by using information available at HTS centres. Seven records were obtained from the centres involved in the study. Unfortunately, only information on age, mass, stature and the oral temperature measurements taken as part of the HTS procedure were available from these records.

3.4 Data analysis

The analysis of the data was aimed at comparing the physical characteristics and oral temperature responses of the female mineworkers who had passed the HTS with those of female mineworkers who had failed the test, as well as with those of the male control group. Regression analysis was used to examine the relationship between the oral temperature responses during the HTS and variables consisting of the physical and physiological features measured prior to the HTS.

In the comparison of the exercise modes used during the HTS, the hypothesis that there was no statistically significant difference between the oral temperature responses of subjects using block stepping and those of subjects using the bicycle was tested.

3.5 Ethics and interaction with subjects

The protocol followed during the study was approved by the Committee for Research on Human Subjects (Medical) of the University of the Witwatersrand, and the Ethics Committee of AngloGold Health Service.

The aims of the investigation were communicated as well as possible to the subjects in a language they understand. The project information and consent forms were available in English, Xhosa and Sesotho. Mine personnel assisting with the study also verbally communicated the information contained on these forms to the subjects.

Subjects participated on the basis of informed consent, and on the understanding that they could refuse to participate and withdraw from the study at any time. Care was also taken to maintain confidentiality so that subjects are not identifiable to persons not involved in the research.

4 Results and discussion

4.1 Physical characteristics

4.1.1 Female mineworkers (study group)

The physical characteristics of the study group are given in Table 4.1.1a. The 5th, 50th and 95th percentiles of age, body mass, body stature and BMI of the female population in the South African National Defence Force (SANDF) are also given in the table.

Table 4.1.1a: Physical characteristics of female mineworkers (study group)

Variable	n	Mean	SD	Min	Max	RSA military population	RSA military population	RSA military population
						5 th percentile	50 th percentile	95 th percentile
Age (yrs)	34	28,9	4,2	22	40	18	26	33
Mass (kg)	34	73,47	11,74	47,4	92,5	49,6	68,3	1 00,3
Stature (mm)	34	1 600	60,5	1470	1 760	1 503	1 730	1 730
BMI	34	28,7	4,4	21,0	37,0	19,6	26,1	38,4
BSA	34	1,76	0,14	1,38	1,98			
BSA/mass	34	243,1	23,7	210	304			
% body fat	24	35,0	6,8	19,0	42,5			
PST heart rate (beats/min)	27	133	14	106	172			

BMI: Body Mass Index

BSA: Body surface area

BSA/mass: Body surface area to mass ratio

PST: Physical selection test

SD: Standard deviation

Min: Minimum

Max: Maximum

The age of the study group ranged between 22 and 40 years. Body mass and stature ranged between 47,4 and 92,5 kg and 1,47 and 1,76 m, respectively. When compared with the anthropometrical data of the military population, two of the female mineworkers tested had a body mass lower than the 5th percentile of the military female population. In the case of one of the above females, her body stature was also below the 5th percentile of the military female population. The rest of the female mineworkers had body masses ranging between the 5th and 95th percentiles of the military female population. In general, the situation is the same as far as stature is concerned, the only exceptions being the one subject below the 5th percentile and the one subject above the 95th percentile. As far as BMI values are concerned, only one subject had a BMI value below the 5th percentile of the military female population, while the BMI values of the rest of the subjects ranged between the 5th and 95th percentiles of the military female population.

Of the 27 subjects who participated in the PST, a total of 17 had heart rates of 120 beats per minute and below on completion of the test which means, at least theoretically, that they have sufficiently high working capacities to perform strenuous work. Five of the subjects had heart rates ranging between 121 and 140 beats per minute and have work capacities sufficient to perform moderate work. Another five subjects had heart rates above 140 beats per minute. It is suggested that individuals falling in this category should not be allocated to arduous tasks or expected to work in high environmental temperatures (Strydom et al., 1980).

Attempts to get an indication of the subjects' fitness levels by means of the Harvard step test were unsuccessful. Only one subject attempted the test but could not complete the minimum stepping time required (one minute) before any classification in terms of fitness level could be made. The other female subjects refused to participate in this part of the study.

4.1.2 Male mineworkers (control group)

The physical characteristics of the male control group are given in Table 4.1.2a. The 5th, 50th and 95th percentiles of age, body mass and body stature of the male population in the SANDF are also given in the table.

Table 4.1.2a: Physical characteristics of male mineworkers (control group)

Variable	n	Mean	SD	Min	Max	RSA military population	RSA military population	RSA military population
						5 th percentile	50 th percentile	95 th percentile
Age (yrs)	17	31,6	6,2	22	44	23	28	36
Mass (kg)	17	71,24	14,78	50,3	102,9	47,0	68	93
Stature (mm)	17	1 724	72,0	1 600	1 860	1 587	1 741	1 875
BMI	17	23,46	3,46	18,5	30,1			
BSA	17	1,84	0,20	1,54	2,27			
BSA/mass	17	262,2	24,7	221,0	306,0			
% body fat	17	18,29	6,44	7,0	27,5			
PST heart rate (beats/min)	17	121,0	11,4	103	138			

BMI: Body Mass Index

BSA: Body surface area

BSA/mass: Body surface area to mass ratio

PST: Physical selection test

SD: Standard deviation

Min: Minimum

Max: Maximum

The age of the study group ranged between 22 and 44 years. Body mass and stature ranged between 50,3 and 102,9 kg, and 1,60 and 1,86 m, respectively. When compared with the anthropometrical data of the military population, two of the male mineworkers had a body mass higher than the 95th percentile of the military male population. Their stature was within the 95th percentile of the military male population. The rest of the male mineworkers had body masses and statures ranging between the 5th and 95th percentiles of the military male population.

Of the 17 subjects who participated in the PST, nine had heart rates of 120 beats per minute and below on completion of the test. This means, at least theoretically, that they have sufficiently high working capacities to perform strenuous work. The remainder of

the subjects had heart rates ranging between 121 and 140 beats per minute and have work capacities sufficient to perform moderate work.

Independent sample t-tests show that the means for the female study group and the male control group differed significantly in terms of the following variables:

- *Stature*: Males were on average taller than females ($p < 0,001$)
- *BMI*: Females had a higher BMI on average ($p < 0,001$)
- Body surface area to mass ratio: Males had a higher ratio on average ($p = 0,028$)
- *% body fat*: Females had higher percentages on average ($p < 0,001$)
- *PST heart rates*: The mean for females was higher than the mean for males, indicating that the latter group had a higher aerobic capacity or aerobic fitness, as measured by maximum oxygen uptake.

The distribution of PST heart rates of the two groups differed significantly: 63% of the females had heart rates equal to or less than 120 beats per minute (males: 53 %), 19% had PST heart rates between 121 and 140 beats per minute (males: 47%), and 19 % of the females had PST heart rates above 140 beats per minute (no males in this category). The above results suggest that the distributions of the aerobic capacities (as predicted by PST heart rates) of the two groups differed, with that pertaining to the females being skewed towards the lower aerobic capacity level (higher PST heart rates). More females were, therefore, falling in the category where they should not be allocated to arduous tasks or expected to work in high environmental temperatures (Strydom et al., 1980) than males. The observed gender difference in aerobic power is well documented (Dill et al., 1977; Shapiro et al., 1980). Patton and co-workers, for example, found that the aerobic power of untrained men was on average 27% higher than that of women (Patton et al., 1980).

4.2 Physical characteristics and HTS results

4.2.1 Female mineworkers

The mean values of the various physical characteristics measured and calculated for a total of 22 subjects who passed the HTS (i.e. classified as potentially heat tolerant) were

compared with those of 12 subjects who failed (i.e. classified as grossly heat intolerant). The mean values, standard deviations (SD) and standard errors (SE) for the above measurements are given in Table 4.2.1a. The resting oral temperatures recorded prior to the HTS are also included in this table.

Table 4.2.1a: Physical characteristics and outcome of heat tolerance screening

Variable	Outcome of HTS	n	Mean	SD	SE
Age (yrs)	Fail	12	28,42	5,16	1,49
	Pass	22	29,14	3,69	0,79
Body mass (kg)	Fail	12	78,93	9,28	2,68
	Pass	22	70,49	12,12	2,58
Stature (mm)	Fail	12	1 610	364,30	10,52
	Pass	22	1 595	70,56	15,04
BMI	Fail	12	30,21	4,11	1,19
	Pass	22	27,81	4,45	0,95
Body surface area (m)	Fail	12	1,82	0,10	0,03
	Pass	22	1,73	0,16	0,03
Body surface area to mass ratio	Fail	12	232,42	16,96	4,90
	Pass	22	248,91	25,13	5,36
Body fat (%)	Fail	5*	36,90	5,26	2,35
	Pass	22	34,45	7,19	1,65
PST heart rate (beats/min)	Fail	5*	144,80	8,22	3,69
	Pass	22	130,59	13,63	2,91
HTS initial oral temperature (°C)	Fail	12	36,83	0,20	0,06
	Pass	22	36,48	0,43	0,09

BMI: Body mass index

PST: Physical selection test

HTS: Heat tolerance screening test

The results of the statistical analyses (Independent Samples Test; t-test for equality of means) indicated that the mean body mass of the “pass” group was statistically significantly lower than that of the “fail” group ($p < 0,05$). The mean body surface area of

the “pass” group was statistically significantly smaller than that of the “fail” group ($p<0,05$), while the latter group’s mean body surface area to mass ratio was also statistically significantly less than that of the “pass” group ($p<0,05$).

The mean of the heart rates recorded on completion of the PST for the “pass” group was lower than that of the corresponding value for the “fail” group ($p<0,05$). A factor that should be considered when interpreting these PST results is the limitation that the mean heart rate of the “failed” group was based on the heart rate responses of only five subjects (see Table 4.2a and Section 3.3).

The mean resting oral temperature of the “pass” group was statistically significant lower than that of the “fail” group ($p<0,01$).

When the information pertaining to the physical characteristics and physiological measurements of all the female mineworkers used in the study is pooled and analysed statistically by means of the Pearson’s correlation test, only the PST result is significantly correlated at 0,01 level (two-tailed) with the oral temperature on completion of the HTS.

4.2.2 Comparison between female and male “pass” groups

The mean values of the various physical characteristics measured and calculated for a total of 22 female mineworkers who passed the HTS (“female” group) were compared with those of a group of 16 males who passed the HTS (“male” group). The mean values, standard deviations (SD) and standard errors (SE) for the above measurements are given in Table 4.2.2a. The body temperatures recorded before and on completion of the HTS are also included in this table.

Table 4.2.2a: Comparison between female and male “pass” groups

Variable	Group	n	Mean	SD	SE
Age (yrs)	Male	16	30,94	5,73	1,43
	Female	22	29,14	3,69	0,79
Body mass (kg)	Male	16	69,26	12,73	3,18
	Female	22	70,49	70,56	2,58
Stature (mm)	Male	16	1 716	66,30	16,58
	Female	22	1 595	70,56	15,04
BMI	Male	16	23,05	3,11	0,78
	Female	22	27,81	4,45	0,95
Body surface area (m)	Male	16	1,81	0,18	0,04
	Female	22	1,73	0,16	0,03
Body surface area to mass ratio	Male	16	264,81	23,08	5,76
	Female	22	248,91	25,13	5,36
Body fat (%)	Male	16	17,94	6,47	1,62
	Female	19	34,45	7,19	1,65
PST heart rate (beats/min)	Male	16	119,94	10,84	2,71
	Female	22	130,59	13,63	2,91
HTS initial oral temperature (°C)	Male	16	36,12	0,55	0,14
	Female	22	36,48	0,43	0,09
HTS final oral temperature (°C)	Male	16	37,40	0,25	0,06
	Female	22	37,44	0,20	0,04
Change in oral temperature during HTS (°C)	Male	16	1,28	0,53	0,13
	Female	22	0,96	0,46	0,10

BMI: Body mass index

PST: Physical selection test

HTS: Heat tolerance screening test

The male group was statistically significantly taller than the female group ($p < 0.01$) on average. The mean BMI of the female group, as well as the mean percentage body fat,

were statistically significantly higher than the corresponding values of their counterparts ($p < 0,01$ in both instances).

The mean heart rate of the male group on completion of the PST was statistically significantly lower than that of the female group, which indicates that the males had higher aerobic capacities than their female counterparts. This observation is in line with findings in the literature which indicate that the maximum aerobic capacity is typically between 25% and 40% greater in men than in women (Fahey, 1994; Patton et al., 1980).

Previous investigations (Havenith and Middendorp, 1990; Havenith et al., 1995) have also indicated that differences in body fat, surface area to mass ratio and aerobic capacity levels account for over 50% of the variance in heat storage among men and women exposed to dry and humid heat stress.

The mean resting oral temperature before commencement of the HTS was statistically significantly lower in the male group ($p < 0,05$).

When the information pertaining to the physical characteristics and physiological measurements of the male and female groups are combined, only the heart rate recorded during the PST is statistically significantly correlated with the oral temperature on completion of the HTS ($p < 0,05$).

4.2.3 Correlation between physical characteristics and body temperature during HTS (all subjects)

The relationship between the oral temperatures on completion of the HTS and the variables consisting of physical and physiological features measured prior to and during the HTS for all the females and all the males tested is given in Table 4.2.3a. Significant correlations ($p < 0,05$) are indicated in bold.

Table 4.2.3a: Significant correlations between physical characteristics and body temperatures for all the females and all the males screened for heat tolerance

Variable	All males	All females
Age	0,37	-0,12
Body mass	0,60	0,21
Stature	0,50	0,23
BMI	0,58	0,11
Body surface area	0,60	0,23
Body surface area to mass ratio	-0,48	-0,19
% body fat	0,31	0,04
PST heart rate	0,59	0,35
HTS initial oral temperature	0,45	0,27

The above observations, namely that the respective indirect parameters of heat tolerance were generally well correlated with body temperature responses to HTS in the all-male group, but not in the all-female group, are of more than passing interest. At first glance, there is a temptation to cite gender differences. However, in 'matched' populations, there is overwhelming research evidence to suggest that differences are slight and often of no practical significance. In fact, poor matching is currently widely regarded as the most important factor explaining the gender discrepancies frequently reported in earlier studies. This may also be valid with regard to the present findings: the poorly correlated responses in the all-female group most probably reflect a confounding interaction of poor physical conditioning, high BMI and anthropometric limitations in carrying out the HTS test, i.e. an unfavourable step height to crotch height ratio.

The relationships between the oral temperatures on completion of the HTS and variables consisting of physical and physiological features measured prior to and during the HTS for all the subjects used in the study (females and males combined) were examined. Significant correlations (Pearson product moment correlation coefficient (r)) are shown in Table 4.2.3b, together with the p-values (p). Correlations are considered significant if the p-value <0.05 .

Table 4.2.3b: Significant correlations between physical characteristics and body temperatures during heat tolerance screening test (females and males combined)

Variable		Stature	BMI	BSA	BSA/Mass	% body fat	PST heart rate	HTS initial To	HTS final To
Mass	r	0,287	0,802	0,918	-0,895	0,502			0,379
	p	0,041	0,000	0,000	0,000	0,001			0,0094
Stature	r		-0,310	0,637		-0,462	-0,355		
	p		0,027	0,000		0,002	0,018		
BMI	r			0,514	-0,901	0,835			0,309
	p			0,000	0,000	0,000			0,037
BSA	r				-0,698				0,332
	p				0,000				0,024
BSA/Mass	r					-0,701			-0,324
	p					0,000			0,028
PST heart rate	r							0,361	0,458
	p							0,161	0,002
HTS initial To	r								0,400
	p								0,0059

BMI: Body Mass Index

BSA: Body surface area

PST: Physical selection test

HTS: Heat tolerance screening test

To: Oral temperature

From Table 4.2.3b it is evident that there is a significant correlation between the outcome of the HTS and body mass, BMI, body surface area, body surface area to mass ratio and aerobic capacity (as predicted by the PST).

In order to ascertain which variables contribute towards explaining the final temperatures, a linear model, with the final temperature during the HTS as dependent variable, with height, age, mass, body mass index, body surface area, body surface area to mass ratio, body fat percentage, PST heart rate and initial temperature during the HTS as independent variables, and with gender as a fixed factor, was fitted. The model

explains 57,5% of the variation in the final temperature during the HTS (adjusted $R^2=42,8\%$). Apart from the constant value, the only significant coefficients ($p<0,05$) were PST heart rates and initial temperatures during the HTS. Not one of the other coefficients, including the coefficient for gender, was significantly different from 0 (Table 4.2.3c).

Table 4.2.3c: Regression model coefficients

Variable	Coefficient	p-value
	26,113	0,000
Stature	3,034	0,474
Age	0,018	0,117
Mass	0,054	0,357
Body mass Index	-0,069	0,308
Body surface area	-3,518	0,460
Body surface area to mass ratio	-0,008	0,259
% Body fat	0.004	0,830
PST heart rate	0,014	0,005
Initial To during HTS	0,275	0,023
If gender is female	0,057	0,844

The model showed that the final temperature during the HTS is estimated to increase by 0,014 °C for every unit increase in PST heart rate and by 0,28 °C for every unit increase in the initial temperature during the HTS.

4.3 Menstrual cycle and contraceptives

It has been well established that, under conditions of compensable heat stress, the menstrual cycle affects thermoregulation. Basal body temperature exhibits a biphasic rhythm in which the body core temperature is approximately 0,4 °C higher in the luteal phase compared with the follicular phase (Frascarolo et al., 1990; Horvath and Drinkwater, 1982). Likewise, the core temperature thresholds for the onset of thermoregulatory sweating, cutaneous vasodilatation and skin blood flow are also higher in the luteal phase compared with the follicular phase (Hessemer and Bruck, 1985;

Kolka and Stephenson, 1997). During uncompensable heat stress, core temperature is significantly higher in the mid-luteal phase than in the early follicular phase (Tanaglia et al., 1999).

Women using oral contraceptives will, similar to non-users, have higher resting core temperatures during the quasi-luteal phase (when exogenous estrogen and progesterone mimic the luteal hormone profile in a non-user) compared with the quasi-follicular phase (when the pill contains a greater amount of exogenous estrogen compared with exogenous progesterone).

A total of 24 female mineworkers were interviewed using the questionnaire given in Appendix A. Nineteen of the women interviewed were taking contraceptives and four were not on any form of contraceptive. One female miner had had a hysterectomy for medical reasons. Of the 19 women on contraceptives, seven were taking an oral combination contraceptive and 12 women were on a medroxyprogesterone injection.

Among the oral contraceptive users, three were in the quasi-follicular phase and two were in the quasi-luteal phase of the menstrual cycle when screened for heat tolerance. The corresponding information could not be established from the remaining two female mineworkers. In this group, one female mineworker failed the HTS. She was in the quasi-follicular phase when undergoing the HTS. This observation could possibly be related to the findings of Tanaglia and co-workers (1999) that oral contraceptive use may, potentially at least, place a woman at a thermoregulatory disadvantage in uncompensable heat stress during the quasi-follicular phase of her cycle.

Among the 12 female mineworkers on the progesterone injection, one failed the HTS. It is interesting to note that none of the studies reviewed to date mention the effects of progesterone injections on thermoregulation in women.

In the case of the group not using oral contraceptives or the progesterone injection, all four of the women were in the follicular phase of the menstrual cycle when screened for heat tolerance. One of them failed the HTS.

Based on the results obtained in this pilot study, one failure could possibly be ascribed to the use of oral contraceptives. There were, however, other factors present that could also have played a role in the level of relative heat intolerance observed. The phase of the menstrual cycle was not shown to be associated with an increased failure rate during the HTS, despite the fact that a woman in the luteal phase of her menstrual cycle has a higher-than-normal resting basal temperature.

4.4 Block stepping vs. cycling

A total of 11 female mineworkers participated in this part of the study. There were no male volunteers. All the females successfully completed the standard HTS where work rate was maintained by means of block stepping. Of these females, only eight were able to complete the HTS when the stationary bicycle ergometers were used. Two of the three subjects who did not complete the latter test were removed from the climatic chamber as result of exhaustion after 15 and 22 minutes, respectively. The other subject had great difficulty in pedalling the bicycle ergometer and decided to stop after eight minutes.

The final oral temperatures, as well as the change in oral temperature above resting values, during the two heat tolerance tests are given in Table 4.4a. The body mass of the subjects and their preferred exercise mode to be followed during heat tolerance screening procedures are also given in this table.

Table 4.4a: Oral temperature (To) responses during the respective heat tolerance tests

Subject	Body mass	Final To (°C)	To increase (°C)	Final To (°C)	To increase (°C)	Preference
	(kg)	(Block-stepping)	(Block-stepping)	(Cycling)	(Cycling)	
1	78,5	37,6	0,9	37,2	1	Bicycle
2	63,0	37,6	0,7	37,4	0,6	Bicycle
3	68,6	37,6	1,0	37,2	0,3	Block stepping
4	76,0	37,6	1,1	37,7	0,8	Bicycle
5	75,0	37,5	0,8	37,3	0,4	Bicycle
6	92,5	37,0	0,6	37,4	0,8	No preference
7	56,3	37,6	0,9	Stopped after 15 min	N/a	Block stepping
8	74,4	37,4	0,4	Stopped after 8 min	N/a	Block stepping
9	83,6	37,4	0,6	37,2	0,3	Bicycle
10	88,1	37,6	0,6	Stopped after 22 min	N/a	Block stepping
11	69	37,7	0,8	37,5	0,8	Block stepping

The body mass of the females mineworkers ranged from 56,3 kg to 92,5 kg, with an average of 75,0 kg (SD = 0,658 kg). The body masses of the three females who were unable to complete the cycling session were 56,3 kg; 74,4 kg and 88,1 kg, respectively. Hence, it does not seem, based on this small sample, that body mass influenced completion or not of the cycling session.

A paired samples t-test was used for statistical analysis. The mean resting oral temperatures at the start of the respective HTS procedures did not differ significantly ($t(7)=1.46$; $p\text{-value}=0.188$). Neither did the oral temperature means differ significantly after the two HTS procedures ($t(7)=1.93$; $p\text{-value}=0.096$).

The distributions of the increase in oral temperature (final oral temperature minus resting oral temperature) for the respective HTS procedures are given in Figure 4.4a. The hypothesis tested was that the mean change in oral temperature did not differ. Despite the apparent difference in these distributions, there was no statistically significant difference between the mean increases for the two HTS procedures ($t(7)=1.8$; $p=0.115$). This may be due to the small sample size and to the large variation in oral temperature increases for the cycling session. The correlation between the increases in oral temperature was not significantly different from 0 ($p=0.686$).

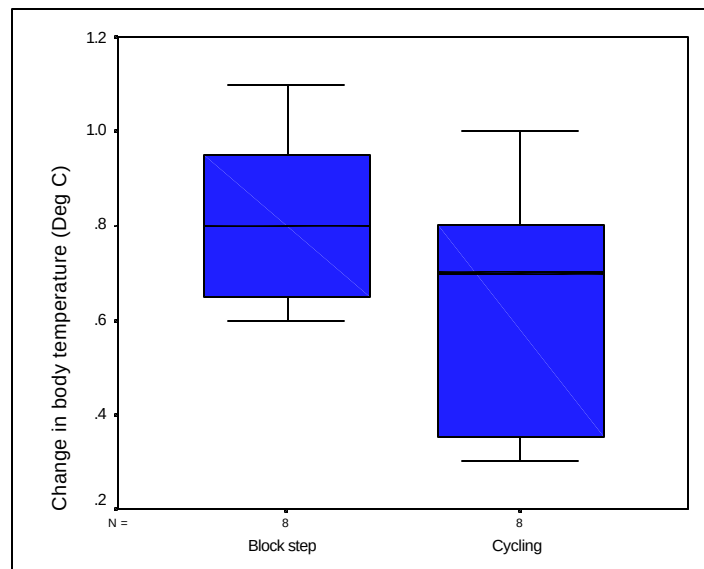


Figure 4.4a: Body temperature distributions during heat tolerance screening tests

The change in oral temperature during the respective HTS procedures is graphically represented in Figure 4.4b. The diagonal line in the figure represents a scenario where the increase in oral temperature during block stepping is equal to a corresponding increase during the cycling session.

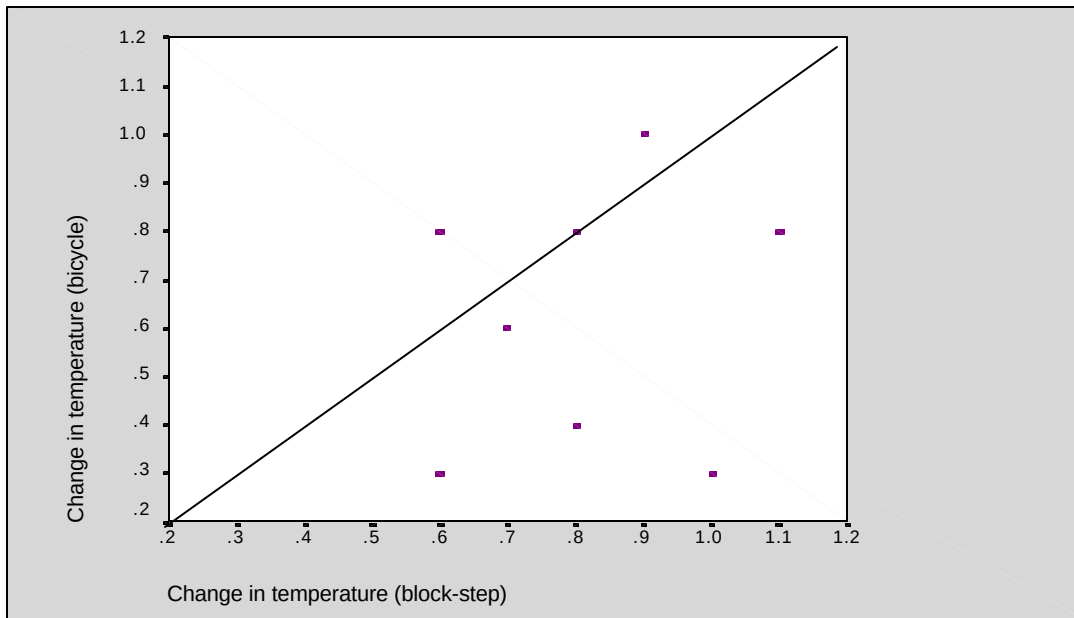


Figure 4.4b: Comparison of body temperature changes associated with block stepping and cycling during heat tolerance screening tests

For two of the subjects, the increase in oral temperature was greater during cycling than during block stepping. In the case of one subject, the increase in oral temperature was the same for both sessions, while the increase in oral temperature during the block stepping session exceeded that recorded during the cycling session for five of the subjects.

The above results show that the mean increase in body temperature does not differ significantly for the two exercise modes, although there seems to be a greater tendency for the increase to be higher for block stepping than for cycling. This will, however, need to be investigated further as this observation may be purely due to chance in view of the relatively small sample size.

Five of the subjects preferred block stepping as the exercise mode during the HTS, five preferred cycling and one subject had no specific preference. The perceived exertion, as determined by the Borg scale, was very similar for both exercise modes and the subjects classified the work rates as ranging between hard and very hard.

From discussions with the subjects, it became clear that some of them were having difficulty in performing block stepping, as the 30 cm stepping block used during the standard HTS was “too high”. This observation is not totally without substance if the gender difference in leg length is considered. For example, at the 5th percentile, the crotch height (which gives an indication of leg length) for the female population is 660 mm compared to 702 mm for the male population. The 95th percentile values for the female and male populations are 815 mm and 881 mm, respectively.

From a practical viewpoint, the use of bicycle ergometers to maintain the required work rate during the HTS may be problematic. Observations made during the study suggest that female mineworkers are not familiar with cycling, not even on standard bicycles. This means that an extensive period of familiarisation with the bicycle ergometers is required before the subjects attempt the HTS. Maintenance of the required work rate on the ergometer while cycling will also require constant supervision during the HTS. In addition, the cost of such ergometers, as well as their mechanical maintenance in a hot humid environment, may be cost-prohibitive.

4.5 Record review of heat tolerance screening results

HTS results of female mineworkers were obtained from the heat tolerance centres on four gold mines and are summarised in Table 4.4.

Table 4.4: Heat tolerance screening results from four heat tolerance centres

HTS centre	Total tested	Passed on first attempt	Passed on second attempt	Passed on third attempt	Passed on fourth attempt	Total failed
A	11	0	2	6	3	0
B	24	21	3			0
C	81	72	3			6
D	25	21	4			0
E	30	26	3			1
TOTAL	171	140(81,8%)	15 (8,8%)	6 (3,5%)	3 (1,8%)	7(4,1%)

The “pass” rate of female mineworkers screened for heat tolerance ranged between 92,5 and 100%. Where the females had difficulty in passing the HTS, they were in certain instances retested (up to four attempts) until they passed the test. This practice is a deviation from current recommendations, namely that in the event of failure of the HTS, candidates may present themselves once more (or even twice) for retesting, but not within a period of two days between consecutive tests. At management’s discretion, however, and taking into consideration individual merits and medical advice, a second retest is permissible. Repeated failure of the HTS would normally disqualify a candidate from working in hot areas. However, each case should be dealt with on individual merit.

Ongoing retesting of an individual basically represents a form of formal heat acclimatisation to the environmental temperature and workload used during the HTS, and therefore is no longer an assessment of risk. Employees “acclimatised” in this way could also be at an unacceptable risk of developing heat disorders when experiencing heat stress at levels higher than those prevailing during the HTS while working underground.

It should be noted that the above results were obtained from operating HTS centres and were not obtained under strictly controlled laboratory conditions. The non-adherence to recommendations (Department of Minerals and Energy, 2002; Kielblock and Schutte, 1998) regarding the maintenance of environmental conditions during the HTS, including the monthly inspections by Environmental Control Departments, could obviously have influenced the outcome of the HTS tests at the centres.

5 Conclusion

The failure rate of female mineworkers during heat tolerance screening (HTS) procedures is not as high as initial test results had suggested. Based on current statistics, approximately 4% of the females tested failed the HTS. The corresponding figure for male mineworkers ranges between 0,5% and 4%.

The results obtained in the present study highlighted the importance of individual anthropometric characteristics in the human response to heat stress. Factors such as

body mass, BMI, body surface area and body surface area to mass ratio played an important role in the outcome of HTS procedures. All of these factors are interlinked.

Physical work capacity (aerobic capacity) has been identified as a key factor in determining individual heat tolerance. The heart rates recorded during the physical selection test correlated well with the oral temperatures recorded on completion of the HTS test. A lower PST heart rate, and thus a higher aerobic capacity (as measured by $\text{VO}_2 \text{ max.}$), is associated with a high level of heat tolerance. A lower aerobic capacity (higher PST heart rate), in turn, is associated with levels of gross heat intolerance, as classified by means of the HTS. A low level of aerobic capacity (often also referred to as poor aerobic “fitness”) has been identified as a risk factor for heat exhaustion in mining (Donoghue et al., 2000).

Within the context of recruiting a labour force to undertake physically demanding work in hot environments, gender matching is irrelevant. The reason is that health risk is defined irrespective of gender. Concessions for gender or any other feature, for example age, work capacity or BMI, would therefore be entirely inappropriate: to make allowances, especially for gender, by imposing less stringent HTS to achieve better pass rates would simply reduce the health risk assessment to a meaningless level.

The above considerations are not intended to suggest that discriminatory or inflexible labour recruitment practices should be applied to females, but rather that the approach should be more circumspect. In this respect, it is proposed that recruitment practices and procedures should recognise that females may well be at a disadvantage vis-à-vis their male counterparts, at least initially. Equally, however, it may well be possible for female aspirants to achieve acceptable standards, for example through work-hardening programmes.

The results obtained from the comparison of the two modes of exercise employed to provide the physical work component during the HTS procedure show that the mean increase in body temperature does not differ significantly for the two sessions, although there seems to be a greater tendency for the increase to be higher for block stepping than for cycling. This will, however, need to be further investigated as it may be purely due to chance in view of the small sample size used.

6 Recommendations

In terms of existing recommendations and standards, all employees who work under “conditions conducive to heat stroke” should be screened for gross or permanent heat intolerance by means of the HTS procedure. Based on the findings of the present study, there is no fundamental reason why such a requirement should not be extended to female mineworkers destined to work under similar conditions.

Current recommendations regarding the assessment of overall fitness for work in heat should be followed without exception, especially those dealing with individuals who fail the heat tolerance screening test.

The introduction of a screening procedure to determine physical work capacity (aerobic capacity) should be considered as part of the assessment of overall fitness for work in heat. Such a test should preferably be conducted before the HTS. Information obtained during the physical work capacity test could form part of the “risk profile” for any employee destined to enter “hot” working environments in the execution of his or her duties and responsibilities. The above information could, in turn, be used to devise proactive risk management strategies. Previous work in this regard (Strydom et al., 1980) could form the basis for such a screening procedure.

In view of their smaller physical work capacity (aerobic capacity) and physical strength, female mineworkers may experience undue physiological strain when performing “strenuous” tasks while working underground. Since no information is currently available on the physiological strain experienced by female mineworkers, it is recommended that this aspect be investigated and that the results obtained be compared with those of male mineworkers involved in similar tasks. Furthermore, if the recruitment of female labour is regarded as an important issue, the development of realistic work-hardening programmes is a logical, if not crucial, subject for further research.

It is recommended that the block stepping routine remain part of the HTS and that bicycle ergometers be used only in exceptional cases, and only when recommended by

a medical practitioner. Individuals using the latter mode of exercise during the HTS should be closely monitored on an individual basis to ensure that the required work rate is maintained for the full duration of the HTS.

In view of the employer's duties and responsibilities in terms of the Basic Conditions of Employment Act, 1997, female mineworkers should be encouraged to inform their employers when they are pregnant and should then be required to work under the conditions outlined in the *Code of Good Practice on the Protection of Employees during Pregnancy and after the Birth of a Child*.

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Appendix A: Medical Questionnaire

What is your present occupation? _____

How many days of the week are you underground for? _____

Are you underground for the full shift? _____

(If no, ask on average how many hours are they underground for.)

Do you have any past medical history? _____

Ask about diabetes, hypertension, thyroid problems, asthma, epilepsy, previous admissions to hospital, TB, arthritis, especially of knees or hip, etc.)

Do you have any past surgical history? _____

(Ask about tonsillectomy, appendectomies, etc.)

Do you presently have any symptoms? _____

(Ask about dizziness, headaches, flu-like symptoms, cough, abdominal pain, etc.)

Describe: _____

Do you smoke? _____

If yes, how many a day? ____ For how many years? _____

If no, did you previously smoke? _____

If yes, how many a day? ____ For how many years? _____

When did you stop? _____

Do you drink alcohol? _____

If yes, what do you drink and how often and how much? _____

(e.g. 2 glasses of wine 3 times a week)

Are you presently taking any medication? _____

If yes, list medication being taken.

Are you on any form of contraceptive? _____

If yes, which one ? _____

(If the subject is on the oral contraceptive, ask where she is on the pack. If she is taking the injection (Depo, Nur-isterate), ask her the date of her last injection.)

If no, when was your last menstrual period? _____

How long is your average cycle? _____

(If the patient has irregular cycles, please make a note of it.)

Do you do any extra-mural activities? _____

(Ask about gym, squash, jogging, etc.)

If yes, what and how often? _____