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Physiological Strain of Miners at Hot Working Places in German Coal Mines

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Abstract: As the percentage of shifts in hot working conditions in German Coal mines had increased to more than 50% during the last decade, a study was carried out to record the physiological strain of miners. Thirty-eight miners participated during 125 shifts. Heart rate and rectal temperature were measured continuously. Sweat losses as well as food and fluid uptake were estimated from measurements before and after shifts. During all shifts mean heart rates resulted in 102.8 min^{-1}, mean rectal temperature was 37.7°C. Mean sweat loss per shift was 3,436 g; mean sweat rates resulted in 494 g/h. Rehydration during the shift at high climatic stress decreased to about 60% of sweat losses. In order to state the organizational frame of work at hot working places in German coal mines, the main features of regulations of work at hot working places are presented.

Key words: Mining, Physical work, Heat, Self-pacing, Dehydration, Medical check-up, Regulations

Introduction

During the last decades several studies were conducted to describe the strain of miners at work. E.g. Foure[1)] studied physical stress for several working tasks within a highly mechanized coal-face. Temming and Rohmert[2)] investigated physical stress at working places underground with different degrees of mechanization. Rohmert and Schott[3)] described body postures in mines. Psychological stress and strain were investigated by Burkhardt and Weber[4)]. Kampmann *et al.*[5)] studied physiological strain of miners during installation and withdrawal of face support. Cardiac strain was investigated by Palenciano *et al.*[6)] in hard coal mines in Spain.

During the last years the climatic stress has increased in German coal mines. This is caused by the increasing depth of the extracted seams and the increase of electrical power used for extraction and transport of coal despite increasing efforts for air cooling in the mines: In 1990 mean depth of working areas was 919 m, per working area a refrigeration capacity of 2154 kW was installed[7)] and in the month of July 50.1% of all shifts were spent in hot working conditions (see below); 1997 mean depth of working areas had increased to 966 m, per working area a refrigeration capacity of more than 4,000 kW was installed and in the month of July 54.3% of all shifts were spent in hot working conditions[8, 9)].

As there were no studies in mines within this range of climatic stress a study was performed to describe the physiological strain of miners at hot working places in German hard coal mining[10)]. The main results of our study will be preceded by a summary of the main features of regulation of work at hot working places in German coal mines in order to state the organizational frame of work.

Regulations of Work in the Heat

In German coal mining special regulations[11)] exist to prevent health impairments due to heat stress at the working place. A working place falls within the scope of the regulation if air temperature exceeds 28°C or Basic Effective Temperature (BET)[12)] exceeds 25°C.

The working time at the working site is reduced to 6 hours

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for miners working more than 3 h at 25°C<BET≤29°C, and to 5 h for miners spending more than 2 1/2 h at 29°C<BET≤30°C. Above BET=30°C work is prohibited in general; only in individual cases approval may be given under several restrictions up to a limit of BET=32°C. Beyond this limit only members of mine rescue teams are allowed to work according to special time-tables[13], the time of mission being limited with respect to climatic conditions. —Additional resting pauses have to be conceded depending on the level of climatic stress.

A miner beginning work at a climatic stress of BET>29°C must not be integrated into a system of piece wages for 14 d. During this time for adaptation he should work more than 2 1/2 h daily within this climate. The same clause applies for a miner that has not worked in this climatic regime for more than 6 months. Miners younger than 21 yr and elder than 50 yr need a special approval from the occupational physician after the medical check-up to be allowed to work in this climatic regime.

In climatically restricted areas a miner only may work if after a medical check-up by an occupational physician no concern exists with respect to his health.

Medical check-ups[14] are repeated at least every 2 yr. Miners who worked more than 80 shifts a year at BET>29°C, and miners younger than 21 yr or older than 50 yr, have to pass the medical check-up every year. A shorter interval for the check-up may be set at the discretion of the occupational physician.

The medical check-up includes a bicycle ergometry (PWC 150) before the beginning of work in hot working conditions; the load during the ergometry shall be increased to 2.1 Watts · body mass/kg. —Concerns with respect to work in the heat may be acute, permanent or restricted to BET>29°C. Diseases leading to restrictions for work in the heat include high blood pressure (without or with medication), high overweight, chronic lung diseases, cardiovascular disease and a low degree of fitness as determined by bicycle ergometry[14].

After a sick-leave[15] a miner has to pass a medical check-up before returning to work; the occupational physician has to estimate whether the sick-leave may have been due to climatic stress.

Materials and Methods

As the study was carried out as a field study we had several preliminary discussions with miners, informing them of the aims of our study, of the parameters to be measured and of their possibility to quit their participation without specifying a reason. Heart rate and rectal temperature would be registered continuously during the shift by means of an intrinsically safe recorder (Oxford Instruments®) and body mass, as well as the mass of drinking fluid and food, would be measured before and after the shift.

The miners who eventually agreed to participate in the study got a feedback on their physiological strain during work by means of a set of individual data and in two meetings they also were informed about the basics of physiology of work in the heat and the general results of the study.

As the miners participating in the study would perform their regular work, they were prepared (electrodes for registration of the electrocardiogram were fastened, rectal probes were inserted by the miners themselves, the recording device was installed and weighing procedures took place) within one hour before the regular begin of the shift. After the regular end of the shift the remaining weighing procedures were completed and the recording devices were dismounted. The miners got a monetary compensation for the extra time needed before and after the shift and for the participation in the study.

Several difficulties showed up in recording physiological data: For the electrocardiogram the signal often was disturbed by electromyograms due to the use of arm and chest muscles during work; because of strong sweat production large shifts of the baseline occurred and also sometimes electrodes loosened. A special computer program was developed that assisted in recognizing and correcting e.g. multiple triggering. —Rectal probes sometimes were lost during the shift and in few cases drinking fluid was given to other miners—a common behaviour of miners that within our study unfortunately hindered the calculation of sweat loss for the respective shift.

Altogether 38 miners participated in our study. In our study data were recorded during 125 shifts; in 111 of these shifts all records and protocols were valid. As anthropometrical data, body height, body mass, age and working time under ground thus far were recorded. As stress parameters, climate, noise, height and inclination of the working site were measured. During the shifts a record of work tasks—and of body postures as well as proportions of static and dynamic work, the results being published elsewhere[10]—was carried out by trained researchers during cycles of work.

Results

Table 1 gives the anthropometric data for the miners that participated in our study; the miners worked underground for (16 ± 5) yr (mean ± std.-dev.). Body mass in relation to body height—as estimated by Broca-Index and BMI—shows some increase compared to standard values (e.g. Seliger and Bartunek[16]).

The weighing of the miners before descent (naked and with full equipment) showed the mass of their equipment to be (13.6 ± 1.5) kg (clothing, safety boots, filter self-rescuer, food and drinking fluid, but without measuring equipment of additionally 1.3 kg). Some miners additionally carried tools or spare parts on their way to the working site, the observed maximum of additional load were flexible tubes with a mass of 14 kg.

Table 2 presents the data of climatic stress at the working places investigated. For analysis the mean of the measured climatic parameters at the working site was calculated—excluding the time of haulage where climatic stress usually was markedly lower. During a lot of shifts also globe temperature was measured, but even near big driving units (600 kW electrical power) in no case a difference of more than 1°C showed up. As climatic indices BET and WBGT (ISO 7243) are displayed.

An example for the records during a shift is given in Fig. 1: heart rate and rectal temperature of a miner working at an advance heading: heart rate quickly follows cardiovascular stress. During the haulage several periods of walking—before and after transport in a train underground and after ascending an internal shaft—may be seen. At the working area the different working tasks cause short increases of heart rate up to 170 min^{-1}. The intermediate increase of body temperature leads to an increased basic level of heart rate—thermal pulses[17]—that normalises during the haulage back to the shaft afterwards. Rectal temperature in general follows the internal heat production; at the begin of the walking period towards the end of haulage however—after transportation in the train—cool blood from the periphery is redistributed in the circulatory system: so the increase of heart rate corresponds to a temporal dip in body temperature. Rectal temperature stabilizes quite well around 38.3°C during the second part of the time at the working site and declines afterwards during the transportation by train, when energy expenditure as well as climatic load are low. The records of working tasks during the time at the working area (bottom of Fig. 1) allow a ranking of tasks with respect to cardiac strain[10].

In order to look for the effects of climatic stress on cardiac strain Fig. 2 gives the median of heart rates (taken for the time between descent and ascent) for all shifts as a function of mean climatic stress at the working area. The values of heart rates show great variation (different miners with different fitness have different working tasks, different time of day [the lowest values being recorded during night shifts][18]) but surprisingly they show no significant increase with climatic stress. As the maximum values of heart rate are quite sensitive to triggering by artefacts, the 95. percentile of heart rates was chosen to give an impression of maximum cardiac strain: Fig. 3 demonstrates great variations of strain (like in the median values), but also no increase with climatic stress. At a mean shift duration of 7 h, the 95. percentile gives the value of heart rate that is exceeded during a total of about 20 min.

Table 1. Anthropometric data of 38 miners participating in the study

	Anthropometric data-38 miners				
	Body height /cm	Body mass /kg	Broca-index /%	BMI /kg/m^2	Age /yrs
Mean	177	85.2	111	27.1	34.3
Std.-dev.	8	14.2	12	3.1	5.8

Tables 3 and 4 give a classification for characteristic parts of the shifts within our records and the respective statistical values: during haulage cardiac strain is approximately 15 min^{-1} lower than during the work at the working area. As the data for the time at the working area (O0) and the time during which records of working tasks were taken (O1) differ only for 0.4 min^{-1}, we conclude that our observation obviously had no great influence on the working attitude of the miners.

Figure 4 gives the median values of rectal temperature as function of BET—a great variation of values is present (the lowest values being recorded during a night shift) but no significant influence of climatic stress is found. The same applies for the maximums of rectal temperature during the shifts (Fig. 5)—during most shifts rectal temperature exceeds 38.0°C; this value is proposed as an upper limit by the WHO[19]. Table 5 displays rectal temperatures for characteristic parts of the shifts according to Table 3; like for heart rate, rectal temperatures for O0 and O1 are quite alike.

The haulage includes long transportation by train underground where the miners are sitting at low climatic stress: When comparing cardiac strain on the way back to the shaft it is—in the mean—only 2.1 min^{-1} increased compared to cardiac strain during the way to the working site. Rectal temperature during the way back has reduced—in the mean—to 0.22°C above the value at the way to the working site[10].

The mean sweat loss per shift showed up as (3,436 ± 1,240) g. Figure 6 depicts a highly significant increase of sweat loss with increasing climatic load; maximum values exceed 6 kg per shift. Sweat rates, calculated for the complete shift

Table 2. Climatic stress at the working places

	Dry-Bulb-Temperature[a] t_{db}/°C	Psychrometric Wet-Bulb-Temperature[a] t_{wb}/°C	Wind velocity[b] v_a/m/s	Basic Effective Temperature /°C	WBGT /°C
Mean	31.2	28.2	1.8	26.3	29.1
Std.-dev.	2.9	3.3	1.1	3.5	3.1
Minimum	21.6	20.0	0.2[b]	16.6	20.5
Maximum	36.3	33.0	6	32.2	33.7

[a]Measured at the working place of the respective miner during the time at the working site.
[b]Wind velocities below 0.2 m/s could not be measured due to the characteristic of the anemometer used.

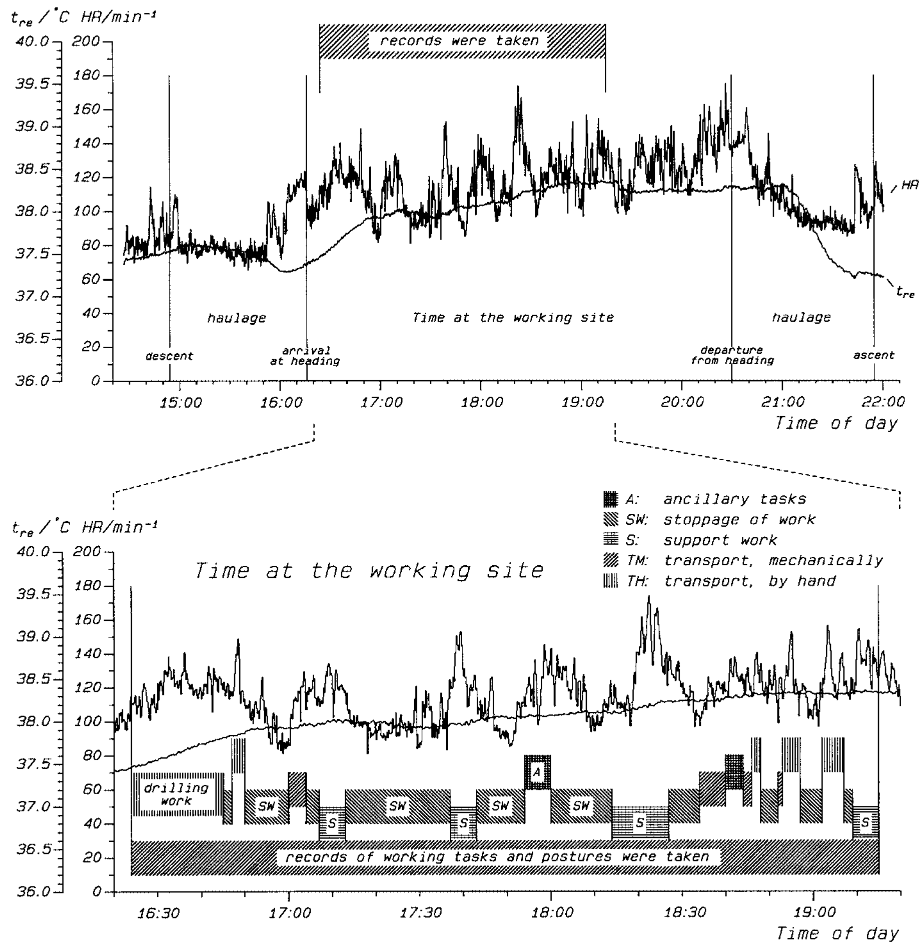

Fig. 1. Heart rate and rectal temperature of a miner working at an advance heading, adjacent to a longwall face.
t_{ab}=32.7°C; t_{wb}=29.6°C; v_a=0.9 m/s; BET=28.7°C; sweat loss: 3.8 kg; intake of drinking fluid: 2.3 kg.

length (descent-ascent) resulted in (494 ± 178) g/h. As found in a lot of studies, sweat losses are not fully compensated by drinking during work. Figure 7 shows that only about 50 to 60% of the sweat losses are replaced during the shift—this has been termed "voluntary dehydration" e.g. by Adolph *et al.*[20]; of course the water loss has to be replenished at the latest by the beginning of the next working shift.

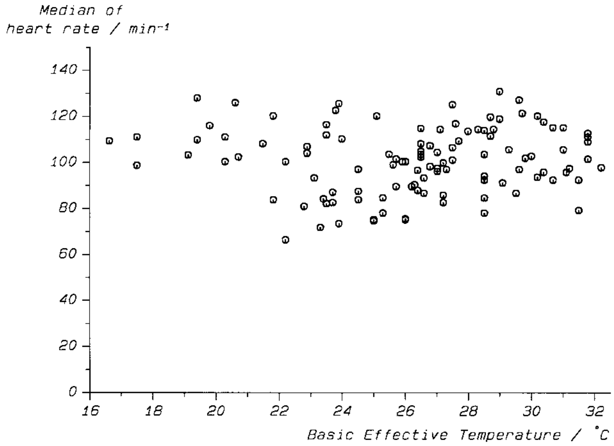

Fig. 2 Median of heart rates (ascent–descent) as a function of Basic Effective Temperature.
Mean value at the working site.

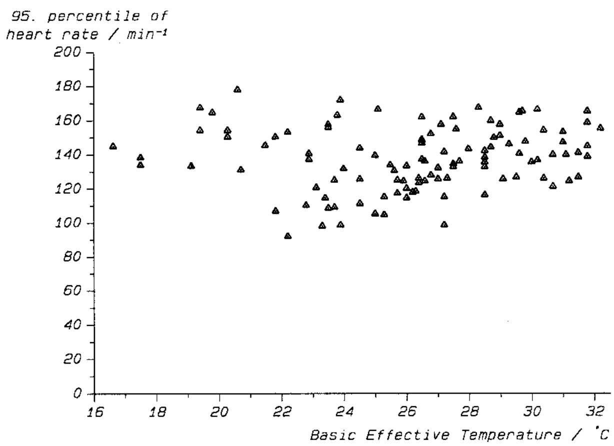

Fig. 3. 95. percentile of heart rates (ascent–descent) as a function of Basic Effective Temperature.
Mean value at the working site.

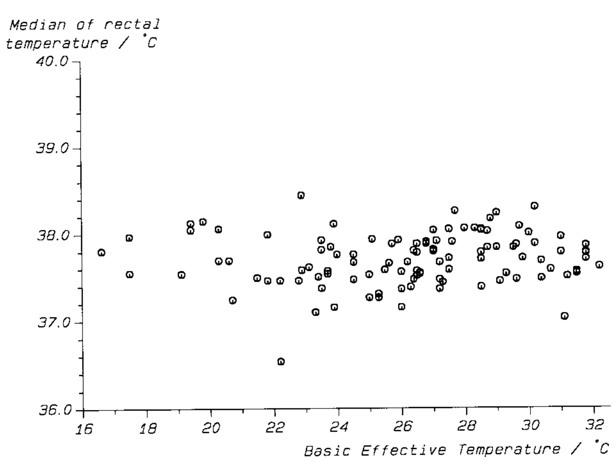

Fig. 4. Median of rectal temperatures (ascent–descent) as a function of Basic Effective Temperature.
Mean value at the working site.

Table 3. Characteristic times of our study for all 38 miners in 125 shifts: time for haulage and time at the working site as well as time at the working site where records of working tasks were taken

Classification of workingtime	Symbol
Time between descent and ascent	G0
Time for haulage (both ways)	F0
Time at the working site	O0
Time at the working site during which working tasks were recorded	O1
Actual working tasks included in the records	W1
Stoppage of work (either due to sequence of operations or rest periods)	SW

Table 4. Characteristic values of heart rates for all 38 miners in 125 shifts for different parts of the working shifts

Classification of working time	Analyzed time /min	Heart rate			
		Mean/ min^{-1}	Std.-dev /min^{-1}	5. percentile /min^{-1}	95. percentile /min^{-1}
G0	52,053	102.8	23.9	67.9	146.5
F0	19,712	93.1	21.3	63.8	132.2
O0	31,624	108.2	23.4	72.5	150.4
O1	26,070	108.6	23.7	71.9	151.3
W1	17,079	112.8	23.4	76.0	154.3
SW	8,999	100.6	22.3	67.4	141.9

Discussion

The most surprising result of our study was that—great intra- and interindividual scattering of data was present—heart rate and also rectal temperature did not increase with climatic load, whereas sweat rate increased. As an explanation we hypothesize that miners reduce their energy expenditure with increasing climatic stress to keep their sensation of strain at an appropriate level (“self pacing”). So a miner may skip the way to a distant telephone if a phone call is not urgent and may order some spare parts for the next day at the end of his shift, when he anyhow passes the telephone. As many working tasks in German mining nowadays are highly mechanized, a reduction of work load must not necessarily lead to a reduction in productivity: if during the time at the working area there is a great percentage of stoppage of work (cf. Tables 4 and 5) due e.g. to the sequence of operation, a miner may reduce his working speed and thereby make use of the time of work stoppage without reducing his productivity. The low fluctuation of rectal temperature during the second part of the time at the working

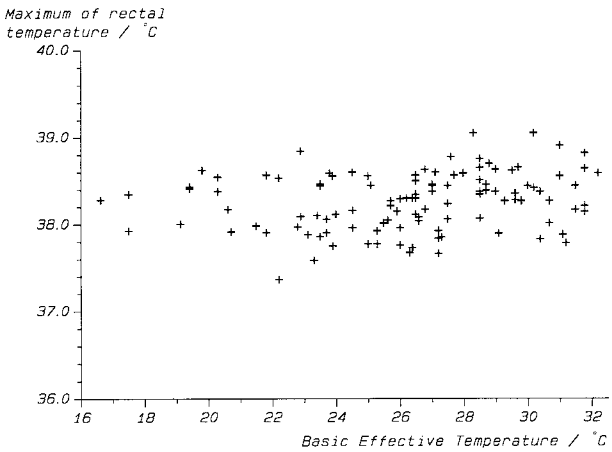

Fig. 5. Maximum of ractal tenperatures (ascent–descent) as a function of Basic Effective Temperature.
Mean value at the working site.

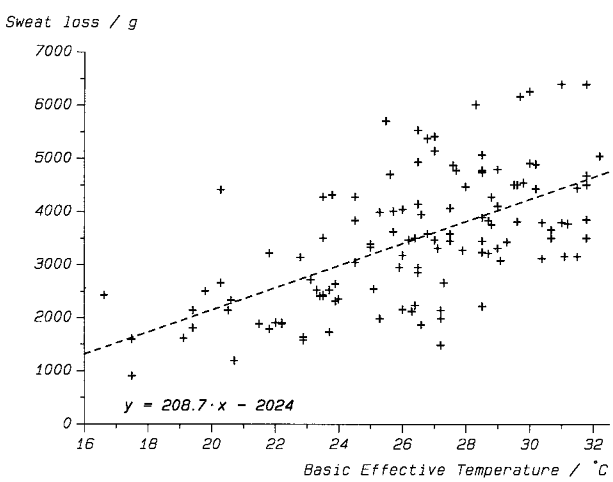

Fig. 6. Sweat loss during a shift (calculated from body mass loss, corrected for food and fluid intake as well as for urine output) as function of climatic stress.

area in Fig. 1—despite marked differences in heart rate being present—supports the hypothesis of “self-pacing”. Goldman[21] reports that “self-pacing” may take place at working tasks that demand less than 30 percent of the maximum working capacity and will occur for tasks demanding 45%.

The outcome of “self-pacing” can be explained by means of a diagram from LIND[22] (Fig. 8): outside the “prescriptive zone”[22], where rectal temperature increases with increasing climatic stress for a given work intensity, a reduction in work intensity may keep the rectal temperature near the old level.

Some decades ago there was a discussion whether physiological regulation or behavioural regulation would have greater influence on the regulation of body temperature[23]. Obviously some elements of behavioural regulation are inborn and also used by animals (e.g. looking up shadow in bright sun) and others have to be learnt by teaching or imitation (amount of drinking that is necessary for tourists in tropic areas, work intensity at unknown working places in the heat, etc.). In humans, heat adaptation also has these two components (e.g.[24]): a physiological adaptation (increase of sweat rate etc.) and a behavioural adaptation (e.g. adaptation of fluid intake to increased sweat rates or adjustment of work intensity to heat balance; a miner may well imitate the behaviour of fellow miners or improve his behaviour according to own experiences). For these reasons the risk of heat illness is increased for beginners at hot working places and in cases where the climatic stress increases unexpectedly, e.g. by failure of a cooling unit[15]. Different from physiological acclimatization, behavioural adaptation may be still present after a leave from the hot working place.

Table 5. Characteristic values of rectal temperature for all 38 miners in 111 shifts for different parts of the working shifts

Classification of working time	Analyzed time /min	Rectal temperature Mean /°C	Std.-dev. /°C	5. percentile /°C	95. percentile /°C
G0	48414	37.67	0.44	36.97	38.36
F0	18247	37.49	0.43	36.84	38.26
O0	29451	37.77	0.40	37.13	38.39
O1	24516	37.78	0.41	37.13	38.39
W1	16122	37.80	0.39	37.20	38.40
SW	8403	37.73	0.43	37.03	38.38

Comparing heart rates during the shifts to the cardiovascular strain during the medical check-up, when a heart rate of 150 min^{-1} will be aimed at, we found that during 92 out of 125 shifts heart rate exceeded 150 min^{-1}. Figure 9 gives the proportion of the shift length (descent-ascent) during which a heart rate of 150 min^{-1} is exceeded for each single shift: e.g. for 20 of 125 shifts heart rate exceeded a value of 150 min^{-1} during more than 10% of the shift length and in 33 shifts during more than 5%. Regarding age-related limits of heart rate, a limit of “200–age/yr” (Fig. 10) still is exceeded in 61 out of 125 shifts; during 7 of 125 shifts it is exceeded for more than 5% of shift length. Taking “220–age/yr” as the age adjusted maximum heart rate, it is shortly exceeded in 14 of 125 shifts, but only during one shift for more than 1% of the shift length (in total for 6.7 min).

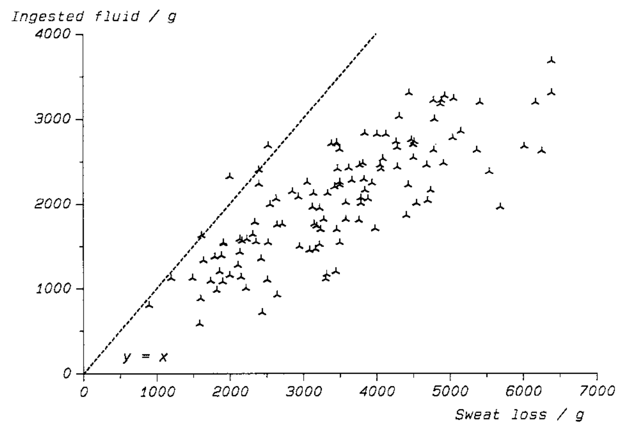

Fig. 7. Ingested fluid during a shift depending from sweat loss; the line represents identity.

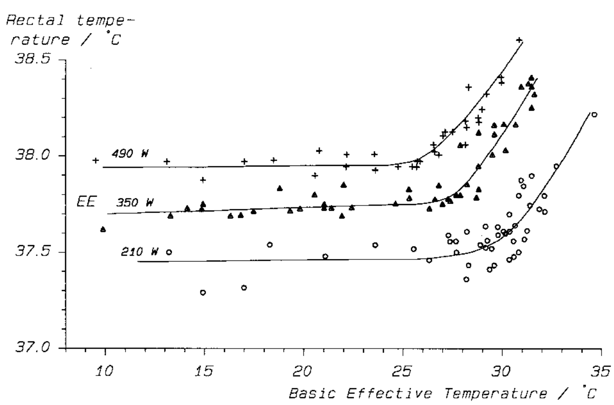

Fig. 8. Rectal temperature as a function of climatic stress for three defferent energy expenditures (EE) in the laboratory. redrawn according to LIND[22].

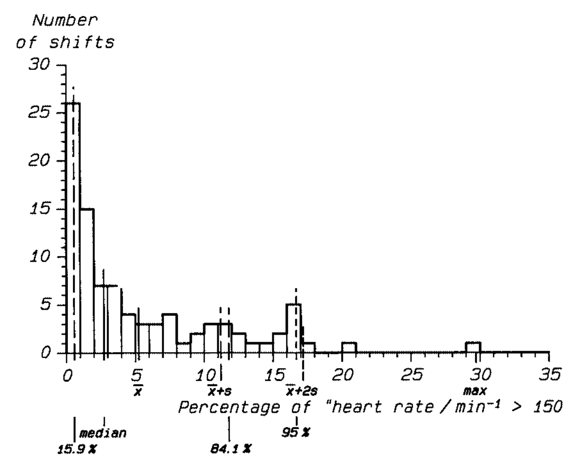

Fig. 9. In 92 out of 125 shifts heart rate exceeded 150 min^{-1}, the percentage of the shift (descent–ascent) during which a heart rate of 150 min^{-1} is exceeded is displayed.

Regarding intervening influences, neither age, nor body mass nor BMI show a significant influence on heart rate or body temperature.

With respect to water balance, water deficit may reach more than 2 kg at the end of the shift (Fig. 7). This deficit has to be compensated by the next working day. In a different study at hot working places in coal mines we found that approximately 10% of 40 miners accumulated an increasing water deficit throughout the working week and restored their body mass only during the weekend[24]. We suggested to the miners at our meetings that they increase their amount of drinking fluid but some of them were vigorously opposed, claiming that an increase of drinking only would result in increased sweat rates. Based on this argument we looked more closely to water balance and found some evidence that the miners in our study—due to sodium loss and carbohydrate usage—may well be in a physiological state of water balance and not in a water deficit[25].

A comparison with results of other studies of physiological strain is problematic, as the degree of mechanization of work, climatic conditions and work organization usually are quite different in different mines within different countries. Temming and Rohmert[2] found at working places with different degrees of mechanization without marked heat stress a mean heart rate of 90.1 min^{-1} and mean sweat rates of 281 g/h. A study on strain of miners during installation and withdrawal of face support[5] yielded mean heart rates of 93.6 min^{-1}, a mean rectal temperature of 37.5°C and mean sweat rates of 200 g/h at air temperatures below 36°C and BET at maximum 29.3°C. The study of Palenciano *et al.*[6] at air

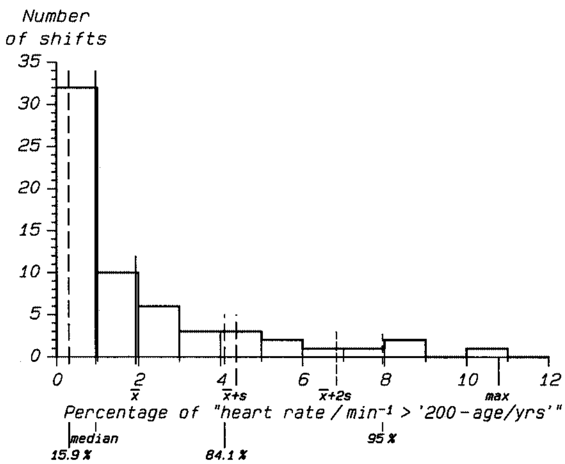

Fig. 10. In 61 out of 125 shifts heart rate exceeded a level of "200–age/yr" min^{-1}; the percentage of the shift (descent–ascent) during which this level is exceeded is displayed.

temperatures below 23°C and high relative humidity showed mean heart rates of 97.3 min^{-1}. The study presented[10] yields mean heart rates of 102.8 min^{-1}, rectal temperatures of 37.7°C but mean sweat rates of (494 ± 178) g/h; due to the high climatic stress (mean value of BET = 26.3°C at the working site, Table 2) sweat rate is by far higher than in all other studies whereas heart rate as well as rectal temperature only seem to be moderately increased—this probably is caused by self-pacing of the miners.

Recommendations

- Miners should be informed that often the amount of fluid ingested is smaller than the sweat loss and that such an imbalance may lead to health impairments—so an increase of fluid uptake may be advantageous in many cases.
- To increase fluid uptake, "preventive drinking" (e.g. ASCM[26]) may be practised before work is started.
- It may be desireable to provide drinking fluid at the working site so the miners need not carry additional mass during haulage in case of very hot working areas and for unexpectedly hard work (repair work, failure of cooling units)—usually the miners carry their drinking bottles themselves.
- As obviously the miners are able of "self-pacing" they should be encouraged to practise it; beginners should be advised to adopt—during acclimatization—the work intensity and drinking behaviour of experienced miners.
- The heart rate during work exceeds the cardiovascular strain during the bicycle ergometry at the medical check-up in many shifts (Fig. 9). So it may be considered[27] whether the cardiovascular strain during the medical check-up should meet heart rates within the "self-pacing" regime (Figs. 2 and 3).

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