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A COMPARATIVE STUDY OF PHYSIOLOGICAL STRAIN OF UNDERGROUND COAL MINERS IN INDIA

Ratnadeep Saha [1], Netai Chandra Dey [1*], Amalendu Samanta [2], and Rajib Biswas [3]

[1] *Bengal Engineering and Science University, Shibpur, Botanic Garden, Howrah, 711103, India*
**Email: netaidey@hotmail.com*
[2] *Department of Occupational Health (A.I.I.H & P.H), 110 C.R.Avenue., Kolkata-700073*
[3] *Dept. of Physiology of Universal College of Medical Sciences, Bhairahawa, Lumbini, Nepal*

Ninety-eight healthy underground coal miners aged between 23-58 years were studied during their activity period. Physiological strain of different category of miners in terms of heart rate was monitored continuously with heart rate monitor that revealed the tasks as heavy to very heavy for them. Oxygen consumption was measured directly by using oxylog-2 machine that corresponded to metabolic costs for different activities ranging from 4.96 kcal/min to 5.47 kcal/min. The mean relative aerobic strain varied from 47.4%-56.8% - depicting acceptable level of physical strain was well encroached by the miners who irrespective of ages and categories showed poor recovery responses. This entails that miners are exerting themselves beyond their capacities where inevitably older workforce face the maximum burden.
Key words: physiological strain; coalminers; heart rate; energy cost

INTRODUCTION

Like all other developing countries, mining plays an important role in developing and strengthening social and economic infrastructure of India. Though increasingly stringent health, safety, and environmental regulations, together with rapid technological advances, have resulted in enormous improvements in man-machine and environmental domains, yet loopholes in implementing regulation keeps millions of miners at severe risk.

In India, occupational health practice is gaining momentum but still it is the miner's plight that no proper systematic health care services are available for them. Studies on workload and energy expenditure in different mining operations particularly for manually operated underground haulage mines are scanty and limited in their scope. It is beyond any doubt that a similar study in the underground coal mining community will be useful to utilize its potential more effectively. Moreover, the knowledge from various aspects of the study will be helpful in evaluating the required levels of physical fitness for working in various categories of mining activities in different age groups.

MATERIALS AND METHODS

Site selection

The Raniganj Coal Field, a major contributor of underground coal production in India, has a considerable number of conventional types of haulage based underground mines. Out of its few areas Kenda that has major coal seams with close proximity of underground mines achieving targeted output per man shift every year was selected for the study. Out of six mines three were deemed suitable based on the cardinal factors that a considerable quantum of coal was gained through developmental procedure of Bord and Pillar method (mostly used) predominantly by manual labours where all the

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three seams of the area were encountered.

Category selection

There were several unit operations including dressing, drilling and blasting (coal preparation), roof supporting, coal loading and tramming that were often practiced simultaneously in a shift. Loaders were known to be the only piece-rated workers (PR workers) whereas others like drillers, dressers, trammers were time-rated workers (TR workers). It was important to mention that the wage cost of these PR and TR workers accounted for to at least 60-65% of the cost per ton (CPT) of coal extracted by this Bord and Pillar method and the major proportion of this wage cost was consumed to compensate the salaries of the PR workers in India. Consequently these huge numbers of workers (since in manually operated haulage mines PR: TR workers remain nearly as 1.5:1) were bound to earn maximum attention and importance from all corners including the management side. Beside these facts the priority-based criteria that had been used were as follows:

- Activities that required devoting significant time continuously in the working areas;
- Activities that were quantitative in nature;
- Activities that were supposed to be relatively physically demanding.

Keeping all these in view, loading and drilling operations were selected for the study.

Drilling

This was performed by a crew consisting of three drillers who were assigned to drill a predetermined number of holes in 8-hour work shifts. It was found that they do their job in two spells as per the drilling pattern approved by the Colliery Manager under the direct supervision of Mining Sirdar. At first one person carried the machine (approx: wt: 30 Kg) and other two pulled the drill cables to the face (work site in underground mines) where checking of machine was done and drilling bits were attached at one end of drilling rods to make the machine ready to drill. The time required for these activities varied crew-to-crew and face-to-face. On completion of holes in a coalface they moved to another place where the next cycle would start.

Loading

This was performed by groups of miners designated as 'loaders' each consisting of 4-7 individuals. The operation involved two simultaneous activities of "shovelling" and "carrying" coal, and accordingly the miners were designated as 'shovellers' and 'carriers'.

Two shovellers shovelled the blasted coals through repeated scoops (weight 6-7 kg) with the help of shovel (2.5 kg) to fill a basket during which they mainly adopted stooping postures. Filling of extra amount of coal by hand also necessitated them to adopt the same postures again. Besides, they also aided in transferring the loaded baskets on to the head of the carriers who carried the loaded baskets (45-55 kg) to a considerable distance for unloading coal over the tubs stationed at a nearby haulage track and would come back for reloading. The traversed distance was termed as lead distance. Each member of the loading group was expected to fill a minimum number of tubs per shift, i.e. at the rate of two tubs per head, and they were eligible to get bonus whenever they would cross this limit.

Subject selection

Healthy and regularly engaged carriers with a minimum work experience of 5 years within the age group of 20-60 years were initially selected by discussing the medical histories with colliery doctors of different mines. Extensive interactions were carried out with them at regular intervals for a period of one month to explain about the objective of the study along with their extent of involvement. Finally, following a random sampling technique stratified on the basis of age a total of 98 miners who had agreed to render themselves voluntarily in accordance with the design of the experiment were incorporated for the study.

Field investigation

a) *Physical parameters:* Weights and heights were measured in kilograms and centimetres, respectively, by using a sensitive human weighing balance and an anthropometric rod. Body Mass Index (BMI) was expressed in kg/m^2 and body surface area (BSA) was calculated from height and weight.

b) *Heart rate:* Working heart rates (WHR) were measured by using lightweight telemetric equipment - Sports Tester PE 3000 (Polar Electro, Finland) at a regular interval of 1 min during activity. The same equipment was used to measure recovery heart rates (Brouha 1960). Net cardiac cost (NCC) was obtained as the difference between WHR and Hr_{rest}. Relative cardiac cost (RCC) was obtained by expressing the NCC as % of the heart rate reserve (HRR) of the subjects. The HRR was calculated as the difference between the maximal and resting heart rates of the subjects.

   Recovery heart rates (RHR) of the subjects were measured at the end of work for a stretch of three minutes designated as RHR 1, RHR 2 and RHR 3, respectively.

c) *Maximal cardio-respiratory performance:* The maximum aerobic capacity of the worker was determined indirectly through step test procedures during their non-working days. The method followed was identical to that of Martiz et al. (1961). Each subject was asked to step in and off a tool of 30 cm high at a rate of 15 times/minute and 25 times/min both for a period of 8 minutes and a tool of 40 cm high at a rate of 25 times/minute for a period of 5 minutes. The rhythm was maintained with the help of a metronome when the heart rate monitor and Oxylog-2 (P.K.Morgan Ltd., UK) measured heart rate and oxygen consumption of the subjects, respectively. Both these parameters of each subject were plotted on a graph and straight lines were fitted through three points by means of the method of least squares. This was then extrapolated to the age predicted maximum heart rate of an individual as proposed by the American Heart Association (1972) to obtain the maximum aerobic capacity.

d) *Working oxygen consumption* (WVO_2): This was measured directly at a regular interval of 10 minutes throughout the spell and average values were taken into account. The use of Oxylog -2 appeared cumbersome and could not be done for all the subjects. Therefore a comprehensive amount (50%) of the selected subjects from each age group of different categories by simple random sampling method was included.

e) *Effective temperature* (ET) and *Wet bulb globe temperature* (WBGT): These were worked out as an index to depict the environmental heat load in the existing coalfaces at regular intervals throughout the shift.

   Each miner was studied on a single day while he was regularly engaged in his assigned task and no instructions were given to them to control the work pace and methods as they could interfere with the main objective of the study.

RESULTS

Physical and physiological characteristics of the miners

It was evident (Table 1) that mean ages of different categories of miners varied from 39.7-44.9 years. Drillers showed the maximum weight (57.9 ± 8.2 kg) and the minimum weight (53 ± 6.3 kg) was observed in the carrier group. The mean BMI for all the miners studied had been within the range of 20.2-21.5 kg/m^2 and most of the miners were within the normal range (18.5-25.0 kg/m^2). The driller group showed the maximum average experience of 22.7 ± 8.2 years along with a mean resting heart rate 68.2 ± 5.2 beats/min. A single factor ANOVA analysis only revealed a significant difference in body weight amongst the rest of the parameters.

Cardio respiratory performances of miners

Table 2 showed that the mean Hr_{max} was the highest in carriers (181 ± 9.3 beats/min) followed by the shovellers (179 ± 9.9 beats/ min). Similarly, the mean HRR was maximal for the carriers and the

Table 1. Physical and physiological characteristics of miners studied.

Parameters	Shoveller n = 37	Carrier n = 39	Driller n = 22	f value	p value
Age (year)	41 ± 9.9 * (25-58)	39.7 ± 9.6 (23-57)	44.9 ± 8.2 (30-58)	2.19	0.12
Height (cm)	163 ± 7 (147.5-176)	162 ± 5.9 (148.5-178)	163.6 ± 5.6 (151-171.5)	0.51	0.60
Weight (kg)	54.7 ± 7.6 (41-68.5)	53 ± 6.3 (43-68.5)	57.9 ± 8.2 (45-71.5)	3.21	0.04
BMI (kg/m^2)	20.6 ± 2.4 (16-25.9)	20.2 ± 2.1 (16.7-26.2)	21.5 ± 2.5 (17.3-26)	2.09	0.13
BSA (m^2)	1.6 ± 0.1 (1.3-1.8)	1.5 ± 0.1 (1.3-1.8)	1.6 ± 0.1 (1.3-1.8)	2.0	0.14
Experience (year)	18.4 ± 8.2 (5-33)	19.3 ±9.5 (5-38)	22.7 ± 8.2 (9-34)	1.76	0.18
HR_{rest} (beats/min)	66.4 ± 6.9 (52-76)	64.5 ± 6 (52-76)	68.2 ± 5.2 (58-78)	2.69	0.07

* Mean ± SD (range); BMI= Body mass index; BSA= Body surface area

Table 2. Cardio-respiratory performance of miners in different categories.

Category	HR_{max} (beats/min)	HRR (beats/min)	VO_{2max} (l/min)	VO_{2max} (ml/min/kg)
Shovellers n = 37	179 ± 9.9 * (162-195)	113 ± 14.6 (89-137)	1.89 ± 0.2 (1.54-2.35)	35 ± 4.6 (28.2-45.7)
Carriers n = 39	181 ± 9.3 (163-197)	117 ± 14.0 (91-143)	2.03 ± 0.19 (1.64-2.6)	38.3 ± 3.7 (30.3-45.6)
Drillers n = 22	175 ± 8.2 (162-190)	107 ± 11.4 (91-125)	2.08 ± 0.2 (1.65-2.48)	36.2 ± 3.3 (31.3-43.1)
F value	2.19	2.98	7.19	6.88
p value	0.12	0.06	0.001	0.002

* Mean ± SD (range); HR_{max}= Maximum heart rate; HRR= Heart rate reserve; VO_{2max}= Maximum oxygen consumption

lowest for the drillers. The mean and standard deviation values of maximal oxygen uptake in absolute and relative terms amongst the three categories of miners ranged between 1.89 ± 0.2 l/min and 2.08 ± 0.2 l/min and between 35 ± 0.2 ml/kg/min and 38.3 ± 3.7 ml/kg/ min, respectively. The difference as observed through the dispersion of ranges yielded a significant variation among the categories at the significance level of 0.01.

Physiological strain in different categories of mining works

Physiological strain in the different categories of miner's working heart rate profiles are presented in Table 3. The mean heart rate during shovelling was higher (134 ± 5.5 beats/min) than in carrying (128 ± 6.9 beats/min) and drilling (123 ± 4.0 beats/min). The net cardiac cost was also seen to be the highest during shovelling (68 ± 6.9). Carrying of coal led to a higher net cardiac cost (66 ± 7.7)

Table 3. Cardiac response profiles for different category of miners.

Category	WHR (beats/min)	NCC (beats/min)	RCC (%)
Shovelling (n = 37)	134 ± 5.5 *	68 ± 6.9	61 ± 6.5
	(119-146)	(52-87)	(45-77)
Carrying (n = 39)	128 ± 6.9	66 ± 7.7	56 ± 8.6
	(115-143)	(51-83)	(42-75)
Drilling (n = 22)	123 ± 4.0	55 ± 5.4	52 ± 5.5
	(116-132)	(46-66)	(41-66)

* Mean ± SD (range); WHR= Working heart rate; RCC= Relative cardiac cost
NCC= Net cardiac cost

Table 4. Energy expense profiles for different category of miners.

Category	WVO_2 (l/min)	WVO_2 (ml/min/kg)	RAS (%)	EE (Kcal/min)
Shovelling	1.09 ± 0.25 *	20.51 ± 2.49	56.8 ± 9.41	5.47 ± 1.23
(n = 21)	(0.68-1.6)	(14.6-24.8)	(38.3-72.3)	(3.4-8.0)
Carrying	1.08 ± 0.13	26.2 ± 6.2	54.2 ± 6.9	5.41 ± 0.64
(n = 20)	(0.81-1.32)	(18.3-38.4)	(41.3-68.6)	(4.05-6.6)
Drilling	0.99 ± 0.13	17.2 ± 1.87	47.4 ± 5.25	4.96 ± 0.63
(n = 12)	(0.63-1.17)	(13.9-21.1)	(34.2-58.3)	(3.15- 5.86)

* Mean ± SD (range); WVO_2= Working oxygen consumption; RAS= Relative aerobic strain;
EE= Energy expenditure

compared to drilling (55 ± 5.4). The mean relative cardiac cost amongst all the miners during different activities ranged from 52 to 61 % of HRR, and shovelling elicited the maximum response. Table 4 illustrates that the mean oxygen uptake in different activities varied from 0.99 ± 0.13 l/min - 1.09 ± 0.25 l/min where the maximum and minimum was seen for shovelling and drilling with a corresponding energy expense of 5.47 ± 1.23 kcal/min and 4.96 ± 0.63 kcal/min, respectively. The physical strain was observed to be the highest for shovelling (56.8 ± 9.41 %) with the least was experienced in drilling.

Figure 1 displayed the physiological parameters viz. WHR, NCC and EE in different categories of mining work for the two different age groups. The value for all the parameters was the highest in shovelling and the lowest in drilling, while carrying showed intermediate levels.

The average working heart rate was the highest for shovellers of age above 40 (136 beats/min) and the lowest for drillers of age below 40 (122 beats/min) with the corresponding mean net cardiac cost of 54 beats/min and the mean energy expenditure of 5.1 Kcal/min. However, the maximum NCC of 70 beats/min and energy expenditure of 5.65 Kcal/min was obtained for younger shovellers. Figure 2 reflected that the recovery heart rate responses had been found to be the lowest in younger carriers and the highest in older shovellers.

Analysis of work activities

Analysis of different tasks revealed that, shovelling and carrying as the constituents of loading activities, had similar durations with respect to average shift time, spell time and cycle time (Table 5), whereas drilling had the least time in terms of total shift time and spell duration. However, the

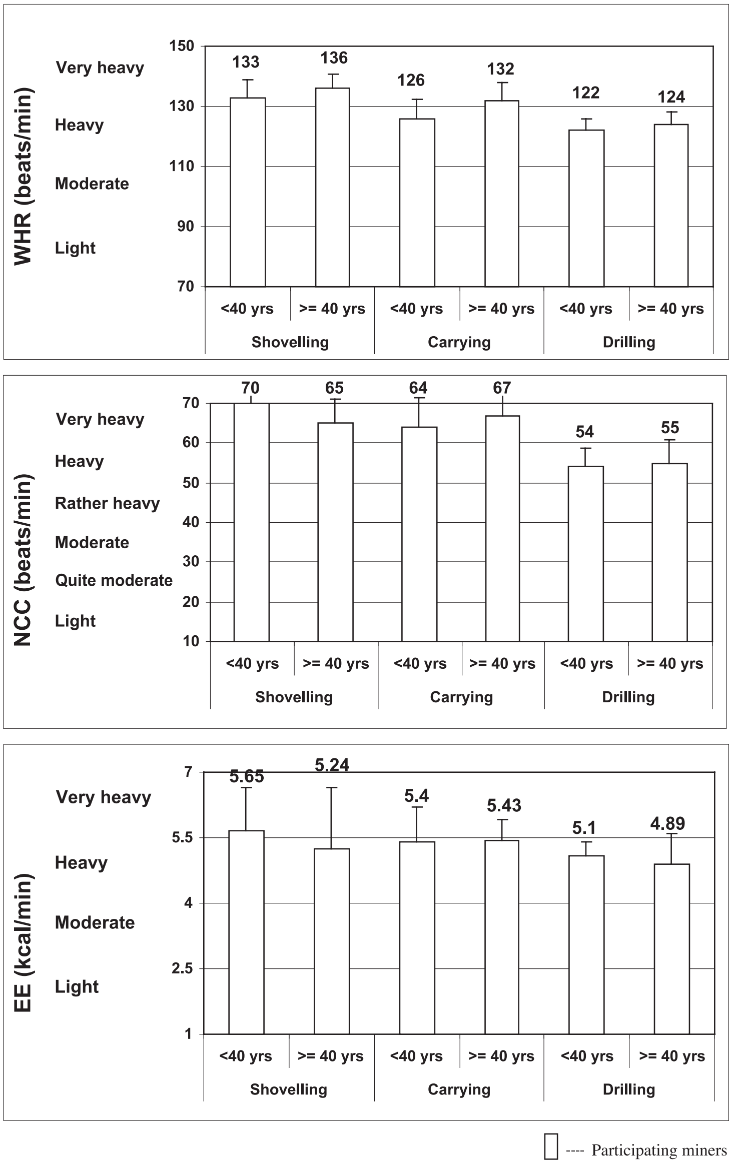

Fig. 1. Comprehensive summary of workload in relation to WHR, NCC and EE.

number of cycles in drilling was conspicuously less resulting in a much higher cycle time as compared to loading activities.

For shovelling, during 85.5% of the entire spell time, miners were engaged in filling baskets with coal either manually or with the shovel when they adopted predominantly static postures. This was followed by 80.6% for drilling holes during which they would keep their hands above and below the shoulder level mainly in standing postures for smooth insertion of drilling rods through the coal-faces. For carrying, where the main activity was to carry the loaded baskets (54.7%) from loading to unloading points reflected its dynamic nature.

Thermal environmental conditions at the workplace

The average picture of environmental heat load is represented in Table 6. The illustrated that the close proximity of dry bulb (31.5 ± 0.96 °C) and wet bulb temperature (29.9 ± 0.94 °C) in the work-

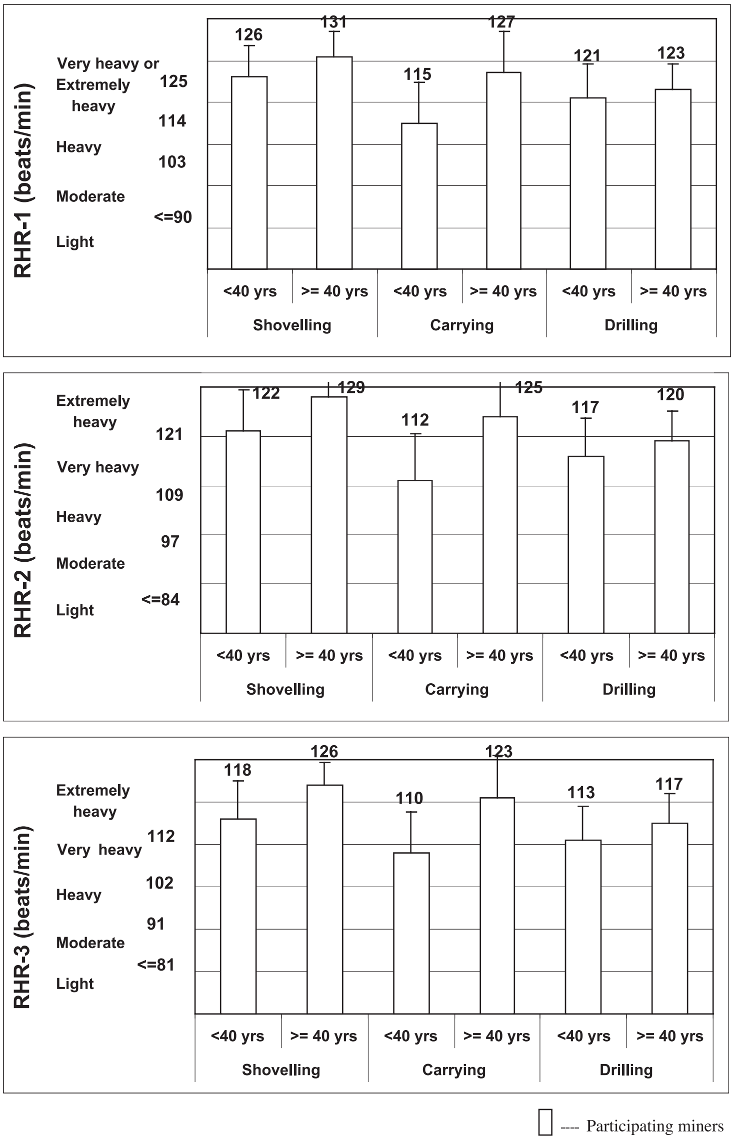

Fig. 2. Comprehensive summary of workload in relation to recovery heart rate (RHR).

sites reflecting the high humidity (88%) with air velocity in the working faces exhibiting stagnancy (0.21 to 0.71 m/sec).

The two different heat stress indices of the workplace determined were WBGT and ET which amounted to be 30.7 °C and 29.5 °C, respectively. The effective temperature revealed that the heat stress prevailing in the workplaces remained within the warm to hot zone according to the Indian classification of environmental conditions (Mookherjee and Sharma, 1953).

Figure 3 shows the work rates of different activities in relation to the observed ET in the workplace of 29.5 °C for different age groups of miners. Amongst the six different groups, the highest work rate of 339 kcal/hour was observed for younger shovellers and the lowest work rate of 281 kcal/hour was found in older drillers. The average work rate for young and older carriers were almost identical, 324 and 326 Kcal/ hour, respectively. For both shovellers and drillers, the work rates for younger groups were higher than for the older counterparts.

Table 5. Description of different categories of underground mining tasks.

Category	Time (min)	Number
Shovelling		
Work duration/shift	106 ± 8.7 (87.2-128.3)*	-
Spells/shift	-	2
Cycles/spell	-	71 ± 13.6 (42-95)
Cycle duration/spell	0.7 ± 0.04 (0.6-0.8)	-
Spell duration/shift	53 ± 9.6 (34.0-71.7)	-
% Time spent by different activities in a spell	Shovelling coal and positioning basket - 62.7 Job done by hands except shovelling - 22.8 Work pause - 14.5	-
Carrying		
Work duration/shift	105 ± 9.7 (86-127)	-
Spells/shift	-	2
Cycles/spell	-	49 ± 10.3 (34 -76)
Cycle duration/spell	1.1 ± 0.18 (0.79-1.7)	-
Spell duration/shift	52.6 ± 8.5 (39-74)	-
% time spent by different activities in a spell	Loaded baskets lifted and carried to the unloading point - 54.7 Unloading of coal and return to the loading point - 45.3	-
Drilling		
Work duration/shift	88.1 ± 4.4 (78-98)	-
Spells/shift	-	2
Cycles/spell	-	2.7 ± 0. 5 (2-3)
Cycle duration/spell	16.4 ± 3.3 (10.0-25.0)	-
Spell duration/shift	44 ± 3.5 (35.0-51.0)	-
% time spent by different activities in a spell	Walking with machine and accessories - 16.1 Machine checking and other activities - 3.3 Drilling holes - 80.6	-

* Mean ± SD (range)

DISCUSSION

It is the nature of work that brings about higher cardiac responses in shovellers than in carriers even though the spell duration remains similar, a fact well supported by various authors (Armstrong et al., 1980; Asmussen, 1981; Kilbom and Persson, 1981). Though the average oxygen consumption remains on the higher side in terms of ml/kg/min amongst the carriers due presumably to the involvement of greater muscle mass (Sanchez, 1979; Neilsen and Meyer, 1987), a slightly higher mean

Table 6. Eenvironmental heat load in the working sites.

Environmental parameters	Mean	SD	Range
Natural wet bulb temperature (°C)	30.5	± 1.02	(27-32)
Dry bulb temperature (°C)	31.5	± 0.96	(28.5-33.5)
Wet bulb temperature (°C)	29.9	± 0.94	(26.5-31.5)
Air velocity (m/sec)	0.37	± 0.12	(0.21-0.71)
Humidity (%)	88.0	± 3.5	(75-93)
Effective temperature (°C)	29.5	± 0.87	(26.5-31.5)
Wet bulb globe temperature (°C)	30.7	± 1.06	(27.5-32.5)

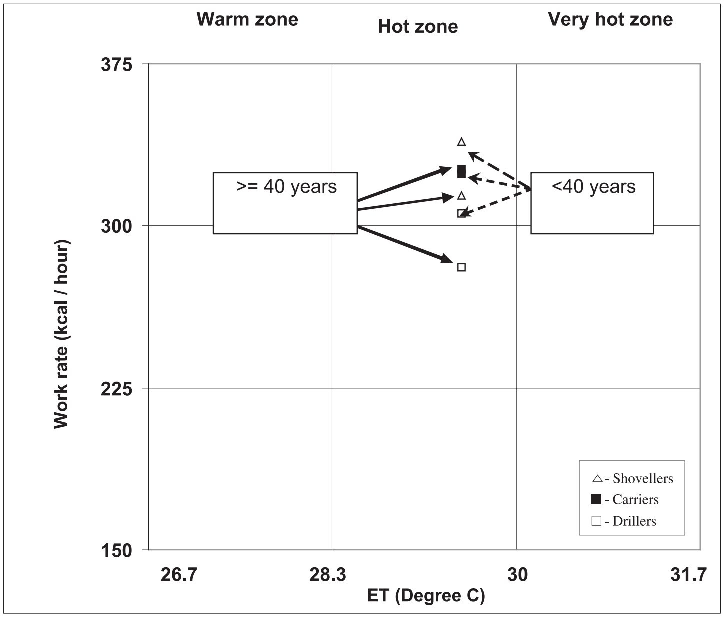

Fig. 3. Work rate in relation to environmental heat stress in different mining activities

metabolic cost in concert with more relative aerobic strain in the shovellers may imply that they experience greater strain than carriers in the same loading group. The higher cost might have resulted due to their frequent changes of stooping postures adopted continuously for transferring load throughout the period with a significant muscular exertion and with increased energy requirement as well (Grandjean, 1988). Between successive cycles drillers get some sort of respite from their immediate static workload of drilling holes while moving from one working site to another. This could be an important factor in bringing down their average cardiac responses in contrast to loaders who are bound to maintain their own pace of work since their work is interlinked in a group. Moreover, the reflection of a comparatively lower energy cost of drillers could underlie behind the fact that static postures are mainly required in providing support and pressure for drilling rods and machines to put the holes in a proper manner. Thus a relatively less muscle masses are involved which reduces energy requirement. Therefore it could well be suggested that differences in postural load along with variability in muscular exertion might have caused such variations in physiological reactions observed.

Heaviness of underground mining activities

The intensity of workload in different mining activities is evaluated in accordance with the scale of heaviness based on working heart rate (Åstrand and Rodhal, 1986) , net cardiac cost (Chamoux et al 1985) and energy expenditure (Ramanathan et al., 1967) (EE). In accordance with these scales (Figure 1), shovelling could be classified as 'very heavy' for both the working groups. Carrying of coal appears to be 'very heavy' for older group but remains 'heavy' only for younger counterparts. Drilling seems to be a 'heavy' for both the age groups. However, on the basis of EE levels, all activities appear to be 'heavy' in nature irrespective of age except shovelling in the younger group. Shovelling work is suggested to be 'very heavy' for them. The scale of NCC clarifies loading activity as 'very heavy' whereas drilling seems to be identified as 'heavy' in nature.

The workload on the basis of recovery heart rate patterns (Samanta, 1984) in the Indian context entails that each of these activities under the present working scenario can be categorized as 'very heavy' to 'extremely heavy' work for all the workers irrespective of job nature with respect to the recovery trend at the end of 1st minute of work (Figure 2). While on the basis of second minute of recovery shovelling emerges as 'extremely heavy' for both the groups and remains the same for aged carriers only. Carrying coal for the younger group along with drilling appears to be 'very heavy' in nature. Interestingly the older group engaged in shovelling and carrying, it still remains as 'extremely heavy' even after the end of the third minute of recovery.

Basically the recovery heart rate patterns indicate dissatisfied recovery for all the workers irrespective of age and activities performed. The sustained and slow recovery pattern after each spell of work not only corroborates to the insufficient capacity of the workers but also implies overexertion of the cardiovascular system (Brouha, 1967; Bernard and Kenney, 1994). This definitely proves to be worse for older groups in the present working situations. The trend of recovery heart rate at the end of the first minute also indicates that the activity would cause excessive cardiovascular strain if continued for all the subjects except the younger group of carriers who on the contrary faces a fair indication of impending strain at the existing situation (Chengalur et al., 2004) .

Physiological strain in relation to environmental heat load

It is clear from the above discussion that the workload experienced by the different groups of workers ranges from "heavy" to "extremely heavy" in accordance with different levels of physiological parameters. The existing ET (29.5 °C) remains above the recommended value of 28.5 °C for the heavy type of work as suggested by WHO (1969).The mean WBGT (30.7 °C) also reflects that the permissible limits for continuous work (25 °C) according to ACGIH (1981) is also exceeded in the working sites.

An Attempt has been made in the present study to comment on the heat stress of the workplace in relation to the work rates adopted. The criteria of prescriptive zone (Lind, 1963a) are referred to as a thermal limit where the body attains a thermoregulatory steady state for a given rate of work. The proposed criterion for the upper limit prescriptive zone is ET of 27.4 °C at a work rate of 300 Kcal / hour. As per the observations in the present study except for the older drillers, all other groups exceed the recommended range of work rate. Therefore the upper limit of the prescriptive zone should be taken into account where high intensity physical activities are involved in order to reduce the heat stress (Lind, 1963b; Wyndham et al., 1967; Van Rensburg et al., 1991).

Actions to avert the risks of heat strain is particularly required where ET is over 27 °C (Hanson et al., 2000; Pickering and Tuck, 1997) since the increased physiological cost of work under such conditions of thermal load may lead to a higher level of effort which could impose deleterious impacts on the health of the workers (Kulagowska, 1997). Basically, the exacerbated environmental condition is likely to be a major contributor to the decreased physical capacity of the workers. This increases the workload irrespective of age and may affect some particular workers since reduction in the maximum aerobic capacity appears to have implications on performance requiring a high percentage of the aerobic capacity. For example, load-carrying ability reduces up to 11% in a hot environment (Snook and Ciriello, 1974) at WBGT of 27 °C. Moreover, such thermally stressful environments are also known to have a negative influence on workforce safety as well (Ramsey et al., 1983).

Comparative physiological strain with other mining tasks

Studies by other investigators (Brake and Bates 2001; Abt and Tranter 1999; Montoliu et al., 1995) indicate that mining jobs are a combination of short bursts of physical activities interspersed with a low demand of tasks. They are of the opinion that physiological strains in mining jobs are not very high on the basis of cardiac response based on the average heart rate recorded over shifts. Since the present studies are restricted to data within the spells mainly, cardiac responses show higher results. The energy cost of the same activities (like shovelling) in restricted working heights is very high (9.3 kcal/min) (Ayoub et al., 1981a) compared to the demand in non-low coal seam mines as evident in our study (5.47 kcal/min). The RCC for different activities is found to be higher in comparison with the results (32%) of Spanish underground miners (Palenciano et al., 1996) and this difference could have been due to the extension of their study extending to four or five shifts among miners doing different activities.

On the contrary, the present results are similar to the findings of underground coal miners (Kamon et al., 1983) while performing escape maneuver at 64% of the maximal aerobic capacity with a mean WHR of 143 beats/min. Physical demands placed on the mechanized and conventional underground gold miners (Van Rensburg et al., 1991) showing consistency in part with these results. Additionally, the mean metabolic cost of drillers is found to be higher than that of Chinese counterparts (Ho, 1984) (2.43 kcal/min), but lower than that of Bulgarian open pit drillers (Mincheva et al., 1995) (5.5 kcal/min).

Although the miners in the present study are acclimatized and their effective time per work shift is less than that for industrial work, they are exposed to undue physical strain and fatigue. This is indicated in particular by their recovery heart rate patterns caused by high workload in combination with thermal stress in accordance with earlier findings (Brouha 1960; Fuller and Smith 1982). Therefore, ergonomic interventions to reduce work load and to minimize thermal stress are of prime importance in the present scenario.

REFERENCES

Abt, G, and Tranter, M (1999) Assessment of heart rate and metabolic rate in an Australian underground coalmine. *Journal of Occupational and Health Safety - Australia & New Zeland*., **15**: 351-357.

American Conference of Governmental Industrial Hygienists (1981) Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes. ACGIH, Cincinnati, OH 45211-4438.

Armstrong, TJ, Chaffin, DB, Faulkner, JA, Herin, GD, and Smith, RG (1980) Static work elements and selected circulatory responses. *American Industrial Hygiene Association Journal*., **41**: 254-60.

Asmussen, E (1981) Similarities and dissimilarities between static and dynamic exercise. *Circulation Research*., **48** Suppl: 1: 3-10.

Åstrand, PO, and Rodhal, K (1986) Text book of work physiology. Mc Graw Hill, New York.

Ayoub, MM, Betha NJ, Bobo M, Burford CL, Caddel K, Intaranont K, Morrissey S, and Selan J (1981a) Mining in Low Coal. Volume 1: Biomechanics and Work Physiology. Final Report- U.S Bureau of Mines Contract No. HO3087022. Texas Tech University, Lubbock.

Bernard, TE and Kenney, WL (1994) Rationale for a personal monitor for heat strain. *Am. Ind. Hyg. Assoc.J*., **55**: 505-514.

Brake, DJ, and Bates, GP (2001) Fatigue in industrial workers under thermal stress on extended shift lengths. *Occp. Med.* (Society of Occ Med, UK), **51**: 7:456-463.

Brouha, L (1960) Evaluation of the physiological requirements of jobs. In: Physiology in Industry: Evaluation of Industrial stress by the physiological reaction of the workers, Pergamon press, Oxford: pp. 82-108.

Brouha, L (1967) Physiology in Industry, 2nd edition. Pergamon Press, Oxford.

Chamoux A, Borel, AM, and Catilina, P (1985) Pour la standardization d' unefrequence cardiaque de repos. *Arch. Mal. Prof*., **46**: 241-50.

Chengalur, SN, Rudgers, SH, and Bernard, TE (2004) Kodak's Ergonomic Design for People at Work, 2nd edition. John Wiley and Sons, Inc, Hobkon, New Jersey.

Fuller, FH, and Smith, PE (1982) Evaluation of heat stress in a hot workshop by Physiological Measurement. *Amer. Ind. Hyg. Assoc*., **42**: 32-37.

Grandjean, E (1988) Fitting the task to the man, 5th edition. Taylor and Francis, London.

Hanson, MA, Cowie, HA, George, JPK, Graham, MK, Graveling, RA, and Hutchison PA (2000) Physiological Monitoring of Heat Stress in UK Coal Mines. IOM Research Report TM00/05.

Ho, Z (1984) The energy expenditure of three categories of labourers in Southern China. In: Protein-energy-requirement studies in developing countries: results of international research. ed. By Rand WM, Uauy R, Scrimshaw NS, United Nations University Press, Tokyo. Retrieved October 10, 2006, from: ttp://www.unu.edu/Unupress/Unupbooks/80481e/80481E00.htm.

Kamon, E, Doyle, D, and Kovac, J (1983) The oxygen cost of an escape from an underground coal mine. *Am. Ind. Hyg Assoc. J.*, **44**: 552-555.

Kilbom, Å, and Persson, J (1981) Cardiovascular responses to combined dynamic and static exercise. *Circulation research*, Suppl **1**: 193-97.

Kulagowska, E (1997) Physical cost of working under conditions of thermal load. *Med Pr.*, **48**: 265-71.

Lind, AR (1963a) A physiological criterion for setting thermal environmental limits for everyday work. *J. Appl. Physiol.*, **18**: 51-56.

Lind, AR (1963b) Physiological effects of continuous or intermittent work in the heat. *J. Appl. Physiol.*, **18**: 57-60.

Martiz, JS, Morrison, JF, Peter, J, Strydom, NB, and Wyndham, CH (1961) A practical method of estimating an individual's maximal oxygen intake, *Ergonomics.*, **4**: 97-122.

Mincheva, L, Khadzhiolova, I, and Deianov, Kh (1995) An occupational physiology study at the Asarel Mining and Milling Works: The evaluation of the workload in the basic jobs in open-pit mines. *Probl Khig.*, **20**: 35-47.

Mookherjee, GC, and Sharma, RN (1953) A report on environmental 'comfort zone' in tropics. *Journal of Science and Industrial Research.*, **6**: 283-87.

Montoliu, MA, Gonzalez, V, Palenciano, L (1995) Cardiac frequency throughout a working shift in coal miners. *Ergonomics*, **38**: 6.1250-63.

Neilsen, R, and Meyer, JP (1987) Evaluation of metabolism from heart rate in industrial work. *Ergonomics*, **30**: 565-572.

Palenciano, L, Gonzalez, V, Santullano, LA, Montoliu, MA (1996) Cardiac frequency in miners recorded during four to five work shifts. *Eur. J. Appl. Physiol. Occup. Physiol.*, **73**: 369-75.

Pickering, AJ, Tuck, MA (1997) Heat: sources, evaluation, determination of heat stress, and heat stress treatment. *Mining Technology*, **79**: 147-156.

Ramanathan, NL, Dutta, SR, Roy, BN, Chatterjee, A, and Mullick, LN (1967) Energy cost of different muscular tests performed by Indian subjects. *Indian Journal of Occupational Health*, **10**: 253-61.

Ramsey, JD, Burford, CL, Beshir MY, and Jensen, RC (1983) Effects of workplace thermal conditions on Safe Work Behaviour. *Journal of safety Research*, **14**: 3.

Samanta, A (1984). Recovery heart rate as a tool for the assessment of work stress. *Indian Journal of Physiology and Allied Sciences*, **38**: 123-28.

Sanchez, J, Monod, H, and Chabaud, F (1979) Effects of dynamic, static and combined work on heart rate and oxygen consumption. *Ergonomics*, **22**: 935-943.

Snook, SH, and Ciriello, VM (1974) The effects of heat stress on manual handling tasks. *Amer. Industr. Hyg. Ass. J.*, **35**: 681-685.

Van Rensburg, JP, Marx, HE, Van Der Walt, WH, Schutte, PC, and Kielblock, AJ, (1991) Estimated metabolic rates associated with underground mining tasks: conventional and mechanised mining operations. COMRO reference report No. 11/91. Project no.GE1B.

WHO (1969) Health factors in working under conditions of heat stress. *WHO Tech. Rep. Series*. **412**, Geneva.

Wyndham, CH, Strydom, NB, Williams, CG, and Heyns A (1967) An examination of certain individual factors affecting the Heat Tolerance of Mine Workers. *J. So. Afr. Incst. Mining and Metallurgy*, pp. 79-91.