

Cardiac workload of dressers in underground manual coal mines

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Abstract

Introduction: Occupational disorders invite absenteeism amongst the miners. Though rapid technological advancement has happened, yet assessment of cardiac workload was largely ignored in underground coal mines in India.

Methods: Physiological stress was evaluated in terms of working heart rate, net cardiac cost and relative cardiac cost. Heart rate was measured during their course of work by heart rate monitor at the coal face. Recovery heart rates and environmental heat load were also assessed.

Results: Heart rate was found to be 117 and 122 beats/min respectively in first and second spell. NCC (49.7 and 54.8 beats /min) and RCC (47% and 52%) exhibit significant variations between spells, whereas rate of recovery had been very poor amongst the workers who regularly exceeded recommended levels of cardiac strain indices. The nature of work depicted it as a heavy job although recovery trend categorizes it heavier than that. ET and WBGT were above the recommended limits as per the guidelines of WHO and ACGIH.

Conclusions: High physiological demand of the job with towering heat stress was found to hinder the recovery process and may cause deleterious impacts on the workers. Ergonomic interventions were highly felt towards job organization and up gradation of environmental conditions.

Keywords: Coalmines, dressers, workload

Introduction

Hostile and dangerous environment is ineluctable in underground mines and hard manual labours are still very much predominant in Indian coal mines. In addition, miners have to encroach excessive heat, high humidity, vibration, dust etc which makes them prone to a variety of associated health risks. All of these are likely to pose occupational disorders which invites absenteeism. Work physiological studies on coal miners, especially on dressers in India is very scanty therefore the present study was conducted to describe the work methods as well as the cardiac strain experienced by them during the actual situation of work.

Methods

From three different underground mines of West Bengal,

India, a total of eight dressers who were regular, relatively healthy, had a minimum work experience of five years and were accustomed to work in heat were selected out of 13. The subjects investigated were less in number since the workers deployed in this category of work had been least in manual coal mines in India. All the subjects agreed to render themselves voluntarily in accordance with the design of the experiment. Extensive interactions were carried out at regular intervals for a period of one month where they were explained about the objective of the study along with their extent of involvement.

Age (years), height (cm), weights (kg), body surface area and body mass index were the principal physical characteristics considered.^{1,2} Resting heart rate (RHR) was measured by allowing the subjects to take rest in a comfortable rest area (Dry bulb temp 21.6 ± 3.1 , Wet Bulb

temp 17.6 ± 2.9 and Relative humidity $67 \pm 8\%$) for at least 30 minutes at the surface. The minimum heart rate obtained during this period was considered as the resting heart rate. Maximum heart rate (HR_{max}) was estimated from age following the equation of American Heart Association.³ Heart rate reserve (HRR) was calculated as the difference between the maximal and resting heart rate of the subjects

Working heart rate (WHR) was measured by using the portable telemetric heart rate monitor - Sports Tester PE 3000 (Polar Electro, Finland) at a regular interval of 1 min during work. Recovery heart rate was measured in sitting posture at the end of work shift. This was obtained by counting the pulse during the last 30 seconds of each minute in the first, second and third minute of the recovery period, i.e. from 30 sec to 1 minute after work stops, from $1\frac{1}{2}$ -2 minute and again from $2\frac{1}{2}$ -3 minute. These three recovery heart rates were designated as P1 (1st recovery heart rate), P2 (2nd recovery heart rate) and P3 (3rd recovery heart rate).

Net cardiac cost (NCC) was obtained as the difference between WHR and resting heart rate and expressed in beats/min. Relative cardiac cost (RCC) was found by expressing the NCC as the percentage of the heart rate reserve (HRR) of the subjects by using the following formula. $RCC = NCC / HRR * 100$.

To assess the thermal conditions, Wet Bulb Globe Temperature (WBGT) was worked out as an index of heat stress along with the effective temperature (ET). All the environmental readings were taken at regular intervals throughout the shift to get an average picture of the heat load throughout the shift. It was important to mention that each miner was studied on a single day while he was regularly involved in his assigned task and no instructions were given to control the work pace and methods. Studies were conducted during general shift between 08.00 to 16.00 hrs.

Descriptive statistics comprising mean, standard deviation and range were worked out for each set of data with standard SPSS version 10. Difference between means were tested by two-tailed t test with level of significance, $\alpha = 0.05$.

Results

Physical and physiological characteristics

Physical and physiological characteristics of the subjects exhibited that the mean age of dressers had been nearly 47 ± 7.2 years with a body weight ranging from 48 to 64.5 kg (Table 1). The BMI of the workers (21 ± 2.7) showed that the subjects were typical of the average populations from eastern India.⁴ The average resting heart rate was found to

be 67 beats / min and heart rate reserve depicts a range from 90 to 123 beats / min.

Table 1: Physical and physiological characteristics of Dressers

Parameters	(n = 8)
Age (year)	46.8 ± 7.2 (35-55)
Height (cm)	161.4 ± 5.9 (152-170)
Weight (kg)	56.1 ± 6.6 (48-64.5)
Body Mass index (kg/ m ²)	21.7 ± 2.7 (18.5-26.2)
Body Surface Area (m ²)	1.58 ± 0.1 (1.46-1.71)
Resting heart rate (beats / min)	67 ± 5.5 (60-76)
Maximum heart rate (beats / min)	173.3 ± 7.2 (165-185)
Heart rate reserve (beats / min)	106.3 ± 12.4 (90-123)

Description of activities

The workers performed two spells of work per shift and two to three cycles of drilling per spell (Table 2). Maximum time was spent in dressing roofs and side walls of a coal face (89%) and walking with dressing rod contributed little (11%) in a single spell. Rest time or pause time observed between spells were due to some mandatory mining activities like “blasting” and “removal of fumes” etc and “loading”, which were performed by other group of workers. Some jobs of stochastic nature (e.g. updation of ventilation which got deranged by blasting violence, derailment of tubs etc) also contribute to this pause time.

Beside the time spent in two spells of work including the pause time in between, a major portion of total shift time was spent in other activities like giving attendance and collecting equipments at the beginning of the work shift prior to their entry into the mine. Time was also spent for walking to and fro journeys to the actual site of coal extraction. It was seen through repeated studies that on an average 150 minutes were spent in these task

Table 2: Description of dressing tasks in underground coal mines

Total work duration /shift [Minutes]	107 ± 6.57 (98-120)
Total Spell duration /shift [Minutes]	53.4 ± 5.28 (46-63)
Total cycle duration /spell [Minutes]	22.2 ± 6.33 (9-35)
No. of Spells / shift	2
No. of cycles / spell	2.4 ± 0.51 (2-3)
% Time spent in a spell	Walking with dressing rod - 10.7 Dressing coal roof and walls - 89.3

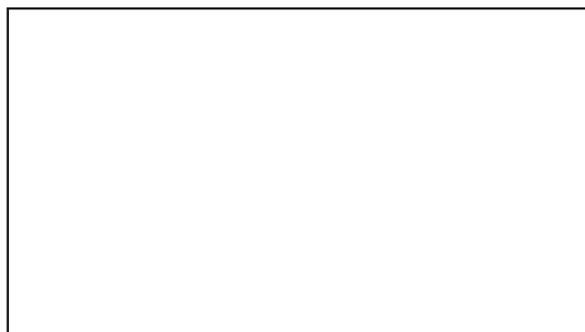
Physiological strain of the dressers

Mean working heart rate in second spell (122 beats/min) has significantly differed than that of the first spell (117

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beats/min). NCC and RCC have also showed significant increased responses in second spell of work except Brouha's index.

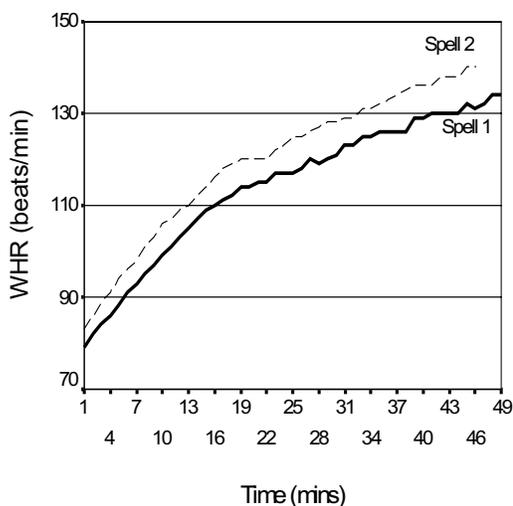
Table 3: Physical workload in two spells amongst Dressers



For a more comprehensive analysis of the physical strain encountered by the dressers in two spells of work, the percentage of dressers exceeding recommended limits of different cardiac strain indices is assessed. The recommended ranges for WHR, limit for continuous work (LCW), RCC and NCC, Brouha's index were exceeded by all the miners in both spells of work (Table 4). However the percentage of the workers exceeding the limits for 50% RCC

Fig. 1: Distribution of WHR of dressers in Spell 1 and Spell2

The initial WHR of the dressers in both spells of work is within 80 to 90 beats / min and it shows a rising trend in general in both the spells. The period of tachycardia is considered as WHR > 100 beats / min and it reaches within initial stages (13th to 16th minutes) of the of respective work spells. A steep rise is observed at first period (from 1st to 22nd minute) when the heart rate rise from the level of 80- 90 beats/min to 120 beats / min. After this a comparatively slower rate of increment of heart rate is observed throughout the rest of the work period. The maximum heart rate attained



significantly found that noticeably higher than the 50% RCC

the recommended limits of physical strain

References	(n = 8)			
	Sp-1	Sp-2		
100 beats/min	100	100		
105 beats/min	100	100		
110 beats/min	100	100		
115 beats/min	37.5	62.5		
120 beats/min	100	100		
Brouha's Index	-10 beats/min	Brouha (1960)	100	100

The recordings of WHR per minute basis for the dressers in two different spells of work was assessed. As the working time for individual subject varies in different spells of work, the graph is constructed by plotting the mean heart rate / minute against the minimum working period of the workers which was 46 minutes and 49 minutes respectively in spell 1 and spell 2 (Fig. 1).

by the workers in the final minute of work was 134 beats/min and 140 beats/min in spell 1 and spell 2, respectively.

Times spent at different RCC levels in two different spells by the dressers was analysed. The percentage of total spell time is plotted against RCC levels divided at regular intervals of 10 %. These figures provide a more proper clarification

of physical strain involved in the task. In spell 1 the majority of the working time (25.9%) is spent at a strain level of 51%-60% of RCC (Fig 2). In contrast to that the subjects in their second spell spend bulk of the work time (26%) at a strain level of 61%-70% of RCC. The total spell time when the physical strain remains above 50% of RCC level has been found to be 49% and 61% in spell 1 and spell 2, respectively. It is also interesting to note that only in second spell workers has spent some of their working time at 81-90% of RCC level too.

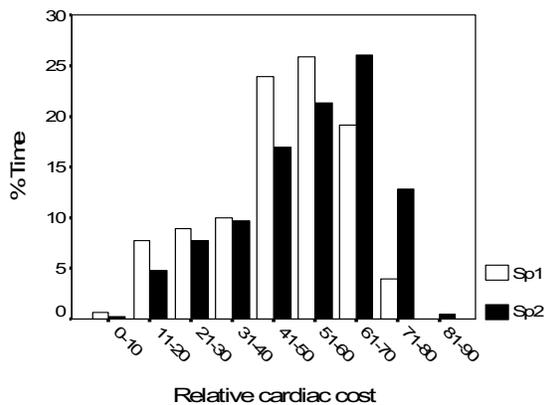


Fig. 2: Percent of time spent by dressers in Spell 1 and Spell 2

The first minute of recovery for all the workers in first and second spell is 119 and 122 beats/min respectively (Fig. 3). In both the spells the rate of recovery is found to be very poor and this is well supported by the result since the Brouha's index fails to show any statistical significance.

The close proximity of dry bulb ($31.5 \pm 0.96^\circ\text{C}$) and wet bulb temperatures ($29.9 \pm 0.94^\circ\text{C}$) at the worksites, reflecting

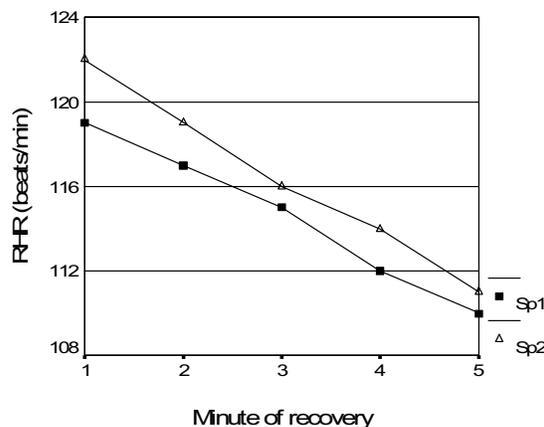


Fig. 3: Recovery trends of dressers after first and second spell of work

high humidity (88%) and conditions in which air velocity at working faces exhibits stagnancy (0.21 to 0.71 m/sec). The ET in different workplaces varied from 26.5-31.5 °C with a mean temperature of 29.5 °C (± 0.87) (Table 5). The mean natural wet bulb temperature was observed to be $30.5 \pm 1.02^\circ\text{C}$ with wet bulb globe temperature values at the different working coalfaces ranging from 27.5-32.5 °C.

Table 5: Mean environmental 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	± 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)

Discussion

The height and weight of the subjects are quite similar to the average populations from eastern India and from BMI values it appears that the subjects were not energy deficient.⁴

The work load entailed by the dressers in the shift was evaluated in accordance with the heaviness scales based on different parameters like working heart rate, recovery heart rate and NCC.⁵⁻⁷ Based on working heart rate and NCC criteria the workload in both spells of work appeared to be “heavy” in nature. However, in accordance with the recovery heart rate criteria applicable for Indian standard the workload appeared to be “very heavy” to “extremely heavy” in nature.

The dressing activity as observed in the work place involved a significant amount of static muscular effort since they have to hold the dressing rod maximally above and at the shoulder level to dress coal face; more often than not beside dressing the blasted area adequate amount of pushing force was also required to break the large layers of coal from the roof side as well as the walls. Furthermore, at times the work was done standing above the heaped coal where the workers experienced a great deal of difficulty in engaging their foot due to the chances of slippage and thereby facing a challenge of postural disequilibria. This pattern of work

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where preponderance of static load was quite clear represented a non-steady work phases of escalating heart rates in both the spells and might have led to a very poor recovery of the workers after first spell of work as evident from the 'no-recovery' pattern for all the workers.^{8,9}

It is quite obvious that the magnitude of physiological response will vary in conjunction with the task performed. Present study depicts similar results like the earlier observations where short burst of physical activity were riveted with low demand of tasks since a part of their working time dressers were involved in low demanding non specific activities performed in the pause time placed between arduous work spells.^{10,11} It is useful to mention that the rest pause in between spells was merely non-volitional (ascribed to the time spent for blasting, loading of coal, updation of ventilation deranged by blasting violence, etc) and was a-periodically placed. So to have a comprehensive recovery they barely enjoy a complete rest period in between spells. These could have been the reasons towards formulating a cumulative stress amongst the workers in the second spell where the physiological responses were found to be significantly higher as compared to the 1st spell. Moreover an elevation of initial heart rate at the beginning of second spell was a very good indicative of increased stress too. Basically recovery from such an increased strain was so poor that no significant difference was observed when the PDI's were considered after two spell of work.

It was also seen that most of the workers crossed their recommended levels of cardiac strain indices and it bears the fact that the activity placed a serious cardiovascular load on miners during working periods. The mean recovery heart rate pattern (figure 4) also exposed dissatisfied recovery for all the workers. The sustained and slow recovery after each spell of work substantiates to the insufficient capacity of the workers and their overexertion on the cardiovascular system¹²⁻¹³ and this could only worse older subjects in present scenario. The trend of recovery heart rate at the end of 1st minute also indicated that the job would cause excessive cardiovascular strain if continued for the subjects.¹⁴

Heart rates as found in the present study showed higher values than that of Bulgarian open cast blasters, diggers and drillers (100-110 beats/ min)¹⁵, Spanish underground coal face miners (103-106.5 beats/min)¹⁶, Australian miners (101-103 beats/min)¹⁰ and Indian underground coal mine trammers (102-105 beats/min)¹⁷ but lower from native underground coal mine carriers (124-133 beats/min)¹⁸ and shovellers (130-138 beats/min)¹⁹ and nearly comparable with

the drillers (117-132 beats/min).²⁰ The higher level of RCC in dressers (44%-58%) can be explained from their significantly lower heart rate reserve level in relation to younger workers when compared with the Spanish underground miners (32%)¹⁶ but lower from their native carrier (50%-66%) and shoveller counterparts (54% - 65%).^{18,19} Interestingly the RCC values are almost within the same range when compared with native coal mine drillers (44% -48%) of similar age.²⁰ Disagreement with the overseas literatures might be due to the continuous observations of heart rates through out the work period extending for four to five work shifts along with recording of heart rates in the rest periods as well. The workload in the present findings was found to be higher in contrast to other non - mining tasks like Indian agriculture and inland fishing job^{21, 22, 23}, British silviculture work²⁴, Steel work²⁵, and car assembly work as well.²⁶

The existing ET in the worksites remained not only above the recommended value (28.5 °C) for heavy type of work as suggested by WHO but remained within hot zone according to the classification of environmental conditions for Indians.^{27,28} The mean WBGT also reflected that permissible limits for continuous work was well encroached as proposed by ACGIH.²⁹ The heavy strain of the job associated with inadequate recovery of the workers can also be imparted to the prevailing thermal stress.^{9,30} Since ET remained over 27 °C actions should be taken to ward off the risks of heat strain^{31, 32} as a high level of physical effort could impose deleterious impact on the miners.³³

Conclusions

It is found that though the average duration of work in underground dressing job is far less than usual industrial sectors yet it can not be undermined. The existing work pattern showed cardiovascular stress with poor recovery of the Indian miners which resulted typically from the involvement of a compromise between one's capabilities and his job requirement irrespective of ages, which may in some circumstances create vital and adverse implications on worker's health issues.

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Conflict of Interest: No

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