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A Study of the Workload of Underground Trammers in the Ranigang Coal Field Area of West Bengal, India

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Thirty healthy trammers were examined in underground haulage mines during their normal activity. Physiological strain in terms of heart rate (HR) varied between 101.6 and 104.7 beats/min with mean net cardiac cost of 33.06 and 34.06 beats/min for younger and older groups respectively. The average relative cardiac cost was lower for younger subjects than for older ones. Oxygen consumption (V_{O2}) was measured with an Oxylog-II machine (UK); subsequently values were estimated. Maximum aerobic capacity was estimated with an indirect method following a standard step test protocol. The responses revealed that the average V_{O2} during the activity was 0.75 and 0.8 L/min, which corresponded to energy expenditure (EE) of 3.8 and 3.97 Kcal/min for younger and older subjects respectively. The workload in terms of HR and EE was moderate, whereas the aerobic strain experienced by aged workers was above the acceptable level.

physiological workload   underground trammer   coal mine   aerobic capacity

1. INTRODUCTION

Although the advent of technology in mining fields has to a certain degree reduced the overall physical stress compared to the pre-mechanization stage, many unique physical and environmental demands still exist in underground mines [1]. In India the conditions have not improved and human drudgery still prevails. It is a universal truth that pushing is preferable to pulling. However both activities have the potential to be stressful for different systems in our body especially if the job is being done in a hostile environment like underground mines. Basically it is harder to start a pushing task (initial forces) than to keep the body in motion (sustaining forces). Physiological responses to such activities mainly involve the musculoskeletal and cardiovascular systems. Since the environment is unfriendly, it hinders excess heat elimination by the circulatory system, making the heart work

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harder to transport energy to the muscles for a successful completion of the job. An increase in age concurrently deteriorates functional capacity [2], which is more evident in miners than in other workers [3]. This is one of the most important reasons—in association with cumulative exposure to adverse working conditions—for leaving the industry [4]. The consequences in coal miners' later life are well documented [5, 6]. Early disorders due to environmental stress combined with other factors cannot not be ignored, either, if serious impairment of miners' health is to be prevented [7]. Miners' hydration is important in underground hot environments, since dehydration reduces the physical capacity to work efficiently [8]. Involuntary dehydration does not occur in well-informed miners [9]. As Indian miners are very poorly educated and consequently too ignorant about their health status to cope with situations at work, the need to address the degree of stress on the cardiovascular system and to measure its functional capability has been felt.

Recent records reveal that in India very little work has been done on opencast miners while underground miners have been totally ignored. This study is undoubtedly exploratory in nature in the field of the application of ergonomics in mining in India. Therefore, this paper focuses solely on face trammers; its aim is to obtain a picture of the degree of physiological strain in the actual work environment in association with a variation of responses with respect to age.

2. METHODS

2.1. Subjects

Thirty underground face trammers were chosen from the Raniganj coal belt of Eastern Coalfields, West Bengal, India. Trammers, who though few in number constitute the core sector, are responsible for lifting coal to the surface. During the study we observed that the age range of the trammers who were specifically placed at the coal front was 30–50 years. The exclusion criteria of the subjects included any symptoms or clinical signs of cardiovascular, musculoskeletal or neurological disorders that could interfere with the interpretation of the experiment. While selecting the subjects special care was taken to establish homogenous groups. Before the study, extensive interviews were carried out with the trammers, during which they were motivated to co-operate as required by the design of the study. Their ability to getting used to the bord and pillar method of working was also taken into account to avoid unexplained variations in the test results. The physical characteristics of the subjects who were eventually selected are given in Table 1.

2.2. Task

The major share of underground coal production in India comes from haulage-based mines, where trammers play a key role. The turn-around of

TABLE 1. Physical Characteristics of the Subjects, *M* ± *SD* (range)

Subjects	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	RHR (beats/min)	Exposure (years)
31–40 years	36.00 ± 3.05	164.40 ± 5.73	55.10 ± 5.44	20.40 ± 1.58	68.00 ± 3.96	15.70 ± 3.49
(*n* =15)	(31–40)	(155–172)	(48–68)	(24.2–17.2)	(62–76)	(9–21)
41–50 years	47.00 ± 2.29	162.00 ± 4.86	52.90 ± 6.11	20.10 ± 1.68	70.00 ± 2.77	29.00 ± 3.39
(*n* =15)	(43–50)	(156–169.5)	(44.5–64)	(17.7–23.0)	(66–74)	(23–35)

Notes. BMI—body mass index, RHR—resting heart rate.

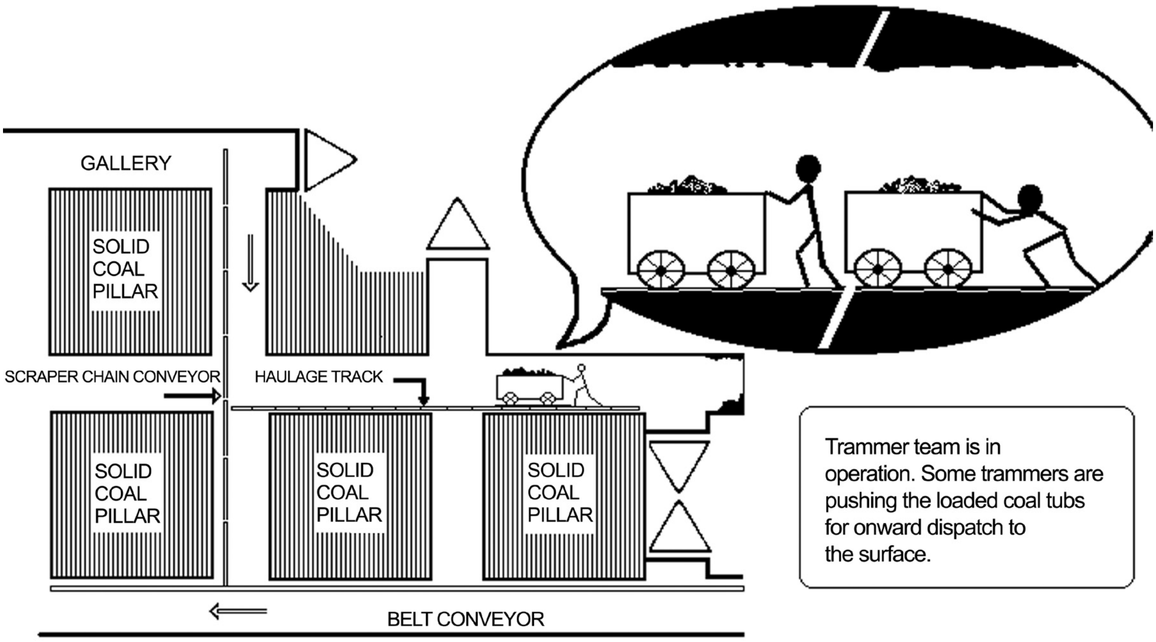

Figure 1. Bord and pillar working layout.

coal tubs during the productive hours depends on the trammers' skill. They work in a team to push empty one-tonne tubs to the coalface for loaders to fill, and then they move the loaded tubs to be dispatched to the surface. They couple and decouple them for onward transmission to the customer (Figure 1).

2.3. Parameters

Resting heart rate (RHR) was measured by noting down the minimum value after allowing the subject to stay in a comfortable, reclining position for at least 30 min prior to his day's work at the surface. The working heart rate (WHR) was measured by placing a stethoscope at the apex of the heart; time was measured with a stopwatch for 10 beats. It was then expressed in beats per minute [10]. WHR was measured at every 4th min of the interval throughout the working phase. The working oxygen consumption (WV_{O2}) was measured with an Oxylog-2 machine (UK) [11] by fitting a mask on the subject's face and placing a small machine on his back. Direct recording of WV_{O2} was done continuously for 10–15 min of work, 5–10 min after the beginning of the activity. The data shown on a liquid crystal display was noted down.

2.4. Maximum Cardiorespiratory Performance

The maximum aerobic capacity (V_{O2max}) of the worker was determined indirectly through a step test procedure. The method followed in this study was identical to that of Martiz, Morrison, Peter, et al. [12]. During this study each subject was asked to step on and off a 30-cm high step at a rate of 15 times/min for 8 min and a 40-cm high one at a rate of 25 times/min. The rhythm was maintained with a metronome. Heart rate (HR) and oxygen consumption (V_{O2}) were measured (for 10 beats) with a stethoscope and Oxylog-2 respectively. Both parameters were plotted for each subject on a graph and straight lines were drawn through three points with the least squares' method. This was then extrapolated to maximum HR of an individual as proposed by the American Heart Association [13].

The relative cost of work was determined in terms of relative aerobic strain (RAS) by expressing the average V_{O2} as a percentage of maximal aerobic capacity (%V_{O2max}) of the subjects. Relative cardiac cost (RCC) was obtained by expressing WHR as a percentage of heart rate reserve (%HRR) of the subjects. Net cardiac cost (NCC) was obtained as the difference between WHR and RHR and expressed in beats per minute.

Dry bulb temperature (DB), wet bulb temperature (WB), natural wet bulb temperature (NWB) and air velocity were recorded; subsequently effective temperature (ET) and wet bulb globe temperature (WBGT) values were worked out as an index to give a picture of the average ambient conditions in which the miners were working.

2.5. Statistical Analysis

A t test for independent variables was done to determine whether there were any significant differences between the test variables within the selected working groups. The computed t was next compared with critical t values to find the level of significance ($p < .05$, .01 and .001).

3. RESULTS

Table 2 depicts the direct and derived physiological responses in the 31–40 and 41–50 age groups of trammers during their underground activities. The mean RCC values were found to be in the same range when compared with the result for Spanish underground miners (32%) [14]. None of the younger subjects crossed the recommended limit of RCC, whereas all the aged counterparts did (30% of HRR). It is worth mentioning that all the important criteria for evaluating strenuousness, except for EE and NCC, showed significant differences between the two groups, which confirmed that the older group had experienced greater strain than their younger counterparts.

To examine the physical strain throughout the shift, WV_{O2} of two subjects from the two groups was continuously monitored at every 4th min of the interval; their HR was recorded too (Figures 2 and 3). It was clear that as time progressed the trammers, irrespective of their age, showed increased physiological responses indicating the cumulative effect of workload. Moreover, the varying job demands throughout the shift also became evident. Mean WV_{O2} was found to be 0.76 ± 0.12 L/min for the younger subject and 0.82 ± 0.11 L/min for the older person. The values were quite similar to mean WV_{O2} values of the respective age groups. The overall mean WHR (102 and 106 beats/min) was found to be 50 and 47% higher than mean RHR, although occasional peaks with a 73 and 69% increment were also observed for the younger and older subject respectively.

Environmental conditions are summarized in Table 3.

TABLE 2. Direct and Derived Physiological Variables in the Subjects, *M* ± *SD* (range), and Their Statistical Analysis

	Subjects		
Variables	31–40 years (n = 15)	41–50 years (n = 15)	p-Value
WHR (beats/min)	101.6 ± 3.33 (96–108)	104.73 ± 2.68 (99–109)	<.010
WV_{O2} (L/min)	0.75 ± 0.05 (0.68–0.85)	0.8 ± 0.03 (0.72–0.86)	<.010
V_{O2max} (L/min)	2.1 ± 0.34 (1.8–2.7)	1.89 ± 0.19 (1.7–2.4)	<.050
V_{O2max} (ml/min/kg)	38.13 ± 2.4 (33.0–41.6)	36.04 ± 2.27 (30.7–38.9)	<.050
RAS (%)	36.2 ± 4.75 (31–44)	42.5 ± 4.47 (33–48.5)	<.001
EE (kcal/min)	3.8 ± 0.35 (3.4–4.3)	3.9 ± 0.15 (3.6–4.3)	*ns*
NCC (beats/min)	33.06 ± 4.9 (25–43)	34.6 ± 3.99 (25–41)	*ns*
RCC (%)	28.6 ± 3.23 (23.1–34.4)	33.8 ± 3.6 (24.5–40.2)	<.001

Notes. WHR—working heart rate, WV_{O2}—working oxygen consumption, V_{O2max}—maximal aerobic capacity, RAS—relative aerobic strain, EE—energy expenditure, NCC—net cardiac cost, RCC—relative cardiac cost.

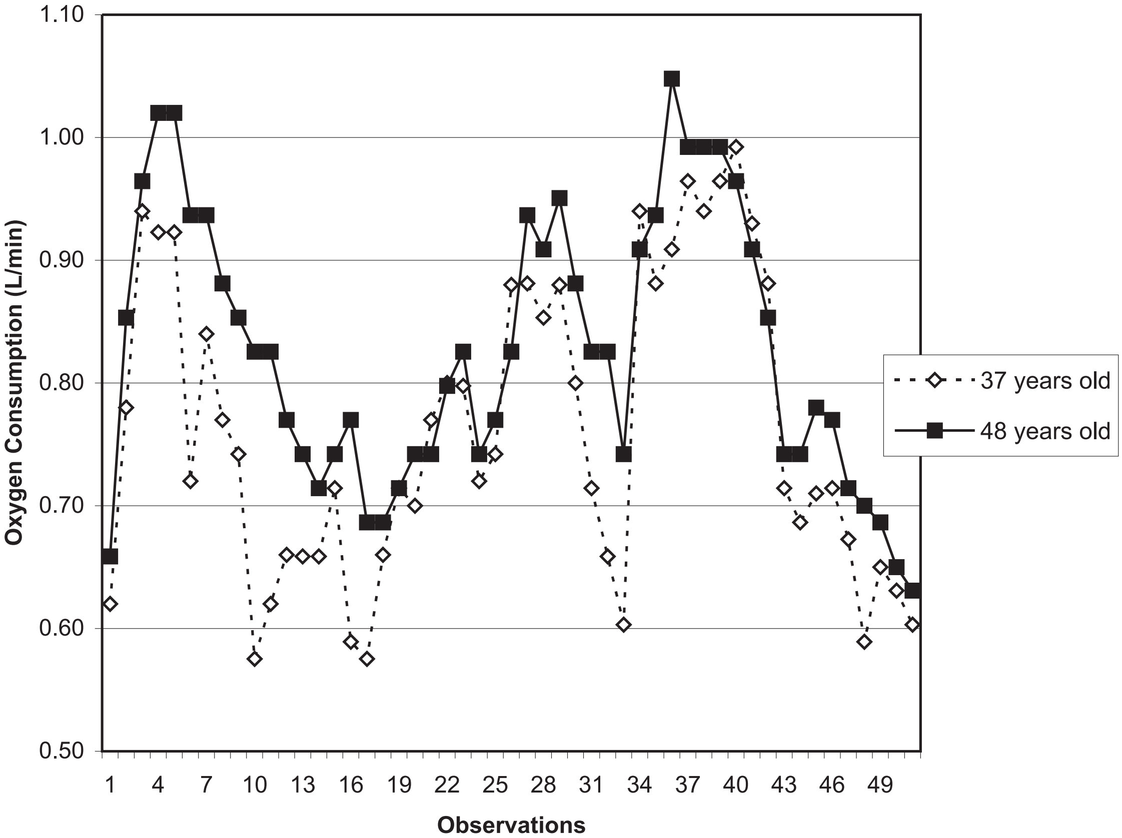

Figure 2. Variation of working oxygen consumption (WV_{O2}) of two face trammers throughout a shift.

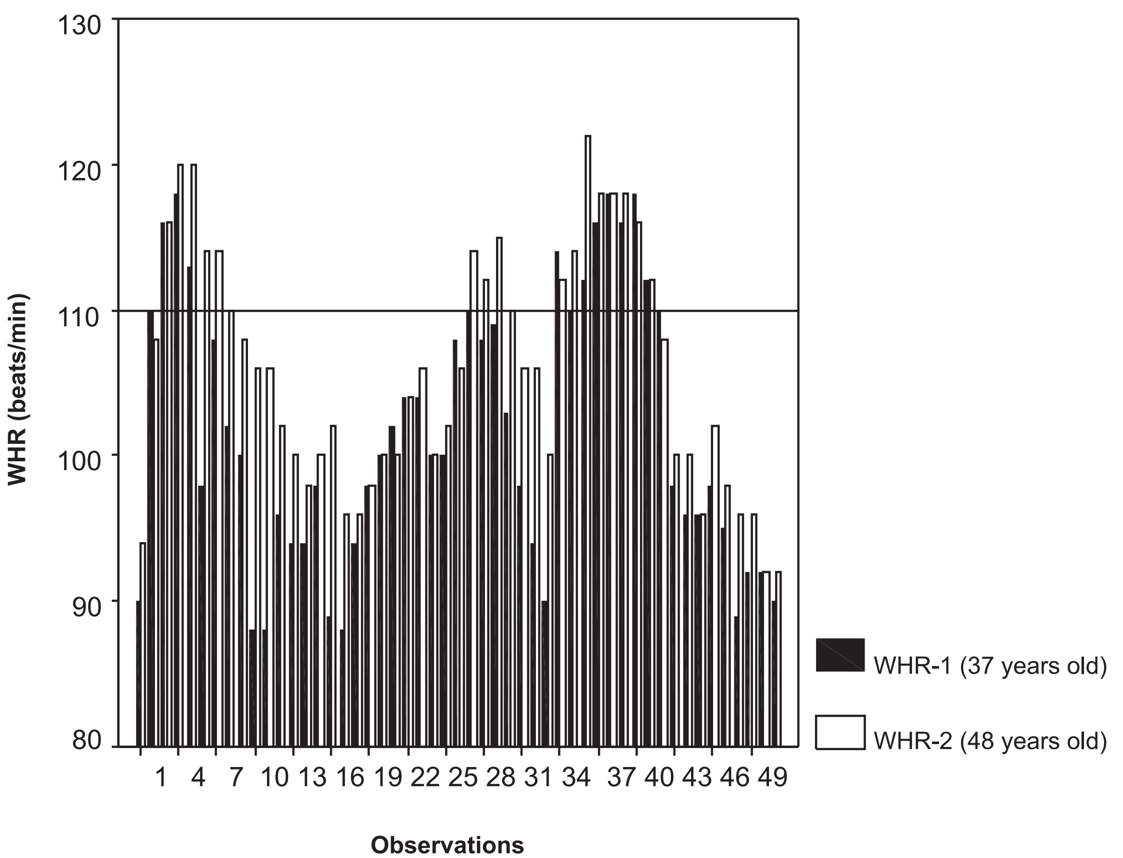

Figure 3. Variation of working heart rate (WHR) of two face trammers throughout a shift. *Notes.* WHR—working heart rate.

TABLE 3. Environmental Conditions in Underground Coalfaces

Variables	*M*	*SD*	Range
NWB (°C)	31.01	0.72	29.50–32.50
DB (°C)	32.03	0.81	30.50–33.50
WB (°C)	30.50	0.64	29.50–31.50
Humidity (%)	89.46	1.55	85.00–93.00
Air velocity (m/s)	0.34	0.07	0.22–0.50
ET (°C)	30.10	0.64	29.00–31.50
WBGT (°C)	31.32	0.73	29.95–32.80

Notes. NWB—natural wet bulb temperature, DB—dry bulb temperature, WB—wet bulb temperature, ET—effective temperature, WBGT—wet bulb globe temperature.

4. DISCUSSION

4.1. Physical Strain of the Tramming Job

HR is the principal parameter monitored in the field. It is not only used in evaluating circulatory strain imposed by the workload of varying intensity [15] with minimal interference of the subject's performance ability but also provides an integrated response to energy requirement and thermal and postural demand [16]. Measuring HR is also less inconvenient in field studies than measuring V_{O2} [17]. As HR response to the same workload is sensitive to many inter- and intra-individual influences, the derived indices were chosen to take into account inter-individual differences [18]. Moreover, NCC being related to RHR is used to evaluate workload strictly associated with the job; while RCC, linked to the subjects' resting and maximal HR, expresses individual circulatory strain better [10, 19]. In this study WV_{O2} was calculated depending on the direct measurement of V_{O2} and concomitant HR on the basis of a general linear relationship existing between them since such estimation is reliable for all practical purposes of field investigation and is quite sensitive, with a variation of ±15% [10]. These estimated values were used to assess RAS and were cross-examined against certain recommended criteria of physical strain that allowed a better evaluation of strain in relation to different parameters.

The physical strain of the present underground tramming job in terms of HR could be compared with underground coalface miners of poorly mechanized mines in Austria [20] and metalliferous miners in Australia [21]. Exertion was also reported for drillers and diggers of Bulgarian opencast mines [22]. RAS of the younger group was comparable with different types of coastal fishing activities, viz., hand line, long line and net fishing [23], while the mean exertion of the older group could be compared with opencast metalliferous Indian miners [24] since both utilized more than 33% of their maximum capacity. Regarding EE the values were found to be higher than for drillers but well below those for ore porters in underground Chinese mines [25].

4.2. Analysis of the Activities

The average total duration of an underground tramming job was 202 min (190–215 ± 7.7 min) during which face trammers did different sorts of activities, including pushing and setting loaded and unloaded coal tubs in the coalfaces, adjusting the wheels by using wooden sticks called pals and using lashing chains to couple the loaded tubs before hauling the set of tubs. In order to dispatch tubs loaded with coal, wires are used for signalling. Observations of these tasks indicated the presence of static and dynamic load where the former involved bending postures maximally during the time of wheel adjustment either at the time of pushing of loaded tubs from a "dip face" against the gradient or at the sites where there was a curved rail track. These activities were often seen together with low demand activities for a comparatively brief period of time. Figure 3 depicts the typical intermittent nature of underground mining tasks with peaks of high-intensity activities as evident in other studies [26]. It was responsible for bringing down the workers' average HR throughout the activity.

4.3. Heaviness of the Job and Cardiovascular Fitness of the Trammer

The physiological gradations of different activities proposed by different researchers are either based on the principal parameters like HR during work

[10], EE [27] or on some derived parameters like NCC [28]. On the basis of such scales of heaviness it appeared that underground tramming was considered a moderate-intensity job.

It was also found that the group with low cardiovascular fitness (i.e., the older group) had much greater oxygen demands than their relatively fit counterparts for a given type of task and this might increase the RAS for the older group, which is reflected in Figure 4 where the degree of RAS in the two workers was different and undoubtedly greater stress was imposed on the older worker and remained higher throughout the period of work. This may be partly due to adverse environmental conditions which may have posed extra cardiorespiratory strain in addition to the factor of age, which limits physical capacity as found in this study too (Table 2). It was revealed that the average V_{O2max} of the younger and older groups was 38.13 ± 2.4 and 36.04 ± 2.3 ml/kg/min, which was lower than that for Indian industrial workers (46.6 ml/kg/min) [29]. The value was found to be lower than that for Australian (39.1 ml/kg/min) and Spanish (43.2 ml/kg/min) miners too [21, 30].

4.4. Rationalization of the Task

The knowledge of acceptable workload is of huge importance in the context of rationalizing a task; the workload of a particular task is often so heavy that it imposes undue physiological strain resulting in fatigue and gradual decrement of work capacity. For a relatively homogeneous group of individuals, the average values of RAS may be considered as a reasonable upper limit for continuous work stretching over several hours, since a number of earlier studies emphasized this parameter in establishing an optimal work limit. This is equally applicable for Indian workers. It was found that irrespective of their usual pace of work and with the usual length of work shift the younger and older groups utilized an average of 36.2 and 45.2% of their V_{O2max} respectively, which is lower for the younger group, but not for their aged counterparts, recommended for

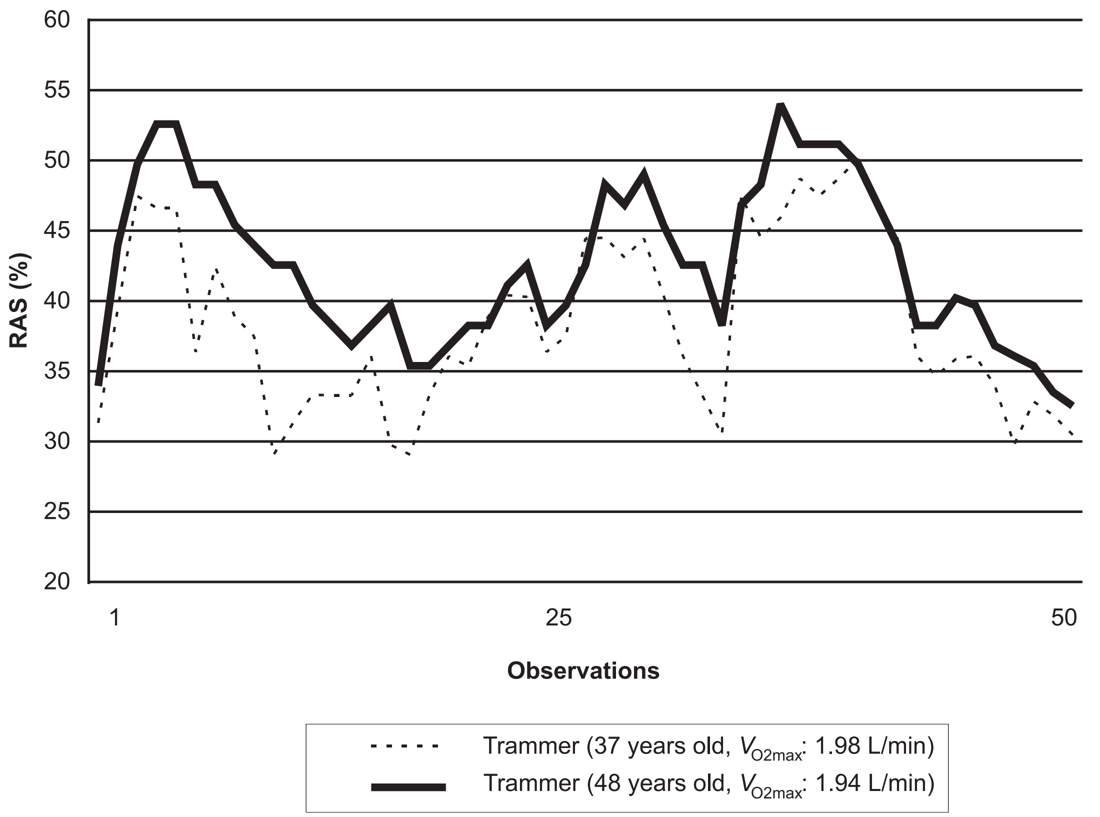

Figure 4. Variation of relative aerobic strain (RAS) of two face trammers throughout a shift.

Indians [31], than the acceptable level of 41% for a mixed, dynamic and static, type of work [32].

4.5. Environmental Conditions

Environmental conditions at the working coalfaces are shown in Table 3. The very sluggish air movement in the coalfaces reflected the high humidity during work. The WBGT value was found to be 31.3 °C, which was far higher than the threshold limit value of the American Conference of Governmental Industrial Hygienists (ACGIH) [33] recommended for continuous work in this type of moderate workload activity (26.7 °C). Even though the total working time (195–215 min) was much shorter than the work pattern for industrial workers (480 min), the prevailing environmental conditions were a major cause of concern irrespective of the strenuousness of the miners' job.

5. CONCLUSION

From this study it can be concluded that in haulage mines, even though underground tramming remains a moderate type of activity and is well tolerated by younger workers, the stress on older individuals cannot be ignored. Mean RCC was above the recommended limits and the aerobic strain was also unacceptable, which could be detrimental and could have harmful effects. In addition, the poor underground environmental conditions could have an added impact on the workers irrespective of age, posing more stress and thereby impairing their performance, especially endurance. An ergonomic intervention programme could be implemented to reduce the static component of the trammers' tasks. Moreover strategies towards upgrading the existing environment are of tremendous importance given the present conditions in underground mines. They should be made more acceptable and comfortable for the workers irrespective of the nature of their job. Furthermore work tasks are bound to evoke musculoskeletal problems. Those problems could be evaluated in a future study.

REFERENCES

1. Gallagher S. Ergonomics issues in mining. In: Karwowski W, Marras WS, editors. The occupational ergonomics handbook. New York, NY, USA: CRC Press LLC, 1999. p. 1893–915.
2. Garg A. Ergonomics and the older worker: an overview. Exp Aging Res. 1991;17(3):143–55.
3. Mincheva L, Nguyen VCh. Physical work capacity of miners. Probl Khig. 1986:11:55–64. In Bulgarian.
4. Turner JA. Predictors of chronic disability in injured workers: a systematic literature synthesis. Am J Ind Med. 2000;38:707–22.
5. Griffiths A. Work design and management—the older worker. Exp Aging Res. 1999;25:411–20.
6. Favre MN, Roche F, Januel B, Rigaudiere P, Seydoux D, Fournel P, et al. Exercise test and evaluation of exertional dyspnoea in former coal miners. Rev Mal Resir. 2002;19(3):315–22. In French.
7. Kampmann B, Piekarski C. Assessment of the risks of heat disorder work encountered during work in hot conditions in German hard coal mines. In: Tochihara Y, Ohnaka T, editors. Environmental ergonomics—the ergonomics of human comfort, health, and performance in the thermal environment. Amsterdam, The Netherlands: Elsevier; 2005. p. 79–84.
8. Sawka MN, Toner MM, Francesconi RP, Pandolf KB: Hypohydration and exercise: effects of heat acclimation, gender, and environment. J Appl Physiol. 1983;55(4): 1147–53.
9. Brake DJ, Bates GP. Fluid losses and hydration status of industrial workers under thermal stress working extended shifts. Occup Environ Med. 2003;60(2):90–6.
10. Astrand PO, Rodhal K. Textbook of work physiology. New York, NY, USA: McGraw Hill; 1986.
11. Oxylog-2. Instruction manual. Gillingham, Kent, UK: PK Morgan.
12. Martiz JS, Morrison JF, Peter J, Strydom NB, Wyndham CH. A practical method of estimating an individual's

maximal oxygen intake. Ergonomics. 1961;4:97–122.

13. The Committee on Exercise, American Heart Association (AHA). Exercise testing and training of apparently healthy individuals: a handbook for physicians. New York, NY, USA: AHA; 1972.
14. Palenciano L, Gonzalez V, Santullano LA, Montoliu MA. Cardiac frequency in miners recorded during four to five work shifts. Eur J Appl Physiol Occup Physiol. 1996; 73(3–4):369–75.
15. Brouha L. Evaluation of the physiological requirements of jobs. In: Physiology in industry: evaluation of industrial stress by the physiological reaction of the workers. London, UK: Pergamon Press; 1960. p. 82–108.
16. Nielson R, Meyer JP. Evaluation of metabolism from heart rate in industrial work. Ergonomics. 1987;30:565–72.
17. Malchaire J, Wallemaeq M. Validity of oxygen consumption measurement at the workplace. What are we measuring? Ann Occup Hyg. 1984;28:189–93.
18. Barbant C, Bedard S, Mergler D. Cardiac strain among women worker in an industrial laundry. Ergonomics. 1989;32:615–28.
19. Costa G, Berti F, Betta A. Physiological cost of apple farming activities. Ergonomics. 1989;20:281–86.
20. Montoliu MA, Gonzalez V, Palenciano L. Cardiac frequency throughout a working shift in coal miners. Ergonomics. 1995; 38(6):1250–63.
21. Brake DJ, Bates GP. Fatigue in industrial workers under thermal stress on extended shift lengths. Occ Med (London). 2001: 51(7):456–63.
22. Mincheva L, Khadzhiolova I, Deianov Kh. An occupational physiology study at the Asarel Mining and Milling Works. The evaluation of the work load in the basic jobs in an open-pit mine. Probl Khig. 1995; 20:35–47. In Bulgarian.
23. Rodhal K, Vokac Z, Fugelli P, Vaage O, Maehlum S. Circulatory strain, estimated energy output and catecholamine excretion in Norwegian coastal fisherman. Ergonomics. 1974;17(5):585–602.
24. Pal AK, Sinha DK. The energy cost of metalliferous mining operations in relation to the aerobic capacity of Indian miners. Ergonomics. 1994;37(6):1047–54.
25. Ho Z. The energy expenditure of three categories of labourers in Southern China. In: Rand WM, Uauy R, Scrimshaw NS, editors. Protein-energy-requirement studies in developing countries: results of international research. Tokyo, Japan: United Nations University Press; 1984. Retrieved October 10, 2006, from: http://www.unu.edu/Unupress/unupbooks/80481e/80481E00.htm
26. Abt G, Tranter, M. Assessment of heart rate and metabolic rate in an Australian underground coalmine. Journal of Occupational and Health Safety—Australia & New Zealand. 1999;15(4):351–7.
27. Ramanathan NI, Dutta SR, Roy BN, Chatterjee A, Mullick LN. Energy cost of different muscular exercise tests performed by the Indian subjects. Indian Journal Occupational Health. 1967;10:253–61.
28. Chamoux A, Borel AM, Catilina P. Pour la standardization d'unefrequence cardiaque de repos. Arch Mal Prof. 1985;46:241–50.
29. Saha PN. Aerobic capacity of dockworkers in Bombay. Am Ind Hyg Assoc J. 1975; 36:311–17.
30. Benavides R. Physical work capacity in coal miners and industrial worker. Rev Med Chil. 1992;120(10):1170–6. In Spanish.
31. Saha PN, Dutta SR, Bannerjee PK, Narayane GG. An acceptable workload for Indian workers. Ergonomics. 1979;22: 1059–71.
32. Rutenfranz J, Hmarinen J, Klimmer F, Kylian H. Workload and demanded physical performance capacity under different industrial working conditions. In: Kaneko M, editor. Fitness for the aged, disabled and industrial worker (International series on sport sciences, 20). Champaign, IL, USA: Human Kinetics; 1990. p. 217–38.
33. TLVs®, Threshold Limit Values for chemical substances & physical agents in the workroom environment with intended changes (for 1981). Cincinnati, OH, USA: American Conference of Governmental Industrial Hygienists (ACGIH).