Third World Ergonomics

KAZUTAKA KOGI and RABINDRA NATH SEN*

*ILO Regional Office for Asia and the Pacific, PO Box 1759, Bangkok, Thailand and *Ergonomics Laboratory, Department of Physiology, Calcutta University, 92 A.P.C. Road, Calcutta 700 009, India*

Abstract. The research and application of ergonomics in Third World countries have been gaining momentum since the 1970s. Given the many constraints in developing economies, the major focus is on practical solutions to differing ergonomic needs and on the participation of people at various levels. There are an increasing number of reports particularly concerning traditional activities and transferred technologies. A review of these reports shows that the configuration of human work needs to be made in the local context in which the work is done. Particularly significant are the implications of varying interactions between work and people with different physical and cognitive features. Equipment and systems that may seem to work in industrialized countries may not always be appropriate in the Third World situation. There have been thus many interesting attempts to redesign work and products taking into account anthropometric, physiological, climatic and organizational differences. Successful examples include reduction of physical load, improved designs of tools, implements, workstations and public facilities as well as better work organization and scheduling. It should be emphasized that the Third World provides an area in which relatively simple ergonomic changes can bring massive advantages to output and safety. Concrete benefits have been gained where practical, low-cost solutions are demonstrated and people at various levels including managers, workers and key personnel are trained. Opportunities could and should be created to utilize ergonomics widely in different Third World settings.

Contents

International Reviews of Ergonomics, 1, 77–118, Edited by David J. Oborne. © Taylor and Francis, 1987

1. Introduction

The research and practice of ergonomics have their roots in wider technological, social and economic developments. Rapid changes taking place in Third World countries are ample sources of ideas to understand these roots and to work for the future. It is worthwhile to discuss existing trends in ergonomics in these countries where concern for its research and application is growing fast.

Despite recent progress, ergonomics is still an emerging area in all these industrially developing countries. The new concern for ergonomics is based on the understanding that it can yield positive results by adjusting human factors in the process of development. Ergonomics is gradually being incorporated into specific programmes for production engineering and safety and health at workplaces with various degrees of technology transfer.

An important question at present is about the extent to which the application of ergonomics differs in Third World settings. Ergonomics is naturally concerned with human aspects of work in whatever situation the work is done. The basic principles should be universal. Nevertheless, various new attempts to apply ergonomics in the difficult conditions different from those in industrialized countries will throw light on the ways and means of wider situation-oriented applications of ergonomics.

There is, however, no established access to the ergonomics-relevant literature from the Third World. Much is published as reports from institutions or meetings with limited distribution, or in a wide range of periodicals and monographs of various disciplines. Fortunately, we have been able to include in our review the papers presented at several recent international meetings, in addition to those contained in journals to which we have had access. They include papers presented at international conferences, in particular the International Symposium on Ergonomics in Developing Countries in Jakarta in 1985 jointly organized by the Government of Indonesia, the International Labour Organization (ILO), the World Health Organization (WHO), the International Ergonomics Association and the South East Asian Ergonomics Society. It is useful to keep in mind that the present review is based on the limited material available at a specific time. It attempts merely to discuss the patterns and trends found in available literature.

The papers reviewed are complex and heterogeneous, reflecting different levels of economic and technological development. Despite this diversity, two common features appear to be relevant to most of these papers. First, there are many attempts to respond to differing human needs in the developing world rather than describe specific aspects of work capabilities. Second, and perhaps more importantly, there are equally numerous attempts to relate the scope to the local context in which work is done.

Keeping these two common features in view, the issues dealt with by the reviewed papers will be discussed according to: basic approaches; local characteristics; redesign and new design trials; practical methods used; and training experiences. Our main focus will be on what concrete results are being achieved in Third World settings. It must be emphasized that developments must be a result of local needs and not of priorities set by outsiders.

2. *Approaches*

While different methods and approaches are evident and the resources used for ergonomics work range from simple to sophisticated, the major focus is on the analysis of workplace problems and on the practical benefits of ergonomics. This focus is clearly seen in the discussion of the role of ergonomics in development (Shahnavaz, 1985a; Sutarman, 1985; Suma'mur, 1985a; Manuaba, 1985a; ILO, 1984; Daftuar, 1975). Shahnavaz (1985a) stresses that the objectives of ergonomics are (*a*) to enhance the effectiveness with which work and other human activities are carried out, and (*b*) to maintain or enhance certain desirable human values in the process, e.g. health, safety and satisfaction. Thus, there seems to be consensus that the approach of ergonomics is the systematic application of relevant information about human abilities, characteristics, behaviour and motivation in the implementation of work and other human activities (Shahnavaz, 1985b).

An effective way towards these objectives is to approach them systematically. The potential of ergonomics in this respect is being increasingly recognized (Suma'mur, 1985a). An ILO report evaluating its international programme for the improvement of working conditions and environment launched in 1976 (ILO, 1984) confirms that in countries such as Algeria, Brazil, India, Indonesia, Mexico and Tunisia, applied ergonomics has made an important contribution to the improvement of work layout, work methods and the processes and organization of work and to the elimination of the negative effects of technology transfer.

At this point it is worthwhile to reflect on the concept of 'industrially developing countries' as stressed by Wisner (1985a) and Sen (1984) in discussing the relevance of ergonomics to development. These countries are by no means underdeveloped as a human society. Our reference should be limited to the industrial aspects of development. The term 'developing countries' in this review is also used in this context.

Practical benefits are sought as there are many common problems in developing countries in which ergonomics can be of great help. They include: low machine utilization and maintenance problems; lack of skills and predominance of low motivation among the local workforce; excessive physical and environmental loads; high turnover and pressure from unemployment; high accident rates; and importation of inappropriate technology (Shahnavaz, 1984; Kogi, 1985a). Weakness in legal standards and their enforcement should also be mentioned.

In view of these common problems, it is considered unwise for developing countries to copy the work methods and procedures of an industrialized country. Here two major orientations in ergonomics research and practice emerge (Thompson, 1972; Wisner, 1985a,b; National Institute of Design, 1985; Shahnavaz, 1985b). They are, on the one hand, customary ergonomics based on traditional or agricultural activities in relation to endogenous self-centred development, and on the other, industrial ergonomics focusing on technology transfer. Interestingly, as Wisner (1985a) noted, most renowned ergonomists in the traditional field also contribute to the use of advanced foreign technology.

An ILO pilot survey by local experts in eight developing countries in Asia showed that many ergonomics improvements are being implemented as part of

Table 1. Improvement actions reported from 64 experts in 8 developing countries in Asia in an ILO Survey. From Kogi (1985a).

Actions taken	Number of examples: Successful	Partially successful	Not successful
Relocating machines	5	3	7
Changing machines, operations of postures	7	4	7
Mechanizing lifting or carrying, providing carts or reducing loads	8	6	4
Arranging for supplies or spares	2	2	2
Inserting rest periods or changing shift systems	2	1	4
Improving lighting, ventilation or heat	15	9	14
Reducing exposure to health hazards	15	21	21
Providing guards, safety device or safety training	5	5	10
Welfare facilities and services	5	3	5
Cultural adaptation and others	6	2	1
Total	70	56	75

the effort to improve workplaces (Kogi, 1985a). Over 30% of implemented improvements reported were in the areas of machine layout and design, workload, working time and job design together (Table 1). Of these, nearly two-thirds were successful or partially successful. This means that, though unreported, there are numerous successful ergonomics attempts.

Under the circumstances, an approach should be established for identifying ergonomic 'needs' with a view to solving them by using available resources. This needs-solving approach is supported by many ergonomists who have come from industrialized countries and collaborated with local experts (Vähäpasse, 1985; Wood, 1985; Holmer, 1986). The approach is also advocated by leading ergonomists within developing countries (Phoon, 1976; Sen, 1984; Hiba, 1985; Manuaba, 1985a; Qian, 1985; Shahnavaz, 1985b).

The most common need of developing countries, such as Indonesia or Thailand, has been suggested by Suma'mur (1985a) and Holmer (1986) as being machine design – including utilization of anthropometric data, traditional tools, work methods, work postures, physical workload, lifting and carrying, monotonous and repetitive tasks, working environment, and the provision of information necessary for work. Shahnavaz (1985a) and Wisner (1985a,b) also add maintenance and cognitive aspects. It is claimed that while solutions could be specific, we should look at various aspects or needs together. This claim is linked with the awareness that a focus on cost-effective aspects is useful in view of scarce resources (Dy, 1979; ILO, 1984).

In contrast, there are few normative studies. One reason is because ergonomics is still at the emerging stage. This would, however, be at least in part related to the needs-oriented approach. Besides, many people find that 'norms' established in industrialized countries are either unsuitable to local people or biased on views of overall human needs. How ergonomics norms will be established in the reality of the Third World is an interesting, but unresolved, issue.

Finally, we need to take into account the constraints that restrict research and practice of ergonomics. These are related to the scarcity of resources and to various technological and administrative problems. The maintenance problem is

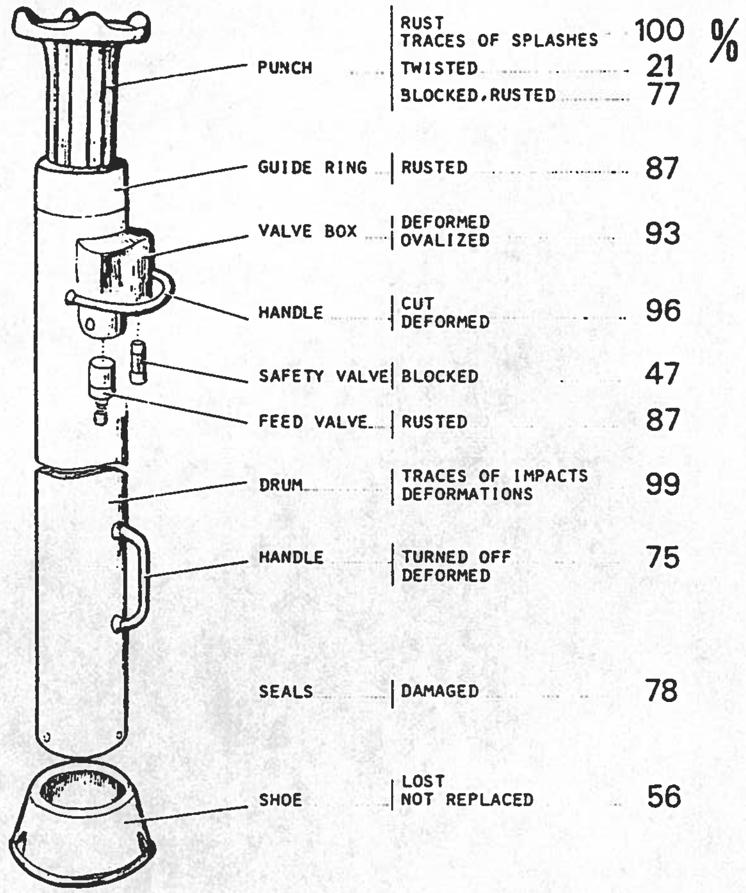


Figure 1. Percent damage observed on 240 hydraulic pit props of 70–120 kg in weight when dismantled at Tunisian phosphate mines. High percentages were related to the effects of climate, phosphates, handling and difficulties of the repair department. From Sahbi (1983).

typical, and is discussed in detail by Sahbi (1983), Shahnavaz (1984) and Wisner (1985a,b). Maintenance is difficult because the choice of technologies is limited and because equipment is heterogeneous and easily damaged in local, tropical conditions, with insufficient information and spare parts available. Overall, transfer of 'soft' technology, or organizational transfer is lacking (Meshkati, 1985; Wisner, 1985a). A typical example is illustrated by the malfunctioning of a maintenance department in a mine in Tunisia (Figure 1). Thus, constraints for ergonomics are often the incomplete transfer of technology and the absence of work organization networks and communication circuits. This man-made nature of constraints requires our attention.

3. *Local features of work demands and capacities*

The variability in the relation between work demands and human capacities receives particular attention in developing countries as a result of the accelerated use of imported or transferred goods. Often these goods cannot be used safely, effectively or comfortably as they do not suit the local climate or the existing habits, customs or capacities of people who use them. Special attention has been paid to differences in body size, physical work capacity, heat effects and cognitive aspects.

Body size differences

There is an increasing number of comparative studies on variations in body sizes and other anthropometric data from developing countries. The results reveal differences in almost every part of the human body, particularly between populations in industrialized and developing countries. Interesting reviews of these differences are given by Sahbi (1983), Sen (1983) and Abeysekera (1985).

Sahbi (1983) noted the large differences between different ethnic and occupational groups as well as between different age groups in body height, body weight and sitting height. The mean body height of males in various populations ranged between less than 160 cm and around 175 cm. Mean body weight in these data ranged between 50 and over 70 kg, and its relation with body height differed greatly between countries. For example, it was considered that equipment which suited the French working population would be equally satisfactory to Tunisian workers from the viewpoint of body dimensions, but not in view of the large differences in weight, nutritional status and muscular forces.

Abeysekera (1985) also emphasized that body dimensions differed not only between countries but also between races of ethnic groups living in the same country, as well as between different age groups. He noted that taller people live in North America, the European Continent and Scandinavia, medium-size people in Africa and the Middle East and shorter people in Latin America, Asia and the Far East. The differences were larger when percentile values are compared (Kennedy, 1975). According to Abeysekera (1985), the ratio of mean sitting height to mean stature ranged between 0·495 for Egypt and 0·543 for Japan. The group average was 0·513 for Africa, 0·520 for the Middle East, 0·522 for Latin America, 0·523 for Europe and North America and 0·532 for East Asia. Nearly all the populations with shorter limbs were from developing countries except the Japanese; whereas Egypt, Tunisia, Sri Lanka, India and Latin America were among those with longer legs.

Sen (1964), Sen *et al.* (1977) and Saha (1985a) noted some differences between Indian workers in different sectors. For male workers in eastern India Sen *et al.* (1977) found a median stature of 161·5 cm with a relatively low body weight of 46 kg and low bone diameters. For workers in western India Sen (1964) reported a median height of 163·0 cm and body weight of 50·6 kg. Thus the reference body weight of eastern Indians would be 45–50 kg and that of western Indians 50–55 kg. In Argentina Hiba and de Luco (1981) found no differences in body height between age groups, but an increase in body weight with age. Suma'mur (1985b) and Soedirman (1985) reported anthropometric data for Indonesian workers and as a standard reference height of Indonesian workers; they suggested 161 cm for males and 152 cm for females. The low sitting height:stature ratio of 0·510 was among the lowest when compared with the corresponding value of other populations (Sen, 1964; Shahnavaz and Davies, 1977; Abeysekera, 1985).

Further, Evans and Courtney (1985) reported that Hong Kong males were taller than Japanese or Korean males but significantly smaller than the Western group.

Hand dimensions, which are crucial in machine and tool design, also differ greatly. For example, hands of West Indian females are significantly larger than West European and Indian hands (Davies *et al.*, 1980). Interesting studies by Courtney and his group (Courtney and Ng, 1984; Courtney, 1984; Evans and Courtney, 1985) revealed that Hong Kong Chinese females had, overall, smaller hands than the UK and USA groups and larger hands than the Japanese, with relatively longer fingers. As discussed by Abeysekera (1985), hand dimensions do not seem to follow the same pattern as statures and sitting heights between industrialized and developing countries. He further found that head dimensions for Sri Lankans were significantly smaller than those of British subjects. It was shown that the head harnesses of helmets from Britain and Sweden, even after adjustment to the minimum, were loose and could not be fitted properly by 40% of Sri Lankans. Examples of the implications of these differences for safety standards are shown in Table 2.

A very important fact in the industrialization process is that body measurements differ significantly between urban and rural areas (Abeysekera, 1985). This tendency is clear from various studies comparing physical capacities of different groups. People from rural areas are, on the average, smaller than those living in urban areas. Nutrition and living standards may be mentioned as reasons.

The need to establish a database of body dimensions, or an anthropometric data bank, is stressed by many of the above authors. At present, available data are still

Table 2. Examples of anthropometric measurements relevant to accident prevention standards.
(a) Machine guarding. From Courtney and Ng (1984).

Parallel sided opening in guarding	Hong Kong Chinese female digit 5		Safety distance standard		
	Range of finger depth	97·5%ile length	BS3402 1971	ILO information Sheet No. 10 1964	DIN 31001 Part 1
6·89–8·91 mm	Depth at tip 7–10 mm	Length first segment 20·98 mm	40 mm	50 mm	15 mm
11·18 mm	Depth at second joint 11–16 mm	Length finger tip to root 63·27 mm (67 mm max.)	65 mm	50 mm	120 mm

(b) Head harness of industrial helmets. From Abeysekera (1985).

Head harness dimension	Sri Lankan	British	Mean of three available types of helmets (min.–max.)
	5th and 95th % iles	5th and 95th % iles	
Circumference	515–570 mm	554–598 mm	540–660 mm
Head length	156–194 mm	188–209 mm	165–240 mm

from only a small number of developing countries. Attempts are being made to develop databases for aspects such as driving cabs, passenger compartments, machine-tool guarding, furniture design, visual display terminal design, and others (Sen and Nag, 1973; Manuaba, 1976; Sen and Ganguli, 1982; Guharay *et al.*, 1984; Evans and Courtney, 1985; Saha, 1985a; Soedirman, 1985; Suma'mur, 1985b).

Physical work capacity

An important area of interest for ergonomics research in developing countries is the study of physical work capacity and its implications for working conditions. Many papers refer to physical capacities different from those of Western workers and to the remarkably heavy physical workload of local workers.

Banerjee (1962), Sen and Nag (1975), Sen and Sarkar (1979), Sen (1982) and Ramanathan and Nag (1982) have presented energy costs of work in India. Many Indian workers were found to perform heavy work. For males of 50–55 kg in body weight, the classification levels of workload in terms of kcal/min were considered to be 1·0–2·5 or 3·5 for light work, 2·5–4·0 or 5·25 for moderate work, 4·0–6·0 or 7·0 for heavy work, 6·0–8·0 or 8·75 for very heavy work, and over 8·0 or 8·75 for unduly heavy work. These levels seemed reasonable in view of body weight differences to Western subjects. Many Indian occupations are thus known to involve heavy work, including materials handling, carrying, tool operation and various kinds of agricultural and mining work (Chakraborty and Guharay, 1966; Guharay *et al.*, 1979). Nag *et al.* (1980a) found that physical activities in agriculture in India usually lay within a moderate level of activity, but that they included periodic spurts of heavy or extremely heavy activities (Table 3).

It should be noted that maximal oxygen uptake estimated for workers in India and many other developing countries is very low. These figures contrast with trained Caucasian or African subjects. For 50 kg body weight, Nag (1981) found maximal oxygen uptakes of 2·35, 2·31 and 2·08 l/min for agricultural workers aged 20–29, 30–39 and 40–49, respectively, compared with 2·46, 2·33 and

Table 3. Categorization of the agricultural work by Indian farmers. From Nag et al. *(1980a).*

Variables	Light	Moderate	Heavy	Extremely heavy
Percent maximum oxygen uptake	Below 25%	Up to 50%	Up to 75%	Above 75%
Oxygen intake (l/min)	<0·435	0·436–0·870	0·871–1·305	>1·306
Energy cost (kcal/min)	<9·10	9·11–18·15	18·16–27·22	>27·23
Man-hours involved (%)	29%	64%	6%	1%
Examples of operations	Sitting work, shelving, fertilizing	Laddering, plucking, weeding, transplanting	Ploughing, water lifting, manual threshing	Pedal threshing, bund trimming

2·1 l/min, respectively, found for industrial workers (Sen and Sarker, 1979). This corresponds to about 41–47 ml/min/kg. Nag *et al.* (1978) found maximal oxygen uptake of about 43 ml/min/kg for males and about 35 ml/min/kg for females, with 15–30% lower values for those in their 30s. Similar results were obtained for Indian subjects (Malhotra *et al.*, 1966; Maitra, 1979), for Thai males (Eriksson *et al.*, 1974) and for Iranian steel workers (Shahnawaz and Tuxworth, 1978).

Comparing Caucasian, Bantu and Bushmen males in a similar state of physical training, Wyndham *et al.* (1963) found a maximum oxygen intake of about 48 ml/min/kg, while oxygen consumption plotted against work rate was lower for Bantu men. They noted that a sedentary existence would reduce this figure to about 40. Wyndham and Heyns (1969) found lower maximal oxygen uptake for the young Bantu.

The fairly large variability in physical work capacity among different groups of workers or between rural and urban people deserves particular attention. Often rural men have lower maximum oxygen uptake than urban men (Wyndham, 1973). This makes relative physical loads of certain groups and agricultural workers particularly high (Htay Htay *et al.*, 1978; Nag and Dutt, 1980; Sen *et al.*, 1983; Siahaan *et al.*, 1985). Agricultural work load often exceeds 50% of the maximum level for both men and women and even for manual work with improved equipment. High physical load is also noted for disabled people with lower physical capacity (Ghosh *et al.*, 1980; Goswami *et al.*, 1984). Nag *et al.* (1980a) found that about two-thirds of the working hours of some Indian agricultural workers were spent doing moderate work, but that their work included various types of heavy work exceeding 50% of the maximum level (Table 3). The time-weighted work demand reached about 30–40% of the maximum oxygen uptake.

Investigating villagers and canal cleaners in Sudan, Awad El Karim *et al.* (1980) found the maximum aerobic capacity among canal cleaners to be significantly lower, by 18%. Stature, body weight, age and lean body mass were similar, and this lower capacity was due to *Schistosoma mansoni* infection among canal cleaners. Similar results were found for Sudanese cane cutters infected by *Schistosoma mansoni* (Collins *et al.*, 1976). More generally, poor nutritional conditions of rural and other groups extensively affect their work capacities (Nag *et al.*, 1978; Sen and Sarkar, 1979; Sen and Nag, 1979; Setiawati, 1985). Khogali (1969) drew attention to the relation between malnutrition and work efficiency of Sudanese workers and the importance of a balanced diet.

Of particular interest is the considerable disadvantage of migrant workers in a new community in which they adjust their way of life (Kunstadter, 1971; Wongphanich, 1984). The pattern of adjustment seems associated with changes in nutritional level, growth, reproduction and communicable diseases.

There are several suggestions about acceptable physical workload, especially from India. Generally, they cast doubt on Western suggestions and propose lower, more reasonable limits. For specific kinds of carrying or manual work of a certain duration, 50% of the maximum level is proposed by some authors (Nag *et al.*, 1978; Chakraborty *et al.*, 1979; Samanta and Chatterjee, 1981). For continuous work, however, about 30–33% of the maximum capacity is considered reasonable (Saha *et al.*, 1979; Sen and Sarkar, 1979; Nag *et al.*, 1980a;

60
61
3 62 H
6 [5 63 L
6 64 –
8 65 L
5 [11 66 E
67
14 68 L
6 [16 69 E
70
18 71 L
7 [20 72 L
22 73 L
23 74 –
14 [29 75 ☒ –
31 76 ☒ L
34 77 ☒ E
34 [40 78 ☒ –
60 79 ☒ ☒ ☒ ☒
69 80 ☒ □
47 [76 81 ☒ L
107 82 ☒ ☒ ☒ ☒ ☒ ☒ –
118 83 ☒ ☒
97 [134 84 ☒ ☒ ☒ –
206 85 ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ L
216 86 ☒ ☒
87

Nag and Chatterjee, 1981; Saha, 1985b). More practically, a heart rate level of 110 beats/min was considered an acceptable workload (Saha *et al.*, 1979). For work with heat radiation from the sun, a heart rate level of 100 beats/min was recommended (Eriksson *et al.*, 1974).

A problem related to physical differences is postural differences. Sitting on the floor, on a low seat or squatting is habitually practised in many developing countries. Sen (1984) points out that there are considerable advantages in sitting on the floor, including lower air temperatures, more venous return, using the leg in work, less lifting work and greater freedom for postural changes. It is true that attempts to change to standing or chair-sitting work sometimes fail because of the neglect of traditional work procedures. Nevertheless, some work near the floor surface appears strenuous and inefficient, often leading to pains in the back and legs (Manuaba, 1976). Nag *et al.* (1985a) found significant muscle activities and ligamentous strain in the legs and back during different floor-sitting postures by Indians.

Attempts have been made in different countries to elevate the working surface to an appropriate height for natural standing or chair sitting (Manuaba, 1976; Yusuf, 1985). For continued work with repeated operations, workstations with natural standing or sitting on a seat of appropriate height would be preferred and would lead to efficient results. The implications of traditional postures, however, need to be studied with due consideration of custom and work procedures.

Heat at work

In many developing countries, the hot tropical climate complicates the emission of body heat and frequently impedes worker productivity. While living in the tropical environment provides acclimatization to heat, the hot and humid conditions of the tropics represent a load to even a healthy man (Sen, 1965, 1966). Many studies are thus devoted to the relation between heat and work.

Studying naturally heat-acclimated Indians, Sen Gupta *et al.* (1977) found a significant decrease in steady-state oxygen consumption with increase in the environmental heat load. While total oxygen cost of the fixed work did not show any significant change, there was a significant increase in the anaerobic fraction of oxygen supply in heat. The maximal oxygen uptake showed a fall in very hot conditions, with a greater fall in humid condition. The results suggest that a moderate physical load in normal conditions could be at the limit of a heavy load in the very hot environment.

Sen and Sarkar (1979) found that maximal oxygen uptake of adult male Indian workers was 2·31 l/min at 21°C in corrected effective temperature (basic), but 2·05 l/min at 27°C and 1·81 l/min at 32°C. They suggest a daily workload of 300 kg/min as a suitable limit for day-to-day work at 27°C and less for higher temperatures. Nag *et al.* (1980b) observed that due to the effective heat load on agricultural workers during the summer season, even a moderate load could be near the limit.

Reduced performance of physical work in the hot environment has also been discussed by Wyndham (1962), Khogali (1969), Strydom *et al.* (1971), Abeysekera (1981), Kuorinka (1983), Muchtadi and Danusugondho (1985) and Soemarna (1985). The need for comprehensive measures has been suggested, including reduction of physical work rates, rest breaks, environmental control and provision of drinking water. To avoid dehydration, replacement of sweat loss by drinking water in small amounts at frequent intervals could be useful (Strydom and Holdsworth, 1968). Complete water balance, however, could be restored only after salt losses were replaced, usually within 2–3 days (Strydom and Holdsworth, 1968).

The relationships between work, heat and nutrition are important for workers exposed for long periods to the hot environment. Edholm (1979) noted that, as found in a farming village in Gambia, balancing between food intake and energy expenditure takes place over long periods of time, but mismatches of short periods could add to the work load. Workers with low physical work capacities should be less able to tolerate heat (Strydom *et al.*, 1971). As shown by Wyndham *et al.* (1962) the lack of a stable diet could reduce capacity for physical work.

The conclusion of Edholm *et al.* (1963) and Edholm (1979) that acclimatization as shown by sweat rate is highly dependent on immediate environmental conditions and does not persist for long without stimulation is also relevant to tropical countries. Kartawikarta (1985) confirmed that complete acclimitization of tropical subjects was also relative and reversible. Thus heat stress in hot workplaces continues to be a serious problem for people in the tropical climate.

The design of air conditioning systems for tropical climates needs to take into account the thermal comfort zone of local people. People in tropical countries feel more comfortable and perform better at relatively high levels of heat and humidity. According to Cilingir (1985), the lower temperature level that Malaysians felt comfortable at was 22·5°C at a high humidity level. At lower humidity levels, temperatures below 23·5°C were considered cold. Sen (1982a) found the comfort zone to be 26·0°C in corrected effective temperature (basic) at 50% relative humidity, and 22·8°C at 30% humidity in Indian workers engaged in light work.

Cognitive differences

Skills and task variety and the relevance of cognitive functions in work performance seem of particular importance to developing countries where new technologies are transferred (ILO, 1983). Wisner (1985a) emphasized differences between countries or races in cognitive aspects which are yet far from obvious. Dos Santos (1985) described operators in the central control rooms of the Rio de Janeiro and Paris subway systems having identical ocular movement patterns. These patterns differed only according to whether or not the operators had previously been train conductors.

Sahbi (1983) demonstrated through work analysis that repair work by Tunisian phosphate miners required complex informal communications. He suggested that adequate organizational support and better communication would be needed to fill the gaps in recognition of repair needs and repair procedures. Meckassoua (1985) showed that the operational image about technical set-up of an illiterate operator in a Central African brasserie was more complete than that of a corresponding operator in France. Rachedi (1986) analysed cognitive mechanisms when reading technical drawings, and found a clear relation between success and school education levels. Deregowski and Dziurawiec (1985) described the difficulties encountered by miners, industrial apprentices and engineering students drawn from traditionally non-pictorial cultures in dealing with technical drawings. Thus, both cultural and educational factors seem relevant to cognitive differences.

Daftuar (1975) discussed the various cognitive aspects of Indians in relation to ergonomics. In addition to differences from the West in family and caste systems, basic implements, housing, clothing, postures and the concept of efficiency, he demonstrated the differences in the legibility of visual displays. With regard to commonly used Indian road signs, on average only 40% of undergraduate students who did not drive could interpret them correctly. For example, the sign for *no horn* was often understood as *blow your horn please*. The signs for *no overtaking* or *road crossing ahead* were seldom interpreted as such. As for the legibility of alphabets of different languages, he suggested that it would relate to both cultural experiences and basic workings of human information processing.

The implications of cross-cultural settings for ergonomics have been discussed by Chapanis (1974), Daftuar (1977), Dy (1979), Ohashi (1985) and Wisner (1985a,b). Attention has also been drawn to difficulties for bilingualism (Sinaiko, 1975; Broadbent, 1977; Daftuar, 1977; Wisner, 1985a). Various factors are shown to influence communication and work performance. Verbal and written communication problems, visual displays, control stereotypes, acceptance of change, attitudes towards work and professions and career prospects are particularly mentioned. Ohashi (1985) describes cross-cultural frictions among Japanese and Filipino crew members on ocean-going 'flag of convenience' vessels which were related to communication, work organization, the concept of safety, daily habits and work load.

There are few studies of population stereotypes in developing countries, although they may have various ergonomic implications. Population stereotypes for colour were studied for Yunan Province Chinese subjects by Courtney (1986). For concepts such as *go*, *off* and *stop*, the Chinese subjects did not yield such clearcut associations as those found with US subjects (Table 4). Red for stop and green for go were not particularly strong. The red for danger might not be so clear for the Chinese for whom it is a colour of happiness and prosperity, he suggests. Sen (1984) also reported that red is considered auspicious by Indians.

Table 4. Comparison between percentage associations for colour stereotypes between Chinese and American people. From Courtney (1986).

	Chinese		US	
Concept	Colour	Percentage	Colour	Percentage
Safe	Green	62·2	Green	61·4
Danger	Red	64·7	Red	89·8
Caution	Yellow	44·8	Yellow	81·1
Go	Green	44·7	Green	99·2
Stop	Red	48·5	Red	100·0
On	Green	22·3	Red	50·4
Off	Black	53·5	Blue	31·5
Hot	Red	31·1	Red	94·5
Cold	White	71·5	Blue	96·1

Further studies seem necessary in relation to the organization of work and skills in different local contexts of developing countries. Sebastian (1985) emphasizes that in the design of work systems, functional completeness, task variety, autonomy and direct feedback from work are essential. Kiggundu *et al.* (1983) point out the importance of studies on administrative reforms and job analysis in developing countries, and suggest that lack of local perspectives still prevail, reducing the long-term utilization of the results.

Lam *et al.* (1985) studied work stress and mental health in office workers in Hong Kong, and found that a satisfactory work content or environment was more important for males and vulnerability of coping ability more important for females. Occupational mass psychogenic illness can result from transcultural aspects (Boxer, 1985). Describing epidemics in Singapore, Chew *et al.* (1976) reported an outbreak among female workers doing repetitive assembly work which included screaming, trancelike states, violent behaviour and pseudo-seizures. The need to take into account the social, cultural and religious backgrounds was stressed.

Ketchum (1984) found that despite cultural differences, Sudan railway workers' and managers' reactions to a bureaucratic enterprise were similar to those of their counterparts in industrialized countries. Because a design along these old principles was certain to yield low performance, a state-of-the-art design emphasizing equally human development and autonomy as locomotive repair tasks was indicated.

Work schedules

Some of the problems related to working time and work schedules are similar to those in industrialized countries, such as long hours of work, insufficient rest periods and holidays and shift work. As many workers migrate from rural to urban areas and from one country to another, changes in work schedules and disciplines at times cause serious problems.

A relatively well documented area is the effects of night and shift work. The number of shift-workers is steadily increasing in developing countries (Kogi *et al.*, 1982; Ong and Hoong, 1982; ILO, 1985a). Relevant studies show that in cultural and geographically different regions, circadian rhythms of human beings react in a very uniform manner when exposed to night work (Kogi *et al.*, 1982). Human circadian rhythms would not be adapted to the night-work pattern (Sen and Kar, 1978; Kogi *et al.*, 1982; Sen *et al.*, 1982). The notion that workers in a tropical climate would prefer to work during the cool night does not hold true (Kogi, 1977, 1986). Particularly in developing countries, the effects on shift-workers are often aggravated by inconveniences in daily life activities and transport and by interference with local customs (Kogi, 1977, 1986; Fischer, 1982; Mahathevan, 1982; Manuaba, 1982b; Wongphanich *et al.*, 1982). In addition to sleep disturbances and psychosocial complaints, the health of these shift-workers is aggravated by frequent lack of hygiene at the workplaces, overcrowded dwellings and diet deficiencies. Khaleque and Rahman (1982) found more numerous health complaints among fixed night-shift workers compared to other groups. Reverente and Ariosa (1982) found more frequent sickness absences among shift-workers than among day workers in the Philippines.

4. Redesign and new design

Many interesting and innovative ideas have been presented from developing countries about the redesign and new design of work and products. Different methods and ideas are applied. One group of such papers deals distinctly with traditional activities and manual labour. Another group deals with transferred technologies and workstations.

Traditional activities and manual work

The main ergonomics attempts concerning traditional activities focus on the reduction of manual work load and the improved designs of tools, implements, transport appliances and simple workstations (Manuaba, 1979, 1985b; Phoon, 1982; Sen and Chakraborti, 1984). It should be noted, however, that the effects of mechanization are also becoming a new focus of attention for ergonomics in agriculture, forestry and cottage industries (Kim, 1979; Manuaba, 1985b). In either case proposed improvements concern energy expenditure, work postures, efficient material and tool handling and safety (Manuaba, 1976; Phoon, 1982; Sen and De, 1984; Nkurlu, 1985).

Agricultural implements are an interesting area. Manuaba (1976) reported that a particular type of hoe (*pacols*) with a 1·535 m handle was identified as the most efficient in terms of work done and the heart rate level. Sen (1984) illustrated how a shovel with an additional handle could reduce strains and increase efficiency. Pradhan *et al.* (1985) recommend a spade of 2 kg or less having a blade–handle angle of 65–70° and a handle diameter of 40 mm for both high and low lift modes of spade work in agriculture. Nag and Dutt (1979), studying oxygen uptake and pulse rate changes, recommend a wheel hoe-type weeder as the most suitable for Indian agricultural workers. Yadav and Gite (1982) also found long-handled tools like rotary weeders more efficient, and a rotary mode of operation of agricultural equipment better than a reciprocating mode.

For use at rice transplanting work at paddy fields, a low-cost, air-inflated rubber seat was designed by Sen and Chakraborti (1985). It allows the worker to pluck seedlings and transplant them later to the prepared field while floating on the water in a sitting position. This ‘float-seat’ was found to yield greater productivity and less waste of time, with a decrease in heart-rate of about 20 beats/min. Improvement of tools to reduce strain by bending or squatting postures was also suggested by Manuaba (1976), Yadav and Gite (1982) and others. Ahmed (1979) presented various forms of less stressful forestry operations in the Philippines, such as the debarking tool shown in Figure 2. It was shown that improved, ‘intermediate’ labour-intensive techniques, such as in tree-cutting, debarking, bush clearing and transportation, led to better postures, efficiency and safety.

Lifting and carrying is another common area of interest. This physically heavy workload has been discussed by many authors (Sen and Nag, 1975, 1979; Manuaba, 1976; Nag and Sen, 1979; Ramanathan and Nag, 1982; Chung, 1985). Iskandar (1985) and some others pointed out the low-back pain problems in lifting and carrying. Manuaba (1976) found a unit load of 15 kg using

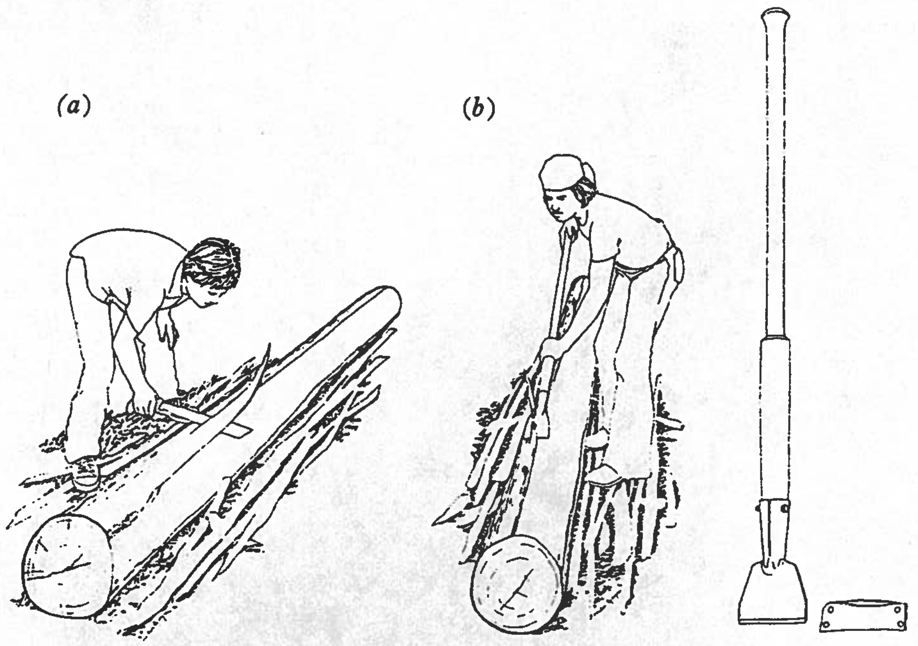
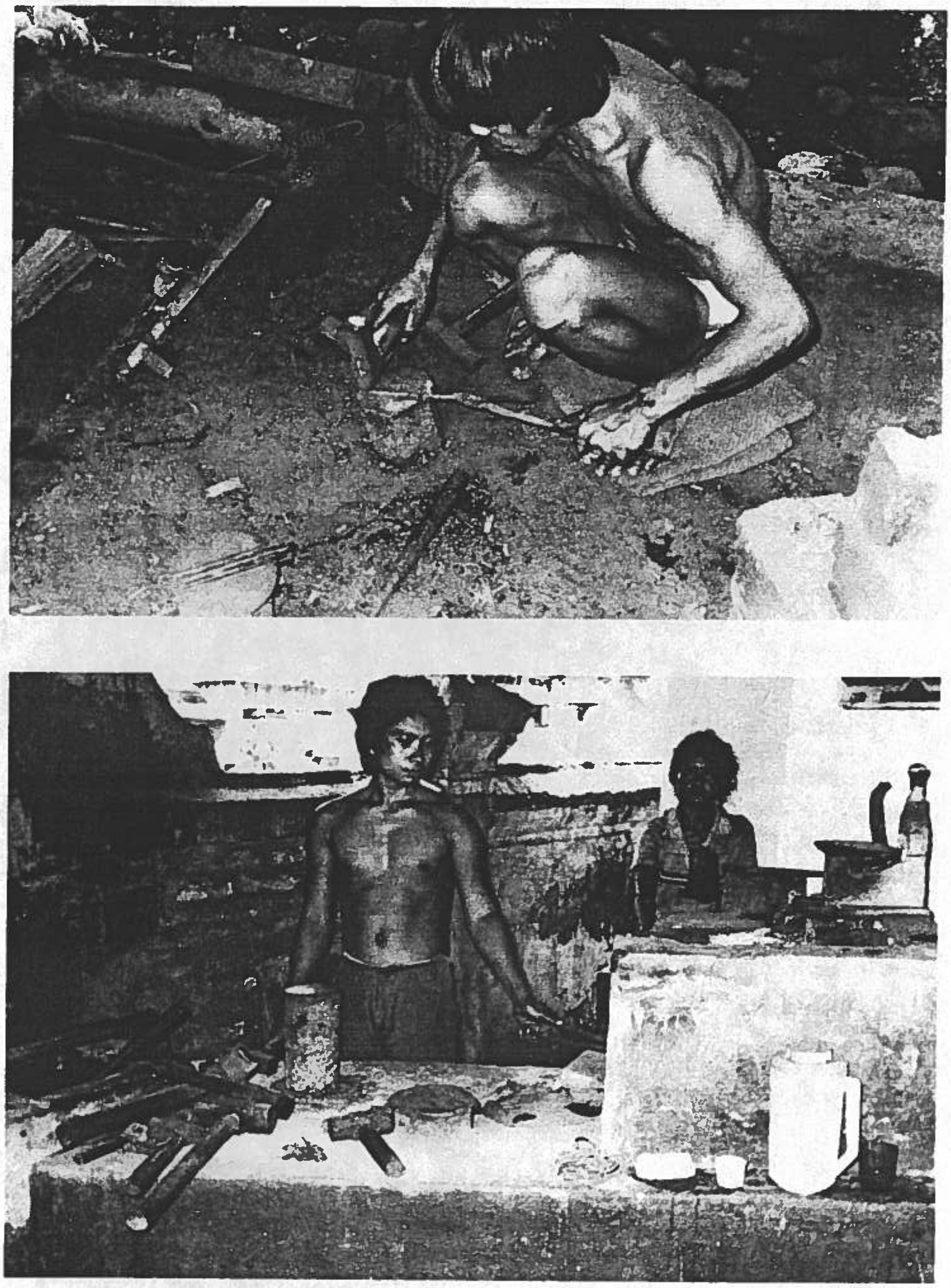


Figure 2. Debarking with a bolo in a stooped position (a) or with a long-handled debarking spud allowing the workers to maintain a semi-upright position (b) in forestry work in the Philippines. The use of a spud also helped reduce the risk of lacerations and bodily contact with the resinous wood. From Ahmed (1979).

compact-size containers optimal, having less physiological cost than larger containers. Dutta *et al.* (1979) suggested that carrying loads on the head could be economical depending on the speed. For hand-pulled carts, Datta and Ganguli (1979) noted that pulling could be effective when the centre of gravity of the cart, when loaded, was at the same level as the puller's centre of gravity. Datta *et al.* (1978) found that a rickshaw was an excellent ergonomic device, with the centre of gravity in front of the axle and allowing the puller to adjust the degree of tilt so that only the smallest downward push was required on the handles. Ergonomic modifications of a pedal-operated cycle-rickshaw were also considered by Sen (1984).

Goswami *et al.* (1986) conducted a detailed analysis of two types of tricycles available in India for persons with severe both-lower-limb disability. They proposed modifications such as putting the arm crank in the middle front of the user, making the crank position adjustable and improving the seat, brake and total weight. Nag *et al.* (1982) also found that mechanical efficiency of such hand-cranked tricycles was best when a hand-rim propulsion system was arranged for two-arm cranking at the heart level.

A series of ergonomics studies by Manuaba (1985b) in cottage industries in villages in Bali, Indonesia demonstrated that manual workstations allowing natural standing or comfortable chair sitting in weaving, ceramics, metalware and other operations could be successfully introduced. They led to better productivity and less strain. These are shown in Figure 3. Kavoussi (1976) reported that



(*a*)

Figure 3 *Examples of a traditional and a newly designed workstation in village industries in Bali, Indonesia. From Manuaba (1985b).*
(a) Traditional operations on the floor in a squatting position and a newly designed station in a standing position.
(b) Traditional pottery work in a narrow space and a newly designed worktable.

(*b*)

improved carpet looms with an adjustable bench seat induced higher output. Sepliarsky and Esterich (1983) showed that an adjustable mini-sidetable and an elbow support could greatly help porcelain work. For manual types of track maintenance work on railways, Nag *et al.* (1985b) presented design modifications such as the attachment of a long handle for wire claws, lighter weight beaters and a cylindrical grip handle for shovels.

Ergonomics has also been applied to improve occupational hygienic aspects of traditional activities (Pinnagoda, 1976). This includes simple ways of reducing exposure to solar heat, noise, arduous tasks dealing with hazardous materials and injury risks. Van Graan and Strydom (1968) suggested a ventilation gap between the hat shell and the inner hat band rather than ventilation holes in hard hats. Howard (1982) reported that a lack of hygiene, such as unprotected feet, induced dermal contamination during low volume paraquat spraying in Thailand. Unlike the urinary level of paraquat of knapsack sprayers and those using foot protection, that of unprotected low volume sprayers rose significantly. Hygienic measures combined with ergonomic improvements seem important.

Suzuki and Soemarwoto (1985) and Suzuki (1982) illustrated how mud splashes in wet rice fields with a particular type of hoe related to a high incidence of conjunctivitis, reaching 10% among farmers in West Java. This was found to be related to the shape of hoes used since similar incidences were not seen among Central Java farmers using hoes with a shorter shaft, a broader blade and a smaller shaft–blade angle (Figure 4).

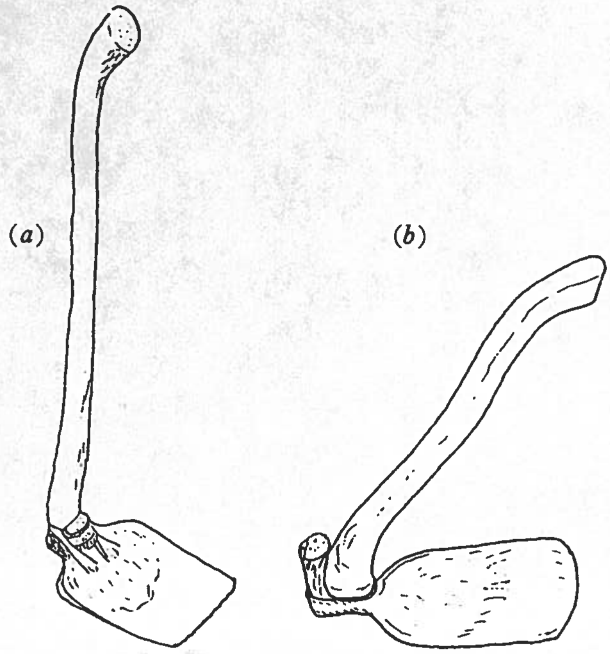


Figure 4. Hoes used in a village in West Java (a) and another village in Central Java (b). The incidence rate of conjunctivitis in a 15-day period was 14 for 330 persons in (a), but 0 for 475 persons in (b). From Suzuki (1982).

Transferred and new technologies

For developing countries, most new technology is transferred from outside and cannot always be expected to be appropriate to the climatic, anthropometric and operational conditions found there. Often, cheaper equipment and processes are imported which may be more dangerous and even illegal in the exporting countries. Similar conditions can also be found in plants of multinational corporations and their affiliates. As local resources for control and adaptation of technology are often insufficient, advantages of technological choices are lost and problems created, as discussed by many ergonomists and relevant reports (Corlett, 1966; Chapanis, 1974; Dy, 1979; ILO, 1982, 1983, 1984; Sen, 1984; Shahnavaz, 1984; Kogi, 1985a; Wisner, 1985a,b). The problems include high rates of accidents and occupational diseases, strenuous and repetitive work, low productivity or poor product quality, equipment deterioration and maladaptation to systems of production.

Reports on the application of ergonomics in the transfer of technology are rapidly increasing. The papers reviewed here represent only part of these attempts. Many of the improvements have been simple and required few resources, showing the large potential in this direction.

A broad systematic approach, looking at various potential areas, seems useful as shown by Manuaba (1976), Phoon (1976), Sen (1984), Sen and Chakraborti (1984), Kogi (1985a), Suma'mur (1985a), Richardson (1985) and Hiba (1985). Such areas include redesign of machinery, tools and vehicles, furniture and worktable design, low-cost mechanization and automation and improved product design. As shown by these reports, a team of ergonomists with the co-operation of people concerned can go a long way, covering a number of areas.

An interesting survey was carried out by Holmer *et al.* (1985) on ergonomics problems in factories in Thailand. Ergonomics problems existed in most factories surveyed, including heavy materials handling, local muscular strain, hand tool design, work postures, repetitive work, heat stress, workplace layout and work organization. These results were in agreement with an ILO pilot study on the feasibility of workplace improvements in small enterprises in Asia (Kogi, 1985a). Both these surveys pointed to the large potential in carrying out simple improvements to these problems.

Also through a survey done in Thailand, Hasle *et al.* (1986) showed that in small-scale industries, immediate improvements were possible in the design of workstations, organization of the workplace and ergonomic guards against cutting machinery, in-running nips and other injury risks as well as in the layout of machines and passageways. From India, Sen and Majumdar (1982) and Sen (1984) also reported that simple improvements, particularly in work methods and tool design, could lead to large benefits. Suggested changes in jute mills were ergonomic designs of weavers' hand knives, spinning hooks, operating procedures avoiding near-misses, improved maintenance of machines, better ventilation and safety training.

Increases in on-the-machine accidents in agriculture have also prompted ergonomics studies into agricultural machines in developing countries (Phoon and Ong, 1985). Shan (1985), for example, found in India that poor feeding systems and workplace arrangements were responsible for the majority of mutilating hand injuries at threshing machines. Design recommendations were given for the crop feeding chute and feed reverse control. Naveiro and Medeiros (1985) designed a new combine harvester cab for Brazilian subjects that allowed better visibility of the cutting edges.

Najoan (1985) reported on the role of ergonomics in the vocational training of industrial designers in Indonesia. She showed examples of improved designs in housing facilities, transportation, educational facilities, furniture and local traditional products. Industrial designers, thus trained, could effectively use ergonomic techniques.

Ergonomics applications seem gradually to be spreading to public facilities. Some attempts have been reported for public buses and subways in several countries. Sen and Nag (1973) and Manuaba (1976) suggested improved designs for driver and passenger seats and hand controls and pedals. Sen (1984) suggested the use of wooden roofs and drop windows and vents at the roof and sides, as seen in local buses, to reduce heat problems in a tropical climate. Courtney and Evans (1985) designed a bus cab to suit the anthropometric characteristics of Cantonese drivers. None of cabs in current use in Hong Kong satisfied these specifications. The most serious deviations requiring improvement were the excessive height of the seat above the floor and pedals, and the inadequate lateral separation of pedals. Sen and Ganguli (1982) described the ergonomic needs of locomotive driving cabs in India, focusing on outside visibility, signal detection, seats, controls and displays, intra-cab environment and shift systems. Sudijono (1985) drew attention to effective signals at railway-road level crossings.

Sumicad and Canela (1979) presented the results of some trials to introduce low-cost automation technology in small manufacturing enterprises in the Philippines, taking advantage of its flexibility and adaptability under socio-economic and technical constraints. They used principles of mechanics, pneumatics, hydraulics and electronics. By means of self-acting components, instruments and fixtures, low-cost automation proved useful in materials handling, production, gauging, inspection and packaging.

In contrast there are many automated and semi-automated processes applied in large-scale plants of multinational corporations. Wisner (1985a,b) discussed in detail how these 'anthropotechnological islands' in developing countries could be effective, but present problems in operation networks involving other local enterprises and in work organization. Wiwoho *et al.* (1985) found relatively slow performance and inaccuracies due to inadequate designs in control rooms in old petroleum plants. They suggested workplace improvements and adequate presentation of information.

The spreading use of office automation is also giving rise to ergonomic concerns. Ong *et al.* (1981) found significantly higher rates of visual fatigue and musculoskeletal complaints among visual display terminal (VDT) operators in Singapore compared with conventional office workers. They recommended improved work tables and chairs, better lighting design and rest pauses. Similar results were obtained by Tan and Ong (1982) among female key-punch operators whose menstruation-related symptoms were aggravated by the physical demands of VDT operation. Ong and Phoon (1986) further found a higher prevalence of visual strain and musculoskeletal complaints among older workers in a data entry centre with an intensive workload. The majority of these operators, aged 31–45, were working mothers.

Maciel (1985) reported an ergonomics intervention in a data processing centre in Brazil. VDT operators were found to have various problems including too high worktables, too narrow leg room, glare, noise, low room temperature and strains from output control. Improvements were made to work tables, chairs, footrests and document-holders. The successful intervention induced a change in the centre's approach to working conditions. Pulket and Kogi (1984) reported the limited value of a free-break system in data entry operators whose local fatigue and eyestrain became remarkable during the shift hours. They recommended improved keyboard positions and regular breaks.

Safety and environmental measures

Many of the above-mentioned papers on ergonomics improvements refer to safety at workplaces. This is based on the fact that, with industrialization, the number of work injuries has considerably increased in many developing countries (ILO, 1984; Ong *et al.*, 1984). Though reports about work-related diseases are limited, they also seem to be increasing with technology transfer (ILO, 1984; Phoon and Ong, 1985). While in industrialized countries machines have become safer to operate during the 1970s and early 1980s, the same cannot be said of developing countries (ILO, 1984). Imported or second-hand machinery often comes with dilapidated or missing safety guards and devices. Maintenance of machinery is also often poor. In these respects, ergonomics can play a significant role (Wisner, 1985a).

Takala (1982) suggested that measures should be widely adopted to cope with new and unexpected problems arising from technologies not adapted to local conditions. Based on his experience in Kenya, he emphasized the importance of simple measures such as good housekeeping, basic safety measures and easy-to-understand instructions. Stephaneck and Donadi (1981) indicated that subjective risk assessment at work would relate to taking improvement action. Peacock and Evans (1982), from experience in Hong Kong, stressed the need for an ergonomic approach to safety so as to create operationally sound systems that could accept human errors, such as installing interlock and automatic guards against presses and injection machines.

Environmental control also relates to enhanced safety and work performance. Measures to reduce thermal stress, in relation to physical workload, are particularly important to the tropical climate (Sen and Sarkar, 1979; Abeysekera, 1981). Manuaba (1976), Sen (1982a,b, 1984), Soemarna (1985) and others have drawn attention to simple measures to reduce thermal stress. They include increased natural ventilation, cross ventilation, changes in workplace layout and heat barriers. Reduction in physical load and adequate work–rest schedules are also important (Sen and Sarkar, 1979).

Crockford *et al.* (1979) and Sen and Dutta (1985) designed low-cost protective clothing for workers in hot workplaces. Sen and Dutta (1985) used lightweight, washable, fire-resistant and vapour permeable fabrics to make an apron-type clothing with outlets for air (Figure 5). Small pieces of reflecting aluminium foil attached to the clothing proved useful in reducing heat radiation and physiological responses to workers. Hiba and de Luco (1982) suggested types of helmet harnesses which were easy to operate and quickly removed.

Positive effects of improved illumination have been demonstrated by Bar and

Figure 5. Protective clothing for workers in hot workplaces: light-weight, washable and low-cost with replaceable aluminium-coated foil sheets and outlets for air. From Sen and Dutta (1985).

Ong (1978). In a typewriter manufacturing plant in Singapore, new lighting arrangements in an assembly line increased output by 22%, with the rejection rate decreased by 14%. Rasyid and Siswanto (1985) showed that after improving lighting from 100 to 500 lux, rolling operations in a cigarette factory in Indonesia increased by 9·5%.

Work organization and schedules

The number of reports on improved work organization and schedules is still very limited in developing countries. This is likely to be because improvements in these aspects are relatively difficult. High local unemployment levels may also be mentioned as a reason. Some attempts are nevertheless seen with respect to the organization of heavy manual work, group work and shift schedules.

Sen and Nag (1975) reported improvements in the work organization of Indian workers handling loads of 30–125 kg. The usual workload was extremely heavy, with an average work heart rate of 143 beats/min and an energy level of over 50% of the maximal working capacity. Improvements to the net optimal energy output of 1200 kcal per 8-hour working day were suggested. For handloom-weavers in eastern India, Sen and Ghoshthakur (1984) considered improvements in the work-rest cycles important to avoid accumulation of fatigue.

Sahbi (1983) and Wisner (1985b) discuss various organizational measures to reduce failures in maintenance of installations. As solutions, more complete transfer of technology including maintenance procedures and instructions are suggested. Organizational aspects also seem important in solving traffic safety problems in developing countries (Haight, 1980, 1983). An example was given by Gattan and Saran (1984) to improve crowd flow for Islamic pilgrims. Zoning and adequate use of symbols and colour coding were suggested.

Concerning new forms of work organization in industrial plants, De (1979) reported successful attempts in India to introduce group work or job rotation schemes, although frequent problems were experienced in changes to work procedures and in cross-skilling. Maule (1965) also found that authoritarian management had severe limitations in developing countries, and that people who were given additional responsibilities were well pleased with their changed role. A report by Ketchum (1984) also confirmed the desirability of introducing autonomous work systems.

Despite various constraints, there are several interesting reports about shift systems which are valid for the local situation in developing countries. Though shift systems are diversified, there is a tendency in some countries to introduce rotation systems with a relatively small number of consecutive night shifts (Kogi *et al.*, 1982; Perera, 1982). Susanto and Koenhendarso (1985) reported a preferred three-shift system in Indonesian petroleum plants with a holiday after each three-day period of a particular shift. Fischer (1986) found that, among shift systems applied in automotive plants in Brazil, rotation systems produced fewer sickness absences and less sleep disturbance.

5. *Practical methods*

Given the various constraints in developing countries, it is imperative to emphasize practical benefits attained through the application of ergonomics. This necessitates the effective use of available resources and the development of practical means of application (Kuorinka, 1985). Especially important are the identification of priority problems and the application of realistic solutions (Kogi, 1985b). Simple methods applicable with certain basic training may be preferable, though the final outcome may not necessarily be technologically simple or premature (Manuaba, 1976; WHO, 1983; ILO, 1984; Sen, 1984; Hiba, 1985). Many of these methods obviously relate to training approaches discussed later and have important theoretical implications.

Two major groups of such practical methods emphasized in developing countries may be mentioned. The first group comprises methods which are inexpensive, reliable and versatile. The second is characterized by the solution-oriented nature of the methods. Both are suitable in field applications.

Several interesting examples can be mentioned for the first group. Davies and Shahnawaz (1977) devised an anthropometer for use in developing countries which was of simple design and construction, quick and easy to use and accurate enough to give consistent results when used by different research workers. The anthropometer consisted of a wooden platform, a seat adjustable in height and rotatable, a vertical hollow-steel column and a horizontal moving arm. Repeated checking showed an accuracy of ± 0·5 cm. There have been some other attempts to use practical methods for body dimension analysis as in the case of Soedirman (1985) and Hiba and de Luco (1981).

Ballal *et al.* (1982) used a self-paced walking test that was simple and acceptable to give a useful measure of physical condition when adjustment was made for anthropometric variation. Each subject was asked to walk three times over a marked 120 m course 'rather slowly', 'at a normal pace' and 'rather fast'. Heart rate was recorded by means of a battery-operated ECG recorder. The heart rate at a standard walking speed of 4·8 km/h was obtained using the regression of the heart rate on the square of the walking speed for each subject. The results were used to compare conditions between different groups. The method seems comparable to the bicycle ergometer, step test or treadmill methods (Tuxworth and Shahnawaz, 1977).

Similarly simplified, reliable assessment techniques of physical load are used in many studies. Examples can be found in papers mentioned concerning redesign of traditional activities including Manuaba (1976, 1982a), Nag and Dutt (1979), Sen (1984), Sen and Chakraborti (1985) and others.

A time saving spot-check method was applied by Moji and Koyama (1985) to a peasant community in West Java for the purpose of collecting time allocation data. Ten 1·5 hour rounds were made between 0500 and 2000 hours, each time identifying what each person was doing. The spot-check was made for over 200 people in both dry and wet seasons. The method proved effective in indicating time allocation features of the villagers by sex, age group and season as a basis of further human ecological studies. Other time-saving methods to check changes in performance or the subjective feelings of a number of people could be used. Examples are the above-mentioned studies by Daftuar (1975), Manuaba (1976), Bar and Ong (1978), Ahmed (1979), Sen and Ganguli (1982), Sen and Majumdar (1982), Yadav and Gite (1982), Rasyid and Siswanto (1983), Lam *et al.* (1985), Shan (1985), Suzuki and Soemarwoto (1985), Goswami *et al.* (1986) and others using performance criteria, and Sen and Ghoshthakur (1984), Pulket and Kogi (1985), Ong and Phoon (1986) and others using subjective reports on their changes with time.

The second group of practical methods includes solution-oriented work assessment methods such as feasibility assessment, checklists, small group work and comparative design assessment.

Assessment of feasible solutions on the basis of interviews and observations is often used. A typical example is the assessment of technologies for improved forestry operations by Ahmed (1979). Many solutions were able to be suggested by showing the benefits in terms of postural or physical loads, fatigue and work outputs. Similarly, feasibility assessment of workplace improvements was done by research teams participating in a pilot study on small enterprises (Kogi, 1985a). The results were effective in demonstrating the extent and areas of possible improvements. Similar assessment of feasible solutions in different aspects of a given work situation was applied by Kim (1979), Sahbi (1983), Gattan and Saran (1984), Maciel (1985) and some others. Haight (1980) pointed out, when discussing traffic safety in developing countries, that tailoring the investigations to preliminary field studies would be important rather than adopting taxonomic categories which might be found to be useful in developed countries. It was stressed that smaller focused studies could lead to specific solutions rather than mass analysis of existing data (possibly unreliable) or of new data (expensive to obtain).

In the same context, corrective checklists have been found useful. For example, the Philippine checklist for improving working conditions (Institute of Labor and Manpower Studies, 1979) consisted of a list of possible improvement measures from which the users could select measures appropriate to a given workplace. The method was based on the findings that such a checklist could be more easily applicable than descriptive or quantitative checklists (Kogi, 1982). A similar checklist was used by Wongphanich (1984) for finding priority measures in textile mills in Thailand. Horino (1985) also applied a similar corrective checklist in problem-solving training of trainees from developing countries.

Checklists of other forms were applied by Hiba (1985), Holmer *et al.* (1985), Hasle *et al.* (1986) and others in evaluating the ergonomics problems of various workplaces. A comprehensive corrective checklist with a limited number of low-cost measures has been used in training courses for small and medium-sized enterprises in the Philippines, India and Thailand (ILO, 1985b, 1986; Kogi, 1985b,c).

Group assessment for finding practical ergonomic improvements also seems practical. As discussed later, the group work based on group discussions on feasible solutions and presentation of their results was successful in encouraging the multi-dimensional scope and immediate action (Kogi, 1985b,c).

Comparative design procedures may also be useful in finding practical solutions. This can be combined with simple assessment methods, such as heart-rate measurement, subjective evaluation, or indications of other benefits, to justify the preference of certain designs (Nag *et al.*, 1982; Yadav and Gite, 1982; Pradhan *et al.*, 1985).

Flexible application of these practical methods will continue to be necessary depending on the ergonomics needs and on the available time frame. They are widely applicable and useful, with the focus on benefits. As discussed in the next section, their implications for participatory approaches seem important.

6. *Training in ergonomics*

It is apparent that ergonomics can be usefully applied in Third World countries to a range of industrial and traditional situations. Therefore, the need for practical ergonomics education and training has been emphasized (ILO, 1983). How to organize training programmes was one of the major themes at the International Symposium on Ergonomics in Developing Countries in Jakarta in 1985. While these programmes should be action-oriented meeting local needs, efforts seemed necessary to be concentrated on priority activities.

In their rapporteur papers to this Symposium, both Baloyi (1985) and Kuorinka (1985) emphasized the necessity to organize training at various levels depending on a country's or an industry's needs. Baloyi (1985) discussed constraints such as lack of appreciation by development decision-makers, rapidly changing technologies without adequate information on preventive or remedial measures and lack of qualified personnel. Policy-oriented training for decision-makers, basic training at schools, universities, vocational training programmes and various enterprise-level training activities were emphasized. Further, Kuorinka (1985) stressed that ergonomics information should be adequately presented at two levels, i.e., reference manuals and instructions for use with transferred technologies and various technical curricula.

A postal survey done by the Centre of Ergonomics for Developing Countries, Luleå University, Sweden showed that ergonomics researchers and practitioners in developing countries had only limited access to current ergonomics information, mainly through personal contacts, meetings and a small number of periodicals (Shahnavaz and Gilroy, 1985). Most were dissatisfied with the inconsistent flow of information and the inapplicability of received information to local needs. While the number of qualified trainers in ergonomics is extremely limited in any developing country, support for organizing effective training programmes is obviously lacking.

A survey of ergonomics training in some developing countries in Asia revealed that existing programmes were far from filling the gap (Kogi *et al.*, 1985). Examples of teaching hours in ergonomics are given in Table 5. Only some engineering and medical schools taught ergonomics and the teaching hours were generally limited. There were no specialized post-graduate courses, and ergonomics was taught as part of post-graduate training in industrial engineering, occupational or environmental health or physiology. A variety of short courses teaching ergonomics for engineers, safety and health personnel and managerial staff, ranging from a few hours to several days, were available. They were organized mostly on an *ad hoc* basis, but reflected the increasing demand for the application of ergonomics. Hiba (1985) noted a similar situation in Argentina. In the Philippines, Hong Kong or Singapore, ergonomics is included in the education of engineering and health professions, but not given full emphasis (Ng, 1976; Cilindro, 1985; Richardson, 1985). In the case of Tanzania, the lack of ergonomics training particularly for these professions has been noted (Vähäpasse, 1985). China is incorporating ergonomics programmes in the training of professionals in labour protection (Xu, 1985).

The training issue in developing countries goes beyond the problems of target groups and curricula. Major issues in ergonomics training concern the development of appropriate modules, teaching aids and materials to be used and their relevance to Third World situations (Manuaba, 1976, 1985a; Sen, 1984; Hiba, 1985). This means that education and training should be priority-based, action-oriented and applicable at various levels, from university to workers' education (Baloyi and Kuorinka, 1985). Sen (1984) also stressed the importance of practical demonstrations and symbolic language.

In terms of action-oriented training, importing ergonomics programmes may not realise the full potential of ergonomics in the Third World context (Wood, 1985; Holmer, 1986); it may be more cost-effective to apply limited resources to priority local needs. Training approaches are being developed in this direction, in addition to basic training and short introductory programmes mentioned above. These new approaches are represented by demonstration and participatory approaches.

Table 5. Examples of teaching hours reported in a survey in some Asian countries. From Kogi et al. *(1985).*

Course	India	Indonesia	Philippines	Singapore	Thailand
Undergraduate					
Engineering	45	12–16		2	
Management		12–16			
Medicine		6–8		1–2	
Health/Physiology	40				38
Forestry			60		
Short courses					
Management staff			2	16	
Safety and health personnel	9–30	2–4	2–4	12	
Forestry personnel			56		
Research workers	30–60				6
Various audience		20–50	3–6		

The demonstration approach is based on pilot activities which can demonstrate examples of ergonomic improvement. Usually, such pilot activities are undertaken at the initiative of an ergonomist or a group of trained people who can communicate with planners, managers and engineers and who have the knowledge and ability to investigate local ergonomics needs. Peacock and Evans (1982) reported the results of some case studies which took this approach. For example, an industrial engineering group studied problems of machine guarding in an electronics equipment firm in Hong Kong and tried out acceptable options for specific machines. Disadvantages of setting guards, such as increases in die-changing time, had to be carefully evaluated. This led to a project to mechanize many of the hand- and foot-operated presses. The emphasis on ergonomics training was concentrated on engineers who were in a position to implement changes.

This demonstration approach seems useful in securing the co-operation of people and agencies in key planning positions, as reported by Manuaba (1976, 1985a). He illustrated how buildings and furniture of certain offices were ergonomically designed and how these examples have helped spread the acceptance of ergonomics in Bali since 1977. Examples of successes were broadcast through television programmes. Student service teams in the community health programme partly undertook ergonomics improvements helping the village heads. He also reported difficulties met in supervising and maintaining the progress in villages. Similar impacts through the exchange of examples were noted by ergonomics units in different countries, as by Phoon (1976), Hoong and Ong (1980) and Richardson (1985) in Singapore, Sen (1984) and others in India, Sahbi (1983) in Tunisia or Hiba (1985) in Argentina.

The participatory approach is based on the direct involvement of managers, workers and other people. The learning-by-doing programme developed by the ILO proved effective in implementing improvements in ergonomics and the working environment in small enterprises in India, the Philippines and Thailand (Louzine, 1982; ILO, 1985b, 1986; Kogi, 1985b). The aim was to give practical advice and enable small enterprises to carry out improvements by self-help. The approach is based on the fact that while their needs are varied, small enterprises

Table 6. Low-cost examples of ergonomics improvements carried out by small-enterprise managers in learning-by-doing training courses. From ILO (1985b, 1986).

Marking and clearing passageways	Non-confusing displays
Improving housekeeping plans	Providing machine guards
Storage using vertical space	Better lighting and ventilation
Providing racks and pushcarts	Creating buffer stocks
Improving materials handling	Increasing communication
Adjusting working heights	Inserting short breaks
Providing good chairs	Providing drinking water
Improving machine feeding	Providing eating places

require practical technological advice at a basic level and empirical evidence (Chico, 1979; Louzine, 1982). The training programmes consisted of workshop sessions to discuss good examples, a checklist exercise and group work to carry out improvements during the programme period. The principles of the training approach thus established are: to build on local practice; to focus on achievements; to act on production-related problems where immediate action can be taken at low cost; to encourage exchange of experience; and to promote worker involvement (Kogi, 1985b,c; ILO, 1985b, 1986).

As shown in Table 6, this approach has led to a range of low-cost improvements. The use of audio-visual aids and a corrective checklist that listed low-cost measures proved useful. Paticularly important was the small group work. A similar approach could be used in a short course (ILO, 1985b). Horino (1985) also used a corrective checklist in problem-solving management training.

These new approaches may be characterized by their enabling methods which offer opportunities and means for the active involvement of managers, workers and other key people. It is interesting that enabling training can lead to immediate improvements in developing countries. Attention is drawn to its learning-by-doing process and the focus on low-cost improvements. Ergonomics in the Third World context will be able to play an increasingly important role if practical support is provided to facilitate multiple, voluntary action.

7. *Scope for ergonomics*

The above analysis of Third World ergonomics leads to the conclusion that the configuration of human work is affected by changing technologies and socio-cultural elements. This is shown in the design and use of equipment and the organization of work systems. Many of the negative effects of technological choices, including those by technology transfer, seem related to the lack of ergonomics considerations in the local context.

Since the 1970s, ergonomics research and practice have been gaining momentum in the developing world. An increasing number of reports show that there are numerous feasible solutions from an ergonomic point of view. Examples are found in traditional implements and activities as well as in the adaptation of transferred technologies. A range of benefits can be identified. Experiences in different Third World settings, now increasingly available, can and should be taken into account.

Particularly significant are the implications of varying interactions between work and people with different physical and cognitive features. Equipment and systems that may seem to work in an industrialized country may not be appropriate in a given setting in a developing country. Ergonomics needs can thus be different between countries or ethnic groups or between rural and urban areas. Climatic, anthropometric, nutritional and organizational differences also yield different needs. It will be necessary to establish an ergonomics data base to support application of ergonomics in different settings. The real problem, however, is the fact that it is unwise simply to copy ergonomics principles. In every process of work and equipment design, the local contexts of tasks, jobs, skills, career, organization and environment require review. The exchange of information on successes and failures in various Third World settings will therefore be of great help.

Further, the Third World settings require practical methods and procedures. Examples can be given of inexpensive, easy-to-apply and reliable methods and practical, solution-oriented procedures. Tailoring design processes to 'field ergonomics' with focuses on specific solutions will be important.

The scope for Third World ergonomics is considerable. It is too important to be left only to technologists or a small number of ergonomists. Education and training with emphasis on interdisciplinarity and participation are especially important. Appropriate and flexible training modules and materials must be developed for use in basic and vocational education and in on-the-job training of key people, managers and workers. Learning-by-doing type participatory programmes will be useful. Within the training, the focus should be on local practice, achievements, inexpensive solutions and exchange of experience. Opportunities should be widely available where various participants can utilize ergonomics.

References

Abeysekera, J. D. A., 1981, Thermal environment and subjective discomfort of glass-factory workers in Sri Lanka. *Journal of Human Ergology*, **10**, 185–192.

Abeysekera, J. D. A., 1985, A comparative study of body size variability between people in industrialised countries and industrially developing countries: impact on the use of imported goods. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Ahmed, I., 1979, Technologies for improved working conditions and environment in Philippine forestry. In *Technology to Improve Working Conditions in Asia* (Geneva: International Labour Office), pp. 98–114.

Awad El Karim, M. A., Collins, K. J., Brotherhood, J. R., Dore, C., Weiner, J. S., Sukkar, M. Y., Omer, A. H. S. and Amin, M., 1980, Quantitative egg excretion and work capacity in a Gezira population infected with *Schistosoma mansoni*. *American Journal of Tropical Medicine and Hygiene*, **29**, 54–61.

Ballal, M. A., Fentem, P. H., MacDonald, I. A., Sukkar, M. Y. and Patrick, J. M., 1982, Physical condition in young adult Sudanese: a field-study using a self-paced walking test. *Ergonomics*, **25**, 1185–1196.

Baloyi, R. S., 1985, Education and training in ergonomics. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Baloyi, R. S. and Kuorinka, I., 1985, Reporter's summary: theme IV. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Banerjee, S., 1962, Studies on energy metabolism. *Indian Council of Medical Research (New Delhi) Special Report No. 43*, 1–31.

Bar, O. and Ong, C. N., 1978, An ergonomic approach to industrial illumination. *Annals of the Academy of Medicine*, 7, 294–298.

Boxer, P. A., 1985, Occupational mass psychogenic illness. *Journal of Occupational Medicine*, 27, 867–872.

Broadbent, D. E., 1977, Language and ergonomics. *Applied Ergonomics*, **8**, 15–18.

Chakraborty, M. K. and Guharay, A. R., 1966, Aerobic working capacity of Indian miners. In *Proceedings of the International Symposium on Human Adaptability of Environmental Conditions and Physical Fitness* (Madras: Defence Institute of Physiology and Allied Sciences), pp. 107–119.

Chakraborty, M. K., Sensarma, S. K. and Mullick, P. K., 1979, Permissible limit for different mining work under various postural conditions. *Indian Journal of Physiology and Allied Sciences*, **33**, 54–64.

Chapanis, A., 1975, National and cultural variables in ergonomics. *Ergonomics*, **17**, 152–175.

Chew, P. K., Phoon, W. H. and Mae-Lim, H. A., 1976, Epidemic hysteria among some factory workers in Singapore. *Singapore Medical Journal*, **17**, 10–15.

Chico, L. V., 1979, Technology and small industry development: some premises. *ILO Tripartite Symposium on Choice of Technology and Employment Generation in Asia, Bangkok, 18–27 June 1979* (Geneva: International Labour Office).

Chung, K. C., 1985, Optimal workload of carrying as gauged by changes in heart rates. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Cilindro, C., 1985, Education and training in ergonomics in the Philippines: current situation, problems and trends. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Cilingir, F. C., 1985, Thermal comfort zone for tropical regions. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Collins, K. J., Brotherhood, R. J., Davies, C. T. M., Dore, C., Hackett, A. J., Imms, F. J., Musgrove, J., Weiner, J. S., Amix, M. A., El Karim, M., Ismail, H. M., Omer, A. H. S. and Sukkar, M. Y., 1976, Physiological performance and work capacity of Sudanese cane cutters with *Schistosoma mansoni* infection. *American Journal of Tropical Medicine and Hygiene*, 25, 410–421.

Corlett, E. N., 1968, A view of the contribution of the ergonomist in underdeveloped countries. *Human Factors*, **10**, 625–628.

Courtney, A. J., 1984, Hand anthropometry of Hong Kong Chinese females compared to other ethnic groups. *Ergonomics*, 27, 1169–1180.

Courtney, A. J., 1986, Chinese population stereotypes: color associations. *Human Factors*, 28, 97–99.

Courtney, A. J. and Evans, W. A., 1985, Bus cab design for Cantonese drivers. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Courtney, A. J. and Ng, M. K., 1984, Hong Kong female hand dimensions and machine guarding. *Ergonomics*, 27, 187–193.

Crockford, G. W., Sen, R. N. and Spencer, J., 1984, The design of work wear and protective clothing for use in the tropics, *Indian Journal of Physiology and Allied Sciences*, **38**, 125–133.

Daftuar, C., 1975, The role of human factors engineering in underdeveloped countries, with special reference to India. In *Ethnic Variables in Human Factors Engineering*, edited by A. Chapanis (Baltimore, MD: Johns Hopkins University Press), pp. 91–113.

Daftuar, C. N., 1977, Engineering psychology in cross-cultural settings. In *Basic Problems in Cross-Cultural Psychology*, edited by Y. H. Poortinga (Amsterdam: Swets and Zeitlinger), pp. 361–371.

Datta, S. R. and Ganguli, S., 1979, An ergonomic approach to the design of Indian hand-pulled carts (thelas). *Indian Journal of Physiology and Allied Sciences*, **33**, 102–106.

Datta, S. R., Chatterjee, B. B. and Roy, B. N., 1978, The energy cost of rickshaw pulling. *Ergonomics*, **21**, 879–886.

Davies, B. T. and Shahnawaz, H., 1977, An anthropometer for use in developing countries. *Ergonomics*, **20**, 317–320.

Davies, B. T., Abada, A., Benson, K., Courtney, A. and Minto, I., 1980, A comparison of hand anthropometry of females in three ethnic groups. *Ergonomics*, **23**, 179–182.

De, N. R., 1979, New forms of work organisation: India. In *New Forms of Work Organization*, vol. 2 (Geneva: International Labour Office), pp. 25–61.

Deregowski, J. B. and Dziurawiec, S., 1985, Some aspects of comprehension of technical diagrams: an intellectual study. *Travail Humain*, **49**, 43–60.

Dos Santos, N., 1985, *Analyse Ergonomique du Travail des Operateurs de Conduite dans une Salle de Controle du Trafic d'une Ligne de Metro*. These Doctorat d'Ergonomie CNAM, Paris (cited in Wisner, 1985a).

Dutta, S. R., Chatterjee, B. B. and Roy, B. N., 1979, Physiological responses during manual carrying of different loads on the head at different speeds. *Indian Journal of Physiology and Allied Sciences*, **33**, 94–100.

Dy, J., 1979, Technology to make work more human. In *Technology to Improve Working Conditions in Asia* (Geneva: International Labour Office), pp. 3–12.

Edholm, O. G., 1979, Work, heat and nutrition. *Indian Journal of Physiology and Allied Sciences*, **33**, 3–6.

Edholm, O. G., Fox, R. H., Adam, J. M. and Goldsmith, R., 1963, Comparison of artificial and natural acclimatisation. *Federation Proceedings*, **20**, 709–715.

Eriksson, R., Yllö, A. and Lundgren, N., 1974, *Thai Workers in Heavy Road Construction Activities: An Ergonomic Pilot Study* (Geneva: International Labour Office).

Evans, W. A. and Courtney, A. J., 1985, The collection, analysis and application of Cantonese anthropometric data. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Fischer, F. M., 1982, Working conditions of the shift workers of the metropolitan area Sao Paulo, Brazil. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 177–193.

Fischer, F. M., 1986, Absenteeism among shift workers of the automotive plants. In *Night and Shiftwork: Long-term Effects and their Prevention*, edited by M. Haider, M. Koller and R. Cervinka (Frankfurt: Verlag Peter Lang), pp. 189–196.

Gattan, K. M. and Saran, C., 1984, Safety and health of Islamic pilgrims in Saudi Arabia. In *Trends in Ergonomics/Human Factors*, vol. I, edited by A. Mital (Amsterdam: Elsevier), pp. 255–260.

Ghosh, A. K., Tibarewala, D. N., Dasgupta, S. R., Goswami, A. and Ganguli, S., 1980, Metabolic cost of walking at different speeds with axillary crutches. *Ergonomics*, **23**, 571–577.

Goswami, A., Ghosh, A. K., Ganguli, S. and Banerjee, A. K., 1984, Areobic capacity of severely disabled Indians. *Ergonomics*, **27**, 1267–1269.

Goswami, A., Ganguli, S., Bose, K. S. and Chatterjee, B. B., 1986, Anthropometric analysis of tricycle designs. *Applied Ergonomics*, **17**, 25–29.

Guharay, A. R., Dutta, P. K., Ray, S. N., Mitra, D. K. and Gupta, J. P., 1984, Ergonomics investigations on winding engine operators. *Indian Journal of Physiology and Allied Sciences*, **38**, 37–45.

Guharay, A. R., Roy, S. N., Dutta, P. K., Gupta, J. P., Mitra, D. K. and Chakraborty, M. K., 1979, Ergonomics and physiological studies on mine rescue workers. *Indian Journal of Physiology and Allied Sciences*, **33**, 86–92.

Haight, F. A., 1980, Traffic safety in developing countries. *Journal of Safety Research*, **12**, 50–58.

Haight, F. A., 1983, Traffic safety in developing countries: part 2. *Journal of Safety Research*, **14**, 1–12.

Hasle, P., Samathakorn, S., Veeradejkriengkrai, C., Chavalitnitikul, C. and Takala, J., 1986, *Survey of Working Conditions and Environment in Small Scale Enterprises in Thailand* (Bangkok: National Institute for the Improvement of Working Conditions and Environment).

Hiba, J. C., 1985, Progressis: a university approach for promoting ergonomics and working conditions. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Hiba, J. C. and de Luco, M. F., 1981, *Relevamiento Antropometrico de Poblacion Argentina: Un Estudio Piloto* (Rosario: Departmento de Diseno Industrial, Universidad Nacional de Rosario).

Hiba, J. C. and de Luco, M. F., 1982, *Analysis Ergonomico de Tres Mecanismos de Sujecion y Tres Tipos de Barbijos para Cascos de Proteccion* (Rosario: Departmento de Diseno Industrial, Universidad Nacional de Rosario).

Holmer, I., 1986, *Ergonomics at NICE* (Bangkok: National Institute for the Improvement of Working Conditions and Environment).

Holmer, I., Takala, J. and Chavalitnitikul, C., 1985, Recognition and implementation of ergonomics in Thailand. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Hoong, B. T. and Ong, C. N., 1980, *Improving our Working Environment: The Ergonomics Approach* (Singapore: National Productivity Board).

Horino, S., 1985, Application of an ergonomics check-list in problem-solving training. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Howard, J. K., 1982, Paraquat spraying: comparative risks from high and low volume spraying techniques. In *Proceedings of 10th Asian Conference on Occupational Health, 5–10 September, Singapore*, vol. 1, pp. 141–144

Htay Htay, P. L. and Mya-Tu, M., 1978, Habitual physical activity of rural Burmese women. *Ergonomics*, 21, 239–252.

Institute of Labor and Manpower Studies, 1979, *Checklist for Improving Working Conditions and Environment*, First Edition (Manila: Institute of Labor and Manpower Studies).

International Labour Office, 1982, *Occupational Safety, Health and Working Conditions and the Transfer of Technology* (Geneva: International Labour Office).

International Labour Office, 1983, *Report on the Asian Workshop on the Role and Potential of Ergonomics for Improvement of Working Conditions and Environment, Singapore, 13–16 September 1982* (Geneva: International Labour Office).

International Labour Office, 1984, *Improving Working Conditions and Environment: An International Programme (PIACT)* (Geneva: International Labour Office).

International Labour Office, 1985a, *Shift Work and Related Issues in Asian Countries* (Geneva: International Labour Office).

International Labour Office, 1985b, *Improvement of Working Conditions and Productivity in Small and Medium-sized Enterprises: Intensive Training Course and Short Training Course (Madras, October 1985), Proceedings* (Geneva: International Labour Office).

International Labour Office, 1986, *Improvement of Working Conditions and Productivity in Small and Medium-sized Enterprises: Training Course (Bangkok, 8–29 April 1986), Proceedings* (Geneva: International Labour Office).

Iskandar, A., 1985, Low back pain problems in lifting and carrying. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Kartawikarta, 1985, Exploration into acclimatisation potentials of hot-humid environments for enhancing work productivity. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Kavoussi, N., 1976, Ergonomics in traditional Iranian industries. *Journal of Human Ergology*, 5, 145–147.

Kennedy, W. K., 1975, International anthropometric variability and its effects on aircraft cockpit design. In *Ethnic Variables in Human Factors Engineering*, edited by A. Chapanis (Baltimore, MD: Johns Hopkins University Press).

Ketchum, L., 1984, Sociotechnical design in a Third World country: the railway maintenance depot at Sennar in the Sudan. *Human Relations*, 37, 135–154.

Khaleque, A. and Rahman, A., 1982, Sleep disturbances and health complaints of shift workers. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 155–164.

Khogali, M., 1969, Malnutrition and working efficiency with special reference to Sudanese workers. In *Ergonomics in Machine Design*, Vol. II (Geneva: International Labour Office), pp. 1011–1018.

Kiggundu, M. N., Jørgensen, J. J. and Hafsi, T., 1983, Administrative theory and practice in developing countries: a synthesis. *Administrative Science Quarterly*, 28, 66–84.

Kim, M. H., 1979, Some considerations on rural health problems from the ergonomics aspect in Korea. In *Proceedings of 9th Asian Conference on Occupational Health, Seoul*, pp. 175–176.

Kogi, K., 1977, Shift work in developing countries. *Philippine Labor Review*, 2(4), 29–40.

Kogi, K., 1982, Practical applications of an ergonomic checklist in work re-design. In *Proceedings of the Regional Seminars on Occupational Health and Ergonomics Application in Safety Control* (Singapore: Society of Occupational Medicine and National Safety First Council), pp. 137–141.

Kogi, K., 1985a, *Improving Working Conditions in Small Enterprises in Developing Asia* (Geneva: International Labour Office).

Kogi, K., 1985b, Participatory approach in applying ergonomics for workplace improvements in developing countries. In *Ergonomics International 85*, edited by I. D. Brown, R. Goldsmith, K. Coombes and M. A. Sinclair (London: Taylor & Francis), pp. 370–372.

Kogi, K., 1985c, Group assessment for finding practical ergonomic improvement: experience in some developing countries. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Kogi, K., 1986, Shift work in different occupations and different countries with special reference to its social aspects in developing countries. In *Night and Shift-work: Long-term Effects and their Prevention*, edited by M. Haider, M. Koller and R. Cervinka (Frankfurt: Verlag Peter Lang), pp. 141–148.

Kogi, K., Miura, T. and Saito, H. (eds), 1982, *Shiftwork: Its Practice and Improvement, Journal of Human Ergology*, **11**, Suppl., 541 pp.

Kogi, K., Horino, A., Manuaba, A., McPhee, B., Ong, C. N., Reyes, A. R. L., Sen, R. N. and Wongphanich, M., 1985, Trends in ergonomics training in Asian countries. *Eleventh Asian Conference on Occupational Health, Manila, 10–15 November 1985*.

Kunstadter, P., 1971, Ecological change and human biology in Northern Thailand. In *The Human Biology of Environmental Change*, edited by D. J. M. Vorster (London: International Biological Programme), pp. 21–30.

Kuorinka, I., 1983, Work capacities with respect to tropical climate and diseases. In *Proceedings of the First International Conference on Ergonomics of Developing Countries, Luleå, Sweden, June 16–17, 1983*, edited by H. Shahnavaz and M. Babri (Luleå: CEDC, Luleå University), pp. 77–85.

Kuorinka, I., 1985, The effect of the presentation of data and the quality of information on the practical application of ergonomics. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Lam, T. H., Ong, S. G., Wong, C. M., Lee, P. W. H. and Kleevens, J. W. L., 1985, Mental health and work stress in office workers in Hong Kong. *Journal of Occupational Medicine*, **27**, 199–205.

Louzine, A. E., 1982, Improving working conditions in small enterprises in developing countries. *International Labour Review*, **121**, 443–454.

Maciel, R. H., 1985, An ergonomics intervention on a data processing bureau. In *Proceedings of the International Symposium of Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Mahathevan, R., 1982, Overview of shift work in developing countries. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 139–145.

Maitra, S. R., 1979, Physiological changes during graded work. *Indian Journal of Physiology and Allied Sciences*, **33**, 7–10.

Malhotra, M. S., Ramaswamy, S. S., Dua, G. L. and Sengupta, J., 1966, Physical work capacity as influenced by age. *Ergonomics*, **9**, 305–316.

Manuaba, A., 1976, Problems of ergonomics in Bali, Indonesia. *Journal of Human Ergology*, **5**, 117–131.

Manuaba, A., 1979, Recent and future ergonomic problems in agriculture. In *Proceedings of 9th Asian Conference of Occupational Health, Seoul*, pp. 172–175.

Manuaba, A., 1982a, "Systems ergonomics" for safety control in Bali. In *Proceedings of the Regional Seminars on Occupational Health and Ergonomics Application in Safety Control* (Singapore: Society of Occupational Medicine and National Safety First Council), pp. 147–149.

Manuaba, A., 1982b, Shift work at hotels in Bali. In *Shiftwork: Its Practice and*

Improvement, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 147–153.

Manuaba, A., 1985a, Implementation of ergonomics at strategic points in development. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Manuaba, A., 1985b, Application of ergonomics to cope with strenuous and hazardous work in agriculture, forestry, plantation and cottage industries. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Maule, H. G., 1965, The application of industrial psychology to developing countries. *International Labour Review*, **92**(4), 1–15.

Meckassoua, K., 1985, *Etude Comparée des Activitiés de Regulation dans le Cadre d'un Transfer de Technologie (Brasserie)*. These Doctorat d'Ergonomie CNAM, Paris (cited in Wisner, 1985a).

Meshkati, N., 1985, A new technical group of the Human Factors Society: International Technology Transfer. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Moji, K. and Koyama, H., 1985, Application of a time-saving spot-check method to a Sundanese peasant community in West Java. In *Health Ecological Survey in Indonesia in 1983/84, Part I* (Shibukawa, Japan: Tanaka Publishing), pp. 98–103.

Muchtadi, F. I. and Danusugondho, I., 1985, Performance characteristics of the Indonesian human body during exercise at different ambient temperatures. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Nag, P. K., 1981, Predicting maximal oxygen uptake of workers engaged in agricultural tasks. *Journal of Human Ergology*, **10**, 25–31.

Nag, P. K. and Chatterjee, S. K., 1981, Physiological reactions of female workers in Indian agricultural work. *Human Factors*, **23**, 607–614.

Nag, P. K. and Dutt, P., 1979, Effectiveness of some simple agricultural weeders with reference to physiological responses. *Journal of Human Ergology*, **8**, 13–21.

Nag, P. K. and Dutt, P., 1980, Circulo-respiratory efficiency in some agricultural work. *Applied Ergonomics*, **11**, 81–84.

Nag, P. K. and Sen, R. N., 1979, Energy cost of some heavy manual work in Bengal. *Indian Journal of Physiology and Allied Sciences*, **33**, 122–127.

Nag, P. K., Sebastian, N. C., Ramanathan, N. L. and Chatterjee, S. K., 1978, Maximal oxygen uptake of Indian agricultural workers with reference to age and sex. *Journal of Madurai Kamaraj University*, 7(2), 69–74.

Nag, P. K., Sen R. N. and Ray, U. S., 1979, Cardio-respiratory performance of porters carrying loads on a treadmill. *Ergonomics*, **22**, 897–907.

Nag, P. K., Sebastian, N. C. and Malvankar, M. G., 1980a, Occupational workload of Indian agricultural workers. *Ergonomics*, **23**, 91–102.

Nag, P. K., Sebastian, N. C. and Malvankar, M. G., 1980b, Effective heat load on agricultural workers during summer season. *Indian Journal of Medical Research*, 72, 408–415.

Nag, P. K., Panikar, J. T., Malvankar, M. G., Pradhan, C. K. and Chatterjee, S. K., 1982, Performance evaluation of lower extremity disabled people with reference to hand-cranked tricycle propulsion. *Applied Ergonomics*, **13**, 171–176.

Nag, P. K., Chintharia, S., Saiyed, S. and Nag, A. 1985a, EMG signals in sitting work postures in women. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva:

International Labour Office).

Nag, P. K., Pradhan, C. K. and Goswami, A., 1985b, *Ergonomics in Railway Track Maintenance Work* (Ahmedabad: National Institute of Occupational Health).

Najoan, H., 1985, Ergonomic aspects in planning of various product designs. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

National Institute of Design, 1985, *Co-ordination Seminar on Ergonomics, 15–16 October 1985, A Report of the Proceedings* (Ahmedabad: National Institute of Design).

Naveiro, R. M. and Medeiros, E. N., 1985, Combine harvester cab design: a case study. In *Ergonomics International 85*, edited by I. D. Brown, R. Goldsmith, K. Coombes and M. A. Sinclair (London: Taylor & Francis), pp. 811–813.

Ng, T. K. W., 1976, Some observations on the needs of ergonomics in industries in Hong Kong. *Journal of Human Ergology*, 5, 149–159.

Nkurlu, J. I., 1985, Ergonomics in the rural sector: Tanzanian example. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Ohashi, N., 1985, Cross-cultural conflicts in overseas working situations in Asia. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Ong, C. N. and Hoong, B. T., 1982, Shift work in manufacturing industries in Singapore. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and K. Saito, *Journal of Human Ergology*, **11**, Suppl., 209–216.

Ong, C. N. and Phoon, W. O., 1986, Influence of age on VDU work. In *Working with VDUs*, edited by B. Knave and P. G. Wideback (Amsterdam: Elsevier).

Ong, C. N., Hoong, B. T. and Phoon, W. O., 1981, Visual and muscular fatigue in operators using visual display terminals. *Journal of Human Ergology*, **10**, 161–171.

Ong, C. N., Phoon, W. O., Tan, T. C., Jeyeratnam, J., Cho, K. S., Suma'mur, P. K., Mahathevan, R., Reverente, B. R., Wongphanich, M. and Kogi, K., 1984, A study of work injuries in eight Asian countries. *Annals of the Academy of Medicine*, **13**(2), Suppl., 429–434.

Peacock, B. and Evans, B., 1982, A comparison of the ergonomic and motivational approaches to safety. In *Proceedings of the Regional Seminars on Occupational Health and Ergonomics Application in Safety Control* (Singapore: Society of Occupational Medicine and National Safety First Council), pp. 142–146.

Perera, S. E. G., 1982, Industrial shift and night work practices in Asian developing countries. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, 11, Suppl., 201–208.

Phoon, W. O., 1976, Application of ergonomic principles in the factories of a developing country. *Journal of Human Ergology*, 5, 161–166.

Phoon, W. O., 1982, The use of ergonomics for traditional industries. *ILO Asian Regional Workshop on the Role and Potential of Ergonomics for Improvement of Working Conditions and Environment, Singapore, 13–16 September 1982.*

Phoon, W. O. and Ong, C. N. (eds), 1985, *Occupational Health in Developing Countries in Asia* (Tokyo: South-East Asian Medical Information Center).

Pinnagoda, P. V. C., 1976, Ergonomics for occupational hygienists in developing countries with examples from Sri Lanka. *Journal of Human Ergology*, 5, 167–172.

Pradhan, C. K., Goswami, A., Ghosh, S. N. and Nag P. K., 1985, Ergodesign and physiological valuation of spade work. In *Proceedings of the International Sym-*

posium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985 (Geneva: International Labour Office).

Pulket, C. and Kogi, K., 1984, Fatigue of visual display unit operators in the free break system. In *21st International Congress on Occupational Health, 9–14 September 1984, Dublin, Ireland: Abstracts*, edited by I. E. Eustace, p. 364.

Qian, H., 1985, Ergonomics in labour protection. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Rachedi, Y., 1986, La lecture de plans dans le batiment: representations au cours de processus de realisation. *Travail Humain*, **49**, 31–41.

Ramanathan, N. L. and Nag, P. K., 1982, Energy cost of human labour in India. *ASCI Journal of Management*, **11**, 110–132.

Rasyid, R. and Siswanto, A., 1985, The effects of illumination on productivity, In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Reverente, B. R. and Ariosa, L., 1982, Sickness absence among shift workers in an industrially developing country. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 195–200.

Richardson, S., 1985, Ergonomics in Singapore: 1967 onwards. In *Proceedings of the International Symposium of Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Saha, P. N., 1985a, Anthropometric characteristics among industrial workers in India. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Saha, P. N., 1985b, Manual work and workload in different industries in India. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Saha, P. N., Datta, S. R., Banerjee, P. K. and Narayani, G. G., 1979, An acceptable workload for Indian Workers. *Ergonomics*, **22**, 1059–1071.

Sahbi, N., 1983, Anthropometric measurements and work analysis related to modern technology used in the Tunisian phosphate mines. In *Proceedings of the First International Conference on Ergonomics of Developing Countries, Luleå, Sweden, June, 16–17, 1983*, edited by H. Shahnavaz and M. Babri (Luleå, Sweden: CEDC, Luleå University), pp. 96–125.

Samanta, A. and Chatterjee, B. B., 1981, A physiological study of manual lifting of loads in Indians. *Ergonomics*, **24**, 557–564.

Sebastian, M., 1985, Ergonomics in industry. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Sen, R. N., 1964, Some anthropometric studies on Indians in a tropical climate. In *Proceedings of the Symposium on Environmental Physiology and Psychology in Arid Conditions*, a special issue of *Arid Zone Research*, **24**, 163–174.

Sen, R. N., 1965, Physical environmental factors affecting health of workers in industry. *Indian Labour Journal*, **6**, 735–746.

Sen, R. N., 1966, Studies on tolerance to dry and wet heat on industrial occupations in India. In *Proceedings of the International Symposium on Human Adaptability to Environmental Conditions and Physical Fitness* (Madras: Defence Institute of Physiology and Allied Sciences), pp. 73–81.

Sen, R. N., 1982a, Certain ergonomic principles in the design of factories in a hot climate. In *Proceedings of the International Symposium on Occupational Safety,* *Health and Working Conditions Specifications in Relation to Transfer of Technology to the Developing Countries* (Geneva: International Labour Office), pp. 123–147.

Sen, R. N., 1982b, Application of ergonomics in the design of factories and equipment for tropical conditions. Presented at *Asian Workshop on the Role and Potential of Ergonomics for Improvement of Working Conditions and Environment, Singapore, 13–16 September 1982.*

Sen, R. N., 1983, Physiological adaptation of people in tropical countries in some of their anthropometric dimensions in relation to thermoregulation. In *Proceedings of the International Conference on Human Genetics and Adaptation, 1–5 February 1982*, Vol. 2 (Calcutta: Indian Statistical Institute), pp. 149–156.

Sen, R. N., 1984, Application of ergonomics to industrially developing countries. *Ergonomics*, **27**, 1021–1032.

Sen, R. N. and Chakraborti, D., 1984, A new ergonomic design of a 'Desi' plough. *Indian Journal of Physiology and Allied Sciences*, **38**, 95–105.

Sen, R. N. and Chakraborti, D., 1985, A new ergonomic "float-seat" for improvement of paddy cultivation in India. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Sen, R. N. and De, A., 1984, Ergonomics of sheafing task in paddy cultivation in India. *Indian Journal of Physiology and Allied Sciences*, **38**, 85–93.

Sen, R. N. and Dutta, N. C., 1985, An ergonomic design of low-cost protective work clothing for furnace workers. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Sen, R. N. and Ganguli, A. K., 1982, Preliminary investigation into the loco-man factor in the Indian railways. *Applied Ergonomics*, **13**, 107–117.

Sen, R. N. and Ghoshthakur, D., 1984, Ergonomic study on work-rest cycle, physiological responses and production rate of handloom-weavers in West Bengal. *Indian Journal of Physiology and Allied Sciences*, **38**, 47–53.

Sen, R. N. and Kar, M. R., 1978, Circadian rhythms in some groups of Indians working in shifts. *Journal of Human Ergology*, **7**, 65–79.

Sen, R. N. and Kar, A., 1984, An ergonomic study on bamboo handicraft workers. *Indian Journal of Physiology and Allied Sciences*, **38**, 69–77.

Sen, R. N. and Majumdar, D., 1982, Ergonomics in relation to occupational safety and health in jute industries in Eastern India. In *Proceedings of 10th Asian Conference on Occupational Health, 5–10 September 1982, Singapore*, pp. 289–298.

Sen, R. N. and Nag, P. K., 1973, Are the Calcutta public buses ergonomically designed? *Indian Journal of Physiology and Allied Sciences*, **27**, 156–157.

Sen, R. N. and Nag, P. K., 1975, Work organisation of heavy load handling in India. *Journal of Human Ergology*, **4**, 103–113.

Sen, R. N. and Nag, P. K., 1979, Optimal work load for Indians performing different repetitive heavy manual work. *Indian Journal of Physiology and Allied Sciences*, **33**, 18–25.

Sen R. N. and Sarkar, D. N., 1979, Occupational daily work load for Indian industrial workers at three different thermal conditions. *Indian Journal of Physiology and Allied Sciences*, **33**, 78–83.

Sen, R. N., Nag, P. K. and Ray, G. G., 1977, Some anthropometry of people of Eastern India. *Journal of Indian Anthropological Society*, **12**, 199–206.

Sen, R. N., Kar, M. R., Roy, J. K. and Ganguly, A. K., 1982, Individual differences in adapting to shift work. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 57–65.

Sen, R. N., Ganguli, A. K., Ray, G. G., De, A. and Chakraborti, D., 1983, Tea-leaf plucking: workloads and environmental studies. *Ergonomics*, **26**, 887–893.

Sen Gupta, J., Dimri, G. P. and Malhotra, M. S., 1977, Metabolic responses of Indians during sub-maximal and maximal work in dry and humid heat. *Ergonomics*, **20**, 33–40.

Sepliarsky, E. R. and Esterick, C. M., 1983, Rediseno e integracion de un puesto de trabajo para el fileteado de vajilia de porcelana. *First Seminar on Optimisation of Working Places, Rosario, 1983*.

Setiawati, D., 1985, Improvement of productivity in labour-intensive projects through food intervention as an aspect of ergonomics. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Shahnavaz, H., 1984, The importance of ergonomics in developing countries. In *Ergonomics in Developing Countries*, edited by H. Shahnavaz and H. Babri (Luleå, Sweden: Luleå University Press), pp. 4–27.

Shahnavaz, H., 1985a, The role of ergonomics in development. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Shahnavaz, H., 1985b, Ergonomics of developing countries, do we need a different approach? In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Shahnavaz, H. and Gilroy, L., 1985, Exchange of ergonomics information on industrially developed countries. In *Ergonomics International 85*, edited by I. D. Brown, R. Goldsmith, K. Coombes and M. A. Sinclair (London: Taylor & Francis), pp. 853–855.

Shahnawaz, H. and Davies, B. T., 1977, Anthropometric study of Iranian steel workers. *Ergonomics*, **20**, 651–658.

Shahnawaz, H. and Tuxworth, W., 1978, The physical working capacity of Iranian steel workers. *Ergonomics*, **21**, 63–71.

Shan, H. S., 1985, An ergonomic appraisal of wheat threshing machine. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Siahaan, O., Yusuf, A. and Chaer, H. A., 1985, Consumption and expenditure of calories among palm oil harvesters. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Sinaiko, H. W., 1975, Verbal factors in human engineering: some cultural and psychological data. In *Ethnic Variables in Human Factors Engineering*, edited by A. Chapanis (Baltimore, MD: Johns Hopkins University Press).

Soedirman, 1985, Anthropometric measurement by Suma'mur's tailor method and by the use of an anthropometer. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva International Labour Office).

Soemarna, N., 1985, Heat stress in a railway workshop. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Stephaneck, P. and Donadi, D. C., 1981, Essai d'appreciation de la gravité subjective des accidents du travail: application dans deux milieux différents selon le niveau de developpement industrial. *Travail Humain*, **44**, 241–250.

Strydom, N. B. and Holdsworth, L. D., 1968, The effects of different levels of water deficit on physiological responses during heat stress, *Internationale Zeitschrift für angewandte Physiologie einschliesslich der Arbeitsphysiologie*, **26**, 95–102.

Strydom, N. B., Wyndham, C. H. and Benade, A. J. S., 1971, The responses of men weighing less than 50 kg to the standard climatic room acclimatization procedure. *Journal of the South African Institute of Mining and Metallurgy*, **72**, 101–104.

Sudijono, 1985, A case study on the effectiveness of traffic signals at railway road level crossings. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Suma'mur, P. K., 1985a, Ergonomics in the national development programmes. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Suma'mur, P. K., 1985b, Anthropometric data in Indonesian working populations in the industrial sector. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Sumicad, R. O. and Canela, E. Q., 1979, Socio-technological impacts of low-cost automation (LCA) technology in Philippines small manufacturing enterprises. In *Technology to Improve Working Conditions in Asia* (Geneva: International Labour Office), pp. 51–63.

Susanto, G. and Koenhendarso, S., 1985, Rest time in refinery operators. In *Proceeding of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Sutarman, 1985, The role of ergonomics in development. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Suzuki, S., 1982, Conjunctivitis due to cultivation work observed among Indonesian peasants. In *Proceedings of 10th Asian Conference on Occupational Health, 5–10 September 1982, Singapore*, Vol. 1, pp. 187–192.

Suzuki, S. and Soemarwoto, O., 1985, *Health Ecological Survey in Indonesia in 1983/84, Part I* (Shibukawa, Japan: Tanaka Publishing).

Takala, J. S., 1982, Occupational accidents in developing countries. *Journal of Occupational Accidents*, **4**, 361–369.

Tan, T. C. and Ong, C. N., 1982, Chronic fatigue in female keypunch operators, work related, and/or menses related. In *Proceedings of 10th Asian Conference on Occupational Health, 5–10 September 1982, Singapore*, pp. 239–246.

Thompson, D., 1972, The application of ergonomics to developing countries. *Applied Ergonomics*, **3**, 92–96.

Tuxworth, W. and Shahnawaz, H., 1977, The design and evaluation of a step test for the rapid prediction of physical work capacity in an unsophisticated industrial work force. *Ergonomics*, **20**, 181–191.

Vähäpasse, A. E. E., 1985, Ergonomic needs in Tanzania. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Van Graan, C. H. and Strydom, N. B., 1968, Temperature changes within hard hats as affected by ventilation holes. *Internationale Zeitschrift für angewandte Physiologie einschliesslich der Arbeitsphysiologie*, **26**, 282–289.

Wisner, A., 1985a, Ergonomics in industrially developing countries. *Ergonomics*, **28**, 1213–1224.

Wisner, A., 1985b, *Quand Voyagent les Usines* (Paris: Syros).

Wiwoho, H., Indro, S. and Gatot, S., 1985, The design of control rooms in Pertamina as seen from the ergonomic view. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Wood, J., 1985, The ergonomist advising in a developing country. In *Ergonomics International 85*, edited by I. D. Brown, R. Goldsmith, K. Coombes and M. A. Sinclair (London: Taylor & Francis), pp. 856–858.

Wongphanich, M., 1984, *Study on Health and Safety Conditions of Manufacturing Industry: An Exemplification of Model Types in Japan and Thailand With Recommendations for Improvement* (Tokyo: Asian Productivity Organisation).

Wongphanich, M., Saito, H., Kogi, K. and Temmyo, Y., 1982, Conditions of working life of women textile workers in Thailand on day shift work systems. In *Shiftwork: Its Practice and Improvement*, edited by K. Kogi, T. Miura and H. Saito, *Journal of Human Ergology*, **11**, Suppl., 165–175.

World Health Organization, 1983, *The Application of Ergonomics in Developing Countries* (Geneva: World Health Organization).

Wyndham, C. H., 1962, Tolerable limits of air conditions for men at work in hot mines. *Ergonomics*, 5, 115–122.

Wyndham, C. H., 1973, The work capacity of rural and urban Bantu in South Africa. *South African Medical Journal*, 47, 1239–1244.

Wyndham, C. H. and Heyns, A. J., 1969, Determinants of oxygen consumption and maximum oxygen intake of Bantu and Caucasian males. *Internationale Zeitschrift für angewandte Physiologie einschliesslich der Arbeitsphysiologie*, 27, 51–75.

Wyndham, C. H., Strydom, N. B., Morrison, J. F., Peter, J., Maritz, J. S. and Ward, J. S., 1962, The influence of a stable diet and regular work on body weight and capacity for exercise in African mine recruits. *Ergonomics*, 5, 435–444.

Wyndham, C. H., Strydom, N. B., Morrison, J. F., Peter, J., Williams, C. G., Bredell, G. A. G. and Joffe, A., 1963, Differences between ethnic groups in physical working capacity. *Journal of Applied Physiology*, **18**, 361–366.

Xu, B. H., 1985, China's ergonomical research in labour protection. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

Yadav, B. G. and Gite, L. P., 1982, Ergonomics in agricultural engineering in India. In *The 8th Congress of the International Ergonomics Association, 23–27 August 1982, Tokyo, Japan*, edited by K. Noro (Tokyo: Japan Ergonomics Research Society), pp. 528–529.

Yusuf, M., 1985, Improvement of productivity through the change in workbenches. In *Proceedings of the International Symposium on Ergonomics in Developing Countries, Jakarta, 18–21 November 1985* (Geneva: International Labour Office).

About the authors

Kazutaka Kogi, Regional Adviser on Conditions of Work and Welfare Facilities, International Labour Organisation Regional Office for Asia and the Pacific in Bangkok, graduated from the Faculty of Medicine of the University of Tokyo in 1957 and obtained a medical licence in 1958. Thereafter he worked as a research member at the Laboratory of Work Physiology of the Institute for Science of Labour in Tokyo until 1965 when he moved to the Railway Labour Science Research Institute in Tokyo. He was a research fellow at the Max-Planck Institut für Arbeitsphysiologie in Dortmund from 1962 to 1964. Returning to the Institute for Science of Labour in Kawasaki in 1978, he worked as a Research Chief at the Division of Work Physiology and Psychology undertaking field and

p 40

experimental studies on ergonomics. From 1980 to 1981 he served as Senior Research Officer (Ergonomics) at the Working Conditions and Environment Department of the International Labour Office in Geneva. In 1983, he rejoined the ILO as Regional Adviser on Conditions of Work and Welfare Facilities responsible for Asia and the Pacific.

Rabindra Nath Sen is University Professor presiding over the Ergonomics Laboratory at the Department of Physiology, University Colleges of Science, Technology and Agriculture in Calcutta. He graduated from Calcutta University in 1952 as a Bachelor of Science and received his Master of Science in 1954 and Doctor of Science in 1961. He worked as Lecturer and Assistant Professor of Physiology at Presidency College in Calcutta from 1958 to 1962. He served as Head, Industrial Physiology Division in the Central Labour Institute in Bombay from 1962 to 1967. He became a faculty member at the Department of Ergonomics and Cybernetics, University of Technology in Loughborough from 1967 to 1970. Returning to Calcutta University in 1970, he has been guiding research for Master of Science and Doctorate degree students in physiology up to the present time. He has conducted a number of field studies on ergonomics aspects of Indian workers and organized international symposia in Calcutta in 1974 and 1983. He gave the Ergonomics Society's Lecture 1983 on the application of ergonomics to industrially developing countries.

ITSTT/1981/III

INTERNATIONAL LABOUR OFFICE

INTERNATIONAL PROGRAMME FOR THE IMPROVEMENT OF WORKING CONDITIONS AND ENVIRONMENT (PIACT)

Inter-regional Tripartite Symposium on Occupational Safety, Health and Working Conditions Specifications in relation to Transfer of Technology to the Developing Countries

(Geneva, 23-27 November 1981)

CERTAIN ERGONOMIC PRINCIPLES IN THE DESIGN OF FACTORIES IN HOT CLIMATES

CERTAIN ERGONOMIC PRINCIPLES IN THE DESIGN OF FACTORIES IN HOT CLIMATES

from a paper by

Dr. Rabindra Nath Sen, B.Sc. (Hons.),
M.Sc., D.Sc. (Cal.), FIIST

Dr. R.N. Sen is Head of the Ergonomics Laboratory,
Department of Physiology,
Calcutta University,
India.

INTRODUCTION

The purpose of the present paper is to examine the application in hot climates of certain scientific and technological developments in connection with the design of industrial buildings where people work. The technological developments that have already changed the pattern of work, the leisure activity and the way of life of many people will undoubtedly affect many more in the coming decade, and it is essential to consider their influence on the human environment so that a total solution for the proper design of the working environment to achieve optimal efficiency, health, comfort, safety and production is attained.

In the Report[1*] of the Director-General, International Labour Office, Geneva, to the International Labour Conference in 1975, the importance of humanising working conditions and environment and the application of ergonomic principles to achieve these have been discussed. The necessity of taking proper measures in developing countries was also stressed, especially to avoid some of the ill-effects of industrialisation in advanced countries, to ensure that benefits for the many are not brought at the peril of the few.

It may appear that the requirements for an ideal environment for machines, such as the proper conditions of temperature, humidity, ventilation, cleanliness, lighting, etc., may be the same for the human operator. However, many workplaces which may serve the needs of the machines with great efficiency fail to provide the essential requirements of the human workers. A human being is immensely affected by the size, shape, pattern, colour or aesthetic qualities of his surroundings, while a machine is entirely unaffected.

It is not enough for buildings in which people work to be conceived as ideal enclosures for sophisticated plants, expensive equipment and complicated machinery. It is not sufficient for a factory or an office building to be just a shell designed around a production flow diagram. The production flow in a modern factory and the work pattern in an office may be of vital importance but the environment in which the workers carry out their tasks is even more important.

The amenities in the form of rest and recreational areas, canteens and other personal facilities are needed by the human operator but not by the machines. The average human worker requires a complete change of environment after a period of at least two hours for mental and physical relaxation and recovery, which are not necessary for the machines.

Human beings will always be required to control, operate and maintain the hardware of industry and commerce, and their safety, health, standard of living, comfort, welfare, efficiency and productivity all depend to a considerable extent on the environment in which they work.

Our society, which is rapidly being changed, must not only be technologically advanced for its survival - it must also be a truly human society. In order to achieve this goal, the builders of the working environment must take into consideration the way in which space, both within and around buildings, is created, and the shapes, sizes, patterns and colours of the space that affect the people and their ways of living - work and recreation.

Today, part of the industrial unrest which is affecting most of the industrialised countries of the world is due to the unbalanced advance of the technological progress with new machinery, new techniques and new materials being put into use often without any proper consideration or understanding of the human problems involved. Because of this, the development may well become self-defeating, for it is of little use devising means of vastly increasing production which may result in industrial strikes, non-cooperation of workers and misery for man and society. How a person lives and how he is affected by his surroundings at work and at home are of paramount importance; imposed life patterns are dangerous, affecting health and behaviour, and creating social unrest, labour turnover, etc. The problems of the working environment in hot climates are even more numerous and of higher magnitude than those in cold climates. Unless correct measures are taken at the very beginning of the design of the working environment, especially in hot climates in the developing countries, so that the creation of workplaces which are physically and mentally satisfying as well as efficient and economic is initiated, it may be too late to do much at later stages or it may be too costly to effect modifications, if at all possible.

---

* For notes see end of paper.

Those who build factories and office buildings seldom used to consider the use of the principles of ergonomics (the science and technology of men at work)[2] with special reference to the effects that rooms, spaces and buildings have on people and their performance. A factory building may be suitable for today's needs but would almost certainly be inadequate for the needs of the future.[3]

In cold climates, workspaces with deep internal areas without windows and in a totally artificial and fully controlled internal environment in a building envelope designed as a solid block with multistoreyed structure due to site limitations or other factors are quite common, since these are more economical and can have more efficient use of available floorspace and the advantage of reclaiming wasted heat from lighting fittings, people, equipment, etc., for air conditioning. With a totally integrated artificially controlled environment, the window ceases to play an important part in providing either light or ventilation. Many of the factories in tropical countries are unfortunately merely copies of the design of the factories built earlier in cold climates and hence not appropriate to what is required for such an environment. Even the design of public buses in hot climates[4,5] are merely copies of those used in cold climates. As a result, the designs which were suitable for providing a warm climate inside the vehicle or factory environment in cold climates were most unsuitable for those in tropical climates, especially when there is a large amount of heat produced on some shop floors, such as in glass, steel and similar hot industries. Many of the new types of factory buildings, therefore, are worse than those found with traditional factory buildings in hot climates.

While standards of industrial building designs in cold climates in developed countries have been rising in urban situations and on isolated sites, most of the designs of industrial buildings in hot climates in developing countries in both urban and rural situations remained in the form of large corrugated iron or asbestos sheds linked only by open space or concrete yards, road or railway lines, waste lands and dumps of materials.

The architect should design the factory buildings in such a way as to bring out the best of the natural possibilities. The task of environmental control is to ensure the best possible indoor thermal conditions by relying on structural (passive) controls, which may obviate the need for any mechanical (active) controls; but even if mechanical controls have to be used, their task will thereby be reduced to a minimum.

APPLIED ERGONOMICS IN FACTORY DESIGN IN HOT CLIMATES

Four basic determining elements in every design problem are function, form, fabricating material and finance. An ergonomist must bring a harmony between these elements in the design of factories for hot climates.

Some of the theoretical aspects of the industrial design of the working environment and factory organisation from the viewpoints of architecture and ergonomics, including psychological aspects, have been discussed earlier.[6,7,8]

An ergonomic study[9] to help design the buildings of a drug factory and also an estate for pharmaceutical industries under the Government of West Bengal in India was undertaken by the Ergonomics Laboratory of Calcutta University, based on some of the principles of ergonomics discussed in the present paper.

The important factors in the proper design of the factories are:

(1) the site in relation to human habitation, landscape, vegetation, altitude, etc.; whether near the periphery of a town or in rural situations or in a valley, etc.; to protect from flood, earthquakes, storms, insects, termites, etc.; to avoid inversion temperature, pollution, etc.; to have good ventilation, low humidity, etc.;

(2) the orientation of the buildings, including roofs, walls, windows, etc., in relation to the wind direction, angle of solar radiation, etc.; to have the best natural ventilation and minimal thermal heating of the buildings, in relation to human comfort, activity and efficiency;

(3) the insulation and thermal capacities of the building materials;

(4) the use of sound material and the form of construction;

(5) correct design of workspace, windows, doors, stairs, corridors, etc., based on the static and dynamic body measurements and motion of the workers.

It is so obvious that the types of factory buildings and building materials for cold climates cannot solve the problems of factories in countries where heat is the dominant problem, where, due to economic reasons, the consequences of poor design cannot be compensated by very costly mechanical air conditioning, and where the workers differ in body form, thermal responses, etc.

Design in relation to meteorological conditions, site, location and layout of surroundings

It is very important for the location and design of factory buildings to consider the meteorological data over the years concerning rain, temperature, sunshine, humidity, speed and direction of wind and smog, etc. If the yearly data are not recorded and analysed, it is essential to have at least data for 12 months for selection of sites and design of factory buildings. Analyses of many of the elements of micro-climate have a deciding role on the site and location of factory buildings, particularly in tropical climates.

Normally, the climate is about 1.5°C cooler for every 300 m elevation in altitude and the factory buildings are more exposed to greater wind speeds, though there may be slightly more solar radiation due to less absorption.

Open, flat or convex sides of the land have the advantage of higher wind speed, but the solar radiation may be greater due to reflection on the surfaces. In contrast, concave forms, such as valleys and hollows, generally have greater mean day temperature, less wind speed and lower night temperature. There are also possible effects of temperature inversion in valleys (Fig. 1). In temperature inversion the normal temperature gradient from warm air near the ground to cold upper air is reversed and cold air is held below a layer of warmer air. This condition, usually invisible, occurs frequently and even in flat sites, as shown in Fig. 2. When this happens the polluted air cannot rise, and so will be trapped near the ground level. It is obvious that factory chimneys of inadequate height in an area of frequent temperature inversions can be a regular source of nuisance.

If an industry is allowed to be situated in the middle of the valleys to gradually spread out until all flat land is filled, it may cause clouds of dusts and smoke to hang over the valleys, as presented in Fig. 3.

The Katabatic flows of air and temperature inversions in valleys are to be considered. The flow of cold air down valley sides occurs in frequent flushes. Regional winds are deflected as a down-wash into a valley and these often carry smoke and fumes down to the floor of the valley.

Local features, including the different types of buildings can substantially modify the air movement and air temperature of the working environment. In olden days, heavy-weight stone or brick buildings with high thermal capacity and with high ceilings were being used in tropical climates to provide comfortable conditions during the summer months as well as in winter. Nowadays, because of the costs, very light-weight buildings with low thermal capacity and with thin concrete slabs are being used, which could heat up quickly during the day and cool down quickly during the night. When large glass windows are provided to increase the natural daylight, it facilitates entry of solar radiation also, which warms the surfaces inside the room, which in turn re-radiate, and this results in the uncomfortable conditions experienced inside the building.

It would be very useful for the designer to know the time of the day and the frequency of observations of sky conditions. A single average figure giving the sky conditions for a typical day of a given month may not reveal significant differences, e.g., between morning and afternoon conditions, which may affect the design of roofs, overhangs and shading devices.

It is important to know the frequency, likely duration and nature of some rare events such as dust storms, thunder storms, earthquakes, tornadoes, hurricanes, floods, etc., since the designer must classify these rare events into those which affect human comfort and those which may endanger the safety of the factory

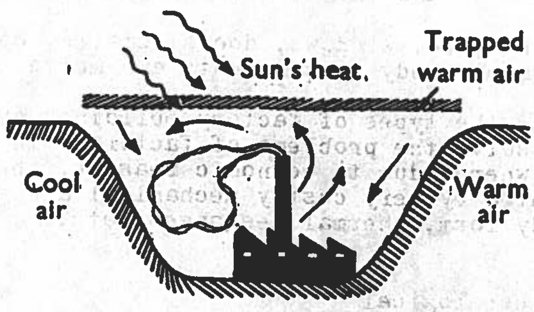


Fig. 1: Possible effects of temperature inversion for a factory in a valley.

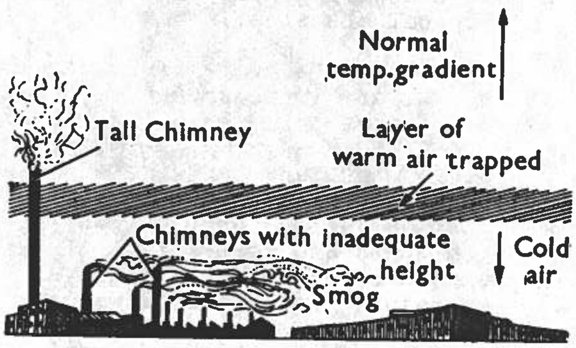


Fig. 2: The effects of a temperature inversion in trapping fine dusts, smoke and fumes near to ground level. Very tall chimneys or stacks only are able to penetrate the inversion layer and discharge their fumes in the rising air.

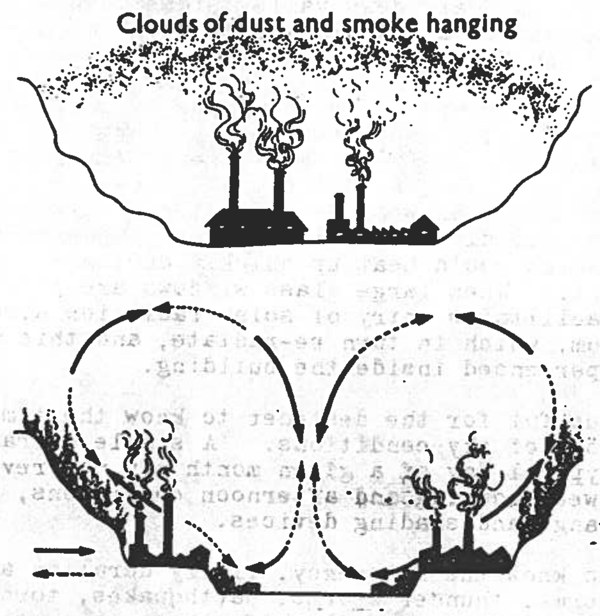


Fig. 3: When factories are built in the middle of valleys, it may cause clouds of dusts and smoke to hang over the valley.

buildings and the lives of the workers. Vegetation, though generally regarded as a function of climate, can influence the local or site climate of a factory. It is an important element in the design of outdoor spaces, providing sun-shading and protection from glare.

The nature and extent of climatic deviations and also their likely effects on the intended building should be assessed early in the design stage, before one is committed to a certain solution which may prove to be difficult to rectify.

There is always a reduction in wind speeds near to the ground - down to 40 per cent over rough terrain and 30 per cent in urban centres - but under certain conditions with less slopes, funnelling, sharp ridges and solid obstructions, wind speed may increase due to suction, turbulence and vortexes as shown in Fig. 4. It is possible to locate sites which would experience a considerable degree of natural wind. The wind velocity on urban sites is reduced to less than half of that in the adjoining open country, but the funnelling effect along a closely built-up street or through gaps between tall building blocks can be more than double the velocity, as presented in Fig. 5. At the leeward corners of obstructions, strong turbulences and eddies can also be set up.

Wind speed can be reduced by 50 per cent by a long horizontal barrier at a distance of ten times the height and by 25 per cent at a distance of about 20 times the height. Hedges, shrubs and trees act as screens to reduce wind speeds near the ground, while having sufficient permeability to prevent excessive turbulence (Fig. 4). Trees reduce dust movement, give a "green" outlook from windows and provide desirable shade from solar radiation. A tall hedge or thick belt of shrubs above eye-level isolates the pedestrian worker or passerby from the mass of industrial plant or buildings. The advantages and disadvantages of trees, hedges, shrubs, etc., should be carefully considered.

In choosing the location of the factory, consideration should be given to siting it not far from workers' residential places so that it does not require several hours of travel to get to work.

The higher the temperature of the air, the more water vapour it can hold. Due to the lowest layer of air being heated by the ground surface during the day, its relative humidity (RH) is rapidly decreased and, as a result, the rate of evaporation is increased when water is available to be evaporated as with an open surface of water or with rich vegetation or with higher air movement. The situation is reversed during the night. On a clear night, especially with still air, the RH increases as the lowest layer of air cools.

The air temperature in a city can be about 8°C higher than in the surrounding countryside and a difference of even 11°C has been observed.

The relative humidity in an urban area is reduced by 5 to 10 per cent due to the quick run-off of rainwater from paved areas, the absence of vegetation and the higher temperature.

Olgyay[10] was the first to propose a systematic procedure for adopting the design of a building to the human requirements and climatic conditions. The system has limited applicability, as the analysis of the physiological requirements is based on the outdoor climate and not on that expected within the factory building in question. It is known that the relation of indoor to outdoor conditions varies widely with different characteristics of the building construction and design. The method, though suitable for application in humid regions where ventilation is essential during the day and there is little difference between the indoor conditions and those out of doors, could lead to erroneous conclusions if applied in hot, dry areas, particularly in hot industries in the sub-tropics.

These include problems of overheating in the summer, of underheating or excessive cooling in winter, of wetness during rainy seasons, etc. Those temperatures below which heating is necessary are 18°C during the day and 15°C at sunrise, although higher temperatures would be desirable.

The intelligent application of the principles of ergonomics to the design of factory buildings in hot climates necessitates some understanding of the heat transfer processes of conduction, convection, radiation and evaporation, as each play an important part in the heat gains and losses in the factory buildings and the workers. Without this understanding, the efficacy of building design may be considerably reduced in the proper use of different materials and in the details of construction to suit the comfort and performance of workers.

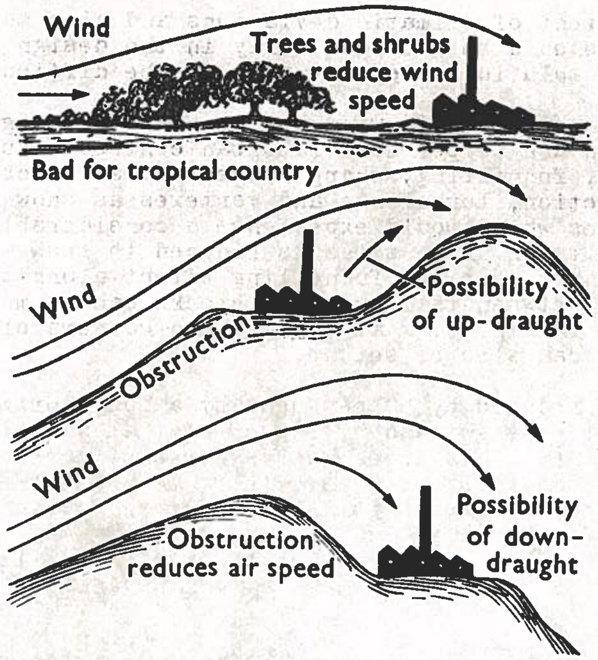


Fig. 4: Trees and shrubs reduce windspeed. Obstructions, though reducing air speed, may produce an up-draught or a down-draught due to funnelling, suction and other effects.

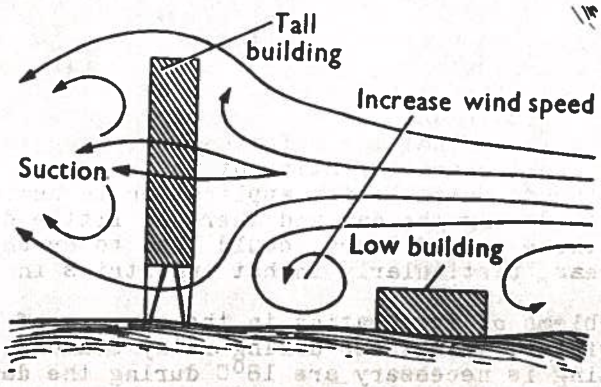


Fig. 5: Phenomenon of tall buildings producing increase of wind speed due to suction and turbulence near low building blocks.

Thermo-regulation, tolerance and comfort of workers

The thermal balance of the human body can be expressed by the following equation:

$$M - E \pm CD \pm CV \pm R = 0,$$

where M is the metabolic heat or energy expenditure, due to activity, shivering, etc., E is the heat loss due to evaporation of sweat or moisture, CD is the conduction heat from contact of warm or cold bodies, CV is the convection heat from the air hotter or cooler than the skin, and R is the radiation heat gain or loss from the sun and sky and hot or cold surfaces.

As soon as the sum of all the factors becomes greater than zero, the blood circulation to the skin surface is increased due to vasomotor adjustments, more heat is transported from the body core to the surface, and the temperature of the skin is elevated with a resultant acceleration of all forms of heat loss to the environment. Conversely, when the sum becomes less than zero, the blood circulation to the skin and hence the skin temperature are reduced and the heat loss processes are slowed down.

The normal skin temperature is between 31°C and 34°C. As the air temperature approaches the skin temperature, convective heat loss gradually decreases. Vasomotor regulation of the human body tries to increase the skin temperature to a higher limit (34°C), but when the air temperature reaches this point, there will be no more convective heat loss.

The four basic factors which directly affect human comfort are air temperature, humidity, air movement and radiation.

The summary of the thermal data at the actual places of work in different hot industries in India[11-16, 49] are presented in table 1. It will be seen that these workplaces are much hotter than similar places in cold countries.

Table 1: Mean maximum thermal data at some of the actual places of work in different hot industries in India

Industries	Dry-bulb temp.		Wet-bulb temp.		Relative humidity %	Globe temp.		Air speed		CET (B)	
	°F	°C	°F	°C		°F	°C	ft/min	cm/sec	°F	°C
Textile mills	99.0	37.3	97.5	36.4	92.0	99.5	37.5	375	190	92.5	33.6
Soap factory	97.4	36.4	81.6	27.6	88.0	100.0	37.8	420	210	84.6	29.2
Steel rolling mills	109.0	42.8	89.0	31.7	46.0	142.0	61.2	1 500	750	97.2	36.3
Coke oven battery	105.0	40.6	75.0	23.9	23.0	174.5	79.2	950	475	101.7	38.7
Foundry	97.0	36.1	83.0	28.4	55.0	135.5	57.5	400	200	95.3	35.2
Glass factory	152.0	66.7	93.0	33.9	10.0	210.0	98.9	1 500	750	105.0	40.6
Outdoors (in shade)	96.4	35.8	86.0	30.0	62.0	102.2	39.0	520	260	101.3	38.5

Note: CET (B) = Corrected effective temperature (basic).

High thermal load in hot industries in a tropical country increases the load on the cardiovascular system by increasing heart rate and blood pressure to force more blood to the skin for cooling by the evaporation of sweat. The high thermal load combined with metabolic heat increases the body temperature and at times may even cause heat disorders in hot climates, whereas the metabolic heat in workers of cold climates helps to combat cold.

For physiological comfort in hot, dry climates, buildings must be adapted to the summer conditions as, in general, the winter requirements will be satisfied by a building in which comfort in ensured for the summer. The low humidity in the hot, dry conditions allows an adequate sweat evaporation rate from the body even in still air, and thus air motion need not be great to prevent discomfort due to moist skin. Natural ventilation during the day is, therefore, unnecessary for evaporative cooling and undesirable for convective heat exchange, and the ambient air speed under "still" air conditions may be taken as 15 cm/sec. This slight air movement is the result of convective air currents caused by surface temperature discrepancies between differently oriented walls. Thus with a wind velocity of 16 km/h (10 mph), the indoor air speed would be expected to range from 35 cm/sec (70 ft/min) with poor ventilation to about 150 cm/sec (300 ft/min) with efficient cross-ventilation. Higher velocities are not necessary for comfort and may even be annoying.

Men at rest can tolerate a greater amount of thermal stress than do men doing hard work.[17] The more vigorous the work, the less easily do the workers tolerate severe thermal stress.

The energy expenditures at different industrial tasks performed by workers in hot climates[11-16,18-20,49] are found to be different from those of their counterparts in developed countries,[21,22] as shown in table 2.

The higher energy expenditure of similar industrial tasks in hotter climates is due to higher metabolism at higher tissue temperature, increased blood flow and sweat gland activity.[22] Moreover, due to mechanisation in developed countries, the peak workload of industrial workers has been reduced, whereas due to the problems of unemployment, poverty, etc., the workload of workers in developing countries did not change.

Table 2: Energy expenditure of Indian adult male workers in different industrial tasks

Industrial tasks	Mean Kcal/min	Range Kcal/min	Industrial tasks	Mean Kcal/min	Range Kcal/min
1. Cotton textile mills			4. Foundry		
Carrying bales	5.2	3.2-6.3	Furnace attending	2.1	1.8-2.4
Carrying laps	4.1	3.7-4.5	Moulding	3.9	3.0-4.8
Drawing	3.9	3.2-4.5	Core making, baking	4.0	1.9-8.5
Spinning (double side)	2.4	2.3-2.5	5. Glass factory		
Winding	2.8	2.7-2.9	Bottle making:		
Sizing	2.2	1.5-3.5	By hand:		
Weaving: 2 looms	1.8	1.3-2.3	Helping	2.6	1.6-3.3
4 looms	1.9	1.7-2.8	Cutting	2.3	1.9-2.6
			Airing	1.6	1.3-1.9
2. Soap factory			By machine:		
Barrel or drum opening	5.4	3.8-6.8	Stacking	1.3	1.2-1.6
Rosin breaking	6.1	5.5-6.7	Sorting	1.5	1.3-1.8
Pan unit attending	3.5	2.9-4.1	Attending furnace	2.4	1.8-3.3
Pumping	3.9	3.6-4.9	6. Manual material handling		
3. Steel rolling mills					
Billet pulling	3.8	2.6-4.5	Lifting	9.8	4.6-14.2
Billet conveying	4.1	3.6-4.7	Carrying	10.0	5.6-13.5
Front roughing	4.9	3.6-6.3	7. Laboratory work		
Bar holding	3.0	1.6-4.4	Standing working	1.7	1.2-2.1
Looping	2.9	2.8-3.1	Sitting working	1.3	1.0-1.6
Coiling, platform operating	1.4	1.1-1.7			

Maximal physical work capacity of industrial workers at comfortable temperature conditions in India[23,24] was found to be much lower (shown in table 3) than that of the westerners in cold climates. The thermal load in hot industries reduces the capacity further,[27,28] as given in table 4. Thus, the proper design of factories in hot climates plays a great role in reducing the thermal load, thereby increasing comfort, performance and productivity of the workers.

Table 3: Maximal physical work capacity (maximal oxygen uptake) of Indian adult male industrial workers with mean body weight (kg) 55.6 ± 0.93 and mean body height (cm) 165.0 ± 0.58 at comfortable thermal conditions

Groups	Maximal oxygen uptake	
	Litres (STPD)/min	ml (STPD)/min/kg
Age groups:		
20 - 29 yr (N = 37)	2.46 ± 0.05	45.23 ± 2.03
30 - 39 yr (N = 31)	2.33 ± 0.04	43.04 ± 1.75
40 - 59 yr (N = 16)	2.13 ± 0.03	34.96 ± 0.90
Occupation groups: (heaviness of jobs)		
Light (N = 7)	1.67 ± 0.02	30.94 ± 1.36
Moderately heavy (N = 19)	1.91 ± 0.05	36.22 ± 0.79
Heavy (N = 30)	2.27 ± 0.05	40.67 ± 1.41
Very heavy (N = 17)	2.50 ± 0.06	41.98 ± 1.99
Extremely heavy (N = 11)	3.17 ± 0.08	55.51 ± 2.26
All groups (N = 84)	2.31 ± 0.14	41.08 ± 1.56

Dry-bulb °F (°C)	Wet-bulb °F (°C)	Globe °F (°C)	Relative humidity %	Air speed ft/min (cm/sec)	CET (B) °F (°C)
83.0 ± 0.10	67.8 ± 0.12	83.0 ± 0.09	47.1 ± 0.33	175.0 ± 2.37	70.6 ± 0.06
(28.4 ± 0.05)	(19.9 ± 0.06)	(28.4 ± 0.05)		(88.9 ± 1.20)	(21.5 ± 0.03)

Mean ± standard error; N = number of subjects; CET = corrected effective temperature (basic).

Table 4: Maximal physical work capacity (maximal oxygen uptake) of Indian adult male industrial workers (N = 84) at three different thermal conditions

Heat stress index CET (B)		Maximal physical work capacity	Maximal oxygen uptake	
°F	°C	KgM/min	Litres (STPD)/min	ml (STPD)/min/kg
70.3 ± 0.34	21.3 ± 0.19	1 025.8 ± 27.2	2.31 ± 0.14	41.08 ± 1.56
80.7 ± 0.42	27.1 ± 0.23	935.8 ± 27.5	2.05 ± 0.05	36.43 ± 1.58
90.2 ± 0.25	32.4 ± 0.14	847.6 ± 27.2	1.81 ± 0.06	32.23 ± 1.36

N = number of subjects; Mean ± standard error; CET (B) = corrected effective temperature (basic).

Among the workers of the cold and hot climates accustomed to such climates, there are also differences in the thermal comfort levels[29,30,49] and the limits not to be exceeded without a risk of endangering health and efficiency considerably, as given in table 5. It is important to note that thermal balance is essential for thermal comfort but it can also be achieved by the thermo-regulatory mechanisms such as blood circulation, sweating, etc., of the body under conditions of discomfort.

Table 5: Optimum comfort zone with typical thermal conditions for Indian adult male industrial workers with usual clothing at different levels of activity in winter and summer seasons

Activity and seasons	Range of comfort CET (B)		Typical thermal conditions: Dry-bulb temp.		Wet-bulb temp.		Relative humidity	Globe temp.		Air speed	
	°F	°C	°F	°C	°F	°C	%	°F	°C	ft/min	cm/sec
Very light work:											
Summer	78.8	26.0	90.5	32.5	74.0	23.4	47	99.0	37.3	500	250
Winter	73.0	22.8	73.5	23.1	56.5	13.6	32	94.0	34.5	30	15
Heavy work:											
Summer	68.9	20.5	82.5	28.1	65.0	18.3	38	90.0	32.2	700	350
Winter	64.5	18.1	75.0	23.9	55.0	12.8	25	80.0	26.7	100	50

CET (B) = corrected effective temperature (basic).

Body shape or the surface to volume ratio has an effect on the thermal preferences. A thin person generally found in hot climates has a much greater body surface than a short, fat person of the same body weight,[31-33] and he or she can dissipate more heat and will tolerate and prefer a higher temperature.

Dark skin of the people in hot climates containing the pigment melanin prevents the penetration of damaging ultraviolet rays and increases the heat emission from the body in the same proportion as it affects absorption; thus it is more resistant to the damaging effects of sunshine.

Men in the older age-groups tolerated severe thermal stress very nearly as men in the younger age groups.[34] In severe heat, the reaction of both groups was very nearly identical, whereas due to the higher body fat and greater amount of clothing, the females have some difference in thermal comfort and tolerance levels. Factories where only females would work should take this and other points into consideration in the design.

A reduction in the amount of work clothing will increase the ability of men to withstand thermal stress, except under conditions involving very great amounts of radiant heat or in circumstances where there is very fast-moving hot air. Men wearing the least clothing withstood more easily the higher temperatures.[35]

All this has a considerable bearing on the design of industrial buildings to produce optimal conditions for the workers. It is obvious that the same design of industrial buildings in cold climates would be very unsuitable for hot climatic conditions due to these differences.

For warm, wet conditions it has been estimated[36] that over 2,000 N/m^2 vapour pressure, every 1 m/s increase in air speed compensates for an increase of 300 N/m^2 in vapour pressure. When the air is completely saturated and warmer than the skin, air movement would only increase discomfort and heat gain. Fortunately, such conditions are seldom met in nature. The highest humidities, even in warm, humid conditions, are experienced when air temperature is below skin temperature, whilst the highest temperatures are accompanied by moderate humidities. But such conditions can quite easily be produced inside factory buildings of poor design and with bad management.

Materials and form of construction

Specific features of design and of structural materials[37] that affect the response of a factory building to exposure to climatic elements are the quantity of solar radiation absorbed in and penetrating the building, the air surface temperatures, the air velocity and the vapour pressure.

In a hot climate, the function of the building envelope is to moderate the daytime heating effects of the external air and solar radiation on the structure and its interior. At the same time, the rate of cooling during the night should not be over-reduced.

In choosing suitable building materials in hot climates, two ambient characteristics are of primary importance: the maximum temperature and the diurnal range dependent on vapour pressure level. A third significant factor is the absorbed solar radiation, which depends on the orientation and external colour of the building element in question. The most important thermo-physical properties are the thermal resistance and heat capacity, which may often be expressed together by the product of the two. But as the mechanisms of heat flow control operating through the two factors are different, the effectiveness, and hence the relative importance, of each with respect to physiological comfort within a building varies differently with the climatic characteristics.

The ground loses much heat by radiation, particularly on clear nights, and soon after sunset its temperature falls below that of the ambient air. The direction of heat flow is reversed from the air to the ground. The lowest layer of air becomes cooler.

A difference of temperature between the inside and the outside, or between different parts of a building, will result in a transfer of heat from the warmer to the cooler areas. Any wall, floor or roof will offer some resistance, but will not entirely prevent heat transfer. The purpose of thermal insulation is to restrict and delay the rate of transfer.

Insulation will be most effective under steady state conditions, or when at least the direction of the heat flow is constant for long periods of time, especially in heated or air conditioned buildings. Where the direction of heat flow is reversed twice in every 24-hour cycle, the significance of insulation will be diminished.

The effect of solar radiation on opaque surfaces can be combined with the effect of warm air by using the sol-air temperature concept of Mackey and Wright.[38] The magnitude of sol-air temperature influenced by the factors of absorbance and surface conductance shows that the selection of colour has some effect; the selection of material is, however, of greater significance. Variations in surface conductance are even less, but a lesser absorbance and a greater surface conductance would reduce the solar heating effect.

By far the greatest source of heat gain can be the solar radiation entering through the windows. This could, in fact, increase the indoor temperature far above the outdoor air temperature. Overheating is a problem in all tropical climates. For the reduction of solar heat gain through windows, four variables are within the control of the designer:

1. orientation and size of windows;

2. external shading devices;

3. internal blinds, curtains, etc.;

4. special glass.

Design of shading devices

In hot climates it is very important to shade the outside walls of a building exposed to high levels of sunlight.[39] This can be done by creating permanent screens or louvre blades, a reinforced canopy or externally applied venetian blinds, or planting tall trees with thick leaves or shrubs. These are very effective when they shade the east and west walls of the building, which are exposed to the morning and evening low-level sunlight.

Shade is required not only against direct solar radiation but also against diffused radiation from the sky which, in tropical regions, may reach very high intensities (0.75 $Kcal/cm^2/day$ on a horizontal surface).

When horizontal adjustable louvres are used, they should be constructed so as to enable their opening at an angle of approximately 120°, so that when required they also direct the air flow towards the occupied zone. In multistoreyed buildings, window overhang shades tend to reflect an appreciable amount of solar radiation on the walls and into the windows of the upper storeys. The vertical shadow angle measures the performance of horizontal shading devices.

Vertical shading devices consist of lower blades or projecting fins in a vertical position. The horizontal shadow angle measures their performance. Narrow blades with close placing may give the same shadow angle as broad blades with wide spacing. It will be seen that this type of device is more effective when the sun is to one side of the elevation, such as an eastern or western elevation. The shading masks with segmental shape will be most effective when the sun is opposite to the building face considered and at a high angle, such as for north- and south-facing walls. To allow sun only at a low angle, this type of device would have to cover the window completely, permitting a view downwards only.

Egg-crate shading devices are combinations of horizontal and vertical elements. The many types of grille-blocks and decorative screens may fall into this category. The construction of shading masks for moderately complex shapes is effective for any orientation depending on detail dimensions.

Once the necessary shadow angles have been established, the design of the actual form of the device will be quite simple and it can be postponed to a later stage when it can be handled together with other considerations, structural or aesthetic, daylight or air movement.

The aridity in hot, dry areas is accompanied by several characteristics of importance to human comfort and to building design. Direct solar radiation is intense, up to 700-800 $Kcal/m^2h$ on the horizontal surfaces, and may be further augmented by the radiation reflected from the barren, light-coloured terrain.

In hot, dry areas the main consideration is to reduce the impact of solar radiation on buildings and to provide shade in the streets, recreational areas, etc. All the internal roads leading to the different buildings of a factory should have shade from the trees planted on the sides of the pedestrian pavement. Where hot, dry winds are associated with dust storms, wind control should be aimed at protecting rather than obtaining the best ventilation. Internal courtyards and patios are often provided for social purposes and also as resting areas. During the day, ventilation is reduced to a minimum to exclude the hot, dust-laden outdoor air from the interior.

In warm, humid regions, the planning should be directed towards optimum ventilation conditions and maximum protection from solar radiation.

Design of roofs and walls

If a heavy-weight roof with an external layer of efficient insulating material, itself protected by a waterproof light coloured (whitewash) covering, is used, heat flow during the day from external to internal layers is restricted by the insulation and reflecting surface and only a small portion of the potential heat is absorbed in the elements.

High heat capacity concrete walls externally insulated by rockwool or expanded plastic and covered by waterproofing materials are suitable for this purpose. All external surfaces should be as near to white as possible. The high thermal capacity of the concrete layer reduces the effect on internal temperatures of any heat which thus penetrates.

The whole roof may be externally covered by a polythene sheeting at a distance of 10-20 cm above the roof surface. Polythene (polyethylene) is transparent to radiation of the wave length around ten microns emitted by the roof, placing little restriction on radiative cooling of the roof at night. The disadvantage of the method is the deterioration of the polythene sheets due to the exposure to the sun, so that they have to be replaced at intervals.

The alternative of double-roofing at much less cost, especially in factories in rural areas in hot climates, is to maintain vegetation on selected portions of the slanting roof.

Orientation and design of windows

In the equatorial location, the main windows should face north or south to avoid solar heat gain. At the higher latitude, though an orientation away from the Equator would receive the least sunshine, it may be desirable to have some solar heat gain in the winter when the sun is low, and so an orientation towards the Equator may be used where the workplace does not generate much heat. In both locations the minor openings at unimportant workplaces should be placed on the east and west sides. Solar heat gain in the west side can be particularly troublesome as its maximum intensity coincides with the hottest part of the day.

If wind is to be captured or a pleasant view is to be utilised, etc., the opening of windows may at times override the solar consideration.

It is generally believed that to give optimum conditions of ventilation, the inlet window should directly face the wind. Any deviation from this direction reduces the indoor air speed. However, this is not always so. In some cases, better conditions can be achieved when the wind is oblique to the inlet windows, particularly when good ventilation conditions are required in the whole area of a workplace. When the wind is oblique (at 45°) to the inlet opening of the same workplace, most of the air volume takes up turbulent, circular motions around the room, increasing the air flow along the side walls in the corners.

Very good ventilation conditions are possible in regions with westerly windows even when the long façade with the inlet windows is turned by 45° to the north-west or south-west, where shading is much easier.

The air movement could be grossly influenced by the way the window blinds or sashes open. If the hinges on the windows are fitted properly depending on direction of prevalence of the wind, the window blinds or sashes would act as deflectors to direct the wind through the windows, whereas if the hinges are fitted in the wrong way, the wind would be directed away from the room. In many of the factories in the tropical climates, just changing the hinges from one to the other side of the window frame may improve the climatic conditions greatly (Fig. 6). This point has been overlooked in many factories in hot climates.

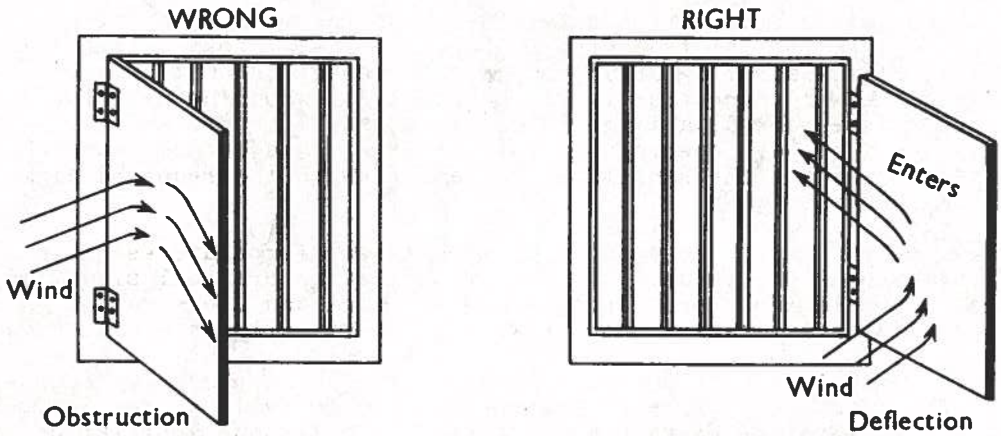


Fig. 6: Correct method of fixing window blinds or sashes so as to facilitate entry of wind from the prevailing direction of wind

Windows may be large but should be protected by movable insulated shutters; apart from small apertures for illumination, both windows and shutters must be closed during the day.

The most effective height of the windows from the human comfort aspect is about 0.5 to 1.5 m above the floor. It is preferable to use horizontally pivoted windows with upper hinges which, when open, would direct the air flow downwards. For hot areas, large sliding walls should be used, which may be kept open most of the time but closed during storms or rain to provide good control of the conflicting requirements for maximum ventilation alternating with wind, dust and rain protection during storms.

It is particularly important in hot areas to have two horizontal strips of window places in different walls, to provide the most adequate arrangements, one at the height of the floor and the other just below the ceiling, thus causing air motion in the room by thermal force during windless hours.

In a centrally heated factory room in a cold climate the opening of a small window for only five minutes may cost a fraction of a dollar due to loss of heat, whereas it may be rightly desirable to open all the windows for greater ventilation in a non-air-conditioned factory room in hot climates.

To minimise the blocking of air flow through fly screens, e.g., in a drug factory, it is preferable to install them at some distance from the wall, rather than directly on the windows. and extending them over a much larger area than the windows. When there is a balcony adjacent to the workroom, it is possible to ensure insect protection with less interference of ventilation by fixing a fly screen around the balcony, thus enabling the entry of air through a wider area.

Good ventilation not only keeps the workers cool and comfortable, it also helps dispersion of odour offensiveness, harmful dusts, fumes and smoke from the working environment which tend to increase with an elevation of air temperature.

In hot tropical climates, fans should be used to increase air movement to at least 0.5 m s^{-1}. High air speed increases the thermal comfort by increasing the evaporation of sweat and the heat loss by convection, both in hot humid and hot dry conditions.

The use of ceiling fans should be avoided in hot climates as these blow back the hot air from the top on to the workers. The inlet air blowers at the floor level or so-called "floor fans" or the circulators sucking the cold air from lower windows are much better. But at much higher air speed the body may gain heat from the hot air, which is to be avoided.

A loss of heat by evaporation of water is utilised in hot, dry climates by passing the air through meshes or weeds soaked with water. But in hot, humid climates this process cannot be used. Much of the sweat which is produced by the body is dripped away and not utilised for cooling the body by evaporation of sweat.

The largest air speed will be obtained through a small inlet opening with a large outlet. When the inlet opening is large, the air speed will be less, but the total rate of the air flow or volume of air passing in unit time will be higher. When the wind direction is not constant, or when the air flow through the whole space is required, a large inlet opening will be preferable. The best arrangements are full wall openings on both sides with adjustable sashes or closing devices which can assist in channelling the air flow in the required direction, following the change of wind.

Unfortunately, it will be found that the highest temperatures often coincide with the least amount of breeze. As this would be the critical situation, the best that can be done is to provide openings as large and unobstructed as possible to make the building as transparent for wind as practically feasible.

The predominance of high humidity necessitates correspondingly high air speed to increase the efficiency of sweat evaporation and to avoid as far as possible discomfort due to moisture on skin and clothes. Continuous ventilation is, therefore, the primary comfort requirement and affects all aspects of building design such as orientation, the size and location of windows, layout of the surroundings, etc. Even with the maximum ventilation there are limits under which comfort can be achieved in a warm, wet climate.

One of the chief causes of discomfort in warm, wet climates is the subjective feeling of skin wetness. Ventilation should ensure a sweat evaporation rate sufficient not only to maintain thermal equilibrium but also to enable evaporation of sweat as the sweat emerges from the pores, without accumulating on the skin. The provision of continuous and efficient ventilation, protection from the sun, rain and insects, prevention of the increase of internal temperature during the day and minimisation during the evening and night are the requirements for the design of a building in warm, wet climates.

To adequately cross-ventilate the areas of a factory building, either all the areas should be provided with doors, windows, etc., on both windward and leeward sides of the building, or those areas on the windward and leeward sides only should be given access through large openings to rooms on the opposite pressure sides.

To raise the building on pillars is advantageous in a warm, wet climate because it enables better ventilation by locating the windows above the zone of maximum damping of wind by the surrounding vegetation, etc., and also by enabling the cooling of the floor from below, which is particularly beneficial at night. In addition, the building is better protected from floods and from termites.

Occasionally, underground rooms are provided in which temperature fluctuations are further stabilised at a level close to the annual average; the summer temperatures are, therefore, much lower than in the buildings above the ground.

Conditions which are perfectly comfortable may produce adverse effects if constant and there is no change at all over prolonged periods.

One of the basic needs of the human being is change and variation, a fact which has been ignored by early research workers. This point is particularly noticeable in mechanically controlled environments, such as in air conditioned buildings, where the environmental conditions can be and often are kept constant within very fine limits. What the designer should aim at is a range of comfort conditions within which considerable variations are permitted.

It is quite interesting to observe that people enjoy natural, cool and fluctuating fresh breezes even when these stop for a few seconds at random, while people complain of the monotonous air movement at the same temperature and constant speed in an artificial climate. If these observations and causes are proved beyond doubt, in future the artificial climate may have to incorporate the random variation of air speed and air temperature within prescribed limits to provide the most comfortable conditions for workers.

The ordinary ventilation in the factories and workshops in hot climates should be at least 5.0 ft^3 (1.4 m^3) per person per minute. The air speed at the head level should be at least 100 cm/s (200 ft/min).

Design in relation to lighting, colour and noise

It is surprising that even today simple issues of heating, lighting and ventilation are too often inadequately considered and acoustic problems are not properly dealt with.

Where rooms or shop floors rely on natural daylight, the maximum practical depth is about 5 m (or 20 ft) from the window wall, and this may be increased to about 7.5 m (or 30 ft) where a scientifically designed combination of artificial and natural lighting is employed. Even mixed lighting by means of daylight and electricity limits the working depth of a shop floor.[40]

The effects of colour on people at work are to be considered for the scientific use of colours in the rooms and shop floors. In hot areas the "cool" blue or green colours, as against "warm" red should be used to give subjective sensations of coolness or impressions of reduced temperature.

The ceiling of a factory building plays an important role, particularly in reducing reverberant noise. Though people, furniture, wall linings, soft flooring, etc., all act to absorb noise to some extent, a considerable proportion of any noise travels upwards to the ceiling. There is a wide variety of acoustically absorbent materials suitable for use in ceilings.[41] The so-called "false" ceiling with sound-absorbing material not only reduces noise but also helps to insulate and thus minimises transfer of heat from a hot roof to the shop floor.

Design in relation to safety, health, pollution and welfare

Normally, factories should be so designed that the use of personal protective equipment against heat, dust, smoke, fumes, noise, accidental injuries, etc., is eliminated or at least minimal. If the hazards cannot be reduced at the source, then personal protective equipment has to be used, but one has to foresee that it might be impossible for the workers to endure wearing protective equipment in hot conditions.

The normal psycho-physiological conditions of activity and rest with recovery from stresses are impeded by unfavourable climatic conditions and the resulting stress on body and mind causes discomfort, loss of efficiency and may eventually lead to a breakdown of health or even cause accidents. It is a challenge for the designer of the factory building to strive towards the optimum of total comfort, i.e., complete physical and mental well-being.

A well-designed working environment includes not only suitable physical conditions of ample ventilation, heat dissipation, illumination and other comfort standards, but also the tangible and intangible amenities that can transform discontent and boredom into interest and a sense of participation by the workers, as for example the availability and use of shower facilities in hot climates, which are very much favoured.

Any industry that has a high "fatality rate" and a poor accident record is inefficient and it loses productivity through the loss of man-hours and discontinuity of work. Many unnecessary burdens are placed on the social services and the economy of the country as a whole and the degree of human suffering is immeasurable. A human life is irreplaceable. Loss of limbs and inability to work only bring misery and personal ruin.

For minimising accidents, the design criteria should take into consideration the major causes and frequency of different types of accidents from the records of similar industries in hot climates.

In hot, dry conditions, the chances of fire are much greater than in cold conditions, and hence greater precautions should be taken and better facilities provided for fire exits, structural fire barriers, safe internal and external access, especially in multistoreyed buildings. Industry has to count the cost of necessary precautions and control measures and the cost will in the long run have to be related to the total benefits to be expected from the process. The costs should be regarded as an essential part of the process and not simply as an added burden to be carried on the back of the manufacturer.

Factories and air pollution

The recent planning policy of most of the countries has been to encourage siting of industrial zones on the outskirts of new towns, or siting state or government-sponsored industrial estates outside townships, mainly to reduce the effects of pollution on the people living in the towns.[43,44] With the ever-increasing number of factories or industries, the threat of air, water and land pollution greatly increases.

To deal with aspects of pollution directly related to the design of landscape and buildings for industries, one has to consider the effects of waste materials or surplus energy generated by various forms of human activity in industry threatening damage to man's health, possessions, food supply, recreation and also to plants, animals and wildlife. In addition, there is pollution due to noise and other environmental nuisances generated from the factory buildings.

Air pollution arises from smoke, fumes and other gaseous emissions, dusts and grit from the factory processes directly discharged into the atmosphere. Obviously, the design of the factory building, including the ventilation system, chimneys, etc., must be done properly to cope with the minimum interference and pollution of the air by toxic and other substances. These pollution problems are enhanced by tropical climates. It is, therefore, very important that industrial plants and buildings be built to help in the effective control of pollution and its reduction.

The effect of a temperature inversion in trapping smoke and fumes near the ground is obvious. It is important to find out the height at which temperature inversion occurs. Very tall chimney stacks with correct height are able to penetrate the inversion layer to discharge their fumes in the rising air and thus avoid pollution (Fig. 2).

The heaviest air pollution comes from the burning of fossil fuels. Coal produces dusts and smoke which are considered specially harmful when trapped as fog. The photochemical smog which arises from the complicated chemical reactions of the emissions of the internal combustion engine in the presence of sunlight is an indirect effect of pollution from industry as it arises from transport movements. In order to avoid these, siting and design of the factory buildings, including the chimneys, should be made scientifically, and for this the effects of inversion and the effects of local microclimate conditions of mechanical and thermal turbulence upon the plumes from tall chimneys or stacks (Fig. 7) have to be considered.

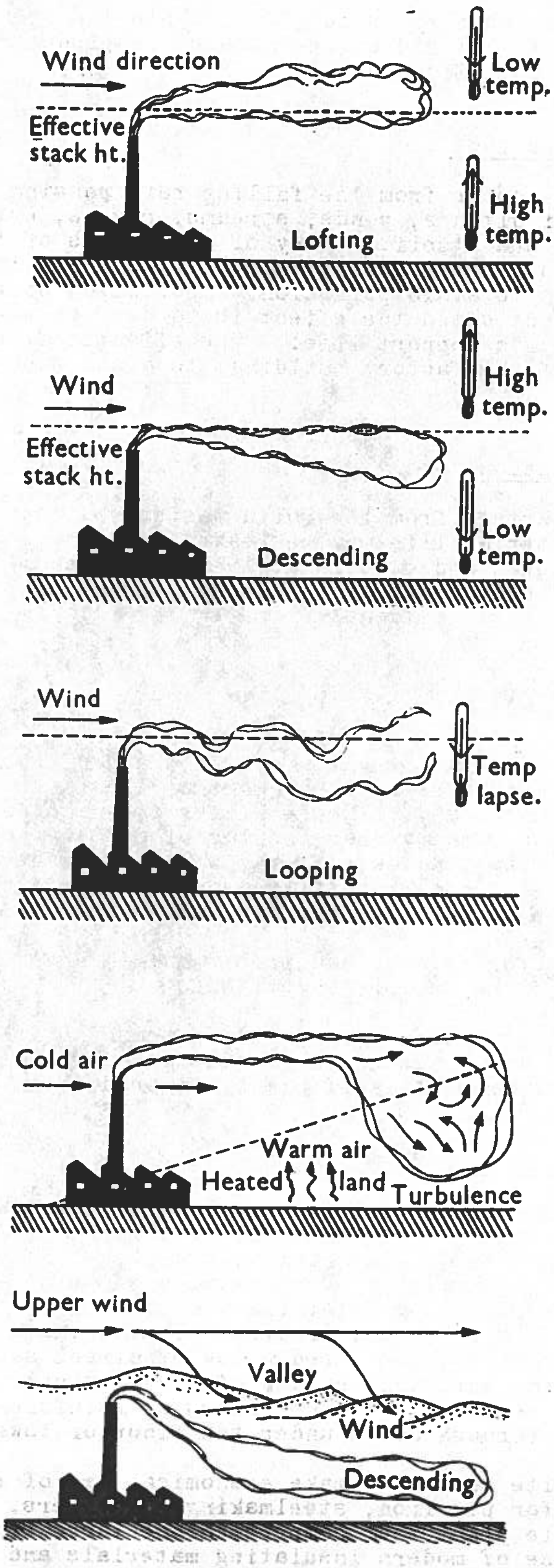


Fig. 7: The effects of local conditions of microclimate upon the trails of smoke from tall chimneys or stacks to show the importance of effective stack height

One trend of modern industry is to get out into the open and not worry about buildings. It is easy to get rid of the gaseous by-products, but the downwind public is becoming more pollution conscious.

Factories and water pollution

Water pollution may occur from the falling rain passing through smoky and polluted air, by ways of ditches, ponds, streams, rivers, estuaries, etc., to the direct polluting of the sea itself. Many of the wastes of the factory are directly discharged into rivers, except in countries where there is strict enforcement of control measures to avoid pollution. Pollution of water may not necessarily render it toxic but often the effect is to deprive the water of oxygen and thus reduce its capacity to support life. The effects of thermal pollution are similar. The design of the factory buildings to avoid such pollution is an important necessity.

Factories and land pollution

Polluting of land arises from the solid wastes. Industrial chemicals destructive to insects and bacterial life may be leaked into the soil from the waste dumped upon it. The toxic and caustic effluents from chemical plants usually involve great risk. The disposal of this must be done properly and the design of the factory building helps this greatly.

Design in relation to storage, cleanliness and maintenance

In tropical countries, the prevalence of hot and dry conditions leads to a lot of dust. The factory should be so designed that the routine storage and maintenance of cleanliness is made easy. Hence either the glass windows should be at the lower level, or the glass windows near the top of a "saw-tooth roof" factory, for example, should have at least a low cost bay with safety guardrails for safe, easy and regular cleaning. A broom brush fitted on rollers so that the windows can be cleaned from the outside by pulling from one end to the other is also useful.

Easy accessibility for regular and proper maintenance of machinery must be considered in the design of the factory shop floor.

Better understanding of certain aspects of human motion and body measurements for use of criteria and for guidance in the design of workplaces are necessary, as wasted movements are a source of inefficiency in production.

Design in relation to power supply

In the days of power crises, it is very important to design factories in hot climates to make much greater use of natural ventilation and daylight. The short supply of energy in the form of electricity, diesel, coal, etc., will be much more aggravated in the years to come.[42] Conceptual ergonomics would suggest the minimum use of these forms of energy in maintaining the comfortable conditions in the factory buildings, especially in hot tropical climates, and maximum use of natural cross-ventilation, natural daylight, reduction of direct solar radiation in heating the roof and walls of the buildings by use of good reflecting double-roofs or vegetation on the roof, good ventilation, sunbreakers or reinforced concrete canopies, forced cold air inlets through ducts under the floor or lower windows.

Nowadays it is quite common to make economical use of fuel by planning coke ovens, blast furnaces for pig iron, steelmaking converters, and fabricating mills on the same site, the whole plant thus comprising one large type of industrial installation making the best use of modern insulating materials and other means to prevent the escape of heat into the surroundings. In future, the factories in hot climates may advantageously utilise solar radiation on the roofs to cool the working environment of the workers.

Design of industrial estates

It is not enough to design one industrial building, even when it is well constructed. It is essential to have ergonomic considerations in designing industrial estates to reduce the cluster of small buildings and to improve the layout by various methods.[43] A logical and scientific flow diagram for intake of raw materials and for output of finished products should be worked out for all the factories in the group, so that efficient road, rail and conveyor systems can be made with common points for packaging, loading and unloading, and common facilities for maintenance, security, safety, medical clinics, canteen, recreation, sports and other organisations, and common services for electricity, fuel, gas, water, steam, compressed air, refrigeration medium, telephone, etc., and a ring circuit of refuse and waste disposal could be economically viable and useful. According to the suitability, any one of the different types of layout or plans[35] such as linear or radial or ring types (Fig. 8) may be used.

In good industrial planning, orderliness and over-all integration are combined and options for maximum future expansion are kept open.

Moderately compact internal planning of factory blocks will be of benefit for most of the year. Courtyard-type buildings are very suitable, since ventilation and light from both the external and internal sides are available. Buildings are to be grouped in such a way as to take advantage of prevailing breezes during the short period when air movement is necessary. A moderately dense, low rise development is suitable for these climates, which will ensure protection of outdoor spaces, mutual shading of external walls, shelter from the wind in the cold season, shelter from dust and reduction of surfaces exposed to solar radiation in the hot season. Wind speed above the level of the bulk of the industrial building blocks in the town, to which the higher buildings are exposed, is much higher. In a hot climate, in particular a humid one, this is obviously an advantage.

When the high buildings have also large horizontal dimensions, they divert the air flow above and over the blocks and cause "wind shadow" behind them (Fig. 4). On the other hand, when the horizontal dimensions are not much larger than those of the lower buildings, the turbulence and pressure difference created around them improves the ventilation conditions of lower buildings in their neighbourhood.

"Industrial parks" or recreation woodlands or "greens" are used as buffer zones between belts of industry.

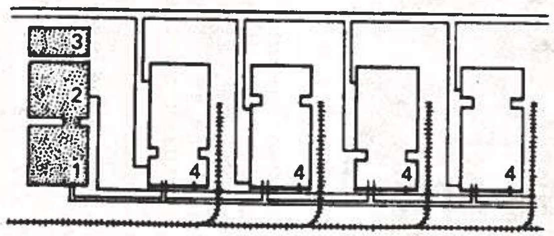
In some planning regulations, importance is given to the patterns of industrial development by which the commercial office centre of a town is segregated from residential and shopping areas. This is going out of favour since it has led to cities becoming dead at night after the office and factory workers have gone home. The type of mixed development is more humane and now acceptable by many.

Control on factory design

Unless the planning, location and design of the factory buildings are properly controlled from the very beginning, it will be extremely difficult to avoid grave situations in the years to come. In many countries, national laws, acts and local rules, regulations and restrictions determine location, construction and material usage in factory buildings.[44] These acts, rules, regulations and restrictions should also be based on the principles of ergonomics and on appropriate guidelines so that effective control can be established to humanise the environment and make for the proper development of the area and the progress of society as a whole.

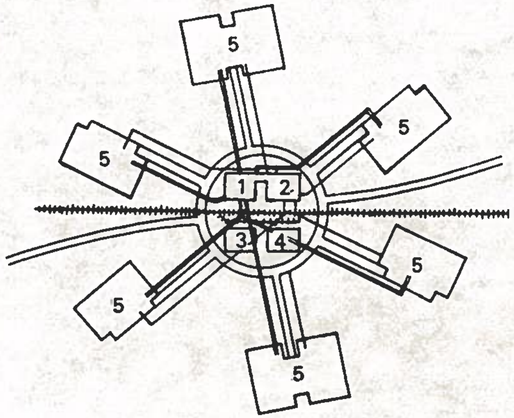
An application to build giving an outline of the proposed factory should be made to the local planning authority. Permission to build should only be given with the condition that a detailed plan be submitted within a stated period. The local authority, through its appointed offices, should have the right of inspection of the work to ensure that the building is constructed according to the approved plan.

The factory inspectorate, like a "watchdog", should make good use of its loud bark and its nose for trouble, but should reserve the use of its sharp teeth for those rare occasions when they might be required to ensure the effective control of properly designed factories suitable for the climate.



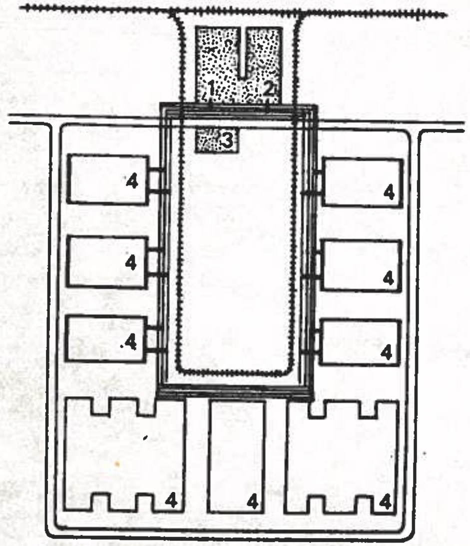
LINEAR PLAN

1 Energy and Heat service
2 Refuse and Waste disposal
3 Welfare services
4 Factory space
▬ Service links
═ Road access
┼┼ Rail access



RADIAL PLAN

1 Energy and Heat service
2 Refuse and Waste disposal
3 Rail goods storage and despatch
4 Welfare services
5 Factory space
═ Service links
═ Road access
┼┼ Rail access



RING PLAN

1 Energy and Heat service
2 Refuse and Waste disposal
3 Welfare services
4 Factory space
▬ Service links
═ Road access
┼┼ Rail access.

Fig. 8: Different types of layout for factory buildings in industrial estates

Notes

[1] Making work more human: Working conditions and environment - Report of the Director-General to the International Labour Conference, 1975, and resolution adopted, International Labour Office, Geneva, 79 pp., 1976.

[2] Sen, R.N.: Ergonomics - Science and technology of man at work: Its role in our national development, presidential address at the Section of Physiology, Proceedings of the 66th Session of the Indian Science Congress, Part II, pp. 53-76, 1976.

[3] Baynes, K.: Industrial design and the community, Lund Humphries, London, 96 pp., 1967.

[4] Sen, R.N. and Nag, P.K.: Are the Calcutta public buses ergonomically designed? Ind. J. Physiol. and Allied Sci. 27: 156-157, 1973; Project Report No. 4, Ergonomics Laboratory, Department of Physiology, C.U., 18 pp. 1972.

[5] Sen, R.N. and Nag, P.K.: Design ergonomics of a few public buses in Calcutta, Proc. 61st Ind. Sci. Cong., Part IV, Section XI, pp. 126-127, 1974.

[6] Union des industries metallurgies et miniers, Paris - L'environment des lieux de travail et l'esthetique industrielle (The working environment and industrial design), Paris, 68 pp., 1957.

[7] Givoni, B.: Man, climate and architecture, 2nd edition, Applied Science Publishers Ltd., London, 483 pp., 1976.

[8] Mills, E.D.: The modern factory, 2nd edition, Architectural Press, London, 215 pp., 1959.

[9] Sen, R.N. and Ghosh, S.: Application of ergonomic principles in the design and setting up of a pharmaceutical factory, Project Report No. 53, Ergonomics Laboratory, Department of Physiology, Calcutta University, 28 pp., 1978.

[10] Olgyay, V.: Design with climate, Princeton University Press, NJ, 185 pp., 1963.

[11] Thermal stress in textile industry, Report No. 17, issued by the Chief Adviser Factories, Ministry of Labour and Employment, Government of India, New Delhi, 96 pp., 1957.

[12] Sen, R.N.: Physical environmental factors affecting health of workers in industry, Ind. Labour J. 6: 735-746, 1965.

[13] Sen, R.N.: Studies on tolerance to dry and wet heat on industrial occupations in India, paper presented at the International Symposium on "Human Adaptability to Environmental Conditions and Physical Fitness" under the auspices of International Biological Programme, New Delhi, 1965, Proceedings, DIPAS, Madras 3, pp. 73-81, 1966.

[14] Sen, R.N., Chatterjee, S.K., Saha, P.N. and Subramanian, A.: Assessment of workload and thermal stress in relation to physiological responses of workers in a cotton textile mill in Bombay, Report No. 3 of the Industrial Physiology Division, Central Labour Institute, Government of India, Bombay, 27 pp., 1964.

[15] Sen, R.N., Saha, P.N. and Subramanian, A.: Assessment of workload and thermal stress in relation to physiological responses of workers in a soap factory in Bombay, Report No. 4 of the Industrial Physiology Division, Central Labour Institute, Government of India, Bombay, 28 pp., 1964.

[16] Sen, R.N., Chatterjee, S.K., Saha, P.N. and Fletcher, J.G.: Rationalisation of work period and rest pause in a steel rolling mill in Bombay, Report No. 6 of the Industrial Physiology Division, Central Labour Institute, Government of India, Bombay, 22 pp., 1966.

[17] Leithead, C.S. and Lind, A.R.: Heat stress and heat disorders, Cassell, London, 304 pp., 1964.

[18] Banerjee, S., Sen, R.N. and Acharya, K.N.: Energy metabolism in laboratory workers, J. Appl. Physiol. (USA), 14: 625-628, 1959.

[19] Banerjee, S., Acharya, K.N.: Studies on energy metabolism of labourers in a spinning mill, Ind. J. Med. Res., 47: 657-662, 1959.

[20] Sen, R.N.: Studies on some aspects of energy metabolism in Indians. Thesis for D.Sc. (Physiology) degree, Calcutta University, 347 pp., 1960.

[21] Durnin, J.V.G.A. and Passmore, R.: Energy, work and leisure, Heinemann Educational Books Ltd., London, 166 pp., 1967.

[22] Consolazio, C.F., Johnson, R.E. and Pecora: Physiological measurements of metabolic functions in man, McGraw-Hill Book Co. Inc., New York, 1963.

[23] Sen, R.N., Roy, B.S. and Sarkar, D.N.: Maximal physical work capacity of Indian industrial workers in relation to age and heaviness of job, Proceedings of the International Conference of the Human Factors Society, Philadelphia, Pennsylvania, USA, 6-9 October 1969, 12 pp.

[24] Sen, R.N. and Sarkar, D.N.: Maximal oxygen uptake of Indian industrial workers at comfortable temperature conditions, Proc. Physiol. Soc. Ind. held at Ganjam, Berhampore, on 21 and 22 April 1973, Ind. J. Physiol. and Allied Sci., 27: 107, 1973.

[25] Åstrand, P.O.: Human physical fitness with special reference to sex and age, Physiol. Rev. 36: 307-335, 1956.

[26] Åstrand, P.O. and Saltive, B.: Maximal oxygen uptake and heart rate in various types of muscular activity, J. Appl. Physiol., 16: 971, 1961.

[27] Sen, R.N.: Effects of thermal stress on maximal work capacity of Indian industrial workers, paper presented at the ICMR Symposium on Health in relation to Work and Heat Stress in Places of Work, held at National Institute of Occupational Health, Ahmedabad, from 27 to 29 January, Proceedings, 1972.

[28] Sen, R.N. and Sarkar, D.N.: Maximal physical work capacity of Indian industrial workers in relation to thermal stress, Proc. 60th Ind. Sc. Cong., Part III, Section XI, p. 715, 1973.

[29] Rao, M.N.: Comfort range in tropical Calcutta, Ind. J. Med. Res. 40: 45-52, 1952.

[30] Sen, R.N. and Ghosh, J.K.: Thermal comfort zone for the people of Bengal, Project Report No. 16, Ergonomics Laboratory, Department of Physiology, Calcutta University, 12 pp., 1975.

[31] Banerjee, S. and Sen, R.N.: Determination of the surface area of the body of Indians, J. Appl. Physiol. (USA), 7: 585-588, 1955.

[32] Banerjee, S. and Sen, R.N.: Body composition of Indians and its relation to basal metabolic rate, J. Appl. Physiol. (USA), 12: 29-33, 1958.

[33] Banerjee, S., Rohatgi, K.S., Mukherjee, M. and Sen, R.N.: Determination of the surface area of the body of Indian females, Ind. J. Med. Res., 46: 669-673, 1958.

[34] Edholm, O.G.: Man - hot and cold, Edward Arnold (Publishers) Ltd., London, 60 pp., 1978.

[35] Campbell, G.S.: An introduction to environmental biophysics, Springer-Verlag, New York, 159 pp., 1977.

[36] Webb, C.G.: Ventilation in warm climates, BRS Overseas Building Notes No. 66, March 1960.

[37] Van Straaten, J.F.: Thermal performance of buildings, Elsevier Publishing Co. Ltd., 1968.

[38] Mackey, C.O. and Wright, L.T.: Periodic heat flow - composite walls or roofs, heating, piping and air conditioning, 18: 107-110, 1946.

[39] Olgyay, V. and Olgyay, A.: Solar controls and shading devices, Princeton University Press, NJ, 190 pp., 1957.

[40] Hopkinson, R.G. and Key, J.D.: The lighting of buildings, Faber and Faber, London, 320 pp., 1972.

[41] Moore, J.E.: Design for noise reduction, Architectural Press, 1966.

[42] Kapur, J.C.: A report on the utilisation of solar energy for refrigeration and air conditioning applications, Solar Energy, 4: 39-47, 1960.

[43] Tandy, C.: Landscape of industry, John Wiley and Sons, New York, 314 pp., 1975.

[44] The Building Regulations, HMSO, London, 1972.

[45] ASHRAE Guide and Data Book: Fundamental and equipment, Am. Soc. Heating, Refrigerating and Air Conditioning Engineers, NY, 1965-66.

[46] Mills, E.D.: Factory Buildings, Leonard Hill, 1967.

[47] Koenigsberger, O.H., Ingersoll, T.G., Mayhew, A. and Sezokolay, S.V.: Manual of tropical housing and building, Part I: Climatic design, Longman Group Ltd., London, 320 pp., 1974.

[48] Ellis, F.P.: Comfort zones for different parts of the world, Hunterian Lecture, Ann. Roy. Coll. Surg. 13: 369-391, 1953.

[49] Sen, R.N.: Unpublished experimental data.

INDIAN JOURNAL OF PHYSIOLOGY AND ALLIED SCIENCES

JANUARY, APRIL, JULY & OCTOBER, 1979

VOL. 33, NOs. 1 - 4

PROCEEDINGS OF THE INTERNATIONAL SATELLITE SYMPOSIUM
ON
WORK PHYSIOLOGY AND ERGONOMICS

HELD IN CALCUTTA FROM 1 - 3 NOVEMBER, 1974

(During the XXVI World Congress of Physiological Sciences, held at New Delhi, 1974)

EDITED BY :

Rabindra Nath Sen and Sachchidananda Banerjee

PUBLISHED BY THE PHYSIOLOGICAL SOCIETY OF INDIA

THE INDIAN JOURNAL OF PHYSIOLOGY AND ALLIED SCIENCES is devoted to promote publication of original research articles on physiology and allied sciences (Biochemistry, Biophysics, Pharmacology, Comparative Anatomy, Zoology, Genetics, Microbiology, Immunology, Physiological Psychology, Work Physiology and Ergonomics, Nutrition etc.). Only those which have not been submitted elsewhere or published will be considered for publication. Short papers as notes or communications related to research methods, techniques or apparatus pertinent to the above fields, subject to editorial consideration are invited for quick publication. Limited number of review articles, proceedings of symposia, proceedings of the scientific meetings of the Physiological Society of India may be published from time to time. Papers published become the copy right of the Society.

All manuscripts, in triplicate, for publication should be submitted either to the Editorial Office or to the Editor-in-Chief or to any one of the regional editors. Neither the editors nor the publishers accept any responsibility for views and statements of authors expressed in their Communications or papers. Details for submission of manuscripts are given under "Information for contributors".

Editorial Office : Department of Physiology, University College of Science.
92, Acharyya Prafulla Chandra Road, Calcutta-700 009

Subscription Rates of the Journal : India : Rs. 150·00 and other countries: $ 50·00 or equivalent, (Postage extra) per year : Single issue—Rs. 40·00 or $ 13·00. Back Volumes, if available, are at special rates, on request.

REPRINT RATE

Upto	50 Copies Per Page	Rs.	20/-
,,	100 Copies Per Page	Rs.	25/-
,,	200 Copies Per Page	Rs.	40/-
,,	300 Copies Per Page	Rs.	50/-
,,	400 Copies Per Page	Rs.	60/-
,,	500 Copies Per Page	Rs.	70/-

Correspondence concerning subscription, proof, requests for single or back numbers, reprint orders, renewals of subscriptions etc. should be sent to the Editorial Office. All remittances should be made payable to 'The Physiological Society of India', 92, Acharyya Prafulla Chandra Road, Calcutta-700 009, India.

Indian Journal of Physiology and Allied Sciences

Vol. XXXIII, Nos. 1-4,

January, April, July, October, 1979

Edited by :

Rabindra Nath Sen and Sachchidananda Banerjee

PROCEEDINGS OF THE INTERNATIONAL SATELLITE SYMPOSIUM ON WORK PHYSIOLOGY AND ERGONOMICS

HELD AT CALCUTTA FROM 1-3 NOVEMBER, 1974

(During the XXVI World Congress of Physiological Sciences, held at New Delhi, 1974)

CONTENTS

Third Scientific Session : Work Capacity and Muscular Exercise :

Fourth Scientific Session : Circadian Rhythm, Thermal Stress and Work Load :

Fifth Scientific Session : Ergonomics, Standards and Design :

Sixth Scientific Session : High Altitude :

Seventh Scientific Session : Energy Expenditure and Nutrition :

Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 1 - 2, 1979

WORK PHYSIOLOGY AND ERGONOMICS

Professor (Mrs.) A. Chatterjee

Dean, Faculty of Science, Calcutta University

Professor P. K. Bose, Pro-Vice-Chancellor of Academic Affairs of the University of Calcutta, Professor S. R. Maitra, distinguished delegates from India and abroad and friends,

It is a proud privilege for me to preside over this memorable occasion. I would like to state at the outset why the International Satellite Symposium is being held in the University of Calcutta under the joint auspices of the Department of Physiology and the Physiological Society of India. This is a continuation of the international Congress of Physiological Sciences, held recently in Delhi, in which eminent scientists from India and abroad participated giving an opportunity to their fellow colleagues to learn about the recent developments on this multidisciplinary subject. The Department of Physiology, University of Calcutta, has been the pioneer in introducing this subject of Work Phyyiology and Ergonomics in the M. Sc. Course in 1971-72 and also in organising researches in this area ; the department has also received encouragement from the Physiological Society of India in this matter. It is, therefore, in the fitness of the things that the International Satellite Symposium has been organised jointly by the Department of Physiology, University of Calcutta and the Physiological Society of India. This affords an opportunity to the scientists working in this particular area to meet and exchange their ideas, thereby enriching the knowledge in "Work Physiology and Ergonomics".

The Symposium on "Work Physiology and Ergonomics" is very appropriate for the present atmosphere in India. India has entered in the industrial age, and modern technology and science are constantly spreading their horizons. So, man and machine should be understood in a scientific way. In such a scientific study not only both man and machine should be studied individually for their work capabilities but also the relation between the two should be more thoroughly understood through a study of the man-machine system as a whole. Man's work depends on physiological and psychological factors and they should be clearly defined. His working place and its environmental

---

Presidential Address at the Inaugural Session of the International Satellite Symposium on Work Physiology & Ergonomics held in Calcutta.

relations need an intensive study like climate, temperature, humidity, vibration, noise and radiation, as they affect his work capacity. Similarly, man's work capability depends on physiological parameters of muscle power and cardiorespiratory capacity which vary with age and sex and require scientific classification. Techniques of Work Physiology and Ergonomics can classify these scientific details of human work capabilities. Machines are designed and constructed by man in factories with more or less clearly defined capabilities. But man's relation with the machine should be developed scientifically by fitting it for human physiological and psychological parameters or, in other words, by an intensive knowledge of the man-machine system. An engineer would not use a machine without knowing its characteristics like power, optimum speed and productive efficiency ; but we find a change in this attitude when human power is to be used as mechanical energy. Man is used arbitrarily without knowing the characteristics like the power of muscles, heart and lungs, his optimum rhythm of work, his physiological working level, his onset of fatigue and recovery during rest. Physiological energy expenditure must be measured because it is the lone accurate way of evaluating the work load and estimating the degree of fatigue. These measurements provide the key to the solution of the problem of what man can do safely. These studies are undertaken in Work Physiology and Ergonomics. Ergonomics is the science and technology of man at work and is an interdisciplinary subject. Calcutta University has given the lead to the rest of India by initiating its study and the students trained here may immensely help to revolutionize the working conditions in industry, agriculture, sports, defence and any other field of human activiy. Other Universities should also follow this lead to produce qualified work physiologists and ergonomists to help our industries and other working institutions to harmonise man with his work in industries and elsewhere.

This international Satellite Symposium during the time of International Physiological Congress has provided qualified scientists in this branch to collaborate with Indian workers. I hope useful discussions will be held and the deliberations of Indian workers and the distinguished delegates from abroad will throw further light on this particular subject, yet to attain the zenith of development. Research activity in this branch should be intensified because of its great impact on the national economy and the productivity of the country.

Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 3 - 6, 1979

WORK, HEAT AND NUTRITION

Professor Dr. Otto. G. Edholm

Human Physiology Division
National Institute for Medical Research
Holly Hill, London.

Some people are born great, some achieve greatness, while some have greatness thrust upon them. I had greatness thrust upon me when I was honoured by being asked to give the Fifth Prof. Subodh Chandra Mahalanabis Memorial Oration.

I will describe some of the adventures my colleagues and I had, in measuring energy expenditure in Man, and outstanding related problems. I started in this field about twentyfive years ago—quite by chance, when I was asked by the British Army to evaluate the food intake of army cadets and to measure their energy expenditure (Edholm, *et al.* 1955).

We found that the cadets spent quite active lives—energy expenditure being about 3,700 kcal per day, and then we tried to match the food intake with the energy expenditure. People are inclined to assume that food intake must equal energy expenditure ; but we found that while food intake tends to match the energy expenditure on the average, in individuals there are big mismatches. In fact, on a daily basis, matching shows that there is no relationship whatsoever between energy expenditure and energy intake.

We thus began to learn that man has a very different nutritonal balancing mechanism than that described by many workers in this field. Thereafter, more studies were carried out to form an idea about how man balances his energy budget.

Summary of the Fifth Prof. Subodh Chandra Mahalanabis Memorial Oration delivered by Prof. Dr. O. G. Edholm on 1st November, 1974 at the Saha Institute of Nuclear Physics Auditorium, Calcutta, in the First Scientific Session of the International Satellite Symposium on 'Work Physiology & Ergonomics'.

Again, the subjects chosen were from the army, as this way more subjects are available, and there is complete control over the subjects and their activities. During this phase, measurements were made using a very sensitive instrument, the Integrating Motor Pneumotachograph (IMP), which the subjects wore all the time except when eating. Again, no connection was found between food intake and energy expenditure on a daily basis, but there was some correlation ($r = 0.7$) on a weekly basis. We concluded that balancing takes place over long periods of time (Edholm,1961).

In Gambia for example, in a farming village, the whole year energy expenditure was measured. Here, food is plentiful at times when the work load is low, and when there is a lot of work, the availability of food is diminished. The subjects were seen to perform their balancing over the whole year—a very long period, indeed. The relation between food intake and body weight was also not very good. In Yemenites, the energy expenditure was seen to be related to the amount of time spent out of doors (between 0600 and 1800 hours).

The Yemen study reveals the remarkable skill man has for working in hot environment. Man is extremely efficient in carrying out work in conditions of considerable thermal stress, without raising the heart rate or body temperature, particularly when not driven by a Sergeant Major. These investigations may be worth carrying out in India (Edholm & Samueloff, 1977).

Among other means of following the energy expenditure, the relation between heart rate and energy expenditure is not a linear one, but reasonably good. So this is a workable way of looking at energy expenditure. This can be done using 'SAMI'—a Socially Acceptable Monitoring Instrument, and is the only way out in cases of subjects (such as bus drivers and conductors) whom it is impossible to convince to wear masks and other paraphernalia. The heart rate shows the pattern of energy expenditure, particularly when monitored over Day/Night, Summer/Winter, and similar periods (Edholm, 1976).

Acclimatisation is a striking characteristic of man's response to a hot environment. Inhabitants of temperate countries when first exposed to heat can be very uncomfortable and may even collapse. With repeated exposures these initially intolerable conditions become gradually less oppressive until eventually they can be experienced without difficulty.

The main feature of acclimatisation is the change in sweat rate which increases with each daily exposure. After some 20 sessions in hot conditions sweat rate will have doubled. Other easily demonstrated changes are the diminishing effect of heat on body temperature and heart rate. These features have been studied in detail in special climatic chambers ; the whole process has therefore been termed artificial acclimatisation. An obvious question has been to ask if artificial and natural acclimatisation are identical.

Two major studies were carried out in the U. K. and Aden by my colleagues and myself. In the first study, the subjects were soldiers stationed in the U. K. who had not experienced hot climates. They were divided into three groups : one was sent to the hot climate of Aden to become naturally acclimatised (NA) ; a second was artificially acclimatised (AA) in climatic chambers in the U. K. ; the third was sent for training in the cool climate of Scotland with no exposure to heat (control). At the end of the treatment period, all subjects were brought to the climatic chambers in the U. K. and tested. The sweat rate and other responses of the natural and artificial acclimatised subjects were similar while the control group in the heat had low sweat rates, high body temperatures and heart rates. All three groups of subjects were flown to Aden, where they carried out a strenuous military exercise. Performance was assessed using two criteria : the number of casualties due to heat and military behaviour judged by three experienced army officers. In the first five days, casualties were similar in the NA and AA groups, but the casualty rate in the control group was much higher. In the second half of the field exercise, the NA group had the fewest casualties ; the AA group had as many as the control group. Throughout the military exercise the NA subjects had the best military performance and the AA subjects the worst. The results were interpreted as showing that natural (NA) and artificial acclimatisation (AA) produced similar effects initially. The subsequent rise in the casualty rate in the AA subjects and their poor military performances were attributed to their lack of military training in the treatment period and their consequent low level of physical fitness (Edholm *et al.* 1963).

The effect of physical fitness was tested in a second experiment in which members of the Parachute Regiment, who have to attain and maintain high standards of physical performance, acted as subjects. Naturally acclimatised and unacclimatised men were studied in Aden. In spite of a high level of physical fitness, the unacclimatised men had many heat casualties ; the acclimatised had hardly any. It was concluded that physical fitness is important, but it cannot substitute for acclimatisation (Edholm, *et al.* 1964).

People who are permanent residents of hot countries have also been studied, specifically to determine whether there are seasonal changes. Kurdish and Yemenite Jews living in the Negev desert of Israel were studied in the summer and the winter. In the summer months temperatures reached 35°C and there were 10 to 11 hours of insolation daily. In the winter mid-day temperature varied considerably but reached 24°C on most days. Insolation averaged 6 to 7 hours daily. The winter weather was rather like an English summer. In spite of this the acclimatisation levels declined dramatically in the winter months. It had been expected that the high level of acclimatisation in the summer would be maintained, at least in part throughout the year. Acclimatisation as shown by sweat rate is clearly highly dependent on immediate environmental coditions and does not persist for long without adequate stimulation (Edholm *et al*. 1973).

In conclusion, I would like to add a post-script to the statements made by Prof. P. K. Bose in his inaugural address. He said that the average intake of Indians is 16,00 to 17,00 Kcal per day, a figure about half that of Westerners. If this is so, then a large portion of the population (half of them) are below this level, and these are working people. If the intake is so low, and people are able to carry on, then this problem (of energy balance in man) is a fascinating one, and at least as challenging as that of Space (Edholm, 1977).

REFERENCES

Edholm, O. G., Fletcher, J. G., Widdowson, E. and McCance, R. A. (1955) : The energy expenditure and food intake of individual men. *Brit. J. Nutr.*, **9** : *286-300.*

Edholm, O.G. (1961) : Energy expenditure and calorie intake in young men. *Proc. Nutrition Soc.* **20** : *71-76.*

Edholm, O. G., Fox, R. H., Adam, J. M., and Goldsmith, R. (1963) : Comparison of artificial and natural acclimatisation. *Fed. Proc.* **20** : *709-715.*

Edholm, O. G., Fox, R. H., Godlsmith, R., Hampton, I. F. G., Underwood, C. R., Ward, E. V., Wolff, H. S., Adam, J. M., and Allan, J. R. (1964) : The effect of heat on food and water intake of acclimatised and unacclimatised men. Army Personnel Research Committee, *Med. Res. Council, London, Report No. APRC 64/16.*

Edholm, O. G., Samueloff, S., Mourant, A. E., Fox, R. H., Laurie, J. A., Lehman, H., Bavley, S., Beaven, G. and Even-Paz, Z. (1973) : Biological studies of Yemenite and Kurdish Jews in Israel. XIII. Conclusions and Summary. *Phil Trans. Roy. Soc. London. B.* **226** : *221-224.*

Edholm, O.G. (1976) : The use of socially acceptable monitoring instruments (SAMI) in 'Man in urban environments' Edited by G. A. Harrison and V. B. Gibson, Oxford University Press. *pp. 167-175.*

Edholm, O. G., and Samueloff, S. (1977) : The Israel Study : the anatomy of a population study In : Population Structure and Human Variation : Edited by G. A. Harrison, International Biological Programme Vol. II, Cambridge Univ. Press. *pp. 219-239.*

Edholm, O. G. (1977) : Energy balance in man. *J. Human Nutrition* **31** : *413-431.*

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 7 - 10, 1979

PHYSIOLOGICAL CHANGES DURING GRADED WORK

Professor S. R. Maitra

Department of Physiology, University College of Science & Technology, Calcutta.700 009.

I thank the Physiological Society of India for selecting me to deliver the Sixth Prof. S. C. Mahalanabis Memorial Oration, which gives me an opportunity to express my regards and gratitude to my great teacher. He inspired me to undertake the study of Physiology with his remarkable lectures on basic Physiology at the Intermediate Science classes in the Presidency College, Calcutta. His command on both English and Bengali languages was unparalleled. I still remember and cherish his wonderful lectures. He was the Father of Physiology as a basic science In India. He himself started the study of Physiology under the Science Faculty of the Calcutta University at the beginning of this century.

I shall try to summerise in this lecture the work which I could do in the Department of Physiology, University College of Science, on "Work Physiology" for nearly a decade. I took my training on "Work Physiology" in the Gymnastikterearetiske Laboratorium of the Institute of Physiology of the University of Copenhagen, Denmark, under the guidance of Prof. Earling Assmussen. On this occasion, I show my gratitude to Prof. Assmussen and also the Institute of Physiology of the Copenhagen University. I shall briefly narrate the work which I could do with a band of research workers, namely Dr. Sankar Koyal (1963), Dr. Satipati Chatterjee (1966), Dr. Pratima (SenGupta) Chatterjee (1964), Dr. Sunil Kumar Das (1969), Dr. Juthika Koley (1970), Dr. Pinaki Chatterjee (1972), and Dr. Sabita Mazumder.

Summary of the Sixth Prof. S. C. Mahalanabis Memorial Oration delivered by Prof. Dr. S. R. Maitra o. Ist November 1974 in the First Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta.

Some experiments were undertaken on human subjects of 12-15 age-groups to measure the following parameters : (i) aerobic capacity or oxygen consumption, (ii) anaerobic capacity or blood lactate level, (iii) heart rate, (iv) vital capacity and (v) pulmonary ventilation. The maximal physical work capacity of the subjects was determined by noting the workload which they could sustain for about 1 to 2 minutes through graded sub-maximal work-load, as indicated by extreme subjective fatigue and at least 70 to 80 mg% blood lactic acid (Table I).

Table I

Physiological parameters of different groups of subjects during maximal workload

Age	Body Weight (kg)	Body Height (cm)	Maximal Work Load (Kgm/min)	Pulmonary Ventilation (l/min)	Maximal O_2 Consumption (l/min)	Blood Lactate (mg%)	Heart Rate (beats/min)
12-15	38-44	150-158	613	38.8	1.38-1.75	60-80	190-200
16-20	46-56	163-175	924	48.3	1.75-2.05	81.6-91.8	198-218
21-25	57-59	164-173	1230	33.4	2.38-2.60	97.8-110.9	230

It appears from Table I that the physical working capacity of our subjects during their development phase from the 12th year to the 25th year as indicated by the maximal oxygen consumtption is increasing gradually upto the 25th year, when the body weight and height also reach their maximum values. The rise of anaerobic capacity also bears a similar relation to age.

We have found that the working condition of a person tends to produce physiological changes inside the body, such as changes in haemoglobin content of blood, number of red cells and white cells in blood, plasma proteins, blood electrolytes, etc. (Matira, 1967). To get an idea how far cellular and blood enzymes are affected during graded exercise, two important enzymes, lactic dehydrogenase (LDH) and malic dehydrogenase (MDH), of muscle, liver and heart of rats, were studied. Both the enzymes were also studied in the blood of human subjects during rest and graded exercise. It is interesting

to note that plasma LDH and MDH increase by 1.5 to 2 times after a work of 600 kg metre/min for 10 minutes in different persons. These enzymes were also increased in the tissues of rats after exercise. Electron microscopic studies revealed an increase in the size and number of mitochondria in those tissues of rats after graded exercise, which has an implication of improved cellular functions after exercise. When a man is doing physical work, we may classify the heaviness of work by measuring his oxygen consumption and lactic acid production. This may be expressed in terms of percentage of one's aerobic capacity as given in Table 2.

Table 2

Heaviness of work in terms of aerobic capacity

Heaviness of work	Percentage of aerobic capacity
Light work	upto 10%
Moderate work	above 10% upto 30%
Heavy work	above 30% upto 60%
Very heavy work	above 60%

I have given above a brief account of some of the research work we could do in the field of Work Physiology in the Physiology Laboratory of the Calcutta University. More such studies should be undertaken on the physical working capacity of our population on regional basis considering also the nutritional status, working habits and the climatic conditions. This will give us a correct picture about man-power, the most important resource of our country and we should be able to use this information properly in industry, agriculture, defence, sports and other activities where the use of physical power of man is needed.

REFERENCES

Chatterjee, S. (1966) : Haematological and allied changes with graded work. D. Phil. thesis of the Calcutta University in Physiology.

Chatterjee, P. R. (1972) : Effect of Exercise on Heart, Liver, Muscle Dehydrogenase Enzyme Systems, D. Phil. thesis of the Calcutta University in Physiology, 130 p.

Koyal, S. (1963) : Studies on characteristics of physical fitness of boys of different age groups. D. Phil. thesis of the Calcutta University in Physiology.

Maitra, S. (1967) : Work Physiology-its background and utility. Presidential Address of the Section of Physiology of the Indian Science Congress, Hyderabad, 21 p.

Sengupta, P. (1964) : Effect of graded work on heart as recorded by electrocardiography and other allied physiological changes in different age-groups. D. Phil. thesis of the Calcutta University in Physiology.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 11-17, 1979

AN INVESTIGATION OF THE ELECTROMYOGRAPHIC RESPONSE IN MAN AT WORK

R. H. Harding, P. R. M. Jones, R. N. Sen* and J. Wyness+

Department of Human Sciences, University of Technology, Loughborough, Leicestershire LEII 3TU, England,
**Ergonomics Laboratory, Department of Physiology, Calcutta University, 92 A. P. C. Road, Calcutta-700 009, India, and*
+The Northern Ireland Polytechnic, Co. Antrim.

The classical method of optimising a work has been to minimise the energy expended by an operator, measured by indirect calorimetry - a technique requiring cumbersome gas collection apparatus, and expensive gas analysis equipment, fairly long periods for the subject to equilibriate to each new condition, with cumulative subject fatigue and time-consuming experimentation. These difficulties are sought to be avoided by using as a relative measure of energy expenditure, an estimation of the muscular effort for the task with the help of suitably quantified surface recorded electromyogram (EMG) whose advantages include less encumbrances and instantaneous responses. The surface EMG being positively correlated with muscular effort (Harding and Sen, 1969 ; Jones, Harding and Wyness, 1971 ; Sen, Harding and Jones 1973), minimisation of the total EMG due to work manipulation should give results which would be similarly predicted from energy expenditure.

Experiments were carried out when oxygen uptake was the indirect variable with the EMG recorded simultaneously, to see whether muscle potentials were a practical and reliable prediction of the task demands. The obtained results indicate a low correlation with oxygen uptake ($r = +0.26$) at this level of work. However, as the whole body EMG can significantly discriminate between differing levels of work it should not be ignored as a suitable research method in the study of man at work.

In ergonomics studies of the human operator's workplace, it is important to be able to make objective comparisons of a series of varying configurations. The accepted metric used is the energy expended by the subject on a set task at the relevant work place. The energy expended is normally estimated from indirect parameters like oxygen consumption which, though an accurate estimation of absolute physiological work putput, suffers from practical disadvantages. For example, it requires the wearing of cumbersome gas collection

Paper Presented at the Second Scientific Session of the International Satellite Symposium on Work Physiology & Ergonomics held at Calcutta from 1 - 3 November, 1974.

apparatus by the subject, relatively expensive equipment for gas analysis and a skilled operator. Energy expenditure estimations also require fairly long periods for the subject to equilibriate to each new experimental condition, resulting in cumulative subject fatigue and time consuming experimentation. Such difficulties in applying the usual absolute measures of energy expenditure may be avoided in solving many practical problems by choosing a relative measure like an estimation of the muscular effort for a task by the suitably quantified electromyogram (EMG). Some of the advantages of the surface-recorded EMG are: (i) the instantaneous nature of the response, significantly reducing experimental times and fatigue effects; (ii) less encumbrances on the subject, provided a suitable technique is adopted for the electrode attachment and lead-running.

Under controlled laboratory conditions, the quantified EMG has been shown by a number of investigators, notably Inman *et al.* (1952) and Lippold (1952), to be highly correlated with certain mechanical functions like constant force, velocity and acceleration of muscle/segment systems. It has always proved difficult to apply these results to real life situations with muscle/body segments operating under varying conditions of tensions and velocities. If, on the other hand, "muscular effort" is recognised as the parameter of real interest in many practical problems, then the total body EMG will strongly reflect this. Table 1 shows a series of graded work tasks; it can be seen that the accompanying EMG adequately discriminates between the different loads. The technique employed to take account of the total body EMG associated with a task has been well-described elsewhere (Harding and Sen, 1970; Sen, Harding and Jones, 1973).

TABLE I

Quantified values of EMG during different activities with 't' values

Activities	Mean Quantified EMG, (mV/min.)	Standard Error	't' values	between activities
1. Lying	8.34	±0.48	—	—
2. Sitting	11.83	±0.63	6.58**	1 & 2
3. Standing	19.78	±0.75	3.60*	2 & 3
4. Walking at 3 m.p.h.	91.83	±2.54	15.29**	3 & 4
5. Walking with a load	144.68	±2.85	2.93*	4 & 5

N = 160 (8 subjects × 4 sessions × 5 samples);

** $P < 0.1$, * $P < 1.0$ } levels of significance

The experiments described in this paper are based on the hypothesis that the surface EMG is positively correlated with increasing muscular efforts. Hence, reduction of the total EMG due to improvement in the work method, should give answers similar to those obtained from energy expenditure (Scherrer and Bourguignon 1959; Jones, Harding and Wyness, 1971; Harding, 1972).

MATERIALS AND METHODS

The set-up for the first experiment is shown in Figure I, where the oxygen uptake is being simultaneously measured with the total body EMG. The investigation was conducted to find the optimum height of a postal parcel delivery glacis from indices which would detect minimal effort.

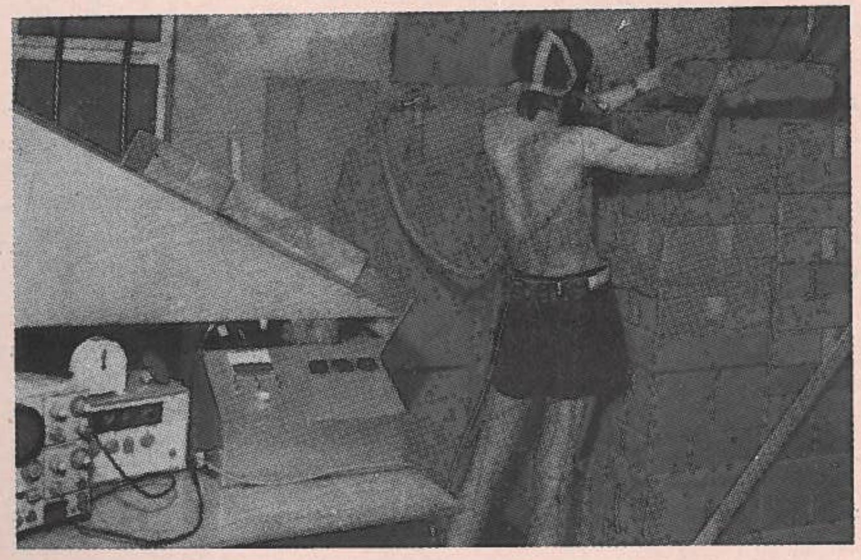


Fig. I.

Figure I : Set-up of Experiment No. I for the measurement of oxygen uptake and total body EMG- at different glacis heights.

Surface electrodes were attached to the subject using a bi-unipolar configuration arranged in pairs on the flexor/extensor muscle groups of the upper and lower extremities (Harding and Sen, 1970). Sixteen pick-up points were thus located, with a further eight sited over the major trunk muscles; these were considered adequate to reflect major activity for this task.

The raw EMG was combined and presented as a single value in millivolts which corresponded to the average muscular effort during several minutes of the task activity.

In the experiment, the subject took parcels from the glacis at a height of 48". He placed 14 layers, i.e., a full load of 10 parcels in each layer on the post-office container's bottom surface which was constantly adjusted to remain at 9" above the ground. The 2 kg parcels were loaded at a fixed rate of 20 min⁻¹ giving a 7 min work period. After a 3 min rest to allow a return of the subject to his pre-exercise state, the experiment was repeated a further 4 times, lowering the glacis by 6 inch step each time.

The mixed expired gas samples were collected over the 7 min period and analysed for O_2 and CO_2 ; the oxygen uptake and energy expenditure levels were determined for the five conditions mentioned above.

The EMG was measured and quantified using the equipment described by Harding and Sen (1969). The EMG's obtained separately from the trunk and extremities were first weighted before combining, to take into account of intra- and inter-subject variations of muscle mass. These weightings were determined from measurement of limb lengths, circumferences and skinfolds (Jones, 1969, 1970). The combined weighted values provided the total body EMG estimation for each of the experimental conditions.

A second experiment was carried out in which the glacis was maintained at a constant height, but the container loading height was varied. The loading surface was also partitioned into three areas, viz., front, centre and rear, each for separate consideration.

RESULTS AND DISCUSSION

Figure 2 shows a typical polygraph record of the active muscles for a subject working at two extreme glacis heights. For the two glacis heights, it will be noticed that muscle activity, while decreasing in one segment of the body, is coupled by an increase in another. This effect poses the problem of meaningful interpretation of the EMG responses from different body segments in view of the differing nature of the lever systems. In an attempt to resolve this problem the authors used the weighting system described, and directly compared the total body EMG with the oxygen uptake, assumed to be the standard reference.

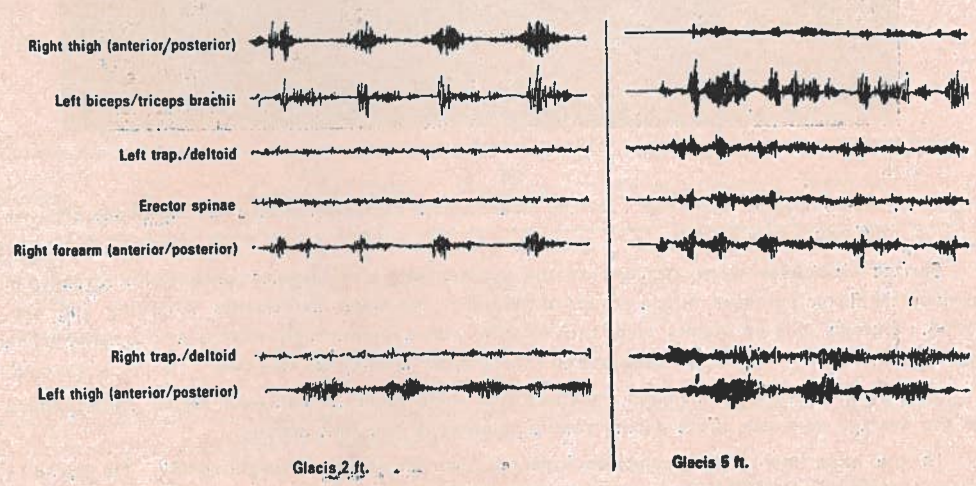


Figure 2 : Typical EMG activity of major muscle groups during loading at two extreme glacis heights.

The two independent variables O_2 and total body EMG are plotted against the glacis heights in Figure 3 and against the container platform heights in different surface positions in Figure 4 for the first and second experiments respectively. It will be noticed that in both experiments O_2 and EMG show similar trends, especially in the second expriment where different areas on the loading surface are compared. Both O_2 and EMG show highly significant ($p \leq 0.01$) differences between all three positions of front, centre and rear.

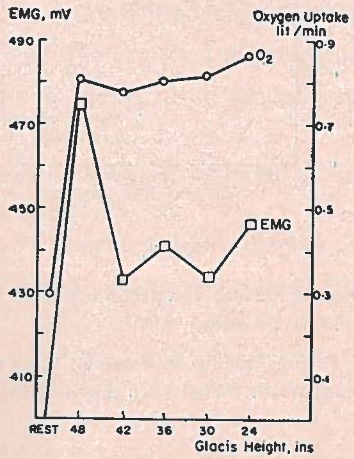


Fig. 3.

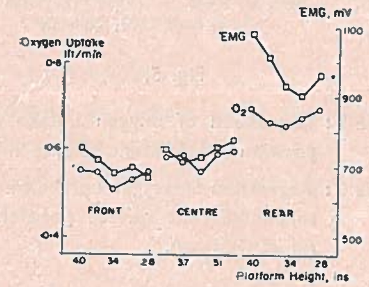


Fig. 4.

Figure 3 : Mean values of total body EMG and oxygen uptake for different glacis heights when fully loading a post-office container in Experiment No. 1 (N=21 males).

Figure 4 : Mean values of total body EMG for different heights of container platform in different surface positions in Experiment Nos. 1 and 2 (N=21 males).

Figures 5 and 6 show the regression of oxygen uptake on total body EMG. It can be seen that the correlation coefficient (**r**) is low and almost identical for both the experiments (**r** = +0.21 and + 0.26, respectively). This low correlation may be attributed to causes like incorrect weightings applied to the EMG from the various parts of the body, especially the trunk where the muscle mass is difficult to estimate. More likely causes probably include differing strategies of the subjects in task performance or large inter-subject variations. However, in spite of these draw-backs, the whole-body EMG can significantly discriminate between differing levels of work, especially submaximal. Therefore, the authors feel that this technique should be given more consideration as a suitable research method in the study of man at work.

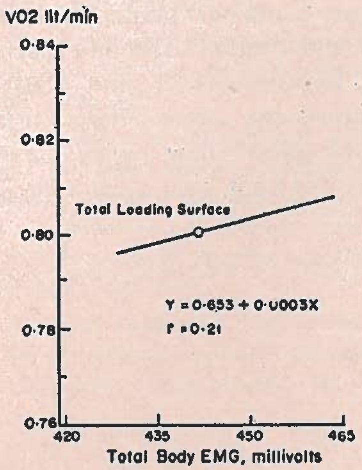


Fig. 5.

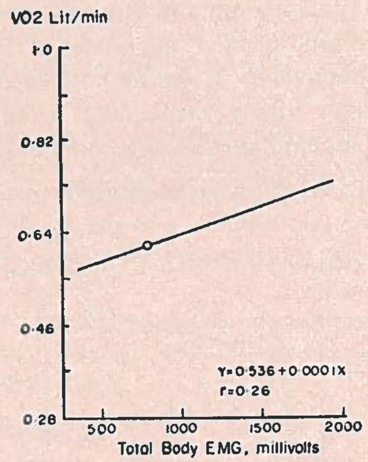


Fig. 6.

Figure 5 : Regression of oxygen uptake on total EMG during loading of a parcel container at one position and different heights in Experiment No. 1 (N=21 males).

Figure 6 : Regression of oxygen uptake on total body EMG during loading of a parcel container at three different surface positions and different platform heights in Experiment No. 2 (N=135 males).

REFERENCES

Harding, R. H. and Sen, R. N. (1969) : A new simple method of quantifying the electromyogram to evaluate total muscular activity. *J. Physiol.*, **204** : *66-68.*

Harding, R. H. and Sen, R. N. (1970) : Evaluation of total muscular activity by quantification through a summing amplifier. *Med. & Biol. Engng.*, **8** : *343-356.*

Harding, R. H. (1972) : Techniques for estimating global electromyograms. *M. Sc. Thesis*, University of Technology, Loughborough, Leicestershire, England.

Inman, V. T., Ralson, H. J., Saunders, J. B., Feinstein, B., and Wright, E. W. (1952) : Relation of human electromyogram to muscular tension. *EEG Clin. Neurophysiol.*, **4** : *187-194.*

Jones, P. R. M. (1969) : Radiographic determination of leg fat, muscle and bone volumes in male and female adults. *J. Physiol.*, **207** : *1-3.*

Jones, P. R. M. (1970) : An application of physiological anthropometry. *Ph. D. Thesis.* University of Technology, Loughborough, Leicestershire, England.

Jones, P. R. M., Harding, R. H. and Wyness, J. (1971) : The ergonomics of parcel filling of containers. *LUTERG Report* **59.** 35 p.

Lippold, O. C. J. (1952) : The relation between integrated action potentials in a human muscle and its isometric tension. *J. Physiol.*, **117** : *492-499.*

Scherrer, J., and Bourguignon, A. (1959) : Changes in the EMG produced by fatigue in man. *Am. J. Physiol. Med.*, **38** : *148-158.*

Sen, R. N., Harding, R. H. and Jones, P. R. M. (1973) : A new electromyographic technique for objective evaluation of muscular effort during exercise. Proceedings of the World Congress of Sports Medicine held in Oxford (6th to 11th September, 1970), *Brit. J. Sports. Med.*, **7** : *135.*

COMMENTS

Dr. S. N. Koyal : Was there any relation between 0_2-pulse and EMG ?

Dr. P. R. M. Jones : We have no data on instantaneous 0_2-pulse, but it is certainly a parameter which we should look into in future.

Dr. O. G. Edholm : Was the heart rate better related to the EMG ?

Dr. P. R. M. Jones : It shows some relationship with $\dot{V}0_2$. They are interchangeable.

Dr. K. Kogi : Your techniques are useful for the description of particular types of activities.

For which other purpose, are your techniques useful ?

Dr. R. N. Sen : Our technique on EMG is an attempt to grade light muscular work where oxygen consumption could not indicate the gradation of work intensity. Heavy muscular work could easily be graded by the measurement of oxygen consumption.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 18 - 25, 1979

OPTIMAL WORKLOAD FOR INDIANS PERFORMING DIFFERENT REPETITIVE HEAVY MANUAL WORK

Rabindra Nath Sen and Pranab Kumar Nag

Ergonomics Laboratory, Department of Physiology, University of Calcutta, 92 A. P. C. Road, Calcutta 700 009, India.

The present study was designed: i) to ascertain the rates of usual work and the energy costs of carrying repeatedly seven different loads (about 30, 60, 75, 85, 90, 90 and 125 kg respectively) by seven different groups of Indian workers using different modes; ii) to grade the work on the basis of physiological responses and also with reference to the total productive physical work performed and iii) to suggest a rational basis of the rate of work.

Some of the mean values of the rates of usual work of different modes and the corresponding energy costs of work per unit time, were determined by using a K. M. Respirometer and a Scholander's gas analysis apparatus.

Based on the analysis of work carried out, the jobs of these seven groups were graded into heavy to extremely heavy. The different modes of handling of loads were compared by obtaining the same total work done and the corresponding energy expenditure. The optimal load was suggested. The mean values of total energy expenditure during working hours including rest pauses and load-free-return-journey were 1900, 2660, 1850, 2240, 2230 2660 and 1725 kcal respectively, indicating very heavy manual work, regardless of instantaneous peak load in any of these cases.

From the results it is concluded that if the daily energy expenditure during 8 hours' work–day is reduced from the high value of 2660 kcal to at least 1500 kcal, the physiological cost of work could be less and the productive life span of these groups of workers may thereby be increased.

Considerable human involvement will persist in the foreseeable future in the material handling jobs in industry, mines, agriculture and other unorganized working sectors of the developing countries. Workers, both males and females of different ages, are called upon in heavy load handling tasks (Sen et *al.*, 1974 ; Sen and Nag, 1975 ; Nag et *al.*, 1979). They work on piece-rate basis and try to earn more by performing jobs as many times as possible. Systematic studies on the problems of work organization of such unorganized and economically backward workers are warranted for the community welfare.

Paper presented at the Second Scientific Session of the International Satellite Symposium on Work Physiology & Ergonomics held at Calcutta from 1 - 3 November, 1974.

The present study was designed (i) to ascertain the rates of usual work and the physiological costs of carrying repeatedly seven different loads by seven groups of workers in different modes, (ii) to grade the work on the basis of physiological responses and also with reference to the total productive physical work performed, and (iii) to suggest a rational basis of attaining a rate of work for the unorganized workers so as to allow them to continue for longer duration without any appreciable accumulation of fatigue and deterioration of performance.

MATERIALS AND METHODS

A total of 43 young males, employed in load handling tasks were selected ; they were grouped on the basis of their experience in handling a particular load and the mode of carrying it. The body weight of the subjects varied between 45.2 to 52.6 kg (average 48.5 kg) and height varied between 154.7 to 167.7 cm (average 161.0 cm). The values had been similar to those of average Indians (Sen, 1964 ; Sen *et al* ., 1977).

During rest, work and recovery phases of usual work, the physiological responses like pulmonary ventilation and oxygen uptake were recorded using traditional open-circuit technique. Work pulse rates were obtained during the steady state of work. The cardiac cost as kg-m/beat and the recovery-pulse-sum were derived from average work and recovery curve. Mathematical treatment of the data were done in an IBM 1130 series computer system of the University.

RESULTS AND DISCUSSION

Of seven groups, there were three types of work : (i) short duration (i. e., from 2 to 3 minutes of load carrying followed by a free walk for approximately the same period) in Gr. 1 and Gr. 2 ; (ii) intermediate periods (i.e., 7 to 12 minutes of load carrying followed by a return journey without load) in Gr. 3 to Gr. 6 ; and (iii) prolonged period (i. e., more than 30 minutes walk at a stretch with a load) in Gr. 7. Detailed description of the groups are presented in Table 1. The walking speed was faster in Gr. 2 and Gr. 7 during carrying of loads on yoke. Slow rate of work was observed while carrying loads on the back with or without supporting straps. Total accumulated work done in kg-m during the working day was the highest in Gr. 6 (viz., 1.68×10^6 kg-m) followed by Gr. 1 (viz., 1.62×10^6 kg-m), though the usual load carried in the latter case was only 30 kg. Gr. 4 and Gr. 5 performed minimum amount of work, viz., 0.57×10^6 and 0.42×10^6 kg-m respectively. The intermediate values for Gr. 2, Gr. 3 and Gr. 7 were in the order of 1.20×10^6, 1.36×10^6 and 1.03×10^6 kg-m respectively. The values of the total work done suggest that the workloads were heavy except in Gr 4 and Gr. 5. However, the resultant rate of work in kg-m min^{-1} was highest in Gr. 2, as the speed of walk was fast and the load was moderate.

Table I

Description of the groups carrying loads in different modes.

Gr. No	Mode of carrying	Place of study	Actual load carried (kg)	Gross weight (body wt +actual load)	Physical work done* (kg-m min⁻¹)	Work-distribution (hr.-min)
1.	Head (short distance)	Egra	30	80	4700	2 hrs 55 min (L.C.)** 3 hrs 45 min (W.) 1 hr 50 min (St.R.)
2.	Yoke (short distance)	Nalikul	60	105	8000	5 hrs 45 min (L.C.) 1 hr 05 min (St.R.) 50 min (S.R.)
3.	Head (medium distance)	Calcutta	85	134	6100	2 hrs 50 min (L.C.) 2 hrs 05 min (W.) 50 min (S.R.)
4.	Back (with strap-short distance)	Darjeeling	90	142	2000	3 hrs 25 min (L.C.) 4 hrs (W.) 1 hr (S.R.)
5.	Back (without strap-short distance)	Ghoom	90	140	1450	3 hrs 30 min (L.C.) 3 hrs 45 min (W.) 1 hr 10 min (S.R.)
6.	Head (medium distance)	Calcutta	125	172	7650	3 hrs (L.C.) 1 hr 55 min (W.) 45 min (S.R.)
7.	Yoke (long distance)	Egra	75	115	7350	2 hrs 20 min (L.C.) 2 hrs 15 min (S.R.) 2 hrs 35 min (W.S.)

* Physical work done as kg-m min^{-1} is obtained by multiplying the gross weight with the speed of walk in meters per minute.

**L.C. = Load Carrying ; W. = Free Walking ; St.R. = Standing Resting ; S.R. = Sitting Resting ; W.S.=Working Sitting.

Physiological responses of the groups during usual work are given in Table 2. Working pulse rate of Gr. 6 was similar to Gr. 2, while the oxygen uptake of the former was the highest, viz., 2.58 litres min^{-1}. Since the working pulse rates of the groups varied between 127 to 152 beats min^{-1}, it appeared that excepting Gr. 1 and Gr. 5, other groups had an occupational load beyond the 50% of maximal oxygen uptake, which has been suggested for the 8-hour working day (Åstrand, 1960 ; Sen, 1967 ; Sen, Ray and Sarkar, 1969 ; Nag, Sen and Roy, 1979).

The rate of work of the seven groups may be classified as heavy to extremely heavy (Sen, Ray and Sarkar, 1969; Sen and Sarkar, 1973; Sen and Nag, 1975). The energy expenditure of Gr. 6 and Gr. 7 may be considered as extremely heavy which corresponds to the demand exceeding 75% of maximal oxygen uptake. Though the rates of work of Gr. 4 and Gr. 5 were less than the other groups, the high physiological responses of the groups may be due to relatively more static components in dynamic work during the usual mode of carrying loads (Nag, Sen and Ray, 1979) on the back with or without a strap around the forehead, and a forward lean to maintain balance.

The cardiac cost, indicative of cardio-vascular responses, was relatively high in Gr. 1 and Gr. 2, compared to the performance of the other groups for the same amount of work. Recovery-pulse-sum of the groups varied from 28 to 153 beats, of which Gr. 2 and Gr. 7 showed the highest values as 153 and 151 beats respectively, suggesting a considerable accumulation of fatigue. These are also evident from the high oxygen uptakes in these two groups. The recovery-pulse-sum of the present subjects exceeded 124 beats in four groups. Except Gr. 1, Gr. 4, and Gr. 5, the recovery-pulse-sum of the subjects were much beyond the permissible endurance limit (Karrasch and Müller, 1951). The recovery-pulse-sum happened to be a single exponential function of the rate of work :

$$\text{Recovery-pulse-sum (beats)} = \exp\ [3.096 + 0.013 \log_e X]$$

where X is the rate of work in kg-m min^{-1} ($r = +0.993$, i. e., significant at 0.1% level). Though not identical, similar exponential forms of variations of the recovery-pulse-sum with increasing rates of work were reported by Müller (1964), Sen and Nag (1975) and Nag, Sen and Ray (1979).

According to the recommendations of the International bodies a subject may not be allowed to carry a load more than 50 to 60% of his or her body weight. But most of the workers of the present investigation are over loaded as they carry loads weighing 1.5 to 3.0 times their body weights. We argue

Table 2

Physiological responses of seven groups of workers.

Gr. No.	Mode of carrying	Average work pulse rate (beats min^{-1})	Recovery pulse sum (beats)	Oxygen uptake (L min^{-1}) STPD	Cardiac cost (kg-m) per extra work pulse	Energy expenditure in working hours (kcal)	Gradation of jobs from oxygen uptake
1.	Head	127.6	38	1.24	156.1	1900	Heavy
2.	Yoke	152.4	153	1.54	137.5	2660	Very Heavy
3.	Head	141.4	125	1.68	100.5	1850	Very Heavy
4.	Back (with strap)	132.2	40	1.23	44.5	2240	Heavy
5.	Back (without strap)	128.0	28	1.22	41.0	2230	Heavy
6.	Head	151.0	129	2.58	115.0	2660	Extremely Heavy
7.	Yoke	143.0	151	2.02	121.6	1725	Extremely Heavy

that in assessing the workload, the speed of walk is also to be combined with the actual load plus the body weight — due consideration has also to be given to the body weight as this has to be carried by the worker simultaneously with the load. So the expression 'rate of work' in kg-m min^{-1} was emphasized in the study. Except Gr. 1, Gr. 4 and Gr. 5, the rate of work of the groups varied between 6100 to 8000 Kg-m min^{-1}. According to Sen and Nag (1975) and Nag, Sen and Ray, (1979), workers similar to Gr. 2, Gr. 3, Gr. 5 and Gr. 7, may carry loads upto 80 kg at 0.89 meter per second. If desired, more loads may also be imposed with downward adjustment of the speed of walk.

As observed from our studies on experienced load-handling workers, the kyphotic curvature of the thoracic vertebral column tended to be a straight line during carrying of heavy loads on head ; obviously, such shifting was pronounced in the older subjects. So, while walking with loads they were bound to move fast, as the centre of gravity changes at every instant. However, because of the much lower centre of gravity and the rhythmic nature of movement, carrying of loads on the yoke is advantageous ; only for half of the time the load was exerted on the shoulder, thus curtailing the static work. Changing of the yoke from one shoulder to the other shoulder can be done at ease by the worker alone, while help from others was essential for putting down the load from the head. Moreover, long yoke provides faster walking or running with little hindrance or obstruction by the load.

For extremely heavy type of jobs in India, a 1200 Kcal level is suggested as the net optimal energy output for the 8-hours working day keeping into account another 300 Kcal for the body maintenance cost during that period (Sen and Nag, 1975). Fatigue allowances were also worked out accordingly, and may be included in the existing allowances at every hour so as to keep the net expenditure equivalent to 150 Kcal per hour. Pooled average work done by the present groups during the 8-hours period was 1.13×10^6 kg-m ; this value included Gr. 4 and Gr. 5, where work done was much less. It could be derived from the suggestions of Sen and Nag (1975) that an optimal workload for the day should be around 0.96×10^6 kg-m, which corresponds to 5300 kg-m min^{-1} ; that means the overall workload of the groups may need be reduced to improve the functional life of the worker. Further, the rate of work needs be compensated for extreme environmental heat gains.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. D. Chakraborti, Mr. G.G. Ray, Mr. M. R. Kar, Mr. A. Chanda and Mr. S. Thappa, for their help in the study.

REFERENCES

Åstrand, I : (1960) : Aerobic work capacity in men and women with special reference to age, *Acta Physiol. Scand.* **49** : suppl 169.

Karrasch, K. and Müller E. A. (1951) : Das verhalten der pülsfrequency in der erhohlungperiods nach korperlicher arbiet, *Arbeitsphysiologie*, **14** : *369-382*.

Müller, E. A. (1964) : Basic physiological criteria to be taken into account for the specification of the maximal load to be carried by a worker, *Occupational Safety and Health Series*, ILO, Geneva, **5** : *20-42*.

Nag, P. K., Sen, R. N. and Ray U. S. (1979) : Cardio-respiratory performance of porters carrying loads on a treadmill, *Ergonomics*, **22** : *897-907*.

Sen, R. N. (1964) : Some anthropometric studies on Indins in a tropical climate, Proceedings of the International Symposium on Environmental Physiology and Psychology in Arid Conditions, *Arid Zone Research, UNESCO, Paris*, **14** : *163-174*.

Sen, R. N. (1967) : Studies on physiological factors limiting work output of Indian workers, *ICMR Report*, 78 *pp*.

Sen, R. N., Ray, B. S. and Sarkar, D. N. (1969) : Maximal physical work capacity of Indian industrial workers in relation to age and heaviness of job. Proceedings of the 13th International Conference of the Human Factors Society, Philadelphia, Pennsylvania, U. S. A., held from 6 th to 9 th October, *12 pp*.

Sen, R. N. and Sarkar, D. N. (1973) : Maximal physical work capacity of Indian industrial workers, *Ind. J. Physiol. & Allied Sci.*, **27** : *107*.

Sen, R. N., Nag, P. K. and Majumder, B. (1974) : An ergonomic study to compare different methods for manual carrying of loads, *Proc.* of the *61st Ind. Sci. Cong., Nagpore, Part IV, 130-131 p.*

Sen, R. N. and Nag, P. K. (1975) : Work organisation of heavy load handling in India, *J. Human Ergology*. **4** : *103-113*.

Sen, R. N., Nag, P. K. and Ray, G. G. (1977) : Some anthropometry of people of Eastern India, *J. Indian Anthrop. Soc.* **12** : *199-206*.

COMMENTS

Dr. C. S. Nair : As Ghoom is at an altitude of 800 feet data obtained could not be compared with those of Sealdah group at sea-leval. Why was the heart rate during work at Ghoom low ?

Dr. R. N. Sen : From the heart rate-oxyen consumption curve we find that the slope is considerably lower in the Sealdah group who were carrying the heaviest load. The low heart rate response might be due their high work capacity and long years of experience in the job.

Dr. K. Kogi : Were the experiments made on the same group ?

Dr. R. N. Sen : The workers had been habituated to do their usual work for 5 to 15 years. Experiments with different loads and with different modes of carrying, therefore, could not be performed on the same group.

Dr. J. N. Maitra : What was the recovery time and heart rate after carrying heavy load ?

Dr. R. N. Sen : About twenty to thirty minutes after cessastion of the work.

Dr. B. W. Hyndman : Have you used heart rate recovery as an index of work capacity ?

Dr. R. N. Sen : The heart rate recovery curve shows the combind affects of work and thermal loads and the work capacity of the indidual group.

Dr. E. J. Hamley : A point that will illustrate the Chairman's comment for controls using the same people, was observed by a student of mine who examined heart rate on carriers in a sago factory. The same people began on less demanding loads taken into the warehouse and heart rate followed load as in Mr. Nag's examples. Where the strongest men were assigned, the movement of very heavy sacs up a 30° slope in the ware-house, they at first showed the predictable heart rates but with habituation they showed decreased rates more effectively than with habituation to the lower load. Perhaps habituation tó work near 100% work capacity is more efficient than to lower rate.

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 26 - 31, 1979

SOME PHYSIOLOGICAL RESPONSES TO HARD WORK IN RACING CYCLISTS

E. J. Hamley* and H. Thomason+

**Department of Ergonomics & Cybernetics, University of Technology, Loughborough, LE11 3TU, England.*

+Human Performance Laboratory, University of Salford, England.

Twelve highly skilled cyclists had been tested on a Müller's cycle ergometer in the labortory with increasing work to exhaustion. The relationships between the maximum oxygen uptake, heart rate, etc. and the ability to perform hard physical work were established.

The ability for hard long-duration physical work is closely related to the maximum capacity of the cardio-vascular system for oxygen supply to the active tissues. It is, therefore, generally assumed that the maximal rate of oxygen consumption ($\dot{V}O_2$ max) is theoritically a good measure of cardio-respiratory performance, since it integrates the effective 'maxima' of several processes concerned in the steady-state transfer of oxygen from the environment to the active tissues (Shephard, 1969). However, in some studies on groups of athletes of similar ability and aerobic capacities, $\dot{V}O_2$ max, did not adequately predict physical ability or winning performances (Costill *et al.* 1971). The purpose of this study was to assess relationships between some selected laboratory measurements using non-invasive techniques and the ability to perform hard physical work on a cycle ergometer.

MATERIALS AND METHODS

Twelve men time-trial cyclists conditioned over the previous 3 - 5 years to laboratory procedures were subjected to continuously increasing work to exhaustion on a Müller's cycle ergometer. The trials of three tests each were carried out three months apart.

A standardised test procedure of work to exhaustion (inability to maintain the required rate of work without experimentor's motivation) was conducted. During this, metabolism was determined by open-circuit spirometry utilizing a low-resistance valve, 3.18 cm (I. D.) tubing, a mixing-sampling chamber, and a Parkinson Cowan CD 4 gasmeter. Expired-air gas samples were analysed for oxygen and carbon-dioxide by paramagnetic and infrared gas analysers, respectively. Heart-rates were monitored electrocardiographically throughout.

Paper presented at the Second Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

RESULTS AND DISCUSSION

Correlation coefficients tests within trials for maximum work done were 0.95 to 0.97.

The physical characteristics of the subjects are shown in Table 1.

Table 1

Physical characteristics of the subjects (N=12)

	Mean	SD	Range
Age (years)	21.7	± 3.1	17.2 - 28.0
Height (cm)	179.8	± 8.0	160.8 - 191.3
Weight (kg)	70.1	± 10.0	63.0 - 82.5
Saddle height (cm)	77.8	± 4.1	69.0 - 84.0

The heart-rate/work-level curve for each subject was analysed by polynomial curve fitting. The dependent heart-rate variable 'y' was treated as a function of the independent work variable 'x' with 'n' levels, expressed as $y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_{n-1}x^{n-1}$. For the addition of each higher order coefficient, a test was made of the sum of the squared deviations accounted for by the additional coefficient against the remaining residual variance.

Table 2

Descriptive statistics and reliability correlation coefficients within trial 1 for the maximum values of the physiological data.

(N = 12)		$\dot{V}e$ STPD L min⁻¹	$\dot{V}O_2$ STPD L min⁻¹	$\dot{V}CO_2$ STPD L min⁻¹	Heart-Rate min⁻¹	Nett work load watts
Test 2	$\bar{x}$	86.4	3.2	3.4	192.4	437.4
S. D. ±		12.1	0.4	0.5	6.3	47.8
	$\bar{r}$	0.73**	0.44	0.81**	0.81**	0.95**
Test 3	$\bar{x}$	91.2	3.2	3.6	193.0	433.0
S. D. ±		10.9	0.3	0.4	6.0	48.1
% VARIANCE, UNACCOUNTED FOR		47%	81%	34%	34%	10%

**Significant at the 99% level of confidence

The results of the descriptive statistics for the maximum values of the physiological data are presented in Table 2. The heart-rate response to work in all subjects for all tests/trials was curvilinear(Fig. 1).

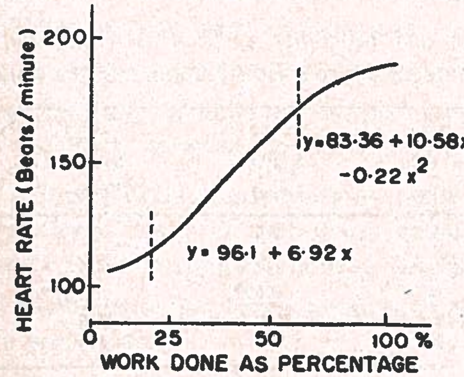


Fig. 1.

Figure 1 : Typical heart-rate-work-done-plot demonstrating curvilinearity

Åstrand and Rodahl (1970) have suggested that sub-maximal values of most physiological parameters demonstrate a relationship with the ability to perform work. In our tests at a sub-maximal level six minutes into work task, during the time when physiological responses were linear with work done, heart-rate alone demonstrated a 0.83 relationship with total work done. However, the effects of continuously increasing work of this type are cummulative. Therefore, it may be more meaningful to look at the physiological data in a cummulative manner, i. e., not maximum values but how those values are attained, hence by integration.

Integration of the data from 1.0 - 6.0 min into the work task was calculated. The reason being twofold :

1. Integrated data for the whole task has the function of time in it. This time is also included in the total amount of work done ; therefore, total integrals and total work done cannot be computed to demonstrate relationships between them.
2. In 1.0 - 6.0 min into the work task, the initial anticipatory responses, i. e., Bowen's effect (1904) in heart-rate, are over and by 6.0 min into the task all subjects were still showing linear responses between the physiological data and work done.

The results of the descriptive statistics for the physiological data integrated from 1.0 to 6.0 min into the work task are presented in Table 3.

Table 3

Descriptive statistics and reliability coefficients within trial I for physiological data integrated from 1.0 - 6.0 min into the work task.

TRIAL I (N=12)	$\dot{V}e$ STPD litres	$\dot{V}O2$ STPD litres	$\dot{V}CO2$ STPD litres	Heart Beats
Test 2	145.5 ±30.4	7.1 ±1.5	6.3 ±1.4	646.7 ±68.3
	0.76**	0.69*	0.75**	0.97**
Test 3	148.4 ±25.1	7.2 ±1.5	6.5 ±1.4	640.0 ±65.9
%VARIANCE, UNACCOUNTED FOR	43%	53%	44%	6%

** Significant at the 99% level of confidence
* Significant at the 95% level of confidence

Computation of the integrals from 1.0 - 6.0 min of the physiological data and total work have been shown the following relationship :

$\dot{V}O_2$, r=0.64 ; $\dot{V}CO_2$, r=0.82 ; and heart beats, r=—0.83 (Fig. 2, Fig. 3).

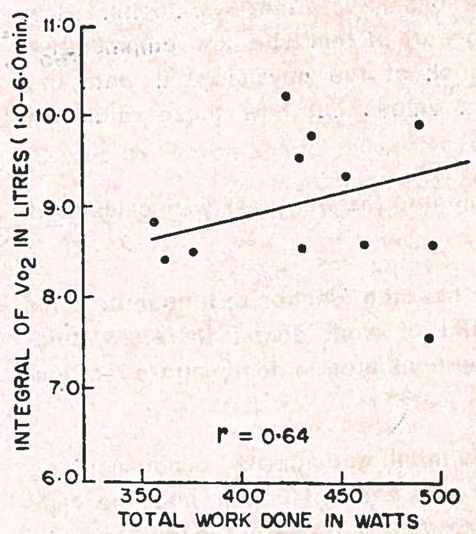


Fig. 2.

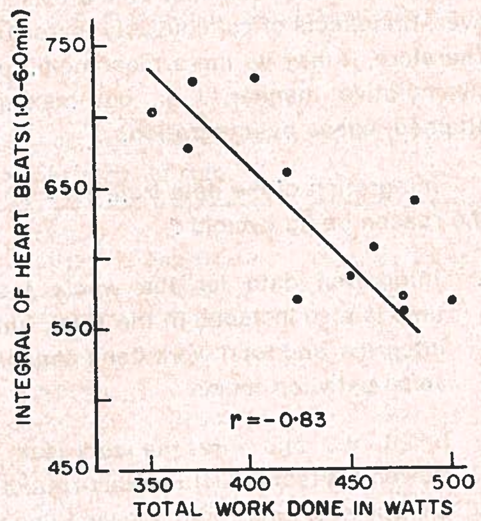


Fig. 3.

Figure 2 : Plot of the integral of $\dot{V}O_2$ in litres for 1.0 - 6.0 min into work task against total amount of work done

Figure 3 : Plot of the integral of heart beats for 1.0 - 6.0 min into work task against total amount of work done

Correlation between the mean maximum work done for the two tests and the racing ability of each subject over 25 miles was 0.97.

From the results, we conclude the following :

1. Subjects must be fully conditioned to the laboratory task and there must be high specificity between the test and their athletic event.
2. In this group of highly skilled performers of similar ability, maximal recordings of physiological data do not demonstrate those factors that may limit performance and/or distinguish between performers.
3. Sub-maximal recordings of heart-rate during the linear phase do distinguish between these performers.
4. Treatment of the physiological data by integration demonstrates that the ability to perform hard physical work on a cycle ergometer is probably dependent on the economical utilisation of a highly developed aerobic capacity and cardio-vascular system. This is shown by higher $\dot{V}O_2$, $\dot{V}CO_2$ and lower heart-rate at sub-maximal levels of performance and the higher reliability correlation of heart-rate between tests and the higher degree of the % of variance unaccounted for in the $\dot{V}O_2$ and $\dot{V}CO_2$ reliability correlations. Similar results, seen by Costill and Thomason (1973) using marathon runners, led them to conclude that successful distance running is dependent on the economical utilisation of a highly developed aerobic capacity and the ability to employ a large fraction of that capacity with minimal accumulation of lactic acid.
5. The high replicability of heart-rate as a physiological measure, as seen in this group, and its relationship with ability to perform hard physical work throughout the work task, suggests that this is a physiological parameter that can be used in these conditions as a valid measure of work done.

REFERENCES

Åstrand, P. O. and Rodahl, K. (1970) : A Text book of Work Physiology. New York, McGraw-Hill.

Bowen, W. P. (1904) : Changes in heartrate, blood pressure and duration of systole resulting from bicycling. *Am. J. Physiol.* *7 : 59-65.*

Costill, D. L., Branham, G., Eddy, D. and Sparks, K. (1971) : Determinants of marathon running success. *Int. Z. Angew. Physiol.*, *29 : 249-254.*

Costill, D. L. and Thomason, H. (1973) : Fractional utilisation of the aerobic capacity during distance running. *Med. & Sci. in Sport*, *5 : 4-9.*

Shephard, R. J. (1969) : *Endurance Fitness.* Toronto, University of Toronto Press.

COMMENTS

Dr. A. R. Guharay : Kindly comment on the air-damped load for compensating frictional heat-loss in Universal Ergostat (Swiss made).

Dr. E. J. Hamley : We do not have any experience.

Dr. S. Koyal : (1) Would you comment on the reliability of Müller's Ergometer and its calibration with regard to ambient temperature ? (2) With regard to Laneoy Ergometer, we found it is inoperative below 40 and above 80 rpm. Would you comment on this ?

Dr. E. J. Hamley : We use Müller's machine because it guarantees continuous, regular work increase and can be calibrated each time. We use it only at the published temperature conditions of 15°-20° C. So, we have no temperature correction problems. The Laneoy of Goddart gives some trouble. The version of the Venodyne ergometer made by Müller has considerable flexibility in use of rates but at low rates below 35 rpm the Venodyne is not reliable and I prefer always to keep the rate within 30% of the average throughout a test. Müller machine must certainly be held exactly without any loss or gain throughout the test and this requires great skill.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 32, 1979

ULTRASTRUCTURAL STUDIES ON THE EFFECT OF HEAVY EXERCISE AND TRAINING ON SKELETAL MUSCLE AND CARDIAC MUSCLE TISSUES.*

Sabita Majumdar and S. R. Maitra

Department of Physiology, University College of Science & Technology, 92, Acharyya Prafulla Chandra Road, Calcutta 700009, India.

Mitochondria in the rat and dog myocardium have been reported as undergoing a general enlargement and becoming somewhat swollen during forced swimming (1,2). The magnitude of these changes appeared to have been considerably less than that which was reported in the gastrocnemius muscle of rats that were sacrificed immediately becoming exhausted after running.

The work of Maitra and Chatterjee (3) and also others have shown that lactic dehydrogenase (LDH) and malic dehydrogenase (MDH) activity of skeletal muscle, cardiac muscle and liver has increased in relation to the grade of work done by the rat.

This fact has, therefore, been investigated by studying the unltrastructure of the tissues under the electron microscope to confirm the celiular component which is responsible for this enzymatic alteration in response to exercise.

It has been observed that as a result of training the mitochondria increased in size and number with very prominent cristae. After an exhaustive exercise the cristae arrangements were completely disrupted and in some cases appeared like vacuoles. In the case of trained and exercised rats, however, the damage was less severe than that in the case of the untrained ones.

REFERENCES

1. Acros, J. C., Sohal, R. S., Sun, S. Argus, M. F. and Burch, G. R. : Exptl. Mol. Pathol. **8** : *49-65*, 1968.
2. Gallnic, P. D. and King. D. W. : Am. *J. Physiol.* **216** : *1502-1509*, 1969.
3. Maitra, S. R. and Chatterjee, P. : Unpublished work.

Paper presented at the Second Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received**

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 34, 1979

AEROBIC CAPACITY OF YOUNG GIRLS—10 TO 18 YEARS OF AGE*

S. R. Maitra, P. K. Banerjee, Pratima Chatterjee and S. Chatterjee

Department of Physiology, University College of Science & Technology, Calcutta University, Calcutta 700009, India.

Aerobic capacity ($\dot{V}O_{2max}$) was found out for 60 girls of 10 to 18 years of age by treadmill running method. It increased from an average value of 861 ml/min in 10 year girls to 1484 ml/min in the 17–18 year group. These values were 6.6 and 8.4 times the respective resting oxygen uptake values. $\dot{V}O_{2max}$ per kg body weight was, however, reduced from an average value of 40 ml/min in prepubertal age-groups to around 36 ml/min in post-pubertal girls. Maximum pulmonary ventilation (VE_{max}) increased from 36 l/min in 10 year girls to 54 l/min in the 17–18 year group. Corresponding increase in tidal volume (TV_{max}) was from 527 ml to 1043 ml, respiratory rate reducing from 69 to 53 per minute. Respiratory equivalent, however, did not show any significant difference and the average value was 40 l of air per l of O_2. On an average VE_{max} was 65% of the maximum breathing capacity and TV_{max} was 45% of the vital capacity. These two ratios also did not differ with age. The maximum pulse rate as well as the recovery pulse rate responses upto 3 minutes of recovery did not show any significant change with age.

$\dot{V}O_2$max and VE_{max} were found to be proportional to height$^{2.2}$ and height$^{1.7}$ respectively and these are close to the expected value of height^{2}. It appears that growth in aerobic capacity and its related functions in the girls are proportional to their growth of linear dimension and the reduction of $\dot{V}O_{2max}$ per kg body weight in the postpubertal age-group may largely be attributed to the increase in the body fat after puberty.

Paper presented at the Third Session of the International Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received**

Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 36 - 41, 1979

CARDIAC ACCOMMODATION TO WORK CAPACITY AS SEEN BY THE ELECTROCARDIOGRAM

H. Thomason* and E. J. Hamley+

*Human Performance Laboratory, University of Salford, England

+Department of Ergonomics & Cybernetics, University of Loughborough, England

Continuous recording of ECG's (VM_5) during work to exhaustion in 12 male time trial cylcists, was carried out. Two tests, two days apart, were used. High replicability between mean maximum work done between tests was seen ($\bar{r}$ 0.97). Analysis of the ECG amplitudes was not possible due to the effects of respiratory movements on them. Analysis of the time intervals within each ECG cycle (electrical cycle of heart) throughout the work to exhaustion demonstrated relationships of some of these intervals with work capacity.

Previous work [Thomason *et al.*, 1968 (a, b), 1969 and Thomason and Hamley, 1974] has demonstrated the relationship between heart-rate and capacity to do work on a cycle ergometer. Preliminary investigation of the electrocardiogram, from which the heart-rate is calculated, demonstrated relationship with work capacity (Thomason and Hamly, 1973, 1974). This study is concerned with the relationships of the electrical activity of the heart with work capacity, as seen in the electrocardiogram.

MATERIALS AND METHODS

Twelve male time-trial cyclists, conditioned over years to laboratory procedures, were subjected to continuously increasing work to exhaustion on a Müller's cycle ergometer.

One trial of two tests, each two days apart, was carried out. Correlation between tests within the trial, for maximum work done, was 0.95 - 0.97. Correlation between maximum work done over all tests and the racing ability of each subject over 25 miles was 0.97.

A standardised test procedure of work to exhaustion (inability to maintain required output without any experimenter's motivation) was carried out. Continuous on-line determination of metabolism and electrocardiogram (heart-rate) recordings were made. The electrocardiogram was taken from chest position VM_5 after Blackburn *et al.* 1967 using fast response recording equipment constructed by Thomason *et al.* (1969, 1971) which complied with the American Heart Association recommendations (1967). Simultaneous recordings of respiratory manœuvres using equipment described in Thomason *et al.* (1969) were made. All recordings were taken on an ultraviolet recorder.

Paper presented at the Third Scientific Session of the International Satellite Symposium on Work Physiology & Ergonomics held at Calcutta from 1 - 3 November, 1974.

To enable accurate measurements of the electrocardiogram to be made, actual paper speed must be known. A small receiver, (Thomason *et al.*, 1971) capable of receiving 60 Kcs pulses from MSF Rugby was constructed. Each pulse was of 10 msec duration and one second apart. The precision of the time interval between these pulses was ±10 microseconds. The paper was developed by exposure to light, thus preventing any change in paper-length due to wet developing and fixing procedures. Time intervals of the electrocardiogram wave-form and amplitudes (New York Heart Association designation 1964) were directly measured using a set of screw-adjusting dividers and a millimetre diagonal interpolation scale of 0.1 mm accuracy. The error in the measurement procedure was found to be less than 1%. The precision of this procedure for individual measurements was ±0.08 mm within the limits of the original measurements at the 95% confidence level. This allows time intervals accurate to 0.01 seconds to be computed from the direct measurements taken in mm. Similar measures of the electrocardiogram amplitudes in mm were made.

RESULTS AND DISCUSSION

A preliminary study demonstrated significantly different variation in amplitude during inspiration and expiration (Table 1).

Table 1

Variation in electrocardiogram amplitude (VM_6) R_s during exercise due to respiratory movements

[At 50% into the work task (N=5) mean of two tests]	
6 beats	Inspiration
$\bar{x}$	24.6 mm
SD	±11.9 mm
F ratio	33.18**
6 beats	Expiration
$\bar{x}$	28.3 mm
SD	± 3.9 mm

**Significant difference at 99% level of confidence

Further work in subjects carrying out positive and negative pressure changes showed that variations in amplitude measures were due to a complexity of variables and were, therefore, not used. No significant differences were demonstrated in the time intervals due to respiratory manœuvres.

Using Wiggers' classical diagram and the work of Green (1970), Folkow and Neil (1971) and Oyuki (1966), the following time intervals were measured and computed : R-R (which is the reciprocal of heart-rate), P-T, (P-R, R-T) and T-P. P-T, termed the electrical systole of the heart, was further divided into P-R and R-T. R-T is the QRST interval, associated with ventricular systole. P-R indicates the atrioventricular conduction time, including conduction through the bundle of

His. T-P is called the electrical diastole of the heart. However, a straight 1 : 1 relationship between the mechanical events, described by systole and diastole and the electrical events does not always hold true.

High replicability was demonstrated between tests for the time intervals throughout the work task (Table 2).

Table 2

Descriptive statistics and reliability coefficients of electrocardiogram time intervals (in seconds) between tests, throughout the work task (N=12).

		WORK TASK			Cessation
		25%	50%	75%	100%
P-T					
test 2	$\bar{x}$	0.31	0.28	0.26	0.24
	SD	±0.02	0.02	0.01	0.01
	r	0.87**	0.89**	0.82**	0.93**
test [illegible]	$\bar{x}$	0.31	0.28	0.25	0.24
	SD	±0.02	0.02	0.01	0.01
T-P					
test 2	$\bar{x}$	0.15	0.10	0.07	0.06
	SD	±0.03	0.02	0.01	0.01
	r	0.70*	0.95**	0.89**	0.70*
test 3	$\bar{x}$	0.16	0.10	0.07	0.06
	SD	±0.03	0.02	0.01	0.01

**Significant at 99% level of confidence
*Significant at 95% level of confidence

The heart rate, R-R, P-T and T-P interval responses to work, for tests 2 and 3 were subjected to polynomial curve fitting and the point into the work task when the relationship became curvilinear, if at all, was noted. This procedure has been described by Brooke and Hamley (1972).

Curvilinearity of heart rate, R-R and T-P intervals to work capacity was demonstrated in all subjects for both tests.

High replicability was demonstrated between tests for the time in minutes when the R-R time interval/work load relationship became curvilinear (r=0.88) and when expressed as a percentage of total work time (r=0.87). Relationships were seen between these two statistics and total work capacity (Fig. 1 and 2).

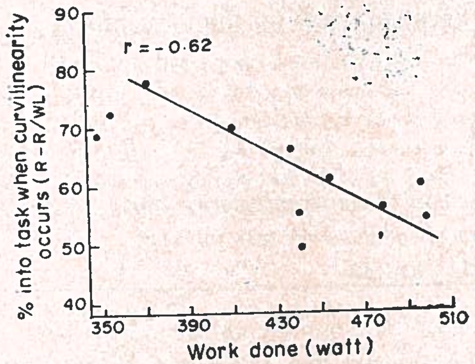


Fig. 1.

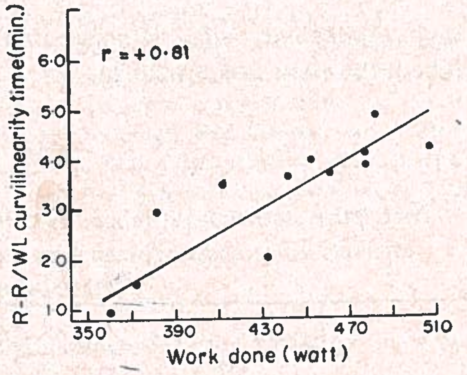


Fig. 2.

Figure 1 : R-R/work load : Correlation of time from point of curvilinearity (in minutes) to cessation of work and total work done.

Figure 2 : R-R/work load : Correlation of time into work task when curvilineavity occurs (expressed as % of total work time) and total work done.

Similar findings were demonstrated for T-P time interval/work load in minutes (r=0.80) and as a percentage (r=0.83).

The time into the work task when the R-R interval/work load became curvilinear was 73.0% ± 9.2%, and for the T-P interval, 64.3% ± 6.7%. The P-T interval demonstrated a linear regression with work done.

Further correlations were demonstrated between the time intervals of the electrocardigram and total work done (Table 3).

Table 3

Correlations between the time intervals of the electrocardiogram and total work done throughout the work task

	25%	6.0 min+	50%	$T\text{-}P_c$ ++	$R\text{-}R_c$ +++	75%	Cessation
R - R	.05	.01	.10	.05	.10	—	—
P - T	.05	.01	.05	.05	.10	.10	—
P - R	.10	.01	—	—	—	—	.10
R - T	.01	.01	.05	.05	.05	.10	—
T - P	—	.10	—	—	—	—	.10

\+ 6.0 min into the work task

++ $T\text{-}P_c$ is the time into the work task when the T-P/work load relationship became curvilinear

+++ $R\text{-}R_c$ is the time into the work task when the R-R/work load relationship became curvilinear

CONCLUSIONS

Results show that these electrocardiogram time intervals are highly repeatable and associated with total work capacity. We feel that these relationships demonstrate heart accommodation to work capacity. The question in point is the fact that meaningful differences in time intervals are demonstrated between high quality performers. These differences are related to ability to perform hard phyical work. Therefore, it is suggested that the better subjects demonstrate better accommodation to work capacity and this can be identified in the time intervals of the electrocardiogram.

REFERENCES

American Heart Association (1967) : Kossman, E: (Chairman) *Circulation*, **35** : *3*.

Blackburn, H., Taylor, H. L. and others (1967) : In : *Physical Activity and the Heart* (Eds.) Karvonen, M. J. & Barry, A. J., Thomas, Co. Ltd., U. S. A.

Brooke, J. D. and Hamley, E. J. (1972) : *Med. & Sci. in Spts*, **4** : *23 26*.

Folkow, B. and Neil, E. (1971) : *Circulation*. Oxford University Press, London.

Green, J. H. (1970) : *An Introduction to Human Physiology*, (2nd Ed), Oxford University Press, London.

New York Heart Association (1964) : *Diseases of the Heart and Blood Vessels*. Kossman, C. E. (Chairman), J. A. Churchill, London.

Oyuki, Y., Seki, M. and Yasagita, N. (1966) : *Proceedings of Int. Cong. Sports Sciences*, (Ed) Kato, K., University of Tokyo Press, *364-365*.

Thomason, H., Hamley, E. J. and Brooke, J. D. (1968 a) : *Journal of Physiology*, **197**.

Thomason, H., Hamley, E. J. and Brooke, J. D. (1968 b) : *Perm. Com. Occup. Health. Int. Sym. 'Fatigue et Stress'*, Paris.

Thomason, H., Hamley, E. J. and Brooke, J. D. (1969) : *Journal of Physiology*, **201**, *33-34*.

Thomason, H., Samain, M. D. and Hamley, E. J. (1969) : *Journal of Physiology*, **204**, *73-74*.

Thomason, H. and Samain, M. D. (1971) : *The Physics Society Handbook*, p280.

Thomason, H., Samain, M. D. and Hamley, E. J. (1971) : *Journal of Physiology*, **212** : *10-12*.

Thomason, H., and Hamley, E. J. (1973) : Proceedings of XXVth Int. Cong. Physiol. Sci., Satellite Sym. In : *Physical Fitness* (Ed.) V. Seliger : Universita Karlova, Praha, *396-404*.

Thomason, H., and Hamley, E. J. (1974) : *Proceedings of Satellite Symposium on Exercise Physiology, Patiala*. IUPS XXVIth Int. Cong. Physiol. Sci., India.

Thomason, H. and Hamley, E. J. (1974) : *Proceedings of the IUPS*, XXVI th Int. Cong. Physiol. Sci. Vol. XI, *p27*, New Delhi.

COMMENTS

Dr. P. R. M. Jones : How do you account for the low non-significant correlations as shown in your last slide with the inter-beat interval ?

Dr. E. J. Hamley : This was included to illustrate that integrated results are required over sufficient beats to straddle a respiratory cycle in this work groups of subjects. In fact, we used 6 beats, but the validity is similar when using 10.

Dr. A. Ghosh : Whether the question of personal inclination in a type of work was considered in assessing the work capacity ?

Dr. E. J. Hamley : The personal motive to handle work at work capacity requires the personal wish to do the work and to be able to repeat the test. External motivation is the emergency motive which can seldom be repeated within the limits we have need. We want work capacity as the maximum attainable rate of work which can be subjected to repeated tests. Our groups were trained to hold the criteria of the test as long as possible since this was also a test of fitness in their racing training program. So, their personal wish to reach test levels was considerable. The observers neither gave any encouragement nor used any coarsion.

Dr. R. Sinha : Whether ECG time intervals studied in the younger age-group could be applicable to elderly age-groups ?

Dr. E. J. Hamley : Probably this is not affected by age-group. We have set up this group to try and calibrate work capacity by a non-invasive and non-interference technique. Our special concern was the validity of ECG intervals as a method of studying cardiac function at the highest work rates in repeated experiments.

Dr. P. K. Nag : Is there any good correlation between R-R and T-T intervals ?

Dr. E. J. Hamley : R-R and T-T need no differentiations ; either could have been used in this work as both give the periodicity. The point is that we are integrating over 6 beats to remove the ventilatory cycle's effects on the beat by beat trace.

Dr. A. Ciplea : Maximum work capacity must not be tested in metal cabinets. It requires an equipment for defibrilation which can be very dangerous.

Dr. E. J. Hamley : Agreed ; such tests require great care and continuous observation on the subject to serve in work capacity tests. All our groups have been followed beat by beat and have been habituated to these tests on many occasions and they are all skilled racing cyclists performing at similar work rates during their sport activities.

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 42, 1979

BENEFICIAL EFFECT OF PHYSICAL EXERCISE IN DIABETIC SUBJECTS*

Subhas Mukerji, A. K. Bhattacharyya and J. R. Chatterjee

N. R. S. Medical College & Hospital, Calcutta-700014, India.

Oral glucose tolerance test was performed in diabetic subjects under resting conditions and graded muscular exercise during the performance of the test. Cases of juvenile diabetis as well as cases of maturity onset diabetis were included in the study.

Following muscular exercise significant reduction of blood level was observed in glucose tolerance test in a large proportion of the maturity onset diabetics, when compared to the blood glucose levels under resting conditions. Some cases of maturity onset diabetis and all the cases clinically diagnosed as juvenile diabetics failed to show this response to muscular exercise.

On the basis of the analysis of the data presented, a new approach of theraputic use of physical exercise in the treatment of diabetics depending upon their response to muscular exercise has been suggested.

The mechanism involved in the hypoglycemic response to muscular exercise with the possible involvement of the factors concerned have been discussed.

Paper presented at the Third Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received**

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 44, 1979

ORGANIZATION OF MOTOR PERFORMANCES AS SUBSTRATE FOR BEHAVIORAL INTEGRATION*

Ajit Maiti

Department of Biochemistry & Biophysics, Institute of Basic Medical Sciences, Calcutta University, Calcutta-700020, India.

Review of physiological feedback studies suggest that all major internal organic mechanisms of the body have reciprocal, dynamic feedback links with the action of skeletal-motor system. Every muscular activity in the physiological state involving any work performance is accompanied by appropriate change in different organizational levels of mental-emotional state, conscious or unconscious, and consequently, by feedback interaction, the integration of efferent motor response occurs. This welfare response in reciprocal behavioral-physiological interaction is intimately involved in controlling and modifying the bioenergetic, timing, synchronism of guidance operations of molecular, cellular, organic and organismic functions on a dynamic basis. Failure of such a built-in as well as learned physiological coping patterns in dealing with overt behaviour with various life stresses may act as a primary cause and excerbating agent in specific maladaptive behaviours involving a wide range of physical and mental disorders. Analysis of the beneficial clinical effects of certain behaviour therapies, e. g., biofeedback, autogenic tranining, meditation, relaxation which employ physical conditioning based on motor performance reflect a close relevance of autonomic-somatic efferent re-organization to a variety of tropotrophic-ergotrophic interactions of the central nervous system. The organization of motor performances through well-balanced regulated exercise and skill development is a type of physiological learning which enables the brain to detect different control of the limbic, extrapyramidal-postural, extrapyramidal-receptor-efferent, viscero-somatic efferent and pyramidal motor systems, thereby, developing a dynamic and dominant adaptation system for the variable control over distorted primitive behaviour.

Peper presented at the Third Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 8 November, 1974. ***Full paper not received**

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 46 - 53, 1979

RELEVANCE OF CIRCADIAN RHYTHM TO FATIGUE OF YOUNG FEMALE DOUBLE-DAY SHIFT WORKERS

Kazutaka Kogi

Division of Work Physiology and Psychology, Institute for Science of Labour, 1544, Sugao, Takatsu-ku, Kawasaki 213, Japan.

To investigate the physiological background of adverse effects of shiftwork on minors, variations of fatigue feelings and perceptual-motor skills of very young female shifters in textile mills were compared with those of day workers. Those shift workers comprising a large number of minors worked a two-shift system in which the morning shift began as early as at 0500 hours and the afternoon shift ended late at 2200 hours. Fatigue feelings of the dull factor dimension were dominant among shifters, who also felt disoriented more frequently than day workers. More marked hydrostatic effects due to sustained standing postures were found for shifters than for day workers. Variation patterns of motor performance and perceptual threshold seemed to be virtually based on the circadian rhythm, being facilitated in daytime and significantly hampered during late evening hours. Blocking in serial responding was more remarkable through the morning shift. These results point to the importance of paying attention not only to the end-of-work fatigue but also to findings related to disrupted phyiological rhythm as in the case of a morning shift of the double-day shift system.

Textile, food-processing, electronics and other relatively labour-intensive industries employ a large number of shift working women in most of the Asian countries (Kogi, 1977). Most female shifters are young, comprising very many minors. Night work is common.

In Japan, where night work of women between 2200 and 0500 hours is prohibited except for certain jobs like health services and telephone operators, the double-day shift systems have widely been applied to industries employing young women in a large number (Kogi, 1962, 1971),the first shift beginning at 0500 hours and the second shift ending at 2200 hours.

Many reports clearly state that shiftwork has adverse effects on well-being and health of the workers, more seriously in night-time work (Rutenfranz, Knauth and Colquhoun, 1976 ; Carpentier and Cazamian, 1977). The double-day shift systems force a substantial phase-shift in the work-sleep cycle in transferring from the morning shift to the afternoon shift and *vice versa*. In double-day shift systems from 0500 to 2200 hours, the time difference in sleeping hours between the two different shifts could amount to 3-4 hours even if the workers lived near their workplaces (Takagi, 1972).

Paper presented at the Fourth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

So the double-day shift workers do not appear to be free from serious adverse effects similar to those of night-including shift systems. Higher illness rates among two-shift working women than among day working women (Brandt, 1969) could thus be explained by the two-shift workers' disturbed biological rhythm. A double-day shift system could deteriorate physical development of young girls (Sakamoto and Matsui, 1972). They confirmed that the mean body weight of girls of age 15 continuously decreased from week to week during the first three months after entering textile mills on a double-day shift system between 0500 and 2200 hours.

This report, presents the results of our field study on young women of textile mills, to examine the physiological background of adverse effects of the two-shift work (0500 - 2200 hours).

MATERIALS AND METHODS

A field study was undertaken to investigate conditions of the double-day shift system specifically applied to young girls of age 15 to around 20 years (Shiozawa, 1962).

RESULTS AND DISCUSSION

The study has revealed marked changes in fatigue scales and psycho-physiological parameters among two-shift working girls of silk-reeling mills in the Kanto District near Tokyo. Very high proportion of women under age 20 actually reflected the employment pattern prevalent in the textile industry of Japan in and around the 1960s (Kogi, 1971). This trend is illustrated by Fig. 1 based on a survey in 1961 (Kogi, 1962). About 60% of women workers of two-shift system were under 20, and 94% under 30 years of age.

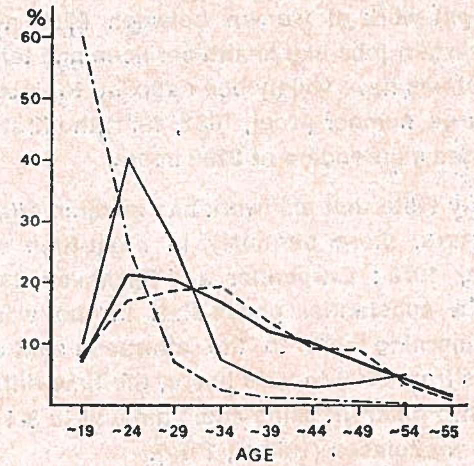


Fig. I.

Figure I. Percentage distribution of shift workers by age in the manufacturing industry of Japan in 1961.
———— male night workers ; — — — — male double-day shift workers ;
———— female night workers ; —·—·—·— female double-day shift workers.

In the silk-reeling mills studied, the shift working girls were suffering from sleep deficit during the morning shift period. A morning shift ran from 0500 to 1330 hours, while the afternoon shift ended at 2200 hours. The morning shifters took lunch after the shift change. The girls worked six straight days in each shift and transferred to the other shift after a weekly holiday. A meal break of 45 minutes was taken during each shift. In the morning shift period, they went to bed early but the sleeping time remained short, because many showed up at a mill much earlier than 0500 to prepare for work and to clean machines ; in addition, the workers had difficulties in falling asleep in the previous evening of every morning shift as their circadian rhythm phase was not ready yet for sleep.

Table 1 gives percentages of female day and shift workers complaining of fatigue feelings after work. These fatigue feelings belong to factor dimensions of dullness-drowsiness and disorientedness (Saito, Kogi and Kashiwagi, 1970). Dull feelings and drowsiness items are shown separately in the Table, for convenience. Difference between day and shift workers was the largest for feelings of the dull factor ; for eyestrain, tiredness in the legs, general tiredness and feeling muddled, the shift workers had a percentage around 20%

Table I

Percentage of various fatigue feelings complained of after work by double-shift workers and day workers of silk mills.

Fatigue feeling	Shift workers	Day workers
DULLNESS		
Feel eye strain	85 . 6 %	58 . 3 %
Tired in the legs	80 . 9	66 . 7
Generally tired	60 . 6	41 . 7
Feel muddled	56 . 4	33 . 3
Rigid in movement	52 . 7	46 . 7
DROWSINESS		
Become drowsy	44 . 7	50 . 0
Heavy in the head	42 . 6	48 . 3
Yawning	29 . 3	48 . 3
DISORIENTEDNESS		
Weary of talking	45 . 7	31 . 7
Difficult in thinking	44 . 1	43 . 3
Uninterested in things	38 . 3	31 . 7
Become irritable	34 . 0	30 . 0

higher than the day workers. But for drowsy feelings, the rate was even higher among day workers than among shift workers. The shift workers had also higher rates than the day workers as to the feelings of disorientedness or disturbed concentration of attention such as being weary of talking to others, having difficulty in thinking, being uninterested in things and becoming irritable.

The physical work intensity was similar for the shift and day workers. Figure 2 shows estimated levels of energy expenditure for a shift period of 8 hours for different jobs. The estimation was based on time study data of these silk mills and was done assuming an adult woman. Zones A, B, C, D and E in the Figure indicate five levels of physical work intensity during an 8-hour

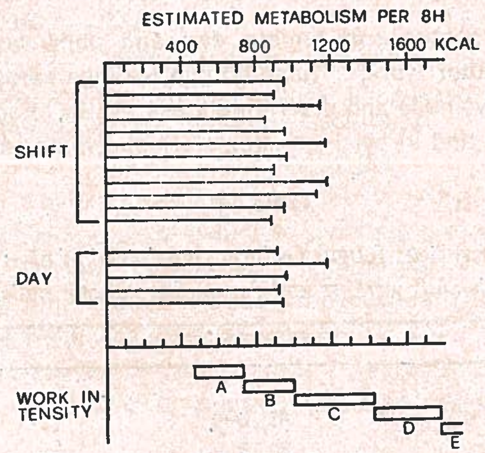


Fig. 2.

Figure 2. Estimated metabolism per 8-hour work for different jobs of shift and day workers of silk mills.

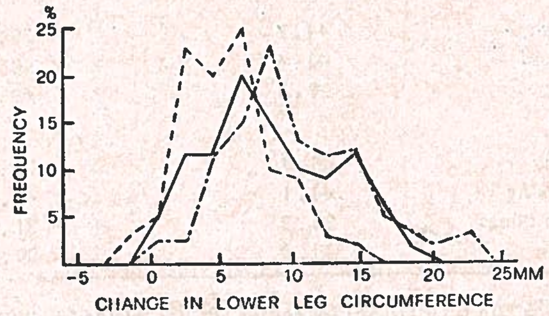


Fig. 3.

Figure 3. Frequency distribution of change in lower leg circumference after work from the pre-work level for morning shift (— - — - —), afternoon shift (————) and day work (— — — —).

shift period of a Japanese female adult, 'A' corresponding to very light work, 'B' to light work, 'C' to moderate work, 'D' to heavy work and 'E' to very heavy work. All jobs of both shift and day work fell in the range of light or moderate work. As all of these jobs were done standing, jobs having an energy level of about 900-1000 kcal/shift could be said to be relatively static, dealing with cocoons and silk yarns or attending machines without moving around much. Other jobs requiring 1100-1200 kcal/shift included walking around and carrying or packaging of products.

Several tests conducted before, during and after work revealed differences in functional conditions between day and shift workers. Figures 3 and 4 give a summary of post-work changes of these test results from the pre-work levels. As Fig. 3 shows, the lower leg circumference was more markedly increased in the morning and afternoon shifts than in day workers. This advanced hydrostatic effect on shift workers might be due to both their long-hour standing and

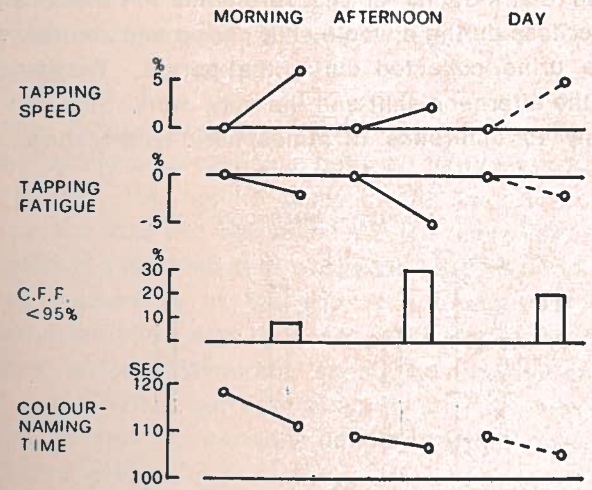


Fig. 4.

Figure 4. Average variations during a shift period in tappping speed, tapping fatigue in terms of change in tapping speed in the second 15-sec period, percentage of those whose C. F. F. decreased more than 5% after work, and colour-naming time for morning shift, afternoon shift and day work.

the time of the day's work. As shown in Fig. 4, variation patterns of tapping performance, perceptual threshold of flicker fusion and colour-naming speed seemed to be virtually linked with the circadian rhythm, which should have been more apparent in the case of shift workers. The increase in tapping speed from the pre- to post-work level was larger for the morning shift and the day workers' shift than for the afternoon shift. The ratio of tapping speed in the second 15-second period to that in the first 15-second period, which would show fatigue by prolonged tapping, was larger for the afternoon shift than for the morning shift or the day work. The percentage of those whose critical fusion frequency of flicker decreased more than 5% after work was the largest for the afternoon shift and the least for the morning shift. This was due to decline of the critical fusion frequency in late evening hours of the afternoon shift and to low starting fusion frequencies at the beginning of the morning shift. The time required in calling the colour of 100 small coloured plates was the longest at the beginning of the morning shift. The colour-naming speed was slower at the end of the morning shift than at the end of the afternoon shift or the day work. These results would imply that the shift workers had to start working the early morning hours under the strong influence of a functionally lowered phase of the circadian rhythm.

Figure 5 gives distributions of measurements on sweat volume in terms of extra-renal water loss during a whole shift period and on the sodium/potassium ratio of the urine collected during that period. The sweat volume was clearly higher for the afternoon shift and the day work than for the morning shift, due primarily to difference in atmospheric temperature. On the other

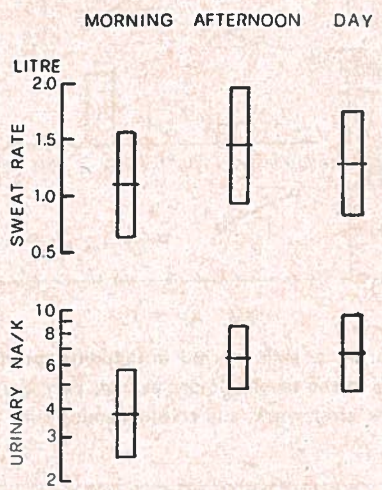


Fig. 5.

Figure 5. Comparison of sweat volume per shift period and of urinary sodium/potassium equivalent ratio for morning shift, afternoon shift ane day work.

hand, the sodium/potassium ratio of the urine collected during the morning shift was on the average lower than that during the afternoon shift or the day workers' shift. This low level of the ratio in the case of the morning shifters was ascribable to the urine excreted in early morning hours. This would be another evidence that the morning shift had to be worked under the strong influence of the circadian rhythm phase that was unfavourable to working activities.

CONCLUSION

These results indicate increased fatigue of double-day shift workers in both early morning work and late evening work. In these abnormal hours, the workers had to work resisting the decline in their functional readiness for work. An elevation of perceptual and motor functions towards the end of a morning shift would not mean a favourable condition for the shift workers. The peculiar changes during the morning shift would rather suggest a disruption of the circadian rhythm of morning shifters by work in spite of a 'sleep' phase of the rhythm.

In conclusion, fatigue of young double-day shift workers could be significantly enhanced by the discrepancies between their working activities and the circadian rhythm. The results point to the importance of not only the end-of-work fatigue but also the disruption in the circadian rhythm. This is especially the case for a morning shift where the observed end-of-work changes might not be so marked as at the end of a normal workday. Taking into account the strictly controlled work of those young female shift workers, their concentrated work under unfavourable conditions and their daily fatigue could adversely affect their health. Current occupational health measures for those workers, including formalistic periodic health examinations, do not seem to prevent such adverse effects.

REFERENCES

Brandt, A. (1969): Über den Einfluss der Schichtarbeit auf den Gesundheitszustand und das Krankheitsgeschehen der Werktätigen. Proceedings of an International Symposium on Night and Shift Work, Ed. by Swensson, A., Inst. Occup. Health, Stockholm, p. 124-152.

Carpentier, J. and Cazamian, P. (1977): Night Work: Its Effects on the Health and Welfare of the Worker, International Labour Office, Geneva.

Kogi, K. (1962): On the present status of shift formation in Japanese industry and mine. *J. Sci. Labour*, **30**: *135-145*.

Kogi, K. (1971): Social aspects of shift work in Japan. *Int. Labour Rev.*, **104**: *415-433*.

Kogi, K. (1977) : Shift work in developing countries. *Philippine Labor Rev.*, 2 (4) : *29-40.*

Rutenfranz, J., Knauth, P. and Colquhoun, W. P. (1976) : Hours of work and shiftwork. *Ergonomics*, 19 : *331-340.*

Saito, Y., Kogi, K. and Kashiwagi, S. (1970) : Factors underlying subjective feelings of fatigue. *J. Sci. Labour*, 46 : *205-224.*

Sakamoto, H. and Matsui, K. (1972) : Time taken for familiarilation with boarding life. *J. Human Ergol.*, I : *189-194.*

Shiozawa, M. (1962) : Sen'i Fujin Rōdōsha no Tachiba kara Mita Genkō Rōdōkijunhō no Mondaiten (Problems of the Labour Standards Law from the viewpoints of female textile workers). Nihon Rōdō Kyōkai Chōsa Kenkyūbu, Tokyo.

Takagi, K. (1972) : Influence of shift work on time and frequency of meal taking. *J. Human Ergol.*, I : *195-205.*

COMMENTS

Dr. R. N. Sen : Have you any comments to offer on the difference in the suitability of females and males as shift workers ?

Dr. K. Kogi : It depends on the pattern of work performed. Female minors are usually engaged in strictly-paced work with less self-control over work. This could lead to larger work-load than in the case of male workers. It seems that more deliberate considerations are necessary for female minors.

Dr. A. K. De : Did you take the menstrual history for the young female workers ?

Dr. K. Kogi : No, but I avoided the inclusion of those having menses at the time of investigation.

Dr. A. K. De : Is the 16 hours' night shift duty used for the experimental purpose or is it the usual duty schedule ?

Dr. K. Kogi : The 16 hours' shift was designed to compare the work-load with the normal 8 hours' shift of the nurses. It is significant that a night-shift of excessive length has a similar effect on physiological functions and performance, compared to the effects the early forenoon hours have on them. The dullness factors and performance needing continuous attention seem to be important in both of these situations.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 54 - 64, 1979

PERMISSIBLE LIMIT FOR DIFFERENT MINING WORK UNDER VARIOUS POSTURAL CONDITIONS

M. K. Chakraborty, S. K. Sensarma and P. K. Mullick*

Central Mining Research Station, Dhanbad and
**Indian Council of Medical Research.*

Mining work in India is still largely dependent on strenuous manual labour frequently performed under different adverse postural condions like stopping or kneeling. A controlled study has been done on 6 pick-miners, 8 shovellers and 8 load-carriers in controlled working conditions under kneeling, stooping and erect postures. The relation between work rates and energy costs for work under various postural conditions has been found out. The maximum permissible work rates for these tasks over a long period have been derived on the basis of the assumption that the miners can be allowed to carry on work upto 50 percent of their maximum oxygen uptake without any undue fatigue, the thermal condition of work being within the permissible limit of 29°C Effective Temperature found suitable for mining work in India.

Mining in India is still largely dependent on heavy manual labour. The age-old method of getting coal by a handpick, shovelling out of even the machine-cut coal and its transportation into the mine-tubs are usually performed manually with heavy muscular exertion and often under unfavourable mining situations like uncomfortable postural conditions in the thin seam or in the inclined faces.

Earlier investigations on carrying heavy loads on the level road have measured mainly the energy requirements, and the efficiency and conditions have been postulated for achieving a certain amount of transport with the lowest energy cost (Bedale and Vernon 1924 ; Brezina and Reichel, 1914 ; Atzler and Herbst, 1929 ; Glasow and Müller, 1951 ; Lundgren *et al.*, 1955 and Müller, 1956). Goldman and lampietro (1962), Gupta and Rohmert (1963) and Müller (1964) have devised methods to find out the limit to load carrying upto which the muscular work could be done without fatigue. In India, Malhotra *et al.* (1962), Malhotra and Sengupta (1965), Das and Saha (1966), Datta *et al.* (1968) ; Dutta and Ramanathan (1970a, 1970b, 1970c, 1971a and 1971b), Sen and Nag (1975) have all reported work on different modes of load carrying and their

Paper presented at the Fourth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

impact on the workers. But the only available information regarding the rationalisation of manual mining operations comes from Humphreys and Lind (1962) who made a comprehensive study on the miners' work, considering various factors like work rate, height of the seam, etc.

The present study is aimed at investigating the postural influences on manual mining operations like pickmining, shovelling and coal carrying, and in formulating the permissible limits for them under the existing mining conditions like work in thin seams, inclined faces, etc.

MATERIALS AND METHODS

Experiments were conducted on three groups of healthy coal miners, viz., (a) pickminers, (b) shovellers and (c) load-carriers. Studies on shovelling and load-carrying were done at the pit-head depot while the pickminers carried out their work at the actual working faces underground. All these operations were studied at controlled work rates under different postures. All the subjects were fully experienced in the work they were asked to perform. Pickminers were asked to perform their work for 5 minutes at different rates in three postural conditions, namely, standing erect, kneeling and stooping. The work rates for such subject during each experiment were decided on a random manner to avoid bias. Rates of pickminers' work were determined by counting the number of strikes of pick each minute.

Shovellers were instructed to shovel out coal at different work rates under erect standing and stooping postures. The rates were regulated as in the case of pickminers by a stop watch.

Load-carriers were asked to carry randomly chosen baskets, loaded with different work loads, unload them at a particular distance and return with the empty baskets for the next turn; the cycles of carrying loaded baskets and returning with empty ones were performed for 5 minutes for each load under three conditions, viz., (a) on the level road, (b) in stopped condition and (c) with 1 : 12 up-hill gradient. The mode of carriage was on the shoulder for level road and up-hill, and for the stooping posture, the loaded baskets were placed just behind the neck.

On completion of the exercise with each load, the subjects were allowed to take rest till the heart rate was restored to the resting level; then they were asked to begin the work for the next load. The rates of walking during the carriage of load were found to be 3 - 4 Km hour^{-1}.

All the experiments were conducted in the morning, 2 hours after the breakfast, to avoid the specific dynamic action of food.

The energy expenditures for all types of work were determined from the analysis of the expired air. Each experiment was repeated and the mean of the two experiments was computed.

RESULTS AND DISCUSSION

Table 1 summarizes the characteristics of the subjects and the thermal environment under which the work was performed.

Table 1

Physical characteristics (Mean and Range) of the subjects performing different mining work

m 29

Category of workers (No. of subjects)	Age (yrs)	Body weight (kg)	Body height (cm)	$\dot{V}O_2$ Max (l/min^{-1}) STPD	Work Environment DB=Dry - bulb temp. WB=Wet - bulb temp. RH=Relative humidity
Pick-miners (6)	29.2 (25-34)	51.2 (48.5-54.0)	160.9 (158.8-164.5)	2.04 (1.81-2.32)	DB 26.7°C WB 26.1°C RH 96%
Shovellers (8)	29.8 (25-35)	47.9 (39.0-53.0)	160.5 (146.0-167.0)	1.88 (1.42-2.28)	DB 30.0°C-32.0°C WB 26.1°C-28.9°C RH 65% - 90%
Load-carrier (8)	27.0 (20-35)	47.1 (42.0-50.5)	160.8 (154.9-168.2)	1.91 (1.54-2.16)	DB 24.0°C-29.5°C WB 17.0°C-23.2°C RH 36% - 60%

Pickmining :

Table 2 shows the energy cost for pickmining at different work rates in (a) standing erect, (b) kneeling and (c) stooping postures, respectively.

Table 2

Energy expenditure (Mean±S.D.) of the coal miners during pick-mining under different postural conditions

Posture	No. of subjects	Energy expenditure (Kcal min^{-1})						
		Number of strikes per minute						
		15-19	20-24	25-29	30-34	35-39	40-44	45-49
I. Standing Erect	6	5.51 ±0.35	5.56 ±0.47	5.94 ±0.43	6.20 ±0.37	6.63 ±0.40	7.06 ±0.58	7.07 ±0.49
II. Kneeling	6	4.17 ±0.54	4.26 ±0.44	5.46 ±0.53	6.25 ±0.38	7.13 ±0.48	8.21 ±0.64	8.65 ±0.21
III. Stooping	6	5.77 ±0.30	6.17 ±0.37	6.82 ±0.79	7.80 ±0.78	8.74 ±0.78	9.86 ±0.51	10.20 ±0.30

The regression equations ($P < 0.005$) for pickmining under (a) erect, (b) kneeling and (c) stooped postures are as follows :

a) $E = 4.221 + 0.065\ P$ ($r = +0.803$; SEE $= 0.414$)
b) $E = 0.532 + 0.181\ P$ ($r = +0.958$; SEE $= 0.443$)
c) $E = 2.412 + 0.173\ P$ ($r = +0.916$; SEE $= 0.631$)

where E is the energy expenditure per man in Kcal minute^{-1}, P is the rate of pickmining, r is the correlation coefficient and SEE is the standard error of estimate. The relation between the energy expenditure and speed of pickmining work in erect posture is found to be significantly different from those for kneeling and stooping postures ($p < 0.005$). Pickmining in erect posture at the lower work levels does not show much difference from those for other postural conditions, but the energy expenditure in erect posture at higher work rates appears to be lower compared to that under other conditions, indicating the postural influence at the higher levels of work. It is found that energy costs of pickmining in erect and kneeling postures are similar at the work rate of 32 strikes min^{-1}, which is equivalent to 6.3 Kcal min^{-1}. Similarly, there should not be any postural difference between erect and stooping conditions of pickmining at 17 strikes min^{-1} of work rate with an energy expenditure of 5.4 Kcal min^{-1}.

Permissible Limit for Sustained Work of Pickmining :

Fig. 1 shows the regression equations for different postural conditions along with the line of permissible limit (at the work level of 5.1 Kcal min^{-1}) worked out at the 50% of the mean estimated $\dot{V}O_2$Max of the subjects. From the points of intersection of this line with the three regression lines at three different points, the prescribed rates for sustained work in erect, kneeling and stooped postures should be 13-14, 25-26 and 15-16 strikes min^{-1} respectively, if fatigue is to be avoided. It is seen from the regression equation that pickmining at the rate of 14 strikes min^{-1} in kneeling and stooping postures need 3.2 and 4.8 Kcal min^{-1} respectively, i. e., 1.9 and 0.3 Kcal min^{-1} less than the corresponding value in erect posture (5.1 Kcal min^{-1}). Surprisingly, the higher work rates prescribed for kneeling and stooping postures cause lower energy costs than that for the erect standing posture.

From practical experience, work under these postures (kneeling and stooping) is found uneconomical for production in comparison to that in erect posture - the miners could collect very little coal under these awkward-postural conditions in comparison to normal erect postures. Pickmining being a very

strenuous work, the miners need higher energy for the proper body movement to exert full effort while the uncomfortable postures always restrict the movement of the large muscle mass reducing the force on the pick. This must be the reason for less energy costs and the smaller production of coal—for an equal amount of production, the miner must work at much higher work rates (higher number of strikes) under these conditions than in erect posture.

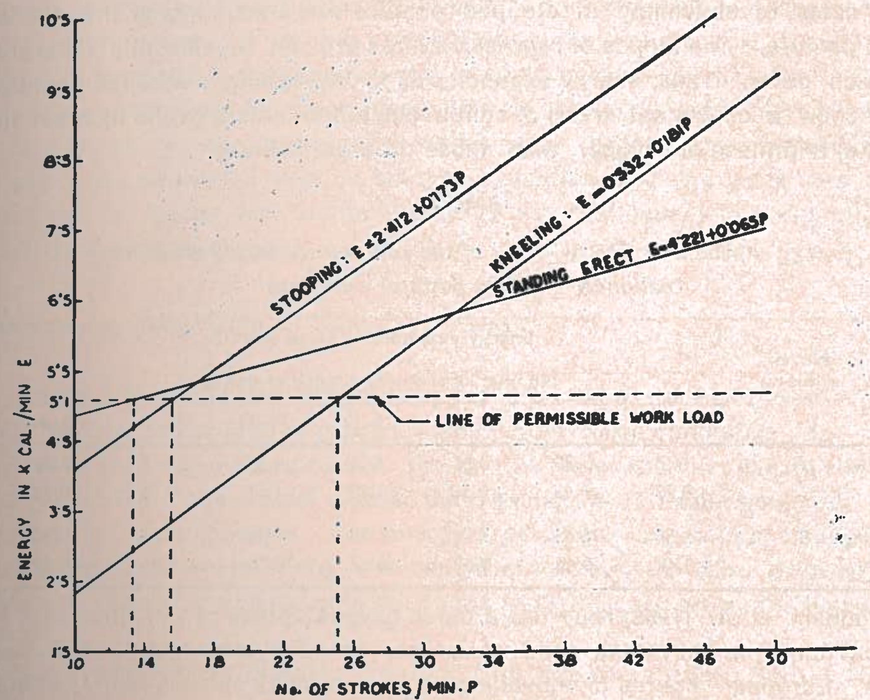


Fig. 1.

Figure 1 : Regression lines for energy costs of pickmining under different postural conditions.

Unfortunately no information is available about the work organisation for pickmining from the view point of work rate. Humphreys and Lind (1962) observed the average energy expenditure of 6.1 and 5.3 Kcal min^{-1} during hewing (pickmining) at the normal pace with a handpick, working either on feet or knees and in the lying condition, respectively.

Shovelling Coal :

Table 3 shows the energy cost of shovelling against different speeds of work, measured by the number of shovelful loads per minute in erect standing and stooped postures. The regression equations ($P < 0.005$) for energy costs at different rates of shovelling under the two postural conditions are as follows:

Standing erect : $E = 2.887 + 0.130\ S$ ($r = +0.815$; $SEE = 0.789$)

Stooped posture : $E = 4.467 + 0.110\ S$ ($r = +0.853$; $SEE = 0.617$)

where E is the energy expenditure in Kcal min^{-1}, S is the rate of shovelling of coal per minute and r is the correlation coefficient. The Table shows that the energy costs of shovelling in stooped posture are always higher than those in erect posture. The slopes of regression lines are not significantly different from each other. Thus, energy expenditures for shovelling in stooped posture always show a consistent trend of continuous increments with the increase in work rate, and these are higher than those in erect posture.

Table 3

Energy expenditure (Mean±S.D.) of the coal miners during shovelling coal under different postural conditions

Posture	No. of subjects	Energy expenditure (Kcal min^{-1}) Number of shovelful loads per minute						
		10-14	15.19	20-24	25-29	30-34	35-39	40-44
I. Standing Erect	8	4.77 ±0.93	5.20 ±0.45	5.65 ±0.50	6.79 ±1.03	6.67 ±1.15	8.13 ±0.75	7.37 ±0.76
II. Stooping	8	5.56 ±0.48	6.41 ±0.46	7.04 ±0.60	7.78 ±0.67	8.38 ±0.78	7.53 ±0.66	9.34 ±0.57

Wyndham *et al.* (1966) reported a mean oxygen uptake of 1.77 litres min^{-1} (8.85 Kcal min^{-1}) in shovelling sand at a rate of 12 cycles min^{-1} in Bantu workers. European figures of shovelling at the rate of 12 shovels min^{-1}, lifting 8 kg load to a height of 1 metre, showed an energy cost of 7.5 Kcal min^{-1} (Spector, 1966). Guharay (1968) reported the mean oxygen uptake in shovelling as 1.38 litres min^{-1}(77% mean $\dot{V}O_2$Max) in 8 miners at the rate of 12-16 min^{-1} with about 4-5 kg of coal per shovel. In a more comprehensive study on European coal miners at different work rates of shovelling in erect standing and kneeling postures, Humphreys and Lind (1962) remarked that at slow rates of shovelling in erect posture, the energy expenditure was higher than that in normal kneeling posture, but at higher rate this was reversed. In their study, the rates of shovelling (30 shovelfuls min^{-1}) was used for both standing and kneeling men and the height and distance of throw were also identical. They observed that the energy expenditure for both postures was about 7.0 Kcal min^{-1} at this rate of work.

The permissible limit for sustained work (at the work level of energy expenditure of 4.7 Kcal min^{-1}), at 50% of the mean estimated $\dot{V}O_2$Max (1.878 litres min^{-1}) of the subjects. It is found from the figure that this corresponds to a work rate of 14 shovels min^{-1} in erect standing posture ; but there is no such condition for the stooped posture. The energy expenditure during shovelling in stooped condition is 5.6 Kcal min^{-1} even at the work rate of 10 shovels min^{-1}, which indicates the impact of uncomfortable stooping condition on shovelling work. It is thus evident from the results that shovelling in awkward postures is a strenuous work needing heavy muscular effort. So, the shovelling rate should be maintained within 14 shovelful loads per minute in erect posture for continuous shift-work, while there is no permissible limit for prolonged shovelling work in stooped condition and the work has to be organised in cycles with suitable intervening rest-pauses to avoid fatigue in the underground shift-work.

Load Carrying Under Different Mining Conditions :

Table 4 presents the energy expenditure values of eight miners in Kcal min^{-1} during the carriage of graded loads under three conditions, viz., (a) on the level road in erect posture, (b) on the level road in stooped condition and (c) up-hill. The Table shows the results of 55 experiments on eight subjects for each posture. The energy expenditure values have been plotted against the gross weight in Kg., i. e. weight of the subjects plus external load carried by them. The regression equations ($P < 0.005$) are presented below :

a) Level Road (Erect) : $E = 0.121 + 0.059L$ ($r = +0.898$; $SEE = 0.250$)

b) Level Road (Stooped) : $E = 0.880 + 0.062L$ ($r = +0.904$; $SEE = 0.441$)

c) Uphill : $E = 0.419 + 0.066L$ ($r = +0.936$; $SEE = 0.589$)

For the E relations, the Y intercepts 0.121 (load carrying on the level road in erect posture) and 0.419 (up-hill load carrying in erect posture) are not significantly different from the origin as evident from 't' tests ('t' 23=0.712 for erect posture and 't' 23=0.419 for 1 : 12 gradient respectively) while for E relation in stooped postures, the Y intercept 0.880 (on the level road) is significantly different from the origin ('t' 23=2.917). Thus, it appears that the miners probably expend some energy in stooping condition even when at rest, indicating the influence of uncomfortable posture effect.

Table 4

Energy expenditure (Mean ± S.D.) of load carrying under different postural conditions on the level road and up-hill gradient of 1 in 12

Road condition	Posture	Body weight (Kg)	Energy expenditure (Kcal min⁻¹) External Load 1 Kg	10 Kg	15 Kg	20 Kg	25 Kg	30 Kg	35 Kg	40 Kg	45 Kg	50 Kg
I. Level Road	Erect (Loaded Basket on the Shoulder)	47.13 ±2.76	2.86 ±0.47	3.30 ±0.42	3.15 ±0.78	4.23 ±0.50	4.29 ±0.57	4.84 ±0.38	5.07 ±0.68	5.33 ±0.19	5.32 ±0.25	5.84 ±0.26
	Stooped (Loaded Basket on the back of the Neck)	47.13 ±2.76	3.86 ±0.59	4.45 ±0.29	4.68 ±0.30	5.08 ±0.59	5.32 ±0.37	5.86 ±0.44	6.35 ±0.10	6.35 ±0.45	6.31 ±0.52	7.09 ±0.43
II. Up-Hill Gradient of 1 in 12	Erect (Loaded Basket on the Shoulder)	47.13 ±2.76	3.87 ±0.64	4.02 ±0.58	4.33 ±0.35	4.82 ±0.30	5.23 ±0.21	5.54 ±0.41	6.00 ±0.22	6.21 ±0.39	6.50 ±0.45	6.94 ±0.41

Recommendation for Maximum Load to be Carried :

For finding the limit to load carrying without producing fatigue, the metabolic level has been chosen at 50% of $\dot{V}O_2$Max of the subjects. The permissible limits for sustained work (at work level of 4.8 Kcal min^{-1}) is 50% of the mean estimated $\dot{V}O_2$Max (1.913 litres min^{-1}) of the subjects with an average body weight of 47.1 kg and 27 years of age. The results show that the gross loads during load carrying (a) on the level road in erect posture, (b) on the level road in stooped posture and (c) up the 1 : 12 gradient in erect posture are 79.0, 62.9 and 65.6 kg respectively, which means that the respective external loads to be carried for a long period by a worker are 31.9, 15.8 and 18.5 kg if his body weight is 47.1 kg (substracting the body weight from the gross load in each case).

The maximum external load that could be carried by a standard Indian worker (55 kg body weight and 25 years of age—Nutrition Advisory Committee, Govt. of India, 1965), are found to be 43.8, 26.1 and 27.6 kg respectively, for different postural conditions (a, b and c) mentioned above.

ILO (1964) recommended a maximum load of 55 kg to be carried on the level ground for Western subject. The majority of the participants of ILO meeting (1964) prescribed the maximum weight of 40 kg for adult male workers for normal load carrying and lifting work, while a few particpitants felt that this should be fixed at 50 kg. Bearing in mind that the same packages may have to be handled in different parts of the world and that the recommended weight should be capable of being handled by less healthy workers, the maximum weight has deliberately been fixed here in the lower range.

Results of the present study indicate that for standard Indian workers, the recommendation of ILO about the maximum weight is quite suitable.

ACKNOWLEDGEMENT

The authors acknowledge with thanks the help and assistance from Sri D. N. Sarkar in the collection of data. The authors are grateful to the mine management for giving all facilities for the work and to the miners for volunteering in the work. The authors express their gratitude to the Director, CMRS, for permission to present this paper in the Symposium.

REFERENCES

Atzler, E. and Herbst, R. (1929): Die Okonomic Des Lastentragens über cine Ebene Strecke, *Arb. Physiol.* **I** : *54-74.*

Bedale, E. M. and Vernon, H. M. (1924) : The Effect of posture and rest in muscular work, *Industrial Fatigue Research Board*, Report No. 29.

Brezina, E. and Reichel, H. (1914) : Der Energieumsatz bei der Geharbeit I, Uber den Marsch auf Horizontaler Bahn., *Biochem Z.* **63** : *170-183.*

Das, S. K. and Saha, H. (1966) : Climbing efficiency with different modes of load carriage, *Ind. Med. Res.* **54** : *866-871.*

Datta, S. R. and Ramanathan, N. L. (1970a) : Ergonomical studies on load carrying up staircases Part I - Effect of external load on energy cost and heart rate *Ind. J. Med. Res.* **58** : *1629-1636.*

Datta, S. R. and Ramanathan, N. L. (1970b) : Ergonomical studis on load carrying up staircase, Part II - Effect of the rate of ascent, *Ind. J. Med. Res.* **58** : *1637-1642.*

Datta, S. R. and Ramanathan, N. L. (1970c) : Ergonomical studies on load carrying up staircasess, Part III - Effect of the mode of carrying, *Ind. J. Med. Res.* **58** : *1764-1770.*

Datta, S. R. and Ramanathan, N. L. (1971a) : Ergonomical studies on load carrying up staircases Part IV - Effect of load, rate of ascent and mode, *Ind. J. Med. Res.* **59** : *145-156.*

Datta, S. R. and Ramanathan, N. L. (1971b) : Ergonomic comparison of seven modes of carrying loads on the horizontal plane, *Ergonomics*, **14** : *269-278.*

Datta, S. R., Roy, B. N., Chatterjee, A. and Mallick, L. N. (1968) : Energy cost of carrying and dumping earth at a building site, *Ind. J. Occup. Health*, **9** : *233-237.*

Glasow, W. and Müller, E. A. (1951) : Das tragen Schwerer Socke in der Ebene and auf einer Treppe. *Arb. Physiol.* **14** : *322-327.*

Goldman, R. F. and Iampietro, P. M. (1962) : Energy cost of load carriage-*J. Appl. Physiol.* **17** : *675-676.*

Guharay, A. R. (1968) : Energy expenditure for different manunal mining operations and mine rescue work - p-98, "Certain aspects of the energy metabolism of workers with special reference to the mining industry of India"- Thesis for the degree of Doctor of Philosophy (Science) of the University of Calcutta, 1968.

Gupta, M. N. and Rohmert, W. (1963) : Muscular fatigue during transport of load in the horizontal plane, *Arbeitswissenschaft* **I** : *110.*

Humphreys, P. W. and Lind, A. R. (1962) : The energy expenditure of coal miners at work - *Brit. J. Industr. Med.* **19** : *264-275.*

International Labour Organisation (1964) : Maximum load to be carried by one worker - *Occupational Safety and Health Series No. 5*, ILO, Geneva.

Lundgren, N. P. V., Sundberg, K. and Lindholm, A. (1955) : A study of the heaviness of work in using power saws in timber cutting, - *Report from the Swedish Forest Research Institute, Bd.* **45** : No. 10, Stockholm.

Malhotra, M. S., Ramaswamy, S. S. and Ray, S. N. (1962) : Influence of body weight on energy expenditure, *J. Appl. Physiol.* **7** : *433-435.*

Malhotra, M. S. and Sengupta, J. (1965) : Carrying of school bags by children - *J. Appl. Physiol.*, **8** : *55-60.*

Müller, E. A: (1956) : Der Transportarbeiter Verb. d deutsch Geschft Arbeitsschutz, **4** : *227-237.*

Müller, E. A. (1964) : Basic physiological criteria to be taken into account for the specification of the maximum load to be carried by one worker - *Occupatiional Safety and Health Series*, No. 5. ILO, Geneva.

National Nutrition Advisory Committee, Govt. of India (1965) : Report to the sub-commitee on nutritional requirement of working class families, Govt. of India.

Sen, R. N. and Nag, P. K. (1975) : Work organisation of heavy load handling in India, *J. Human Ergology*, **4** : *103-113.*

Spector, W. S. (1966) : Handbook of biological data (ed), W. B. Saunders and Co., Philadelphia and London p. 347.

Wyndham, C. H., Morrison, J. F., William, C. O., Heyns, A., Margo, E., Brown, A. N. and Astrup, J. (1966) : The relationship between energy expenditure and performance index in the task of shovelling sand, *Ergonomics*, **9** : *371.*

COMMENTS

Dr. E. J. Hamley : From your results would you favour :

a) that one should calibrate each posture as a preload value to subtract from the normal common work load (50% of $\dot{V}O_2$Max) ? or (b) that one should publish a different load limit for each posture listed specifially ?

Dr. M. K. Chakraborty : It is possible to work out the limit in both the ways. However, it appears better to have separate load limit for each postural condition. The same may also be desirable for different ways of load carrying.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 66–75, 1979

CIRCADIAN RHYTHMS AND ADAPTATION IN SOME INDIAN SHIFT WORKERS AND CONTROL SUBJECTS

Rabindra Nath Sen and Manas Ranjan Kar

Ergonomics Laboratory, Department of Physiology, Calcutta University, University Colleges of Science, Technology & Agriculture, 92 Acharya Prafulla Chandra Road, Calcutta 700 009, INDIA

A preliminary study was undertaken to find suitable parameters and their phase relations to industrial shift changes for designing routine tests to preselect shift workers.

Five male industrial shift workers with 3 shift rotations and four male volunteers simulating 2 shift rotations were studied. Their oral temperature and heart rate were taken at hourly intervals; sleep duration and micturition frequency during every twentyfour hours were also recorded.

All the shift workers and control subjects exhibited circadian rhythm of oral temperature (OT) and heart rate (HR) which for most of the time exhibited parallel trend in respect of phase and amplitude. In the control subjects, shift rotation brought practically no change in phase and amplitude of OT and HR rhythms; but they were dissociated from each other at a very late stage of night shift, whereas in the industrial workers of the night shift the amplitude was reduced and dissociation of the two parameters was less.

The control subjects slept less and micturated more in the night shift than in the day shift. The industrial workers, in general, slept and micturated almost evenly in all the three shifts, although there were a few with significant inter-shift differences in this respect in relation to the time taken for adaptation.

Flexibility, dissociation, etc., of the circadian rhythm and the implications are discussed in the light of adaptability and also the need for future studies.

The bio-environment changes with the time in rhythmic rather than random fashions. These environmental rhythms impart periodicity to life processes including the psycho-physiological body systems (Bunning, 1959 ; Brown, 1957 ; Halberg *et al.*, 1959 ; Pittendrigh, 1957). Living routines have to be moulded according to the most dominant rhythm, viz., the circadian or daily or diurnal rhythm, because many important parameters are seen to follow this circadian rhythm (Conroy and Mills, 1970 ; Siegel *et al.*, 1969 ; Colquhoun, 1971 ; Persson, 1968 ; Halberg, 1962). Even industrial production is seen to be higher in the day work than in the night work for most of the people (Wyatt and Marriott, 1953).

Paper presented at the Fourth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

When work schedules require round-the-clock activities, deviations from the habitual routine of circadian rhythm occur in industrial shift working or in emergency services of Police, Army or hospitals. Some people can adapt to the new deviated schedule (i.e., synchrony) with various time lags (Wyatt and Marriott, 1953). People who cannot adapt, suffer through their psycho-physiological systems sometimes with irreversible damages like gastric ulcers ; production as well as shop-floor safety also become endangered. The present study endeavours to find the most suitable parameters for the adaptability to shift changes.

MATERIALS AND METHODS

One group consisted of five male industrial shift workers, aged 22-30 years and working in three weekly-rotating shifts (06 : 00 - 14 : 00 hrs, 14 : 00 - 22 : 00 hrs, and 22 : 00 - 06 : 00 hrs). The control group, consisting of four male healthy normal persons of the same age-group as that of industrial workers, was subjected to two weekly-rotating shifts (10 : 00 - 18 : 00 hrs and 22 : 00 - 06 : 00 hrs). The control subjects had no previous experience of shift change routine and were engaged in sedentary academic pursuits and passive recreational activities during the shifts in contrast to their counterparts in the factory, who were engaged in active jobs like preparing parts of small tools in lathe machines.

All the subjects were examined every hour and oral temperature (OT) and heart rate (HR) were taken hourly for 24 hours with properly calibrated clinical thermometers and stop-watches, except during sleep. Drinks or vigorous physical activity unrelated to the scheduled job were forbidden before the data were recorded. During sleep, monitoring was done only if the subjects woke up spontaneously. Micturition frequencies and sleep hours were recorded. Besides, the time for the main meals, tiffin, bath, defecation, etc., and recreations were recorded. The study was continued for three full rotations of shifts and the subjects were conditioned for one week with trials prior to the final recording of data.

Statistical treatments were done to obtain the amplitude of the rhythm in different parameters and their statistical significance levels were computed.

RESULTS AND DISCUSSION

A. OT and HR Rhythms :

i) Parallelism and dissociation of circadian rhythm : phase, amplitude and shift differences : Cumulative graph of OT and HR for all the industrial shift workers for all the days of each of the three shifts show that these circadian rhythms were parallel to each other in both phase and amplititude in shift A (Morning) and shift B (Afternoon) (Figure 1). But the night shift was different with mean values and amplitudes less than those of shifts A and B as shown in Tables 1 and 2. This is presumably due to the modification of the OT and HR rhythms by the night work, which tended to boost up the OT and HR.

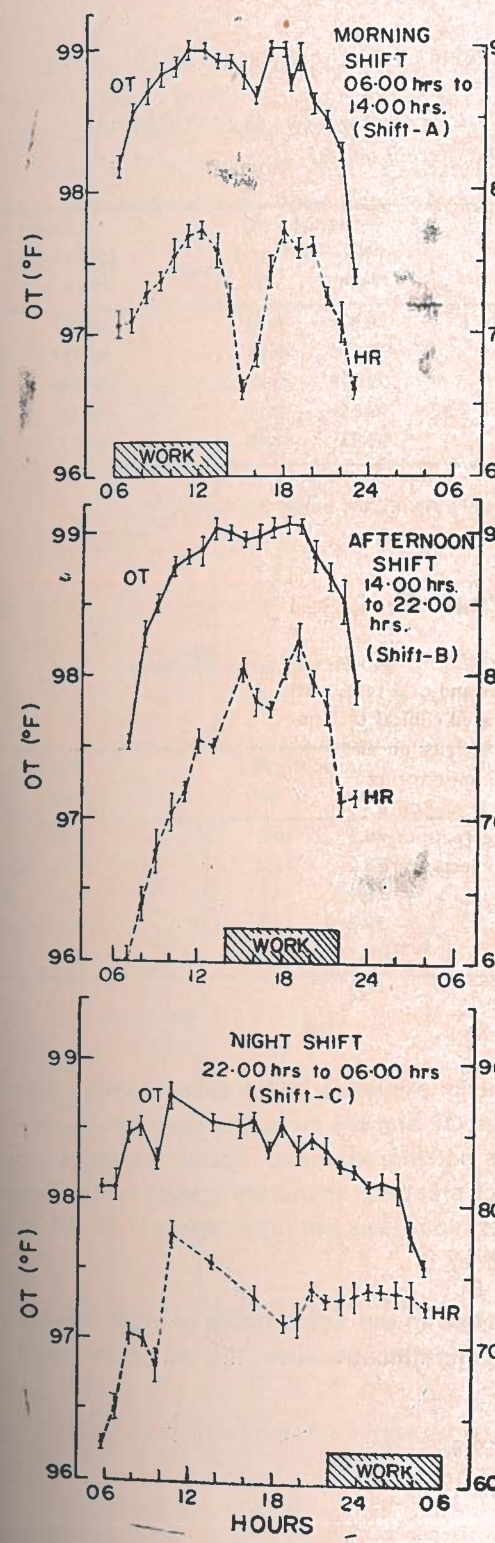


Figure 1 : Industrial shift workers : circadian rhythm of oral temperature and heart rate.

Table 1

Oral temperature of male industrial shift workers in each 24-hours in three different shifts

SUBJECTS	Morning (A) (0600 - 1400 hrs)		Afternoon (B) (1400 - 2200 hrs)		Night (C) (2200 - 0600 hrs)	
	Mean	SD	Mean	SD	Mean	SD
SNDB (D= 8)	98.91	0.14	98.82*	0.13	98.53*	0.09
BM (D=10)	98.63	0.06	98.61*	0.15	98.20*	0.13
MG (D=10)	98.52	0.12	98.71*	0·11	98.44*	0.14
SM (D=12)	98.64	0.15	98.65	0.11	98.56	0.16
PS (D=10)	98.61	0.12	98.82	0.10	98.37	0.08

D=Number of days of observation ; *Values are significant below 5% level.

Table 2

Heart rate of male industrial shift workers in each 24-hours in three different shifts

SUBJECTS	Morning (A)		Afternoon (B)		Night (C)	
	Mean	SD	Mean	SD	Mean	SD
SNDB (D= 8)	80.3	9.8	76.5	10.3	74.3	9.4
BM (D=10)	72.6	11.5	78.2	12.2	73.5	11.9
MG (D=10)	73.1	10.6	76.4	9.1	70.6	8.5
SM (D=12)	77.5	8.1	79.2	12.5	74.1	10.2
PS (D=10)	78.3	10.4	82.1	12.1	75.2	8.7

D=Number of days of observation ;

In the control subjects not much apparent differences were noticed between the day and night shifts in the OT and HR circadian rhythms (Figure 2), since the change of living routine was not thorough and social contacts continued as before and there were lack of sleeping chambers (required for proper daysleep in isolation). Moreover, work load was not high enough to compete with the circadian rhythm for dominance.

Dissociation of the two parameters in the same hours of night during the week with day-shift could not be investigated because the subjects used to sleep at night in day-shift.

ii) Inversion or flexibility of the circadian rhythm : Although workers like Teleky (1943) found an inversion of the rhythm in night shift, the same was not observed in the present investigation probably because the heaviness of the job was not sufficiently high to overcome the influence of circadian rhythm altogether—the job of these industrial workers were as simple as thread cutting

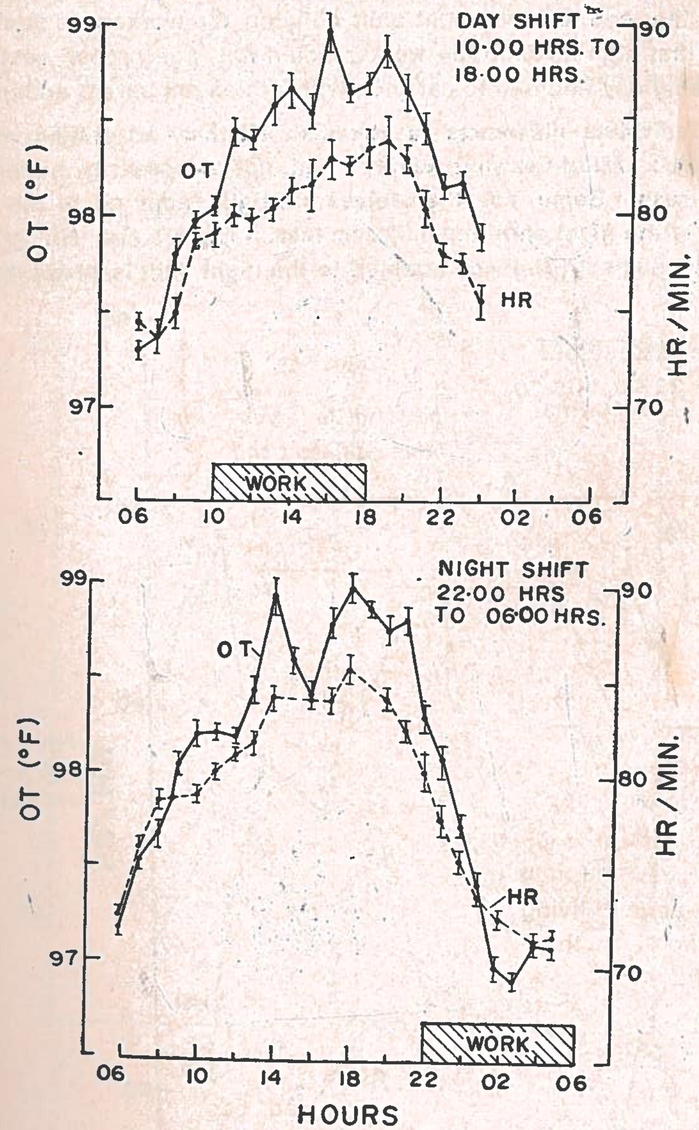


Fig. 2.

Figure 2 : Control subjects : circadian rhythms of oral temperature and heart rate.

etc. in a lathe machine. The night work in the present study could not invert HR circadian rhythm. Kleitman and Kleitman (1963) takes the HR rhythm not as a physiological rhythm like the circadian one, but as a simple periodicity easily coupled with the routine of living.

iii) Indication of stress through circadian rhythm : Unlike in shifts A and B, the OT and HR of the industrial workers in night shift remained at a higher level at the end of the night shift obliging the workers to start the following day with that high level so the worker could not get proper rest prior to the next working day and had to carry on with prolonged unrest and internal stress.

iv) Individual differences in circadian rhythm - adaptation or synchrony to the schedule : All of the shift workers did not necessarily suffer equally due to the stress. Some got themselves partially adapted to the new work-rest schedule of the night shift and suffered less. The OT and HR graph for night shift of one subject (BM) who adapted to the night shift is presented in Figure 3.

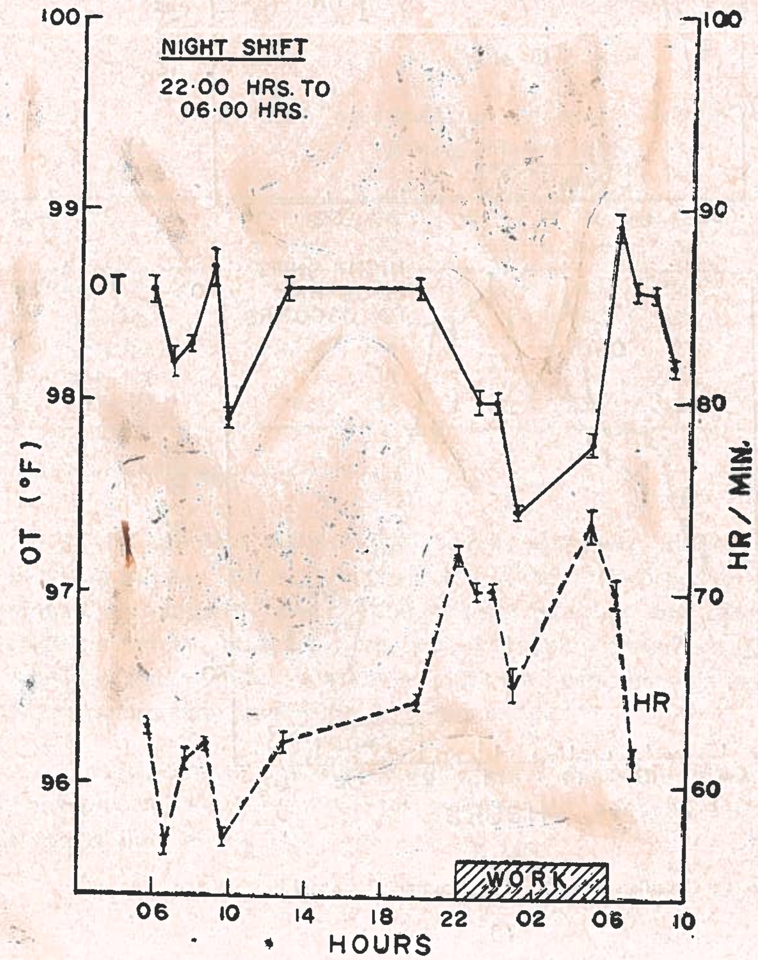


Figure 3 : One industrial shift worker (BM) (Adapted subject in night work)

It showed that the night work raised the OT and HR levels decoupling themselves from the circadian clock and it went down during the rest period at the day time. Thus, he was not desynchronous with the changed work-schedule and was not stressed by the high values.

v) Individual variations in circadian rhythm — non-adaptation or de-synchrony : OT and HR graphs for night shift of another subject (SNDB) is given in Figure 4. This subject didnot like the night shift and used to suffer from indigestion, defecation troubles, etc. in the week of night-shift having the same

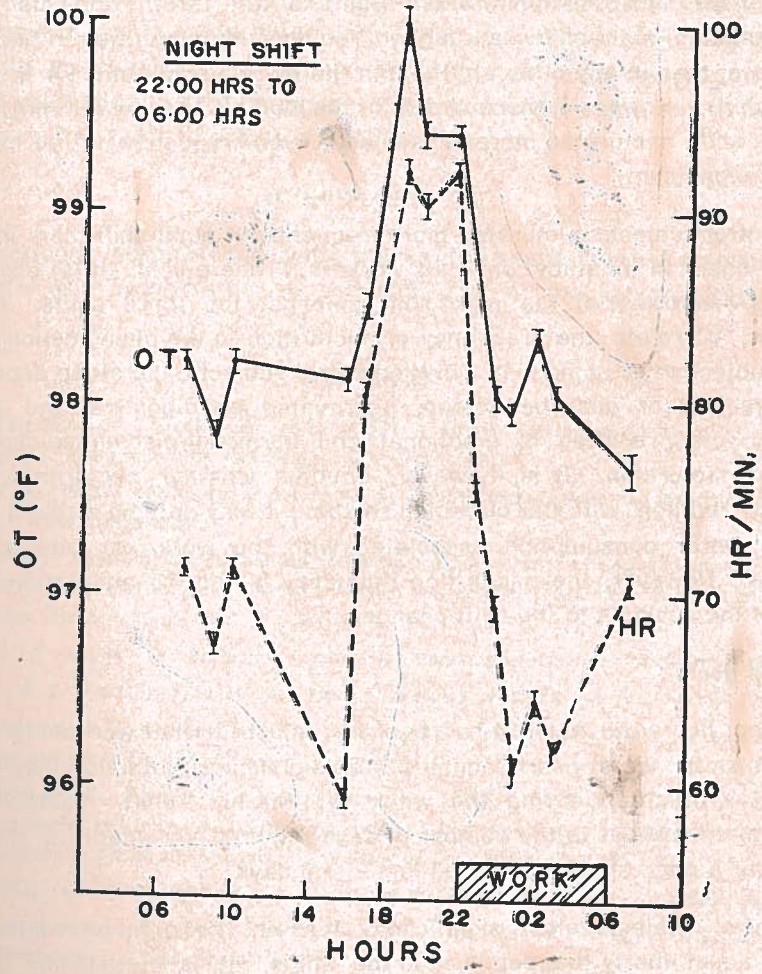


Fig. 4.

Figure 4 : One industrial shift worker (SNDB) (Non-adapted subject in night)

type of job as the above mentioned subject (BM). The influence of circadian rhythm was stronger than the influence of work load. His OT and HR followed the old circadian rhythm, went down at night as they would in normal routine, and did not rise during night work. As the OT and HR remained very high at noon, he had difficulty to have proper sleep with a consequent lowering of his output in the factory. These are the signs of non-adaptation to the situation.

B. Micturition Frequency :

Individual variations for inter-shift differences in micturition were seen amongst the industrial shift workers (Sen and Kar, 1978). Subjects like SNDB who resented night-shift had higher frequency of micturition in the night shift (7.4 times) than in any other shift (4.9 in the morning shift and 5.4 in the afternoon shift). However, the majority of the workers, having not much repulsion to night shift, micturated more or less with even frequency in all three shifts (p : not significant).

Control subjects micturated more frequently in night-shift than in day-shift except one. In a study on shift workers, Froberg *et al.* (1972) observed that diuresis was lowest in the night-shift amongst the three shifts. He didnot, however, correlate the frequency of micturition to the phenomenon of adaptation (subjective or objective). In the control subjects, the sleep deprivation or unsatisfactory or disturbed sleep, aggravated by digestive and defecation troubles, etc., resulted in emotional and hormonal disbalance causing more frequent micturition. It is, however, doubtful whether micturition frequency has any relation with the circadian rhythm ; it may only be a result of fluctuations in water consumption associated with the work-rest ratio during the 24-hours. However, the micturition frequency hinted the adaptation/non-adaptation of the subjects to the shift changes.

C. Sleep Hours :

Sleep hours (in each 24-hours) of the industrial shift workers for the three different shifts were nearly equal (p : not significant), although they were less satisfied with sleep during the week with the night-shift. There were inter-individual differences in the number of days required to adapt to the change of shift for a good sleep. It varied fom 2 to 6 days.

Control subjects slept significantly less in the night-shift although they enjoyed equal liberty to sleep in both the shifts. It is statistically significant ($p<0.02$). The social cues are important in regulating the human circadian rhythm (Aschoff *et al.*, 1971). As mentioned earlier the control subjects have

several difficulties to go through the night shifts. As they were non-industrial and sedentary, and their job was passive, it failed to dominate over the circadian rhythm in influencing the systems.

CONCLUSION

Adaptation/non-adaptation were seen to be reflected in various ways in the four parameters studied, and sometimes also through gastro-intestinal troubles. Amongst these four paramenters, it is hard to resolve on sleep or micturition as there are difficulties in their objective studies (e.g., record of the quality of sleep by portable EEG machines, proper measurement of the urine volume in each micturition, etc.). Rather, OT and HR may be more dependable as objective indications of adaptation and the magnitude and period of adaptation to shift changes. Further extensive studies are necessary to choose routine tests to pre-select shift workers.

ACKNOWLEDGEMENT

The authors acknowledge with thanks the whole-hearted co-operation of the workers who volunteered as subjects, and of the factory management as well.

REFERENCES

Aschoff, J., Fatranska, M., Giedke, H., *et. al.* (1971) : Human circadian rhythms in continuous darkness : Entrainment by social cues. *Science* **171** : *213.*

Brown (Jr.), F. A. (1957) : The rhythmic nature of life - In 'Recent advances in invertebrate physiology.' *Univ. Oregon Publ.*

Bunning, E. (1959) : Physiological mechanism and biological importance of endogenous diurnal periodicity in plants and animals. 'Photoperiodism and related phenomena in plants and animals.' *Am, Ass. Adv. Sci (Wash). Pub.* **55** : *507.*

Colquhoun, W. P. (Ed.) (1971) : Biological rhythms and human performance. Academic Press (Lond.).

Conroy, R. T. W. L. and Mills, J. N. (1970) : Human circadian rhythms. J & A Churchill, (London).

Froberg, J., Karlson, C. G., and Levi, L. (1972) : Shift work, study of catecholamines excretion, self ratings and attitudes. *Stud. Laboris. Salutis* **11** : *10.*

Halberg, F., Halberg, E., Barnum, C. P., and Bitter, J. J. (1959) : Physiologic 24-hr. periodicity in human beings and mice, the lighting regimen and daily routine. 'Photoperiodism and related phenomena in plants and animals.' *Am. Ass. Adv. Sci. (Wash). Publ.* **55** : *803.*

Halberg, F. (1962) : Circadian rhythms in experimental medicine. *Univ. Minn. Med, Bull.* **34** : *158.*

Kleitman, N. and Kleitman, E. (1963) : Effects of non-24 hr routines of living on oral temperature and heart rate. *J. Appl. Physiol.* **6** : *183.*

Persson, B. M. (1968) : Analysis of diurnal rate of longitudinal growth of bones. *Acta Orthop. Scand.* **39** : *8.*

Pittendrigh, C. S. (1957) : Diurnal rhythms as clocks. Symp. on Biol. Rhythms, *Nat. Acad. Sc.(USA). April, 24.*

Sen, R. N. and Kar, M. R. (1978) : Circadian rhythms in some groups of Indians working in shifts. *J. Human Ergology (Japan). 7 : 65-79.*

Siegel, P. V., Gerathewohl, S. J. and Mohler, S. R. (1969) : Time zone effects. *Science* 164 : *1250.*

Teleky, L. (1943) : Problems of night work : influence on health and efficiency. *Indus. Med.* 12 : *758.*

Wyatt, S. and Marriott, R. (1953) : Night work and shift changes. *Brit. J. Indus. Med.* 10 : *164.*

COMMENTS

Dr. S. Chakraborty : Will you please let us know the duration of service of the control and industrial workers, since this has a relevance with their adaptability to shift work ?

Mr. M. R. Kar : Control group subjects are non-industrial workers having no previous experience of shift change or industrial work. Industrial workers has the experience of 5 to 6 years in this shift-change routine.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 76, 1979

PHYSIOLOGICAL CRITERION TO SET THE LIMIT OF CONTINUOUS EIGHT HOURS WORK EVERYDAY IN INDUSTRY

S. K. Das, S. P. Chatterjee, P. Chatterjee, S. R. Maitra & B. P. Sinha

Department of Physiology, University Colleges of Science & Technology Calcutta University, Calcutta-700009, India

The physiological criterion to set the limit of continuous 8 hours-work is not clearly known. In the present experiment it is reported that man should not work continuously for 8 hours work by employing more than 50% of his maximum work capacity ($\dot{V}O_{2max}$). If 60% of $\dot{V}O_{2max}$ is involved, the subject exhibits the onset of fatigue by an increase of heart rate, blood pressure, rectal temperature and O_2 consumption, while sweat secretion decreases usually after 6 or 7 hours of work or in other words the steady state relationship breaks. The fall of sweat secretion reveals fatigue of the sweat glands though water loss was compensated every hour equally. Thus the work at 60% of $\dot{V}O_{2max}$ produces higher strain on the cardiovascular, metabolic and thermoregulatory systems and leads gradually towards fatigue and exhaustion when the duration of work is 8 hours. It is concluded that the limit of continuous 8 hours-work should be 50% of $\dot{V}O_{2max}$ and this is applicable only when the working environment is comfortably cooler. It is peculiar that when water supply is more than one and half times the loss during 60% of $\dot{V}O_{2max}$, sweat glands were not fatigued and O_2 consumption and rectal temperature remained unchaned while heart rate and blood pressure steeply rose and approched towards cardiovascular fatigue.

Paper presented at the Fourth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. *Full paper not received

Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 78 - 83, 1979

OCCUPATIONAL DAILY WORK LOAD FOR INDIAN INDUSTRIAL WORKERS AT THREE DIFFERENT THERMAL CONDITIONS

Rabindra Nath Sen and Devendra Nath Sarkar

Ergonomics Laboratory, Department of Physiology, University Colleges of Science, Technology and Agriculture, Calcutta University, Calcutta-700 009, India.

Studies on acclimatized industrial workers showed that the maximal physical work capacity (work for a short period) or maximum oxygen uptake in different groups determined by a single session test on a bicycle ergometer depended on their age, heaviness of their jobs and thermal conditions. The occupational work capacities of these workers based on Leistungs-Puls-Index (L. P. I.) were also suggested. A tentative classification of heaviness of jobs for Indian workers based on their physiological responses at comfortable thermal conditions was made.

The present study was carried out to evaluate the optimal work load (work for a long period) suitable for these workers based on the physiological responses such as pulse rate, oral temperature, oxygen consumption, sweat loss, etc., during continuous work on a standard bicycle ergometer at three different thermal conditions [about 70, 80 and 90° F Corrected Effective Temperature (Basic)] maintained in the laboratory.

Based on the different physiological responses at different thermal conditions, the average work rates which appeared to be safe and suitable for these Indian workers for day–to–day work for months without undue fatigue, were suggested.

India stands second in the world in regard to the source of man-power. It is of utmost importance to utilise manpower in the best possible way by the use of Ergonomics/Human Factors.

Maximal physical work capacity of workers is the work which yields greatest oxygen uptake possible for an individual whereas occupational work capacity is the highest work level permissible in daily occupational work. The differences in the body size, physique, physical fitness, ethnological adaptations, thermal tolerance, nutritional status, socio-demographic factors, daily and seasonal activities are mainly responsible for the unsuitability of data from other countries being applied **in toto** in case of Indians.

Sen (1967), Sen *et al.* (1969, 1972, 1973) determined the maximal physical work capacity of Indian industrial workers at three age-groups, with five different occupations and at three thermal conditions. Sen and Sarkar (1972) determined the occupational work capacity of these workers.

Paper presented at the Fourth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

The present study was undertaken to arrive at the daily occupational work load from data based on different physiological responses at different thermal conditions and different work rates for long period of work.

MATERIALS AND METHODS

Maximal Physical Work Capacity :

Eighty four medically checked, healthy workers selected from three different age-groups (i) 20-29, (ii) 30-39 and (iii) 40-59 years and five different occupations from light to extremely heavy, acted as volunteers. Each worker was subjected in the laboratory to different rates of standard work on a modified von Döbeln's (1954) mechanical bicycle ergometer, varying from 150 to 1500 Kgm/min. in steps. Three different grades of standard work were performed in an air-conditioned room where the thermal conditions were maintained at about 70° F (21.1° C) Corrected Effective Temperature (Basic) [CET(B)] without any thermal radiation, whereas in the other two thermal conditions [i. e., about 80° F (26.7° C) and 90° F (32.2°C) [CET(B)] each worker was exposed to parallel thermal radiation on front and back by several three-stage-controlled room-heaters.

The maximal physical work capacity of each worker was determined by the method of Maritz *et al.* (1961). Monetary and socio-psychological incentives, in an attempt to maximally motivate the subjects were given for attaining the highest load that could be maintained at least for two minutes. There was a gap of at least a week between the determinations in each thermal condition.

The heat stress index [CET (B)] in each thermal condition was obtained from the data on dry-bulb, wet-bulb and globe temperatures and Kata thermometer cooling time.

Occupational Work Capacity and Leistungs - Puls - Index (L.P.I). :

Each of the workers was subjected to a Müller's magnetic brake bicycle ergometer. The test was done by continuously increasing the rate of work in a single 12 minute session, slowly from 0 to 600 Kpm/min, pedalling with 60 double beats/min of a metronome. The continuous recording of pulse rates was done at each minute with the help of a stethoscope and a stop-watch. The expired air was collected in a Douglas bag from 2nd to 12th minute (for 10 minutes) to determine the oxygen consumption.

Conversion of LPI to Maximal Oxygen Uptake :

The maximal oxygen uptake according to Müller's method (1962) as modified by us is given below : Maximal oxygen uptake = 12/LPI + 0.17 lit/min (STPD).

Occupational Daily Work-Load :

The optimal work load suitable for these workers were based on the physiological responses, such as pulse rates, oral temperature, oxygen consumption, sweat loss, etc., during continuous work at three different rates on a standard bicycle ergometer at three different thermal conditions. The suitability was judged from the load at which the pulse rate remained in a more or less steady condition over the long period of work for at least 50 minutes.

RESULTS AND DISCUSSION

The physical characteristics of Indian adult male industrial workers who acted as volunteers for the measurement of work capacity are given in Table 1.

Table 1

Physical characteristics of Indian adult male workers for work capacity measurements

Age-Groups	Age (yrs.)	Body Weight (kg)	Body Height (cm)	Mean Skin Fold (mm)
20-29 yrs. (N=37)	25.5±0.44	53.6±1.35	165.5±0.82	7.3±0.63
30-39 yrs. (N=31)	34.0±0.49	54.8±1.54	163.5±1.09	7.0±0.68
40-59 yrs. (N=16)	48.5±1.25	61.6±1.62	166.9±0.96	7.7±0.90
All Groups (N=84)	33.0±0.99	55.6±0.93	165.0±0.58	7.3±0.39

Mean ± Standard Error ; N=Number of subjects

Maximal Physical Work Capacity : This is presented in Table 2.

Table 2

Maximal physical work capacity (maximal oxygen uptake) of Indian adult male industrial workers at comfortable thermal conditions

Groups	Maximal oxygen uptake Litres (STPD)/min	ml (STPD)/min/kg
Age groups :		
20-29 yrs (N=37)	2.46±0.05	45.23±2.03
30-39 yrs (N=31)	2.33±0.04	45.04±1.75
40-59 yrs (N=16)	2.13±0.03	34.96±0.90
Occupation groups : (heaviness of jobs) :		
Light (N=7)	1.67±0.02	30.94±1.36
Moderately heavy (N=19)	1.91±0.05	36.22±0.79
Heavy (N=30)	2.27±0.05	40.67±1.41
Very heavy (N=17)	2.50±0.06	41.98±1.99
Extremely heavy (N=11)	3.17±0.08	55.51±2.26
All groups (N=84)	2.31±0.14	41.08±1.56

It will be seen that the maximal physical work capacity decreases with aging and increases with heaviness of usual job.

However, the value of maximal oxygen uptake in the present investigation is much lower than 4.11 liters STPD/min obtained by Åstrand (1952, 1956) on physical education students, 3.50 liters (STPD)/min obtained by Robinson on American men (1938).

Tentative Classification of Degree of Heaviness of Jobs : These are given in Table 3.

The values are lower than those of the Westerners (Christensen, 1953).

The thermal data of three different thermal conditions in which maximal physical work capacity measurements were made are given in Table 4.

Maximal oxygen uptake of Indian adult male industrial workers at three different thermal conditions is presented in Table 5.

Table 3

Tentative classification of strains in different types of jobs according to the physiological responses of young Indian workers in comfortable climates

Physiological Responses	Classification of strains in jobs: Very Light	Light	Moderately Heavy	Heavy	Very Heavy	Extremely Heavy
Oxygen uptake (litres/min)	<0.35	0.35-0.70	0.70-1.05	1.05-1.40	1.40-1.75	>1.75
Energy expenditure (kcal/min)	<1.75	1.75-3.50	3.50-5.25	5.25-7.00	7.00-8.75	>8.75
Heart rate (beats/min)	< 75	75-100	100-125	125-150	150-175	>175
Sweating rate (ml/hr.-average for 8-hour work day)	—	<140	140-280	280-420	420 560	>560

Table 4

Thermal data (N=252) of three different thermal conditions for work capacity measurements

Dry-Bulb (°F)	Wet-Bulb (°F)	Globe (°F)	Relative Humidity (%)	Air Velocity (Ft/min)	CET (Basic) (°F)
83.0±0.10	67.8±0.12	83.0±0.09	47.1±0.33	175.0±2.37	(Comfortable) 70.6±0.06
91.2±0.13	75.7±0.17	96.0±0.09	48.8±0.41	132.1±2.94	(Warm) 80.7±0.08
100.5±0.15	84.8±0.21	111.4±0.12	51.8±0.41	121.0+2.55	(Very Hot) 90.3±0 04

Mean±Standard Error ; CET (B) = Corrected effective temperature (basic). N = No. of observations.

Table 5

Maximal oxygen uptake of Indian adult male industrial workers (N=84) at three different thermal conditions

Thermal Conditions [CET (B)] °F (°C)	Maximal Oxygen Uptake: Litres (STPD)/min	ml (STPD)/min/kg
70.3±0.34 (21.3±0.19)	2.31±0.04	41.08±1 56
80.7±0.42 (27.1±0.23)	2.05±0.05	36.43±1.58
90.2±0.25 (32.4±0.14)	1.81±0.06	32.23±1.36

N=Number of subjects ; Mean±Standard Error ; CET(B)=Corrected effective temperature (basic)

The maximal physical work capacity of all workers was found to diminish gradually for increase of temperature from 70° F to 90° F CET(B).

The differences for different groups in different thermal conditions were statistically significant at 5% level as revealed by Student's 't'-test.

Occupational Work Capacity and Leistungs-Puls-Index : These are given in Table 6.

Table 6

'Leistungs-Puls-Index' (LPI), work pulse sum (WPS), occupational work capacity (OWC) of Indian adult male industrial workers at [70°F CET(B)]

Age Group Years	LPI	WPS	OWC (K. cal/min)	OWC as percentage of MPWC (%)
20-29 N=37	5.08 ±0.18	348.8 ±14.0	2.67 ±0.10	21.7
30-39 N=31	4.33 ±0.18	318.4 ±22.5	3.07 ±0.13	26.4
40-59 N=16	3.81 ±0.28	302.7 ±26.0	3.54 ±0.23	33.2
All groups N=84	4.56 ±0.12	328.8 ±19.4	2.98 ±0.14	25.8

Mean±Standard error. MPWC = Maximal physical work capacity.

As it would bs seen the LPI did not increase significantly in higher age-groups indicating no reduction of occupational work capacity with age. According to Müller (1962) the fitter and stronger a person, the lower will be his LPI. The lower the LPI the higher would be the energy expenditure which the subject is able to sustain.

Miximal Oxygen Uptake Determined from LPI :

The mean maximal oxygen uptake obtained from the LPI at about 70° F [CET (B)] was 2.53 litres/min in young workers (20 to 29 yrs age-group) which was lower than 4.3 litres/min obtained by Rutenfranz *et al.* (1959) among young workers and 4.2 litres/min obtained by Åstrand(1952, 1956). The actually determined maximal oxygen uptake value for our young workers at about 70° F [CET(B)] was 2.46 lit/min. which was slightly lower than that obtained from LPI.

From student's 't'-test it was seen that there is no significant difference of LPI among the different age-groups.

Occupational Daily Work-load :

The physiological responses of workers during and after continuous work on a bicycle ergometer at three rates and at three different thermal conditions showed that at comfortable condition sedentary workers could perform continuously at 250 Kgm/min and extremely heavy group at 400 Kgm/min, whereas in very hot condition the values were 150 and 300 Kgm/min respectively. From the study it may be concluded that in a tropical climate in India the occupational daily work load of 300 Kgm/min at 80° F [CET(B)] appears to be safe and suitable for the Indian workers for day-to-day work for months without undue fatigue.

ACKNOWLEDGEMENT

The authors acknowledge with gratitude the financial support of the Indian Council of Medical Research, New Delhi. The whole-hearted cooperation of the workers who acted as volunteers in the study is also gratefully acknowledged.

REFERENCES

Åstrand, P. O. (1952) : Experimental studies of work in relation to sex and age. Ejnar Munksgaard, Copenhagen.

Astrand, P. O. (1956) : Human physical fitness with special reference to sex and age. *Physiol. Rev.* **36** : *307-335.*

Christensen, E. H. (1953) : Physiological evaluation of work in Nykroffa Iron Works ; In : Symposium on Fatigue (Ed : W. F. Floyd and A. T. Welford), H. K. Lewis, London, pp. *93 108.*

Maritz, J. S., Morrison, J. F., Peter, J., Strydom, N. B., and Wyndham, C. H. (1961) : A practical method of estimating an individual's maximal oxygen intake. *Ergonomics*, **4** : *97-122.*

Müller, E. A. (1962) : Occupational work capacity. *Ergonomics*, **5** : *445-452.*

Robinson, S. (1938) : Experimental studies of physical fitness in relation to age. *Arbeitsphysiologie*, **10** : *251-323.*

Rutenfranz, J. and Hettinger, T. H. (1959): Zuf. Kinder heilk-kundu, **83** : *65 68.*

Sen, R. N. (1967) : Studies on physiological factors limiting work output of Indian workers, Report to the Indian Council of Medical Research, pp. **78** :

Sen, R. N., Roy, B. S. and Sarkar, D. N. (1969) : Maximal physical work capacity of Indian industrial workers in relation to age and heaviness of job. Proceedings of the 13th International Conference of the Human Factors Society, Philadelphia, Pennsylvania, U. S. A., 6-9th October, pp **13**.

Sen, R. N. and Sarkar, D. N. (1972) : Effects of thermal stress on maximal physical work capacity of Indian industrial workers. Proceedings of ICMR National Symposium on 'Health in Relation to Work and Heat Stress' at NIOH, Ahmedabad, 27-29 January, 1972 ; ICMR Technical Report Series No. 15, Division of Publications & Information, New Delhi, p. *159.*

Sen, R. N., Roy, B. S. and Sarkar, D. N. (1973) : Maximal physical work capacity of Indian industrial workers. *Ind. J. Physiol. & Allied Sci.* **27** : *107.*

Sen, R. N. and Sarkar, D. N. (1972) : Occupational work capacity of Indian adult male industrial workers in relation to age. Proceedings of the Seminar on 'Man at Work' at the Central Labour Institute, Govt. of India, Bombay, 11-14 April.

Von Dobeln, W. (1954) : A simple bicycle ergometer. *J. Appl. Physiol.*. **7** : **222-224.**

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 84, 1979

INFLUENCE OF DYNAMIC AND STATIC COMPONENTS OF MUSCULAR WORK ON HEART-RATE WHILE "PUSHING TROLLEYS"

H. Monod, S. P. Dutta and J. Sanchez

Laboratory of Work Physiology, CNRS, University of Paris. France

The paper describes a series of experiments carried out to assess the influence of static and dynamic components of muscular work on changes in heart rate while performing a simple task, viz., pushing a trolley. Six healthy subjects (4 males, 2 females) have been considered for the investigation. An experimental set-up consisting of a treadmill and a system of pulleys has been used to simulate body movements during the process of pushing a trolley. Experiments each of 10 min duration have been performed at two speed levels (2 km h^{-1} and 3 km h^{-1}) and four load levels (3 kg, 6 kg, 9 kg and 12 kg). Heart rate has been continuously recorded during (i) walking on the treadmill at predetermined speeds without pushing, (ii) pushing against a known load without moving, (iii) walking at predetermined speeds while pushing against known loads. The results have been expressed in terms of cardiac cost which may be defined as the total number of the heart beats for a particular work period above the mean level of resting pulse rate observed before the start of the activity in question.

A linear relationship has been obtained between cardiac cost and the work load for each of the three conditions described above. The three straight lines thus obtained are divergent ; further, it has been observed that for the same load at either speed, the sum of the individual cardiac costs for pushing alone (static component) and for walking alone (dynamic component) is less than the measured cardiac cost when pushing and walking simultaneously at the same load and speed level. A logarithmic relationship has been obtained between the cardiac cost of pushing against a fixed load at a predetermined speed (Ct) and the cardiac cost of the static (Cs) and dynamic (Cd) components when the last is performed at the same speed or load level. This is of the form :

$$Ct = Cs^{x_1} \times Cd^{x_2}$$

The multiple coefficient of correlation for Ct with Cs and Cd varied between 0.83 and 0.89 for each subject. The non-linearity of the above relationship may be explained by the fact that whereas static work or dynamic work alone could be considered relatively light, an association of the two components results in a work-strain which is high with the heart rate often near levels of 140–160 beats min^{-1}

Paper presented at the Fifth Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. *Full paper not received

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 86 - 92 1979

ERGONOMICS AND PHYSIOLOGICAL STUDIES ON MINE RESCUE WORKERS

A. R. Guharay, S. N. Ray, P. K. Dutta, J. P. Gupta,
D. K. Mitra and M. K. Chakraborty,

Central Mining Research Station, Dhanbad-826001, Bihar, India.

Mine rescue workers attend to their duties under very inclement environment in the event of mine accidents. They require high degrees of physical fitness and skill and undergo refresher practices at the Rescue Training Galleries, at the Regional Rescue Stations or at the colliery pits. During practice or actual rescue operations, they are supplied with pure oxygen for respiration from a breathing apparatus.

A physiological study had been carried out on rescue workers under practice at the training galleries and colliery pits to arrive at the physiological costs of rescue operations, safety and performance limitations. Their physical fitness indices were studied. On the basis of the study, recommendations for recruitment and retirement standards had been made.

A rescue worker should have all round physical and mental fitness to perform heavy and hazardous operations in the events of accidents and explosions. Normal environmental conditions in Indian coal mines are hot and humid, laden with toxic dusts and sometimes, noxious gases.

Humphreys and Lind (1962) made a fine study on mine rescue workers in England. Roantree (1950) studied rescue workers engaged in fire fighting underground in an Indian gold mine. Chakraborty and Guharay (1963) carried out a study on rescue trained personnel. The present investigation is a furtherance of the previous one, based on work physiological and ergonomic studies.

Most mine rescue workers are chosen from the supervisory staff and some from the mine workers. They are initially trained rigorously at the Mines Rescue Station under the supervision of trained officers. Afterwards, they need to attend 8 refresher practices every year. A thorough medical check-up is made once or twice a year.

Paper presented at the Fifth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

The captain of a rescue team is entrusted with the responsibility of work-supervision and safety of the whole team of 6 members. They need to work for 2 hours, with rest pauses of 2-5 min after every 10-15 min of work to avoid too much exhaustion. They are provided with a self-contained breathing apparatus, having a two hours' supply of pure O_2. The oxygen is delivered from a small cylinder carried on the back of an individual, at the rate of 2 litres min^{-1}. Mostly Proto Mark IV Breathing Apparatus weighing approx. 15.5 kg are used. Sometimes, Drager Breathing Apparatus weighing 12.7 kg are supplied for practice.

India has a Central Coal Mines Rescue Station Committee at Dhanbad and a number of Regional Rescue Stations. Each has a permanent brigade of rescue workers, besides a contingent of trained rescue personnel.

The present study was carried out at the Dhansar Regional Rescue Station, where 700 active enlisted rescue workers are imparted training and refresher practice.

MATERIALS AND METHODS

The group of 40 trained rescue workers (age 22-48 years), comprised of managers, supervisors and some other categories of coal mine workers studied were in perfect health. They worked with equal share of exertion in rescue work.

The Rescue Station Training Galleries have arrangements for creation of artificially severe atmospheres as expected in actual mine rescue operations.

The experiments were carried out in April and May, 1974. The energy costs of various activities were determined by a standard method using Kofranyi and Michaelis Respirometer (Max-Planck Institute Model 59). The rescue workers used a Proto apparatus and inhaled oxygen during normal practice, but during the period of observations the Proto mouthpiece was disconnected and the mouth-piece of the respirometer put in. They inspired gallery air instead of pure oxygen during this period. It was ensured that the lungs were completely flushed with gallery air before the expired air samples in activity were collected in rubber bladders and were immediately transferred to Henderson-Bailey sample bottles by displacement of mercury. The gas analysis was done in a Lloyd Gas analyzer. The oxygen consumption was calculated with proper corrections for NTP.

The resting $\dot{V}O_2$, heart rate, oral temperature, blood pressure, etc., were determined before the commencement of the actual rescue practice. The subjects were allowed to rest for a minimum of 30 mins till their heart rates stabilized. This was repeated on the second day, when their $\dot{V}O_2max$ was determined on a Fleisch Universal Ergostat using the method of Åstrand (1952).

Energy costs were determined in different observations connected to rescue work, viz., fire brick stopping, sand bag stopping, stretcher carrying, crawling, gradient walking with stoop, cog setting, etc.. Fluid balance was studied by weighing the invididual before the start and end of the two hours' shift.

A brief dietory history was taken for a pariod of 7 days for each individual.

Environmental data were taken in the laboratory room, training gallery and colliery pits, wherever experiments were carried out.

A brief description of the rescue operations are given below :

Sand bag stopping — This consists of carrying 2 sand bags (10 kg each) at a time for about 5 meters by an individual in a relay processes. The subjects carried 15-20 bags per min.

Brick stopping — This is a similar process with fire bricks (3.5 kg each) instead of sand bags. The workers carried about 25-30 bricks per min.

Stretcher carrying — This consists of carrying a dummy (56 kg), a stretcher (11 kg), Novox respirator (11 kg) and other accessories, making a total of about 80 kg. This is usually carried by 2 workers.

Cog setting — This consists of carrying cogs and making a frame for roof support. The subject carries 5-6 Cogs (15-20 kg each) to a distance of 5 meters, for frame setting (square or rectangle) per min.

Walking — The rescue workers need to walk a long distance inside the collieries, sometimes stooping, sometimes crawling, with bad under-foot conditions. The experiments were done when they were walking along an upward gradient of approximately 1 : 7.

Crawling — In practice inside the training galleries or while moving through thin coal seems, the workers needed to crawl cautiously to avoid damaging the breathing apparatus.

In the training galleries the shift time was 2 hours, with an initial physical exercise of weight pulling of 25.5 kg hung through a simple pulley. This weight pulling was done for 10-15 times by each individual, before undergoing actual rescue practice.

In the colliery pits the practice time was about 90 mins. A complete time study of each shift was made.

RESULTS AND DISCUSSION

In the group of subjects, the supervisory categorised rescue workers' monthly salary ranged from Rs. 500/-to Rs. 1500/-. In the non-supervisory group, the salary range was Rs. 250/-to Rs. 450/- per month.

The physical and physiological characteristics of the rescue workers are presented in Table 1.

The mean average age was 32.5 years with a range from 22 to 48 years. Mean body height was 170 cm and mean body weight, with shorts, was 62.1 kg. Almost all had a body weight above 56 kg. "Reference worker" of **Nutrition Advisory Committee** of the Government of India (1965) weighs 53 kg with average body height 163 cm. This had been decided by certain adjustments of the "reference man" recommended by N.A.C., which refers to a man of 25 years age with 55 kg body weight and height 168 cm. The daily calorie requirement for an industrial worker with moderate activity was set at 2800. But for heavy work like mining this has been set at 3232 kcals per day. From the dietary history of the subjects studied the diet they consumed was found to be satisfactorily balanced with animal protein or milk protein and other essential dietary constituents. The calorie intake was around 2600 to 3000 kcals. This seems to be adequate for the supervisory category, but may be slightly deficient for the non-supervisory category. They satisfied the reference standards of N.A.C. regarding their heights and weights.

Table I

Physical and Physiological Characteristics of Rescue Workers

Physical characteristics			Physiological characteristics						
Age (yrs)	Height (cm)	Weight (kg)	Activity	$\dot{V}O_2$ lit/min S.T.P.D.	$\dot{V}O_2$ ml/kg/min S.T.P.D.	H.R. beats min^{-1}	B.P. mm Hg Syst	B.P. mm Hg Diast	Oral temp. °F (°C)
			Resting	0.22	3.54	74	120	74	98.1 (36.72)
32.5	170	62.1	Maximal Exercise	1.80	28.98	180	160	64	98.5 (36.94)

The heart rate and $\dot{V}O_2$ in resting and in different rescue operations are presented in Figure 1.

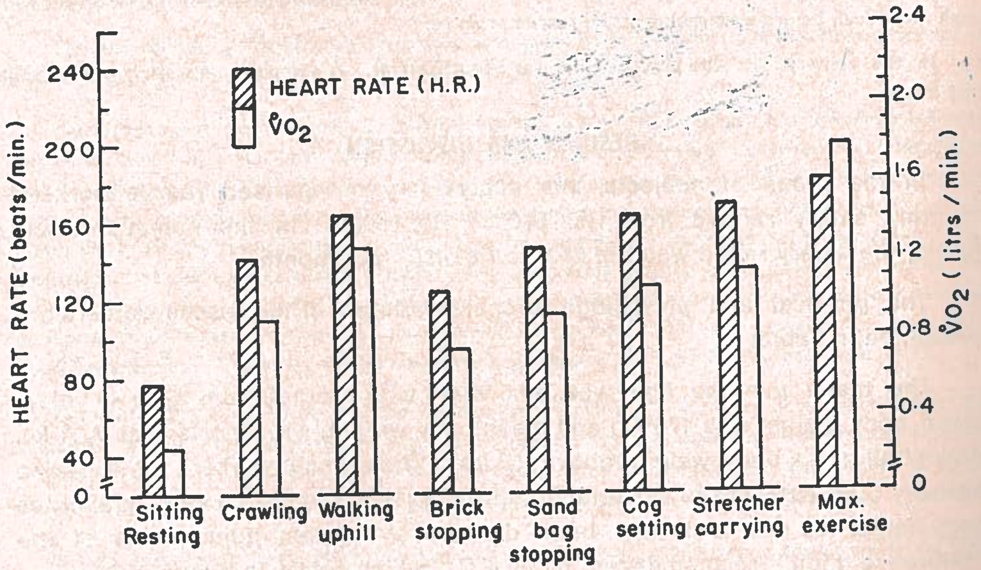


Fig. 1.

Figure 1 : Heart rate and $\dot{V}O_2$ of the workers in resting and in different rescue operations.

Regarding their resting sitting metabolism, the $\dot{V}O_2$ was 0.22 litres min^{-1} S.T.P.D. or 3.54 ml kg^{-1} min^{-1}. The resting sitting heart rate was 74 beats min^{-1} and the average blood pressure was 120mm Hg systolic and 74mm Hg diastolic. The resting oral temperature was 98.1°F (36.72°C).

The average maximal aerobic capacity of the group was 1.80 litres min^{-1} S.T.P.D. or 28.98 ml kg^{-1} min^{-1}. The $\dot{V}O_2max$ of the younger group (22-30 years) was above 2 litres min^{-1}, whereas for the aged group above 40 years (40-48 yrs) it ranged from 1.50 to 1.68 litres min^{-1}.

The average blood pressure at the exhaustive level of work was around 160/64mm Hg syst/diast. There was a diminution in the diastolic blood pressure at maximal exercise.

The oral temperature after cessation of work was 98.5°F (36.94°C). This 0.40°F (0.22°C) rise from resting condition was evident in almost all subjects.

Average heart rate at maximal exercise level was 180 beats min^{-1}. This rate was higher (190-210 beats min^{-1}) in younger subjects and lower (160-180 beats min^{-1}) in older (40 +) group of subjects.

In rescue practice, brick stopping showed $\dot{V}O_2$ of 0.74 litres min^{-1} with a pulse rate of 123 beats min^{-1}. In stretcher carrying $\dot{V}O_2$ was 1.15 litres min^{-1} and pulse rate recorded was 168 beats min^{-1}. Walking along an upward gradient of 1 in 7 in a half stoop posture was quite tiring. $\dot{V}O_2$ was 1.29 litres min^{-1} and corresponding heart rate was 164 beats min^{-1}. In sand bag stopping, $\dot{V}O_2$ was 0.92 litres min^{-1} and pulse rate attained was 146 beats min^{-1}. In cog setting, $\dot{V}O_2$ was 1.05 litres min^{-1} and pulse rate was 162 beats min^{-1}. In crawling $\dot{V}O_2$ was 0.91 litres min^{-1} with a heart rate of 142 beats. min^{-1}.

Brick stopping, sandbag stopping and crawling $\dot{V}O_2$ was 41%, 51% and 50% of $\dot{V}O_2$ max respectively. These operations when carried out at the usual speed of work already mentioned, were within the safe and tolerable limits of work ; pulse rates were also not very high. But when they were carried out at higher speeds, it proved tiring, as found in subjects who worked with competitive spirit.

In walking, the physiological cost was high, particularly in steep gradients and thin coal seams. It was a mixture of dynamic and static work with much of isometric load on back muscles, particularly in stooping. Isometric load hinders blood flow (Åstrand 1970) contributing extreme and unavoidable discomfort.

Here the gradient chosen was only 1 in 7, the most frequent gradient seen in mines. But in deep mines and horizon mines, the gradients encountered were even 1 in 1 where steel ladders were used, with equally difficult passage through coal seams. The rescue workers need very often to walk miles together underground, to reach the rescue or accident site. Pulse rates varied here from 150 to 180 beats min^{-1}. The $\dot{V}O_2$ was approximately 72% of maximal. This proved quite difficult for older subjects, who reached near maximal working conditions and required a good amount of rest for recovery.

In strecher carrying also, similar difficulty was encountered in view of the higher physiological load associated with it. $\dot{V}O_2$ was 64% of maximal and the average pulse rate was 164 beats min^{-1}.

Cog setting also was hard work for the rescue workers, particularly during the carriage of cogs. $\dot{V}O_2$ was approx. 59% of $\dot{V}O_2$max and the average pulse rate was 162 beats per min.

The training gallery working environment had a D.B. 34-39°C, W.B. 23-28°C and R.H. 29 to 68%. The air velocity was 10 to 25 ft per min, whereas in the laboratory room D.B. range was 27-38°C, W.B. 21-27°C and R.H. was 18-84%.

In the colliery pits the temperature range was 28-34°C D.B., 25-34°C W.B. and R.H. 92 to 100%. Air movement was below 10 to 20 ft/min.

In the shift time study in the training galleries working time was 63.7%, resting 29.8% and stray walking 6.5% of 2 hours' work shift.

In the collieries the total working time, including walking was 78% and resting 22% of the 90 mins' work shift. The average loss in body weight in the 2 hours gallery working was around 0.75 kg per individual and in the collieries it was around 1 kg for the 90 mins' work shift. It was apparent that the thermal stress and work stress were high for the rescue workers.

It is obvious that the individual's maximal aerobic power plays a decisive role in his work capacity. Working close to $\dot{V}O_2$max has a less safety margin (Åstrand 1970). Considering all the above points it is recommended that the initial recruitment of the rescue workers should be done with caution. Mere medical examination will not suffice. Besides their physical fitness, they should have a minimum body weight of 55 kg, somewhat mesomorphic in somatotype and the $\dot{V}O_2$max should be at least 25ml/kg/min for the individual. The age at the time of recruitment should be preferably below 35 years.

Considering the diminution in working capacity with age and the demands of rescue work, it is recommended that the retirement age should be fixed at 45, when there will be 10-15% reduction in the $\dot{V}O_2$max.

ACKNOWLEDGEMENT

Thanks are due to the Superintendent, Rescue Station, Dhansar, for granting permission to work and offering the necessary facilities. The co-operations from the Medical Officer, Rescue Station and the Staff were spontaneous and praise-worthy.

We are obliged to the Director, CMRS for initiating this investigation and for continuous encouragement.

REFERENCES

Åstrand, P. O., (1952) : Experimental studies of physical working capacity in relation to sex and age, Ejnor Munksgaard, Copenhagen, *1952*,

Astrand, P. O. and Rodahl, K. (1970) : Text Book of Work Physiology, *Mc Graw.Hill, 1970.*

Chakraborty, M. K. and Guharay, A. R. (1963) : Some observations on the physiological responses in mines rescue work, *Ind. J. Indust. Med.*, 9 : *156.*

Humphreys, P. W. and Lind, A. R. (1962) : Energy expenditure of coal miners at work, *Brit. J. Indust. Med.*, 19 : *264.*

Roantree, W. B. (1950) : Work in high air temperature in a fire in Mysore mine, Kolar Goldfield, *Tr. Instn. Min. Met.*, 60 : *513.*

COMMENTS

Dr. R. Sinha : (1) According to the rescribed $\dot{V}O_2$max of 25ml/kg body weight around 50 kg, the total $\dot{V}O_2$max will come to $25 \times 50 = 1250$ml. Is it correct ?

(2) Whether the patients were screened Radiologically for the existence of pulmonary fibrosis (Caplan's syndrome), which will influence the O_2 transfer ?

Dr. A. R. Guharay : (1) Yes ; $\dot{V}O_2$max of 25ml/kg/min of a man weighing say, 50 kg will come to 1.25 lit/min. This is rather low. Minimum recommended body weight is 55kg.

(2) We have a radiology section for making surveys and follow up studies for occupational respiratory diseases. The worker were free from any respiratory disease.

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 94 - 100, 1979

PHYSIOLOGICAL REPONSES DURING MANUAL CARRYING OF DIFFERENT LOADS ON THE HEAD AT DIFFERENT SPEEDS

S. R. Dutta, B. B. Chatterjee and B. N. Roy,

Section of Physiological & Industrial Hygiene, All India Institute of Hygiene & Public Health, Calcutta - 700 073.

Experiments were conducted with healthy adult male subjects to find out the energy cost of carrying loads on the head at different speeds. The physiological parameters like energy expenditure (Kcal min^{-1}), pulmonary ventilation (litres min^{-1} at BTPS), peak heart rate, etc., were monitored. The energy expenditure tended to increase to a much greater extent on increasing the speed than on increasing the loads carried. Heavy loads need be carried with a slow speed from the physiological standpoint. The effects of different loads and speeds on the physiological variables have been scrutinized.

The manual carriage of loads is a principal type of job available to the unskilled workers in under-developed countries. Heaviness of this task is also apt to be higher than most other types of jobs employing manual workers in industry, commerce or agriculture. There is, therefore, a need for an intensive study of this task from different angles so that various contributory factors are well assessed with regard to the heaviness of task and any regulatory practices aimed at limiting the physiological strain of the job may be made on a rational basis. Since the weight of the load and the speed of its transport are important factors influencing the heaviness of the job of carrying load on the level ground, and since load is most commonly carried on the head in this country, the following study involved the principal physiological strain, viz., the energy expenditure, produced during the carriage of loads of different weights on the head.

MATERIALS AND METHODS

Five male casual labourers, accustomed to load carrying and of average good health and sufficient fitness to undertake the load carrying tasks, were engaged in the present study. Three loads, weighing 20, 30 and 40 kg were prepared by weighing requisite amounts of stone chips into three baskets and sewing them up in hessian covers. Each subject was required to walk without any load (0 kg) and with the above three loads on the head at speeds of 3, 4, 5 and 6 km/hour for 10 minutes. One, out of the 16 possible load-speed combinations, was randomly allotted to a subject

---

Paper presented at the Fifth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

on a given day till all the tasks had been performed. The speed of walking was adjusted by one of the authors walking beside the subject with a stopwatch in hand, on a level stretch of a long covered verandah, with 0.05 Km distances marked. The subjects were instructed to report between 10 A.M. and 12 noon after finishing their breakfast at least 3 hours earlier in order that the specific dynamic action of food might not interfere.

Energy expenditure was determined by collecting expired gases during the last two minutes' walking. The Douglas bag and accessories were not added to the load carried by the subject. The volume of collected gases was measured in a meter and aliquot samples were analysed in duplicate according to standard methods described by Consolazio *et al.* (1963). Heart rate was measured in the standing posture, by timing 30 beats with a stopwatch immediately on completion of the walk, which is referred to as the 'peak heart rate'.

RESULTS AND DISCUSSION

The physical characteristics of the subjects are prsented in Table 1. The mode of load carriage employed in the present study was the preferred mode in this region. In selecting the speeds of carriage, consideration was given to the observations on the average range of the walking speed of a sample of healthy male Indian workers (Ganguli, (1973). The loads required to be carried were those considered 'permissible', viz., 30 kg and those 10 kg more or less (Sen and Nag, 1975).

Table I

Physical Characteristics of the Subjects

Subject No	Age yrs	Height cm	Weight kg
1	44	170.0	62.3
2	22	161.0	40.2
3	50	173.5	50.6
4	36	155.5	43.3
5	21	160.0	48.0
Mean	34.6	164.0	48.88
S. D. ±	12.95	7.5	8.52

The energy expenditure values are presented in Figure 1. Separate regression lines have been fitted to the values observed for each of the four loads at each speed. The correlation (r) of energy expenditure and load seemed to be quite high at all walking speeds and the coefficient were practically uniform varying between +0.87 for the speed of 4 Kmph and +0.92 for the speed

of 5 Kmph. A consideration of the regression equations, in the basic linear form, $y = mx + c$, also shows certain peculiar similarities. The multiplier of the independent variable (load) is very nearly identical for the equations for

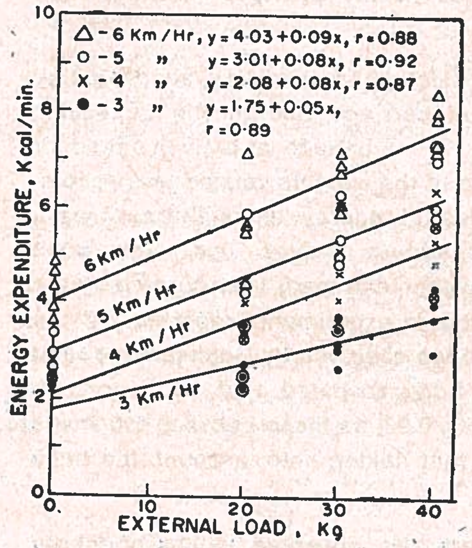


Fig. 1.

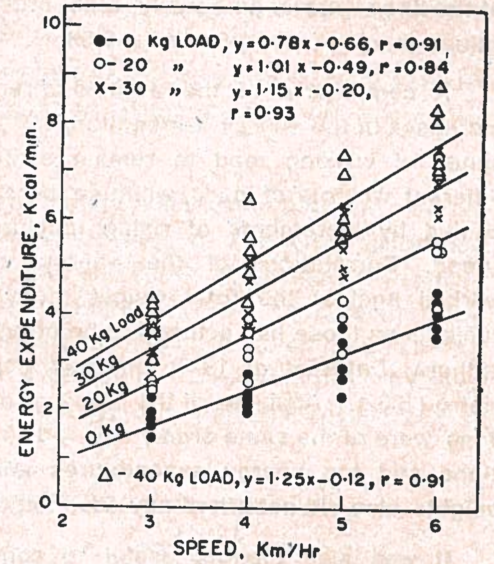


Fig. 2.

Figure 1 : Regression of energy expenditure on external load during their carriage at four different speeds on the level.

Figure 2 : Regression of energy expenditure on the speed of carriage while carrying different loads on the level.

speeds of 4, 5 and 6 Kmph making the three straight lines practically parallel. The constant quantities (c) in the three equations were close to 2, 3 and 4 respectively. Only the equation for the speed of 3 Kmph differed in its slope from the others being less inclined to the X-axis. This was due to the fact that the energy expenditure with no external load at 3 Kmph was much closer to the corresponding value for the walking speed of 4 Kmph than those for the other two speeds which differed from each other and also from the values for the speed of 4 Kmph to a larger extent. From the low degree of the slope of the regression line, it would seem that in walking at the low speed of 3 Kmph with or without external loads, the contribution of the energy expenditure for upright standing was relatively much greater than that of the walking speed or those of the loads themselves. This was also reflected in relatively small degrees of cardio-acceleration observed during carriage of different loads at that speed.

Figure 2 shows the speeds of load-carriage along the X-axis. The four regression lines have been drawn through the energy expenditure values for carrying each of the four loads, 0, 20, 30 and 40 kg, respectively, at the 4 specified speed. The correlation coefficients (r) between the two variables for each of the lines were of an equally high order as in the previous plotting, their values ranging from +0.84 to +0.93.

A comparison of the two sets of regression lines, therefore, suggests that increases in the energy expenditure of load carriage due to the increasing speed of walking tend to remain similar in magnitude at a given speed for different weights of loads, while an increase in the weights carried was accompanied by increments of rising magnitudes of energy expenditure at each speed. Correlations of the energy expenditure values had also been worked against the total weight (body weight and load) transporated by the subjects as these had seemed to be of greater in experiments reported by the authors (Datta *et al.* 1973) and had also been observed by Goldman and Iampietro (1962). Analyses of the present set of data revealed that such correlations were of the same order, viz., +0.81 to +0.92, as those between the loads alone and the energy expenditures and that taking into account the body weights also did not afford any advantage.

It was also thought useful to compare the observed values of energy expenditure with those obtained from the comprehensive predictive formula propsed by Givoni and Goldmen (1971), which takes into account the nature of the terrain, different walking speeds, loads and also the upward slope of path, along which the load is carried. The slope was zero and the terrain factor for concrete flooring on which the subjects walked was taken as 1, its nature being much the same as the walking surface of a treadmill for which unity was assigned as the value of the terrain factor. The calculated values were all markedly lower than the observed ones except those corresponding to the carriage of 0 and 20 kg loads at 3 kmph speed, where the observed values were slightly less than the calculated ones. According to the stipulations that the predictive formulae were to be used when the product of the external load (kg) and the velocity (kmph) was numerically less than 100, only the observed values of energy expenditure at 3 kmph for carrying 0, 20 and 30 kg at 3 kmph, those for carrying 0 and 20 kg at 4 and 5 kmph and the values for carrying no loads at 6 kmph speed could strictly be compared with the predicted ones. Even then, as already pointed out, except for the two values at 3 kmph mentioned above, the observed values were substantially higher than the pedicted ones and the magnitude of this difference rose with the rise in the walking speed. Givoni and Goldman had plotted the values of energy expenditures

in Kcal hr^{-1} kg^{-1} (body weight+load) against the speeds of carriage, giving a series of curves at different grades because of the exponential nature of the predictive formula. The corresponding observed values when plotted, lay above the curve for 0% grade (level ground) and were linearly disposed. There was thus no good reason for rssuming any non-linear relationship between the energy expenditure and either the load or the speed of carriage. The tacit assumption made by Givoni and Goldman about the constancy of the values in Kcal hr^{-1} kg^{-1}(body weight+load) at a given speed was also not correct as this value increased in small but definite amount with increasing amounts of load at the same speed.

Since the energy expenditures are clearly functions of both the external load carried and the walking speed taken individually, a combined expression was sought to be evolved for external load and speed of carriage, with which the energy expenditure varied in a regular manner. It was found empirically that the product of velocity in kmph raised to the power 2.3 and the external load in kg could be used as a combined expression. The results of plotting the energy expenditures in Kcals hr^{-1} against this function resulted in a paraboloid curve (Figure 3).

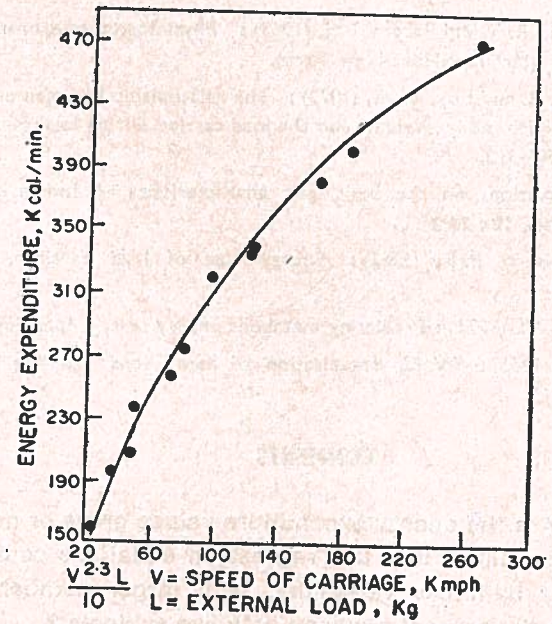


Fig. 3.

Figure 3 : Variation of energy expenditure in carrying loads with an empirical combined function of load and speed.

Since the energy expenditure tends to increase to a much greater extent by increasing the speed of cariage than by increasing the loads, this task should be carried out at as slow a speed as possible with as heavy a load as can be carried, so that manual carriage is economical regarding its monetary as well as physiological costs. There seems to be a dearth of research work in defining the reasonable upper limit of load for manual carriage in a given mode, from physiological standpoints. Nor is it possible to predict definitely from the present data how well the observed relationship holds for walking speeds much lower than those studied.

ACKNOWLEDGEMENT

The authors wish to acknowledge the kind encouragement by the Director, All-India Institute of Hygiene & Public Health, for the present study. They would also like to acknowledge the help received from Shri R. C. Datta, in statistical calculations.

REFERENCES

Consolazio, C. F., Johnson, R. E. and Pecora, L. J. (1963) : Physiological measurements of metabolic functions in man. (McGraw-Hill : New York).

Datta, S. R., Chatterjee, B. B. and Roy, B. N., (1973) : The relationship between energy expenditure and pulse rates with body weight and the load carried during load carrying on the level, *Ergonomics*, **16** : *507-513.*

Ganguli, S. (1973) : Observations on the basic gait characteristics of Indian industrial workers, *Indian J. Indust. Med.*, **10** : *28-35.*

Goldman, R. F. and Iampietro, P. F., (1962) : Energy cost of load carriage, *J. Appl. Physiol.*, **17** : *675-676.*

Givoni, B. and Goldman, R. F., (1971) : Predicting metabolic energy cost, *J. Appl. Physiol.*, **30** : *429-433.*

Sen, R. N. and Nag, P. K., (1975) : Work organisation of heavy load handling in India, *J. Human Ergology*, **4** : *103-113.*

COMMENTS

Dr. R. N. Sen : 1) Are the energy expenditure values gross or net ?
2) Don't you think that the regression equations could have higher predictability and less variability, with larger number of subjects, compared to the present study on only five subjects ?

Dr. B. B. Chatterjee : 1) Gross, (2) Yes, I do. But we wanted to use the same subjects for all the load-speed combinations.

Dr. S. N. Koyal : Have you ever calculated the ventilatory equivalent of oxygen for the loads ?

Dr. B. B. Chatterjee : No.

Dr. K. Kogi : It is known that people prefer to walk faster than the economic optimum determined by energy cost measurements. Do these people also prefer walking faster while carrying load than your recommendations ?

Dr. B. B. Chatterjee : Through personal observations of manual load carrying we feel that the preferred speed is around 5 kmph.

Mr. A. De : Does the 0_2 consumption vary according to load as well as speed for the age variations of the experimental subjects ?

Dr. B. B. Chatterjee : Not to such an extent as to interfere with the conclusion of this experiment where the energy cost was relatively high.

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 102-106, 1979

AN ERGONOMIC APPROACH TO THE DESIGN OF INDIAN HAND-PULLED CARTS (THELAS)

S. R. Datta and S. Ganguli*

Dept. of Physiological and Industrial Hygiene, All India Institute of Hygiene and Public Health, Calcutta-700 073, India

**Dept. of Orthopaedics, University College of Medicine, Calcutta University, Calcutta-700 006, India*

An investigation was undertaken on a group of cart-pullers and also on a small sample of carts to find out if there was any relationship between the dimensions of these two components of the resultant man-machine system. It has been observed that the height of the cart while pulling was not equal to the puller's centre of gravity level from the floor. In a loaded cart, the centre of gravity of the cart is likely to be raised by 10 to 12cm. This adjustment will bring the centre of gravity of the cart with the puller's centre of gravity.

The primary step in the design of a man-machine system is to ascertain the performance criteria, tasks and objectives of the system as a whole. However, unless the functional requirements of the machine component and the role, abilities and limitations of the human operator/user are studied separately and equally critically, the two constituent parts can never be married to each other to produce the desired results.

As far as the machine component is concerned, the following requirements are to be fulfilled :

i) It must perform, effectively, the function for which it is intended.

ii) It should be properly proportioned to the body dimensions of the operator/user. In suitably adjusted mechanical implements, the ratio of the external mechanical work done by the system as a whole to the total energy expenditure during any activity, characterizes the functional efficiency and should approach a maximum value.

Paper presented at the Fifth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

iii) It should be suitably adjusted to the strength and working capacity of the operator/user, which depend on the latter's age, sex, body build and training. The aim is prevention of premature fatigue.

iv) It must be adopted to the senses of the operator/user.

v) Its capital and operating costs should be low, but not too low to the extent of sacrificing performance.

Since majority of these requirements concern the human operator, he deserves more critical attention among the two components. As regards the human component, the most important are his energy cost aspects, which again are directly related to his anthropometric characteristics or body dimensions. The knowledge of various body dimensions is essential while designing man-machine combinations, not only for human comfort and efficiency, but also for effectiveness of the work output.

In India, the manually pulled hand-cart ('thela') is an age-old equipment for transportation of materials and goods. Its design is essentially the product of an agriculture-intensive rural civilization and is likely to have evolved by the process of trial and error.

The present investigation was undertaken with the object of ascertaining the relationships, if any, between the body dimensions of the cart-pullers and the dimensions of the cart and thereby identifying the folk norms for the design of such carts (Drillis, 1963).

MATERIALS AND METHODS

Anthropometric data were collected in a group of 50 normal, healthy, adult male cart-pullers-age (years): 31.3 ± 8.07 ; height (cm): 163.5 ± 5.06. The following measurements were taken by a steel tape :

Vertical (in the erect standing position with the right arm fully extended) :

y_1 = sole of foot to ankle joint ; y_2 = sole of foot to knee joint ; y_3 = sole of foot to the centre of gravity of the body (the anterior superier iliac spine was taken as the externally visible reference point for the body's centre of gravity) ; y_4 = sole of foot to shoulder joint ; y_5 = stature or full height ; y_6 = sole of foot to tip of middle finger of the fully extended right arm.

Horizontal (with both arms abducted by 90° to be in the horizontal plane) :

x_1 = length of foot ; x_2 = tip of extended middle finger of the hand to wrist joint ; x_3 = tip of extended middle finger of hand to elbow joint ; x_4 = tip of extended middle finger of hand to shoulder joint ; x_5 = tip of extended middle finger of hand to the sagittal plane ; x_6 = tip of extended middle finger of hand to opposite shoulder joint ; x_7 = tip of extended middle finger of hand to opposite elbow joint ; x_8 = total arm span, i. e., maximal horizontal distance across the tips of middle fingers of the extended arms.

RESULTS AND DISCUSSION

The means and standard deviations of the above mentioned vertical and horizontal dimensions are presented in the following Table :

Vertical (all dimensions in cm) :

	y_1	y_2	y_3	y_4	y_5	y_6
Mean	6.9	47.8	94.9	134.3	163.5	209.7
S. D. ±	1.2	3.1	4.1	5.4	5.1	6.2

Horizontal (all dimensions in cm) :

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
Mean	25.5	18.2	44.7	71.3	87.4	104.1	126.3	171.0
S. D. ±	1.8	1.4	1.8	3.3	3.4	4.6	3.3	2.6

The average dimensions of a standard handcart or 'thela' (sample size : 6) were measured to be as follows (all dimensions in cm) :

Length of the cart = 416.5 ; Maximum width = 80.7 ; Minimum width = 61.0 ; Total length of the horizontal bar in front of the cart = 42.2 ; Total diameter of the wheel = 114.3 ; Height of the cart while pulling = 83.0 ; Space in between the two wheels = 111.8 ; Width of the rim of the wheel = 11.9.

The approximate relationship between the dimensions of the puller's body and the cart were observed to be as follows :

i) Length of the cart = $2y_6$ = Twice the height with extended arm.

ii) Total length of the horizontal bar in front of the cart = $(x_6 - x_4)$ + 10 cm = Shoulder width + 5 cm clearance on either side.

iii) Height of the cart while pulling = y_3 − 12 cm = height of the centre of gravity of a standing man less adjustments for downward displacement of the C. G. of the cart with load on.

y_6 renders maximum occupation of space by the body in the vertical dimension of elements in buildings for human use (Ahluwalla, 1970). Application of this dimension has also been advocated by Le Corbusier (Corbusier, 1951) in his system of human proportions which he had named 'Modulor'. Therefore, the relatioship between y_6 and the length of the cart may be explained as a manifestation of the aforesaid folk norm system.

The second relationship. given above, is easily understood and needs no special explanation.

The third relationship confirms one of the most fundamental principles of biomechanics and ergonomics. It is known that the energy cost of any human activity is directly proportional to the displacements of the body's centre of gravity in different planes. The greater the displacements, the higher are the energy costs. Therefore, in man-machine systems, the height of the resultant centre of gravity should be as close to the height of the centre of gravity of the human body components from the floor as possible. Interestingly the design of the implements for human use, evolved through ages, have inadvertently taken care of this principle. An investigation of flax (i. e., plant grown for its textile fibre and its seeds) scutching (Drillis, 1935) reported that the optimum (displaying 100 per cent efficiency) board height was found to be equal to 57 per cent of the operator's height. This was in very close agreement with the established folk norm of it - ten fists. At the same time, this height was also observed as very close to the height of the centre of gravity of the operator's body, which may vary between 56 and 61 per cent of the height. Board which were 10 cm higher or lower appeared to decrease the work efficiency up to 20 per cent. Another investigation on the scythe (Drillis, 1963) which serves for cutting grass and dry stalks of crops, led to similar observations. The lower grip is so fixed that it reaches the level of the anterior superior iliac spine or is ten hands or ten fists from the base of the scythe which is again equivalent to 57 percent of the operator's height, that is, height of his centre of gravity from the floor. As a matter of fact, some indications in the direction that the angular momentum of the entire body about its common centre of gravity decreases when the body segment are closer to the C. G. were given by Fischer (1906) and Elftman (1939).

In view of the above, it was considered quite likely that there may exist some relationship between the height of the cart, while pulling, and the puller's centre of gravity level from the floor. The present analysis has identified this relationship. It has been noted here that the height of the cart, while pulling, is not equal to the puller's centre of gravity level from the floor. The observed adjustment by 12 cm may be explained by the fact that in a loaded cart, the centre of gravity of the cart is likely to be raised by 10 to 12 cm thus being coplanar with the puller's centre of gravity. Further detailed investigations may confirm it.

CONCLUSION

The present investigation has indicated the existence of relationships between the body dimensions of Indian cart-pullers and the dimensions of the hand-pulled Indian carts (**'thela'**). The folk norms which might have been used in the design of such carts, have also been identified.

REFERENCES

Ahluwalla, J. J. S (1970) : The system of proportions. *Japan Architect*, November, pp. *103-109*.

Corbusier, Le. (1951) : *The Modulor*. Faber and Faber, London, 2nd Edition.

Drillis, R. (1935) : Flax precessing (in Latvian), *Latvian Encyclopaedia*, Riga, **12** : *23644-23661*.

Drillis, R. J. (1963) : Folk norms and biomechanics. *Human Factors*, **5** : *427-441*.

Elftman, H. (1939) : The rotation of the body in walking. *Arbeitsphysiologie*, **10** : *477-484*.

Fischer, O. (1906) : *Theoretische Grundlagen fur cine Mechanik der lebenden Korper*. B. Teubner, Leipzig.

COMMENTS

Dr. J. N. Mukherjee : Does altered posture modify relationship between the height and length of the puller ?

Dr. S. Ganguly : It does. That is why for their particular man-machine system an adjustment has been made in the following manner : Working height of the cart without any load on = Height of the centre of gravity of the puller from the floor-12 cm.

Dr. S. K. Guha : How does your design differ from the conventional 'Thelas' ?

Dr. S. Ganguly : The investigation was conducted on conventional 'Thelas' only. Samples of 6 thelas were picked up from the street for taking measurements. We have not made any new design.

Mr. A. De : I think, the design of the cart should be made to avoid the injury of the testis down and the heart above. Do you justify ?

Dr. S. Ganguly : This aspect has not been looked into in our investigation. However, it might be interesting to study this aspect in our future work on the subject.

Dr. R. N. Sen : 1) Have you actually determined the centre of gravity in these 50 subjects while standing ?

2) What is the variability in the measurements of the carts studied ?

Dr. S. Ganguly : 1) Yes ; 2) Sample size was 6 ;

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 108, 1979

EFFECT OF ALTITUDE ON GENERAL COLD ACCLIMATISATION*

C. S. Nair, P. M. Gopinath, O. P. Tiwari and A. Das Gupta

Physiology Research Cell, R & D Organisation, Ministry of Defence, Darjeeling, India

Effect of simultaneous acclimatisation to altitude and cold and altitude alone at 3300 m on general cold acclimatisation was studied for 6 weeks on 20 human subjects who had never been to altitude. The findings indicated that simultaneous acclimatisation to altitude and cold was advantageous rather than stress-wise acclimatisation. Cold tolerance and cold acclimatisation were neither inhibited nor delayed if human subjects were forced to acclimatise to both the stress simultaneously from the day of their arrival at altitude. Cold acclimatisation after hypoxia acclimatisation did not offer any advantage over simultaneous acclimatisation to altitude and cold on human subjects at 3300 m. The native high landers of 3300 m maintained a lower peripheral and a higher core temperature in contrast to natives of Andes (4500 m) who exhibited a lower core and higher peripheral temperature.

Paper presented at the Sixth Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received**

CARDIO-PULMONARY RESPONSES TO EXERCISE DURING ACCLIMATIZATION TO ALTITUDE AND COLD*

C. S. Nair, P. M. Gopinath and Jaishankar

Physiology Research Cell, R & D Organisation, Ministry of Defence, Darjeeling, India

Effect of simultaneous acclimatisation to altitude and cold and altitude alone at 3300 m on 20 human subjects who had never been to altitude was studied for six weeks. Cardio-pulmonary response to submaximal exercise was used as a test to assess the degree of tolerance/acclimatisation to altitude. The findings indicated that simultaneous acclimatisation to altitude and cold was advantageous rather than stress-wise acclimatisation. Cold stress did not affect altitude tolerance or acclimatisation. In stress-wise acclimatisation, viz., when subjects were acclimatised first to altitude and then to cold, a reduction in altitude tolerance was observed on superimposition of cold stress. Moderate physical training and acclimatisation at 3300 m for six weeks did not improve the physical performance on return after sojourn at sea level. Simultaneous acclimatisation to altitude and cold at 3300 m made the subjects better suited for higher altitude. The probable explanation for these findings are discussed.

Paper presented at the Sixth Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received**

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 109, 1979

EFFECT OF PHYSICAL TRAINING AT 1800m ON CRITICAL FLICKER FREQUENCY (CFF) IN MAN*

C. S. Nair, P. M. Gopinath and C. M. Kumar

Physiology Research Cell, R & D Organisation, Ministry of Defence, Darjeeling, India

Critical Flicker Fusion Frequency (CFF) was recorded on 24 young soliders of 22-26 years age at 740m (Delhi) and at simulated altitudes of 2100m and 3300m in a chamber. After these measurements the subjects were taken to 1800m and CFF was recorded. They were divided into two groups. One group was given intense physical training and the other group moderate physical training for six weeks. During this period the CFF was recorded at regular intervals. They were then taken back to Delhi where CFF was again determined. Results indicated that intense physical training restored deterioration in CFF ; in fact they showed a statistically significant improvement on re-test at sea level (Delhi). The improvement of CFF may be taken as improvement in the mental functions of the individual to physical training at altitude. Moderate physical training at 1800m also restored the deterioration in CFF but the process was delayed and the re-test values did not show significant improvement over the initial values. Possible causes are explained.

Paper presented at the Sixth Session of the International Satellite Symposium on Work Physiology and Er gonomics held at Calcutta from 1 - 3 November, 1974. *Full paper not received

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 110-117, 1979

CAUSES OF LOW RESPIRATORY SENSITIVITY TO HYPOXIA IN HIGHLANDERS

Haripada Chattopadhyay and Debendra Nath Sarkar

Department of Physiology, Presidency College, Calcutta-700 073, India

The mechanism of the physiological adaptation of the native highlanders, is not yet fully understood. This peculiarity of the highlanders, like the Sherpas of the Himalayas, may have occurred either due to a genetic mutation or a genotypic selection, or due to an adaptive modification of the respiratory control system of the body on account of the continued hypoxia in the uterine and postnatal developemental phase.

Sherpa highlanders were divided into five groups on the basis of the altitude of the place of their birth.

Ventilatory response to hypoxia and hypercapnia produced by breathing different gas mixtures containing varying proportion of oxygen, carbon dioxide and nitrogen, were studied in all the groups including a control group of lowlanders of a different genetic type. It was found that the peculiar blunted response to hypoxia was markedly present only in the first group born at 4000 m. In the second group born at about 2,700 m., this insensitivity was appreciably present, but not to the extent of the first group. But there was no significant difference between the ventilatory responses of the other groups. This indicates that the respiratory peculiarity of the Sherpa highlanders is of developmental origin.

Though many physiological effects of high altitude on human subjects have been established during the last few decades and a few comparative studies have been made on the lowlanders and the highlanders both in the Himalayas and in the Peruvian Andes, still there are many unsolved problems in the physiology of acclimatization and adaptation to high altitude. The most fascinating problem in high altitude physiology is the mechanism by which the native highlanders of the Himalayas and the Andes develop natural acclimatizarion, which allows them to work and live in the hypoxic environment of the high altitude with greater ease. The blunted ventilatory response to hypoxia of the Himalayan highlanders (Sherpas) has been investigated by Milledge and Lahiri (1967). They found that the ventilatory response of the

---

Paper presented at the Sixth Scientific Session of the International Satellite Symposium cn Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

highlanders to hypoxia was considerably less than that of the lowlanders. Lefrancois *et al.* (1968) observed a low hypoxic drive to ventilation in resting highlanders at altitude in Bolivia. Lahiri *et al.* (1969) also found that lifelong hypoxemia is associated with a low ventilatory response to acute hypoxemia and supported the hypothesis that lifelong hypoxemia may contribute to the blunted sensitivity to hypoxia in highlanders, due to the underdevelopment of the chemo-receptor mechanism in them. These observations suggest the interesting possibility that adaptation in early post-natal period may be the crucial phase in natural anatomical and physiological development patterns and response characteristics of individuals. The other possible explanation of this peculiarity of the highlanders is that this may have occurred due to a genetic mutation or a genotypic selection. The present study was undertaken to find an answer to this problem whether the low respiratory sensitivity to hypoxia observed in the highlanders is genetically determined or is an adaptive response to hypoxia in postnatal development.

MATERIALS AND METHODS

The work was carried out mainly on Sherpa subjects born at different altitudes of the Himalayan region. The subjects were divided into the following groups on the basis of the altitude of the place of their birth, as follows :— (I) Sherpa highlanders born and raised during the early period of their lives in an altitude of about 4,000 m. (II) Sherpa highlanders born and raised at 2,700—3,000 m. (III) Sherpas born and raised at about 2,000 m and (IV) natives (Nepalese) of Himalayan foot-hills, who were born and raised at about 1,000 m. (V) Sea-level dwellers (Bengalees). Most of the altitude natives were of the well-known Sherpa stock (Tibetan-Nepalese). Some of the high altitude Sherpa subjects of the first group were well known mountaineers. All bjects studied were healthy and most of them had experience in mountain climbing.

The ventilatory response to hypoxia and hypercapnia was measured by the steady-state technique of Lloyd, Jukes and Cunningham (1958) as well as by the transient response to three breaths of pure nitrogen ("Nitrogen Test") technique of Dejours (1962). The steady state effects of various levels of PAO_2 and $PACO_2$ on ventilation was determined by giving the subjects a particular gas mixture to breathe until a steady ventilation was achieved ; end-tidal samples were then collected and the minute ventilation was determined. Each subject was seated at rest for ten minutes, prior to each experiment. A mouth piece and a noseclip was used. His pulse rate and respiration rate were noted. The vital capacity and breath-holding time of the subject were also determined after necessary rest in three different observations on a separate day and the mean values were calculated. The subject was allowed to breath through a Lloyd valve which was coupled with a Rahn-Otis end-tidal sampler. For the "N_2 test" experiments, the subject was allowed to inhale three breaths of pure nitrogen which produced a transient change in PAO_2. This was repeated at three minutes intervals, and after each breath, an alveolar gas sample was collected and analysed. All gas analyses were done by using a Lloyd-Haldane gas analyser. Most of the experiments with Sherpa highlanders were done at the Physiology Research Cell Laboratory at the Himalyan Mountaineering Institute, Darjeeling (2000 m). Studies on sealevel subjects were done at Calcutta.

RESULTS AND DISCUSSION

Table 1 shows some of the common physiological parameters like vital capacity, breathholding time, resting pulse rate and resting respiration rate of the different groups of subjects. Table 2 shows the resting PAO_2, $PACO_2$ and VE of the groups. There is no significant difference in the vital capacity of the subjects in the different groups. However, the high altitude natives of Group I have the maximum breath-holding capacity and it is significantly different from that of Group III. There is no significant difference in the pulse rate between the groups. The respiration rate is lowest in Group I. The

Table I

Comparison of some physiological parameters (mean ± S.D.) in different groups (N = no. of subjects)

Groups	Characteristics	Pulse Rate (Resting) per minute	Respiration Rate (Resting) per minute	Vital Capacity (l)	Breath-holding Time (Seconds)
Group I (N=5)	Sherpa Natives born at 4,000 m.	68 ± 2.45	14.4 ± 1.67	4.23 ± 0.18	124 ± 9.71
Group II (N=4)	Sherpa Natives born at 2,700 m.	73 ± 6.21	17.00 ± 1.15	3.55 ± 0.29	93.50 ± 16.42
Group III (N=9)	Sherpa Natives born at 2,000 m.	69 ± 5.74	17.55 ± 1.33	4.01 ± 0.49	82.55 ± 13.66
Group IV (N=3)	Himalayan Natives born at 1,000 m.-1,300 m	70 ± 2.00	18.00 ± 2.00	3.66 ± 0.10	59.66 ± 4.72
Group V (N=6)	Sea-level lowlanders (Bengalees)	71 ± 8.73	16.16 ± 0.98	4.16 ± 0.68	68.83 ± 14.33
Comparing Gr. I and Gr. III		N. S.	P<1%	N. S.	P<0.1%
Comparing Gr. III and Gr. V		N. S.	P<5%	N. S.	N. S.

resting PAO_2 is the lowest in Group I, and is significantly lower than all other groups. Similarly the resting $PACO_2$ is also significantly lower in Group I than in Group III. The pulmonary minute ventilation is also significantly lower in Group I than in Group III.

Table 2

Comparison of some common respiratory parameters (mean ± S.D.) in different groups (N = no. of subjects)

	Resting PAO_2 (mm. Hg.)	Resting $PACO_2$ (mm. Hg.)	Resting VE (l./min BTPS)
Group I	104 ± 1.43	32 ± 0.93	11.9 ± 0.52
Group II	116 ± 2.03	36 ± 2.87	13.8 ± 4.81
Group III	115 ± 9.01	41 ± 3.18	16.1 ± 3.59
Group IV	112 ± 0.65	39 ± 1.54	15.6 ± 0.30
Group V	125 ± 6.39	43 ± 1.53	12.4 ± 2.56
Comparing Gr. I/Gr. III	P<1%	P<0.1%	P<1%
Comparing Gr. III/Gr. V	P<2.5%	N. S.	P<5%
Comparing Gr. II/IV	P<2.5%	P<0.1%	N. S.

Steady state measurements of ventilatory sensitivity to hypoxia in the different groups are shown in Figure 1. Ventilation (VE l/min BTPS) has been plotted against $PACO_2$ at three levels of PAO_2. Comparing the hypoxic responses of the different groups, it is found that the response slope ($VE/PACO_2$) is the least in Group I. The response slope in Group I is significantly less than in Group II. But comparing the response slope in Group I with those of Group III, Group IV and Group V, the difference is much more striking. From these data it can be observed that of all the groups studied, the Group I, *i. e.*, the highlanders born at 4000 m, are the least sensitive to hypoxia. Although the distrinctly blunted response to hypoxia is found in Group I, there is an appreciable blunted response to hypoxia in Group II also. The behavior patterns of the other groups are not significantly different from one another. When the ventilation values were plotted against the PAO_2 values (Figure 2) the rise in ventilation due to alveolar hypoxia is again found to be lowest in the highlanders of Group I, at the different levels of hypercapnia. In this case also the subjects of Group II show a similar trend as those of Group I, though to a small extent only. The difference between the other groups are not

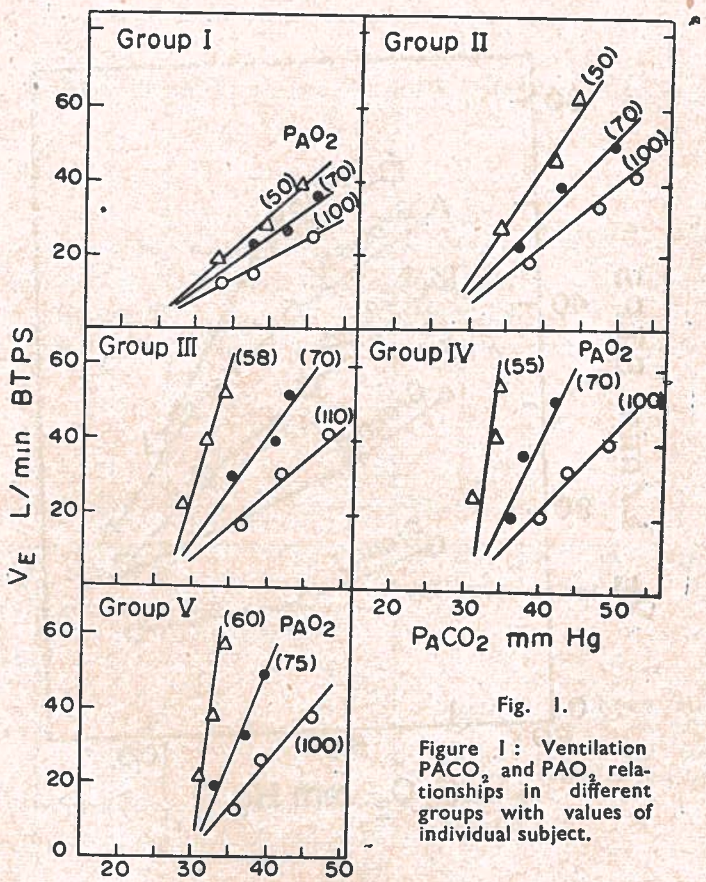


Fig. 1.

Figure 1 : Ventilation $PACO_2$ and PAO_2 relationships in different groups with values of individual subject.

always significant. When the transient hypoxia is produced by the inhalation of pure nitrogen in the so-called "N_2 test" and the fall of PAO_2 in the three consecutive breaths are plotted, the results are also similar. It was observed that Group I subjects behaved differently from the other groups. In this case also the difference between the response curves of Group I and Group II subjects is the minimum (Figure 3).

These results again confirm the previous findings of earlier workers that the Sherpa highlanders who were born at about 4000 m or above have a distinctly blunted sensitivity to hypoxia. The second conclusion which may be made is that the blunted hypoxia is not likely a genetic characteristic but is probably due to a developmental cause. The subjects of Group I, Group II and Group III, though belong to the same Sherpa stock, but were born and raised at different altitude, show different respiratory behaviours. The subjects

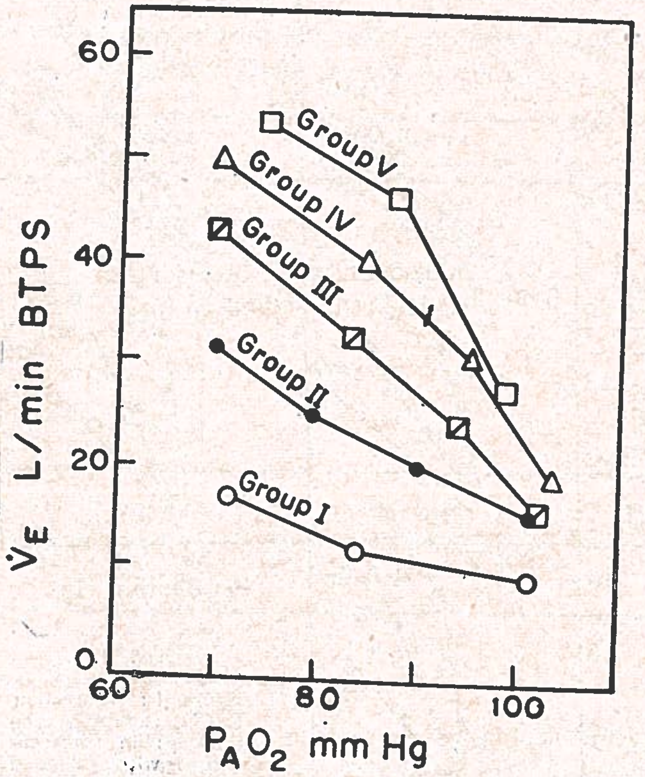


Fig. 2.

Figure 2 : Ventilation and PAO_2 relationships in different groups.

of Group II, who were born at 2,700 m, shows a perceptible insensitivity to hypoxia, though not to the extent of Group I, whereas, the subjects of Group III behave in the same way as the subjects of Group IV and Group V, in their respiratory responses to hypoxia. From the results it seems probable that the blunted response to hypoxia is developed in persons born at an altitude of 2,500 m or above, and the degree of the insensitivity is proportional to the altitude of birth above that threshold, and is not dependent on genetic factors.

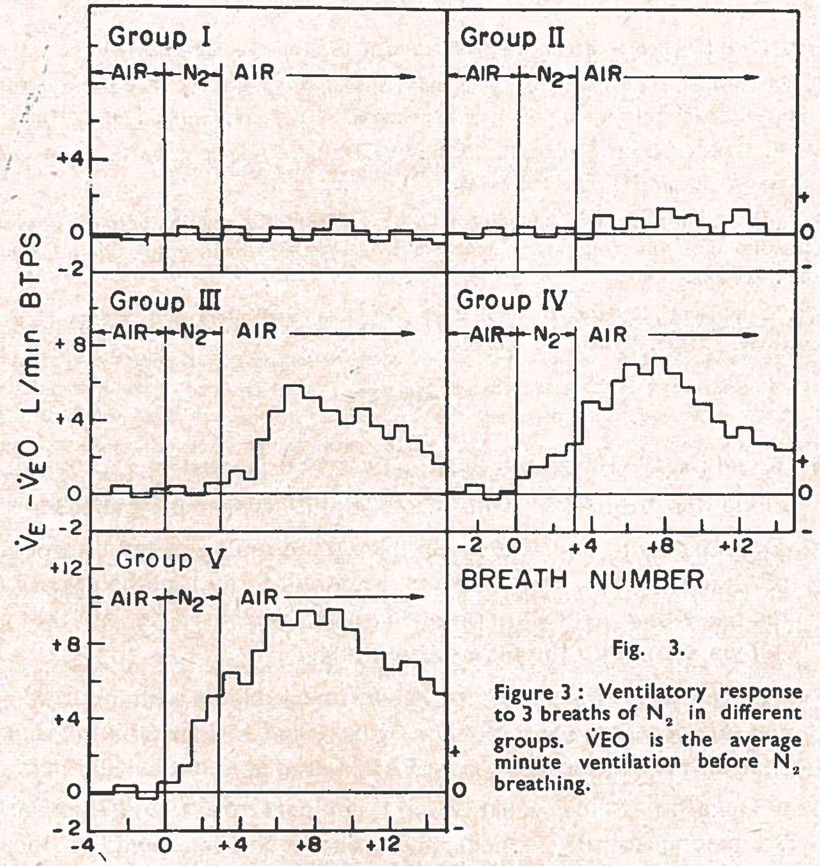


Fig. 3.

Figure 3 : Ventilatory response to 3 breaths of N_2 in different groups. $\dot{V}EO$ is the average minute ventilation before N_2 breathing.

ACKNOWLEDGEMENT

The authors are grateful to the Indian Council of Medical Research, New Delhi, for a financial grant which made this study possible. They are also indebted to Group Captain B. Bhatia, the then Director of Basic Research Laboratories, Ministry of Defence (R & D), Government of India, for kind permission to work in the Physiology Research Cell at the Himalayan Mountaineering Institute, Darjeeling, West Bengal. They also gratefully acknowledge the help and co-operation of Dr. D. P. Chattopadhyay and Mr. C. S. Nair, Officers-in-Charge, Physiology Research Cell, Darjeeling, during the different periods of the work. Above all, the authors are grateful to the Sherpa subjects who volunteered themshelves for this work and specially the Sherpa Instructors of HMI, Darjeeling.

REFERENCES

Dejours, P. (1962) : Chemoreflexes in breathing. *Physiol. Rev.* **42** : *335-358.*

Lahiri, S. Edelman, N. H., Cherniack N. S. and Fishman, A. P. (1969) : Blunted hypoxic drive to ventilation in subjects with life-long hypoxemia. *Fed. Proceed.*, **28** : *1289-1295*.

Lefrancois, R., Gentier H. and Pasquis, P. (1963) : Ventilatory oxygen drive in acute and chronic hypoxia. *Respir. Physiol.* **4** : *217-228*.

Lloyd, B. B., Jukes, M. G. M. and Cunningham, D. J. C. (1958) : The relation between alveolar oxygen pressure and the respiratory response to carbon dioxide in man. *Quart. J, Exptl. Physiol.* **43** : *214-227*.

Milledge, J. S. and Lahiri, S. (1967) : Respiratory control in lowlanders and Sherpa highlanders at altitude. *Respir. Physiol,*, **2** : *310-322*.

COMMENTS

Dr. S. N. Koyal : (1) Have you done any Dejour's test ? (2) What is the slope for $\dot{V}E/PACO_2$ with hypoxic and hypercapric gases?

Dr. H. Chattopadhyay : (1) Yes ; we have done the so called "Nitrogen test" of Dejour where the subjects breathed three breaths of pure N_2 and the transitory hypoxia produced were measured in all the groups. But we did not do the pure oxygen test.

(2) The slope for the $\dot{V}E/PACO_2$ for the subjects with induced hypoxia and hypercapnia were 1.02 for Group I and 1.64 for Group II and above 3 for all the other groups, at a PAO_2 value of about 55-60 mm of Hg.

Dr. Subhas Mukerji : Since your Group I subjects are the most experienced and belong to the highest age-group including some of the world renowened Sherpas, the difference observed by you may be due to experience and training.

Dr. H. Chattopadhyay : We do no think the greater period of training of the Group I subjects would make any significant difference. Besides, they are also the oldest of the lot, and should have some handicaps due to aging. This would nullify what ever advantages they might have on account of longer period of experience in mountain climbing.

Dr. P. R. M. Jones : How do you know what constitutes an environmental difference unless you take the group out of their habitual environment and study them elsewhere after, of course, required acclimatisation.

Dr. H. Chattopadhyay : We studied them all at Darjeeling, where laboratory facilities were available. There is some difference in temperature and barometric pressure between their habitats and Darjeeling.

Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 118 - 121, 1979

RESPIRATORY SENSITIVITY TO CARBON DIOXIDE IN MAN AT REST AND WORK

Ashis Sinha and Haripada Chattopadhyay

Department of Physiology, Presidency College, Calcutta-700073, India

The alveolar tension of carbon dioxide ($PACO_2$) and carbon dioxide sensitivity were determined in persons living at sea-level and at medium altitude after they inhaled different amounts of carbon dioxide diluted with oxygen and nitrogen. In both the groups the sensitivity was less at lower $PACO_2$, attained the maximum value at a certain range of $PACO_2$ and then with increasing $PACO_2$ declined again. The sensitivity, however, was maximum in the $PACO_2$ range of 37–40 mm of Hg in the medium altitude subjects and in the $PACO_2$ range of 41–45 mm of Hg in the sea–level subjects. The implications of these changes have been discussed.

It is well known that over a certain range of the alveolar tensions of carbon dioxide ($PACO_2$), the pulmonary ventilation ($\dot{V}E$, BTPS) varies linearly with $PACO_2$. Lloyd *et al.* (1958) found a method to determine the value of the lower CO_2 threshold of Nielsen and Smith (1951) below which this linearity does not hold and observed that the threshold was almost identical with the resting $PACO_2$ in adult subjects. The present study is related with the ventilation-$PACO_2$ line and carbon dioxide sensitivity and threshold derived from that line at different ranges of $PACO_2$.

MATERIALS AND METHODS

Sea-level (Bengalee) and medium altitude (Sikkimese) male subjects, fasting for four hours, were given gas mixtures containing different amounts of CO_2 diluted in 44% O_2 and N_2 to inhale. At a steady-state ventilation, obtained after 10 minutes of inhalation, Rahn-Otis end-tidal samples were collected. Simultaneously the pulmonary ventilation was measured by collecting the expiratory air for a timed period and the minute ventilation ($\dot{V}E$, BTPS) was determined. The end-tidal samples were subsequently analysed in a Lloyd-Haldane gas analyser (Lloyd, 1955). $\dot{V}E$, BTPS was then plotted against the corresponding $PACO_2$ and the neighbouring points so obtained were connected by straight lines. The CO_2-sensitivity at a certain range of alveolar $PACO_2$ was obtained by measuring the slope of the straight line obtained at the range of $PACO_2$ in question and the threshold by extrapolating the CO_2-response curve at the same range of $PACO_2$ to the $PACO_2$ axis Lloyd *et al.*, (1958).

Paper presented at the Sixth Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

RESULTS AND DISCUSSION

In both groups of sea-level and medium-altitude subjects the sensitivity was less at lower $PACO_2$, attained the maximum value at a certain range of $PACO_2$ and then with increasing $PACO_2$ declined again. The only difference between the groups, however, lay in the range of $PACO_2$ where the sensitivity was maximum. This range was from 37-40 mm Hg $PACO_2$ in the medium altitude subjects and from 41-45 mm Hg $PACO_2$ in the sea-level subjects (Tables 1 and 2).

Table I

CO_2 sensitivity at different ranges of $PACO_2$ (at sea-level) in sea-level subjects.

Subjects	Ranges of $PACO_2$ (mm Hg)	CO_2 sensitivity l/mm Hg. $PACO_2$
1	34 - 41	1.33
	41 - 45	1.83
	45 - 62	0.50
2	37 - 41	2.12
	41 - 45	4.89
3	37 - 41	2.15
	41 - 45	5.25
4	36 - 39	0.56
	43 - 45	5.42
5	36 - 39	0.39
	43 - 45	10.00

Table 2

CO_2 sensitivity at different ranges of $PACO_2$ (at sea-level) in medium altitude subjects.

Subjects	Ranges of $PACO_2$ (mm Hg)	CO_2 sensitivity l/mm Hg. $PACO_2$
6	33 - 36	1.15
	37 - 41	2.12
	44 - 49	1.56
7	37 - 41	2.50
	41 - 44	1.31
	44 - 49	1.75
8	33 - 35	0.03
	35 - 37	1.00
	37 - 41	1.56
	41 - 43	1.36
	43 - 50	0.83

The claim of Nielsen and Smith (1951), and many others subsequently, that the CO_2 response curve assumes linearity above the lower threshold implies that the respiratory mechanism shows maximum sensitivity just after crossing the zero level. But a gradual rise to a maximum value to be followed by a fall, as suggested by the present findings, seems more physiological.

This has some applied implications, as well. Previously (Lahiri *et al.*, 1967) we observed that the value of the Co_2 threshold (B) went far below the resting $PACO_2$ in younger subjects if B was determined from the intercept made by the average CO_2 response curve on extrapolation on the $PACO_2$ axis as per usual practice. This gap between B and the resting $PACO_2$ was a physiological impossibility resulting from the wrong assumption that the CO_2 sensitivity could be same at all ranges of $PACO_2$. The CO_2 sensitivity at younger ages was in fact, very low at lower ranges of $PACO_2$ over the threshold as against its high value at higher ranges of $PACO_2$. The artefact gap between B and the resting $PACO_2$ in younger subjects, however, disappeared when the CO_2 response curve obtained in the $PACO_2$ range of maximum sensitivity was extrapolated to the $PACO_2$ axis (unpublished). To extrapolate the CO_2 response curve obtained only in the $PACO_2$ range of maximum sensitivity to the $PACO_2$ axis would, therefore, be a better method than the usual practice for drawing the CO_2 response curve for the purpose of comparison of parameters like CO_2 threshold and CO_2 sensitivity between subject groups like males and females, aged or young etc. or of the same subject group under different conditions like exercise and rest.

The difference between the sea-level and medium-altitude subjects with regard to the range of $PACO_2$ of maximum CO_2-sensitivity was consistent with the lower value of the resting $PACO_2$ and CO_2 threshold in medium-altitude subjects. The medium altitude subjects were well acclimatised at sea-level, since their stay at sea-level, interrupted only by a very few occasional visits to their homeland, varied from one to six years. The variation noted above between the groups was thus beyond the scope of acclimatisation. It might be genetically inherited or acquired over years of exposure to the environments of the medium altitude at the early infancy.

The data corroborate with the previous observation that there is a variation in CO_2 sensitivity among different groups of people in the different regions of the world (Sinha and Chattopadhyay 1967).

ACKNOWLEDGEMENT

The authors are thankful to the subjects for excellent co-operation.

REFERENCES

Lahiri, S., Chattopadhyay, H. P., Sinha, A. and Karmakar, P. C. (1967): Respiratory response to carbon dioxide in man. *Nature,* **213** : *393-394.*

Lloyd, B. B. (1955): A development of Haldane gas analysis apparatus *J. Physiol.,* **143** : *5p-6p.*

Lloyd, B. B., Jukes, M. G. M. and Cunningham, D. J. C. (1958): The relation between alveolar oxygen pressure and the resiratory response to carbon dioxide in man. *Quart. J. exp. Physiol.,* **43** : *214-227.*

Nielsen, M. and Smith, H. (1951): Studies on the regulation of respiration in acute hypoxia. *Acta Physiol. Scand.,* **24** : *294-313.*

Sinha, A. and Chattopadhyay, H. P. (1967): Effect of age on respiratory reactions to carbon dioxide in man. *Proceed. 54th Ind. Sci. Cong.,* Part **III** : *570-571.*

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 122-127, 1979

ERGONOMIC COST OF SOME HEAVY MANUAL WORK IN BENGAL

Pranab Kumar Nag and Rabindra Nath Sen

Ergonomics Laboratory, Department of Physiology, University Colleges of Science, Technology and Agriculture, Calcutta University, 92, A. P. C. Road, Calcutta 700 009.

Energy intake and energy expenditure of some heavy manual workers in West Bengal were determined. Anthropometric characteristics of the subjects were also recorded.

The anthropometric surveys showed that the groups of under-fed people covered in the study were not strikingly different from the other adequacely nourished people. However, meso-ectomorphic component was predominant in them and there were tendencies of not loosing body weight, although some workers reduced 4 to 6% of their body weights within about 2 years.

Daily energy intake of the workers of the differnt groups were as follows: load handlers-3580 Kcal; Agricalture labourers-2990 Kcal; workers in cottage industries-2840 Kcal and those of printing industriy-2210 Kcal. Relatively higher energy expenditures were noted in load handlers and agricalture laboures as compaeed to the other groups of workers. In about 75% of the workers, the energy intake was deficient but the workers could maintain their reasonable speed of work and sustain the anthropometric and muscular abilities for years. This might be due to nutritional adaptation and capability for energy balance over long periods.

Knowledge about the energy metabolic status of population groups has fivefold practical applications in (i) providing a basis for dietary recommendations, (ii) judging suitability of a task in relation to the capacity of the worker and so matching a man for recruitment to work and *vice versa,* (iii) restructuring the work-rest pattern suitable for the working day, (iv) scheduling the tasks over the work shift to minimise fatigue, and also (v) fixing wage policies according to the heaviness of jobs. Therefore, so long as the situation of human employment prevails, measurements of energy intake and expenditure would continue to interest Applied Ergonomists for ensuring the cost-effectiveness of the working class.

The present study deals with the questions relating to the metabolic balance and growth maintenance of the workers in an unorganised working

Paper presented at the Seventh Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

class. The study also aims at relating the food procuring ability with the work performance and sustenance of the bodily status of workers.

MATERIALS AND METHODS

One hundred and ninety six subjects (age ranges between 19 to 40 years), representing 1100 members in 18 localities of the eastern part of the country, were covered under the study, 22% of the sample was constituted by rural-based load handling workers, 14% by cottage industrial workers like conchshell artisans and handloom workers, 11% by moderate industrial workers like those of printing industry, while as large as 53% of the consisted of sample landless labourers essentially maintaining agricultural life. Anthropometric characteristics of the subjects were recorded by standard techniques (Sen 1964 ; Sen *et al.*, 1977).

Detailed occupational and leasuretime activities of the subjects were recorded by the diary technique and time and motion study. Energy expenditure of work operations were measured in 56 workers using traditional open-circuit technique ; the working day and 24 hours' energy expenditures were obtained (Sen, 1960). The food procuring abilities and the foodstuff consumed by the workers were recorded with the help of questionnaire and individual food-weighing techniques.

RESULTS AND DISCUSSION

The anthropometric dimensions of the workers are presented in Table 1.

Table 1

Percentile distribution of anthropometric dimensions of unorganised workers (N=196)

Dimensions	PERCENTILES 5th	25th	50th	75th	95th
Age (years)	14.5	16.8	20.5	25.6	36.7
Body weight (kg)	35.7	41.1	45.9	49.7	56.9
Lean body weight (kg)	34.5	40.3	43.8	46.2	49.4
Body height (cm)	150.8	156.6	161.5	165.5	171.9
Biceps skinfold (mm)	2.1	2.8	3.2	4.2	5.4
Triceps skinfold (mm)	3.5	4.3	5.2	6.3	10.0
Sub-scapular skinfold (mm)	4.6	5.8	6.9	8.4	11.9
Supra-iliac skinfold (mm)	3.0	3.9	4.7	6.1	11.2
Thigh skinfold (mm)	3.9	5.3	6.5	8.4	11.9
Radio-ulnar bone diameter (cm)	4.6	5.0	5.3	5.6	6.4
Olecranon diameter (cm)	6.7	7.3	7.7	8.1	9.5
Epicondylar diameter (cm)	8.3	9.0	9.3	9.8	10.0
Acromial height (cm)	123.1	128.6	133.2	137.8	142.3
Mid-arm circumference (cm)	19.3	21.3	22.5	23.7	26.0
Mid-thigh circumference (cm)	35.4	38.8	41.4	43.2	45.5
Chest (mid-tidal) circumference (cm)	71.5	75.5	78.7	81.6	85.8

Energy expenditures of the occupational groups, are presented in Table 2. Relatively higher energy expenditures were noted for the load handling and agricultural workers for 8 hours working day as well as for 24 hours during the working seasons. The physiological demand of agricultural workers during off-seasons are not known. Moderate industrial workers are subjected to less work-load compared to other groups (Banerjee *et al.*, 1959 a, b ; Sen *et al.*, 1964 a, b'. Average energy intake of the load handlers was found to be 3580 kcal, while corresponding values for the cottage industrial workers, moderate printing industry workers, and agricultural workers amounted to 2840, 2210 and 2990 kcal respectively. As indicated earlier (Nag *etal.*, 1978), the 75th percentile value of energy intake was 2730 Kcal. They consume mostly carbohydrates, the cheapest of the proximate principles, with low amounts of costlier animal proteins and fats. 75th percentile values for the total protein, proteins from animal sources and fats comsumed were only 87, 14 and 53 gm respectively. Protein is largely obtained from foods with high carbohydrate contents. Energy equivalent of the oxygen consumption for one litre volume for the groups always amounted to more than 5 Kcal, clearly indicating the major contribution of carbohydrates in their energy supply. Workers take a large quantity of rice with some salt and a piece of dried fish and sometimes, mixed vegetables. Occasionally they resort to fishing and may supplement their diets with a small quantity of animal protein. Absolute food procurements in terms of nutritive values are more or less similar among the unorganized sectors in different parts of the country (Nag *et al.*, 1978). However, differences in food habits were noted due not only to the economic reasons but also to religious and sectarian reasons. Tribal groups of the interior villages go for hunting, at least once or

Table 2

Energy intake and expenditure of some occupational groups from unorganised sectors

Occupational groups	Energy Intake	Energy Expenditure 24 hrs	8 hrs
Load handlers			
(i) short distance	—	3320	1900
(ii) intermediate distance	3580	—	2260
(iii) long distance	2980	2930	1725
Cottage industry	2840	2780	1560
Printing industry	2210	2240	1430
Agricultural workers	2990	3070	2120

twice in a month and consume a considerable amount of animal proteins during a period of only a few days. However, occasional peak consumption periods were difficult to identify in this nutritional survey.

About 75% of the workers seemed to be underfed, i. e., deficient in energy content of food. They could not meet up the deficit since their daily monetary income does not exceed 7 Rupees. In earlier days, the daily wage was paid in kinds, i.e., in the form of cooked food from the employer, which helped to balance the energy expenditure.

On the basis of the present market rate of the foodstuffs, the workers had given away the daily work output at about 45 to 55% cost of their earnings. With 3 or 4 dependent members in the family, the worker runs at a deficit of 150 to 160% in terms of food procurement. On including other expenses for housing, clothing, transport, education and medicine, the deficit increases to about 180 to 190%, thus demanding a larger input in his means of subsistence to maintain himself in better conditions as a labouring individual. Sometimes the workers do not get any work and thus has no earning. So they skip the meal or take only a little food on that day. Frequency of skipping the meal is five to six days in a month. Landless agricultural workers have only one meal in a day. On the contrary, when avilable, they work throughout the week without any off-day. It needs to be revealed how the workers with the poor daily wages can maintain their reasonable speed of work and sustain the anthropometric and muscular abilities for days, months and even years.

The body weight of the 75th percentile population was 49.7 kg. The range of values of other parameters like bone diameter, acromial breadth, olecranon and epicondylar bone diameters, bi-trochanteric breadth, lean body weight, etc., established that the meso-ectomorphic body component was predominant among the workers. No notable change was observed in the body dimensions during a couple of months. In some cases, the workers lost 5 to 10% of their body weight during the last 2 years. It is not clear how they could manage to maintain a reasonable state of the body with a marginal energy input. Minnesota experiments (Keys *et al.*, 1950) indicated that a loss of body weight by 25 to 30% reflects a severe degree of semi-starvation. To avoid functional changes, Kriger (1921) set the lethal level of the loss of body weight at 20% for the younger section and at 40% for the adult section of the population. Indians with low body-weights may be acting as small human machines requiring less amount of food as fuel, both for rest and for work (Banerjee and Sen, 1958). Perhaps they could thereby sustain the meso-ectomorphic body components throughout the life-span. Whether this is a case of nutritional adaptation, as proposed by Beaton (1967), needs to be thoroughly examined.

Although enough information is not available about the standard of performance in skilful actions, it seems that the present groups are quite capable of carrying out their daily tasks around the age of 40. However, the decreasing trend of the maximal working capacity was indicated with increasing age (Sen *et al.*, 1969). The maximal physical work capacity at 40 to 49 years was only about 13% less than at 20 to 29 years.

Hence, sustained workload at the older age would mean that they are performing at the cost of longivity and functional life. Other factors like ill-health, hot climate, poor working conditions, different socio-cultural practices, etc., undoubtedly influence the efficiency and productivity of workers. In an apparent answer to the question of what should be the allowable maximum energy expenditure, the present authors suggested 1500 Kcal as the gross output for 8 hours' occupational work (Sen and Nag, 1975). The suggested rationalization may be suitable except during very cold winter and hot summer months, during which the optimal level of energy output needs to be modified on the basis of the gain or loss of body heat.

There is a considerable scope for future research on various degrees of under-nutrition on the body status, work capacity and functional life of the workers.

REFERENCES

Beaton, G. H. (1967) : Nutrition, (Academic Press, London).

Banerjee, S. and Sen, R. N. (1958) : Body composition of Indians and its relation to basal metabolic rate, *J. Appl. Physiol.* 12 : *29 33.*

Banerjee, S., Sen, R. N., Acharya, K. N., and Chattopadhyay, D. P. (1959 a) : Studies on energy metabolism of labourers in a spinning mill, *Ind. J. Med. Res.* 47 : *657-662.*

Banerjee, S., Sen, R. N. and Acharya, K. N. (1959 b) : Energy metabolism in laboratory workers, *J. Appl. Physiol.* 14 : *625 628.*

Keys, A., Brozek, J., Henschel, A., Mickelsen, O. and Taylor, H. L. (1950) : The biology of starvation, (The University of Minnesota Press. Minneapolis).

Kriger, M. (1921) : Ueber die atropie de menschikehen organs bei inanition, *Z. angew Anat. Konstitutional*, 7 : *17-134.*

Nag, P. K., Sen, R. N., Ray, G. G. and Chakraborty, D. (1978) : Nutritional and energy metabolic status of Indian workers performing heavy manual jobs, *J. Madurai University*, 7 : *47-52.*

Sen, R. N. (1960) : Studies on some aspects of energy metabolism in Indians. Thesis for D. Sc (Physiology) degree of the Calcutta University, *347 pp.*

Sen, R. N. (1964) : Some anthropometric studies on Indians in a tropical climate, Proceedings of the Symposium on Environmental Physiology and Psychology in Arid Condition, *Arid Zone Research*, (UNESCO, Paris) **24** : *163-174*.

Sen, R. N., Chatterjee, S. K., Saha, P. N. and Subramanian, A. (1964 a) : Assessment of work load and thermal stress in relation to physiological responses of workers in a cotton textile mill in Bombay, **Report No. 3**, Industrial Physiology Division, Central Labour Institute, Bombay, *27 pp*.

Sen, R. N., Saha, P. N. and Subramanian, A. (1964 b) : Assessment of work load and thermal stress in relation to physiological responses of workers in a soap factory in Bombay, **Report No. 4**, Industrial Physiology Division, Central Labour Institute, Bombay, *28 pp*.

Sen, R. N., Roy, B. S. and Sarkar, D. N. (1969) : Maximal physical work capacity of Indian industrial workers in relation to age and heaviness of job, *Proceedings of the International Conference of the Human Factors Society*,, Philadelphia, Pennsylvania, U.S.A. (6th to 9th October), *13 pp*.

Sen, R. N. and Nag, P. K. (1975) : Work organisation of heavy load handling in India, *J. Human Ergology*, **4** : *103-113*.

Sen, R. N., Nag, P. K. and Ray, G. G. (1977) : Some anthropometry of people of eastern India, *J. Indian Anthrop. Society*, **12** : *201-208*.

ACKNOWLEDGEMENT

The authors acknowledge with thanks the technical assistance of Sri A. K. Ghosh, G. G. Ray, D. Chakraborti and M. R. Kar in the present study.

COMMENTS

Dr. Subhas Mukerji : In terms of costing, it appears that workers themselves were consuming more then 50% of the total food consumption by the family to maintain his calorie balance. Do you think that the brunt of the economic inadequacy was felt by the dependent family members comprising 4 to 5 heads. ?

Mr. P. K. Nag : Yes.

Ind. J. Physiol, & Allied Sci. Vol. 33, (1 to 4) : 128, 1979

VENTILATORY CONTROL AND ACID-BASE BALANCE DURING CYCLE ERGOMETER AND TREAD-MILL WORK*

Sankar N. Koyal, B. J. Whipp, G. A. Bray, D. Huntsman and K. Wasserman

Dept. of Medicine, U.C.L.A., Harbor General Hospital Complex
Torrance, California, U.S.A.

Tht cycle ergometer and treadmill are the two most common instruments used for exercise testing. To determine the extent to which gas exchange differs in these two forms of exercise, minute ventilation, the breathing pattern, and acid-base measurements were made at comparable levels of O_2 uptake.

Twenty sedentary male subjects with no history of cardio-pulmonary diseases (age-proup 21-33 years) were selected for this study. Exercise was performed on a cycle ergometer (Lanooy) at 50, 100 and 150 watts for 15 minutes each or to fatigue forcing cessation of work. There were rest periods of 1-2 hours between work rates. Three work rates of similar duration and O_2 uptake were performed on the treadmill. Ventilatory and gas exchange variables were measured continuously breath-by-breath and processed by a mini-computer at rest and during each work test. Arterial blood was sampled at rest and during the last minute of each work rate for measurement of lactate pH, PCO_2, bicarbonate and PO_2.

At comparable levels of oxygen uptake, the values for arterial lactate, VCO_2, $\dot{V}E$, VT were higher for cycle ergometer than treadmill exercise. These differences are best accounted for by a greater degree of metabolic acidosis, presumably secondary to increased anaerobiasis which occurred with cycle ergometer work. The increase in $\dot{V}E$ for the cycle ergometer over the treadmill work at a given $\dot{V}O_2$ is linearly related to the difference in bicarbonate for the two tests. The increase in $\dot{V}E$ in the cycle ergometer test is accounted for by an increase in $\dot{V}T$. There was no difference in breathing frequency at any given $\dot{V}O_2$ between the two forms of exercise.

Paper presented at the Sevetth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received.**

Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 130 - 137, 1979

AVERAGE DAILY ENERGY EXPENDITURE OF COAL MINERS IN INDIA

M. K. Chakraborty, S. K. Sensarma and D. N. Sarkar

Central Mining Research Station, Dhanbad, Bihar, India

A study was undertaken in a coal mine in Jharia to determine the whole day's energy expenditure of the miners by time analysis of various underground mining work, sleep and off-duty activities.

The study included Pickminers, Shovellers, Load-carriers, Trammers, Machine Drivers, Machine Helpers, Drillers, Timber Mistries and Timber Mazdoors. Their average daily energy expenditure varied between 2379 Kcal (for Machine Drivers) and 3309 Kcal (for Trammers).

Banerjee *et al.* (1959) found the mean daily energy expenditure of spinning mill workers as 3050 Kcal including 1662 Kcal during factory work. Sen *et al.* (1964a) found the mean daily energy expenditure of various categories of cotton textile workers to lie between 1954 to 3247 Kcal of which 713 to 1861 Kcal were spent during factory hours while their daily energy intake was between 2261 to 2749 Kcal. They (1964b) also reported the ranges of average daily energy expenditure and intake of various categories of soap factory workers to be 2173 to 3322 and 2320 to 3059 Kcal respectively. The energy expenditure of steel Rolling Mill workers (Sen *et al.*, 1966) found to vary from 1.16 to 4.64 Kcal $min.^{-1}$ Durnin and Passmore (1967) reported a mean energy expenditure of 4 to 5 Kcal min^{-1} for a miner (65 kg) for the total time underground. They considered about 2,000 Kcal as the possible expenditure at work by a miner having a total daily energy expenditure of about 4,000 Kcal.

The report to the Government of India by ILO (1967) mentions the energy expenditure of Indian coal miners in a shift to lie between 731 and 1253 Kcal based on a study on 41 coal miners only. The present study included detailed time analysis of various work underground and determination of the energy expenditure during these work spells and various activities outside the mine to estimate the daily total energy metabolism.

Paper presented at the Seventh Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

MATERIALS AND METHODS

The study included altogether 132 coal miners, chosen at random. They comprised of 21 Pick-miners, 24 Shovellers, 25 Load Carriers, 10 Trammers, 11 Machine Drivers, 12 Machine Helpers, 14 Drillers, 7 Timber Mistries and 8 Timber Mazdoors.

The subjects were of moderate physical build and health status. Of them, 116 were in 24-39 years age-group, 12 were in the range of 40-49 years, and 4 were between 50 and 55 years. All had considerable experience of 5-15 years' underground work, except a few CRO miners with less than 5 years' experience.

Average Daily Energy Expenditure of the Miners :

A miner's normal day consisted of about 8 hours each for sleep, shift-work and other off-duty activities.

Energy Expenditure During Sleep :

The energy expenditure during 8 hours' sleep was calculated from the basal metabolic rate of 1.130 Kcal/kg body weight/hour as derived by Banerjee et. *al.* (1959).

Time Study and Total Energy Expenditure for the 8-hour Shift :

Each miner was followed during the whole period of the underground shift, from the pit bottom at the start till the return to the pit-head at the end of the shift. Times spent in all the activities including productive work and the periods of inactivity were obtained.

The energy costs of all the operations including rest were estimated from the oxygen consumption. A factor of 5 was used in converting the oxygen uptake in litres min^{-1} to energy cost in Kcal min^{-1}. These different energy costs for unit time were multiplied by the duration from the time study.

Off-duty Activities :

By the questionnaire method, the average time spent for all off-duty activities outside the colliery, including the house-hold work, etc., were obtained. The energy expenditures were calculated from the values reported by other Indian investigators (Banerjee *et al.* 1959). The energy expenditure values (per kg of body weight per hour) for off-duty activities were taken as follows ; sitting work ; 3.235 Kcal ; sitting rest ; 1.418 Kcal ; walking : 3.502 Kcal ; standing rest : 1.574 Kcal.

RESULTS AND DISCUSSION

Time Study :

Table 1 represents the analysis of the time study of the miners category-wise and shows spasmodic nature of the miners' activities and considerable periods of inactivity due to either rest pauses between work-spells or mechanical failure of haulage system. The inactive periods varied from 28.8 to 48.7% of the total shift. The inactivity period was minimum for trammers (28.8%)

Table 1

Time study (Mean ± S.D.) of the coal miners during daily shift-work underground

Category and number of miners	Travelling time (min)	Period of inactivity (resting min)	Time for pushing empty tubs (min)	Time for actual work (min)	Total time spent under-ground (min)
Pickminer (21)	45 ± 12	171 ± 65	13 ± 2	189 ± 59	417 ± 46
Shoveller (24)	39 ± 10	164 ± 27	13 ± 5	202 ± 60	417 ± 51
Load-carrier (25)	46 ± 8	160 ± 43	15 ± 3	199 ± 49	419 ± 51
Trammer (10)	40 ± 10	138 ± 17	—	302 ± 10	480 ± 0
Machine-Driver (11)	60 ± 9	152 ± 20	—	107 ± 34	319 ± 21
Machine Helper (12)	62 ± 11	137 ± 20	—	152 ± 9	351 ± 21
Driller (14)	82 ± 12	146 ± 15	—	71 ± 10	300 ± 14
Timber Mistry (7)	117 ± 11	199 ± 19	—	165 ± 24	480 ± 0
Timber Mazdoor (8)	68 ± 20	216 ± 22	—	197 ± 14	480 ± 0

and more pronounced in drillers, machine drivers and timber mazdoors (48.7%, 47.6% and 45% respectively), and about 4% for others.

The time spent in travelling by various categories of miners was in the range of 8.3 to 27.3%. The travelling time was minimum (8.3%) for trammers who worked near the pit bottom while those for the drillers, timber mistries, machine drivers and machine helpers were 27.3%, 24.4%, 18.8% and 17.7% respectively.

The time for different types of mining work varied from 24.0 to 62.9% of the shift period with 24.0%, 33.6% and 34.2% respectively, for drilling, machine driving and timber work and it was maximum (62.9%) for trammers. Timber mazdoors, machine helpers, pickminers, load carriers and shovellers spent time which ranged from 40.8 to 48.2%. The results for loaders and pickminers agree with earlier findings (Mukherjee *et al.*, 1970), a discrepancy of about 12% was found only in case of trammers.

Energy Expenditure for Shift-work :

Miners expend considerable energy in travelling and miscellaneous activities besides their duty-work. The energy cost of travelling was minimum (7.0%) for trammers and maximum (39.1%) for drillers. The energy expenditures for different categories of miners during rest were found to be 10.1 to 23.8% of the total energy costs of the shift. The corresponding value reported by Humphreys and Lind (1962) was 16%.

The energy expenditures for actual productive work of different categories were 55.9 (for Timber Mistry) to 82.9% (for Trammers) of the total energy expenditure of the shift, except the drillers and machine drivers for whom the figures were 37.9% and 47.8% respectively.

Table 2 shows the mean shift period energy cost for productive work for each category. Though the shift period was not strictly 8 hours, except for Trammers and Timber workers, the total energy expenditure underground has been expressed for 8 hours' shift for all categories.

The mean total energy expenditures for various categories of miners were between 1044.4 and 1821.9 Kcal per man per 8 hour shift, the highest and lowest values being for trammers and machine drivers respectively.

Daily Energy Expenditure :

Table 3 shows the mean values of the total energy expenditure of the

Table 2

Energy expenditure (Mean ± S.D.) of the coal miners during daily shift work

Category and number of miners	Age (Yr)	Body weight (kg)	Gross mean energy expenditure for actual work underground (Kcal/min)	Gross mean energy expenditure during the shift (Kcal/min)	Total energy expenditure for the shift (Kcal)
Pickminer (21)	31.8 ±5.6	49.1 ±3.2	5.5 ±0.4	3.40 ±0.56	1409.7 ±236.2
Shoveller (24)	32.6 ±5.7	52.8 ±3.6	4.2 ±0.66	2.85 ±0.21	1192.6 ±201.7
Load-Carrier (25)	30.0 ±7.4	50.1 ±5.2	4.8 ±0.5	3.17 ±0.37	1330.4 ±226.2
Trammer (10)	37.1 ±9.0	52.7 ±8.5	5.0 ±0.8	3.80 ±0.47	1821.9 ±224.9
Machine Driver (11)	32.7 ±8.2	47.3 ±3.7	3.1 ±0.5	2.18 ±0.19	694.4 ±69.1
Machine Helper (12)	31.9 ±7.7	48.0 ±4.0	4.0 ±0.3	2.78 ±0.24	973 ±66.0
Driller (14)	32.0 ±5.7	47.4 ±3.4	3.7 ±0.5	2.33 ±0.23	694.9 ±51.9
Timber Mistry (7)	29.3 ±3.3	47.4 ±3.6	4.5 ±0.3	2.71 ±0.19	1322.6 ±57.8
Timber Mazdoor (8)	37.4 ±1.9	46.1 ±4.5	4.1 ±0.2	2.60 ±0.45	1246.5 ±67.5

Table 3

Total daily energy expenditure (Mean ± S.D.) of coal miners

Category and number of miners	Energy expenditure during 8 hrs' sleep (Kcal)	Energy expenditure during off-duty work of 8 hours (Kcal)	Energy expenditure during 8 hours shift-work underground (Kcal)	Total energy expenditure for 24 hours period (Kcal)
Pickminer (21)	444.1 ± 29.0	941.6 ± 61.4	1630.9 ± 269.6	3016.6 ± 314.8
Shoveller (24)	477.1 ± 32.6	1011.7 ± 68.5	1366.2 ± 102.1	2837.1 ± 404.5
Load-carrier (25)	453.1 ± 48.7	959.8 ± 103.4	1522.9 ± 177.1	2935.0 ± 221.0
Trammer (10)	476.5 ± 63.8	1011.0 ± 134.9	1821.9 ± 224.8	3309.3 ± 381.9
Machine Driver (11)	427.7 ± 27.1	907.0 ± 71.1	1044.4 ± 92.1	2379.2 ± 148.0
Machine Helper (12)	433.9 ± 11.5	920.1 ± 76.8	1333.4 ± 115.5	2687.4 ± 180.7
Driller (14)	428.8 ± 30.7	968.0 ± 65.1	1115.8 ± 111.7	2453.7 ± 162.5
Timber Mistry (7)	428.7 ± 32.1	909.1 ± 68.1	1322.6 ± 57.6	2660.5 ± 119.0
Timber Mazdoor (8)	417.0 ± 40.3	884.1 ± 85.4	1246.5 ± 67.5	2547.6 ± 125.0

miners during 8 hours' sleep, 8 hours' off-duty activities and 8 hours' underground shift, along with their total daily energy expenditure.

The mean values of daily energy expenditure for different categories of miners were between 2379.2 and 3309.3 Kcal per man respectively, the maximum and minimum values being for trammers and machine drivers respectively. The average daily energy expenditure for pickminers, shovellers and load carrier were 3016.6, 2837.1 and 2936.0 Kcal per man. The work-loads in tramming, pickmining, shovelling and load-carrying were greater comparatively. The daily energy expenditures of 2379.2 to 3309.3 Kcal for all categories of Indian miners were within the limits of the values recommended by the FAO (1950 and 1957).

Considering the lower body weight the Indian miners may be considered to be performing hard physical labour like that of the European miners (Guharay, 1972).

REFERENCES

Banerjee, S., Acharya, K. N., Chattopadhyay, D. and Sen, R. N. (1959): Studies on energy metabolism of labourers in a spinning mill - *Ind. J. Med. Res.* 47 : *657-662.*

Durnin, J. V. G. A. and Passmore, R. (1967): Energy, work and leisure - Heinemann Educational Book Ltd. (London).

Food and Agricultural Organisation, United Nations (1950): Committee on Calorie Requirements - Nutr. Stud. No. 5, U.N.

Food and Agricultural Organisation, United Nations (1957): Calorie Requirements, Nutr. Studies No. 15, U.N.

Guharay, A. (1972): Comparative studies in energy metabolism and physical work capacity of Indian and European miners. In : Perspective in Nutrition, Ed : R. Rajalaxmi, University of Boroda, *p 14-19.*

Humphreys, P. W. and Lind, A. R. (1962): The energy expenditure of coal miners at work - *Brit. J. Industr. Med.* 19 : *264-275.*

International Labour Organisation, Geneva (1967): *Report to the Government of India on "Physiology in Mines"*, ILO/TAP/India/R. 23.

Lehmann, G., Muller, E. A. and Spitzer, H. (1950): Der Calorienbedarf bei Gewerblicher Arbeit, *Arbeitsphysiologie*, 14 : *166-172.*

Mukherjee, R. N., Gopal Krishnan, W., Banerjee, A., and Chakraborty, M. K. (1970): Full shift dust exposure in Indian coal mines, *Ind. J. of Industr. Med.* 16 : *113-121.*

Sen, R. N., Chatterjee, S. K., Saha, P. N. and Subramanian, A. (1964a): Assessment of work load and thermal stress in relation to physiological responses of workers in a cotton textile mill in Bombay, Industrial Physiology Division, Report No. 3, Ceintral Labour Institute, Bombay, *pp. 27.*

Sen, R. N., Saha, P. N. and Subramanian, A. (1964b) : Assessment of work load and thermal stress in relation to physiological resp:n:es of workers in a soap factory in Bombay, Industrial Physiology Division - Report No. 4, Central Labour Institute, Bombay. *pp. 28.*

Sen, R. N., Chattejee, S. K. Saha, P. N. and Fletcher, J. G. (1966) : Rationalisation of wcrk period and rest pause in a steel rolling mill in Bombay. Report No. 6, Industrial Physiology Divisi:n, Central Labour Institute, Bombay. *pp. 22.*

ACKNOWLEDGEMENT

Authors are grateful to Sri P. K. Mullick, for statistical analysis and to the mine management and the miners for their whole-hearted co-operation.

COMMENTS

Dr. K. Kogi : Do your energy expenditure data refer to an 8-hours' shift including resting period ? How long is the resting period per shift ?

Dr. M. K. Chakraborty : Yes, it is an 8 hours' shift. The resting period depend on the work-intessity and the work requirement. It varies between 29% and 48% of the shift, the minimum being for the Trammers and maximum being for the Drillers and Machine Drivers.

Dr. K. Kogi : We find it preferable to adopt a lower energy cost limit of around 1600 Kcal per shift at least for normal Japanese male workers compared to the Germen criteria of 2000 Kcal.

Dr. M. K. Chakraborty : In India also, we find similar energy expenditure as in the case of Japanese. This must be due to the lower body weight of the Indian and Japanese workers in comparison to German workers. In Indian miners we find that the energy expenditure is similar to that of Germans on the unit body weight basis.

Ind. J. Physicl. & Allied Sci. Vol. 33, (1 to 4) : 138, 1979

PHYSIOLOGICAL RESEARCH REQUIRED FOR A MODEL OF SINUS ARRHYTHMIA CHANGES WITH MENTAL LOAD*

J. W. H. Kalsbeek and B. W. Hyndman

Ergonomics Psychology Laboratory, T.N.O., Zuiderzeeweg 10, Amsterdam, the Netherlands

The exact physiological mechanisms that produce changes in sinus arrhythmia (SA) during central nervous system (CNS) loading associated with information handling are obscure.

A series of hypotheses-testing experiments to find a parameter which most systematically reflects CNS loading associated with information handling (ultimately to measure reserve capacity) were undertaken. The effect of such loading on the regulation of blood pressure, an important index in cardiopathology, was also observed.

The SA was scored by calculating the average total power of the low-pass digitally filtered cardiac event sequence of delta functions. This scoring technique was shown to give a reliable indication of mental loading in decision-making tasks.

The spontaneous rhythmic activity of blood pressure and vasomotor activity ensuring the precise homeostasis of blood pressure and body core temperature has a key element of threshold response of efferent activity to the controlled variable. A non-circadian biological rhythm may be the switching activity of a threshold element within the physiological control system concerned to achieve homeostasis. The role of biological rhythms is the maintenance of precise homeostasis.

Further co-ordinated applied and fundamental research on national and international levels on these lines are necessary.

Paper presented at the Seventh Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974. ***Full paper not received.**

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 139-141, 1979

SOME VISUAL RECORDS OF THE SYMPOSIUM

Figure 1 : Reception to the participants in the International Satellite Symposium before the Inaugural Session.

Figure 2 : Audience in the First Scientific Session of the Symposium.

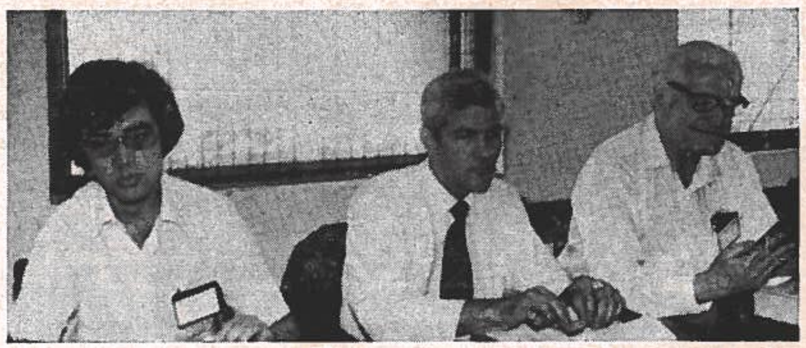


Figure 3 : Dr. B. W. Hyndman, Dr. E. J. Hamley and others discussing.

Figure 4 : Academicians attending Session of the Symposium at the auditorium of the Saha Institute of Nuclear Physics.

Fig. 5.

Fig. 6.

Figure 5 : Dr. O. G. Edholm delivering Prof. S. C. Mahalanobis Memorial Oration in the First Scientific Session of the Symposium.

Figure 6 : Dr. O. G. Edholm and Dr. P. R. M. Jones in the midst of academic discussions.

SOME VISUAL RECORDS OF THE SYMPOSIUM

Figure 7 : Prof. S. R. Mukherjee, Prof. S. R. Maitra, Dr. E. J. Hamley and Mrs. Hamley at a get-together.

Figure 8 : Dr. P. R. M. Jones, Miss. H. C. Cursitor, Mrs. Hamley and Dr. E. J. Hamley listening to the academic discourses at a session.

Ind. J. Physiol. & Allied Sci. Vol. 33 (1 to 4) : 142-145, 1979

INTERNATIONAL SATELLITE SYMPOSIUM ON WORK PHYSIOLOGY & ERGONOMICS CALCUTTA, 1974

LIST OF PARTICIPANTS

Chakraborty, M. K. : Health Division, Central Mining Research Station, Barwa Road, Dhanbad-1, Bihar.

Chatterjee, Satipati : Dept. of Physiology, Calcutta University, Calcutta-700009.

Chattopadhyay, Haripada : Dept. of Physiology, Presidency College, Calcutta-700012.

Choudhury, Jamuneswar : Dept. of Physiology, Gauhati Medical College, Gauhati-4, Assam.

Das, Sunil Kumar : Dept. of Physiology, Calcutta University, Calcutta-700009.

Edholm, O. G. : Human Physiology Division, National Institute for Medical Research, Holly Hill, England.

Ghosh, Arun Kumar : Dept. of Biochemistry, Institute of Basic Medical Sciences, Calcutta University, Calcutta-70020

Guha, A. K. : Britannia Biscuit Co. Ltd. 15, Taratala Road, Calcutta-700054.

Guha, S. K. : Philips (India) Ltd., Bombay.

Guharay, Asit Ranjan : Work Physiology Section, Central Mining Research Station, Barwa Road, Dhanbad-1, Bihar.

Hamley, Ernest J. : Dept. of Ergonomics and Cybernetics, University of Technology, Loughborough, Leicestershire, England.

Hyndman, B. W. : Laboratory for Ergonomics Psychology, TNO, Zuiderzeeweg 10, Amsterdam, Netherlands.

Jones, Peter Roy. M. : Dept. of Human Sciences, University of Technology, Loughborough, Leicestershire, England.

Kogi, Kazutaka : Laboratory for Work Physiology, Railway Labour Science Research Institute, Kokubunji, Tokyo 185, Japan.

Koyal, Sankar N. : Dept. of Medicine, Harbor Hospital Complex, Torrance, California, U.S.A.

Maiti, Ajit Kumar : Dept. of Biochemistry, Institute of Basic Medical Sciences, Calcutta University, Calcutta-700020.

Maitra, Susil Ranjan : Dept. of Physiology, Calcutta University, Calcutta-700009.

Majumder, Sabita : Dept. of Physiology, Calcutta University, Calcutta-700009.

Monod, H. : Laboratory of Work Physiology, University of Paris, CNRS, 91, Bd. De L' Hospital, Paris, France.

Mukherji, Subhas : Dept. of Physiology, N. R. S. Medical College, Calcutta-700014.

Sen, Rabindra Nath : Ergonomics Laboratory, Dept. of Physiology, Calcutta University, Calcutta-700009.

Thomason, Harry : Human Performance Laboratory, University of Salford, Salford, England.

ASSOCIATE PARTICIPANTS

Bagchi, Pranati : Dept. of Physiology, Calcutta University. Calcutta-700009.

Bhattacharyya, Aloke Kumar : N. R. S. Medical College, Calcutta-700014.

Chatterjee, B. B. : Section of Physiological & Industrial Hygiene, All India Institute of Hygiene & Public Health, Calcutta-700012.

Chatterjee, Amar : Dept. of Physiology, Raja Peary Mohan College, Uttarpara, Hooghly, West Bengal.

Datta, S. R. : Section of Physiological & Industrial Hygiene, All India Institute of Hygiene & Public Health, Calcutta-700012.

Ghosh, Ajit Kumar : Katwa College, Burdwan University, Katwa, Burdwan, West Bengal.

Gopinath, P. M. : Physiology Research Cell, R. & D. Organisation, Ministry of Defnce, Darjeeling-734101.

Nag, Pranab Kumar : Dept. of Physiology, Calcutta University, Calcutta-700009.

Nair, C. S. : Physiology Research Cell, R. & D. Organisation, Ministry of Defence, Darjeeling-734101.

Roy, U. S. : Physiology Research Cell, R. & D. Organisation, Ministry of Defence, Darjeeling-734101.

Sinha, Ashis : Dept. of Physiology, Surendra Nath College, Calcutta-700009.

Nath, Pranabesh : Dept. of Physiology, K. N. College, Berhampore, West Bengal.

LIST OF OBSERVERS

Brahmachari, Haridas : R. & D. Organisation, Ministry of Defence, Tansen Road, Gwalior-2.

Chakraborty, Satyabrata : Hindustan Lever Ltd., 63, Garden Reach, Calcutta-700024.

Chatterjee, Pratima : Dept. of Physiology, Calcutta University, Calcutta-700009.

Chatterjee, Suchitra : Dept. of Physiology, Calcutta University, Calcutta-700009.

Chatterjee, Manjushree : R. G. Kar Medical College, Calcutta-700004.

Chatterjee, J. R., : Dept. of Medicine, N. R. S. Medical College, Calcutta-700014.

Cursiter, Hary Clouston : Dept. of Human Sciences, the University of Technology, Loughborough, Leicestershir, England.

Dasgupta, Shakuntala : Dept. of Physiology, Calcutta University, Calcutta-700009.

Datta, Suradish : Dept. of Physiology, Ananda Mohan College, Calcutta-700009.

Das Gup'a, Amiya Kumar : Dept. of Physiology, Calcutta University, Calcutta-700009.

Deb, C C. : Dept. of Physiology, Calcutta University, Calcutta-700009.

Fouzdar, G. K. : Education Emporium, Chittaranjan Avenue, Calcutta-700012.

Ghosal, Madhu Sudan : Dept. of Physiology, Surendra Nath College, Calcutta-700009.

Ghosh, Ban Behari : Dept. of Physiology, Calcutta University, Calcutta-700009.

Kundu, H. B. : Defence Institute of Work Study, Landour Cantt., Mussoorie, Uttar Pradesh.

Medda, Ajit Kumar : Dept. of Animal Physiology, Bose Institute, Calcutta-700009.

Mukherjee, J. N. : Dept. of Physiology, City College, Calcutta-700009.

Mukherjee, Chitralekha : Dept. of Physiology, Calcutta University, Calcutta-700009.

Sinha, Bhabani Prasad : Dept. of Physiology, Calcutta University, Calcutta-700009.

ASSOCIATE OBSERVERS

Basu, Jayasree : Dept. of Physiology, Calcutta University, Calcutta-700009.

Bagchi, Pratima : Dept. of Physiology, Calcutta University, Calcutta-700009.

Biswas, Narendra Mohon : Dept. of Physiology, Calcutta University, Calcutta-700009.

Chakraborty, Ila : Dept. of Physiology, Rammohon College, Calcutta-700009.

Guha, Tapan : Saha Institute of Nuclear Physics, Calcutta-700009.

Kar, Manas Ranjan : Dept. of Physiology, Calcutta University, Calcutta-700009.

Mukherjee, Ratna : Dept. of Physiology, Calcutta University, Calcutta-700009.

Rahaman, M. A. : City College, Calcutta 700009.

Roy, Purnima : North Bengal University, West Bengal.

Roy, Arun : Dept. of Physiology, Ananda Mohan College, Calcutta-700009.

Sarkar, Dipak : Dept. of Physiology, Calcutta University, Calcutta-700009.

Som, Nirmal Chandra : Dept. of Physiology, Tamluk College, Midnapore, West Bengal.

LIST OF CHAIRMEN AND CO-CHAIRMEN :

1. Prof. Banerjee S.
2. Mr. Bhatia, S. P.
3. Dr. Chakraborty, M. K.
4. Dr. Chakraborty, S.
5. Prof. (Mrs.) Chatterjee, A.
6. Dr. Chatterjee, B. B.
7. Dr. Chattopadhyay, H. P.
8. Dr. Edholm, O. G.
9. Dr. Hamley, E. J.
10. Dr. Jones, P. R. M.
11. Dr. Kogi, K.
12. Prof. Maitra, S. R.
13. Prof. Monod, H.
14. Prof. Sadhu, D. P.
15. Prof. Sen, A.

LIST OF RAPPORTEURS :

1. Mr. Banerjee, S. N.
2. Sm. Banerjee, T.
3. Sm. Basu, J.
4. Sri Chakraborty, D.
5. Sm. Chatterjee, S.
6. Dr. (Mrs.) Chatterjee, P.
7. Miss. Cursiter, H. C.
8. Dr. Datta, S.
9. Sm. Guha, A.
10. Sri Kar, M. R.
11. Sri Kundu, H.
12. Sri Nag, P. K.
13. Sri Nath, P.
14. Sri Roy, A. K.
15. Sri Roy, G. G.
16. Dr. (Miss.) Roy, P.
17. Sri Sadhu, A.
18. Sri Sarkar, D.
19. Sri Sinha, A.

INFORMATION FOR CONTRIBUTORS

Manuscripts should be as per style of the papers published in the current issue of the Journal. Authors must check the form, length, abstracts, symbols, abbreviations, footnotes, references and illustrations as per instructions outlined below.

Form : Manuscripts must be submitted in *triplicate* in typewritten double-spaced with wide (8 cm) margin along with two copies of illustrations, tables and references. The text should be concise and consistent as to the spelling and abbreviations. *The first page should have only the title, authors' names, institution of origin with its address, and any relevant footnotes.* Tables and captions for illustrations should be on separate pages and each lebelled properly. The editors reserve the right to make necessary changes in the style and form without consulting the author.

Length : Full length research papers should normally not exceed 10 printed pages including figures, tables and references (1 printed page=2 typed pages, 30 lines/page). They should include an Abstract, brief Introduction, Methods. Results, Discussion, Acknowledgements, if any, and References. Short papers or communications, should be usually less than 4 printed pages (3000 words) including one or two tables and illustrations and reference.

Abstract : An Abstract of not more than 200 words is required for papers, and shorter one for notes and communications and should be submitted in triplicate. *Symbols and Abbreviations* must conform to those used by the Biochemical Journal or the style of Quarterly Cummulative Index Medicus.

References : References should be placed at the end of the paper in alphabetical order and arranged as follows : author's name and initials, year, title of the Journals (abbreviated according to the rules adopted in the Biological Abstract list, or of World List of Scientific Periodicals), volumes, first page number. Citation of references in the text should be indicated by the family name followed by the year of publication.

When more than one paper by the same author (s) have appeared in one year, the convention will be : (1970 a, b, c). References may be cited in numericals in the text but it must be arranged alphabetically as mentioned above. References to books or review articles should include the author's name followed by initials, year, title of the article or book, publishers, place of publication, edition with editor's name, if any, and the number of pages.

Illustrations and Diagrams should be kept to a minimum ; they should be numbered and marked on the back with the author's name. Legends or captions accompanying illustrations should be typewritten on seperate sheets, but their position in the text should be indicated in the manuscript. All illustrative material should be in such a form as to admit of photographic reproduction without retouching, redrawing or setting of marginal types. The expenses for a limited number of figures upto three will be borne by the Journal ; additional expenses for larger number of blocks or for colour printing will have to be defrayed bv the author. Photographic and photomicrographs on glossy papers should be submitted unmounted.

Repetition of information in the text and legends should be avoided. Data given in graphs or tables must not duplicate each other.

Line drawings should be made with India ink on plain white paper. All lines must be sufficiently thick to reproduce well, and decimal points, periods, dots or symbols etc. must be bold enough to allow any necessary reduction. The original drawings and a copy of each are to be submitted.

Gally proof is sent to the senior author and he is responsible for detecting errors in printing as well as the content.

The senior author will receive free of charge a copy of the issue of the Journal containing the paper. Additional copies or reprints may be purchased at the time of publication, if application is made on the order form sent with the proof.

INDIAN JOURNAL OF PHYSIOLOGY
AND ALLIED SCIENCES

VOL. XXXIII, NOs. 1 - 4,
JANUARY, APRIL, JULY & OCTOBER, 1979

CONTENTS

PROCEEDINGS OF THE INTERNATIONAL SATELLITE SYMPOSIUM ON WORK PHYSIOLOGY AND ERGONOMICS :

Journal Published by : Sri A. K. Dasgupta on behalf of the Physiological Society of India, 92, Acharyya Prafulla Chandra Road, Calcutta-700 009 at The Prints, 8, Sanatan Sil Lane, (Dharani Dhar Sarani) Calcutta-700 012.
Cover Printed by : Allied Printers, 17, Panchanan Ghosh Lane, Calcutta-700 009.

W

APPLICATION OF ERGONOMICS IN THE DESIGN OF FACTORY AND EQUIPMENT FOR TROPICAL CONDITIONS

by R N SEN

Ergonomics Laboratory, Department of Physiology
Calcutta University, 92 APC Road, Calcutta-700009
INDIA

INTRODUCTION

In recent years, the effects of technological developments in changing the pattern of work, life style, leisure activity of working population are well recognized. In any country, the government, management and trade unions have to consider these effects at their individual and collective levels so that the negative effects are minimized and the positive effects are enhanced.

The multidisciplinary subject, Ergonomics, may be defined as the science, technology and art of man at work, which tries to optimize the interactions of MAN-MACHINE-MILIEU (ENVIRONMENT).

The efficiency, productivity, safety, health, standard of living, comfort and welfare, all depend to a considerable extent on the environment in which and on the machines with which the workers work. The problems of the working environment in hot climates are even more numerous and of higher magnitude than those in cold climates. High thermal load in tropical country aggravated by the hot processes in industries like glass, steel etc. increases the load on the cardiovascular and thermoregulatory systems of the body of workers by increasing heart rate and blood pressure to force more blood to the skin for cooling by the evaporation of sweat. When the work load is high, more blood (with oxygen and nutrition) are necessary for the working muscles. The high thermal load combined with high work load (metabolic heat) increases the body temperature and at times may cause heat disorders if proper measures are not taken to avoid disfunctioning of the thermoregulatory system of the body.

DESIGN OF FACTORY

At the very initial stage of design of factory buildings, equipment etc, correct measures should be taken otherwise it may be too late to do anything at later stages or it may be too costly to modify the faulty design, if at all possible.

The factory builders seldom considered the use of the principles of ergonomics. Many of the factories established in hot climates are blind copies of the design of the factories built earlier in cold climates and hence not suitable for what is required for such an environment specially for hot industries such as foundry, glass, steel etc or hot humid conditions as in textile mills, soap factory.

The basic principles of ergonomics in factory design suitable for hot, humid climates can be applied to bring a harmony between the elements of fellow-men, function, form, fabricating material, finance and future, so that the workers can carry out their tacks with optimal conditions of safety, health, comfort, efficiency and productivity.

The important factors to be considered for the proper design of the factories including both the space within and around buildings are:

(1) Site and location of the factories in relation to the meteorological conditions, human habitation (rural or urban), landscape, vegetation, altitude, valley etc, protection from floods, earthquakes, storms, insects, termites and avoidance of inversion of temperature, pollution etc.

(2) Orientation of the buildings, arrangements of roofs, walls, windows, overhangs, shading devices etc in relation to the wind direction, angle of solar radiation etc to have the best natural ventilation and minimal artificial lighting or heating of the buildings, and also in relation to human activity, efficiency and comfort.

(3) The insulation, thermal capacities, noise absorbing and light reflecting properties of building materials, use of durable and satisfactory material and proper form of construction.

(4) Correct design and layout of plants, work space, rest rooms, canteens, windows, doors, stairs, corridors and the fittings, based on the static and dynamic body measurements and different movements of the workers including their thermal responses, machine maintenance requirement and other ergonomic principles.

A typical example of improper design of a factory could be cited. The technology of manufacturing sulphur was imported from Poland in Iraq *in toto* without considering the local conditions. So a factory suitable for cold conditions in Poland when was built in Iraq without arrangements for proper ventilation and reduction of heat stress, the factory failed miserably. The sulphur dioxide and sulphuric acid fumes in hot and humid conditions posed great threat to the safety and health of the workers in that factory.

(1) Site, location, meteorological conditions

They are very important for the design of factory buildings. Rain, temperature, humidity, sunshine, prevalent speed and direction of wind and smog, etc would affect the design of the factory buildings. In an area of frequent temperature inversions, the polluted air cannot rise as it is trapped near the ground level. A factory with an inadequate height of chimney at this site can be a regular source of nuisance. Vegetation giving a green outlook may provide sun-shading and protection from glare but may also reduce wind speed very necessary in hot factories. Location of the factory must be chosen so that the workers do not require several hours of travel to get to work.

(2) Orientation of buildings and arrangements of roofs, walls etc.

With an outdoor wind velocity of about 16 kmh (or 10 mph), the indoor air speed is expected to range from 35 cm/sec (70 ft/min.) in case of poor ventilation to about 150 cm/sec (300 ft/min) with efficient cross ventilation. With more vigorous work, the workers are able to tolerate less thermal stress. Hence the design of factory shop-floor must take into consideration minimization of thermal load and the level of activity by the worker. The peak work load of workers in developed countries has been reduced by mechanisation but it did not change in developing countries due to the problem of finance, unemployment etc. The height of the roof of factory shade is very important to reduce the thermal load on the workers. Too low height of roof makes the workplace abnormally hot. Hence the proper design of factories in hot climates can play a great role in reducing the thermal and work load thereby increasing performance, productivity and comfort of the workers.

(3) The insulation and thermal capacity of the building materials and shading devices:

In hot climate the function of the building envelope is to moderate the day time heating effects of the solar radiation and external air on the structure and its interior. This depends on the thermal resistance and heat capacity of the structural materials. Care should be taken that the rate of cooling during the night is not over-reduced.

The greatest source of heat gain by a factory building can be the solar radiation entering through the windows or roofs. Direct solar radiation may be up to 700 to 800 kcal/m²/h on the horizontal surfaces. This could in fact increase the indoor temperature far above the outdoor air temperature. For reduction of solar heat gain the following are to be considered:

(a) orientation and size of the window.
(b) external shading devices to shade especially the east and west walls of the building exposed to high levels of sunlight.
(c) The height of the ceiling (roof).

All the internal roads leading to the different buildings of a factory should have shade from the trees planted on the sides of the pedestrian pavement.

The material of the factory should be so chosen that the effects of noise are minimized.

(4) Design of roofs, walls and window

Walls of concrete or brick with cement plaster, externally insulated by rockwool or expanded plastic and covered by waterproofing materials are suitable. All external surfaces should be as near to white as possible. The whole roof may be externally covered by a polythene sheeting at a distance of 10 to 20 cm above the roof surface. Polythene is transparent to radiation of the wave length around 10 μ emitted by the roof, placing little restriction on radiative cooling of the roof at night. However, the polythene sheets have to be replaced at intervals.

In place of double-roofing, the factories in rural areas should maintain vegetation on selected portions of the slanting roof.

For good natural ventilation windows should be large. The most effective height of the windows is about 0.5 to 1.5 m above the floor.

The air movement could be grossly influenced by the way the window blinds or sashes open. If the hinges on the windows are fitted properly depending on the direction of prevalence of the wind, the window blinds or sashes would act as deflectors to direct the wind through the windows, otherwise the wind would be directed away from the room. The ordinary ventilation in the factories in hot climates should be at least 1.5 m^3 (5 ft^3) per person per minute. The air speed at the head level should be at least 100 cm/s (200 ft/min).

(5) <u>Design in relation to lighting, colour and noise:</u>
It is regretable that even today simple issues of heating, lighting and ventilation are too often inadequately considered and acoustic problems are not properly dealt with at the design stage.

For natural daylight the maximum practical depth is about 5 m (20 ft) from the window wall and this may be increased to about 7.5 m (30 ft) where a scientifically designed combination of artificial and natural lighting is employed.

For the scientific use of the effects of colour on people at work, the "cool" blue or green colours as against "warm" red colour should be used to give subjective sensations of coolness or impressions of reduced temperature.

(6) <u>Design in relation to welfare</u>
A well-designed working environment includes not only suitable conditions for ample ventilation, good heat dissipation, proper illumination and other comfort standards, but also the tangible amenities that can transform discontent and boredom into interest and a sense of participation by the workers. As for example, the availability of canteen, cool rest room, recreation room, cool drinking water, washing facilities including the use of shower in hot climate are very much favoured.

(7) Design in relation to storage, cleanliness and maintenance

The prevalence of hot and dry conditions leads to a lot of dusts. The factory should be so designed that the routine storage and maintenance of cleanliness is made easy. For example, the glass windows should be at the lower level, or the windows near the top of a "saw-tooth roof" factory should have at least a low cost bay with safety guardrails for safe, easy and regular cleaning.

Easy accessibility for regular and proper maintenance of machinery must be considered in the design of the factory shop floor.

DESIGN OF INDUSTRIAL ESTATES

It is not enough to design one industrial building, even when it is well constructed. Ergonomic considerations are essential in designing industrial estates to reduce the cluster of small buildings and to improve the layout by various methods. A logical and scientific flow diagram for intake of raw materials and for output of finished products should be worked out for all the factories in the group, so that efficient road, rail and conveyor systems can be made with common points for packaging, loading and unloading, and common facilities for maintenance, security, safety, medical clinics, canteen, recreation, sports etc and common services for telephone, electricity, fuel, gas, water, steam, compressed air, refrigeration medium etc and a ring circuit of refuse and waste disposal could be economically viable and useful.

DESIGN OF EQUIPMENT

The design of all machinery and equipment should be according to the body measurements, muscle power, normal motion stereotype of the workers. Normally, factories should be so designed that the use of personal protective equipment against heat, noise, dust, smoke, fumes, accidental injuries is eliminated or at least minimal. If the hazards cannot be reduced at the source, then personal protective equipment has to be used, but in hot and humid climate, it might be impossible for the workers to endure wearing protective equipment. Use of ergonomically designed good, low resistance, respirators or masks are the solution for such problems.

As wasted movements are a source of inefficiency in production, the use of different aspects of human motion and body measurements as criteria and for guidance in the design of workplaces, workshop layout, are necessary.

The use of ceiling fans should be avoided in hot climates as these blow back the hot air from the top on to the workers. The inlet air blowers at the floor level or so-called "floor fans" or the circulators sucking the colder air from lower windows are much better.

RECOMMENDATIONS

In order to achieve the best possible results the following recommendations are made:

(1) Guidelines and specifications for the design of factories, industrial estates, machineries, clothing, personal protective equipment based on the principles of ergonomics suitable for tropical countries in Asia be formulated by ILO in collaboration with Ergonomists, representatives from Government, management and trade unions of the member countries. These guidelines/specifications could be adapted to the local conditions prevailing in a particular country. Moreover, ILO could promote the clearing house activities on alternative designs.

(2) Each proposal for building a new factory along with a detailed plan should be critically examined by the planning authority, Factory Inspectorate, regarding the site, orientation, ventilation, heat sources, lighting, noise, machine layout etc.

(3) The existing factory buildings, machinery and equipment should be inspected jointly by the factory inspectors, management and workers' representatives. This inspection should be done at regular intervals with special reference to improving thermal and work loads.

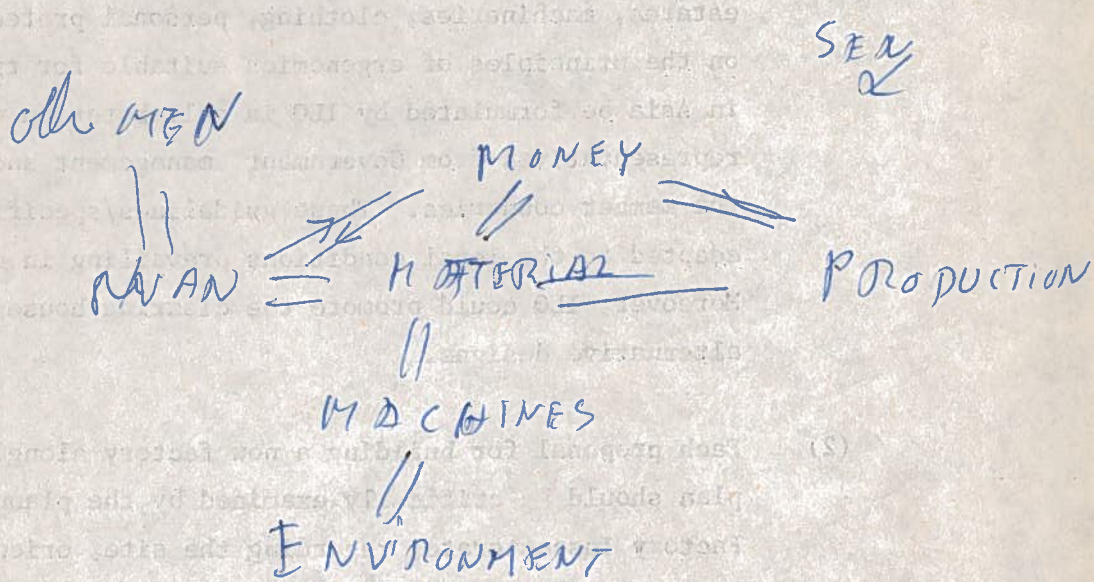
(4) In factories of tropical climate the use of natural and cross ventilation, simple thermal barriers, natural lighting, suitable work clothing should be encouraged.

(5) ILO could support collaborative research on ergonomics aspects of design of factory buildings plant, equipment, work and protective

clothing suitable for tropical countries.

(6) The content of courses such as civil engineering, architecture, environmental sciences, should include topics on ergonomic design of buildings with special reference to ventilation, lighting and noise.

(7) Many of the factories in developing countries may not have finance at the initial stage to pay for the cost of improving ventilation system, equipment or other facilities required to improve working conditions. Either governmental authorities or other agencies should give loan or subsidy towards improving working conditions or expenses on this account be exempted from tax.



Ind. J. Physiol. & Allied Sci. Vol. 33, (1 to 4) : 78 – 83, 1979

35

OCCUPATIONAL DAILY WORK LOAD FOR INDIAN INDUSTRIAL WORKERS AT THREE DIFFERENT THERMAL CONDITIONS

Rabindra Nath Sen and Devendra Nath Sarkar

Ergonomics Laboratory, Department of Physiology, University Colleges of Science, Technology and Agriculture, Calcutta University, Calcutta-700 009, India.

Studies on acclimatized industrial workers showed that the maximal physical work capacity (work for a short period) or maximum oxygen uptake in different groups determined by a single session test on a bicycle ergometer depended on their age, heaviness of their jobs and thermal conditions. The occupational work capacities of these workers based on Leistungs-Puls-Index (L. P. I.) were also suggested. A tentative classification of heaviness of jobs for Indian workers based on their physiological responses at comfortable thermal conditions was made.

The present study was carried out to evaluate the optimal work load (work for a long period) suitable for these workers based on the physiological responses such as pulse rate, oral temperature, oxygen consumption, sweat loss, etc., during continuous work on a standard bicycle ergometer at three different thermal conditions [about 70, 80 and 90° F Corrected Effective Temperature (Basic)] maintained in the laboratory.

Based on the different physiological responses at different thermal conditions, the average work rates which appeared to be safe and suitable for these Indian workers for day-to-day work for months without undue fatigue, were suggested.

India stands second in the world in regard to the source of man-power. It is of utmost importance to utilise manpower in the best possible way by the use of Ergonomics/Human Factors.

Maximal physical work capacity of workers is the work which yields greatest oxygen uptake possible for an individual whereas occupational work capacity is the highest work level permissible in daily occupational work. The differences in the body size, physique, physical fitness, ethnological adaptations, thermal tolerance, nutritional status, socio-demographic factors, daily and seasonal activities are mainly responsible for the unsuitability of data from other countries being applied **in toto** in case of Indians.

Sen (1967), Sen *et al.* (1969, 1972, 1973) determined the maximal physical work capacity of Indian industrial workers at three age-groups, with five different occupations and at three thermal conditions. Sen and Sarkar (1972) determined the occupational work capacity of these workers.

Paper presented at the Fourth Scientific Session of the International Satellite Symposium on Work Physiology and Ergonomics held at Calcutta from 1 - 3 November, 1974.

The present study was undertaken to arrive at the daily occupational work load from data based on different physiological responses at different thermal conditions and different work rates for long period of work.

MATERIALS AND METHODS

Maximal Physical Work Capacity :

Eighty four medically checked, healthy workers selected from three different age-groups (i) 20-29, (ii) 30-39 and (iii) 40-59 years and five different occupations from light to extremely heavy, acted as volunteers. Each worker was subjected in the laboratory to different rates of standard work on a modified von Döbeln's (1954) mechanical bicycle ergometer, varying from 150 to 1500 Kgm/min. in steps. Three different grades of standard work were performed in an air-conditioned room where the thermal conditions were maintained at about 70° F (21.1° C) Corrected Effective Temperature (Basic) [CET(B)] without any thermal radiation, whereas in the other two thermal conditions [i. e., about 80° F (26.7° C) and 90° F (32.2°C) [CET(B)] each worker was exposed to parallel thermal radiation on front and back by several three-stage-controlled room-heaters.

The maximal physical work capacity of each worker was determined by the method of Maritz *et al.* (1961). Monetary and socio-psychological incentives, in an attempt to maximally motivate the subjects were given for attaining the highest load that could be maintained at least for two minutes. There was a gap of at least a week between the determinations in each thermal condition.

The heat stress index [CET (B)] in each thermal condition was obtained from the data on dry-bulb, wet-bulb and globe temperatures and Kata thermometer cooling time.

Occupational Work Capacity and Leistungs – Puls – Index (L.P.I). :

Each of the workers was subjected to a Müller's magnetic brake bicycle ergometer. The test was done by continuously increasing the rate of work in a single 12 minute session, slowly from 0 to 600 Kpm/min, pedalling with 60 double beats/min of a metronome. The continuous recording of pulse rates was done at each minute with the help of a stethoscope and a stop-watch. The expired air was collected in a Douglas bag from 2nd to 12th minute (for 10 minutes) to determine the oxygen consumption.

Conversion of LPI to Maximal Oxygen Uptake :

The maximal oxygen uptake according to Müller's method (1962) as modified by us is given below : Maximal oxygen uptake = 12/LPI + 0.17 lit/min (STPD).

Occupational Daily Work-Load :

The optimal work load suitable for these workers were based on the physiological responses, such as pulse rates, oral temperature, oxygen consumption, sweat loss, etc., during continuous work at three different rates on a standard bicycle ergometer at three different thermal conditions. The suitability was judged from the load at which the pulse rate remained in a more or less steady condition over the long period of work for at least 50 minutes.

RESULTS AND DISCUSSION

The physical characteristics of Indian adult male industrial workers who acted as volunteers for the measurement of work capacity are given in Table 1.

Table I

Physical characteristics of Indian adult male workers for work capacity measurements

Age-Groups	Age (yrs.)	Body Weight (kg)	Body Height (cm)	Mean Skin Fold (mm)
20-29 yrs. (N=37)	25.5±0.44	53.6±1.35	165.5±0.82	7.3±0.63
30-39 yrs. (N=31)	34.0±0.49	54.8±1.54	163.5±1.09	7.0±0.68
40-59 yrs. (N=16)	48.5±1.25	61.6±1.62	166.9±0.96	7.7±0.90
All Groups (N=84)	33.0±0.99	55.6±0.93	165.0±0.58	7.3±0.39

Mean ± Standard Error ; N=Number of subjects

Maximal Physical Work Capacity : This is presented in Table 2.

Table 2

Maximal physical work capacity (maximal oxygen uptake) of Indian adult male industrial workers at comfortable thermal conditions

Groups	Maximal oxygen uptake Litres (STPD)/min	ml (STPD)/min/kg
Age groups :		
20-29 yrs (N=37)	2.46±0.05	45.23±2.03
30-39 yrs (N=31)	2.33±0.04	45.04±1.75
40-59 yrs (N=16)	2.13±0.03	34.96±0.90
Occupation groups : (heaviness of jobs) :		
Light (N=7)	1.67±0.02	30.94±1.36
Moderately heavy (N=19)	1.91±0.05	36.22±0.79
Heavy (N=30)	2.27±0.05	40.67±1.41
Very heavy (N=17)	2.50±0.06	41.98±1.99
Extremely heavy (N=11)	3.17±0.08	55.51±2.26
All groups (N=84)	2.31±0.14	41.08±1.56

It will be seen that the maximal physical work capacity decreases with aging and increases with heaviness of usual job.

However, the value of maximal oxygen uptake in the present investigation is much lower than 4.11 liters STPD/min obtained by Åstrand (1952, 1956) on physical education students, 3.50 liters (STPD)/min obtained by Robinson on American men (1938).

Tentative Classification of Degree of Heaviness of Jobs : These are given in Table 3.

The values are lower than those of the Westerners (Christensen, 1953).

The thermal data of three different thermal conditions in which maximal physical work capacity measurements were made are given in Table 4.

Maximal oxygen uptake of Indian adult male industrial workers at three different thermal conditions is presented in Table 5.

Table 3

Tentative classification of strains in different types of jobs according to the physiological responses of young Indian workers in comfortable climates

Physiological Responses	Classification of strains in jobs					
	Very Light	Light	Moderately Heavy	Heavy	Very Heavy	Extremely Heavy
Oxygen uptake (litres/min)	<0.35	0.35-0.70	0.70-1.05	1.05-1.40	1.40-1.75	>1.75
Energy expenditure (kcal/min)	<1.75	1.75-3.50	3.50-5.25	5.25-7.00	7.00-8.75	>8.75
Heart rate (beats/min)	< 75	75-100	100-125	125-150	150-175	>175
Sweating rate (ml/hr.-average for 8-hour work day)	—	<140	140-280	280-420	420 560	>560

Table 4

Thermal data (N=252) of three different thermal conditions for work capacity measurements

Dry-Bulb (°F)	Wet-Bulb (°F)	Globe (°F)	Relative Humidity (%)	Air Velocity (Ft/min)	CET (Basic) (°F)
83.0±0.10	67.8±0.12	83.0±0.09	47.1±0.33	175.0±2.37	(Comfortable) 70.6±0.06
91.2±0.13	75.7±0.17	96.0±0.09	48.8±0.41	132.1±2.94	(Warm) 80.7±0.08
100.5±0.15	84.8±0.21	111.4±0.12	51.8±0.41	121.0+2.55	(Very Hot) 90.3±0 04

Mean±Standard Error ; CET (B) = Corrected effective temperature (basic). N = No. of observations.

Table 5

Maximal oxygen uptake of Indian adult male industrial workers (N=84) at three different thermal conditions

Thermal Conditions [CET (B)] °F (°C)	Maximal Oxygen Uptake	
	Litres (STPD)/min	ml (STPD)/min/kg
70.3±0.34 (21.3±0.19)	2.31±0.04	41.08±1 56
80.7±0.42 (27.1±0.23)	2.05±0.05	36.43±1.58
90.2±0.25 (32.4±0.14)	1.81±0.06	32.23±1.36

N=Number of subjects ; Mean±Standard Error ; CET(B)=Corrected effective temperature (basic)

The maximal physical work capacity of all workers was found to diminish gradually for increase of temperature from 70° F to 90° F CET(B).

The differences for different groups in different thermal conditions were statistically significant at 5% level as revealed by Student's 't'-test.

Occupational Work Capacity and Leistungs-Puls-Index : These are given in Table 6.

Table 6

'Leistungs-Puls-Index' (LPI), work pulse sum (WPS), occupational work capacity (OWC) of Indian adult male industrial workers at [70°F CET(B)]

Age Group Years	LPI	WPS	OWC (K. cal/min)	OWC as percentage of MPWC (%)
20-29 N=37	5.08 ±0.18	348.8 ±14.0	2.67 ±0.10	21.7
30-39 N=31	4.33 ±0.18	318.4 ±22.5	3.07 ±0.13	26.4
40-59 N=16	3.81 ±0.28	302.7 ±26.0	3.54 ±0.23	33.2
All groups N=84	4.56 ±0.12	328.8 ±19.4	2.98 ±0.14	25.8

Mean ± Standard error. MPWC = Maximal physical work capacity.

As it would bs seen the LPI did not increase significantly in higher age-groups indicating no reduction of occupational work capacity with age. According to Müller (1962) the fitter and stronger a person, the lower will be his LPI. The lower the LPI the higher would be the energy expenditure which the subject is able to sustain.

Miximal Oxygen Uptake Determined from LPI :

The mean maximal oxygen uptake obtained from the LPI at about 70° F [CET (B)] was 2.53 litres/min in young workers (20 to 29 yrs age-group) which was lower than 4.3 litres/min obtained by Rutenfranz *et al.* (1959) among young workers and 4.2 litres/min obtained by Åstrand(1952, 1956). The actually determined maximal oxygen uptake value for our young workers at about 70° F [CET(B)] was 2.46 lit/min. which was slightly lower than that obtained from LPI.

From student's 't'-test it was seen that there is no significant difference of LPI among the different age-groups.

Occupational Daily Work-load :

The physiological responses of workers during and after continuous work on a bicycle ergometer at three rates and at three different thermal conditions showed that at comfortable condition sedentary workers could perform continuously at 250 Kgm/min and extremely heavy group at 400 Kgm/min, whereas in very hot condition the values were 150 and 300 Kgm/min respectively. From the study it may be concluded that in a tropical climate in India the occupational daily work load of 300 Kgm/min at 80° F [CET(B)] appears to be safe and suitable for the Indian workers for day-to-day work for months without undue fatigue.

ACKNOWLEDGEMENT

The authors acknowledge with gratitude the financial support of the Indian Council of Medical Research, New Delhi. The whole-hearted cooperation of the workers who acted as volunteers in the study is also gratefully acknowledged.

REFERENCES

Åstrand, P. O. (1952) : Experimental studies of work in relation to sex and age. Ejnar Munksgaard, Copenhagen.

Astrand, P. O. (1956) : Human physical fitness with special reference to sex and age. *Physiol. Rev.* **36** : *307-335.*

Christensen, E. H. (1953) : Physiological evaluation of work in Nykroffa Iron Works ; In : Symposium on Fatigue (Ed : W. F. Floyd and A. T. Welford), H. K. Lewis, London, pp. *93 108.*

Maritz, J. S., Morrison, J. F., Peter, J., Strydom, N. B., and Wyndham, C. H. (1961) : A practical method of estimating an individual's maximal oxygen intake. *Ergonomics,* **4** : *97-122.*

Müller, E. A. (1962) : Occupational work capacity. *Ergonomics,* **5** : *445-452.*

Robinson, S. (1938) : Experimental studies of physical fitness in relation to age. *Arbeitsphysiologie,* **10** : *251-323.*

Rutenfranz, J. and Hettinger, T. H. (1959): Zuf. Kinder heilk-kundu, **83** : *65-68.*

Sen, R. N. (1967) : Studies on physiological factors limiting work output of Indian workers, Report to the Indian Council of Medical Research, pp. **78** :

Sen, R. N., Roy, B. S. and Sarkar, D. N. (1969) : Maximal physical work capacity of Indian industrial workers in relation to age and heaviness of job. Proceedings of the 13th International Conference of the Human Factors Society, Philadelphia, Pennsylvania, U. S. A., 6-9th October, pp 13.

Sen, R. N. and Sarkar, D. N. (1972) : Effects of thermal stress on maximal physical work capacity of Indian industrial workers. Proceedings of ICMR National Symposium on 'Health in Relation to Work and Heat Stress' at NIOH, Ahmedabad, 27-29 January, 1972 ; ICMR Technical Report Series No. 15, Division of Publications & Information, New Delhi, p. *159.*

Sen, R. N., Roy, B. S. and Sarkar, D. N. (1973) : Maximal physical work capacity of Indian industrial workers. *Ind. J. Physiol. & Allied Sci.* **27** : *107.*

Sen, R. N. and Sarkar, D. N. (1972) : Occupational work capacity of Indian adult male industrial workers in relation to age. Proceedings of the Seminar on 'Man at Work' at the Central Labour Institute, Govt. of India, Bombay, 11-14 April.

Von Döbeln, W. (1954) : A simple bicycle ergometer. *J. Appl. Physiol..* **7** : *222-224.*