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Physiological Research of Defence Interest in India: Part II–Studies in Thermal Stress, Noise Exposure Hazards, Bioclimatology, Physical Work Capacity, and Effects of Ageing

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ABSTRACT

Scientific evaluation of the caloric requirements of our defence personnel under various operational scenarios has helped rationalise the service ration scale appropriate to each scenario.

Some of our troops have often to work under extremely hot- dry or hot-cold environments which are generally known have adverse effect on the human body. Consequently, the nature of heat illness cases among army personnel and the contributing factors, the requirement of sodium and potassium in summer, quantification of the impact of thermal stress on the physical work capacity and mental functions, prediction of endurance time and safe exposure time while working under hot environments, have been extensively studied.

Exposure to high noise levels is a hazard during gunfire as well as operation of machinery such as engines of ships. Auditory and non-auditory effects due to exposure, and the measures to minimise noise exposure, have been studied. Durations of safe exposure to different noise levels have been prescribed.

Another important area covered is the effect of ageing on physical and capacities. The findings would be useful in the optimal deployment of troops in different tasks.

Defence physiologists have also carried out basic research whose results would be handy in the setting of norms and standards for important physiological parameters and for the ergonomic/physiological evaluation of implements and instruments.

1. RATIONALISATION OF SERVICE RATION SCALES

Before 1963 there were two different ration scales for troops stationed at high altitudes, one providing 5500 kcal for troops stationed between 2743 and 4267 m (9000 and 14,000 ft), and the other providing 6500 kcal for troops at 4267 m (14,000 ft) and above. These were *ad hoc* high calorie scales based on an earlier American report that calorie requirement is enhanced at very low environmental temperatures. In 1963, Army Headquarters wanted these scales to be reviewed. DIPAS carried out time-and- motion studies and energy expenditure studies, and scientifically evaluated the calorie requirement. Based on these studies, a ration scale providing 4900 kcal, which included a cushion of 300 kcal anu consisted of palatable items, was recommended[1]. The revised scale was adopted in 1963 itself. In 1966 there was a second review study, as a result of which the cushion of 300 kcal was deleted, and a new scale providing 4600 kcal, and containing items and quantities based on the expressed preferences, was recommended[2]. These measures, apart from providing need-based palatable items of food, also cut down enormous wastages.

The revised ration scale contained 138 g of fat. There was an apprehension that due to lack of oxygen at HA, such high quantities of fat may not be relished and may not also be absorbed. A carefully designed study by DIPAS at altitudes of up to 4700 m revealed that the

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digestibility and utilization of dietary fat were unaffected even at levels of intake[3] of 324 g at 3800 m, and 232 g at 4700 m .

Similar scientific evaluation of the other ration scales was also done, and a ration scale providing 4100 kcal was formulated[4] for peace and field areas of up to 9000 ft. Ration scales formulated for various categories of personnel are as follows: 3640 kcal for submarine crew[5], 4300 kcal for officers at HA[6], 3968 kcal for pioneers and 3522 kcal for various tradesmen in the Border Roads Organization located at altitudes above[7] 2500 m, and 3360 kcal for boys in Sainik and Military schools[8]. For hospital diet, a new scale providing 3990 kcal was drawn and two separate paediatric diets and special diets for hepatic, renal and diabetic patients were also suggested[9].

2. THERMAL STRESS

2.1 Nature of Heat Illness Cases

The Indian Armed Forces are exposed to extremely hot dry or hot humid conditions. Even though the troops do enjoy the status of heat acclimatized individuals in view of their living in a tropical climate, yet the severity of the operational situations is perhaps beyond their acclimatization, as is shown by a number of heat illness cases admitted in the military hospitals. This problem was extensively and critically studied by DIPAS. Review of heat illness cases reporting to the military and general hospitals during 1963-64 revealed that the majority of the cases were heat syncope cases occurring under hot humid conditions. Incidence of heat stroke cases increased under hot dry conditions where the maximum temperature exceeded 40.6 °C. 25 percent of such cases proved to be fatal. 55 per cent of the cases were exercise-induced heat exhaustion ones and 24 per cent were heat hyperpyrexia cases which occurred at environmental temperatures between 41 and 43.5 °C. Heat exhaustion due to salt/water deficiency and heat cramps were few. In the light of the above findings, outdoor duties were recommended to be totally avoided between 1100 and 1700 hr in the months of June and July[10]. Another significant observation was that hot humid climates impose a greater strain on the thermoregulatory system than hot dry climate[11].

2.2 Sodium Chloride Requirement in Summer

In a few interesting and important studies on the requirement of sodium chloride during summer months, it was noticed that the 19-20 g of sodium chloride contained in the normal ration is adequate even when strenuous military training is undertaken under such hot environments as 104 °F (40 °C), and the sweat loss is 9-10 litres during the day[12-15].

2.3 Potassium Requirement

Even while engaged in moderately strenuous physical activities for 3 h in an environment of 40 °C DB and 32 °C WB, daily dietary intake of 2.15 mg of potassium resulted in a negative potassium balance[16]. Though under hypohydration of such circumstances the sweat rate comes down, the concentration of K^+ in sweat increases, and accounts for the negative balance. Because more severe exertion may takes place under field conditions, especially under hotter conditions, a liberal intake of potassium was recommended[17].

2.4 Impact on Physical Work Capacity

Studies showed that while the maximal oxygen uptake capacity (VO_2 max), which is a measure of physical work capacity, is considerably reduced under hot and very hot conditions, the oxygen cost of the task itself is increased. This is mainly due to the anaerobic fraction of oxygen cost of exercise going up. There is a concomitant increase in the lactic acid content of blood. This results in an early onset of fatigue[18-20].

2.5 Impact on Mental Functions

Psychological functions of mental alertness, associative learning, reasoning ability, and dual performance efficiency were found to be adversely affected under hot environments. The deterioration was more under hot humid conditions than under hot dry conditions. Deterioration sets in around 30 °C (WB)[21]. The impact of the extent of body dehydration on some mental functions was also reported. Mental functions of concentration, eye-hand coordination and substitution deteriorated on an average by 5 per cent, 15 per cent and 28 per cent after 1 per cent, 2 per cent and 3 per cent body dehydration respectively[22].

2.6 Safe Exposure Time

Having studied the adverse effects of thermal stress, defence physiologists made attempts to predict the safe exposure period in relation to work rate and Wet Bulb Globe Temperature (WBGT) index of the environment.

A nomogram was prepared which will be useful in regulating the duration of training or other activities to be performed under hot working conditions[23].

2.7 Routine Surveys

To meet the requirements of Army Headquarters, routine surveys were carried out on the environmental heat stress experienced by personnel in specific situations.

3. BIOCLIMATOLOGY

Since troops are to be stationed at locations with a wide range of climatological conditions, it became necessary to evaluate systematically the severity in different stations. This was done by the Defence Laboratory, Jodhpur, and DIPAS. A new climatic index, 'Linear Dryness Index', was evolved, which is based on the annual average values of precipitation and the diurnal range of ambient temperatures, and indicates the aridity of the place[24,25]. A nomogram for quick evaluation of the index has also been prepared[26].

To provide comfort to patients, military hospitals in hot regions need to be air conditioned. At the same time there should be a norm to decide on the stations to be covered. To meet this latter requirement, a practical index, 'Monthly Excess Maximum Effective Temperature' (MEMET), was evolved[27].

To help assess the climatic hazards under severe cold exposure conditions at HA, nomograms were developed for: (a) hygrometry at subzero conditions (frost point); (b) wind chill factor related to altitude; (c) tolerance time; and (d) a new Cold Stress Index in relation to environment, clothing and activity[28].

For evaluating the thermal stress armed forces experience while undertaking severe manual work under hot environments, two new thermal stress indices, 'Dry Bulb Vapour Pressure (DVP) Index' and 'Globe Vapour Pressure (GVP) Index', were also developed[29].

4. NOISE EXPOSURE HAZARDS

Exposure to high noise levels is known to cause auditory impairment as well as nonauditory effects. Consequently, surveys were conducted to monitor the prevailing noise levels in potential work places where armed forces personnel operate. Prevalence of noise-induced hearing impairment among concerned personnel was also studied, and remedial measures were explored.

Whereas the safe level for occupational exposure for 8 h has been prescribed as 90 dB_A, levels as high as 100-136 dB_A were found in many locations on INS VIKRANT[30]. During sail, engine rooms in naval ships recorded 120 dB_A. 70 per cent of the personnel exposed to this environment were found to be suffering from mild to moderate hearing impairment. Seventy eight per cent of the engine room ratings and 46 per cent of others suffered from loss of hearing[31]. Those with more than 10 years' service were conspicuously affected[32]. In the exposed individuals, non-auditory effects such as raised BP and increased heart rate were also noticed[33]. Elevation of levels of free cholesterol, gamma globulin and cortisol were also observed in these personnel, suggesting that cholesterol esterification process may have been modified, thereby making them more prone to cardiovascular pathology[34].

Continuous exposure of rats to 110 dB for 3 weeks resulted in changes in blood components suggestive of coagulopathy[35]. Such continuous noise exposure of armed forces personnel may not be likely.

Simultaneous exposure to heat and high noise levels (105 dB) impaired the work output much more than due to heat alone[36].

As a preventive measure, personnel were advised to use ear defenders. Other ameliorative measures were also tried. Thus, breathing of carbogen [a mixture of oxygen (95 per cent) and carbon dioxide (5 per cent)] was found to reduce the temporary threshold shift of hearing, possibly through its counteracting effect on the noise-induced vaso-constriction of the blood vessels in the otic region[37]. An extension of this study revealed that pre-as well as post-noise exposure administration of carbogen even for 5 min could be beneficial[38]. The therapeutic role of administration of carbogen to bring relief to men with sensorineural hearing loss was established[39]. Since ameliorative measures may not always be available to the personnel, an attempt was also made to predict the safe duration of exposure to different noise levels, if no ameliorative measure was used[40].

5. PHYSICAL WORK CAPACITY

5.1 Estimation of VO_2 max

In the area of physical work capacity, DIPAS' scientists have studied the influence of temperature on energy cost[41,42], influence of body weight on the energy expenditure in any manual task[43], and prediction of energy expenditure from exercise ventilation[44,45] and from exercise heart rate[46]. Maximal oxygen uptake (VO_2 max) is taken to represent the potential work capacity. But it is difficult to estimate it in the field. In field studies, the correlation between VO_2 max and speed in running was good. Hence, as a field test 1.6 km shuttle run was recommended[47-49]. Another simple and practical method proposed was to plot the oxygen consumption in 4 submaximal exercises against the corresponding heart rates, and through extrapolation to heart rate value of 190, to find out the oxygen consumption at that level. This would be VO_2 max[50]. A predictive formula was developed using the heart rate, ventilation (lung) and oxygen uptake during rest and during a submaximal exercise, maximum voluntary ventilation and maximum heart rate (accepted to be 190)[51]. An attempt was made to predict VO_2 max even from body weight[52].

5.2 Estimation of Oxygen Debt

Normally, for determining the oxygen debt (anaerobic capacity), oxygen consumption is to be measured for as long a period as 1 h after exercise, which is cumbersome. To overcome this, a nomogram was developed for prediction of oxygen debt based on oxygen uptake values at 0-2 min and 0-8 min intervals after exercise[53]. A prediction equation was also worked out[54]. These would be useful in making oxygen debt measurements at high altitudes.

5.3 Estimation of Endurance Time

Another area wherein original contributions were made is the prediction of endurance work capacity or endurance time. Initially, it was shown that endurance time in any exercise is directly related to the extent of aerobic efficiency during that exercise and this could be predicted by an exponential equation[55]. As the severity of work increases, the anaerobic component of the total energy cost also increases, and aerobic/anaerobic ratio decreases. Making use of this, a prediction equation was developed[56], and later, a statistical model was also proposed[57]. These predictive equations will be useful in designing work-rest schedules.

Endurance time while working in a hot environment is complicated by the effect of thermal stress on sweat glands as well as on the cardiorespiratory system. DIPAS studied this and came out with multiple regression equations using sweat rate, work load, thermal stress index and skin temperature[58] the parameters used being interdependent.

5.4 Prediction of Endurance Time from 'Dyspnoeic Index'

Yet another area where some new ideas were proposed was 'dyspnoeic index' during exercise. It was noticed that the respiratory stress experienced by an individual in terms of dyspnoeic index, DI_{Ex} (exercise ventilation as a per cent of maximum voluntary ventilation) is able to predict the endurance duration irrespective of differences in work rates and altitudes. An empirical equation was proposed[59]:

$$t = 3.3 \times (100/DI_{Ex})^3$$

Subsequently, a regression equation

$$t = 5.511 \times (100/DI_{Ex})^{2.135}$$ was reported.

Dyspnoeic index in a standard exercise was found to have good correlation with time for 1 mile run (–0.539) and the number of steps in an endurance step test[60].

Further refinement was made by proposing that a combined index of cardiorespiratory strains during maximal or near-maximal effort was superior to any single stress index for predicting endurance time[61].

5.5 Effect of Drugs on Physical Work Performance

Intake of 3.5 g of monopotassium and monomagnesium DL aspartate, 24 hr prior to exercise, was found to improve the performance by 22.6 per cent[62]. The feasibility of such drug administration is, however, doubtful.

6. EFFECT OF AGEING ON PHYSICAL AND MENTAL CAPACITIES

6.1 Physical Capacity

Information on the critical age/ages above which the physical and mental capacities come down is of interest not only to the armed forces but also to the civil administration. The problem has been studied by DIPAS. The physical work capacity, as determined by a number of field tests and controlled laboratory measurements, fell significantly after 30 years and the fall became more prominent after 37 years[63,64]. The mean value for maximum heart rate attainable during exercise started falling at the age of 30 years, and declined gradually from the level of 188 beats/min at 30 years to 186, 174 and 170 at the mean ages of 34, 46 and 53 years respectively in the study groups. Corresponding values for maximal oxygen uptake were 44.3, 42.1, 39.9 and 36.9 ml/kg-min (i.e. 100, 95, 90, and 83 per cent) respectively[65]. A similar progressive deterioration above 30 years was recorded in another study on civilian fire-fighting personnel[66].

6.2 Mental Capacity

The mental function of immediate memory was observed to be independent of age up to 45 years. Numerical ability improves up to 35 years and gets stabilized thereafter. Learning speed and perceptual efficiency progressively deteriorate above 30 years[67]

7. TOXICOLOGY

DIPAS scientists have also studied toxicity problems of national importance. One of the studies ruled out the possibility of lead poisoning among workers in some defence factories[68]. Toxicology of methyl isocyanate (MIC) was studied in depth[69]. It was surmised that MIC intoxication leads to impairment of brain function probably through stagnant hypoxia[70].

8. ASSISTANCE TO RESOURCES DEVELOPMENT EFFORTS

Defence physiologists have also carried out projects which helped in setting standards, such as in evaluating the quality of implements used by the army and in evolving new techniques.

In the early sixties prefabricated huts were to be used at high altitudes. After carrying out ventilation studies DIPAS prescribed the floor area and space requirement norms, which were used by the R&D Engineers[71]. For monitoring the activity of cutaneous receptors in nerve injury, frostbite and neuropathy cases, special microelectrodes were developed[72]. A dehumidifying equipment was designed and developed for use in naval armament depots[73].

In order to assist the Army Headquarters in procuring quality implements, many commonly used items were subjected to ergonomic/physiological evaluation tests and users were advised. In some cases, suggestions were also made for design changes. Such items covered digging tools[74], shovels[75], mosquito nets[76], a passive night observation device for use by the artillery in the observation posts[77], and indigenously manufactured ear plugs for use in noisy situations[78].

Standards which would be of use to the army have also been set. These cover normal height-weight relation[79], body weight-VO_2 max relation[80], norms for scores in respect of a battery of screening tests which would be used to evaluate candidates at recruitment centres[81], and a new battle physical efficiency test for high altitudes[82].

Realizing that the expertise available in the defence laboratories should be made use of to solve some of the national relevance without, of course, hampering their primary interests, DIPAS scientists studied the various physiological capacities and anthropometric measurements of different categories of Indian athletes of class, and came up with norms for screening parameters to identify promising athletes for different events[83].

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