Environmental, Physiological and Human Factor Research

The success of military missions depends on advanced weapon systems and well-trained fighting-fit soldiers. The soldiers, deployed under different climatic conditions like cold high mountains, hot deserts, hot humid coastal regions, jungles, etc., face immense hardship, which adversely affects their operational efficiency. Work efficiency of humans under these climatic conditions is largely affected due to physiological and metabolic adjustments. Defence Institute of Physiology and Allied Sciences (DIPAS), one of the life sciences laboratories of Defence Research and Development Organisation (DRDO), is a premier institute in the country working in the field of physiology, biochemistry and nutrition with a view to improve the operational efficiency of soldiers in relation to micro and macro environments. The Institute has modern infrastructure for physiological, biochemical, biomedical and molecular (proteomics and genomics) research in relation to holistic health and performance improvement.

The major areas of research at DIPAS are physiology of high altitude, cold and hot environments, exercise physiology, neurophysiology, nutrition, immunomodulation, occupational health, anthropometry and ergonomics along with biochemistry, biotechnology, genomics and proteomics as new frontiers. Basic and applied researches conducted by DIPAS in a laboratory set-up and actual field conditions have been translated into recommendations and products for making life of soldiers comfortable with improved efficiency. This issue of Technology Focus highlights notable contributions and technologies developed by DIPAS which have defence applications. Some of these technologies have civilian spin-off also.

High Altitude Research

High altitude is characterised by hypoxic environment, cold and ultraviolet (UV) radiations, which causes adverse effect on work efficiency and cognitive functions of an individual along with acute mountain sickness, and sometimes debilitating frost-bite or life threatening diseases like high altitude pulmonary edema (HAPE) and cerebral edema (HACE).
DIPAS has standardised and developed acclimatisation schedules, nitric oxide therapy for HAPE, treatment for cold injuries, heating devices and rapid induction strategies for troops posted at high altitude locations.

**Acclimatisation Schedule and Tenure of Posting at High Altitude**

DIPAS has standardised acclimatisation schedule (staging of acclimatisation) for the Indian army for induction of troops at high altitude locations on the basis of a detailed longitudinal study of physiological, psychological, biochemical and hormonal profile of active soldiers under high altitude field conditions. This has helped the army in significantly reducing altitude-related maladies. A study carried out at sea level and at different intervals, during prolonged stay at different altitudes and than one month after return to sea level helped in establishing total tenure of posting for two years at 2700-4500 m and 3 months above 4500 m. This schedule has proved safe and effective for keeping troops physically fit under stressful conditions at high altitude.

**Nitric Oxide Therapy of HAPE**

Treatment with a combination of nitric oxide (15 ppm) and oxygen (50 per cent) significantly improves oxygen diffusion capacity of lungs in HAPE patients. Commercially available nitric oxide delivery systems work in conjunction with a ventilator whereas patients suffering from HAPE breath spontaneously. DIPAS has developed an indigenous nitric oxide and oxygen delivery system in collaboration with sister DRDO establishment R&DE (Engrs), Pune. The indigenous system helps in providing precise gas mixture of 15 ppm nitric oxide and 50 per cent oxygen. The system (Mark II) comprises a mass flow controller, which assures accurate mixing of gases prior to delivery to the patient through analysers with display of levels of gases. The gas mixture can be delivered at two flow rates, 10 and 24 l/min, depending upon the condition of the patient. The system is also useful in prevention/treatment of various other conditions/ailments like acute respiratory distress syndrome (ARDS), neonatal paediatric pulmonary hypertension, cardiorespiratory disorder, congenital heart disease, primary pulmonary hypertension, lung transplantation and cardiac surgery.

**Treatment of Cold Injuries**

Therapeutic re-warming in decoction of tea-leaves and combined therapy of pentoxifylline, aspirin and vitamin C with prophylactic application of Aloe Vera cream is found very effective in the treatment of cold injuries. DIPAS has developed Alocal, an Aloe Vera-based cream containing 50 per cent Aloe juice (w/w).
It is non-greasy, and does not freeze on flake at sub-zero temperatures. In addition to frostbite, this cream can be used for burns, wounds, ulcers, cracking and chapping of skin, cuts and antiseptic dressing.

**Space Heating Devices**

DIPAS has developed improved version of kerosene-based *bukhari* to keep living space warm at high altitude. The new device is safe, keeps the carbon monoxide levels below detection limits, and is fuel efficient. The double walled jacket, special burner and exhaust system with protection against backflow of air are some of its key features. Besides, a solar heated hut *Sourja* with provision of charging batteries from solar and wind energy has also been designed and fabricated for cold regions.

**Rapid Induction Strategies**

In case of emergency, when proper acclimatisation at high altitude is not possible, use of pharmacological agents such acetazolamide and glucocorticoid has been found beneficial to prevent acute mountain
sickness. Possibility of using hypoxia mimetics (agents which stabilise hypoxia inducible factor HIF1-α), viz., cobalt chloride, and intermittent hypoxic training at sea level is being evaluated for rapid acclimatisation at high altitude. Studies are on for rapid induction by providing oxygen enrichment shelters to the troops at high altitude.

Research in Desert Environment

Desert poses challenge for human adaptability because of decreased performance due to high ambient temperature, intense solar radiations, hot winds and loose sandy terrain. Similarly, hot humid environment causes much discomfort as benefit of cooling through evaporation of sweat is compromised. Work or exercise in hot environment causes heat stress. The physiological strain imposed by exercise-environmental stress depends on the individual’s metabolic rate and capacity for heat exchange with the environment. Physical work increases metabolism by 5 to 15 times of the resting rate. The effectiveness of the thermoregulatory system in defending body temperature is influenced by the acclimatisation status, aerobic fitness and hydration level of an individual. When core temperature of body rises above 41 °C due to heat exposure, pathological conditions and failure of thermoregulatory mechanism, the physical and mental performance deteriorates rapidly and condition may become life threatening. Heat acclimatisation depends not only on temperature to which one is exposed but also on the levels of physical activity. Proper acclimatisation reduces physiological strain with respect to heat stress, improves physical work capabilities, thermal comfort, and protects an individual from heat-related disorders. The most important biological response for heat acclimatisation is the lowering of sweat threshold.

A survey conducted by DIPAS to know the causes of heat disorders showed that while 55 per cent illnesses were due to exercise-induced heat exhaustion, heat pyrexia accounted for 24 per cent and was reported on the days when temperature was between 41-43.5 °C. It was suggested to avoid outdoor activities between 1100-1700 h in months of June and July, which has resulted in complete prevention of heat casualties. The existing acclimatisation schedule being followed by Indian soldiers is 110 min heat exposure with sub-maximal work daily for eight days.

Heat acclimatisation is short lived and decelerates rapidly if individual is exposed to cold climate. In a study 12 Indian male soldiers were acclimated to heat for eight days at 45 °C dry bulb temperature and 30 per cent relative humidity, and were subsequently exposed to 10 °C for 21 days (4 h/day). The study showed significant loss, in the range of 45-56 per cent, in heat acclimatisation, both in terms of oral temperature and heart rate during exercise. However, within three days, full acclimatisation status was regained.

Another study was conducted to find out cross-adaptability between cold and heat stress as this was supposed to develop general adaptive resistance following exposure to stress. Normally, excess body heat is reduced by various physiological mechanisms. When air temperature is above skin temperature, evaporation of sweat is the only mechanism to loss heat. Fluid loss due to sweat is compensated by water consumption to prevent dehydration. The dehydration limits physical and mental performance and can be life threatening.

Several studies, conducted to evaluate effect of graded hypohydration on physical work capacity and mental functioning, have pointed significant decrease in these functions at 3 per cent hypohydration. Significant decrease in plasma volume at 3-4 per cent hypohydration was reported using radiotracer (iodinated serum albumin). On rehydration, the plasma volume recovered quickly in case of 3 per
cent hypohydration. But in 4 per cent hypohydration, group restoration was not complete within the time used for sampling, which suggests loss of water from intracellular compartments. Use of ion specific rehydration fluid, i.e., K⁺ rich fluid, which is a major ion of intracellular compartment, was therefore suggested.

Adequate fluid replacement overshadows all other considerations of nutrient requirements in a hot environment. Drinking adequate water in hot conditions prevents dehydration, heat illness and reduced performance. Heat acclimatisation relatively has no effect on water requirements. Thirst is a poor indicator of hydration status. Intense thirst is usually noticed at 5 to 6 per cent body weight loss due to hypohydration. By this time individual’s physical performance is compromised.

Severe hypohydration can lead to decreased blood volume and increase in plasma osmolality, which can result in decreased sweating and heat dissipation. Eighty per cent of the energy metabolised during exercise in hot environment is liberated as heat (only 20 per cent is utilised as mechanical work) and 80-90 per cent of heat dissipation during work in a hot-dry environment is accomplished by the evaporation of sweat. Each millilitre of sweat evaporated from the skin leads to heat loss of approximately 0.6 kcal.

Sweating vary to a great extent from individual to individual, but can reach 2 l/h. A study conducted on 4000 Indian soldiers in Barmer and Ferozpur Sector for determining salt and water requirements at 33.5 °C showed the sweat rate about 1.9 kg/h. To ensure safety under this rate of sweating, 9-10 l of water intake per day is required; salt deficiency was not noticed with existing ration without any supplementation of salt. There is a difference in sweat gland activity of efficiently acclimatised and unacclimatised individuals in terms of number of active sweat glands and location. Back and forearm are the main places that provide efficient cooling. Hypohydration, in large part, depends upon sweat rate, which in turn is determined by workload and duration of the work done. Other environmental factors are solar load, wind speed, relative humidity and clothing. To prevent hypohydration, fluid should be taken regularly whether one is thirsty or not. Taking water before prolong work in heat is less beneficial compared to same quantity ingested during short intervals during work.

DIPAS has developed a bismuth-telluride-based solid-state cooling system to combat the high heat loads encountered by the troops inside tanks in hot desert conditions. The system has been found very effective and provides micro-climate cooling capable of
removing 300 W of heat at 55 °C ambient temperature. DIPAS is presently working on miniaturisation of this device to make it man-mounted and effective to provide comfortable working environment to all the crew members with the available power source of the tank.

**Nutritional Support**

Adequate nutritional support is must for maintaining highest level of physical fitness under different climatic conditions and operational situations. DIPAS has made significant contributions in the field of military nutrition since 1963 when the ration scale for high altitude was introduced. Subsequently, various ration scales such as peace and field scales, high altitude officer's ration scale, submarine ration scale, different diets for army hospitals, ration scales for military and sainik school boys, and ration scales for tradesmen and pioneers under Border Road Organisation were evaluated for adequacy and suggestions were made to improve their nutrient contents. Under snow-bound hilly terrain with sub-zero temperatures, energy expenditure is in the range of 4500-5000 kcal per day. Similarly, under extreme conditions weight loss due to high altitude anorexia is very common. To ameliorate ill effects of anorexia, a variety of palatable food items were advised for inclusion in the ration. Efforts are being made to elucidate exact mechanism of altitude anorexia so that a preventive or curative agent can be developed. Appetite regulatory peptide hormones such as leptin and ghrelin have emerged as potential targets. In recent studies, effects of appetisers have been evaluated at high altitude and products (soups and munches) developed by sister DRDO laboratory DFRL have been found very effective.

DIPAS periodically reviews the nutritional requirements and adequacy of ration scales for the three forces under different climatic conditions, during basic and specialised trainings such as commando and high altitude warfare, and for the coast guards both in eastern and western naval commands. Energy requirements have been evaluated using standard methods such as oxygen consumption and latest techniques (doubly-labelled water and accelerometry-based activity monitoring devices were used for the study). Ration scales of armed forces are well balanced in macro and micronutrients to provide adequate nutrition support to soldiers whose energy requirements are in the range of 3600-5000 kcal under specific operational conditions or training.

DIPAS is also investigating role of specific vitamins, minerals, antioxidants and nutraceuticals for the performance enhancement of soldiers. Studies related to vitamin requirements at high altitude when soldiers are taking MRE (Meal Ready-to-Eat), have indicated that there is no need of extra vitamin supplementation resulting in saving of the exchequer. Basic studies on gastrointestinal functions and digestibility of nutrients at high altitude and also during energy restriction have got very good citation in scientific literature.

**Multiple-Stress Model for Evaluation of Adaptogenic Activity**

DIPAS has developed an experimental cold-hypoxic-restraint (CHR) model for the evaluation of anti-stress and endurance promoting products (herbal or synthetic) with adaptogenic activity (providing
nonspecific resistance against stress). The model has been accepted by the scientific community and pharmaceutical industry. The model has helped in identifying composite Indian herbal preparations (CIHP I and II) as effective anti-stress agents for soldiers deployed at high altitude and at low intensity conflict areas.

**Anthropometric Databases**

Indian army comprises multiethic population with diverse anthropometric characteristics. The need to design clothing and personal protective warfare equipment for the armed forces necessitated the collection of appropriate anthropometric data spread over a very large population of Indian forces. DIPAS carried out an anthropometric study involving 11458 Indian army and 2072 Indian naval personnel. Measurements of 76 body dimensions/composition were made in four age groups of 18-22, 23-28, 29-33 and more than 33 years. The vast heterogeneous Indian military population was divided into nine size groups based on the chest and waist girths, specifically for designing of clothing to manage inventory with ease. The feedbacks of fitment trials were highly encouraging. Anthropometric database on 7587 Air Force personnel has also been generated and nomograms formulated on the basis of body mass index (BMI) in a desirable range of 18-25, per cent body fat (desirable <20) and waist-hip ratio (<0.9). Sizing of uniforms, personal equipment, protective clothing and life-support systems has also been formulated. Recommendations on height-weight nomogram on the basis of per cent of body fat (<20) for males and BMI (18-23) for men and women have been accepted by the Indian Air Force for assessing the health status in the induction medical examination. Recommendations on sizing parameters for various items of flying-clothing for Indian Air Force pilots have also been accepted and implemented.

Anthropometric database on Indian women has also been created to narrow down the gap of information and to address the need of women who intend to adopt various professions. The data on 4350 female students of 12-20 years age from schools and colleges from 31 locations from 27 states and union territory of Andaman and Nicobar were collected on percentile values of body composition, various dimensions and precise anatomical landmarks for taking measurements, ergonomic, and human-factor engineering aspects. This database will find its use in setting recruitment standards for females in various services from different regions of the country and provide knowledge about their health status, their needs related to clothing, and personal safety gadgets. It will also provide necessary information for ergonomic designing of workspaces, seats, controls, etc.

**Ergonomic Evaluation of Workstations and Systems**

DIPAS has facility for ergonomic evaluation of various workstations with respect to spatial accommodation, posture, clear vision of working field and operational comfort in office systems and sub-systems. The workstations, designed with computer-
aided human modelling, include LCA cockpit, missile launchers, command posts, ground systems and other military vehicles. Forty-five human models of Indian Army and IAF pilot population have been developed based on anthropometric data of Indian soldiers. Using these, evaluation of LCA PVS cockpit, hull and turret of Abhay, light armoured wheeled vehicle, light specialised vehicle, military command post of BrahMos, different radar consoles and command post, and modern submachine carbin have been made. DIPAS participated in MBT Arjun Programme since beginning and provided valuable inputs related to physiological, ergonomic and human-factor evaluations at various stages of the Arjun’s development.

An ergonomic design of bulletproof jacket and its prototypes, made by coordinated efforts of different DRDO laboratories, are being evaluated for development. Physiological evaluation of NBC clothing under simulated hot conditions and shelters has also been carried out by DIPAS. Use of eye movement recording system along with physiological monitoring (cognitive ergonomics) has been made for suggesting suitable font type, display of signals and information in different workstations.

**Load Carriage and Backpack Design**

A soldier has to carry arms, ammunition and food under stressful operational conditions, viz., heat, cold, sandy and snow-bound hilly terrains. The performance of a soldier is affected by load handling capacity. DIPAS carried out studies in actual field conditions for standardisation of load carrying ability of the individual soldier. Variations in physiological criteria poses a constrain to suggest any specific limit for lifting task, however 33 per cent \( O_2 \text{ max} \) was found to be more reasonable criteria for recommending the lifting limits. Also, maximum acceptable weight lifting (MAWL) capacity has been evaluated in 1800 turning asymmetric operations in three different heights and three different frequencies for 8 h operation by psychophysiological technique. The MAWL was highest (29.8 kg) in floor to knuckle height in 1 lift per min and lowest (14.6 kg) in knuckle to shoulder height in 8 lifts per min.

The physiological optimum speed at which the energy cost in load march influenced by magnitude of the load carried as well as the steepness of the terrain was also studied. Using a quantitative relation \( F=\)
6.5 x $S^{0.7}$ (where $F$ is the percentage fall in optimum speed and $S$ the steepness of the terrain in per cent), the optimum marching speed for different terrain and load conditions can be easily worked out.

DIPAS has designed a one-load carriage ensemble (backpack) based on ergonomic principles for Indian armed forces. First physical prototype of the same has been developed. This backpack is an integrated height adjustable system and contains space for keeping the items like haversack, additional sleeping bag, INSAS rifle, etc. This prototype of the integrated backpack was evaluated and compared with the physiological responses of the existing load carriage ensemble (LCe). Physiological responses (HR, VO$_2$, VCO$_2$, EE, RF, VE and per cent VO$_{2 \text{ max}}$) of soldiers were recorded at 0 and 5 per cent gradients while walking at 4.5 km/h speed with 21.3 kg load in both the LCe. The existing LCe include Pack 08, haversack, web and INSAS rifle.

**Indigenous Hyperbaric Chamber: Samudrasuta**

An indigenous hyperbaric facility, *Samudrasuta*, has been developed for research on underwater physiology and medicine, treatment of decompression illness,
and hyperbaric oxygen therapy for carbon monoxide poisoning, post-operative recovery and treatment of certain type of malignancies. It consists of two decompression chambers—a static clinical chamber (for 2 to 5 patients at a time) has been installed at Shore Hospital, INHS Asvini, and other a portable chamber that can accommodate one person (divers/patient) for transfer from remote areas. Both chambers are capable of operating at 5 bar (6 ATA) and provide safe, reliable temperature and humidity control along with breathable gases.

*Samudrasuta* is equipped with state-of-the-art biomedical instrumentation like wireless ECG, EEG, blood pressure and transcutaneous oxygen monitor for monitoring of critical physiological variables. The system follows rigorous safety norms and is fire proof.

**Evaluation of Cognitive Functions**

DIPAS also monitors cognitive functions under environmental extremes and sleep deprivation. The Institute has various type of maze systems to study different behaviour of laboratory animals. Efforts are being made to develop protective strategies against decline in cognitive functions under stressful environments. Study of changes in circadian rhythm and stress response under polar environment has been carried out both in the Arctic and Antarctica. Immune functions and changes in melatonin levels, appetite regulating peptides have been studied by regular participation in different Antarctic expeditions.

**Prevention of Noise-induced Hearing Loss**

Noise-induced hearing loss (NIHL) is an occupational problem of armed forces as well as civilians working under excessive noisy environment. Breathing of Carbogen, a gas mixture of 95 per cent oxygen and 5 per cent carbon dioxide, has been found beneficial in prevention and treatment of NIHL in various studies/clinical trials conducted by DIPAS. Initially, a single-user Carbogen Breathing System was developed by DIPAS. Keeping in view the requirements of larger populace engaged in noisy occupational environments, e.g., maintenance and operation of aircraft, various firing ranges, ordinance factories and industrial workshops of army, a kiosk-type multi-user system equipped with 10 user stations has been fabricated to facilitate inhalation of Carbogen by 10 persons at a time. The system can be installed at designated place near the noisy workstations for easy access to the users and has been designed for the minimum footprint while accommodating 10 user stations. Each breathing site/
outlet, similar to the single unit assembly, contains a control panel on the top fitted with red and green LED indicators to indicate the start and continuation of the Carbogen supply. A buzzer warns the user on the completion of the five minutes. The system timer is battery operated and can be easily converted to function on mains. A nebuliser humidifies the gas before its inhalation through a double valve breathing mask. The flow of gas is indicated in the flow meter with the help of a float and can be adjusted to deliver a regulated flow rate to the desired level of resting minute ventilation. Six 47 litre gas cylinders housed in the body of the equipment supply the Carbogen to the 10 breathing sites. However, the system can also functionoperate with one or more cylinder(s); leaving the other sites free for easy replacement of cylinders.

**Alternative, Herbal and Complementary Medicines**

DIPAS is also working on alternative, herbal and complimentary medicines in pursuit of health and well-being of the Indian soldiers. Some of the developments made by DIPAS are described here:

**Neem Contraceptive**

A contraceptive from neem oil has been developed after extensive evaluation of spermicidal activity, and sub-acute and acute toxicity studies. The formulation, in the form of pessary (CONCEPT) using the spermicidal fraction from the neem oil (NIM-76) has been developed. The pre-clinical toxicity studies at DIPAS and Rallis Research Laboratory and Phase I clinical trials at AIIMS, Delhi, and PGIMER, Chandigarh, have successfully been completed with encouraging results. This product has also been found effective against various bacterial infections. National and international patents have been obtained.

**Customised Yoga Packages for Health**

Beneficial effects of yoga (asana and pranayama) on body homeostasis and for improving the performance (both mental and physical) of soldiers under different climatic extremes and training have been established by extensive scientific studies by DIPAS. Different yoga packages have been developed and instructors from army are being trained by professional yoga trainers to impart training to larger population. Yoga will be introduced gradually as a part of basic training in all the three wings of armed forces.

**Herbal Wound Healer**

A wound healing cream (DIPAS HERBOHEALER), effective against different types of general and chronic conditions.
type of wounds like diabetic and burn wounds, is being developed from extract of a high altitude plant. Wound healing efficacy of various extracts is being evaluated using physical, clinical and biochemical markers of healing.

Herbal Adjuvant

An herbal adjuvant (DIP-HIP), developed and evaluated along with various antigens for immunogenic activities, has been found at par with alum, the only adjuvant approved for human use. Besides, herbal lipid lowering agent, anti-stress agent and memory enhancing cocktail are in the process of preclinical evaluation.

Future Scenario

The tasks of soldiers are likely to get more and more complex with advancement of technology and each soldier will have to perform multitasks at a time with highest degree of accuracy and precision under global environments. Maintaining highest level of cognitive and physical performance will be possible by using integration of modern technology-intensive sciences (genomics, proteomics, transcriptomics, metabolomics, nutrigenomics, etc.), nanotechnology and system biology. Efforts are being made to develop predictive markers for acclimatisation, performance and screening of suitable individuals for specific tasks/missions with respect to environments.

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