

21 Prediction of severe body cooling in a hypobaric environment

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Major changes in the heat transfer processes on the human body under hypobaric environments occur in heat transfer coefficients for convection ($h'c$) and for evaporation of sweating ($h'e$). A ratio ($h'e/h'c$) is known as the Lewis relation and is defined in terms of barometric pressure (P_b), in Torr, by $LR=(h'e/h'c) = 2.2(760/P_b)$. In the equation above a term ($h'c$) is also affected by (P_b) and is given by $h'c=hc(P_b/760)^{0.55}$, where (hc) represents a sea level value. These relationships indicate that at 0.4 ATM the rate of convective heat loss decreases as much as 40%, contrary to the evaporative cooling power of the environment which increases up to 50%. The following equation describes the rate of respiratory dry and evaporative heat losses, ($C + E$) res, at a barometric pressure P_b in terms of the rate of pulmonary ventilation and enthalpy difference between exhaled and inhaled air.

$$(C + E) \text{ res} = Vbtps \cdot (P_b - P_a) / 760 \cdot 10^3 / 28.34 \cdot T^* (i_{ex} - i_{in})$$

where:

$Vbtps$ = pulmonary ventilation, body temperature and pressure, saturated with water vapor in l/hour

P_a = ambient vapor pressure in Torr

T = absolute temperature in K

i_{ex}, i_{in} = enthalpy of exhaled and inhaled air in kcal/kg.DA

As is well known the volume of pulmonary ventilation increases inverse-proportionally to the barometric pressure. And furthermore enthalpy of expired air increases significantly under hypobaric conditions, since the water vapor content is not affected by ambient pressure in the thin air. Thus assuming the exhaled air is saturated with the water vapor, the product of the increased $Vbtps$ and enthalpy difference ($i_{ex} - i_{in}$) is several times as much at high altitude compared with sea level conditions. For example at 0.4 ATM or at an altitude of about 7000 meters with ambient air temperature of minus 30 degrees C, man may lose 80 to 100 kcal of body heat in one hour, since his pulmonary ventilation rate is expected to increase as much as five times, and this heat loss corresponds to the resting metabolic energy. In other words man may lose all of his metabolic heat through respiration. It seems that quite a few numbers of fatal accidents at high altitudes might be caused by the failure of physiological adaptation related with the hypoxia. However, severe body cooling resulting from hyperventilation may also easily extend the climber to the limit of his physiological tolerance.

22 Effects of training at altitude on physical performance

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Study of mechanisms of high altitude physiology and acclimation to hypoxic stress particularly under the added stress of exercise has been a popular topic of investigation for more than a century. The term hypoxia is derived from Greek and means simply "less than a normal amount of oxygen". Hypoxia resulting from altitude exposure is termed hypoxic hypoxia and results in a reduced arterial oxygen content from a decrease of the partial pressure of oxygen in inspired air (P_{iO_2}).

Strenuous exercise itself induces an arterial hypoxemia in athletes under normobaric conditions and thus athletic performance is particularly compromised at altitude.

Devising methods to minimize the effect of an oxygen deficiency in the surroundings is a challenging environmental ergonomic problem and has been attempted by a variety of methods including:

- i) Hypobaric exposure of subjects in decompression chambers prior to hypoxic exposure
- ii) Chemical suppression of negative metabolic reactions to hypoxia
- iii) Prior attainment of a high degree of fitness by potential altitude sojourners

- iv) Design of optimal patterns of movement to high altitude in order to minimize its debilitating effects through gradual acclimatization
- v) Design of portable devices simulating altitude effects which may be worn while training in normobaria in order to effect prior acclimation

The effectiveness of these methods will be analysed in this review particularly in light of the varying cardiorespiratory characteristics required to operate at peak levels at medium or high altitudes revealed in the recent literature by such studies as Operation Everest I (American Everest Scientific Expedition) and Operation Everest II (the USA I.E.M. 40 day decompression chamber expedition).

23 Cardiorespiratory adjustments to work in cold hypoxic environments

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During submaximal workrates, a competition exists between the cutaneous circulation and the working muscles for blood, the former attempting to enhance heat loss and thus maintain thermal equilibrium, and the latter to adequately supply the muscles with oxygen. The present study investigates the adjustments made during exercise in hypoxic environments and also examines the added effect of cold on the cardiorespiratory and thermoregulatory systems.

Six male subjects exercised on a bicycle ergometer at 50% of their maximal working rate, at an ambient temperature of 0°C and 20°C, inspiring either 20% O₂/80% N₂ or 12% O₂/88% N₂. Subjects participated in the exercise trials on a weekly basis. The order of the trials was randomized and periodic tests of maximal oxygen consumption were conducted throughout the experimental period to account for any training effect. Physiological variables were monitored continuously during a five minute period of unloaded pedalling and the twenty minute work regime. The non-invasive Fick method was used to assess cardiac output and stroke volume during minute fifteen of the work period.

Results indicate no difference in the core temperature or cardiac output during the four experimental conditions: I. Normoxia/20°C; II. Normoxia/0°C; III. Hypoxia/0°C; and IV. Hypoxia/20°C. In the normoxic conditions (I. and II.) the reduction in heart rate during exercise in 0°C was accompanied by an elevated stroke volume. Hypoxic environments (III. and IV.) induced dramatic increases in ventilation and heart rate with a concomitant decrease in stroke volume.

It is concluded that a cold environmental stimulus in hypoxic environments aids venous return by enhancing vasoconstriction. The cold ambient conditions allow a greater dissipation of metabolic heat generated through exercise and thus reduce the competition for blood between the exercising muscles and the cutaneous circulation.

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24 Modelling human exposure to altered pressure environments *T.R. Hennessy*, Admiralty Research Establishment, Teddington, Middlesex, United Kingdom

During a reduction in environmental pressure inert gas forms in some tissues and if the pressure drop is too large or rapid a critical excess quantity of undissolved gas will