Attenuation of Heat Induced Physiological Strain by 100% Oxygen Breathing

Sqn Ldr MB Dikshit*, Capt AM Mahmoodi†, and EM Iyer‡

Abstract

ELEVEN healthy male volunteers were exposed to an environment of 57°C DB, 35.50°C WB during air breathing and 100% oxygen breathing. The latter procedure reduced excess heat storage at the end of the heat exposure, thereby increasing the time taken to reach the level of physiological strain at which performance decrement is likely to occur. This demonstrates an increase in tolerance to severe heat stress. Further experiments suggest that the beneficial effect of 100% oxygen is due to an increased respiratory heat exchange (RHE) because of the dryness of the gas.

Introduction

IAF pilots flying low level high speed missions in the summer have often commented that breathing 100% oxygen during such flights makes them feel more comfortable and less fatigued. Such a phenomenon could be due to psychological reasons, due to cooling of the face produced by a stream of cool dry oxygen or due to physiological causes which actually reduce heat induced physiological strain.

It was therefore thought it worthwhile to compare the effects of 100% oxygen breathing and ordinary air breathing during exposure to a simulated, commonly encountered, inflight hot environment on recognised heat strain indices. The results indicate that 100% oxygen breathing during heat exposure significantly attenuates heat strain.

Material and Methods

Eleven healthy Air Force male volunteers acted as subjects. Their physical characteristics are summarised in Table I. These men were well motivated and familiarised with the heat stress laboratory and hence psychological factors were not expected to play any significant role in their physiological responses to the severe heat stress.

TABLE I

Physical characteristics of subjects (n = 11)

	Age (yrs)	Height (cms)	Weight (kg)	Body surface area (M^2)
Mean	31.9	170.2	65.0	1.75
s.d.	±5.1	±5.1	±7.1	±0.2

Each subject was exposed on two occasions at least 5 days apart, to a hot environment of 57°C dry bulb (DB) and 35.50°C wet bulb (WB)– an Oxford Index of 38.7°C– for a period of 50 minutes. This temperature profile is commonly encountered during our routine summer flying conditions in fighter sorties which usually last for about 50 minutes.

On one occasion, the subject breathed room air through a Mk 17E oxygen regulator connected to his PQ Oxygen mask while on the other, he took in 100% oxygen through the same regulator/mask assembly. He also wore routine flying clothing.

The subjects were exposed to a thermally controlled environment of 21°C DB, 19°C WB for ½ hour prior to entering the hot cockpit, as well as during recovery after the heat exposure.

Head of the Dept. of Physiology, Institute of Aviation Medicine, IAF, Bangalore - 560 017.

C/o. Iraqi Air Force, Govt. of Iraq.

SSO I (Bio-Chem), Dept. of Physiology, Institute of Aviation Medicine, IAF, Bangalore - 560 017.

The following physiological parameters were recorded just prior to entering the hot cockpit and at 10 minutes intervals during the heat exposure. (During recovery only HR and temperature were recorded at 5 minutes intervals).

(a) *Heart rate (lead II ECG)* : This was recorded on one of the channels of a Grass model 5C Polygraph.

(b) *Skin temperature* : From chest, arm, right thigh, right leg with thermocouples whose output was directly recorded on to an Ellab, Electrolaboratory (Copenhagen) electric thermometer. The skin sites were chosen to calculate mean skin temperature (Tsk).[12]

(c) *Oral temperature* : This was recorded with the help of a thermistor probe whose output was read directly on to a Yellow Springs Instruments Telethermometer (Range 20°C to 42°C). The probe and thermometer were calibrated against a standard mercury surface contact laboratory thermometer for temperatures 30°C to 45°C.

(d) *Sweat loss* : This was taken as the difference in weight before and after the experiments as observed on an Avery balance (reading to within ± 10 grams) expressed as mgm/cm²Body surface area/min[6]. From the above parameters the following heat strain indices were calculated.

(i) Heat storage in kilocals/m²

$$= \frac{\text{Wt Kg} \times 0.83 \times \text{rise in mean body temp}^{8}}{\text{Body surface area m}^2}$$

MBT was calculated as $2/3\ T_{oral} + 1/3\ Tsk$[1].

(ii) Accumulative circulatory strain index (IC)[7]

$$= 85\ \text{HO}\ \log \frac{85}{(85 - \triangle \text{HR})}$$ where HO was the control heart rate and $\triangle$ HR is the change in HR.

(iii) Modified Craigs index (IS)[8]

$$= \frac{\text{HR}}{100} + \triangle T_{oral} + \text{sweat loss in Kgs/hr.}$$

In this equation T_{oral} was used instead of T_{rectal} as T_{oral} is a better indicator of core temperature in conditions of rapidly changing T_{core}[17].

Statistics : Standardised 't' test[1] was used to compare the mean differences of the heat strain indices as observed in the two experimental conditions at the end of 50 minutes. During recovery the slopes of the heart rate and mean body temperature curves were compared by weighted averages. All values have been expressed as mean $(\overline{X}) \pm$ Sd of X.

Results

Two of the subjects developed symptoms of acute discomfort at the end of 40 minutes and had to be taken out of the hot cockpit. While they have been included in the calculation of IS, IC as these parameters are independent of the time factor, they are shown separately for heat accumulation. (Table II).

TABLE II

Heat storage in kilocals/M² in subject numbers 2 and 10. Duration of heat exposure 40 minutes

Sub. Nos.	Breathing air	Breathing 100% Oxygen
2	66.1	58.9
10	77.5	62.0

Heat Storage : In 9 subjects who completed 50 minutes of heat exposure in both protocols is given in Fig. 1. In the air breathing experiments there was a heat gain of 88.4 ± 10 (Sd of $\overline{X}$) kilocals/m² while with oxygen breathing the heat gain was 79.8 ± 6.6 kilocals/m². The difference of 8.6 kilocals/m² was statistically significant ($P < 0.05$). Two subjects who could not complete the air breathing also showed lesser heat accumulation with 100% oxygen breathing (Table II).

When the heat storage in 9 subjects is plotted as a function of time (Fig 2), it is seen that this parameter increases linearly for both the experimental conditions.

Modified Craigs Index (IS): At the end of heat exposure (Fig 1) IS was 3.79 ± 0.5 (Sd of X) with oxygen breathing. This was significantly less than an IS of 4.33 ± 0.53 incurred due to air breathing ($P < 0.01$) (Fig 1).

Accumulative Circulatory Strain Index (IC) : IC also indicated a significant reduction ($P < 0.05$) in heat strain (Fig 1) due to breathing 100% oxygen (IC = 1934.4 + 545.4 Sd of $\overline{X}$) as compared to the IC due to air breathing (2429.6 ± 610.4).

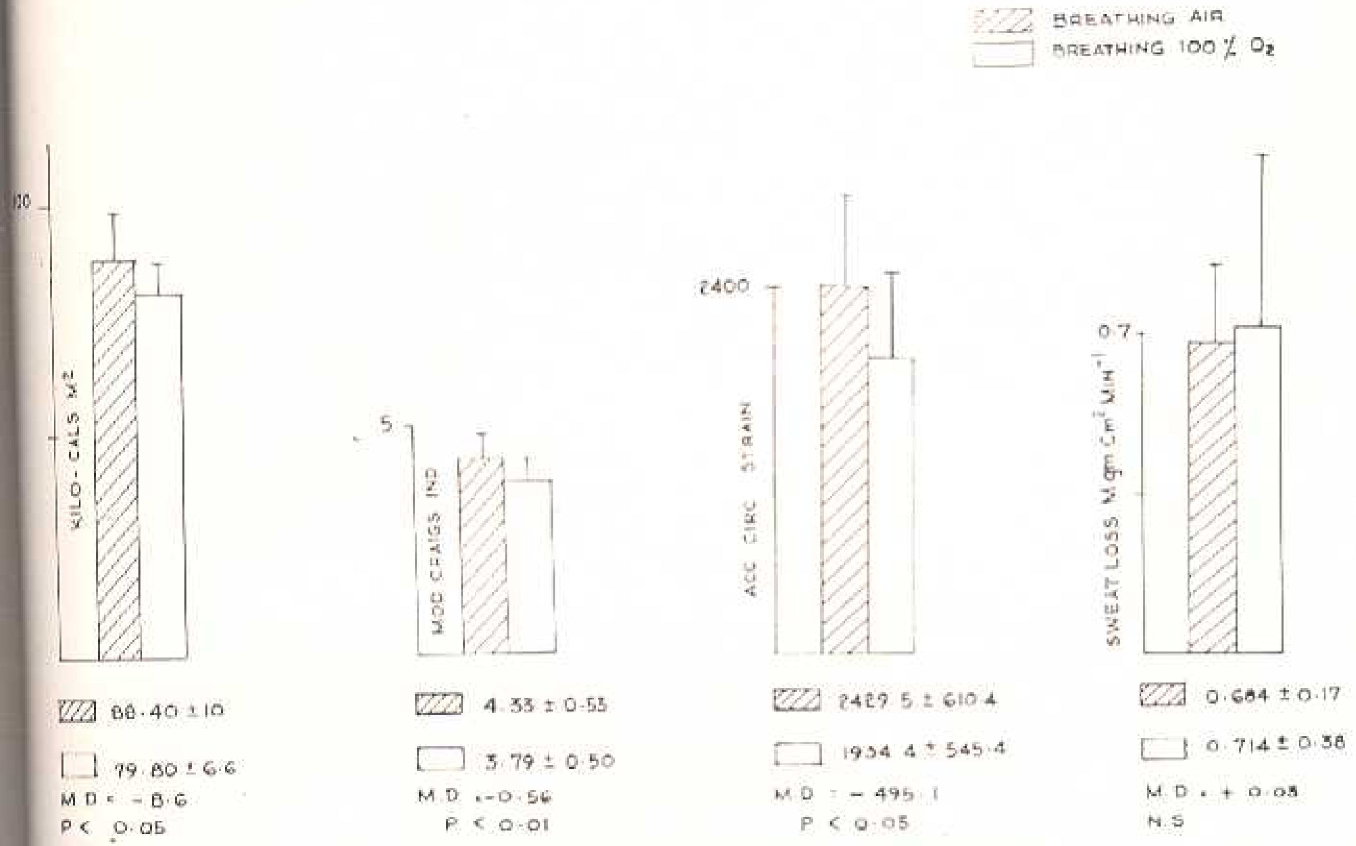


Fig. 1 Heat Strain Parameters during Air Breathing & 100% O_2 Breathing

The linear relationship of HR to the heat accumulation is given in Fig 3.

Sweat: There was a slight increase in the mount of sweat produced due to 100% oxygen reathing (0.714 + 0.38) mgm of sweat/cm²/min as ompared to the air breathing experiments (0.684 ± 17). The difference (Fig 1) however was not ignificant (P > 0.05).

The slope of recovery heart rate after air breathig showed a faster recovery as compared to oxygen reathing experiments as calculated by weighted verages while there was no difference in the slope of recovery of MBT. The recovery patterns of HR nd MBT are shown in Figs 4, 5.

iscussion

An exposure to a severely hot environment as is kely to be met with inflight, especially during tropical summer conditions would impose a considerable egree of heat strain upon the aircrew and compromise erformance [18].

In this series of experiments the hot environment simulated is the one most likely to be recorded in the actual flight situation[16]. At the end of 50 minutes of exposure to this environment, while breathing room air, the subjects accumulated 88.4 kilocals/m² of excess heat, at which performance deterioration is expected to begin. Blockley et al[2] had suggested that performance deterioration occurs at about 63% of the heat storage level at tolerance limit. Heat adapted subjects tend to reach the end of their tolerance to severe heat when they have accumulated about 110 kilocals/m² of heat, as calculated from Sinha & Verghese[16] and thus our values at the end of 50 minutes of exposure to the experimental environment are a fairly accurate estimate of the excess heat storage at the beginning of performance deterioration.

100% oxygen breathing resulted in a significant reduction of heat storage at the end of the experiment (Fig. 1). The fact that two of the subjects who could not complete the heat exposure while breathing air, did so while breathing 100% oxygen,

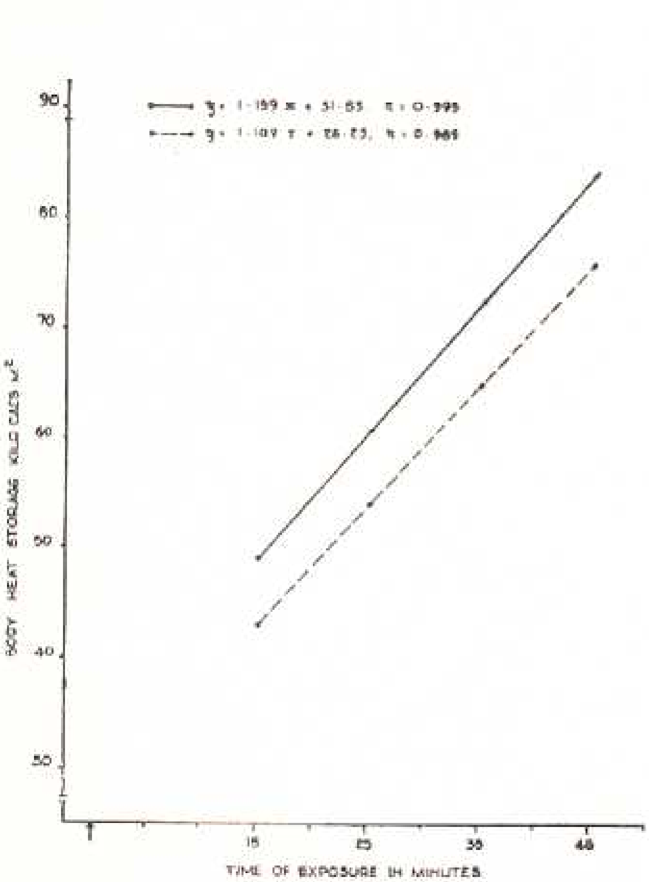


Fig. 2 Body heat storage (Kilo Cals/M²) is plotted against time of Exposure in mints. (—) Air Breathing, (--) O_2 Breathing experiments. The equations are Regression Equations. (Reproduced with permission from Av Med June 1980)

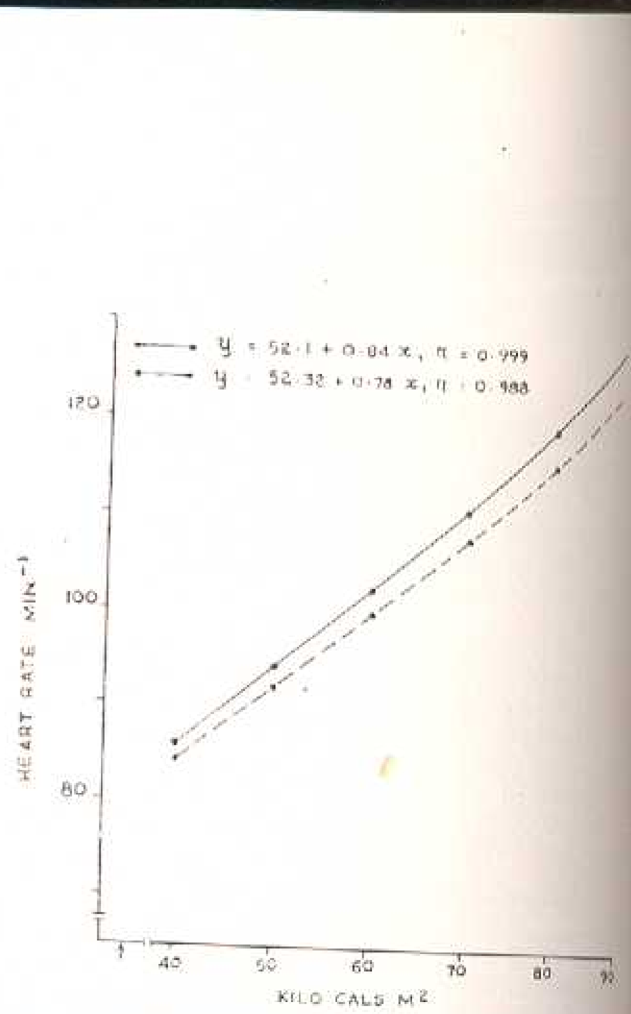


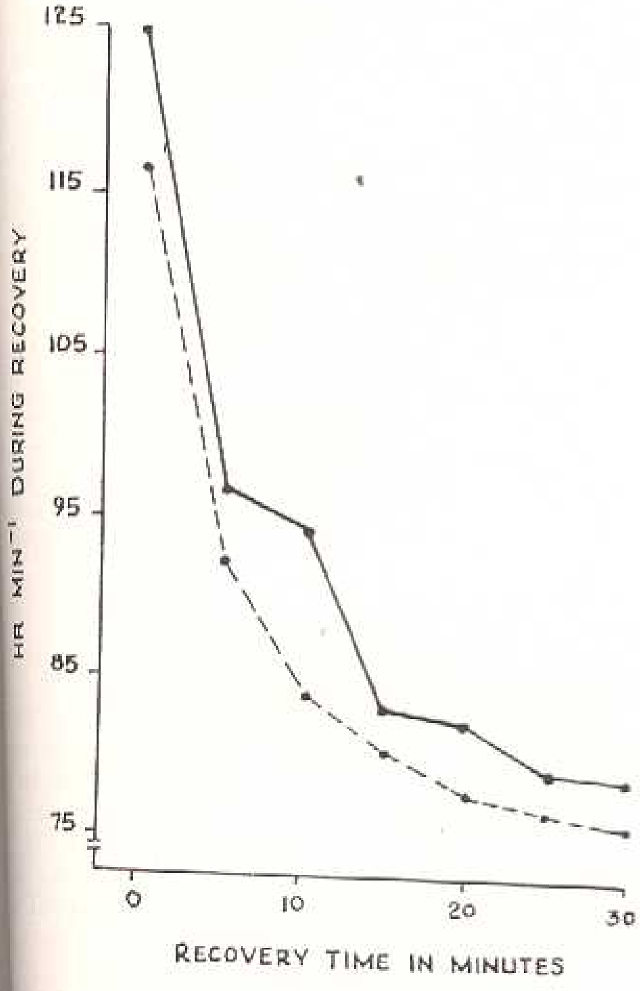
Fig. 3 The Relationship of Body Heat Storage (Kilo Cals/M² and Heart Rate (Beats Min⁻¹) during Heat Exposure while Breathing Air (—) and Breathing 100% O_2 (--). The equations are Regression Equations.

goes to farther substantiate this evidence. When the decrease in heat accumulation due to 100% oxygen breathing is considered on a temporal basis, it is seen from Fig 2 that 79.6 kilocals/m² of excess heat (which was accrued at the end of 50 minutes of oxygen breathing) was gained at the end of 41.5 minutes of air breathing. This indicates an extension of heat tolerance by 8.5 minutes due to oxygen breathing. Such gain will be a valuable aid to a pilot flying under adverse hot weather conditions, especially towards the end of the mission and is considered to be of significant benefit.

The mechanism by which 100% oxygen produces this beneficial effect could be due to (i) change in quantity or quality of sweating (ii) an increased respiratory heat exchange (RHE) due to the dryness of the gas or (iii) a combination of both factors.

Heat exposure increases oxygen consumption though the increase is not significant[15]. But the sweat gland metabolism may be sensitive to even this slight increases in VO_2 and therefore greater amount of sweat may be produced due to more oxygen availability by 100% oxygen breathing. Also, the vasodilatory effect of body heating[14] which may be counteracting the peripheral vasoconstrictor effect of 100% oxygen[4] will farther enhance the oxygen availability of sweat glands. However, in this series of experiments eventhough there was some increase in sweating, it was not significant (Fig. 1).

About 10% of body heat is lost by respiratory heat exchange[9]. This is dependent upon factors such as minute ventilation, water content of the inspired air and latent heat of water vapour[3]. It may be that breathing 100% oxygen which is a very dry gas, promotes RHE, aided by an increase in ventilation which occurs on exposure to heat[9]. To ascertain this, we exposed seven of our subjects in a separate series of experiments to the same degree of heat stress while breathing air dried by passing it over silica gel and compared the heat storage (82.1 kilocals/m²) with that incurred by them during their ambient air (AA)-



g. 4 Recovery Heart rate Min^{-1} after Heat Exposure. e subjects (N=10) recovered at 21°C DB 18°C WB with Air ocity 175 ft Min^{-1} while breathing ambient air. After Breathing Air,– –After Breathing 100% O_2.

ilocals/m^2 and oxygen breathing (00) - 79.2 ilocals/m^2- experiments (Table III). The dry air eathing also significantly reduces heat storage able III). Therefore the dryness of the breathing xture plays a contributory role in promoting the E and alleviating heat strain. This view is farther engthened by the fact that in 6 of our subjects o breathed humidified oxygen (OH) the heat rage was significantly higher than in the 00 eriments (Table IV).

As no single index of heat induced physiological ain has yet been formulated[13], two other indices the modified Craigs Index (IS) and accumulative ulatory strain (IC) were also estimated. It is seen

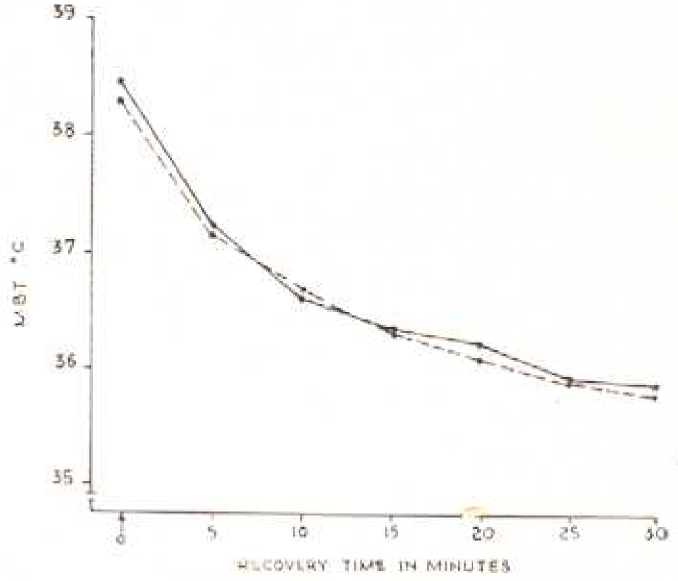


Fig. 5 Recovery of mean body temperature °C (MBT°C) after Heat Exposure. Recovery after Air Breathing Experiments is denoted as (–) and after O_2 Breathing Experiments as (- -)

(Fig.1) that these two indices also show a significant reduction and therefore strongly support our suggestion that 100% oxygen does aid in reducing heat induced physiological strain.

TABLE III

Body heat storage (Kilocals/M^2) ($n=7$)

Sub. No.	Ambient air (AA)	Dry air (DA)	100% Oxygen (00)
1	86.73	77.42	67.50
3	76.04	77.01	74.85
4	83.0	78.2	80.95
5	107.48	101.5	83.93
6	78.91	81.1	77.13
8	96.12	79.9	90.25
11	95.91	79.40	79.76
Mean	89.03	82.07	79.20
s.d.	± 11.08	± 8.68	± 7.16

Mean Difference

AA — DA = −6.96 ($P<0.05$)
AA — OO = −9.83 ($P<0.05$)
DA — OO = 2.87 ($P>0.05$)

TABLE IV

Body heat storage (Kilocals/M²) : 100% Oxygen(00) & humidified oxygen (OH) (n=6)

Sub. No.	100% oxygen (00)	Humidified oxygen (OH)
1	67.5	73.2
2	66.3	83.2
3	71.90	89.7
4	81.00	85.8
5	83.90	87.3
8	90.30	101.6
Mean	77.3	86.8
s.d.	± 9.5	± 9.2

Mean difference 00 — OH = + 9.5
$P < 0.01$

100% oxygen breathing at 1 ATA results in some degree of bradycardia[4,5,19]. However this change, even though of significance, only amounts to about 8.8 beats/min at the end of 45 minutes of oxygen breathing[19]. It is seen from Fig 3 that at a body heat storage of 79.8 kilocals/m² attained at the end of 100% oxygen breathing for 50 minutes, the X HR was 116.9 beats/min. while, for the same degree of body heat storage when breathing air, the $\overline{X}$ HR as read off from Fig 3 was 118. This small difference of 1.1 beats/min would be due to the bradycardia effect of 100% oxygen breathing, which could have been modified due to the physiological effect of heat on the cardiovascular system, which takes the brunt of the stress[7,19]. It is also interesting to note that the IC as incurred by our subjects was 2429 at a body heat storage of 88.4 kilocals/m² while Gold[7], for the same degree of heat storage, reports an IC around 7000. This could be attributable to the fact that individuals well adapted to severe heat conditions exhibit a lesser degree of circulatory strain as they may have developed more effective sweating mechanisms to dispel excessive heat.

100% oxygen breathing does not hasten recovery from exposure to severe heat stress (Fig 4 & 5) and therefore is of no benefit in reducing inter exposure period which may be of consequence during routine operations.

Conclusions

These experiments have shown that 100% oxygen breathing reduces heat induced physiological strain and is expected to be of benefit in helping a pilot to increase his tolerance to severe heat stress. Minor side effects such as delayed aero otitis[10], aero atelectasis[11] can be easily avoided by using the oxygen regulator on the airmix mode on and off during flight, for short durations.

The most probable mechanism of action of this beneficial effect is due to a promotion in RHE because of the dryness of the gas. However, eventhough insignificant, pure oxygen seems to be more beneficial than dry air in producing its effect. Also, the sweat output increases with oxygen though insignificantly. Therefore, apart from the dryness, oxygen may be producing its action, though only partly, by other physiological mechanisms.

Acknowledgement

The authors are thankful to Air Cmde JS Sant, Air Officer Commanding, Institute of Aviation Medicine, IAF for suggesting experiments for determining mechanism of action of oxygen, and Dr CA Verghese, Head of the Department of Physics for his comments. The subjects are thanked for their co-operation and Shri PLN Rao for a part of the statistical analysis.

References

1. Bancroft, H. Introduction to Biostatistics. Harper Row. New York, 1966.
2. Blockley, W.V., Mc Cutcheon, J.W., Lyman, J. and Taylor, C.I. Human Tolerance for high temperature aircraft environment. J. Aviat. Med. 25 : 515-522, 1954.
3. Deal, C.E. (Sr), McFadden, ER., Ingram, R (Jr), Stranes, H.R. and Jaegar, J.J. Role of respiratory heat exchange in production of exercise induced asthma. J. Appl. Physiol : Respirat. Environ. Exercise Physiol. 46 : 467-475, 1979.
4. Dripps, R.D. and Comroe (Jr), J.I. The effect of inhalation of high and low oxygen concentrations on respiration, pulse rate, Ballistocardiogram and arterial oxygen saturation (oximeter) of normal individuals. Am. J. Physiol. 149 : 277-291, 1947.
5. Eggers, G.W.N., Paley, H.W., Leonard, J.J. and Warren, J.V. Haemodynamic responses to oxygen breathing in man. J. Appl. Physiol. 17 : 75-79, 1962.