Original Article

Physiological Strain Responses at Simulated Thermal Environments as Applied to Military Flying in Hot Weather Conditions

PK Banerjee

Fourteen normal healthy men were exposed to three simulated thermal environments of air temperature: 40, 45 and 50°C, each with 50% relative humidity, for a duration of 60 min or less when they reached their subjective endpoint of tolerance. At 40°C, mouth temperature (T_m) and heart rate responses were found to stabilise by 30 min of exposure, with no further indications of body heating till 60 min. At 45°C, thermal strain measures showed continued increase although 60 min of exposure, the mean terminal Tm value reaching very close to the recommended upper limit of body heating criteria for aircrew. On exposure to 50°C, subjects were found to incur excessive body heating and show signs of intolerance. Fifty per cent of them reached their subjective end points of tolerance by 40 to 47 min of exposure, others continuing till 60 min with indications of acute thermal strain. Within 30 min of exposure to this environment, the mean Tm response of the subjects exceeded the recommended upper limit of aircrew body heating.

Keywords: Thermal strain, simulated heat exposure.

In low level military flying, cockpit temperature can often reach dangerously high level in hot climatic conditions[1-4]. The heat stress problem is particularly severe in high performance aircraft, when the natural climatic heat load is further aggravated by aircraft factors and the design considerations limit the capacity of the onboard cooling system, thereby leading to higher cockpit temperature than that of the ambient[5,6]. Though the actual recordings of the cockpit temperature in respect of fighter aircraft in IAF fleet are not many, it appears most likely that during low level exercises undertaken in the summer months, cockpit temperature would often be in the range of 40-50°C. A few studies in the field indicated the same[7,8].

From the flight safety point of view, the potential hazards of undue body heating in aircrew are well recognised[9,10]. Flying restrictions in hot weather conditions to effect maintenance of aircrew within certain physiological limits of body heating have been proposed[1,8]. This paper presents the findings on the degree of body heating as incurred in normal healthy male volunteers on exposure to three different simulated settings of hot environmental conditions in the range that is likely to occur in cockpit while flying low level in hot summer months.

Material and Methods

Fourteen normal healthy male volunteers from among the staff members of Institute of Aviation Medicine were the subjects of this study. Age and physical characteristics of the subjects are shown in Table I.They underwent exposure to three simulated heat stress environments of air temperature: 40, 45 and 50°C each with 50% relative humidity and air movement around 17 m/min on three different days. The wet bulb dry bulb (WD) index of these three environments amounted to be 31.9, 36.1 and 40.7°C respectively. The three experiments on each subject were completed within a period of 10 days with a minimal interval of 2 days between the experiments. Each subject was clothed in a cotton brief, flying overall, inner helmet and canvas shoes. On all three occasions the duration of exposure was 60 min or less when the subjects reached their subjective end point of tolerance. Oral temperature (T_m) and heart rate measurements were made after 30 min of resting in an airconditioned room (T_{db} 25°C) and at every 10 min of exposure to simulated heat stress. T_m was measured with the help of a sublingual thermistor on an Ellab thermometer. Heart rate was determined from ECG tracings on a Nihon Kohden Electrocardiograph. Sweating rate for the total duration of exposure was measured by differential nude body weight taken before and after heat exposure and expressed in gm per m^2 BSA per hour.

Result

The mean physiological thermal strain responses of 14 subjects at 10 min intervals of exposure to three simulated heat stress environments, viz., T_{db} of 40, 45 and 50°C each with a relative humidity of 50% are presented in Tables II, III and IV respectively. While all 14 subjects could endure the scheduled duration of 60 min at T_{db} of 40° and 45°C, only 7 subjects could do so when exposed to T_{db} of 50°C. Two subjects reached their subjective end point of tolerance at 40 min and 5 subjects could continue till 40 - 47 min of exposure at this environment.

At T_{db} of 40°C, the mean T_m showed a moderate increase from its pre-exposure value of 36.7°C to reach 37.2°C at 40 min of exposure and was maintained as such for the remaining 20 min duration. The mean heart rate went upto 89 by 30 min and maintained. The mean sweating rate was 123 g/m^2/hr.

At T_{db} of 45°C, the mean T_m showed continuous rise from its pre-exposure value of 36.7°C to reach 37.9°C at 60 min of exposure. The mean heart rate also showed continuous rise from 78 bpm to reach 117 bpm at 60 min. The mean sweating rate of the subjects at this environment was 245 g/m^2/hr.

On exposure to T_{db} of 50°C, the mean T_m showed a continuous and sharp rise to reach 39°C at 60 min in the subjects who could endure that long. The mean heart rate reached 139 bpm at 50 min, data including the terminal values of those tolerating upto 45-47 min. At 60 min, the mean heart rate response of 7 subjects was 141 bpm. The mean sweating rate at this environment was 482 g/m^2/hr.

Figure shows the mean T_m responses of the subjects at different time intervals of exposure to three simulated thermal environments as against the upper safe limit of T_m for the aircrew[1].

Discussion

Physiological thermal strain responses seen at the three simulated thermal environments (Tables II-IV) enable identifying the patterns of body heating in seated men on usual sortie time exposure to the hot environment conditions in the range that can occur in the cockpit environment while flying low level fighter sorties in tropical summer months.

At air temperature of 40°C with 50% rh (WD index: 31.9°C), body heating was found to stabilise by 30-40 min of exposure with Tm around 37.2°C and heart rate around 90 bpm, with the overall sweating rate of 123 g/m2/hr. These thermal strain responses are indicative of an acceptable level of heat stress, that, though remaining much above the comfort zone, would not endanger the well being of the aircrew as well as his flight performance. Billingham and Jones1 formulated the criteria of upper safe limit of body heating in aircrew as Tm of 38°C, heart rate of 130 bpm and sweating rate of 300 g/m2/hr. The observed values of body heating parameters for 60 min exposure to 40°C with 50% rh are found to be very much within the above safe limits.

The mean values of T_m and heart rate at different time intervals of exposure to T_{db} of 45°C with 50% rh (WD index: 36.1°C) show a continuous increase in body heating althrough the 60 min of exposure that was tolerated by all 14 subjects. The group mean values of the body heating parameters at 60 min exposure to this environment are found to be well within the limits of physiological end point of thermal tolerance as noted in earlier studies[11,12]. However, when compared with the Billingham and Jones[1] criteria of upper safe limits of aircrew body heating, the mean thermal strain responses of the subjects, particularly their T_m data were found to reach quite close to the upper limits at around 60 min of exposure. The possibility of cockpit temperature reaching this9 high has to be viewed with sufficient caution permitting flying only with appropriate restrictions. This simulated temperature condition falls at the upper region of the 'Caution Zone' of Fighter Index of Thermal Stress (FITS) as proposed by Nunneley and Stribley[6] for USAF operations.

On exposure to air temperature of 50°C with 50% rh (WD index: 40.7°C), volunteers started showing frank subjective intolerance. Seven out of 14 subjects reached their subjective end point within 40 to 47 min of exposure. Also 7 subjects, who could complete the scheduled duration of 60 min exposure, exhibited a very high T_m value of 39°C, which was dangerously close to the maximal value of core temperature reported at the end point of tolerance while exposed to hot wet environments[11,12]. The average tolerance time in similar thermal environment (WD index) had earlier been reported to be about 50 min[12]. As it would be seen in Fig 1, within 30 min of exposure itself the mean T_m of the present group of subjects exceeded the recommended aircrew body heating limit of 38°C. A cockpit environment of similar thermal severity must therefore be considered as grossly inadequate, unsafe and dangerous for flying.

The possibility of the cockpit temperature reaching a dangerously high level is quite high if low level exercises are undertaken in hot weather conditions. The results of the present study bring about the temporal response in the degree of body heating on exposure to three different severities of thermal environment in the concerned range and demonstrate the occurrence of body heating beyond the acceptable limit as recommended for aircrew once the WD index reaches above 36°C.

Table - I Age and physical characteristics of the subjects (n = 14)

	Age (yrs)	Height (cm)	Body Weight (kg)	Body Surface Area (m^2)
Mean	31.9	171.3	62.0	1.73
± sd	8.0	4.8	5.8	0.09
Range	20-41	163-177	52-69	1.58-1.84

Table - II Physiological thermal strain reactions on exposure to T_{db} 40 °C with rh 50% (n = 14)

Strain Parameters		Pre-exposure	Time of Heat Exposure (min) 10	20	30	40	50	60
T_m (°C)	m	36.70	36.90	37.80	37.10	37.02	37.20	37.2 0
	± sd	0.22	0.23	0.27	0.24	0.26	0.24	0.23
Heart rate (bpm)	m	75	83	87	88	89	90	91
	± sd	8.2	9.6	9.4	8.9	8.2	8.0	7.8
Sweat rate (g/m2/hr)	m							123
	± sd							32

Table - III Physiological thermal strain reactions on exposure to T_{db} 45 °C with rh 50% (n=14)

Strain Parameters		Pre-Exposure	Time of heat exposure (min) 10	20	30	40	50	60
T_m (°C)	m	36.8	37.2	37.40	37.50	37.70	37.80	37.90
	± sd	0.25	0.23	0.25	0.26	0.23	0.26	0.33
Heart rate (bpm)	m	78	89	97	102	106	112	117
	± sd	7.7	8.9	9.7	10.5	11.0	12.8	13.7
Sweat rate ($g/m^2/hr$)	m							245
	± sd							59

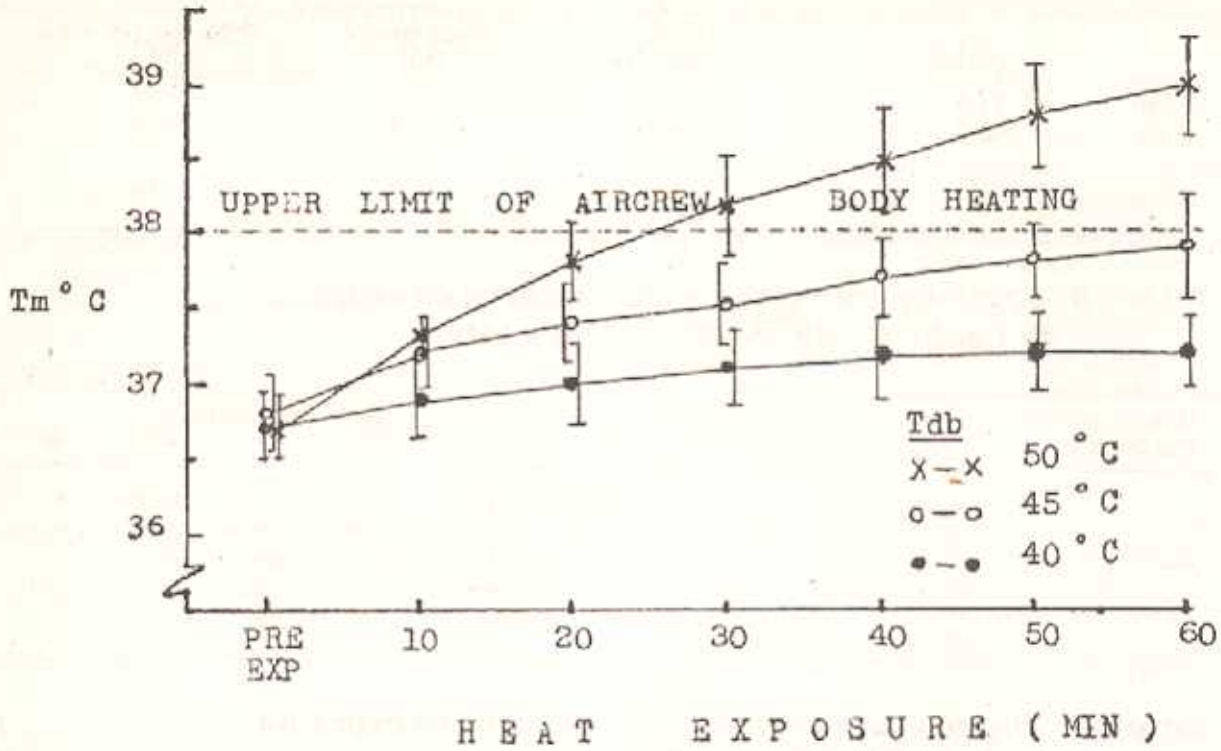
Table - IV Physiological thermal strain reactions on exposure to T_{db} 50 °C with rh 50% (n=14)

Strain Parameters		Pre-exposure	Time of heat exposure (min) 10	20	30	40	50 *	60 **
T_m (°C)	m	36.7	37.30	37.80	38.20	38.50	38.80	39.00
	± sd	0.19	0.13	0.25	0.30	0.31	0.29	0.31
Heart rate (bpm)	m	75	95	109	121	130	139	141
	± sd	10.3	13.2	11.5	13.1	12.9	10.3	2.1
Sweat rate ($g/m^2/hr$)	m							482
	± sd							123

* n = 12 including the terminal values of 5 subjects reaching their subjective tolerance point at 45-47 min.

** n = 7 subjects who endured 60 min of exposure.

Figure. Oral temperature responses at three simulated thermal environments.



Maintenance of aircrew within an acceptable limit of body heating while flying in hot weather conditions would obviously necessitate a detailed objective appraisal of the cockpit thermal environment vis-a-vis local ambient temperature so as to formulate an appropriate time frame for permitted flying in respect of different types of aircraft.

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