Physiological Criteria of Upper Limits of Body Heating

PK BANERJEE

Ten normal healthy male volunteers were subjected to acute heat exposure in the simulated air temperature of 50°C with 60% relative humidity. While six could continue for the scheduled duration of 60 min, four subjects showed symptoms of acute distress, and were withdrawn earlier. An analysis has been made of their physiological strain responses at terminal point, and these results are compared against the available criteria of upper safe limits of body heating as proposed by earlier workers.

The use of objective physiological criteria in defining tolerance point of human beings during acute heat exposure has its special importance in military aviation where heat is a major environmental stress. The subject of using simple physiological measures to mark the upper safe limit has long intrigued workers in the field.

The present study observes the physiological thermal strain reactions of healthy male volunteers on exposure to acute heat stress to the degree that is commonly observed in low level high speed flying in extreme summer. Significance of these strain measures has been discussed in relation to heat tolerance and the criteria of upper safe limit of body heating as proposed by earlier workers.

Material and Methods

Ten normal healthy male volunteers (age : 28-40 yrs, height : 163-177 cms, weight : 51-74 kg), unacclimatized to heat, were exposed to a simulated thermal environment of **Tdb** : 50°C, **Twb** : 39°C with air velocity of 55 ft/min for a minimum period of 60 min.

Mouth temperature (**Tm**), skin temperatures and heart rate measurements were made under pre-exposure resting condition and at every 15 min of heat exposure. Skin temperature was measured from 4 sites, viz., chest, upper arm, thigh and calf, and the mean skin temperature (**Tsk**) was computed from their weighted average using a formula proposed by Ramanathan[3]. These temperature measurements were taken with an Ellab electrical thermometer with the help of appropriate skin thermocouples and oral thermister. Heart rate on ECG lead II was recorded on a Polygraph Grass Model 5C. Sweat loss was determined from the difference in nude body weight before and after the heat exposure.

Subjects were selected from amongst the laboratory personnel, and were motivated enough to continue for the scheduled duration of 60 min unless they were severely distressed.

Results

Four out of the total 10 subjects failed to continue for the scheduled duration of 60 min. While 2 of this intolerant group continued for 55 min, one could coutinue till 47 min and the other till 30 min only.

Table I shows the mouth temperature (**Tm**), mean skin temperature (**Tsk**) and heart rate responses of all the 10 subjects during pre-exposure rest at thermoneutral condition and every 15 min of heat exposure till 60 min or at terminal point when it was earlier. Tm at 60 min or at terminal points varied between 37.8 and 39.2°C while 2 subjects reached their tolerance point at **Tm** 38.1°C only. Highest **Tsk** values ranged from 37.4 to 38.9°C. Two of the intolerant subjects, however, reached their tolerance at 37.8°C of **Tsk**. While peak heart rate varied from 118 to 164 beats per min, the intolerant group discontinued at heart rates ranging from 148 to 164 beats per min.

Table II shows the sweating rate of the subjects during the course of heat exposure and the heat accumulation incurred by them at 60 min or at the terminal point of heat exposure. Sweating rate of the subjects varied from 270 to 560 g/hr/m² BSA with no apparent differences between those who continued till 60 min and those who could not. Subjects in the heat intolerant group discontinued at heat accumulation of 61.1 to 88.9 Kcal/m² BSA, whereas one subject in the other group continued up to 113.4 Kcal/m² of heat gain.

TABLE—I

Body Temperature and Heart Rate Responses to Acute Heat Exposure

Subjects	Pre-exposure values			Time of heat exposure											
				15 min			30 min			45 min			60 min		
	Tm	Tsk	HR	Tm	Tsk	HR	Tm	Tsk	HR	Tm	Tsk	HR	Tm	Tsk	HR
MBD	37.0	33.8	80	37.1	36.0	98	37.3	36.9	124	37.9	37.6	144	38.4	38.2	164
EMI	36.2	32.7	66	36.8	35.8	80	37.2	36.6	92	37.5	37.0	102	37.8	37.4	118
NSB	35.9	33.1	74	37.0	36.2	84	37.4	37.0	96	37.8	37.4	108	38.1	37.8	118
MKV	36.9	33.8	84	37.4	36.6	100	37.9	37.4	126	38.5	37.9	138	38 9	38.4	152
MKS	36.4	32.9	80	37.3	36.7	104	37.7	37 2	116	38.3	37.8	132	38.7	38.1	132
JMW	36 9	34.4	80	37.8	36.8	112	38.5	37.7	132	39.1	38.3	150	39 2	38.9	150
*DYR	36.6	33.1	90	37.2	36.3	108	37.6	37.2	144	37.9	37.6	154	38.1	37.8	164
*SSN	36.3	34.3	68	37.2	37.1	100	38.2	37.7	116	38.8	38.4	128	39.1	38.8	150
**BRS	36.5	34.3	88	37.3	36.7	116	38.1	37.5	138	38.5	37.9	148			
***PKS	37.0	33.8	94	37.4	27.1	128	38.1	37.8	148						

* Continued for 55 min ** Continued for 47 min *** Continued for 30 min

TABLE—II

Sweating Rate and Heat Accumulation Induced by Heat Exposure

Subjects	Tolerance time (min)	Sweating Rate (g/hr/m² BSA)	Heat Accumulation Kcal/m² BSA
MBD	60	430	76,9
EMI	60	270	81.4
NSB	60	400	98.3
MKV	60	380	96.7
MKS	60	300	105.8
JMW	60	535	113.4
DYR	55	345	81.4
SSN	55	340	88.9
BRS	47	560	74.7
PKS	30	445	61.1

Discussion

The use of a physiological measure like deep body temperature, skin temperature or heart rate for defining the tolerance point would have been most objective. In earlier reports,[5,6] deep body temperature of 39.2°C and/or heart rate of 180 beats per min were found to coincide with tolerance limits. In subsequent studies[7], however, termination of exposure on the reason of acute subjective distress has been found to occur at a rectal temperature of 38.3°C, and heart rate of 143 beats/min. In the present study, 2 subjects discontinued because of acute subjective complaints when their Tm was only 38.1°C. The heart rates of 2 subjects who could not continue for the scheduled 60 min were 148 beats per min.

Various workers[5,7,9] have emphasized on the skin temperature response during heat stress as a better physiological indicator of tolerance point. Verghese et al[9] and Pandolf and Goldman[7] observed that the convergence of Skin and deep body temperature coincided with the tolerance point.

As revealed in Table I of the present study, complete convergence of the skin and oral temperatures never occurred in our subjects including those who reached their subjective tolerance limits. Doubt remains as to whether these subjects who could not continue for the scheduled 60 min duration, actually reached their tolerance point. At this point it will be useful to quote Blockley et al[3] ad verbatim. "The definition of the physiological state at the tolerance time is as follows :

a) Presence of symptoms of heat exhaustion such as faintness, nausea, dyspnoea, tingling of the extremities, mental distraction and confusion, compulsive restlessness.

b) Heart rate in excess of 140 beats per min."

All the 4 subjects who discontinued had heart rates in excess of 140 beats per min and their subjective complaints included nausea, numbness and tingling sensation in the arms and legs and restlessness. The author himself was one of these subjects.

Blockley et al[2] observed that the body can accept a fixed quantity of heat before reaching a state of incipient collapse. In their studies they observed an average value of 77 Kcal/m² which pertained to the least heat resistant individuals among their experimental subjects. In the present study the least heat resistant subject showed a heat accumulation of 61.1 Kcal/m² (which is close to Blockley et al's observation) whereas 2 of the 10 subjects continued beyond 100 Kcal/m² of heat gain (Table II).

It then appears that individual's distress and subjective symptoms and perhaps willpower to continue with the distress symptoms vary to a very large extent and the conventional physiological thermal strain measures, viz., body temperature and heart rate are not as objective as often claimed in defining the tolerance point. It will be more pragmatic to define a limit of body heating which pertain to 95% of a healthy population and a further assessment of heat resistance amongst a population can be based on a standard protocol where time to reach that stipulated upper limit will make the score.

Billingham and Jones[1] proposed the following criteria of upper limits of safe body heating for aircrew : Tm 38°C, heart rate 130 beats/min, sweating rate 300 g/hr/m² in unacclimatized men.

The above proposed limits appear to be suitable for the least heat resistant subjects of the present study and justify their distress and discontinuation thereby. The safe body heating limits for aircrew, as proposed by Billingham and Jones[1], are validated in the observations of the present study.

References

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