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PREFLIGHT HEAT STRESS AND RECOVERY

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13

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13. ABSTRACT

Changes in physiological responses during heat stress as experienced in summer preflight operations have been studied with four sitting, resting subjects wearing Air Force standard fighter clothing assemblies. After exposure to chamber temperatures of 45, 50, and 55 C (25 mmHg water vapor pressure and 1.1 m/sec air velocity) for either 30 or 60 minute periods, the temperatures were lowered rapidly (5 minutes) to 15, 20, and 25 C, respectively, for a 30-minute poststress recovery period. Skin temperature, rectal temperatures, heart rates, body heat storages, sweat and evaporation rates were determined and graphically presented. The time required to return to prestress baseline physiological values for all thermal stress conditions is given in tabular form. As expected, recovery time was a function of the ambient recovery temperature level that followed the heat exposure. The recovery temperature should not be lower than 20 C if discomfort is to be avoided. Heart rate decrease appears to be a reliable indicator for recovery. The rectal temperature remained at an elevated level after all other measured physiological responses returned to baseline level. In an additional series, applying identical heat stresses, the subject's head was ventilated with 2.5 CFM dry air at 10 C. In comparison to the experiments without head ventilation, reduced skin temperatures and increased evaporation rates were observed.

Key Words: Thermal stress
Ground operation of aircraft
Biothermal research
Recovery from heat stress

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FOREWORD

This study was initiated and conducted by the Barothermal Branch of the Environmental Medicine Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433.

This technical report has been reviewed and is approved.

CLYDE R. REPLOGLE, PH.D.
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SECTION I

INTRODUCTION

During standby, ground, and low altitude operation of aircraft, crew members are sometimes exposed to high thermal stresses. Cabin temperatures up to 55 C have been measured during such situations. Even with the aircraft's air conditioning system in operation, little cabin cooling may be expected when the aircraft electronic equipment has to be maintained at proper operation temperature. The thermal stress may last 30 to 60 minutes until sufficient cabin cooling is available. Numerous investigators have determined physiological responses to heat exposure and have established tolerance limits (3, 8, 10, 11). Also, the effect of transient environmental conditions have been studied. Belding et al (1) determined rates of restoration of body heat content to preheat stress levels to establish conditions that promote rapid recovery from exposure to heat. Extensive studies have been made about recovery from work under heat stress (1, 2, 4, 7, 8). However, insufficient information is available to determine recovery times from heat stress levels and exposure durations experienced by the sitting, resting, clothed subject under preflight environmental conditions. Since the cabin temperature can be modified in normal aircraft operation, it is of interest to determine cabin temperature levels tolerable or desirable for regaining baseline physiological values. The manner in which the observed physiological parameters (skin and rectal temperature, heart rate, body heat storage) decline may show which is the most faithful indicator of the general state of recovery. The present study was designed to obtain such information.

In some operational situations, a small quantity of cool air from the aircraft air conditioning system is available, but not sufficient for effective cooling of the cabin. Therefore, an effort was made to use a small amount of cool air to ventilate the head. Physiologic reactions were compared with those obtained under the same heat stress conditions without head ventilation. Kissen (7) and other investigators demonstrated that cooling of the head reduces physiological strain more efficiently than cooling other body parts of equal and even greater surface area.

SECTION II

PROCEDURE

The subject was seated on a chair in the Laboratory's "Environmental Test Facility" wearing a thermistor equipped one piece cotton underwear under the standard Air Force fighter clothing assembly (Nomex flight coverall, anti-G suit, and lightweight flight jacket). Light socks, heavy flight boots, light gloves, and an oxygen mask equipped helmet (HGU-2A/P) completed the clothing assembly. The insulation of the clothing assembly was 1.25 Clo as determined by the copper manikin technique. In this technique, the surface of a thin walled copper manikin is uniformly heated by 15 adjustable electrical heating circuits. From the copper manikin's surface temperature and area, the applied wattages, and ambient temperature, the insulation value Clo $\left[1\ \text{Clo} \quad \frac{0.18\ \text{C HR M}^2}{\text{Kcal}}\right]$ can be calculated.

The chair was attached to an automatic, continuously balancing, recording, weighing system to determine body weight loss (evaporative). Three chamber temperatures (45, 50 and 55 C) were selected. After exposure to these heat stress levels for either 30- or 60-minute periods, the chamber temperature was lowered to 15, 20 and 25 C, respectively, within 5 minutes and the subject stayed in the chamber for an additional 30 minutes. Each test condition was repeated four times. Table 1 shows the experimental matrix in detail.

TABLE 1
*EXPERIMENTAL MATRIX**

AMB TEMP (C)	EXPOSURE TIME (MIN)	AMB TEMP CHANGE TO (C)	EXPOSURE TIME (MIN)	NOTES
45	30	15	30	
45	30	25	30	
45	60	25	30	
45	60	—	—	HEAD VENTILATION
50	30	15	30	
50	30	25	30	
50	60	25	30	
50	60	—	—	HEAD VENTILATION
55	30	20	30	
55	30	25	30	
55	60	25	30	
55	60	—	—	HEAD VENTILATION

*IN ALL EXPERIMENTS:
WATER VAPOR PRESSURE 25 mmHg
AIR VELOCITY 1.1 m/sec
CHANGE FROM HIGH TO LOWER AMBIENT TEMPERATURES WAS COMPLETED WITHIN 5 MINUTES

The hyperthermic exposure periods of 30 minutes were selected because thermal equilibrium is established in the aircraft after this period and usually ground operations do not exceed 30 minutes. To cover extreme cases, the thermal stress period was extended to 60 minutes in an additional series of experiments. The cooling period of 30 minutes was considered sufficient for recovery from thermal exposures of either 30 or 60 minutes. A water vapor pressure of 25 mmHg was selected under the assumption that evaporation of sweat will produce high humidity in the aircraft cabin. In still another series of experiments, ventilation of the face and neck was provided under the same hyperthermic conditions as before.

An air spray bar was attached to an operational helmet (HGH-2A/P) along its rim circling the face and neck. The spray bar consisted of a flexible plastic tube ($\frac{1}{2}$ inch DIA) with small ($\frac{1}{12}$ inch DIA) equally spaced ($\frac{1}{2}$ inch apart) jet holes. Dry air with a flow rate of 2.5 CFM and 10 C was supplied with high velocity to the forehead, cheeks, chin, and neck. The spray bar installation did not require a modification of the helmet configuration and did not interfere with the use of the visor of the helmet or the face mask.

The subjects participating in these studies were healthy Air Force personnel in the age range of 28 to 41 years, weight 60-80 kg, and surface areas 1.86 to 2.02 m^2. Seventeen skin temperatures and the rectal temperature were recorded within 18 seconds in intervals of 5 minutes. The heart rate was obtained from an oscilloscope display in 5-minute intervals. The sweat loss was determined by weighing the nude subject before and after the experiment. The evaporative weight loss was taken from the continuous write-out on the strip chart of a multirange Bristol recorder connected to the weighing system of the test facility. Oxygen uptake was computed from Beckman F-3 readings in 3-minute intervals.

SECTION III

TEST RESULTS AND DISCUSSION

Figure 1 illustrates physiological responses to the hyperthermic and poststress (recovery) environments. The recovery exposures, following either the 30- or 60-minute heat exposure, were 30 minutes in duration and were achieved within 5 minutes of the temperature change initiation. The coding of the ambient temperature lines is retained in the graphing of the physiological reactions corresponding to these temperatures.

Skin temperature (t_s) decrease occurs as an immediate response to the lowering of the ambient temperatures. Shivering and discomfort were experienced when the recovery ambient temperature was lowered to 15 C. For this reason, a minimum recovery temperature of 20 C was selected to follow heat exposure of 55 C. None of the adverse symptoms of shivering or general discomfort were associated with the recovery temperature regimens of 20 and 25 C.

Rectal temperature (t_r), after a brief initial decline, rose above control values and remained elevated, even throughout the 30-minute exposure to the relatively cooler poststress environment.

Heart rate (beats/minute) showed a continuous rise throughout the 30- and 60-minute heat exposure and decreased concurrently with the lowering of the ambient air temperature during the recovery phase of the experiments.

As mentioned before, all experiments were repeated four times with a different subject and all indicated values (fig. 1) are averaged values with the exception of the 50 C experiment with a cooling temperature of 15 C. The low heart rate of this subject may be due to his intensive athletic training.

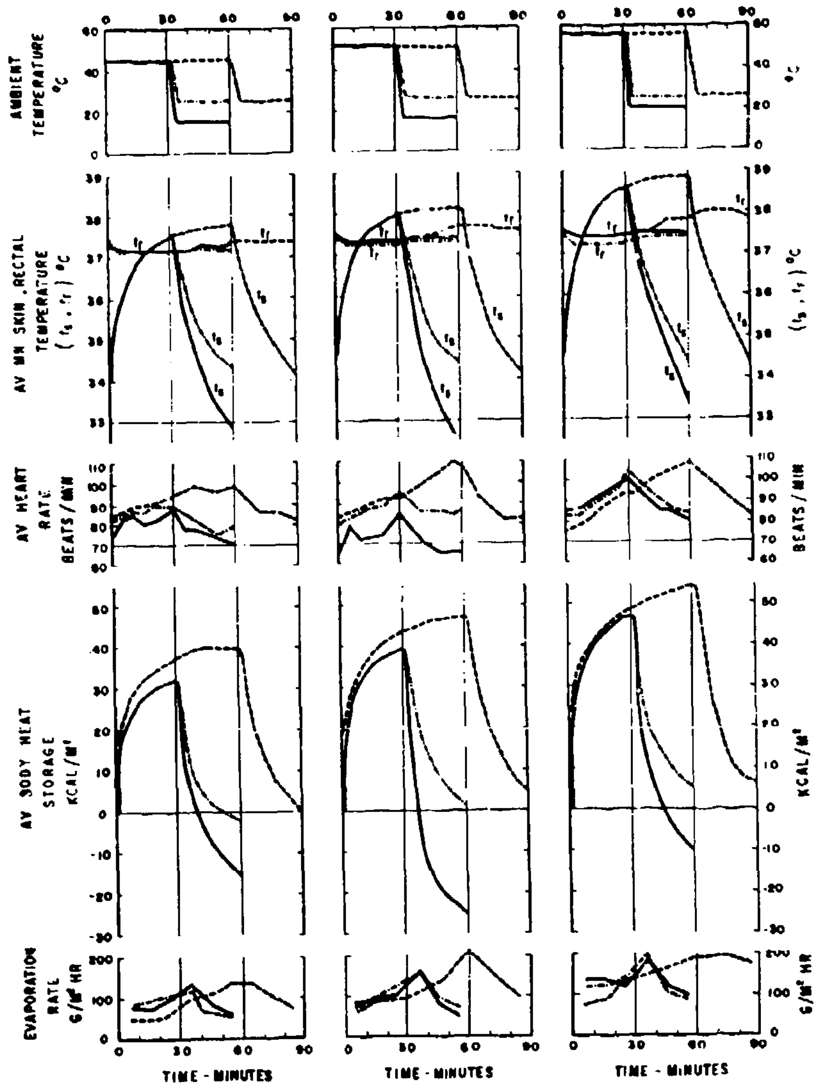

FIGURE 1. THIS FIGURE ILLUSTRATES THE VARIOUS HYPERTHERMIC AND RECOVERY TEMPERATURE LEVELS EMPLOYED AND THE ASSOCIATED PHYSIOLOGIC RESPONSES. The figure should be regarded as three vertical sub-groups of graphs. The left, middle, and right columns deal with heat stress exposures of 45 C, 50 C, and 55 C, respectively. The line coding for the left and middle columns is as follows: ——— and — · — · — represent 30-minute heat exposure with recovery temperatures of 15 C and 25 C, respectively; — — — — 60-minute heat exposure with a recovery temperature of 25 C. The line coding for the column to the right of the figure is as follows: ——— and — · — · — · represent 30-minute heat exposure with recovery temperatures of 20 C and 25 C respectively; — — — — 60-minute heat exposure with a recovery temperature of 25 C. This coding scheme also applies to the graphic display of the physiologic responses associated with that subgroup.

In general, the slopes of the decline of the heart rate suggest that the recovery characteristics of this parameter are not dependent on preceding heat stress duration.

Recovery time (minutes) the time required to attain the baseline level of skin temperature, heart rate, and body heat storage, see table 2.

Evaporation rates (clothed weight differentials) (g/m² HR) were derived at intervals of 10 minutes from the records of the automatic balancing system (fig. 1). Evaporation rates conform directly with the duration of thermal stress and may be a function of increased clothing wetness. Lowering the high ambient temperature caused an immediate decline of evaporation rates.

TABLE 2. EXPERIMENTAL CONDITIONS AND RECOVERY FROM HEAT STRESS

ENVIRONMENTAL CONDITIONS				TIME REQUIRED FOR PHYSIOLOGICAL RESPONSES TO DECREASE FROM MAXIMUM VALUES TO BASELINE LEVEL MIN		
	EXPOS	CHANGE*				
AMB TEMP	DURATION	TO AMB TEMP	Duration			
C	MIN	C	MIN	BODY HEAT STORAGE	SKIN TEMP	HEART RATE
45	30	15	30	10	15	15
45	30	25	30	20	30	15
45	60	25	30	30	30	15
50	30	15	30	5	15	10
50	30	25	30	30	30	10
50	60	25	30	30	30	20
55	30	20	30	15	20	15
55	30	25	30	30	30	25
55	60	25	30	30	30	30

*AMBIENT TEMPERATURE CHANGE WAS COMPLETED AFTER 5 MINUTES IN ALL EXPERIMENTS.

During some experiments it was possible to add *oxygen uptake* to the list of monitored parameters. Figures 2, 3 and 4 show the ambient temperature profiles and those of skin temperature, heart rate and O_2 consumption. All three sample graphs show a peak in heart rate and O_2 uptake, when the ambient temperature is lowered. A small reduction on O_2 uptake, during the recovery period is indicated.

The effect of *head ventilation* (2.5 CFM dry air of 10 C) is demonstrated in tables 3 and 4. Table 3 compares physiological reactions of subjects exposed to the same environmental conditions, with and without ventilation of the head. In table 4, the data are given which represent the differences between terminal and baseline values for rectal, skin and mean body temperatures and heart rate. The skin temperatures and consequently the mean body temperatures show marked differences. The evaporation rates are also higher during head ventilation. Contrary to Kissen's findings (7) the heart rates are not affected by head ventilation. This may be due to the lower heat stress and the different mode of ventilation.

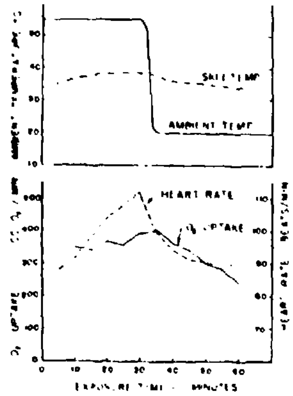

FIGURE 2. SKIN TEMPERATURE, HEART RATE, AND O_2 UPTAKE AT 55 C AMBIENT TEMPERATURE CHANGED TO 20 C AFTER 30 MINUTES.

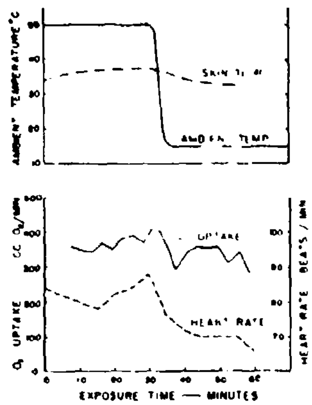

FIGURE 3. SKIN TEMPERATURE, HEART RATE, AND O_2 UPTAKE AT 50 C AMBIENT TEMPERATURE CHANGED TO 15 C AFTER 30 MINUTES.

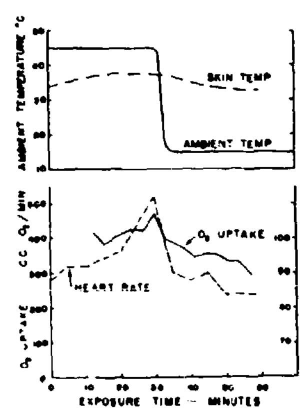

FIGURE 4. SKIN TEMPERATURE, HEART RATE, AND O_2 UPTAKE AT 45 C AMBIENT TEMPERATURE CHANGED TO 15 C AFTER 30 MINUTES.

TABLE 3. PHYSIOLOGICAL REACTIONS TO HEAT STRESS WITH AND WITHOUT HEAD VENTILATION.

	AMBIENT TEMPERATURE								
	45 C (1 HR)			50 C (1 HR)			55 C (1 HR)		
	HEAD VENTIL CFM (10 C)		DIFF	HEAD VENTIL CFM (10 C)		DIFF	HEAD VENTIL CFM (10 C)		DIFF
	0	2.5		0	2.5		0	2.5	
RECT TEMP C									
AFTER 30 MIN	37.2	37.3	+0.1	37.2	37.2	0	37.2	37.3	+0.1
AFTER 60 MIN	37.4	37.4	0	37.7	37.5	−0.2	37.8	37.8	0
SKIN TEMP C									
AFTER 30 MIN	37.8	37.0	−0.8	37.7	37.3	−0.4	38.3	37.8	−0.5
AFTER 60 MIN	37.9	37.2	−0.7	38.1	37.5	−0.6	38.8	37.9	0.9
MEAN BODY TEMP C									
AFTER 30 MIN	37.3	37.1	−0.2	37.4	37.3	−0.1	37.6	37.4	0.2
AFTER 60 MIN	37.5	37.2	−0.3	37.8	37.5	−0.3	38.1	37.8	−0.3
HEART RATE BEATS/MIN									
AFTER 30 MIN	95	91	−4	95	95	0	100	98	−2
AFTER 60 MIN	98	95	−3	108	104	−4	108	109	+1
BODY HEAT STORAGE KCAL/M²									
AFTER 30 MIN	31	32	+1	40	32	−8	45	37	−8
AFTER 60 MIN	43	37	−6	50	40	−10	60	50	−10
SWEAT EVAPORATED G/M² HR	95	109	+14	110	145	+35	140	182	+42

TABLE 4. DIFFERENCES IN PHYSIOLOGICAL RESPONSES BETWEEN BASELINE AND FINAL VALUES.

	AMBIENT TEMPERATURE								
	45 C (1 HR)			50 C (1 HR)			55 C (1 HR)		
	HEAD VENTILAT CFM (10 C)			HEAD VENTILAT CFM (10 C)			HEAD VENTILAT CFM (10 C)		
	0	2.5	DIFF	0	2.5	DIFF	0	2.5	DIFF
Δ RECT TEMP C	0	−0.1	−0.1	0.3	0	−0.3	0.4	0.4	0
Δ SKIN TEMP C	3.9	3.7	−0.2	4.1	1.4	−2.7	5.5	3.7	−1.8
Δ MEAN BODY TEMP C	1.3	1.1	−0.2	1.6	0.5	−1.1	2.1	1.3	−0.8
Δ HEART RATE BEATS/MIN	12	12	0	25	25	0	34	29	−5

CONCLUSIONS

- The heat stress levels (45, 50 and 55 C) and the duration of exposure to heat (30 and 60 minutes) did not produce intolerable physiological strain.
- Recovery time from heat stress was dependent upon the temperature level following the heat exposure.
- Evaporative cooling during recovery was suppressed by high humidity.
- The recovery cabin temperature should not be lower than 20 to 25 C if uncomfortable cooling rates are to be avoided.
- Heart rate and skin temperature are faithful indicators of the progress of recovery from heat stress.
- Head ventilation was well accepted and produced reduced skin temperature and increased evaporation of sweat.

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