Effects of Electrolyte Ingestion on the Heat Induced Physiological Strain Parameters during Exposure to Acute Heat and the Recovery

P K Banerjee,* Sqn Ldr S P Sastry** and F M Iyer***

Abstract

HEAT induced physiological strain parameters, *viz*: the mean body temperature (MBT), the heart rate and the sweat loss were studied in 10 normal healthy male subjects during *two* 30 min. exposures to simulated environment (DB: 50°C, WB: 39°C) and in the 30 min. recovery periods following each exposure with and without prior ingestion of KCl and NaCl. Ingestion of KCl and NaCl amounting to what one expected to lose through sweat in the course of the trial, was found to increase the sweat loss significantly compared to that observed in the control trial. No significant differences in terms of increase in MBT and the heart rate were, however, obtained between the control trials and the elecrolyte trials.

Prior ingestion of KCl in a larger dose (about 1 gm) was found to aggravate the physiological strain reaction, particularly in terms of circulatory strain which was found to be significantly higher at the terminal min. of exposure and during the recovery as compared with the values obtained in control trials.

The effects of prednisolone (5 mg) were studied on three subjects. The trend observed was a greater increase in MBT, heart rate and sweat loss over those in the control trials.

Introduction

Dehydration and loss of salt leading to a state of fatigue and lassitude are associated with [...] stress. Aircrew engaged in low level high speed [...] in tropical summer conditions are exposed to [...] degree of thermal stress. Earlier studies on [...] subjects revealed that the loss of Na salt was [...] compensated even when the exposure to thermal stress was prolonged because an adequate amount [...] salt was available in their diet (Malhotra[?] [...] Malhotra et al[6]). But with respect to K^+ balance the situation appears to be different. Malhotra et [...] observed that in the summer months, the potassium depletion through sweat was considerably [...] in healthy Indian males and this might lead [...] causation of some features of heat disorders, [...] weakness and lethargy.

The present study is a direct approach [...] determine the effects of ingestion of K^+ prior [...] exposure to acute heat stress. The effects were studied in terms of the heat induced physiological strain during heat exposure and recovery.

Method

Ten healthy volunteers in the age group [...] 35 years, were taken as subjects in the present [...] Their heights and weights were recorded. The [...] ranged between 157 to 178 cms while body weights ranged between 50 and 66 kgs.

Thermal stress corresponding to those [...] in low level high speed sorties were simulated [...]

* Senior Scientific Officer, Gde I, Dept of Physiology Institute of Aviation Medicine, IAF, Bangalore - 560 017.
** Officer i/c Dept of Physiology, Institute of Aviation Medicine, IAF, Bangalore - 560 017.
*** Senior Scientific Officer, Gde I, Dept of Physiology, Institute of Aviation Medicine, IAF, Bangalore - 560 017.

chamber. The temperature settings in the hot chamber are given in Table 1.

For the purpose of measuring sweat loss, subject was weighed with under-wear, using a sensitive manual weighing balance. Then the subject was made to wear flying overalls over cotton undergarments, type G-inner helmets and shoes. Subject was instrumented for measurements of oral and skin temperatures using Ellab electrical thermometer. The mean skin temperature (MST) was calculated based on the measurement taken from four sites of the body, viz. chest, upper arm, thigh and calf. Appropriate weightage for the temperature values was given as recommended by Ramanathan[8]. Mean body temperature was computed by giving a weightage of 0.65 to oral temperature and 0.35 to mean skin temperature. Subject was also instrumented for lead I ECG. ECG was recorded on one channel of a Grass model 5 Polygraph. All these parameters were recorded after keeping subject sitting for ten minutes in a resting room which had an effective temperature of 26°C.

Subject was given 250 ml of water and was exposed to the hot cockpit environment for a duration of 30 minutes. Physiological parameters were monitored every 10 minutes. Subject was then made to recover from the heat induced physiological strain in recovery room, the effective temperature of which was maintained at 29°C, for a duration of 30 ... recovery room are given in Table 1. Subject was re-exposed to hot environment for another period of 30 mins. after administering 250 ml of water subsequent to that he was again made to recover for a period of 30 mins. Monitoring for body temperatures and ECG for every 10 mins. was continued in the recovery and re-exposure phases.

Body weight was determined after second phase of recovery and sweat loss calculated taking into account the weight of the water administered. These trials were termed as control trials. This was conducted for all the ten subjects.

In the second set of experiments, the subject was instrumented as in the control trial and before subjecting him to the first exposure to hot cockpit he was given KCl along with NaCl. The amount of these salts administered was calculated on the basis of the subject's total sweat loss in the control trial and the average concentration of these salts in sweat as reported by Lewis.[4] The amount of water ingested and other details of the experiment were same as in control trial. Five subjects from the total of 10 (control) were studied in these trials and these are termed as trials with electrolyte soln-1.

In the third set of experiments, the subject was given 0.96 gm of KCl before the onset of the first exposure to hot cockpit. The water ingestion and other details were same as those in the earlier trials. Seven subjects from the total of 10 (control) were studied in this set of experiments and these trials are termed as trials with electrolyte soln-2.

In the fourth set, the subject was given 5 mg tablet of prednisolone one hour before the first exposure to heat. The water and electrolyte ingestion and the other details remained the same as those in the trials with electrolyte soln-1. Three subjects were studied in this trial.

Results

Changes in Mean Body Temperature (MBT) from the pre-exposure resting value at the end of the exposures and at 10, 20 and 30 min. of recovery following the exposures are given in Table 2. The values for the control trails and the trials with electrolyte soln-1 are presented and compared statistically. The mean increase in MBT at the end of the first exposure was 2.24°C in the control trials and 2.04°C in the trial with electrolyte soln-1. At the end of the second exposure the mean increase in MBT was 2.58°C for controls and 2.44°C with electrolyte soln-1. Similarly, the 10, 20 and 30 min. recovery values of changes in MBT were also showing lower values during the trials with electrolyte soln-1, compared to those obtained in the control trials. The mean difference were, however, found to be not significant statistically.

Table 3 shows the changes in the heart rate from the pre-exposure resting value at the end of the exposures and during the recovery period. The mean values for the control trials and the trials with electrolyte soln-1 have been compared statistically. The mean increase in terminal heart rate were found to be lower in the trials with electrolyte soln-1 than in control trials. In the recovery period also, lower values of increase in heart rate were observed in the electroylte trials than in the control trials. But as

TABLE 1.

Thermal environment in the pre-exposure rest room, simulated hot cockpit and simulated recovery room

	DB (°C)	WB (°C)	Relative humidity (%)	Air movement (ft/min)	Effective temperature (°C)	Oxford index (°C)
Pre-exposure rest room (mean values)	29	24	65	50	26.0	24.7
Simulated hot cockpit	50	39	50	40	40.0	40.6
Simulated recovery room	35	26	50	100	29.0	27.4

TABLE 2

Changes in MBT from the resting value (°C) in the last minute of heat exposure and during recovery with and without ingestion of electrolyte soln—1

Subjects	FIRST EXPOSURE								SECOND EXPOSURE							
	Terminal		Recovery						Terminal		Recovery					
			10'		20'		30'				10'		20'		30'	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
SS	2.4	2.6	0.8	1.3	0.6	0.7	0.4	0.7	3.1	2.9	1.3	1.2	0.6	0.9	0.2	0.3
GV	2.5	2.0	1.6	1.2	1.3	0.7	1.3	0.5	2.8	2.8	1.7	1.5	1.1	0.8	0.8	0.5
VD	1.7	1.6	0.5	0.5	0.0	−0.1	−0.1	−0.3	1.7	1.4	0.3	−0.2	−0.6	−0.7	−1.2	−1.1
GS	1.8	1.8	0.6	0.8	0.2	0.5	0.1	0.1	2.0	2.0	0.8	0.5	0.3	0.2	−0.1	−0.3
DS	2.8	2.2	1.0	0.5	0.5	0.1	0.3	0.0	3.3	3.1	1.3	1.3	0.8	0.8	0.6	0.6
Mean	2.24	2.04	0.90	0.86	0.52	0.42	0.40	0.20	2.58	2.44	1.08	0.86	0.44	0.40	0.06	0
±Sd	0.50	0.41	0.40	0.38	0.50	0.30	0.50	0.40	0.70	0.72	0.54	0.70	0.65	0.67	0.79	
Mean diff	−0.20 NS		−0.04 NS		−0.10 NS		−0.20 NS		−0.14 NS		−0.22 NS		−0.04 NS		−0.06 NS	

C = Control trial
E = With electrolytes ingestion.

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TABLE 3

Changes in heart rate from the resting value (beats/min)in the last minute of heat exposure and during recovery with and without ingestion of electrolyte soln–1

Subjects	FIRST EXPOSURE								SECOND EXPOSURE							
	Terminal		Recovery						Terminal		Recovery					
			10′		20′		30′				10′		20′		30′	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
SS	39	32	17	12	6	4	6	4	34	40	20	8	5	6	2	4
GV	46	40	6	4	2	6	−4	6	48	40	10	14	−2	8	2	4
VD	36	38	16	2	2	−2	2	−6	40	36	20	10	20	6	16	−2
GS	44	50	18	19	12	8	3	8	56	54	20	24	8	21	4	8
DS	40	36	16	16	10	12	8	14	52	38	28	16	22	14	14	6
Mean	41.0	39.2	14.6	10.6	6.4	5.6	3.0	5.2	46.0	41.6	19.6	14.4	10.6	11.0	7.6	4.0
±S.d	4.0	6.7	4.9	7.4	4.6	5.2	4.6	7.3	8.9	7.1	6.4	10.2	10.2	6.5	6.8	3.7
Mean diff	−1.8 NS		−4.0 NS		−0.8 NS		2.2 NS		−4.4 NS		−5.2 NS		0.4 NS		−3.6 NS	

C = Control trial
E = With electrolytes ingestion.

in the case with MBT, the mean differences in the changes in heart rate for these two trials were not found to be significant statistically.

The individual values with the mean and standard deviation of sweat loss during the control trials and the trials with electrolyte soln-1 are shown in Table 4. The mean values of sweat loss were found to be 972 and 1100 gms. for the control and the electrolyte trials respectively and the mean difference was found to be significant at 5% level.

TABLE 4

Sweat loss in control trials and in trials with ingestion of Electrolyte Soln–1

Subjects	Sweat loss (gm)	
	Control trial	Electrolyte trial
SS	780	820
GV	700	840
ND	820	1040
GS	1220	1300
DS	1340	1500
Mean	972	1100
± Sd	288	296
Mean diff	128 ($p < 0.05$)	

Table 5 shows the individual values of changes in MBT at the end of the exposures and during the recovery period for the control trials and the trials with ingestion of electrolyte soln-2. The mean differences shows less increase in MBT at the end of the first exposure and in the recovery period following the first exposure in the trials with electrolyte soln-2, compared to those in the control trials. But at the end of the second exposure and in the recovery period following the electrolyte trials greater increases in MBT were observed. In no instances, however, the differences were statistically significant.

Table 6 shows the changes in the heart rate over the pre-exposure value at the end of the exposures and during the recovery period following the exposures for the control trials and the trials with electrolyte soln-2. The mean values of increase in the heart rate at the end of the first exposure were 35.0 and 42.9 beats/min for the control trials and the trials with electrolyte soln-2 respectively; the same were 46.6 and 55.1 beats/min for the second exposure. These differences were found to be statistically significant. In all instances, the mean values of changes in the heart rate during recovery were also higher with ingestion of electrolyte soln-2, and the mean differences were found to be significant in all the cases except in the last min of recovery from the second exposure.

Table 7 shows the sweat loss values in the control trials and in the trials with electrolyte soln-2. The mean values were 954 and 978 gms respectively, with no significant differences between them.

Table 8, 9 and 10 show the comparative analysis of the changes in MBT, heart rate and the sweat loss for the control trials and the trials with prednisolone. The mean values of increase in MBT were found to be initially less with prednisolone but since the second exposure, these show higher values in the prednisolone trials compared to those observed in the control trials. The increase in the heart rate during the exposure and the recovery was found to be always higher with prednisolone compared to those observed in the control trials. Sweat loss was found to be higher in the trials with prednisolone than in the control trials. No statistical analysis could, however, be made between the results of these two trials as the samples number was only three.

Discussion

Reported values of K^+ concentration in sweat show an average figure of about 4.2 mEq/litre, i.e. 17 mg% (Lewis[4]) and in certain circumstances it may be higher than in plasma and may reach as high as 9 mEq/litre (Schwartz and Thaysen[11]). Malhotra et al[7] observed the K^+ concentration in sweat to be considerably higher than in plasma in acclimatised persons and he suggested that the expected K^+ loss in persons working in severe heat in the tropics could exceed the dietary intake for the same, resulting in precipitation of heat illness in such circumstances. Some of the features of heat disorders like weakness and lethargy have actually been found in K^+ deficient diet (Gordon and Andrews[1]). Plasma K^+ level was, however, found to be usually maintained within the normal limits

TABLE 5

Changes in MBT from the resting value (°C) in the last minute of heat exposure and during recovery with and without electrolyte soln-2.

Subjects	FIRST EXPOSURE								SECOND EXPOSURE							
	Terminal		Recovery						Terminal		Recovery					
			10′		20′		30′				10′		20′		30′	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
GV	2.5	1.6	1.6	0.5	1.3	0.3	0.8	0.2	2.8	2.7	1.7	1.1	1.1	0.3	0.8	0.0
VD	1.7	1.8	0.5	0.5	0.0	0.2	−0.1	0.0	1.7	2.2	0.3	1.1	−0.6	0.4	−1.2	0.0
GS	1.8	2.1	0.6	0.9	0.2	0.4	0.1	0.3	2.1	2.6	0.8	1.5	0.3	0.6	−0.1	0.3
EI	2.3	2.0	1.2	1.2	0.8	1.0	0.8	0.8	2.7	2.6	1.6	1.6	1.0	1.1	0.1	0.9
TJ	2.0	2.1	0.8	1.2	0.4	0.6	0.2	0.3	2.4	2.6	1.1	1.2	0.4	0.6	−0.1	0.3
MR	2.1	2.0	1.0	1.3	0.5	0.7	0.4	0.1	2.3	2.5	1.3	1.3	0.6	1.1	0.6	0.5
ND	2.2	2.7	1.0	0.8	0.8	0.5	0.7	0.3	2.4	2.6	1.4	0.9	0.5	0.6	0.2	0.1
Mean	2.08	2.04	0.95	0.91	0.57	0.53	0.41	0.28	2.34	2.54	1.17	1.27	0.47	0.57	0.04	0.30
±S.d	0.28	0.34	0.37	0.33	0.43	0.27	0.36	0.25	0.37	0.16	0.49	0.26	0.56	0.31	0.64	0.32
Mean diff	−0.04 NS		−0.04 NS		−0.04 NS		−0.13 NS		0.20 NS		0.10 NS		0.20 NS		0.26 NS	

C = Control trial

E = With electrolyte ingestion

TABLE 6

Changes in heart rate from the resting value (beats/min) in the last minute of heat exposures and during recovery with and without ingestion of electrolyte soln-2

Subjects	FIRST EXPOSURE								SECOND EXPOSURE							
	Terminal		Recovery						Terminal		Recovery					
			10′		20′		30′				10′		20′		30′	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
GV	46	36	6	12	2	6	−4	8	48	58	10	26	−2	8	2	4
VD	36	49	16	33	2	23	2	23	40	55	20	27	20	15	16	13
GS	44	54	18	24	12	16	3	10	56	71	20	36	8	24	4	20
EI	22	37	18	20	10	6	14	12	50	52	34	36	26	32	30	28
TJ	31	44	14	27	8	20	7	17	46	48	26	23	18	21	14	21
MR	42	44	10	20	2	12	−2	8	50	60	22	28	14	20	10	16
MD	24	36	0	8	−8	8	−10	8	36	44	10	18	4	14	−2	10
Mean	35.0	42.9	11.7	20.8	4.0	13.0	1.4	12.3	46.6	55.1	20.3	27.7	12.6	19.1	10.6	16.0
± Sd.	9.6	7.0	6.8	9.1	6.7	6.8	7.8	5.7	6.7	9.3	8.5	6.5	9.8	7.7	10.7	7.9
Mean diff	7.9 *		9.1 **		9 *		10.9 **		8.5 **		7.4 *		6.5 *		5.4 NS	

* = Significant at $p < 0.05$
** = Significant at $p < 0.01$

C = Control trail
E = With electrolyte ingestion

TABLE 7

Sweat loss in control trials and in trials with Electrolyte Soln-2

Subjects	Sweat loss (gm)	
	Control trial	Electrolyte trial
GV	700	640
VD	820	930
GS	1220	1050
EI	840	660
TJ	1260	1230
MR	840	890
ND	1000	1450
Mean	954	978
Sd±	214	293
Mean diff	24 NS	

n acute exposure to heat (Harrison[2]) and in salt depletion heat exhaustion (Leithead and Lind[3]). But a reduction in the total exchangeable K^+ needing its replacement is well expected in certain circumstances.

As observed in Tables 2 and 3, a prior ingestion of K^+ (average amount: 172 mg in 328 mg of KCl) with Na^+ (average: 1.52 gm in 3.86 gm of NaCl) produced less increase in MBT and heart rate during heat exposure and the recovery, as compared to the values obtained during control trials with no ingestion of electrolytes. Though the differences were not significant statistically the observed trend was encouraging. The sweating was found to be significantly higher ($p < 0.05$) in the trials with electrolytes than in the control trials.

In the second series of the study when seven subjects were studied with ingestion of a larger dose of K^+ (0.5 gm in 0.96 gm of KCl), the changes in the terminal and the recovery MBT values did not show any consistent and significant differences compared to those in the control trials (Table 5). However, in terms of the heart rate responses, the trials with this dose of K^+ showed significantly higher increase at the end of the exposure and during the recovery than those observed in the control trials (Table 6). The mean sweat loss in these trials was found to be more or less same as that observed during control trials. The overall influence of the ingestion of K^+ (0.5 gm) prior to an acute heat exposure was thus found to be aggravating the heat induced physiological strain, particularly in terms of the circulatory strain. In view of the limited design of the present study no explanation could be offered for the physiological mechanism for such deleterious effects of K^+.

Prednisolone, a very potent glucocorticoid, is considered to be concerned with the body's response to stress. Its mineralocorticoid effects in the retention of Na^+ and H_2O and in K^+ loss becomes a problem only with prolonged high dosage therapy in excess of 40 mg dail (Rastogi[9]). The dose tried in the present study was only a single dose of 5 mg prednisolone which was thus much below the limit where its mineralocorticoid effects could be felt. But the trends that its effects showed in terms of increase in MBT, particularly in the second exposure and recovery (Table 8), and in the increase in heart rate (Table 9), were indicative of aggravating the thermal strain reactions during acute exposure to heat stress.

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TABLE 8

Changes in MBT from the resting value (oC) in the last minute of heat exposure and during recovery with and without ingestion of Electrolytes and Prednisolone

Subjects	FIRST EXPOSURE								SECOND EXPOSURE							
	Terminal		Recovery						Terminal		Recovery					
			10′		20′		30′				10′		20′		30′	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
MR	2.1	2.1	1.0	1.3	0.5	1.0	0.4	1.0	2.3	2.4	1.3	1.7	0.6	1.2	0.6	1.0
ND	2.2	2.0	1.0	0.5	0.8	0.1	0.7	−0.2	2.4	2.7	1.4	1.3	0.5	0.6	0.2	0.3
RC	1.9	1.7	0.6	0.8	0.4	0.4	0.3	0.2	1.7	2.4	0	1.3	−0.5	1.0	−0.5	0.9
Mean ± Sd	2.07	1.93	0.87	0.87	0.57	0.50	0.47	0.33	2.13	2.50	0.90	1.43	0.20	0.93	0.10	0.73
Mean diff	−0.14		0		−0.07		−0.14		0.37		0.53		0.73		0.63	

C = Control trial
E = With electrolytes & prednisolone

TABLE 9

Changes in heart rate from the resting value (beats/min) in the last minute of heat exposure and during recovery with and without ingestion of Electrolytes and Prednisolone

Subjects	FIRST EXPOSURE								SECOND EXPOSURE							
	Terminal		Recovery						Terminal		Recovery					
			10′		20′		30′				10′		20′		30′	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
MR	42	36	10	12	2	6	−2	2	30	50	22	30	14	18	10	8
ND	24	44	0	8	−8	8	−10	6	36	46	10	28	4	8	−2	6
RC	20	28	8	18	4	8	2	8	20	34	6	10	4	8	4	8
Mean	28.7	36.0	6.0	12.7	−0.7	7.33	−3.3	5.3	35.3	43.3	12.7	22.7	7.3	11.3	4.0	7.3
Mean diff	7.3		6.7		8.03		8.6		8.0		10.0		4.0		3.3	

C = Control trial
E = With electrolyte and prednisolone

TABLE – 10

Sweat loss in control trials and in trials with Electrolytes and Prednisolone

Subjects	Sweat loss (gm)	
	Control trial	Prednisolone trial
MR	840	950
ND	1004	1116
RC	810	1060
Mean	885	1042
Mean diff	157	

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