A STUDY OF STRESS IN FLYING DURING TROPICAL SUMMER, SOME PHYSIOLOGICAL AND BIOCHEMICAL CHANGES IN INDIAN PILOTS

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ABSTRACT

During this investigation attempts have been made to approach the general problem of flying fatigue in summer from both physiological and psychological aspects. This paper presents the result of physiological and biochemical changes.

Changes in body weight, rectal temperature, haemotocrit value, blood glucose, and eosinophil count have been studied. Loss of body weight, increase in rectal temperature and haematocrit value did not give sufficient indication of haemoconcentration. The change in the level of blood glucose was also not very significant. Fall of eosinophil count was of the order of only 16-17 percent.

From the above facts it appears that normal squadron flying for about an hour in an environment prevailed during the trial does not involve any severe degree of stress.

For the purpose of studying the phenomenon of stress, some fundamental studies are needed from the standpoint of cortical response.

Introduction

It is a recognised fact that a change in the environmental condition may cause stress in the human system and that flying may also produce such stress is thus conceivable. Considerable importance was attached to the subject of flying stress during the last war and afterwards, and a good deal of information has so far accumulated on this phenomenon. But there is sufficient indication that more quantitative data need to be collected to throw further light on this subject. As there is paucity of data on flying stress in the case of Indian pilots it has been proposed to make some study along this line. Before dealing with the problem of stress under severe or emergency condition, it has been considered desirable to ascertain what happens in the peacetime squadron flying activities.

The present investigation was undertaken primarily with the object of developing understanding which might help in the planning of similar work in future. In this connection some physiological and biochemical changes as affected by flying over Delhi in summer were studied and the results are reported in this paper.

EXPERIMENTAL

General Procedure

This investigation covered the period from the 1st of June to the 8th of July, 1954. Experimental subjects were ten pilots belonging to one of the fighter squadrons based at Palam Air Field. They were divided into five groups and each group was studied once a week according to Latin Square arrangement. Physiological measurements and samples of venous blood were taken on two occasions, once before take-off, and again after landing. During this period they were instructed not to take any food or drink, and not to pass urine or to subject themselves to any kind of physical stress other than the usual preflight activities. They flew normally between 0915 hours and 1015 hours and the actual flying time was obtained from each of them. As far as possible the time lag between the initial recording of observations and the take-off, and similarly between the landing and final observations, was tried to be reduced.

Physiological and Environmental Measurements and Analysis of Blood

Physiological measurements included recording of nude body weight and rectal temperature. Only in few cases the weight of clothing was taken. Venous blood was collected and stored properly for the estimation of W.B.C. count, haemoglobin, haematocrit values, and glucose, according to standard methods ([1,2,3]). Slides were also taken simultaneously for differential counts. Eight hundred white blood cells were counted for estimating the number of eosinophils as recommended by Bonner ([4]).

Environmental conditions on the ground during flying and temperature of the cockpit of vampire aircraft parked outside the hangar were recorded according to recognised methods ([5]).

A battery of psychological tests were also given to the subjects to assess reaction time, mental alertness, etc., before take-off and after landing along with the previous measurements, by a psychologist and the details will be presented in a separate report.

RESULTS AND DISCUSSION

Particulars of Test Subjects

Relevant particulars of the subjects with regard to their age, total service and approximate flying hours on vampire at the beginning of this investigation are given in Table 1. With the exception of two subjects (C-1) and C-2) other groups were fairly comparable.

TABLE I

Relevant Particulars of the Test Subjects

Subject	Age (years)	Approximate hours on vampire	Total service (years)	Total number of observations
A-1	21	20	2	5
A-2	20½	25	2½	5
B-1	20	35	3	5
B-2	21	200	2	3
C-1	24½	130	5	1
C-2	28	50	9	2
D-1	20	32	2	5
D-2	21	30	2	5
E-1	23	27	3	4
E-2	21	80	3	2

Environmental Measurements

It might be conceived that heat and flying are two important factors operating in this connection. To have an idea of the former, information pertaining to the environmental condition around the pilot on the ground and also in the aircraft while flying is necessary. Data on ground temperature are shown in Table II, and the data on cockpit temperature of an aircraft on the ground as compared to the ambient temperature simultaneously recorded are given in Table III. It would be observed that temperature is considerably higher in the cockpit. A pilot has to remain in this environment for about 5 to 10 minutes and sometimes longer before he actually leaves the ground.

TABLE II

Average Environmental Measurements on the Ground Expressed in C.E.T., as Recorded During Flying on the Days of Observation

Group of subjects	Observation week				
	1st	2nd	3rd	4th	5th
A	85·6	88·3	85·3	91·6	84·4
B	70·2	88·0	86·5	89·1	89·9
C	79·8	87·1	Flying cancelled due to bad weather		
D	79·6	86·6	88·3	85·3	82·2
E	88·3	87·9	89·9	88·0	Flying cancelled

TABLE III

Environmental Measurements in Vampire Cockpit Outside the Hangar

Date and time	Dry bulb temperature (°F)		Wet bulb temperature (°F)		Globe temperature (°F)		Remarks
	Ambient	Aircraft	Ambient	Aircraft	Ambient	Aircraft	
9-6-54 1100 hours	103	119	78	87	136	140	canopy closed
10-6-54 1100 hours	105	119	75·8	87	128	139	,,
15-6-54 1015 hours	98	106	75·6	78	118	130	canopy opened
17-6-54 1010 hours	98·5	103	75	80	122	125	,,

Cockpit temperature during flying could not be recorded. It may, however be mentioned that although the air temperature falls rapidly with altitude, temperature in the cockpit remains relatively higher since it gains heat while flying from several sources(6). Hence one might assume that cockpit temperature would appreciably rise during flying, specially at low altitude. This assumption has been corroborated from opinion expressed by pilots during interrogation.

Sweat Loss and Rectal Temperature

Total body weight loss has been expressed as oz/m²/hr and the relevant data are shown in Table IV. To assess the amount of sweat that became ineffective, clothings were also weighed before and after each mission in the case of some subjects. Relevant data on the amount of sweat trapped in flying clothings and 'smalls' and percent of sweat evaporated are given in Table V.

The pilots did not exhibit any of the recognised symptoms of dehydration other than slight rise of rectal temperature, flushing of the skin and thirst. From relevant literature (7, 8) it appears that this amount of sweat loss can be amply compensated by the extravascular fluid reserve, specially from the skin, and as such it is not expected that there will be any appreciable change in effective blood volume. This was also borne out from the data on haematocrit values as discussed later.

TABLE IV

Sweat Loss in Ounce per Hour

Subjects	1st week		2nd week		3rd week		4th week		5th week	
	Total loss	loss m^2/hr	Total loss	Loss m^2/hr	Total loss	Loss m^2/hr	Total loss	Loss m^2/hr	Total loss	Loss m^2/hr
A-1	25·0	10·9	18·0	6·3	17·0	9·1	31·0	10·2	18·0	7·5
A-2	21·5	16·4	30·0	15·5	28·5	10·3	28·5	9·4	22·0	10·6
B-1	17·0	3·8	22·0	7·4	22·0	7·0	31·5	9·6	28·5	13·3
B-2	16·0	4·5	12·5	5·3	21·0	7·7	Bad weather	..	..	
C-1	18·0	Subject was not available.								
C-2	28·5	6·5	30·5	10·5	Subject was not available.					
D-1	18·5	4·5	29·0	7·7	27·5	9·6	36·5	12·4	16·0	6·6
D-2	28·5	7·4	39·5	10·1	43·0	17·9	38·5	11·2	42·0	11·4
E-1	24·0	7·2	37·0	15·2	32·0	11·2	31·0	9·9	Bad weather	
E-2	32·0	11·9	44·0	14·8	Subject was not available.					

Data on sweat loss, rise of rectal temperature and the nature of exercises performed are presented in Table VI with the object of giving some idea of the relative amount of stress involved in different types of flying exercise.

TABLE V

Average Total Sweat Loss, Sweat Uptake of Flying Clothings and Percent of Sweat Evaporated

Subject	Total sweat loss (oz)	Sweat uptake of flying clothing (oz)	Sweat evaporated (percent)
A-1	22·0	3·5	84·1
A-2	26·3	5·0	80·9
B-1	26·7	5·0	81·2
B-2	21·0	7·5	64·3
C-2	30·5	8·5	72·1
D-1	26·6	6·3	76·4
D-2	41·1	12·0	70·8
E-1	31·5	8·0	74·6

It appears that rocket firing caused significant rise of sweat loss and rectal temperature as compared to other flying exercises. There was no significant difference between other three exercises. It was not possible, however, to

assess the extent to which each of the several factors, namely, environmental condition, mental stress, physical activity, etc., contributed individually towards the above changes.

TABLE VI

Sweat Loss, Increase of Rectal Temperature and Types of Flying Exercise

Type of exercise	Sweat loss (oz/m²/hr)	Increase in rectal temperature (°F)
Formation	10·2	1·0
	9·4	0·5
	3·8	1·5
	4·5	0·5
	6·5	0·5
	12·4	1·25
	11·2	1·0
Average	8·3	0·89
Snake climb	6·3	1·0
	15·5	0·75
	7·4	1·5
	5·3	0·5
	7·7	1·0
	10·1	1·0
	7·2	1·25
	11·9	1·25
Average	8·9	1·03
Rocket firing	9·1	0·75
	10·3	1·0
	7·0	1·5
	13·3	2·5
	10·5	1·0
	9·6	0·5
	17·9	1·5
	15·2	1·0
	11·2	1·0
	14·8	1·0
Average	11·9	1·18
Cloud flying	4·5	0·5
	7·4	1·25
	6·6	0·5
	11·4	1·0
Average	7·5	0·81

Haematocrit Values

The average change in packed cell volmue was found to be quite small and hence the data as shown in Table VII do not appear to suggest that the flying caused any significant degree of haemoconcentration. This point was also borne out from the data on sweat loss already discussed (*vide* Tables IV and V). It may be pointed out further that no appreciable change in haemoglobin content as determined occasionally could be noticed as a result of the different types of flying exercise.

TABLE VII

Change in Packed Cell Volume as a Result of Flying

Subject	P.C.V. Percentage			Average rise
	Before flying	After flying	Rise	
A-1	48·0	47·0	—1·0	—0·50
	45·5	44·5	—1·0	
	46·0	46·5	+0·5	
	44·5	44·5	0·0	
	46·0	45·0	—1·0	
A-2	46·0	47·0	+1·0	+0·60
	47·5	46·0	—1·5	
	46·5	46·5	0·0	
	47·0	49·5	+2·5	
	45·5	46·5	+1·0	
B-1	46·0	46·0	0·0	—0·75
	45·5	44·5	—1·0	
	47·5	45·5	—2·0	
	46·0	44·5	—1·5	
	45·0	45·0	0·0	
	48·0	48·0	0·0	
B-2	46·0	46·0	0·0	+0·13
	47·5	46·0	—1·5	
	44·0	45·0	+1·0	
	44·5	45·5	+1·0	
C-1	46·0	46·0	0·0	0·0
C-2	45·5	46·0	+0·5	+0·25
	45·0	45·0	0·0	
D-1	52·0	52·0	0·0	+0·20
	50·5	50·5	0·0	
	50·0	50·0	0·0	
	49·0	50·0	+1·0	
	48·0	48·0	0·0	
D-2	45·0	45·0	0·0	+0·40
	46·5	45·5	—1·0	
	44·0	46·0	+2·0	
	45·0	45·0	0·0	
	44·5	45·5	+1·0	
E-1	52·0	49·0	—3·0	—0·38
	51·5	51·0	—0·5	
	48·0	50·0	+2·0	
	48·5	48·5	0·0	

Blood Glucose

The data on blood glucose are presented in Table VIII. Individual variations were quite wide and there was some tendency for this constituent to rise. Though it is known that significant rise in blood sugar may occur under the influence of emotional stress or sometimes by exercise ([9]), such a small rise as noted here may not have any real significance.

TABLE VIII

Level of Blood Glucose before and after Flying (mg/100 ml of blood)

Subject	Before flying	After flying	Change	Average change
A-1	79·6 84·5 98·0 89·0	85·2 90·0 106·0 98·0	+5·6 +5·5 +8·0 +9·0	+7·02
A-2	92·6 80·5 92·0	93·8 86·5 92·0	+1·2 +6·0 +0·0	+2·40
B-1	77·0 80·0	80·5 87·5	+3·5 +7·5	+5·50
B-2	70·0 98·0	80·0 106·0	+10·0 +8·0	+9·0
C-2	98·0 87·0	87·0 85·0	—11·0 —2·0	—6·50
D-1	86·5 86·0 89·0	84·4 88·0 90·0	—2·1 +2·0 +1·0	+0·30
D-2	80·5 81·0	87·0 72·3	+6·5 —8·7	—1·1
Average	..	..	..	+2·37

Eosinophil Count

In view of the fact that a good deal of emphasis has been placed recently on eosinophil count in connection with studies on stress ([10–16]) it was proposed to see how the number of eosinophil cells would change in the case of the pilots under test. Data of eosinophil counts taken before and after flying are shown in Table IX.

TABLE IX

Eosinophil Count as affected by Flying

Subject	No. of observation	Eosinophil count/cmm blood		Percent fall	Average fall %
		Before flying	After flying		
*A-1	1	1742	1441	17·3	
	2	1601	1375	14·1	
	3	1370	1060	22·6	
	4	1360	1290	5·1	23·4
A-2	1	281	143	49·1	
	2	488	413	15·4	
	3	489	293	40·1	
B-1	1	417	159	61 9	
	2	408	445	—9·0	
	3	545	469	13·9	
	4	236	164	30·5	
	5	355	276	22·3	27·4
B-2	1	182	73	59·9	
	2	100	65	35·0	
	3	86	82	4·7	
C-1	1	250	187	25·2	26·9
C-2	1	390	234	40·0	
	2	473	399	15·6	
D-1	1	222	124	44·1	
	2	153	98	35·9	
	3	108	99	8·3	
	4	89	77	13·5	
	5	127	66	48·0	25·9
D-2	1	159	174	—9·4	
	2	288	162	43·8	
	3	84	65	22·6	
E-1	1	114	100	12·3	
	2	62	65	—4·8	16·7
	3	47	27	42·5	

*This subject was probably suffering from allergy or helminthic infection.

There had definitely been a tendency for the count to fall. Individual as well as weekly variations were quite high and the average fall in the case of various groups ranged from 16 to 27 percent approximately.

In the absence of an elaborate experiment it was not possible to assess quite definitely the significance of the above fall in eosinophil count. However, the recent work of Thorn et al [11] points to the fact that a fall of eosinophil count below 50 per cent does not signify a stress sufficient to stimulate the secretion of adrenal steroids. In the light of this observation it may be inferred that normal squadron flying in an environment that prevailed during the present trial does not seem to put the pilots under any severe stress. Data

on eosinophil count in different types of flying exercises are given in Table X. It will be observed that formation flying and cloud flying caused relatively greater fall in eosinophil count. Opinion survey carried out in large number of aircrews [17] also showed that both formation flying and instrument flying are two of the most potent factors which cause fatigue to the pilots. Further investigation along this line may throw more light on the value of eosinophil count as an index of flying stress.

TABLE X

Fall in Eosinophil Count in Relation to the Type of Exercise

Type of flying	Eosinophil fall %	Average fall %
Formation	22·76	38·1
	—57·9*	
	61·9	
	59·9	
	25·2	
	40·0	
	13·5	
	43·8	
Snake climb	17·3	23·4
	49·1	
	—9·0	
	35·0	
	35·9	
	12·3	
Rocket firing	14·1	11·2
	15·4	
	13·9	
	22·3	
	4·7	
	15·6	
	8·3	
	—4·8	
Cloud flying	44·1	26·3
	48·0	
	—9·4	
	22·6	
Height climb (aerobatics)	5·1	22·6
	40·1	

*Not included in the calculation of average fall. This figure is very erratic and no argument can be advanced at present to substantiate this behaviour. Similar variations were also observed by other workers.

In order to explain fully the significance of any degree of eosinopenia the nature of the various factors causing it has to be known. The normal hourly and daily variations in the case of test subjects have to be worked out under controlled conditions. To have some idea of hourly variations in the eosinophil count, observations were taken on a few laboratory workers. Data are shown in Table XI. It is apparent that there has been perceptible rise from 1400 hours. Similar trend was also reported by Rud [18]. It would be of interest to see in this connection the change during the twenty four hours as well.

TABLE XI

Hourly Variations in Eosinophil Count of Subjects in Airconditioned Room (Average temp. 80–82°F)

Time	Subject No.								Average Eosinophil count
	1	2	3	4	5	6	7	8	
1000	328	233	703	221	194	135	120	376	289
1200	430	187	476	247	128	174	234	288	271
1400	603	270	845	343	179	231	481	369	415
1600	620	347	1135	352	350	263	479	450	500

Further data were taken on eosinophil counts of the above subjects to study the effect of one hour exposure to the sun. Blood samples were collected at four different times, namely, at 1000 hours, 1400 hours and 1600 hours in the air conditioned room and 1 to 2 minutes before the termination of the exposure which lasted from 1100 to 1200 hours. During the exposure, the subjects dressed in the usual summer clothing were sitting on chairs on the roof of the laboratory. It will be seen from the data in Table XII that heat treatment checked the normal trend of eosinophil rise in the afternoon. Some degree of decline of the order of about 13 per cent at 1400 hours with a tendency to rise at 1600 hours seemed to have taken place. For statistical analysis it will be necessary, however, to study the above points with a few more subjects.

TABLE XII

Effect of One-hour Exposure in the Sun on Eosinophil Count (1100 hours to 1200 hours)

	Subject No.								Average Eosinophil count
	1	2	3	4	5	6	7	8	
1000 hrs.	..	285	930	228	179	127	388	435	367
1200 hrs.	..	174	798	155	265	96	310	358	308
1400 hrs.	..	231	722	146	179	195	276	368	302
1600 hrs.	..	349	812	240	305	261	401	405	396
Average CET between 1100 and 1200 hrs.	89·0	88·0	89·0	88·5	88·6	88·0	88·0	89·0	

As eosinopenia is reported to result from adrenal response to stress in man, a comparison of the changes in circulating eosinophils with changes in 17-hydroxycorticoid excretion would provide a better means of assessing the extent to which activation of the adrenal cortex contributes to the total stress response of the pilots [11]. This was not, however, possible at this stage.

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REFERENCES

1. Wintrobe, M.M. Clinical Haematology (1951).
2. Napier, L.E., and Das Gupta, C.R. Haematological Technique (1945).
3. King, E.J. Micro-analysis in Medical Biochemistry (1951).
4. Bonner, C.D. Eosinophil Levels as an Index of Adrenal Responsiveness. The Factors that affect value of eosinophil counts. J. Am. Med. Assoc. 148: 634 (1952).
5. Bedford, T. Basic Principles of Ventilation and Heating (1948).
6. Lindes, D. Requirements for Protection against thermal hazards of high speed flight. J. Aviation Med. **22**, 358 (1951).
7. Courtice, F.C. Body fluid distribution in injury. Brit. Med. Bull. 10:5 (1954).
8. Kleiner, I.S. Human biochemistry, p. 458 (1951).
9. Peters, J.P., and Van Slyke, D.D. Quantitative clinical chemistry. Vol. 1, 166 (1946).
10. Selye, H. The physiology and pathology of exposure to stress (1950).
11. Thorn, G.W., Jenkins, D., and Laidlaw, J.C. The adrenal response to stress in man. Recent Advances in Hormone Research. 8:171 (1953).
12. Wake, R.F., Graham, B.F., and McGrath, S.D. A study of the eosinophil response to exercise in man. J. Aviation Med. 24.: 427 (1953).
13. Gofton, J.P., Graham, B.F., McGrath, S.D., and Cleghorn, R.A. Evaluation of changes in eosinophil level in studies of adrenocortical function and stress. J. Aviation Med. 24:123 (1953).
14. Goften, J.P. and McGrath, S.D. Studies of adrenocortical function in long distance fliers. J. Aviation Med. 24:107 (1953).
15. Domanski, T.J. and Nuttall, J.B. The physiological recognition of strain associated with flying. J. Aviation Med. 24:441 (1953).
16. Murphy, C.W., Gofton, J.P., and Cleghorn, R.A. Effect of long range flights on eosinophil level and corticoid excretion. J. Aviation Med. 25:242 (1954).
17. Williams, G.O. Fatigue and flying accidents. F.P.R.C. Report No. 492.
18. Rud, F. The eosinophil count in health and mental disease. A biometrical study. Acta. Psychiat et Neurol. Suppl. 40 (1947). Cited by Bonner, C.D. (*vide* ref. 4).