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SAM-TDR-62-112

STRESS RESPONSES OF PILOTS FLYING 6-HOUR OVERWATER MISSIONS IN F-100 AND F-104 AIRCRAFT

TECHNICAL DOCUMENTARY REPORT NO. SAM-TDR-62-112

August 1962

School of Aerospace Medicine
Aerospace Medical Division (AFSC)
United States Air Force
Brooks Air Force Base, Texas

Project No. 7758, Task No. 59579

FOREWORD

This report was prepared by the following personnel at the 831st Tactical Hospital, U. S. Air Force, George Air Force Base, California, and the School of Aerospace Medicine:

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The authors are grateful for the technical assistance of Edgar W. Williams, A/1C Jack Donahue, A/1C John Anderson, A/1C Jesus Garcia, S/Sgt Coley Devlin, and Robert M. Rice; and for the statistical assistance of Alton J. Rahe.

ABSTRACT

From postflight urine and blood samples, stress was appraised in two groups of pilots flying overwater missions of 6 hours' duration in F-100 or F-104 aircraft. Control determinations were made on a third group of pilots on an off-duty day. Urinary determinations included epinephrine, norepinephrine, corticosteroids (17-OHCS), sodium, potassium, inorganic phosphate, urea, uric acid, and creatinine. Blood determinations included free and conjugated hydrocortisone and corticosterone-like fractions. Flying raised corticosteroid levels in plasma but not in urine. Levels for the F-100 group were higher than for the F-104. Urinary epinephrine and norepinephrine values for the flying groups were significiantly above those for the control, values for the F-104 group exceeding those for the F-100. Differences in flying groups appear to relate to aircraft characteristics, weather conditions, and flying experience. Both flying groups showed high urinary excretion of urea and uric acid, but only in the F-104 group was sodium and potassium excretion elevated. Flying induced no variation in urinary phosphate. Singly and collectively, these determinations are basic to future studies on flight stress.

This technical documentary report has been reviewed and is approved.

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1. INTRODUCTION

Appraisal of the physiologic "cost" of flying, while highly desirable, is technically difficult. While there is much to indicate that flying in single-place, high-performance aircraft imposes physiologic loads on the flyer, quantitative evaluation is lacking. Postflight biochemical evaluation appears to be promising (1-4), but the research along these lines has been very limited. In the present investigation an attempt has been made to characterize and assess flying strain in pilots during relatively long flights over water in single-place aircraft, the F-100 and the F-104. A battery of determinations was employed which relates to autonomic, endocrine, and metabolic activities. Most of the physiologic functions selected for study proved to be flight-sensitive, and differentiation of flying groups and of individuals was accomplished on the basis of certain of these biochemical determinations.

2. METHODS

One group of 14 pilots flew F-100 aircraft on a navigational nonstop mission from Hickam Air Force Base, Hawaii, to George Air Force Base, Calif., 2,295 nautical miles. There were two in-flight refuelings. This was a day mission of 5 hours 45 minutes, which represented the final leg of a flight from Clark Air Force Base, Philippine Islands, with stopovers at Guam and Hickam. The group had participated in a joint deployment/employment/redeployment exercise at Clark Air Force Base, Philippine Islands, over a 15-day period. The average age was 28 years, and average total flying experience for the group amounted to 1,282 hours.

Received for publication on 30 March 1962.

All pilots obtained at least 6 hours of sleep and were out of bed at 0600 hours. There was approximately 3 hours' station time prior to take-off. The flight was over water, except for approximately 15 minutes prior to landing. Weather was excellent, and no complaints were offered other than the fatigue of sitting for that period of time.

The second group was comprised of 13 F-104 fighter pilots flying nonstop from the Azores to Myrtle Beach Air Force Base, S.C., 2,448 nautical miles, on a 6-hour navigational flight. This group was returning home after a 4-month deployment of temporary duty in Spain. Sleep ranged from 4 hours for 2 individuals to 8 for the others. The time out of bed was at 0300, and take-off was an average of 2½ hours later. There were three in-flight refuelings and approximately 2 hours of flight in weather. The average age was 29 years, and the average flying experience was 2,426 hours.

To provide control data, 12 additional jet pilots were studied on an off-duty day. Urine and blood samples were obtained from the members of the two flying groups immediately upon landing and from the members of the control group at a time comparable to that for the flying groups. Urinary pH was estimated with indicator paper (pHydrion) as soon as possible after collection, then acidified (2 ml. conc. HCl/250 ml. urine), and diluted to standard volume. By use of standard technics (5-7), the urine samples were analyzed for 17-hydroxycorticosteroids (17-OHCS), epinephrine, norepinephrine, urea, uric acid, creatinine, inorganic phosphate, sodium, and potassium.

Plasma was analyzed for free and conjugated 17-hydroxycorticosterone (hydrocortisone) and a corticosterone-like compound according to the fluorescence method of Sweat (8). The conjugated forms of these steroids were determined by use of a modification of Sweat's method (unpublished). Statistical analysis was performed to determine whether the flying groups differed from the control or from each other. In addition, correlational analysis was accomplished.

3. RESULTS

Through misunderstanding, urine samples were not obtained from 5 of the F-100 pilots. In addition, one member of this group did not provide a blood sample. The control group was to have contained one more subject; but overdilution of the subject's urine made the results questionable, and exclusion of these data seemed proper. One blood sample for the control group was lost in transit. It is thought that these missing data in no way affected the final conclusions, since large differences in treatment groups were obtained for many items in this battery of tests.

Data on urine volume and pH are included merely for completeness (table I). Since these were not timed urine collections, the high urine volumes do not necessarily have meaning. The pH values for the two flying groups were higher than the control, but determinations of this sort made under field conditions must be considered qualitative rather than quantitative, since they were made with indicator paper and after some delay. The pH values are, therefore, ancillary to the electrolyte determinations.

Phosphate values for the two flying groups did not differ significantly from the control (table I). Sodium values for these groups were relatively high, but statistical significance was obtained only for the F-104 group. Potassium values were also relatively high, and statistical support was obtained only for the F-104 group. The Na/K ratio for the F-104 group was elevated significantly, but that for the F-100 group was not.

Evidence of altered nitrogen metabolism was obtained for both flying groups, urea and uric acid values exceeding control limits (table I). The two flying groups, however, did not

TABLE I

Postflight biochemical variation

Urinary variable	Control (n = 12)	F-100 (n = 9)	F-104 (n = 13)
Volume (ml.)	115	238	693
pH	5.8	6.2	6.1
Phosphate (mg./100 mg. creatinine)	30	28 (NS)	27 (NS) (NS)
Sodium (mEq./100 mg. creatinine)	8.1	11.2 (NS)	14.6 (<.001) (NS)
Potassium (mEq./100 mg. creatinine)	3.3	4.5 (NS)	4.2 (<.05) (NS)
Na/K (mEq./mEq.)	2.4	2.6 (NS)	3.6 (<.02) (NS)
Urea (gm./100 mg. creatinine)	0.92	1.52 (<.02)	1.26 (.001) (NS)
Uric acid (mg./100 mg. creatinine)	29	44 (<.05)	47 (<.001) (NS)

Values in parentheses indicate significance of differences; those for the F-100 group refer to the difference between this group and the control. The upper figure of each pair for the F-104 group refers to the difference between this group and the control. The lower figure or notation refers to the difference between flying groups.

differ significantly from each other either in urea or in uric acid excretion.

Urinary epinephrine and norepinephrine values for the F-100 group were much greater than the control (table II), and the F-104 group had values that were significantly higher than those for the former flying group. Urinary 17-OHCS values for the flying groups, however, did not differ significantly from the control. In striking contrast, plasma corticosteroids were elevated in the flying groups, and on this basis there was even differentiation of the flying groups.

Correlation coefficients are presented in table III. The table includes only those pairs of variables that showed significant correlation in at least one group of subjects. As presented, it appears that the degree of association for certain pairs of variables was altered by conditions. Further analysis, however, showed that the variation in correlation coefficient with groups was significant in only a few cases (table IV).

In an attempt to compare individuals, a "strain index" was derived. Ten measures were incorporated into the index—namely, epinephrine, norepinephrine, phosphate, sodium, potassium, the Na/K ratio, urea, uric acid, urinary 17-OHCS, and plasma hydrocortisone. Each of the constituent determinations was expressed as percent of the mean value obtained for the control group, and the "index" is merely the average value for the ten. On this basis, control subjects ranged from 73 to 127, the F-100 pilots from 95 to 256, and the F-104 pilots from 158 to 243. For comparing the three groups, graphs are presented in figure 1. Three of the F-100 pilots have values which are either within the control range or barely above; thus, it seems that they flew without manifesting strain.

4. DISCUSSION

This study, which is preliminary in nature, provides good leads for future research. Despite the low number of subjects and unavoidable losses of specimens, flight effects were

TABLE II

Postflight endocrine evaluation

Hormone	Control	F-100	F-104
Urinary	(n = 12)	(n = 9)	(n = 13)
Epinephrine	0.25	1.28 (<.005)	1.82 (<.001) (<.05)
Norepinephrine	1.23	3.57 (<.01)	5.72 (<.001) (<.01)
17-OHCS	280	373 (NS)	298 (NS) (NS)
Plasma	(n = 11)	(n = 13)	(n = 13)
Free hydrocortisone	8.2	21.2 (<.001)	13.2 (<.001) (<.001)
Conjugated hydrocortisone	8.0	20.5 (<.001)	13.1 (<.001) (<.001)
Free corticosterone-like	3.3	8.6 (<.001)	5.4 (<.001) (<.001)
Conjugated corticosterone-like	3.4	8.0 (<.001)	4.8 (<.001) (<.001)

Urinary values = µg./100 mg. creatinine.
Plasma values = µg./100 ml.

TABLE III

Correlations

Paired variables	Control		F-100		F-104	
	r	P	r	P	r	P
Free F – Conjugated F	.89	<.001	.97	<.001	.96	<.001
Free B – Conjugated B	.68	<.05	.94	<.001	.37	NS
Free F –Urinary 17-OHCS	.71	<.02	−.43	NS	.17	NS
Free F – Urinary K	.64	<.05	.55	NS	−.28	NS
Conjugated F – Urinary NE	.62	<.05	.21	NS	−.19	NS
Urinary E – Urinary Na	.64	<.05	.32	NS	.38	NS
Urinary E – Urinary PO_4	−.72	<.01	.22	NS	−.71	<.01
Urinary E – Urinary NE	.43	NS	.79	<.02	.75	<.01
Urinary Na/K – Urinary Na	.82	<.01	.78	<.02	.57	<.05
Urinary K – Urinary Urea	.18	NS	.85	<.01	.23	NS
Conjugated F – Urinary PO_4	−.13	NS	.25	NS	.57	<.05
Conjugated B – Urinary Na	.33	NS	−.22	NS	−.59	<.05
Urinary E – Urinary 17-OHCS	.33	NS	.49	NS	.55	<.05
Urinary Na/K – Urinary K	−.08	NS	−.22	NS	−.61	<.05
Urinary Na – Urinary 17-OHCS	.32	NS	.03	NS	.62	<.05

F = hydrocortisone; B = corticosterone-like material; 17-OHCS = 17-hydroxycorticosteroids; E = epinephrine; NE = norepinephrine; K = potassium; Na = sodium; Na/K = sodium/potassium.

TABLE IV

Comparison of correlation coefficients

Paired variables	Control vs. F-100	Control vs. F-104	F-100 vs. F-104
Free F – Conjugated F	NS	NS	NS
Free B – Conjugated B	NS	NS	<.01
Free F – Urinary 17-OHCS	<.05	NS	NS
Free F – Urinary K	NS	<.05	NS
Conjugated F – Urinary NE	NS	NS	NS
Urinary E – Urinary Na	NS	NS	NS
Urinary E – Urinary PO_4	<.05	NS	<.05
Urinary E – Urinary NE	NS	NS	NS
Urinary Na/K – Urinary Na	NS	NS	NS
Urinary K – Urinary Urea	<.05	NS	<.05
Conjugated F – Urinary PO_4	NS	NS	NS
Conjugated B – Urinary Na	NS	<.05	NS
Urinary E – Urinary 17-OHCS	NS	NS	NS
Urinary Na/K – Urinary K	NS	NS	NS
Urinary Na – Urinary 17-OHCS	NS	NS	NS

demonstrated. The finding of high urine volume in the flying groups may be more than accidental since altered breathing patterns can lead to polyuria (9). Pilots in jet aircraft tend to hyperventilate (10-12). The pH trend and the urine volume values, when considered together, suggest hyperventilation, and additional support was provided by sodium and potassium. Statistical support was obtained only for the F-104 group, but the sodium and potassium values for the F-100 group approximated those for the F-104 group. Apparently,

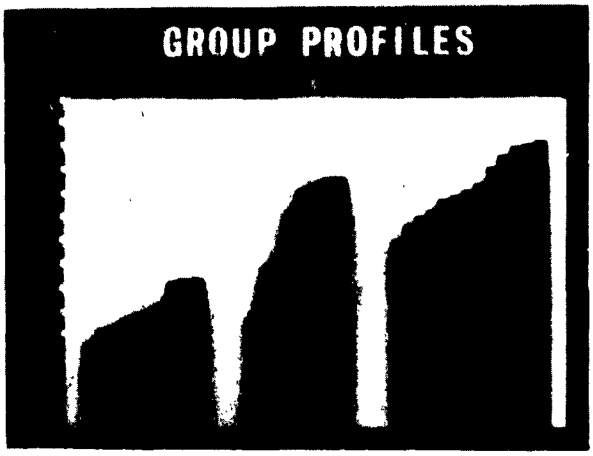

FIGURE 1

the lack of statistical significance in the F-100 group stems partly from the low number of subjects.

Phosphate values for both flying groups tended to be low, and hypophosphaturia may result from hyperventilation, provided that concomitant metabolic acidosis does not have a masking effect. With high urea and uric acid values as evidence of increased catabolic activity, there is reason to think that phosphate excretion reflected the effects of opposing factors, respiratory alkalosis and metabolic acidosis.

Norepinephrine values for the flying groups provide evidence of unusual activity in the sympathetic nervous system, and the epinephrine values indicate unusual activity in the adrenal medulla. Of importance is the finding that the group which encountered turbulence showed greater deviation from the control.

Plasma corticosteroid values for the flying groups supply evidence of adrenocortical activation, but urinary corticosteroids gave negative results. This may be accounted for by the fact that increases in urinary corticosteroids lag behind any that appear in blood, the lag time amounting to about 2 hours (13). With this knowledge, it may be inferred that adrenocortical stimulation was a late event during these flights.

The variation in plasma corticosteroids in the two flying groups deserves brief consideration. Unlike the urinary catecholamines, which appear to relate to weather, plasma corticosteroids seem to relate to aircraft differences or to flying experience. The F-100 has a tendency to undulate in flight and must be flown by manual control at all times. It is a more sensitive aircraft than the F-104 and, therefore, requires high concentration. The fatigue developed in this aircraft has been rated as three times that in the F-104.

Although aircraft qualities seem to account for the differences in adrenocortical responses in the two flying groups, another factor must be recognized. The F-100 group had had about half as much flying experience as the F-104 group. Stressors, when acting for the first time, induce adrenocortical responses of fairly large magnitude; with continued or repeated stimulation, however, these responses diminish in magnitude. The F-104 group, because of greater experience, may have become less responsive to flight factors. Indeed, had they not encountered turbulence, they might not have shown elevated plasma corticosteroids. Additional studies must be made before final conclusions can be drawn. The present results clearly indicate that aircraft qualities, flying experience, and unusual events must be carefully evaluated.

The present results indicate that plasma corticosteroids are flight-sensitive, while urinary corticosteroids seem not to be. The F-100 group tended to show increased corticosteroid excretion, but only 9 of the 13 subjects were examined on this basis. In future studies, it seems advisable to collect urine 2 hours after landing. The desirability of using urine rather than blood makes such studies important.

Of interest is the finding that the highest "strain" was found in a pilot who was known to be apprehensive and poorly motivated for flying. The one who was second from the top had instrument failure and was separated from his flight for 2½ hours. The third high man was a flight leader in the F-104 group, and the fourth high man was the unit commander. The fifth and sixth high men had various flying difficulties, and the seventh in rank was the mission leader. These findings suggest that the "index" reflects such factors as unusual events, responsibility, and innate differences; still, such results may be merely fortuitous. They deserve mention, but only through continued study can any conclusions be drawn.

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2. Endocrine effects of flying
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