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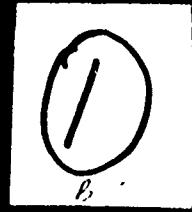
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CHANGES IN PLASMA CORTICOSTEROIDS AND
BICARBONATE AS A RESULT OF PILOTING
SUPERSONIC AIRCRAFT

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**CHANGES IN PLASMA CORTICOSTEROIDS AND BICARBONATE AS A RESULT
OF PILOTING SUPERSONIC AIRCRAFT**

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CHANGES IN PLASMA CORTICOSTEROIDS AND BICARBONATE AS A RESULT OF PILOTING SUPERSONIC AIRCRAFT

While flying high-speed military aircraft, pilots frequently hyperventilate to a degree sufficient to induce marked alkalosis. Psychogenic factors are thought to be responsible for the hyperventilation. Comparison was made of pre- and postflight plasma bicarbonate (determined titrimetrically) and corticosteroid levels (Sweat's technic) for 20 instructor pilots and 47 student pilots flying F-100 aircraft for 50 minutes. No differentiation of students and instructors was possible on the basis of either pre- or postflight values; therefore, the data for the two groups were combined. The plasma bicarbonate value following the flight was $1.1 \pm .24$ mEq./liter (mean \pm S.E.) lower than before the flight. Free 17-hydroxycorticosterone was increased $5.8 \pm .70$ μ g./100 ml., while conjugated 17-hydroxycorticosterone increased $5.7 \pm .75$. The free corticosterone-like fraction increased $3.1 \pm .34$ μ g./100 ml., while the conjugated corticosterone-like fraction increased $3.2 \pm .35$. Each of these changes was significantly different from zero ($P < .001$). No statistically significant correlation was found between the fall in bicarbonate and any of the increases in steroid fractions.

Balke et al. (1), using respiratory gas sampling technics, established that the incidence of hypocapnia among student pilots during flights in jet aircraft varies with the speed and performance rating of the aircraft (in T-33, F-86, and F-100 aircraft the incidence was 41, 63, and 78 percent, respectively). Hypocapnia in the flying situation is believed to be the result of hyperventilation which is psychogenic in origin. Balke et al. (2) measured the decrement in psychomotor performance which results from passive hyperventilation (under laboratory conditions) and found that it was gradually lessened in subjects who were hyperventilated for 30 to 60 minutes per day for a period of two weeks. However, the reductions in plasma bicarbonate concentration induced by hyperventilation at the beginning and at the end of the period of adaptation were not greatly different, indicating that adaptive mechanisms involve factors other than those which prevent respiratory alkalosis.

Balke et al. (3) found that students who were beginning their training in jet aircraft (T-33) were, as a group, highly susceptible to hyperventilation — exhibiting a marked per-

formance decrement when passively hyperventilated in the laboratory. While students who had advanced to F-100's were not tested in this same manner, it seems safe to assume that they would have experienced hyperventilation repeatedly and would be, therefore, less susceptible.

In the present study, which is concerned with hyperventilation in F-100 pilots, plasma bicarbonate and corticosteroid determinations were made immediately before and after relatively short flights. Comparison was made of instructors and students to ascertain whether the difference in flying experience is reflected by these parameters. Bicarbonate determinations provide a means of detecting in-flight hyperventilation, and in theory, corticosteroid determinations might differentiate the susceptible from the tolerant ones.

METHODS

Venous blood samples were obtained at approximately 10 minutes before and after 50-minute flights in F-100 aircraft at Nellis Air Force Base, Nev. Twenty instructors and 47 students served as subjects. Plasma bicarbonate determinations were made promptly by

use of a titrimetric method (4). Aliquots of plasma were frozen and later analyzed for 17-hydroxycorticosterone and a corticosterone-like fraction by the method of Sweat (5). After chloroform extraction (to remove unconjugated steroids for the above-mentioned determinations), the entire aliquot was incubated with glucuronidase (6) and then processed according to Sweat's method to provide an estimate of conjugated steroids of these same two types.

It was not possible to obtain data on both bicarbonate and steroids in every case, but this was done for 22 of the subjects.

RESULTS

Mean pre- and postflight values for plasma bicarbonate and corticosteroids for instructors and students are compared in table I. Since no

TABLE I
Plasma bicarbonate and corticosteroids in F-100 pilots

Variable	Group	n	Preflight	Postflight	Change
Bicarbonate (mEq./liter)	Student	30	29.6	28.3	- 1.3
	Instructor	13	28.6	28.0	- 0.6
	Difference		NS	NS	NS
	Total group Probability	43	29.3	28.5	-1.1 ± .24* <.001
Free 17-hydroxycorticosterone (µg./100 ml.)	Student	35	12.2	18.0	+ 5.8
	Instructor	11	12.6	18.2	+ 5.6
	Difference		NS	NS	NS
	Total group Probability	46	12.3	18.0	+5.8 ± .70 <.001
Free corticosterone-like fraction (µg./100 ml.)	Student	35	5.7	8.8	+ 3.1
	Instructor	11	5.6	8.7	+ 3.1
	Difference		NS	NS	NS
	Total group Probability	46	5.7	8.8	+3.1 ± .34 <.001
Conjugated 17-hydroxy- corticosterone (µg./100 ml.)	Student	35	13.0	18.8	+ 5.8
	Instructor	11	13.0	18.3	+ 5.2
	Difference		NS	NS	NS
	Total group Probability	46	13.0	18.7	+5.7 ± .75 <.001
Conjugated corticos- terone-like fraction (µg./100 ml.)	Student	35	6.1	9.5	+ 3.3
	Instructor	11	6.1	8.7	+ 2.6
	Difference		NS	NS	NS
	Total group Probability	46	6.1	9.2	+3.2 ± .35 <.001

*Mean ± S.E.

significant differences between instructors and students were found, data for the two groups were combined. For the total group, the reduction in bicarbonate and increases in steroid fractions differed significantly from zero ($P < .001$).¹

Computed from mean values, the ratio of free 17-hydroxycorticosterone to free corticosterone-like fraction (F/B ratio) remained constant (pre- and postflight values were 2.2 and 2.1, respectively; the corresponding ratios for the conjugated fractions were 2.1 and 2.0, respectively). Calculated from mean values, the ratio of free to conjugated 17-hydroxycorticosterone and the ratio of free to conjugated corticosterone-like fraction remained close to unity.

No significant relationship was established for the fall in bicarbonate and the increase in each of the steroid fractions in the 22 subjects for whom complete data were obtained. The correlation coefficients obtained for bicarbonate vs. free 17-hydroxycorticosterone, bicarbonate vs. free corticosterone-like fraction, bicarbonate vs. conjugated 17-hydroxycorticosterone, and bicarbonate vs. conjugated corticosterone-like fraction were, -0.39 , -0.17 , -0.34 , and -0.04 , respectively.

DISCUSSION

Appraisal of the physiologic state during flight in single place aircraft is technically difficult, since no interference with the pilot's activities is permissible. Certain necessary procedures both before and after flight prevented the taking of blood samples at the most desirable times. While there is little reason to think that the results would have been different if the flight samples had been taken at less than 16 minutes before take-off, the lapse of approximately 10 minutes between the time of landing and the time of obtaining the post-flight sample certainly contributed to the results. The variability noted in bicarbonate

change probably represents different degrees of in-flight hyperventilation complicated by different rates of recovery. Nevertheless, on the basis of reductions in bicarbonate, 21 of the 30 students (70 percent) and 9 of the 13 instructors (69 percent) may be regarded as having been hyperventilating. The figure for the student group is only slightly below that obtained by other means (1) for F-100 student pilots. The finding that instructors and students gave similar results was unexpected, but perhaps it should not have been, since the "student" pilot in the F-100 is far from being an inexperienced pilot — it is only that he is perfecting his skill in this particular aircraft that makes him a "student."

The lack of correlation between the changes in corticosteroid fractions and the change in bicarbonate may be due in part to the delay in obtaining postflight samples. During the early part of the recovery period, when there is an unsteady state, it is impossible under field conditions to decide to what extent post-flight determinations reflect reversals in both bicarbonate and steroid changes. If the changes in the steroid fractions are dependent upon or triggered by the alkalosis, it would seem that even in the unsteady recovery state there should be some evidence of relationship. There was a hint of a correlation between 17-hydroxycorticosteroid increase (either free or conjugated) and the decrease in bicarbonate, but it was only a hint, lacking statistical significance.

Ralke *et al.* (2) reported that passive hyperventilation for 60 minutes under laboratory conditions induced in adapted subjects an 8 percent increase in hematocrit and a 12 percent rise in plasma protein. While it is quite likely that water loss from the blood contributed to the increases in corticosteroid fractions noted in the present study, it was not the sole factor, since these latter changes exceed those due to hemoconcentration, amounting to 46 percent for the free and 44 percent for the conjugated 17-hydroxycorticosterone and 54 and 52 percent, respectively, for the free and conjugated corticosterone-like fractions. Furthermore, for each of the steroid fractions the ratio of free to conjugated remained constant. The fact that

¹Statistical analyses were performed by Dr. M. B. Danford, Department of Biometrics, School of Aviation Medicine, USAF.

the ratios of free to conjugated approached unity is consonant with the findings of Brown et al. (7) on normal subjects.

We cannot conclude that hyperventilation was the cause of the increases in plasma corticosteroids. It may be that the mental state which led to hyperventilation led also to the changes in corticosterone concentration, possibly by the hypothalamic-hypophyseal pathway, but this remains to be determined. Persky (8) found the level of endogenous hydrocortisone in the plasma of "anxious" patients to be 80 percent greater than that of normal subjects. This suggests that the psychogenic factor in flying may be of the nature of anxiety or has the same effects as anxiety. In flights lasting 1½ hours, members of B-52 crews consistently exhibited increases in plasma corticosteroids (9).

While entirely speculative, it is possible that activation of the adrenal medulla or the sympathetic nervous system also may have occurred and may have caused reductions in splanchnic blood flow, which in turn could have led to a reduction in the rate of removal of steroid substances from the blood. However, Persky (8) found a more rapid disappearance rate of hydrocortisone from the plasma of anxious patients after a test load.

With the same technic for the estimation of plasma corticosteroids, Hale et al. (10) found no significant increase in the free fractions in subjects who experienced mild hypoxia for 25 minutes and who showed a moderate elevation in the respiratory quotient, thus indicating hyperventilation. This apparent lack of agreement between the results of the field and laboratory studies may be a further indication of the presence of a psychogenic factor in the flying situation which was absent in the simulated experiments in the laboratory.

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