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PHYSIOLOGICAL RESPONSES OF PILOTS TO SEVERE WEATHER FLYING

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There is little doubt that flying an aircraft in or around storms produces some degree of emotional stress. Emotional reactions are of course modified by the pilot's experience, type of aircraft, severity of the storm and proximity to severe turbulence. It is possible that flying through storms might also produce certain specific physiological effects other than those associated with emotional stress. For example, severe turbulence may be transmitted to the body of the pilot resulting in difficulties in breathing,[4] vision,[2] and inability to make fine adjustments;[6] severe buffeting might also result in temporary, if not permanent, damage to certain organs.

Pilot experience may be an important factor in the emotional responses to severe weather flying; a highly trained pilot who is unavoidably committed to flying in close proximity to a severe storm is more able to evaluate the gravity of his circumstances and is more skilled in the handling of his aircraft during unusual conditions. For these reasons a thorough study of pilot reactions to severe weather flying should include subjects who have had a great deal of flying experience as well as those who are relatively new to flying. It should be pointed out, however, that it is the inexperienced pilot who, because of his inability to evaluate weather data properly, is most likely to run afoul of severe storms.

Because of the risks involved in in-flight studies of this type, especially those involving inexperienced pilots, it was decided that preliminary baseline studies employing skilled professional pilots should first be attempted. An invitation to CAMI scientists from the Director of the National Severe Storms Laboratory of the United States Weather Bureau, to participate in project Rough Rider during the spring of 1965, provided a unique opportunity for studies on experienced test pilots flying high-performance aircraft through drastic weather conditions. During the spring, storm build-ups in the Oklahoma area are frequent, rapid, and violent. Such storms are often accompanied by tornadic winds, lightning and varying amounts and forms of precipitation.

In conducting these studies the fullest cooperation was received from personnel of the U.S. Weather Bureau and scientists from the Royal Aircraft Establishment (RAE), Bedford and Farnborough, England. Pilots of the Royal Air Force and the Air Registration Board served as subjects for these studies and their enthusiastic cooperation is appreciated.

METHODOLOGY

Subjects: Four pilot subjects volunteered for these studies. All were experienced test pilots; three were officers of the Royal Air Force assigned to the RAE and one was a test pilot from the Air Registration Board, London. All were between the ages of 30 and 40 and were in apparent good health.

Aircraft: The aircraft used for storm penetration flights was a Scimitar F. MK. 1, a single-seat, twin engine naval interceptor which had been modified for the Rough Rider missions. The two perimeter-mission aircraft were both Canberras, also modified for the Rough Rider missions. One, a PR MK. 9, is a high altitude photo-reconnaissance aircraft which in these studies carried a crew of three; the other, a B MK. 6, carried a crew of two.

Sampling Procedures: Experiments of opportunity were performed during May and early June, 1965. All samples were taken between 30 minutes and one hour before take-off time. Subjects were instructed to empty the bladder completely into a clean polyethylene bottle which was immediately placed into an ice bath. Each subject was then weighed while wearing only light underclothing. Following this, subjects donned their flight suits and left the ready-room to file flight plans and began pre-flight checks.

Approximately 30 minutes after each aircraft had landed, subjects returned to the ready-room and were immediately weighed under conditions similar to those of the pre-flight weighing; following this urine was again collected.

The volume of each sample was recorded and one portion of the sample was specially prepared for catecholamine assay. These portions were placed in vials containing dry sodium metabisulfite (0.5 mg/ml urine) and frozen. Additional portions were also withdrawn and frozen in separate vials for all other analyses.

Analytical Methods: All analytical results are expressed in terms of urinary creatinine output. Urinary creatinine output is relatively constant in individual subjects and the expression of other urine components in units per unit weight of creatinine provides an approximately uniform reference system.

Magnesium and calcium were measured by the methods of Hill [7, 8] which were slightly modified for analyses of urine.

Sodium and potassium were estimated by the standard Technicon Auto-Analyzer method and chloride concentration was measured by the method of Cotlove.[1] Creatinine concentration was measured using a modification of the procedure of Pino, *et al.*[10] Total urinary catecholamine (CATAM) levels were determined by a semi-automated fluorometric procedure.[5] Levels of hemoglobin in urine were estimated by an automated molecular sieve technique.[9]

Flight Profiles: In most cases flights of the Scimitar involved penetration of storm clouds. Two pilots flew these missions. One flight, made to test aircraft instruments, did not involve cloud penetration; in one other instance, the same subject prepared for a Scimitar mission but the flight was cancelled approximately 125 minutes following the pre-flight sampling. Both Scimitar pilots also served, on several occasions, as pilots of the Canberra aircraft (B–6). These aircraft flew around storm areas and were used to photograph smoke trails and to conduct a variety of radar observations.

Evaluations of the turbulence encountered by each of the Canberras were made from MK. 13 fatigue meters on board each aircraft. This meter records frequency of vertical accelerations in excess of pre-set gravitational limits. A "totalized turbulence" was computed for each flight of the Canberras by converting the gravitational limits of each channel to relative (zero reference) gravitational units, multiplying each channel value by the frequency of deflections and adding the products of all channels regardless of sign. Assessments of turbulence for the storm penetration flights were extracted from the pilots' reports.

RESULTS

Changes in catecholamine (CATAM) output during the storm penetration and perimeter flights are given in Tables I and III. Average change (Δ) in the CATAM output during the 15 penetration flights was +13.7 ng/mg creatinine (Subjects A and B, range −14.7 to +58.8 ng/mg creatinine). On one occasion (flight #17) subject B prepared for a penetration flight which was subsequently cancelled; the change in CATAM output in a sample taken 125 minutes later was +0.6 ng/mg creatinine. During 19 perimeter flights change in urinary CATAM output average +4.6 ng/mg creatinine (Subjects A, B, C, D; range −12.3 to +23.7 ng/mg creatinine).

Urine flow during both Scimitar and Canberra missions was relatively stable for each individual. In all but two flights ,urine flows ranged between 0.2 and 0.6 ml/m^2/hr. No trends in this variable relative to the severity of flight conditions could be detected (Tables I, III).

Variations in the urinary excretion of electrolytes were of such magnitude that no clear relationship with the severity of conditions could be observed (Tables II, IV). Changes in urinary hemoglobin during penetration flights (Table I) and storm-perimeter missions (Table III) were small and appeared to be independent of the severity of turbulence.

Pre-flight weights of the subjects changed relatively little over the duration of the study. No relationship between the weight loss during the flights (which represents, under these conditions, a loss in body water) and the severity of the flight conditions was detected (Tables I, III). Water losses due to thermoregulatory demands could not be assessed.

TABLE I. Physiological Responses of Pilots to Storm Penetration Flights.

Flight Number	Subject	Urine Total Catecholamines (nanogm/mg creatinine)			Urine Hemoglobin (µg/mg creatinine)			Body Weight (kilograms)			Weight Loss (gm/M²/hr.)	Urine Flow During Flight (ml/M²/min.)	Turbulence*	Summarized Pilot Comments
		Pre-Flight	Post-Flight	∆	Pre-Flight	Post-Flight	∆	Pre-Flight	Post-Flight	∆				
1	A	83.2	68.5	-14.7	0	0	0	71.62	71.48	0.14	41.2	0.6	-	No pirep. Subject's first flight of project.
2	A	27.8	52.8	+26.1	0	0	0	71.46	71.33	0.13	35.6	0.4	L	Hail encountered. Brief periods of turb.
3	A	41.4	59.9	+18.5	0	0	0	71.69	71.55	0.14	35.3	1.0	L-M	"Number" of penetrations. Occnl hvy rain with hail. Canopy misting.
4	A	--	31.8	--	0	0	0	71.63	71.48	0.15	28.0	0.5	L	Nine penetrations. Occnl hvy rain. Prolonged updrafts encountered.
5	A	42.7	72.1	+29.4	0	0	0	71.24	70.97	0.27	51.4	0.4	M	Nine penetrations. Difficulty in control due to buffeting. Hvy rain, wt. snow. One lightning strike. Shock to pilot.
6	A	71.4	61.2	-10.2	0.7	0	0.7	71.63	71.31	0.32	84.8	0.3	-	No pirep.
7	B	34.3	49.4	+15.1	0.1	0.1	0	80.87	80.45	0.42	121.4	0.5	L	Four penetrations. Radio-trans. failure. Occnl engine icing.
8	B	32.7	41.4	+ 8.7	0.1	0.1	0	81.12	80.74	0.38	82.2	0.6	M	Four penetrations. Hail and wet ppt. Lateral rocking on third penetration.
9	B	17.9	26.9	+ 9.0	0	0.1	+0.1	81.14	80.74	0.40	96.1	0.6	L	No penetrations. Instrument check, clear air turb. encountered.
10	B	28.1	35.9	+ 7.8	0.8	0.6	-0.2	80.58	80.38	0.20	76.3	0.5	L	Three penetrations. Strong surf. winds. No control problems.
11	B	15.3	38.9	+23.6	0	0.5	+0.5	80.80	80.48	0.32	79.9	0.4	-	No pirep.
12	B	42.1	50.2	+ 8.1	0	0.7	+0.7	--	--	--	--	0.5	M-H	Five penetrations. Severe vertical gusts. Wet ppt with hail. Pitch control difficult.
13	B	28.6	87.4	+58.8	0.3	0.7	+0.4	80.65	80.34	0.31	100.5	0.4	M-H	Ltn strike, shock to pilot on 1st penetr. Difficulties in pitch-roll control. Incidence ind. jammed. Failure of all pres. instr. Confusion due to oscillation from autostblr. malfunct. Sensation of being close to stall. Water in cockpit. Windscreen iced during ldg.
14	B	31.9	49.0	+17.1	0.5	0.9	+ 0.4	79.94	79.62	0.32	99.4	0.4	M	Subj. flew Canberra earlier on same day. Lateral rocking. Airframe icing. Windscreen icing. Flying accuracy poor. Port engine difficulties. Four penetrations.
15	B	45.1	43.0	- 2.1	0.2	0.2	0	80.79	80.38	0.41	120.9	0.4	L-M	Four penetrations. Lateral rocking. Indic. cabin pressure failure.
16	B	35.0	45.7	+10.7	0.3	0.4	0.1	80.47	80.08	0.39	93.7	0.5	M	Eight penetrations. Lateral rocking.
17	B	32.2	32.8	+ 0.6	1.3	1.7	+0.4	81.99	81.71	0.28	71.6	0.9	-	Flt. Cancelled. Subject sedentary for 125 min.

*From Pireps; L: light, M: medium, H: heavy

TABLE II. URINE ELECTROLYTE CONCENTRATIONS OF PILOTS BEFORE AND AFTER STORM PENETRATION FLIGHTS (MICROEQUIVALENTS PER MG. CREATININE).

		Sodium			Potassium			Chloride			Magnesium			Calcium		
Flt No	Subj	Pre-Flt	Post-Flt	Δ	Pre-Flt	Post-Flt	Δ	Pre-Flt	Post-Flt	Δ	Pre-Flt	Post-Flt	Δ	Pre-Flt	Post-Flt	Δ
1	A	--	161	--	--	172	--	172	155	-17	4	3	-1	--	14	--
2	A	89	99	+10	52	34	-18	112	124	+12	6	6	0	11	10	-1
3	A	88	202	+114	27	29	+2	82	201	+119	4	7	+3	15	23	+8
4	A	--	104	--	--	36	--	93	123	+30	--	7	--	--	17	--
5	A	126	211	+85	46	47	+1	126	177	+51	4	4	0	12	18	6
6	A	--	67	--	--	53	--	108	103	-5	1	3	+2	--	13	--
7	B	--	129	--	--	56	--	256	146	-110	--	2	--	--	6	--
8	B	120	162	+42	30	41	+11	117	157	+40	3	2	-1	10	6	-4
9	B	--	99	--	--	38	--	117	162	+45	4	4	0	--	11	--
10	B	147	144	-3	51	29	-22	119	158	+39	5	5	0	14	9	-5
11	B	123	118	-5	68	54	-14	191	134	-57	4	3	-1	8	3	-5
12	B	128	132	+4	61	42	-19	139	152	+13	4	3	-1	6	5	-1
13	B	136	97	-39	37	29	-8	131	101	-30	5	4	-1	1	9	+8
14	B	95	113	+18	41	46	+5	93	122	+29	3	3	0	9	9	0
15	B	--	82	--	--	33	--	47	83	+36	3	3	0	--	2	--
16	B	122	138	+16	36	36	0	116	143	+27	4	3	-1	4	2	-2
17	B*	75	135	+60	82	48	-34	75	102	+27	2	2	0	5	12	+7

* Flight cancelled; subject sedentary for 125 minutes.

TABLE III. PHYSIOLOGICAL RESPONSES OF PILOTS FLYING STORM PERIMETER MISSIONS.

Flt No	Subj	Urine Total Catecholamines (nanogm/mg Creatinine			Urine Hemoglobin μgm/mg Creatinine			Body Weight (Kilograms)			Weight Loss gm/M²/Hr	Urine Flow During Flight Me/M²/Min	Turbulence *
		Pre-Flt	Post-Flt	Δ	Pre-Flt	Post-Flt	Δ	Pre-Flt	Post-Flt	Δ			
18	C	31.0	32.1	+ 1.1	0	0	0	77.40	77.05	0.35	86.0	0.4	23.8
19	C	44.1	31.8	-12.3	0.6	0.1	-0.5	77.54	77.22	0.32	70.4	0.3	10.6
20	D	27.3	40.6	+13.3	0	0	0	75.57	75.20	0.37	42.3	0.2	9.7
21	D	26.6	28.8	+ 2.2	0.1	0	-0.1	76.42	75.96	0.46	69.8	0.3	1.4
22	D	27.4	51.1	+23.7	0	0	0	76.38	76.08	0.30	37.3	0.2	4.2
23	D	30.0	51.0	+21.0	0.3	0	-0.3	75.94	75.72	0.22	40.4	0.3	5.6
24	D	33.6	36.5	+ 2.9	0.1	0	-0.1	75.92	75.72	0.20	36.8	0.1	10.1
25	D	27.4	50.7	+23.3	0.1	0	-0.1	--	--	--	--	0.5	4.0
26	A	28.1	32.7	+ 4.6	0.2	0	-0.2	71.63	71.25	0.38	37.3	0.2	23.9
27	A	35.4	44.8	+ 9.4	--	0	--	71.19	70.92	0.27	51.4	0.3	48.6
28	B	32.9	37.1	+ 4.7	0.1	0.2	-0.1	80.65	80.00	0.65	108.1	0.3	4.9
29	B	41.6	51.4	+ 9.8	0	1.6	+1.6	81.00	80.32	0.68	168.8	0.6	--
30	C	34.7	24.9	- 9.8	0	0	0	77.70	77.28	0.42	81.2	0.4	10.8
31	C	--	32.0	--	--	0	--	--	--	--	--	--	11.9
32	C	33.0	30.0	- 3.0	0	0	0	77.94	77.50	0.44	80.3	0.4	3.5
33	C	39.4	35.3	- 4.1	0	0.6	+0.6	77.75	77.46	0.29	54.4	0.4	24.0
34	C	30.8	32.3	+ 1.5	0	0	0	78.30	78.00	0.30	42.6	0.3	18.5
35	C	32.9	27.3	- 5.6	0	0.1	+0.1	78.43	78.11	0.32	52.1	0.5	2.1
36	C	37.9	33.2	- 4.7	0	0	0	77.45	77.24	0.21	40.6	0.4	4.9

TABLE IV. URINE ELECTROLYTE CONCENTRATIONS OF PILOTS BEFORE AND AFTER STORM PERIMETER MISSIONS (MICROEQUIVALENTS PER MG. CREATININE).

Flt No	Subj	Sodium Pre-Flt	Sodium Post-Flt	Sodium Δ	Potassium Pre-Flt	Potassium Post-Flt	Potassium Δ	Chloride Pre-Flt	Chloride Post-Flt	Chloride Δ	Magnesium Pre-Flt	Magnesium Post-Flt	Magnesium Δ	Calcium Pre-Flt	Calcium Post-Flt	Calcium Δ
18	C	66	104	+38	33	51	+18	129	126	-3	7	5	-2	11	10	-1
19	C	179	88	-89	70	52	-18	203	108	-95	4	4	0	13	8	-5
20	D	67	80	+13	56	51	-5	91	127	+36	4	2	-2	1	3	+2
21	D	130	128	-2	61	75	+14	145	143	-2	3	2	-1	3	8	+5
22	D	59	64	+5	74	74	0	87	73	-14	2	2	0	2	4	+2
23	D	95	90	-5	49	78	+29	84	131	+47	3	2	-1	9	9	0
24	D	46	44	-2	57	144	+87	66	88	+22	2	1	-1	5	3	-2
25	D	55	102	+47	55	76	+21	78	111	+33	3	2	-1	1	0	-1
26	A	--	83	--	--	42	--	70	94	+24	3	5	+2	--	2	--
27	A	--	99	--	--	41	--	78	118	+40	4	3	-1	--	12	--
28	B	126	120	-6	53	42	-11	154	123	-31	4	2	-2	10	8	-2
29	B	190	123	-67	69	50	-19	195	128	-67	4	3	-1	1	10	+9
30	C	50	92	+42	40	41	+1	39	86	+47	4	4	0	7	8	+1
31	C	--	91	--	--	43	--	--	99	--	--	6	--	--	8	--
32	C	129	64	-65	92	55	-37	262	132	-130	4	4	0	16	8	-8
33	C	143	109	-34	57	64	+7	132	149	+17	6	6	0	12	11	-1
34	C	105	78	-27	49	35	-14	97	72	-25	4	4	0	9	7	-2
35	C	149	159	+10	68	60	-8	162	153	-9	7	6	-1	14	11	-3
36	C	221	130	-91	42	44	+2	174	118	-56	5	3	-2	7	8	+1

DISCUSSION

Of the physiological responses to severe weather flying, changes in the urinary output of catecholamines seemed most closely related to the severity of weather and the occurence of unusual incidents during the missions. Various degrees of turbulence were experienced during all flights but an apparent correlation between intensity of turbulence and CATAM output was noted only in missions involving the Scimitar aircraft (Fig. 1). It may be significant that for this aircraft evaluations of turbulence intensity were made by the pilots, whereas turbulence history of the Canberra aircraft was taken from the fatigue meter. The CATAM response to turbulence may be mediated more through emotional responses than through specific effects of vibration on organ systems. The better correlation of subjective evaluations of turbulence with urinary CATAM changes is consistent with this hypothesis; however, the low correlation with fatigue meter records in perimeter missions may only reflect the narrow range of turbulence to which these aircraft were exposed. Extrapolations between these data are to be made with caution.

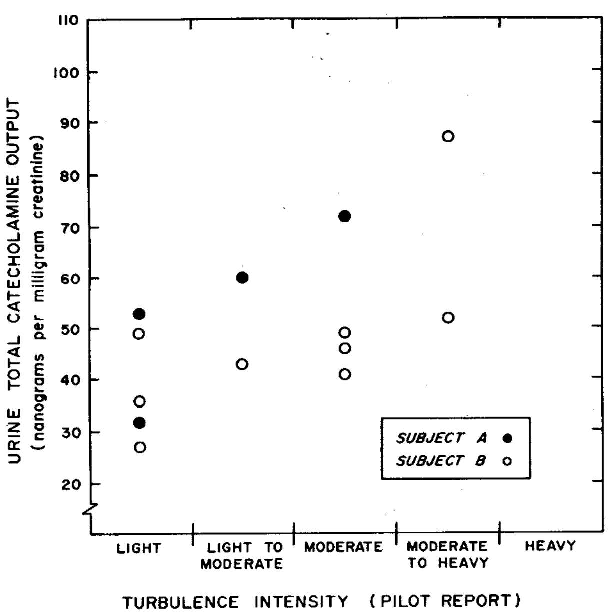

FIGURE 1. Relationship between urinary total catecholamine output during the penetration flights and the pilots' assessment of the turbulence encountered.

Although it is not possible to separate the turbulence effects from other vagaries of the flights (as reported by the pilots) certain missions in which unusual incidents occurred were also accompanied by large increases in the CATAM output. In flight number 13, for example, serious mechanical difficulties were encountered in addition to a lightning strike which produced a shock to the pilot. The urinary output of catecholamines increased during this flight by nearly 60 ng/mg creatinine. During flight number 9, this same subject flew a routine instrument check; CATAM output increased only 9 ng/mg creatinine.

While these data may provide some information on the stresses incurred during severe weather flying, some peculiar responses are difficult to interpret. For example, of eight flights made by subject C in the Canberra aircraft, the CATAM output decreased during flight on six occasions. During the two flights for this subject in which an increase occurred, the change was slight (approximately 1 ng/mg creatinine). It may be that this subject was somewhat apprehensive about his flights or perhaps the preflight circumstances were more stimulating than actual flying. The use of psychological tests in conjunction with catecholamine studies might clarify these results.

In the interpretation of CATAM data as indices of stress one precaution should be noted: the response of sympathoadrenal systems to stress may be significantly retarded by hypocapnia,[11] thus hyperventilation, if this response occurred during certain flights (subject C?), may have depressed CATAM release.

During the present studies the concentrations of hemoglobin in urine were measured with a new ultra-sensitive method. This technique was developed for studies of physiological variations in hemoglobin output rather than for detection of gross pathological changes. Leakage of small amounts of hemoglobin into the urine may be considered as reversible and non-pathological findings; Emerson, *et al* [3] demonstrated that leakage of large amounts of hemoglobin and intact erythroplastids into the urine (resulting from partial occulsion of the renal vein) was completely reversible. Slight elevations in urinary hemoglobin may reflect minor fluctuations in renal venous pressure or perhaps failure of renal tubular reabsorption. The significance of these changes cannot be assessed as this time, but the phenomenon deserves further study.

Although other physiological measurements made during this study did not reflect the stressful circumstances encountered, it is possible that the characteristics of the testing situation may have obscured some subtle changes in those parameters. For example, water loss due to emotional sweating may be related to sympathoadrenal activity, but no relationship between total water loss and urinary CATAM output could be detected in the present study. Water losses due to thermoregulatory demands could have far exceeded the losses due to emotional sweating; thus, total water loss would relate more closely with thermal load than with sympathetic activity.

From the present study it may be concluded that severe weather flying can be stressful even in highly trained and experienced pilots. Furthermore, the turbulence component of severe weather seems to be directly associated with the level of sympathoadrenal response if turbulence is evaluated in terms of the pilots' assessment of it.

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