Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-AM-76-13		

4. Title and Subtitle	5. Report Date
STRESS IN AIR TRAFFIC CONTROLLERS: EFFECTS OF ARTS-III	6. Performing Organization Code
	8. Performing Organization Report No.
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9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, Oklahoma 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	13. Type of Report and Period Covered OAM Report 14. Sponsoring Agency Code

15. Supplementary Notes

This research was conducted under Tasks AM-B-73-PHY-61, AM-B-73-PHY-62, AM-C-73-PSY-39, AM-C-74-PHY-61, AM-C-74-PHY-62, AM-C-74-PSY-39, AM-C-75-PHY-61, AM-C-75-PHY-62, and AM-C-75-PSY-52.

16. Abstract

Physiological, biochemical, and psychological assessments of stress in air traffic controllers were made at Los Angeles (LAX) and Oakland (OAK) Terminal Radar Approach Control (TRACON) facilities before and after installation of Automated Radar Terminal Systems-III (ARTS-III). Heart rates of controllers on duty or at rest scarcely changed from before to after ARTS-III installation. Total stress increased at both TRACONs, and the increase was entirely due to elevated catecholamine excretion. Steroid excretion was significantly reduced at both facilities after ARTS-III installation.

Scores on the A-State scale of the State-Trait Anxiety Inventory indicated that introduction of ARTS-III had no appreciable effect on work-related anxiety levels of controllers. The post-ARTS-III A-State means for both facilities were not significantly elevated. A-Trait was unchanged at LAX but decreased significantly at OAK. Assessments of A-State showed significant work-related increments but tended to be low.

There were no correlations between anxiety and physiological data.

17. Key Words	18. Distribution Statement
Stress Air Traffic Controllers Urine Biochemistry Anxiety Inventory	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22 Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENT

The authors wish to express their gratitude to all controllers who served as subjects in these studies. Our special thanks go to the Los Angeles and Oakland FAA officials; without their cooperation and help these studies could not have been accomplished.

STRESS IN AIR TRAFFIC CONTROLLERS: EFFECTS OF ARTS–III

I. Introduction.

The computer-based Automated Radar Terminal Systems-III (ARTS-III) supplies the air traffic controller with positive aircraft identification and three-dimensional data regarding its location and movement in the airspace, and thus contributes enormously to safety. ARTS-III also eases the workload of controllers by reducing intercontroller coordination, flight strip activity, communication with pilots, and activity related to radar and radio adjustments. ARTS-III differs operationally from the old radar system in several ways. Controllers do not carry out as much "face to face" coordination but must communicate by telephone. ARTS-III calls for a great deal of keyboard work in use of the computer. The radar consoles are arranged in islands equipped with horizontal cathode ray tubes, and the lighting level is somewhat higher in the new terminal radar approach control (TRACON) facilities than it was in the old ones. Many other environmental changes accompanied ARTS-III: temperature is more closely controlled, decor is pleasant, and eating facilities are improved. Parking is close by, whereas it had been in fairly remote areas at the towers. The beneficial effects of ARTS-III might be reflected in measurably reduced physiological and psychological stress.

The effect of ARTS-III on controller stress was estimated from pre- and post-ARTS-III measurements made at Los Angeles (LAX) and Oakland Bay Area (OAK) TRACON facilities. When the pre-ARTS-III measurements were made at Oakland in August 1972 (OAK–1) and at Los Angeles in November 1972 (LAX–1), the TRACONs were located in the towers. When the post-ARTS-III studies were carried out in July 1974 (LAX–2) and November 1974 (OAK–2), the TRACONs were located in buildings separate from the towers. ARTS-III had been operational for about 5 months at the times of LAX–2 and OAK–2. Results at the two TRACONs were so similar that they are reported together.

II. Methods.

Thirteen controllers served as subjects in LAX–1 and 17 in OAK–1. Nine of the original 13 controllers (69 percent) at LAX and 11 of the original 17 (65 percent) at OAK served as subjects in the post-ARTS-III studies. Urine data were obtained from seven of the nine LAX–2 subjects (78 percent).

Subjects reported to the temporary laboratory areas in the TRACONs 30 minutes before going on duty. They were fitted for ambulatory electrocardiography as previously described.[4] Electrocardiograms (ECGs) from all subjects were recorded on tape throughout each of five 8-hour day shifts. Prework heart rates were measured during recording system checkout at the time of electrode application. ECG tapes were spot checked at the end of experimental periods to verify that the recordings were technically good. ECG tapes were later reduced to 1-minute heart rates in the laboratory at the Civil Aeromedical Institute (CAMI).

Each subject was instructed to void and discard urine prior to retiring the night before each day of biomedical observation and to collect a complete urine specimen on arising. This specimen was used as the reference specimen in all biochemical estimates of stress. The subject was similarly instructed to void and discard urine just before going on duty and to collect in one vessel all urine he voided during the 8-hour work period. The specimen was used as the "work specimen" in estimates of stress.

Urine was collected in 1-quart plastic bottles that contained dry boric acid as a preservative. When each urine specimen was delivered to the temporary laboratory, it was immediately marked with a code number, logged, and placed in a freezer. Specimens were kept frozen until they were thawed for analysis at CAMI.

Urine was analyzed for 17-ketogenic steroids (st), epinephrine (e), and norepinephrine (ne), and creatinine (cr).[5] In this report, results are expressed as micrograms per 100 milligrams of cr. From these results stress indices were calculated as described in an earlier publication.[6]

The State-Trait Anxiety Inventory (STAI)[9] was used to measure stress arousal of a psychological nature in controllers. Immediately before and just after each work period, each controller completed the A-State scale of the STAI, which measures current anxiety level. The A-Trait scale of the STAI, a measure of anxiety proneness or typical level of anxiety, was presented to each controller just before the initial shift of the study and again at the completion of the last observed workshift.

Tape recorders were attached to the TRACON tape recorders to record radio transmissions between controllers and pilots. It originally had been planned to reduce these tape recordings to total controller-pilot communication time as a measure of workload. Because controller-to-controller communication was recorded in LAX–2 and OAK–2 and was not recorded in LAX–1 and OAK–1, communication time could not be used as a reliable comparative measure of workload. Instead, the busiest approach control sector at both LAX and OAK was identified, the recorder channel on which the radio transmissions of that sector were recorded was played back in real time, and counts were made of the number of controller-pilot contacts and of the total number of aircraft contacted during each 8-hour work period. From these counts the number of contacts per aircraft was calculated.

III. Results.

Heart Rate. Table 1 shows heart rates for individuals under prework and working conditions. Mean heart rates were the same under working conditions for the pre- and post-ARTS-III studies. The LAX–1 mean prework heart rate was slightly higher than the corresponding mean working value, whereas the LAX–2 mean prework heart rate was the same as the LAX–2 mean working value. The OAK–1 mean prework heart rate was lower than the corresponding mean working value, whereas the OAK–2 mean prework and working values were the same.

TABLE 1. Individual Heart Rates

	LAX-1			LAX-2			OAK-1			OAK-2		
Subject	Pre-Work	Work	Percent Δ	Pre-Work	Work	Percent Δ	Pre-Work	Work	Percent Δ	Pre-Work	Work	Percent Δ
1	92	85	(7.2)*	89	94	6.0	79	80	1.3	84	86	2.0
2	81	77	(5.8)	73	84	15.0	66	81	23.2	73	73	0
3	78	59	(23.5)	74	58	(21.6)	89	101	14.1	103	98	(4.9)
4	97	99	2.6	85	89	4.9	74	78	5.7	79	75	(5.9)
5	80	66	(17.4)	70	69	(1.9)	71	88	24.9	70	78	11.3
6	95	92	(3.5)	90	92	1.8	76	89	17.2	83	92	10.9
7	92	92	0	88	87	(0.7)	83	73	(11.4)	93	88	(4.9)
8	87	79	(9.4)	87	77	(11.4)	69	71	2.8	64	60	(6.2)
9	66	72	9.4	63	67	6.7	65	73	12.6	68	70	3.1
10							72	75	4.7	81	80	(1.1)
11							75	74	(0.9)	80	82	1.9
$\bar{X}$	85	80		80	80		74	80		80	80	
S.D.	10	13		10	13		7	9		11	11	

* Parenthesis indicate that working value is less than resting value.

Table 2 shows that there are no significant differences at either TRACON in the group mean heart rates during work at the various positions.

Urine Chemistry. Table 3 shows the resting (night sleep specimen) and working values for st, e, and ne for LAX–1 and –2 and OAK–1 and –2. Resting-to-working differences are significant for all three stress indicators. Both resting and working levels of excretion of st were significantly reduced in the LAX–2 and OAK–2 groups from the levels in LAX–1 and OAK–1. The resting level of e excretion was not significantly different between the LAX–1

TABLE 2. Comparisons of Heart Rates During Different Activities*

First Activity	Average Heart Rate	Second Activity	Heart Rate	Significance Level**
LAX-1 AR	80	LAX-2 AR	81	N.S.
LAX-1 DR	79	LAX-2 DR	80	N.S.
LAX-1 Others	80	LAX-2 Others	81	N.S.
LAX-1 Prework Heart Rate	85	LAX-2 Prework Heart Rate	80	.01
LAX-1 Average All Positions	80	LAX-2 Average All Positions	80	N.S.
OAK-1 AR	78	OAK-2 AR	79	N.S.
OAK-1 DR	79	OAK-2 DR	79	N.S.
OAK-1 Others	82	OAK-2 Others	81	N.S.
OAK-1 Prework Heart Rate	74	OAK-2 Prework Heart Rate	80	.01
OAK-1 Average All Positions	80	OAK-2 Average All Positions	80	N.S.

*AR = Arrival Radar, DR = Departure Radar, Others = Data Positions, Coordination Work, Supervision and Training

**Wilcoxon matched-pairs signed-rank test

TABLE 3. Comparisons of Levels of Urinary Stress Metabolites at Los Angeles (LAX) and Oakland (OAK) TRACONs Before and After ARTS-III Installation

	st				e				ne			
Facility	Rest	Work	Δ	p	Rest	Work	Δ	p	Rest	Work	Δ	p
LAX-1	521.3	1152.5	631.2	.01	0.38	1.19	0.81	.01	2.07	4.26	2.19	.01
LAX-2	382.9	700.1	317.2	.01	0.76	1.95	1.19	.01	3.30	5.42	2.12	.01
Δ	138.4	452.4			0.38	0.76			1.23	1.16		
p	.05	.01			N.S.	.01			N.S.	N.S.		
OAK-1	485.1	899.2	414.0	.01	0.39	1.25	0.86	.01	1.59	2.58	0.99	.01
OAK-2	319.7	679.5	360.8	.01	0.76	2.26	1.50	.01	2.24	3.47	1.23	.01
Δ	166.4	220.6			0.37	1.00			0.64	0.89		
p	.01	.01			.01	.01			.05	.01		

and –2 groups; however, the working level of e excretion was significantly elevated in the LAX–2 group. Both resting and working levels of e excretion were significantly greater in the OAK–2 group than in the OAK–1 group. Norepinehrine showed an insignificant change at LAX and a significant change at OAK from before to after ARTS-III installation.

TABLE 4. Stress Indices for Various Air Traffic Control Facilities

Facility	C_s	c_{st}	c_e	c_{ne}
O'Hare Tower	1.05	1.41	0.75	0.98
Opa Locka Tower	0.84	0.64	0.74	1.15
Atlanta ARTCC	0.82	0.76	0.34	1.37
Miami ARTCC	0.76	0.61	0.71	0.96
LAX-2	0.75	0.25	0.69	1.31
Houston Intercontinental Tower (1970)	0.74	1.27	0.29	0.65
OAK-2	0.72	0.23	1.31	0.61
Houston Intercontinental Tower (1971)	0.68	0.89	0.62	0.52
OAK-1*	0.60	0.62	0.76	0.43
LAX-1*	0.60	0.66	0.34	0.81
Fort Worth ARTCC	0.34	0.22	0.58	0.20

*Values for OAK-1 and LAX-1 were derived from all controllers participating in those studies. See Table V for values from controllers who served in pre- and post-ARTS-III studies.

An earlier report[6] described a stress index (C_s) that was derived from mathematically adjusted (c) values of st, e, and ne. This index greatly facilitates the comparison of stress at different air traffic control (ATC) facilities. Table 4 shows the values for the composite index, C_s, together with c_{st}, c_e, and c_{ne} at the air traffic facilities studied thus far. It is evident from Table 4 that total stress was greater in LAX–2 and OAK–2 than in LAX–1 and OAK–1. Further, it is evident that the increase in total stress is entirely due to increased excretion of catecholamines, because steroid excretion was actually reduced in LAX–2 and OAK–2.

Table 5 shows a comparison of stress indices calculated from data of individual controllers who participated in both studies. Three controllers at LAX and two at OAK showed decreases in C_s, all controllers at LAX and all but one at OAK showed decreases in c_{st}, all LAX controllers and all but one OAK controller showed increases in c_e, and three controllers at LAX and two at OAK showed decreases in c_{ne}.

TABLE 5. Stress Indices From Individual Controllers Before and After ARTS-III Installation

	C_s		c_{st}		c_e		c_{ne}	
LAX	1	2	1	2	1	2	1	2
Subject								
1	0.90	1.25	0.96	0.34	0.48	1.80	1.25	1.61
2	0.42	0.37	0.64	0.20	0.20	0.50	0.42	0.41
3	0.30	0.36	0.48	0.32	0.09	0.18	0.32	0.57
4	0.48	1.28	0.33	0.21	0.38	1.11	0.72	2.51
5	0.62	0.47	0.55	0.14	0.43	0.67	0.89	0.60
6	0.52	0.47	0.68	0.34	0.20	0.42	0.69	0.65
7	0.42	1.42	0.59	0.33	0.29	0.59	0.38	3.42
OAK	1	2	1	2	1	2	1	2
Subject								
1	0.45	0.68	0.58	0.51	0.53	0.99	0.24	0.54
2	0.73	0.72	0.50	0.27	1.21	1.17	0.50	0.72
3	0.57	0.47	0.56	0.21	0.49	0.59	0.67	0.60
4	0.35	0.71	0.31	0.29	0.29	1.56	0.44	0.28
5	0.46	0.69	0.90	0.37	0.23	1.08	0.25	0.63
6	0.42	0.86	0.59	0.43	0.24	1.27	0.43	0.88
7	0.27	1.36	0.20	0.21	0.28	2.83	0.34	1.05
8	0.18	0.57	1.17	0.05	0.15	1.01	0.22	0.65
9	0.40	0.84	0.73	0.15	0.28	1.81	0.20	0.56
10	0.33	0.47	0.61	0.16	0.22	1.03	0.17	0.22
11	0.22	0.74	0.31	0.10	0.16	1.33	0.20	0.79

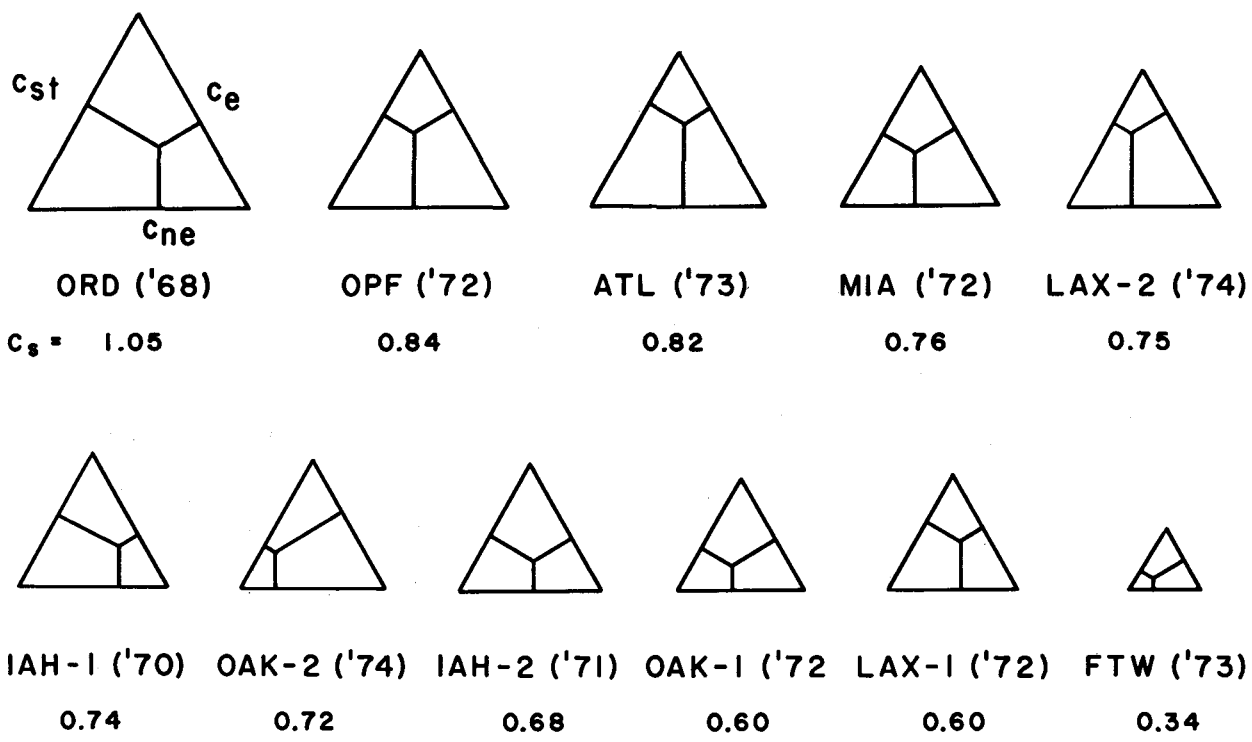

FIGURE 1.—Ranking of total stress in ATC facilities by size of Streng triangles. The internal lines represent the relative contributions of 17–ketogenic steroids (c_{st}), epinephrine (c_e), and norepinephrine (c_{ne}) to total stress; the internal lines also show the relationships between c_{st}, c_e, and c_{ne}.

The data in Table 4 can be presented graphically (Fig. 1 and 2) on the Streng triangle.[12 13] In this diagram the values for c_{st}, c_e, and c_{ne} are represented by lines diverging at angles of 120° from a common point. Lines constructed perpendicular to the ends of the diverging lines form an equilateral triangle, the altitude of which is equal to the sum of the lengths of the divergent lines. The altitudes (thus the area) of the triangle is proportional to C_s, the average of c_{st}, c_e, and c_{ne}. One can quickly gain an appreciation of relative stressfulness by simply comparing the sizes of the triangles representing the different ATC facilities (Fig. 1). In addition, one can easily see the relative contribution of each of the three metabolites to total stress. In the cases of LAX and OAK, it is apparent that steroid excretion is greatly reduced in LAX–2 and OAK–2 from the levels in LAX–1 and OAK–1 (Fig. 2). The increase in total stress can easily be seen to be due entirely to elevated catecholamine excretion.

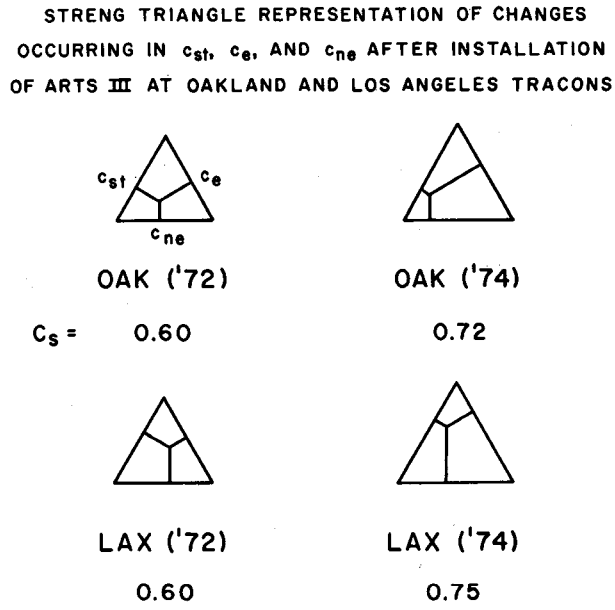

FIGURE 2.—Streng triangles showing the increase in total stress in OAK–2 and LAX–2. See Figure 1 legend for explanation.

Psychological Data. The mean A-Trait score for LAX controllers (31.3) was somewhat higher than the mean for controllers at OAK (27.7); however, this trend just failed to achieve accepted levels of statistical significance. Thus, baseline, or typical, levels of anxiety were roughly comparable for both groups, with the OAK controllers indicating slightly less general proneness to anxiety.

The A-State results (Table 6) were very similar for both LAX and OAK controllers. Participants at both facilities reported slightly higher mean A-State scores after ARTS-III installation, but the increases did not approach statistical significance. Thus, it is clear that acquisition of the ARTS-III display had no effect, beneficial or otherwise, on anxiety levels of controllers.

TABLE 6. Mean A-State Raw Scores for Air Traffic Controllers Before and After ARTS-III Installation

	Pre-ARTS-III		Post-ARTS-III	
	Mean	S.D.	Mean	S.D.
LAX	30.9	6.0	33.4	6.3
OAK	30.3	4.2	31.2	4.2

In previous studies of anxiety in air traffic controllers,[5 7 11] the most consistent finding has been a significant increase in A-State scores from before shifts to after shifts. In the present study, the effect was found to be significant only for the OAK group ($p \leq .01$ for both pre- and post-ARTS-III assessments) (Table 7). The LAX controllers showed the same overall trend; however, in both the LAX–1 and LAX–2 evaluations, three of the nine participants typically reported substantive decreases in A-State from before to after shifts, compared with only one such instance for the 11 controllers at OAK. It is worth noting, however, that if the additional four controllers at LAX who participated in the pre- but not the post-ARTS-III study are added to the analysis, the LAX–1 comparison of before- and after-shift A-State scores achieves significance ($p \leq .05$), which raises a question whether some nonrandom selection process was operating at LAX during the two assessments.

TABLE 7. Mean A-State Raw Scores for LAX and OAK Controllers Before and After Workshifts

	Pre-ARTS-III		Post-ARTS-III	
	Before	After	Before	After
LAX	28.4	33.3	31.9	35.0
OAK	28.1	32.5	28.4	34.1

Comparison of Physiological and Psychological Data. As an additional step, analyses were conducted on the possible relationship between the physiological measures obtained in these assessments and the STAI data. In general, there was little, if any, correspondence between the two sets of data. Neither A-State nor A-Trait levels related to working or resting heart rate, C_s, c_{st}, c_e, or c_{ne} values. Analyses of changes in A-State levels also were not correlated with changes in these physiological measures.

TRACON Workloads. In LAX–1 there were 13,806 radio contacts with 1,803 aircraft (7.66 contacts per aircraft) on the busiest approach control sector. In LAX–2 there were 14,210 contacts with 1,860 aircraft on the same sector (7.64 contacts per aircraft). In OAK–1 there were 8,712 contacts with 1,190 aircraft (7.32 contacts per aircraft), and in OAK–2 there were 8,827 contacts with 1,238 aircraft (7.13 contacts per aircraft). Thus, the number of aircraft and number of contacts both increased by 3 percent at LAX. At OAK, the number of aircraft increased by 4 percent, while the number of contacts increased by only 1 percent.

IV. Discussion.

The possibility that controller physiological and psychological stress would be reduced by ARTS-III was not demonstrated at LAX and OAK.

Other FAA studies[1 2] of the effects of ARTS-III on controller workload in the TRACONs at Houston Intercontinental Airport and at Boston Logan Airport have shown a net reduction in air traffic controller activities. Similarly, the objective measures of workload in the present study show either a net decrease in workload

or insignificant change as a result of ARTS-III. Therefore, the increase in total physiological stress cannot be attributed to increased workload.

Conversations with controllers and supervisors uniformly indicated that ARTS-III is a large step forward in air traffic control. None who were interviewed would willingly return to the old methods. However, there was also general agreement that 5 months' use is not long enough to develop total familiarity and trust in the equipment. Controllers at both LAX and OAK stated that a complete evaluation by controllers would be possible only after a good deal more experience had been gained in this new work environment.

Thus, the increase in the estimated total stress, entirely accounted for by increased catecholamine output, may be viewed as being based on controllers' attitudes at that time toward ARTS-III. At the time of these studies, controllers' attitudes were somewhat ambivalent. Controllers liked the reduction in coordination both with other facilities and within the TRACON, they liked the sense of privacy at the radar islands, and they liked the decor and the illumination level. They did not like the location of the telephone panel and the inconvenience occasioned by unfamiliarity of other ATC facilities with new TRACON procedures.

The reduced level of excretion of st, under both resting and working conditions, after ARTS-III installation indicates reduction in chronic stress. The chronic stressor that is reduced from before to after ARTS-III installation cannot be positively identified, but it may relate to improve morale in the new quarters, enlarged controller responsibility and thus less direct supervision, and improved labor-management relations.

With respect to A-State levels, the findings are generally typical of those obtained from other controller populations; to wit, working as an air traffic controller has some, apparently normal, arousing qualities as evidenced by the average increase in A-State scores from before to after shifts. Though of insufficient frequency to be considered a clear trend in the present study, the few individual exceptions to this finding may reflect certain diversionary characteristics of the work for some persons who have higher-than-average levels of chronic anxiety. If subsequently confirmed, this would lend support to Spielberger's[8] hypothesis that persons relatively high in A-Trait may be diverted from internalized stimuli that are cues for anxiety responses by engaging in absorbing tasks; this observation was also considered by Smith[10] in the assessment of anxiety in student pilots.

The failure of A-Trait and A-State measures to correlate in any way with the physiological measures employed in this study is consistent with the norm for such studies.[3] Of many possible explanations for this lack of correspondence, perhaps the simplest is that the physiological and psychological measures assess different aspects of the possible reactions to stress situations. Be that as it may, it is clear that whatever the physiological cost of work as an air traffic controller, the psychological impact, at least as reflected in anxiety states, is not particularly dramatic.

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