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16. Abstract

Physiological and biochemical measurements of stress in 14 Opa Locka Tower (OPF) controllers indicated that the principal stressor at that facility was the heavy volume of air traffic. Controllers responded to this stressor with a large increase in urinary output of catecholamines. A stress index, C_s, shows that OPF ranks second in stressfulness in the nine stress studies carried out at eight ATC facilities. Baseline values show that off-duty stress at OPF is low. The results of this study emphasize that a battery of tests is necessary for adequate definition of stress in this personnel group.

17. Key Words
Stress index, Urinary stress indicators, Heart rate

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COMPARISON OF OPA LOCKA TOWER WITH OTHER ATC FACILITIES BY MEANS OF A BIOCHEMICAL STRESS INDEX

I. Introduction.

Opa Locka Airport (OPF), located in a close-in suburb of Miami, Florida, is predominantly a general aviation airport served by an air traffic control tower that is in operation 16 hours per day (0700–2300). Until recently, OPF had an annual traffic count exceeding 600,000 and was ranked second nationally in total aircraft operations. It was outranked only by O'Hare (ORD), the busiest airport in the world. At the time of this study (March 1972), some of the training activity that had accounted for much of OPF's large volume of traffic had been dispersed to other airports and the annual traffic count had been reduced to 389,062. As a result, OPF is now ranked 10th nationally in total aircraft operations.

Work of the type and intensity of that at OPF is found at only a few facilities in the country; therefore, research was indicated to quantitate stress in OPF controllers and relate this stress to that in controllers at other facilities. Estimates of stress at other ATC facilities are included in this report; however, stress at those facilities will be discussed in subsequent reports.

II. Methods.

The OPF tower was manned by nine journeymen, three trainees, and two supervisors, all of whom volunteered to participate in this project. Controllers at OPF worked a 5-day week consisting of either 2 days and 3 evenings or 3 days and 2 evenings. Observations were made on each of the 14 controllers on two consecutive day shifts. Time limitations on the project precluded additional observation.

On reporting for work, subjects were fitted with sensors and ECG tape recorders to enable the continuous recording of electrocardiograms (ECG) throughout the work period.[7] (The procedure for making this recording has been described in a previous report.[4]) An observer kept an activity log so that heart rates (HR) were related only to periods of air traffic control; i.e., all off-position periods were excluded from the data at the time of tape playback.

Subjects collected morning urine specimens on each of the 2 days of their participation. These specimens, which consisted of urine formed during night sleep, were used for determining baseline values of 17-ketogenic steroids (st), epinephrine (e), and norepinephrine (ne). Subjects were asked to void before going on duty and to collect (in special plastic bottles) all the urine subsequently formed during the 8-hour work period.

Urine specimens were preserved by means of dry boric acid placed in the collection bottles. The specimens were cooled in insulated cases during the collection periods and were stored in a freezer immediately after the collection periods. The frozen specimens were shipped by air freight to the Aviation Physiology Laboratory at the FAA Civil Aeromedical Institute, Oklahoma City, and remained frozen until they were thawed for analysis. All values for steroids and catecholamines were expressed as micrograms per 100 milligrams of creatinine.

The ATC workload was recorded on tape as the total radio transmission time (incoming and outgoing calls) for each subject while he was on the Ground Control, Local Control 1, or Local Control 2 position. Local Control 1 handled traffic on Runway 9L/27R; Local Control 2 handled traffic on 9C/27C and 9R/27L. Prevailing winds were easterly, so other runways were rarely used. No workload was recorded for the Flight Data (FD) position because no radio transmissions were involved.

Table 1. Percent Change in Heart Rate (HR) by Subject

Subject	Resting HR (avg bpm)	Working HR (avg bpm)	% Increase (decrease)
1	95	99	5
2	68	86	26
3	78	96	22
4	90	99	10
5	88	108	23
6	69	68	(1)
7	61	89	46
8	93	97	4
9	78	90	15
10	60	89	48
11	65	87	34
12	75	93	25
13	71	90	27
14	86	97	12

III. Results.

Heart Rate. The preshift HR of each subject was determined with the subject standing while the recording equipment was tested at the time of electrode application. The percent change in HR for each subject from the preshift condition to the working condition is listed in Table 1.

While there were no significant differences in HR between the three radio positions at OPF, there was a difference ($P \leq 0.02$) between the Local Control 1 and FD positions.

When all comparable work positions at various ATC towers are considered (Table 2), HR's at OPF were 9 percent higher than those at ORD in 1968[4] ($P \leq 0.01$), 18 percent higher than those at Houston Intercontinental Tower (IAH) in 1970[5] ($P \leq 0.001$), and 12 percent higher than those at IAH in 1971 ($P \leq 0.05$).[6]

Table 2. Comparison of Heart Rates (HR) at OPF with Three Other ATC Towers

HR (avg bpm)			P
OPF	Other		
92	(ORD)	84	0.01
92	(IAH '70)	78	0.001
92	(IAH '71)	82	0.05

Urine Biochemistry. Table 3 lists 2-day averages for st, e, and ne for each subject under baseline and working conditions. For the group, st excretion during work increased by 182 percent over the baseline condition, e increased by 370 percent, and ne increased by 115 percent.

Comparison of ATC facilities is rendered difficult because the rankings of stress by metabolite do not often agree. Ranking of stress by ne excretion may not agree with the ranking of stress by e or st. It thus became desirable, if not imperative, to integrate the various biochemical stress indicators into one number that would represent stress.

A universal stress index has not been formulated. Such an expression would be exceedingly useful in bringing order out of the confusion presently surrounding the subject. In this laboratory has been devised a limited index that falls short of universal application but is useful within a given population that is homogeneous with respect to the stressor (e.g., the air traffic controller population). The calculation of this index is presented in Figure 1.

TABLE 3. Comparison of Urinary Excretion of Stress Indicators by OPF Controllers (µg/100 mg Creatinine)

	st		e		ne	
Subject	**B***	**W****	**B**	**W**	**B**	**W**
1	453.9	745.9	0.48	1.99	3.62	8.64
2	542.7	1334.6	0.47	2.60	3.66	4.68
3	282.8	1021.1	0.30	0.93	1.64	2.81
4	870.8	1226.4	0.53	3.17	2.86	6.65
5	242.1	652.0	0.46	1.80	1.55	3.51
6	611.4	1076.9	0.49	2.49	3.47	4.38
7	448.2	1162.0	0.39	1.44	2.09	4.30
8	717.6	1344.9	0.40	1.77	2.29	5.61
9	392.2	673.8	0.38	1.11	1.95	3.36
10	592.1	1457.8	0.57	2.10	2.77	4.06
11	429.4	666.4	0.46	1.56	2.61	4.00
12	634.3	752.3	0.36	1.21	2.68	3.07
13	804.8	935.3	1.02	2.25	3.31	6.52
14	719.9	1024.8	0.72	1.43	4.73	7.27
$\bar{X}$	553.0	1005.3	0.50	1.85	2.80	4.91

*B = Baseline value
**W = Work value

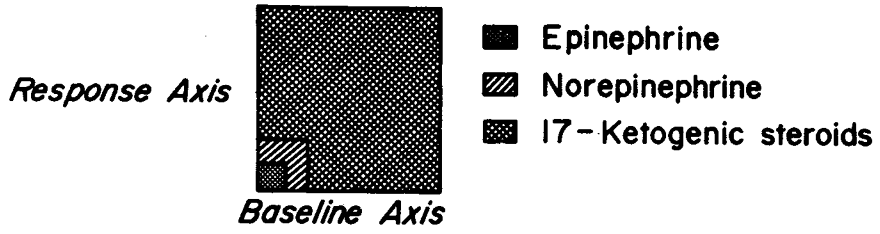
Our index, expressed as "C_s," is calculated from the urinary content of st, e, and ne expressed as micrograms per 100 milligrams of creatinine. Though the creatinine-based ratio is not necessary for computation of this index, it was chosen because of uncertainties regarding urine collection periods and urine volumes that were inherent in specimens collected in the field under conditions not as strictly controlled as they might be in the laboratory. Any other basis for expression of excretion of these substances would be equally useful provided the units were consistently used throughout the calculation. Because the three compounds occur in the approximate ratio of 500 st:10 ne:1 e, some weighting procedure was necessary to prevent st from being the sole determinant of the index.

Weighting was accomplished by dividing the individual night sleep (baseline) and work (response) values of each metabolite by the mean of all the values of each metabolite in the entire controller population from which data have been collected in the nine studies carried out to date. This weighting factor, referred to as the "grand mean" and expressed as "$\bar{X}_G$," is calculated for each metabolite (2, Figure 1). The stability of $\bar{X}_G$ is essential if valid comparisons of C_s are to be made, for if $\bar{X}_G$ changes, so do all the C_s values calculated prior to the change. More than 2,000 observations have been made on 210 controllers, and all of these data were entered in a Hewlett-Packard 2100A computer. $\bar{X}_G$ was recomputed as each observation for e, ne, and st was added. The initial variation was large, but by the time 2,000 observations had been recorded, the variation was reduced to less than 5 percent. If C_s previously calculated is changed as a result of a change in $\bar{X}_G$, the numerical value of C_s only will change; the comparative ranking will not change.

For reasons to be discussed later, it is desirable to integrate the baseline and response values. This procedure is carried out simply by obtaining the product of the weighted baseline value and weighted response value for each metabolite.

CALCULATION OF STRESS INDEX

1. Epinephrine (e) < Norepinephrine (ne) << 17-Ketogenic steroids (st)



2. For each metabolite,

a) Obtain a Grand mean ($\bar{X}_G$)

$$\bar{X}_G = \frac{\Sigma X_B + \Sigma Y_R}{n}, \quad X_B = \text{All baseline values.} \quad Y_R = \text{All response values.}$$

b) Weight each individual baseline value (X) and each individual response value (Y).

$$\frac{X}{\bar{X}_G} = W_B = \text{Weighted baseline value.}$$

$$\frac{Y}{\bar{X}_G} = W_R = \text{Weighted response value.}$$

c) Compute product (c) of baseline and response values for each metabolite.

$$(c) = (W_B)(W_R)$$

3. Compute Stress Index (C_S) by averaging c-values of all metabolites.

$$C_S = \frac{(c_e + c_{ne} + c_{st})}{3}$$

FIGURE 1. (1) Diagrammatic illustration of the disproportionate amounts of st, ne, and e in urine; (2) method of weighting st, ne, and e to make each of them equally representative in (3) the calculation of the stress index C_S.

This product is expressed as "c" (2, Figure 1). Thus, there are c_{st}, c_e, and c_{ne}.

The final index, C_s, is obtained from the average of c_{st}, c_e, and c_{ne} (3, Figure 1). The average is used so that the index can be expanded to include other measurements. Since C_s is dimensionless, any other measurement for which there are baseline and response values can be added.

C_s can be computed for individuals, for facilities, for various work positions, for any particular work shift, or for any other condition. The requirements are that there be baseline and response data and that there be sufficient data from which a reliable grand mean can be computed. C_s has been computed for each controller who participated in the nine studies carried out at eight ATC facilities. Table 4 shows the distribution of C_s by facility and the level of significance of the difference between each of them.

Table 4 shows that OPF ranks second in stressfulness to ORD, the highest stress facility on the list, and is not significantly different from ORD. OPF is significantly different from Fort Worth ARTCC (FTW), the lowest stress facility on the list. Results from other facilities are listed and will be discussed in future reports.

Since data were obtained at OPF only on the day shift, comparison of OPF day shift C_s with day shift C_s at other facilities is presented in Table 5. Again, OPF is significantly different only from FTW.

Table 6 shows a ranking by C_s of facilities studied. Values for c_{st}, c_e, and c_{ne} are also shown, and it is obvious that OPF ranks second highest of the facilities by virtue of high c_e and c_{ne}. In other words, work at OPF is characterized by outputs from the sympathetic nervous system (ne) and the adrenal medulla (e). The secretions from these two sources would be expected to result in temporarily elevated blood pressure, increased heart rate, quickened reaction time, increased body heat, and increased alertness. Table 7 shows a ranking of facilities by c_{st}, c_e, and c_{ne}.

Table 8 shows that C_s at OPF is correlated significantly with c_{st}, c_e, and c_{ne}. Table 8 further shows that c_{st} is not significantly correlated with c_{ne} and is weakly correlated ($P \leq 0.05$) with c_e and that c_e is not significantly correlated with c_{ne}.

Figure 2 shows in graphic form the relationship between c_{st}, c_e, and c_{ne} and emphasizes that OPF is mainly characterized by outputs from the sympathetic nervous system and the adrenal medulla.

Workload. Table 8 and Figures 3, 4, 5, and 6 show the relationship between C_3, c_{st}, c_e, and c_{ne} and workload defined as radio transmission time. Workload is weakly correlated ($P \leq 0.05$) with C_s and c_{ne} and is strongly correlated ($P \leq 0.01$) with c_e. Workload is not significantly correlated with c_{st}.

TABLE 4. Biochemical Stress Index (C_S) Differences for Various ATC Facilities

Facility	C_s	LAX	OAK	IAH ('71)	IAH ('70)	MIA ARTCC	ATL ARTCC	OPF	ORD
FTW ARTCC	0.34	0.26*	0.26*	0.34**	0.40**	0.42**	0.48**	0.50**	0.71**
LAX	0.60	-	-	0.08	0.14	0.16	0.22	0.24	0.45**
OAK	0.60	-	-	0.08	0.14	0.16	0.22	0.24	0.45**
IAH ('71)	0.68	-	-	-	0.06	0.08	0.14	0.16	0.37**
IAH ('70)	0.74	-	-	-	-	0.02	0.08	0.10	0.31*
MIA ARTCC	0.76	-	-	-	-	-	0.06	0.08	0.29*
ATL ARTCC	0.82	-	-	-	-	-	-	0.02	0.23
OPF	0.84	-	-	-	-	-	-	-	0.21
ORD	1.05	-	-	-	-	-	-	-	-

* Indicates $P \leq .05$
** Indicates $P \leq .01$

Duncan's New Multiple Range Test

TABLE 5. Biochemical Stress Index (C_S) Differences for Various ATC Facilities (Day Shift Only)

Facility	C_s	LAX	OAK	ATL ARTCC	MIA ARTCC	IAH ('71)	OPF	IAH ('70)
FTW ARTCC	0.39	0.21	0.21	0.25	0.37*	0.40*	0.45**	0.53**
LAX	0.60	-	-	0.04	0.16	0.19	0.24	0.32
OAK	0.60	-	-	0.04	0.16	0.19	0.24	0.32
ATL ARTCC	0.64	-	-	-	0.12	0.15	0.20	0.28
MIA ARTCC	0.76	-	-	-	-	0.03	0.08	0.16
IAH ('71)	0.79	-	-	-	-	-	0.05	0.13
OPF	0.84	-	-	-	-	-	-	0.08
IAH ('70)	0.92	-	-	-	-	-	-	-

* Indicates $P \leq .05$
** Indicates $P \leq .01$

TABLE 6. C_s, c_{st}, c_e, and c_{ne} for Each ATC Facility Studied (Ranked by C_s)

Facility	C_s	c_{st}	c_e	c_{ne}
FTW ARTCC	0.34	0.22	0.58	0.20
LAX	0.60	0.66	0.34	0.81
OAK	0.60	0.62	0.76	0.43
IAH ('71)	0.68	0.89	0.62	0.52
IAH ('70)	0.74	1.27	0.29	0.65
MIA ARTCC	0.76	0.61	0.71	0.96
ATL ARTCC	0.82	0.76	0.34	1.37
OPF	0.84	0.64	0.74	1.15
ORD	1.05	1.41	0.75	0.98

TABLE 7. Ranking of C_s, c_{st}, c_e, and c_{ne} for Each ATC Facility Studied

Facility	C_s	Facility	c_{st}	Facility	c_e	Facility	c_{ne}
FTW ARTCC	0.34	FTW ARTCC	0.22	IAH ('70)	0.29	FTW ARTCC	0.20
LAX	0.60	MIA ARTCC	0.61	ATL ARTCC	0.34	OAK	0.43
OAK	0.60	OAK	0.62	LAX	0.34	IAH ('71)	0.52
IAH ('71)	0.68	OPF	0.64	FTW ARTCC	0.58	IAH ('70)	0.65
IAH ('70)	0.74	LAX	0.66	IAH ('71)	0.62	LAX	0.81
MIA ARTCC	0.76	ATL ARTCC	0.76	MIA ARTCC	0.71	MIA ARTCC	0.96
ATL ARTCC	0.82	IAH ('71)	0.89	OPF	0.74	ORD	0.98
OPF	0.84	IAH ('70)	1.27	ORD	0.75	OPF	1.15
ORD	1.05	ORD	1.41	OAK	0.76	ATL ARTCC	1.37

TABLE 8. Correlation Coefficients of C_s, c_{st}, c_e, and c_{ne} and Workload

	c_{st}	c_e	c_{ne}	Workload (transmission time)
C_s	.70**	.81***	.88***	.64*
c_{st}	-	.59*	.38	.19
c_e	-	-	.52	.77**
c_{ne}	-	-	-	.55*

$* \ P \leq .05$
$** \ P \leq .01$
$*** \ P \leq .001$

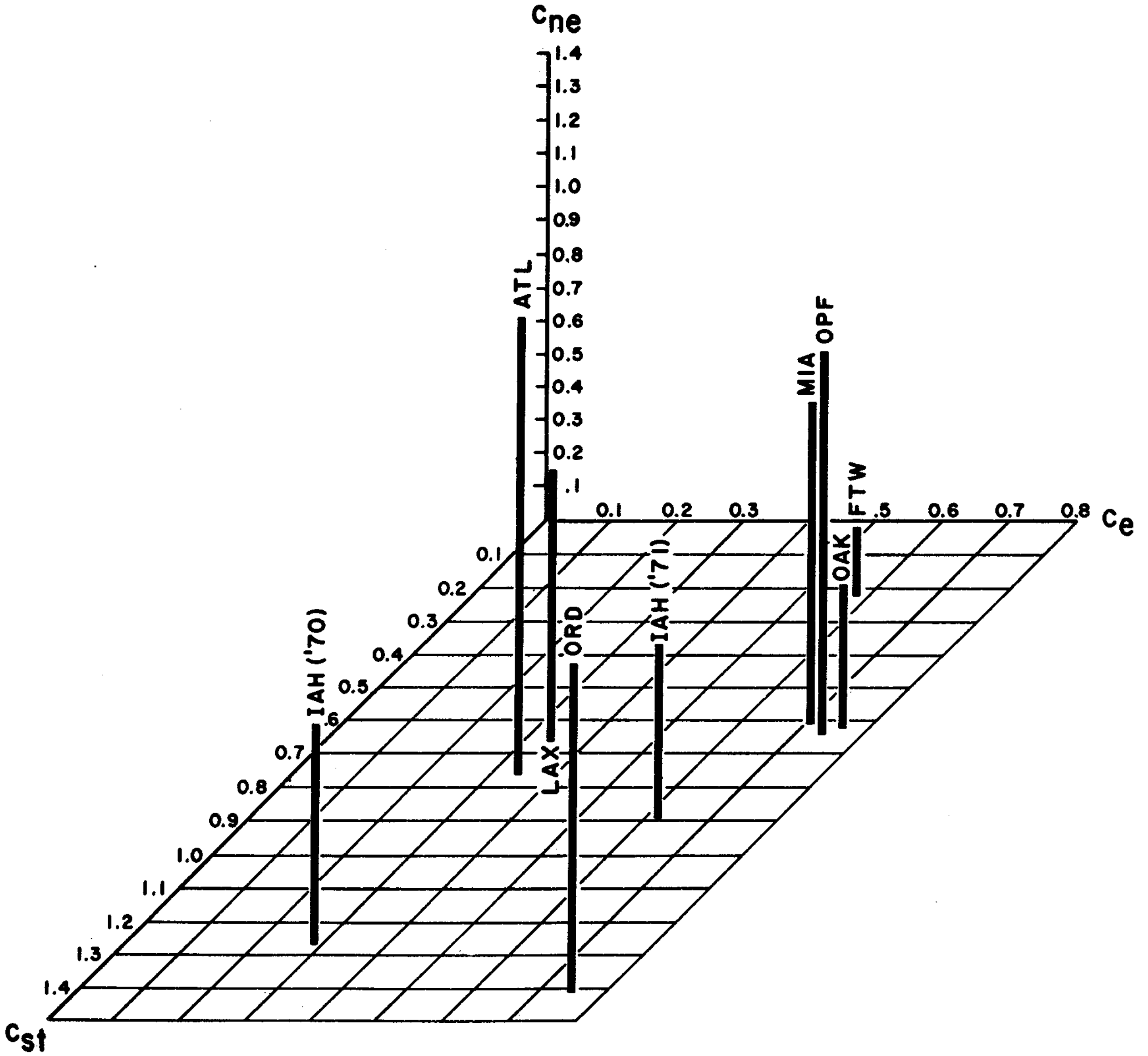


FIGURE 2. Graph of the relationship between c_{st}, c_{ne}, and c_e.

IV. Discussion.

Even though OPF's air traffic congestion is considerably below its historic high level, it is still an extremely busy airport. In good weather, radio traffic on local control is virtually continuous. The OPF controllers respond to this workload with e and ne outputs that place them next to ORD controllers and are not significantly different from theirs. ORD controllers are ranked first because of their heavy adrenocortical output. At OPF, c_{ne} exceeds and c_e effectively equals those values for ORD controllers.

The stress index presented in this paper is essentially a product, rather than a ratio, of normalized baseline and work-related values. As such, the baseline values are coequal with the response values in defining the level of stress of an individual or, by aggregation of individuals in the same place, of a facility. Others[2] have used an index based on the work-to-baseline ratio. Such an index may show a high degree of stress when the baseline is low and the response is only moderate; conversely, it may show a low stress response when the baseline is high. Further, the ratio index is based on the assumption that the output of stress indicators will increase as a result of activity; such may not be the case. Occasionally, the activity-related

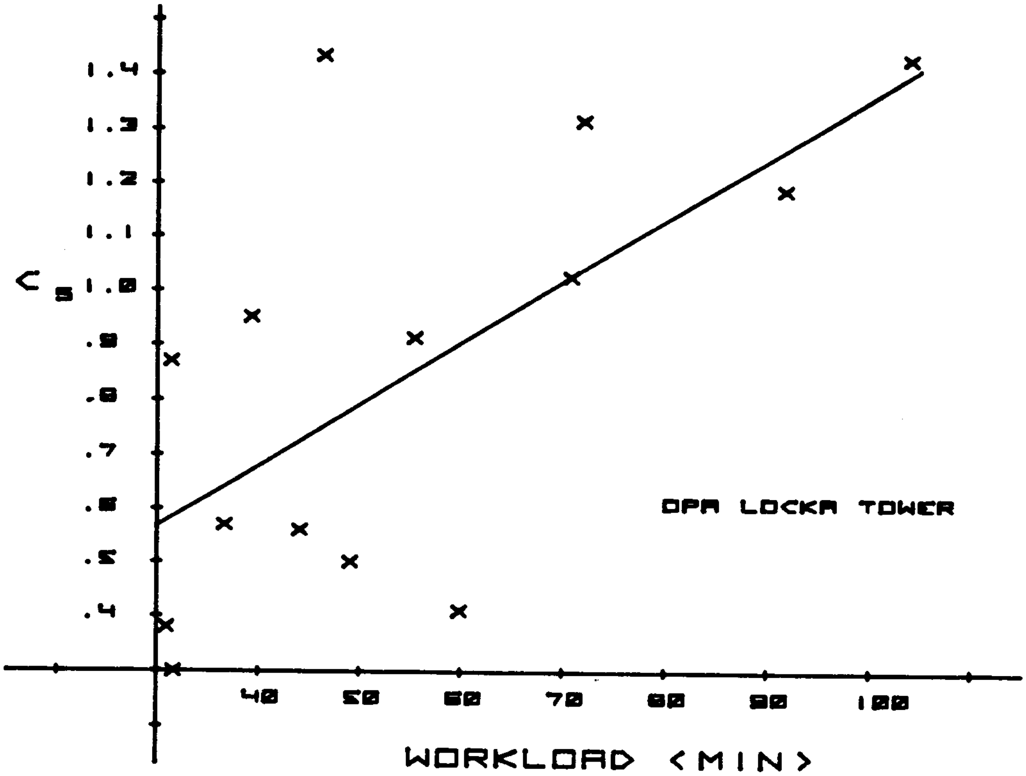


FIGURE 3. Relationship between C_s and workload represented by minutes of radio communication time.

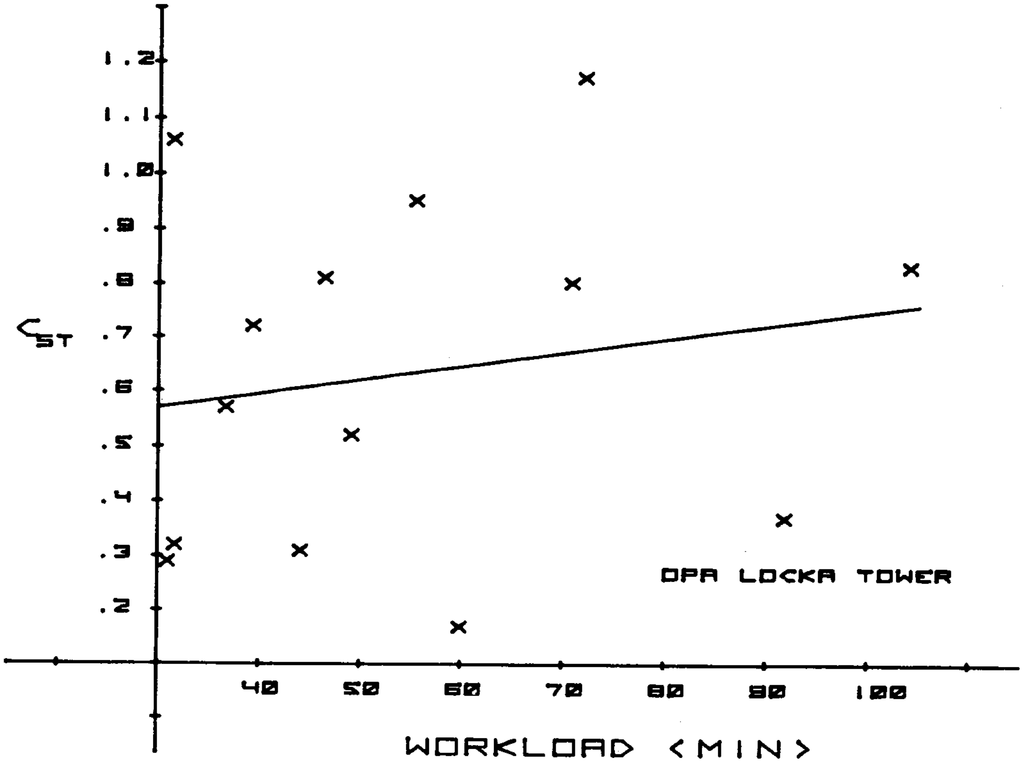


FIGURE 4. Relationship between c_{st} and workload represented by minutes of radio communication time.

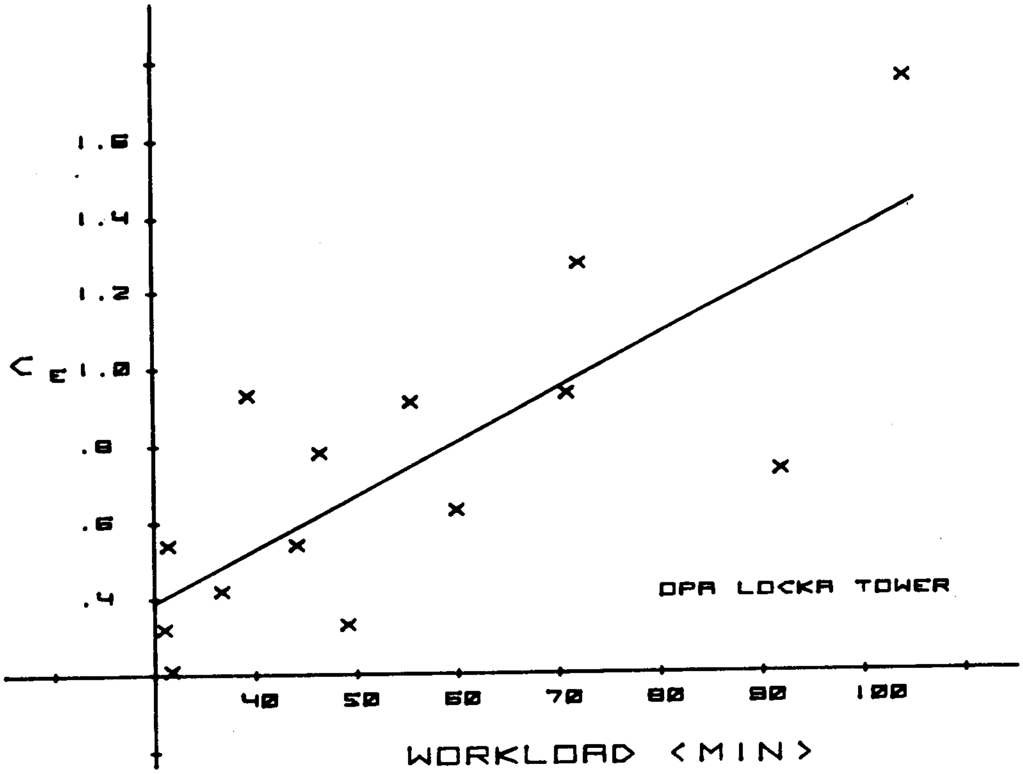


FIGURE 5. Relationship between c_e and workload represented by minutes of radio communication time.

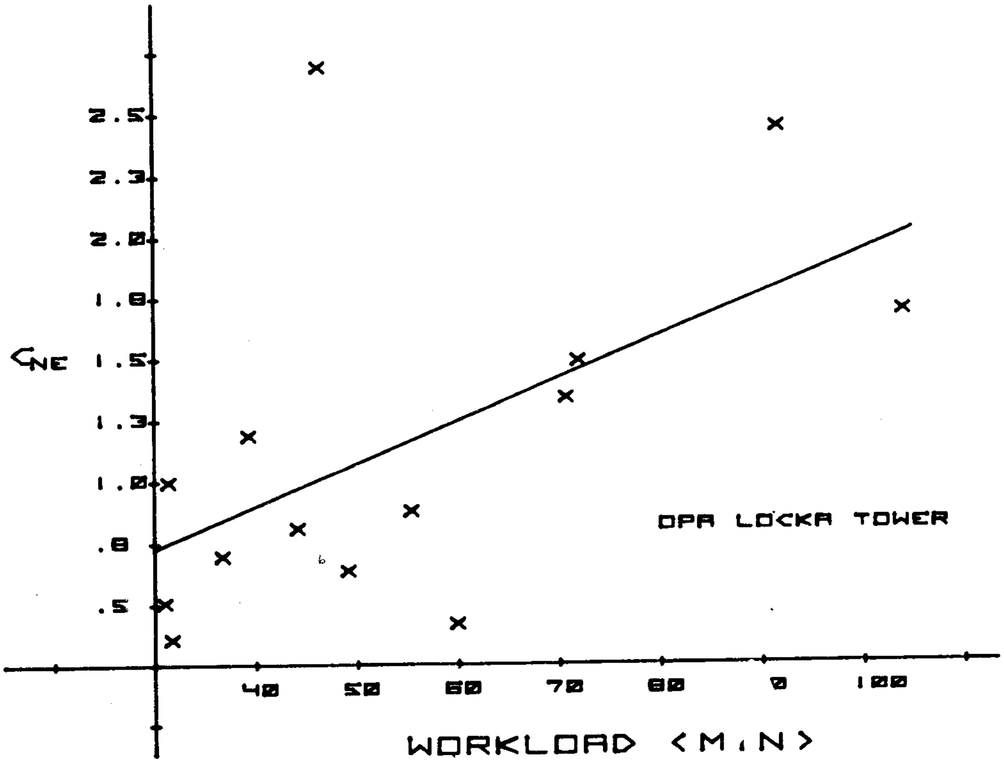


FIGURE 6. Relationship between c_{ne} and workload represented by minutes of radio communication time.

values are lower than the baseline values, presumably because activity (work) represents relief from some unknown off-the-job stressor. With the product index, these difficulties are avoided.

Figures 7, 8, and 9 show in graphic form and Table 9 shows in tabular form the relationship between baseline and work values at the facilities studied. It is clear from these presentations that the baselines for ne and st at the various facilities differ significantly. It is also clear that the responses to work, as represented by st, e, and ne, vary significantly among the different facilities, an indication that the controllers not only start from different stress baselines but rise to different stress levels during work. Thus, one must take into consideration the interaction between baseline and work values if the total stress exhibited by an individual is to be estimated. It is important to estimate total stress, for off-duty stresses undoubtedly are carried over into the work period and work stress is just as certainly taken home with the controller from the job.

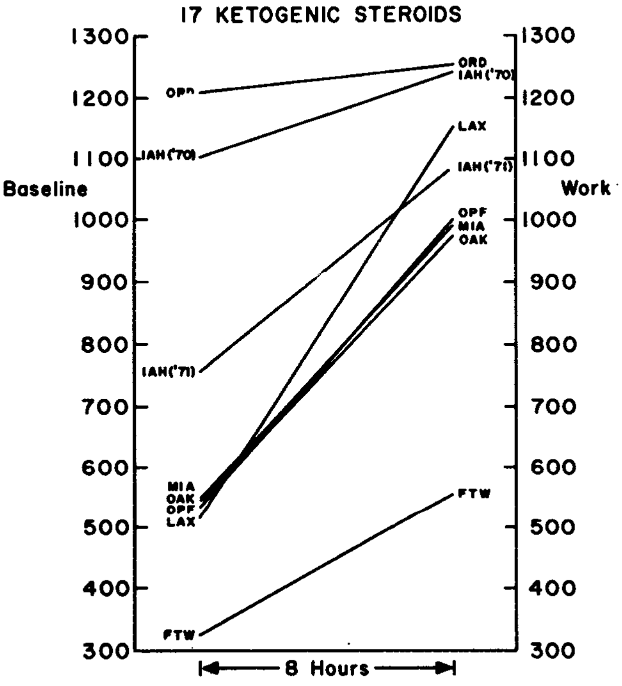


FIGURE 7. Relationship between baseline (night sleep specimen) and response (8-hour pooled work specimen) at the various facilities. Ordinate is μg 17-ketogenic steroids per 100 mg of creatinine. See Table 9 for numerical data.

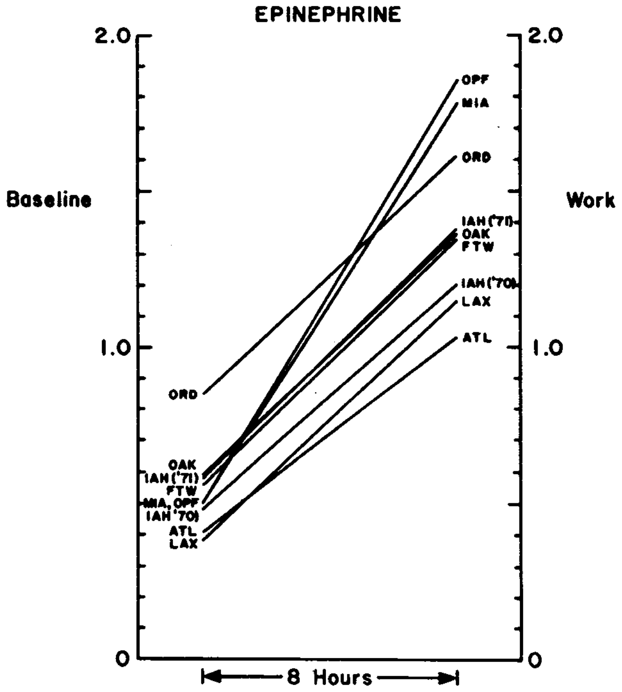


FIGURE 8. See legend for Figure 7. Ordinate is μg epinephrine per 100 mg of creatinine.

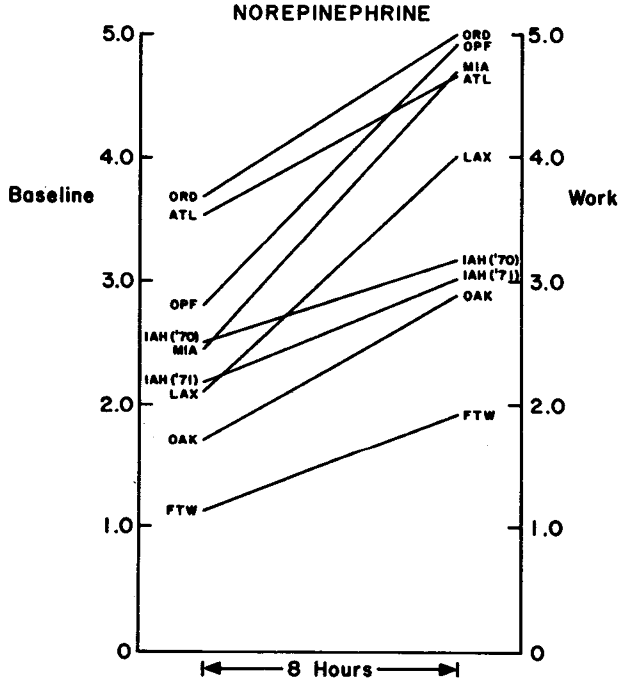


FIGURE 9. See legend for Figure 7. Ordinate is μg norepinephrine per 100 mg of creatinine.

TABLE 9. F-Ratios and Significance of Difference of Baselines and Response Levels at ATC Facilities

	st	e	ne
Baseline	7.6428 ($P \leq 0.01$)	0.7501 (N.S.)	2.3995 ($P \leq 0.05$)
Response	7.5573 ($P \leq 0.01$)	4.1895 ($P \leq 0.01$)	9.2499 ($P \leq 0.01$)

The baseline values at OPF are low, an indication that off-duty activities, generally speaking, have a low stress content. Life for this group does not appear to be characterized by continual high-level stress. Kagan and Levi[3] emphasize that adrenal cortical stimulation occurs as a final common (nonspecific) response to a great variety of stimuli but that the anterior pituitary-adrenal cortical axis is slower to respond and is less sensitive than is the hypothalamic-sympathetic-adrenal medulla axis. OPF controllers do respond with a moderate increase in adrenal cortical output, but the major response is via the hypothalamic-sympathetic-adrenal medullary system. This response is strongly related to workload, whereas steroid excretion is not.

The elevated HR exhibited by OPF controllers is a cardiovascular manifestation of sympathetic arousal shown also by elevated catecholamine excretion. The increase in metabolic rate attendant on the intensity of the work is also evidenced by the elevated e excretion. These biochemical indicators confirm what is so evident from observation of these controllers as they work—that in their intense involvement in controlling aircraft in a highly congested airspace, these men are responding in the classical manner described by Walter B. Cannon.[1]

Although a meaningful definition of stress has not yet been proposed, it is clear that, at least for now, any estimate of stress will have to rely on a battery of tests that will provide insights into the functioning of more than one system. Clearly, the reason for this is that the body's response to a stimulus is not absolutely nonspecific and there is some degree of stimulus-response specificity.

This concept is revealed by the use of the index and is illustrated in Tables 6 and 7. For example, C_s for Houston Intercontinental Tower (IAH) in 1970 is disproportionately influenced by c_{st}, whereas C_s for Atlanta ARTCC (ATL) is disproportionately influenced by c_{ne} and Ft. Worth ARTCC (FTW) by c_e. Factors that were identifiable at those facilities probably accounted for the differential response. Certainly, the data from OPF clearly indicated a strong correlation between catecholamine excretion and our workload concept. Likewise, the low c_{st} appears to indicate that stress at OPF is not sufficiently strong or continuous to cause the high level of steroid excretion that is evident at some other facilities.

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