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PHYSIOLOGICAL RESPONSES IN AIR TRAFFIC CONTROL PERSONNEL: HOUSTON INTERCONTINENTAL TOWER

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16. Abstract

Biochemical and physiological indices of stress showed that the level of stress of 16 air traffic controllers at the Houston Intercontinental Airport Tower was indistinguishable from that of control populations. While the level of stress was lower than that among O'Hare Tower controllers, both groups showed about the same degree of adaptation. Day work (heavy traffic load) at Houston was characterized by elevated levels of all stress indicators as compared with the mid-shift (light traffic); epinephrine excretion increased significantly during the last half of the mid-shift as compared with the first half. Urinary stress indicators (17-ketogenic steroids, epinephrine, norepinephrine) were all significantly elevated during day sleep as compared with night sleep, indicating less effective rest during day sleep. The data support the practice of controllers moving from high-stress, high-density locations to lower-density facilities when either air safety or the controller's well-being is in question.

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PHYSIOLOGICAL RESPONSES IN AIR TRAFFIC CONTROL PERSONNEL: HOUSTON INTERCONTINENTAL TOWER

I. Introduction.

Physiological and biochemical measurements made on 22 air traffic controllers at the old (1968) O'Hare Airport Tower in Chicago indicated that the heavy traffic evening shift was principally characterized by a sympatho-adrenomedullary response, and that the light traffic midnight-to-8:00 a.m. shift (mid-shift) was further characterized by adrenocortical hyperactivity. Further, it was shown that recovery during the off-duty period (day sleep) was incomplete during a week of mid-shifts. Plasma phospholipid determinations as well as urine chemistry indicated that O'Hare controllers were under considerable stress. The various indicators showed that the stress was comparable to that experienced by combat personnel, populations of schizophrenics, air crews on extended flights, and altitude chamber technicians experiencing six hours of decompression.[6-8]

It is necessary to express stress in comparative terms because standard units of stress have not been established. The findings of the present study at Houston Intercontinental Tower, a medium-density facility, are intended to be compared with those at O'Hare Tower and thus ultimately establish a spectrum of stress for air traffic controllers engaged in different types and intensities of work. Such data would be useful in personnel placement and career progression planning.

The approach in this experiment, as with the study at O'Hare, was to compare the physiological responses of Houston controllers on the heavy traffic day shift (0800–1600) with their responses on the light traffic mid-shift (0000–0800).

II. Methods.

Sixteen controllers (5 crew chiefs, 9 journeymen, 2 trainees) volunteered for the study. Each subject was observed during five consecutive day shifts (0800–1600) and five consecutive mid-shifts (0000–0800).

A. *Physiological Measurements.* Instrumentation consisted of dry ECG electrodes[13] from which led 36 ga. insulated copper wires connected by means of a 3-wire cable to an Avionics Model 350 Electrocardiocorder. The ECG was recorded on tape continuously throughout the work periods. The taped ECG's were reduced to one-minute heart rates on a tape reproducer that was connected to an electronic counter. The counter accumulated one minute of recorded ECG and then dumped the count through a printer onto paper tape. Activity logs were kept by observers for correlation with the heart rates. The logs were also used to exclude periods of physical activity such as walking up and down stairs, meal breaks, etc., that might affect the heart rate in a way unrealted to the ATC task.

At the time of instrumentation, pre-shift heart ratewas noted for a one-minute period in connection with an operational check of the recording system. This rate cannot truly be considered as a resting heart rate because of preceding physical activity incident to reporting for work (walking from the parking lot, going to the locker room, "horseplay," anxiety about biomedical procedures, etc.).

B. *Biochemical Measurements.* Urine was collected from each subject throughout the two work weeks that each subject was under observation. The two on-duty collection periods were the first four and the last four hours of each shift. An overnight specimen was collected following each day's work. As each collection period began with the bladder empty, the urine collected was fairly representative of that period. At the end of the first four hours of work the subjects were asked to void, thus terminating that collection period. The second collection period was terminated at the end of the work day.

Urine was collected into screw-cap plastic bags containing 50 gm of dry boric acid. At the end of a collection period the urine volume was measured and a 50 ml aliquot was placed in a plastic

bottle containing 2 cc of 1.2N HCl. This aliquot was frozen and later analyzed for epinephrine and norepinephrine. The remainder of the urine was placed in a 500 ml plastic bottle and frozen at the work site. When a sufficient number of specimens had accumulated, they were shipped by air to the Civil Aeromedical Institute in Oklahoma City and stored in deep freeze until thawed for analysis.

The sample containing only boric acid was used for the analysis of 17-ketogenic steroids; the aliquot which had been further acidified (to 0.04N) with HCl for analyses of catecholamines, creatinine, Na+ K+. To minimize errors in precise timing of the urine collection and partial loss of sample, data were reported in weight units (e.g. nanograms, etc.) per 100 mg of creatinine. Creatinine was measured by an automated modification of the Jaffe method.[9] A two-channel atomic absorption instrument (Instrumentation Laboratories, Model 353) was used to measure Na+ and K+; the instrument was calibrated against standards and blank diluent. Catecholamines were measured by adsorption onto 500 mg of alumina, elution with acetic acid, and fluorometric analysis by a method essentially that of Fiorica and Moses.[3] Catecholamine standards used to calibrate the method were dissolved in a medium saturated with boric acid containing 0.04N HCl because of the tendency of the catecholamines to form strong borate complexes.

An automated modification of the Norymberski technique[2] was developed for the analysis of 17-ketogenic steroids; details of the technique will be reported later. Essentially, it involves prior reduction of interfering 17-ketosteroids and subsequent oxidation of ketogenic compounds, followed by extraction and purification of the extract; the extract is dried *in vacuo*, dissolved in methanol and analyzed by an automated device which employs an on-line extraction to remove interfering chromogens. Data are corrected for loss of sample by measuring the recovery of added C^{14}-cortisol, and for incomplete oxidation by comparison with companion data from control tubes containing cortisol in amounts representing an average urine concentration.

A 15 ml blood specimen was drawn into a heparinized plastic syringe from the antecubital vein of each subject at the end of each work week that they were under observation and a third specimen was taken when each subject returned to work after two days off. The blood specimens were immediately centrifuged and the blood plasma was removed and frozen. Thus, three blood specimens were taken from each subject. The accumulated frozen plasma specimens were taken by courier to the Naval Air Development Center (Johnsville), Warminster, Pennsylvania where the plasma specimens were analyzed for phospholipids by the method of Dawson[1] as used by Polis, et al.[10-12]

C. *Description of the Site and Conditions of Work.* The Houston Intercontinental Tower is a new structure of the golf-tee type with the Terminal Radar Approach Control (Tracon) room located on the ground floor. An elevator is used to go from the Tracon room to the cab. Controllers normally change positions approximately every two hours, working about half of the time in the cab and half in the Tracon.

At the time of this study the tower was operating on a "straight five-day" shift rotation pattern: each controller worked five evening shifts, five day shifts, evenings again, five days again, and finally five mid-shifts, with each five-day work week followed by two days off. Thus each controller would have been scheduled to work "mids" every fifth week but the traffic on the shift was so light one man could usually handle it. The rest of the team then "doubled back" on to the day or evening shifts for the fifth week of the sequence so that, in practice, each man worked a week of mids every 6–10 weeks. For this study, however, two controllers manned the tower during the mid-shift, one in the cab and one in the Tracon room.

The tower has since abandoned the straight five-day shift rotation pattern in favor of the 2–2–1 rotation (a five-day work week consisting of two evenings, two days, and one mid). On the 2–2–1 rotation, the controllers work a different shift every day. A comparison of the controllers' physiological responses to these two shift rotation patterns will be the subject of a subsequent report.

Houston Intercontinental Airport is a relatively new facility with two long runways, one east-west and one southeast-northwest, with their westerly ends approximately each other so that the runways form a blunt V open to the southeast. One runway is ordinarily used for takeoffs and the other for landings, thus expediting the flow of traffic. There are numerous high-speed

turnoffs from the runways; the taxiways are wide and straight; and the ramp areas are capacious and arranged in an orderly way. The airport property, located about 18 miles north of Houston, is extensive and being removed from heavily populated areas aircraft noise is not a disturbing factor for the citizens of the city. Noise complaints, so frequent at O'Hare, were not a factor for controllers to deal with at Houston.

Houston Approach Control handles approaches and departures at several other airports in the area including Ellington AFB and Hobby Airport. Intercontinental Airport is primarily an air carrier terminal with little general aviation traffic, in this respect similar to O'Hare. At the time of this study Intercontinental had about 500 operations per day and the Tracon worked about 200 additional aircraft per day. At the time of the O'Hare study, that airport had up to 2000 operations per day.

All these features at Houston Intercontinental contribute to an airport that is apparently ideal from the standpoint of air traffic control: spaciousness, moderate traffic density, new and comfortable facilities, good visibility, runways that do not cross, flat terrain, and wide protected areas. Most of these conditions are in exact contrast with those that obtained at O'Hare at the time of that study. Houston Intercontinental should, hypothetically, be situated lower down on the air traffic controller stress spectrum than was O'Hare if work load and physical working conditions are the principal stressors. The old O'Hare Tower, on the other hand, was antiquated with respect to equipment and physical appointments for the comfort and convenience of controllers. Facilities in the new tower at O'Hare are presumed to have rectified those problems.

III. Results.

A. *Heart Rate.* Mid-shift/day-shift comparisons are presented in Table 1. Because only one controller was in the cab and one in the Tracon on the mid-shift, numbers of subjects were too few for statistical treatment of the data, except for the approach control position in the Tracon. There, the elevation of the heart rate on the day shift is significant at the one percent level of probability. In all cases heart rates on the day shift are higher than those on the mid-shift. When different work positions are compared on the two shifts, there are only a few places where the heart rate differences are statistically significant. On the day shift approach control (84 beats per minute (bpm)) is slightly, but significantly, higher ($p \leq 0.05$) than ground control (80 bpm). Heart rates were generally lower during cab work than during radar work; however, cab work gave rise to slightly higher heart rates than did coordinator work in the Tracon. On the mid-shift the only significant difference (≤ 0.05) is between local control in the cab (77 bpm) and approach control (75 bpm). While this difference has statistical validity, the physiological significance of a 2 bpm difference is questionable.

Individual mean heart rates were invariably lower on the mid-shift than on the day shift; the decreases ranged from 3%to 29%.

When tower and day-off activities were compared, a few points of statistically significant difference emerged (Table II). Again, the physiological significance of some of the small differences must be doubted.

1. Comparison with O'Hare. Heart rates of O'Hare controllers were invariably higher than those of Houston controllers (Table III). Several points of statistically significant difference are apparent, primarily on the day shift. For comparison, radar and cab positions at each of the two towers have been combined to show that the two facilities do not differ significantly on the mid-shift, but do differ on the day shift (evening shift at O'Hare). None of the work positions gave rise to significantly different heart rates on the mid-shift. On the day shift, however, the cab positions did give rise to significantly higher rates at O'Hare. Pre-work heart rates on both shifts were significantly higher at O'Hare than at Houston.

B. *Urine Chemstry.*

1. Epinephrine (E). Values for E excretion are listed in Table IV. Work load-related adrenomedullary hyperactivity is apparent on the day shift, increasing five to six times over E excretion during night sleep. All values for E excretion during day shift work significantly exceed the values for mid-shift work.

With regard to mid-shift work, the last half of the shift is characterized by E excretion significantly exceeding that found during the first half. Day sleep after the mid-shift gave rise to

an insignificantly greater E excretion than did work on the first half of the mid-shift. However, E excretion during the last half of the mid-shift significantly exceeded E excretion during day sleep. E excretion during day sleep significantly exceeded E excretion during night sleep. The excretion of E during day work, however, is more than twice E excretion during day sleep, indicating the effect of work load.

2. Norepinephrine (NE). The mid-shift is characterized by relative sympathetic nervous system quiescence, whereas the day shift causes moderate sympathetic stimulation (Table V). The day shift is characterized by NE excretion roughly 1.5 times the excretion of NE on the mid-shift. The last half of the day shift leads to insignificantly higher NE excretion compared to the first half of the day shift. NE excretion on the first half of the mid-shift does not significantly exceed the excretion during either day or night sleep. NE excretion during the last half of the mid-shift is significantly greater than NE excretion during night sleep, but not significantly greater than NE excretion during day sleep. Day and night sleep cannot be distinguished by NE excretion with statistical validity.

3. Adrenocortico-steroids (ACS). 17-ketogenic steroid values are listed in Table VI. The pattern of excretion is similar to that of the catecholamines in that the day shift values significantly exceed the mid-shift values. ACS excretion during day sleep is not significantly different from ACS excretion during day work. ACS excretion during day sleep significantly exceeds ACS excretion during mid-shift work and night sleep. ACS excretion actually falls to its lowest level during mid-shift work and is at its highest level during the first half of day shift work.

4. Comparison with O'Hare. Urine from O'Hare controllers was analyzed for 17-hydroxycorticosteroids; urine from Houston controllers was analyzed for 17-ketogenic corticosteroids. Both compounds are valid stress indicators. However, an exact equivalance between them has not been reliably established for all levels of excretion. For comparison, therefore, on-shift values from both groups of controllers were converted to percent of the baseline values. Baseline, in both cases, was taken to be the mean of steroid excretion during night sleep. These baseline percentages were then treated as individual statistics for each urine specimen at each facility.

Table VII compares data from both facilities. At both facilities ACS excretion during the first half of the day shift (0800–1200 at Houston, 1600–2000 at O'Hare) significantly exceeded the level of excretion during the last half. Likewise, ACS excretion during the first half of the day shift significantly exceeded ACS excretion during the first half of the mid-shift. At both facilities ACS excretion during the first half of the day shift did not significantly exceed ACS excretion during day sleep. Further, at both facilities, ACS excretion during day sleep significantly exceeded ACS excretion during the mid-shift.

The two facilities differ in that ACS excretion during work on the first half of the day shift and last half of the mid-shift at O'Hare are not significantly different; whereas, at Houston ACS excretion during the first half of the day shift significantly exceeds ACS excretion during the last half of the mid-shift. The last half of the mid-shift at O'Hare was characterized by a significantly elevated ACS excretion over the last half of the day shift. At Houston, the difference in ACS excretion during those work periods is also significant; however, the day shift value exceeds the mid-shift value. At O'Hare, ACS excretion during day sleep significantly exceeded ACS excretion during the last half of the day shift; at Houston, the difference was insignificant. The difference between ACS excretion during day sleep and during the last half of the mid-shift was not significant at O'Hare; at Houston ACS excretion during day sleep significantly exceeded ACS excretion during the last half of the mid-shift.

Table VII shows, in terms of percentages of the baseline values, that ACS excretion during the last half of the day shift at Houston significantly exceeded ACS excretion on that shift at O'Hare. ACS excretion during day sleep is not significantly different at the two facilities. The mid-shifts at the two facilities do not differ significantly with regard to controllers' excretion of ACS.

5. Sodium (Na). Na excretion was significantly greater during day shift work than during mid-shift work (Table VIII). Na excretion was significantly greater during day shift work than during night sleep, but not significantly elevated

over Na excretion during day sleep. There was no significant difference in Na content of the night work samples, nor was there any significant difference in Na content of night work samples and night or day sleep samples.

6. Potassium (K). K excretion during the first half of the day shift differs significantly from K excretion during night work (Table IX). K excretion is significantly reduced during night sleep below K excretion during all work periods. K excretion during day sleep significantly exceeds K excretion during night sleep.

D. *Blood Chemistry.* Table X shows that total plasma phospholipid concentration does not vary significantly with any of the work or day-off conditions. With regard to phosphatidyl glycerol, however, the levels are significantly higher on the day shift than on the mid-shift. Neither work condition is associated with phosphatidyl glycerol concentrations significantly different from levels on days off.

1. Comparison with O'Hare. Total plasma phospholipid levels in O'Hare controllers were significantly higher than the levels in Houston controllers (Table XI). The Houston air traffic controllers did not differ significantly from control values. Because of the elevated total phospholipids in the O'Hare population, all individual phospholipids are correspondingly elevated, and significantly so, over the Houston group. However, when the individual phospholipid levels are normalized as percent of total phospholipid, it becomes apparent that lecithin and phosphatidyl glycerol comprise about the same percentages in both populations. The two tower groups differ significantly with regard to phosphatidyl ethanolamine, cardiolipin, and phosphatidic acid.

IV. Discussion.

Qualitatively, the results at Houston are similar to those obtained at O'Hare. Day work at Houston is generally more stressful than mid-shift work, as indicated by all measures except total phospholipid, and it is presumed that the heavier traffic load on the day shift is the factor responsible. At O'Hare there was evidence of adrenocortical hyperactivity at the end of the mid-shift, presumably caused by the heavy dawn traffic. At Houston there is some evidence of a similar hyperactivity in that E, NE and ACS excretion all increase during the last half of the mid-shift; however, E was the only metabolite for which the increase was statistically significant. Day sleep after the mid-shift at Houston was not as effective as night sleep as indicated by the higher excretion of all adrenal products during day sleep than during night sleep.

Quantitatively, it is evident upon comparisons of catecholamines that the Houston group as a whole is not greatly different from various control groups and is operating at a lower level of stress than other groups engaged in strenuous or hazardous work (Table XII). Table VII shows the comparison of O'Hare and Houston results normalized as percent of the baseline. It is apparent from this chart that the principal difference between the two facilities occurs on the mid-shift where the greater work load at O'Hare is reflected in elevated catecholamine excretion.

ACS excretion can only be compared by means of normalized data since the same techniques were not used for both towers. Table VII shows that the principal difference with regard to adrenal cortical activity occurs on the last half of the day shift. The two groups do not differ on the mid-shift.

Comparison of 17-OH corticosteroid excretions of O'Hare controllers with other groups on which the same measurements were made reveal that, when on duty, O'Hare controllers rank somewhat below aircrews flying long missions; when asleep in the daytime, they rank slightly above on-duty aircraft mechanics. The Houston controllers rank considerably below values given for 17-ketogenic steroid excretion for the general population. These observations on urine chemistry are interpreted to mean that both groups of air traffic controllers are well adapted to their jobs but are autonomically responsive to the work load, as reflected in their excretion of catecholamines. In that regard, it is apparent that the O'Hare group was operating at a considerably higher level of excitation than were other groups, including the Houston controllers (Table XII).

The plasma phospholipid data generally support the catecholamine data in that the mid-shift at Houston is indicated to be less stressful than the heavy traffic day shift. At O'Hare no difference based on plasma phospholipids could be detected. Comparatively, the O'Hare group significantly exceeds various control and stressed groups, including Houston controllers, with re-

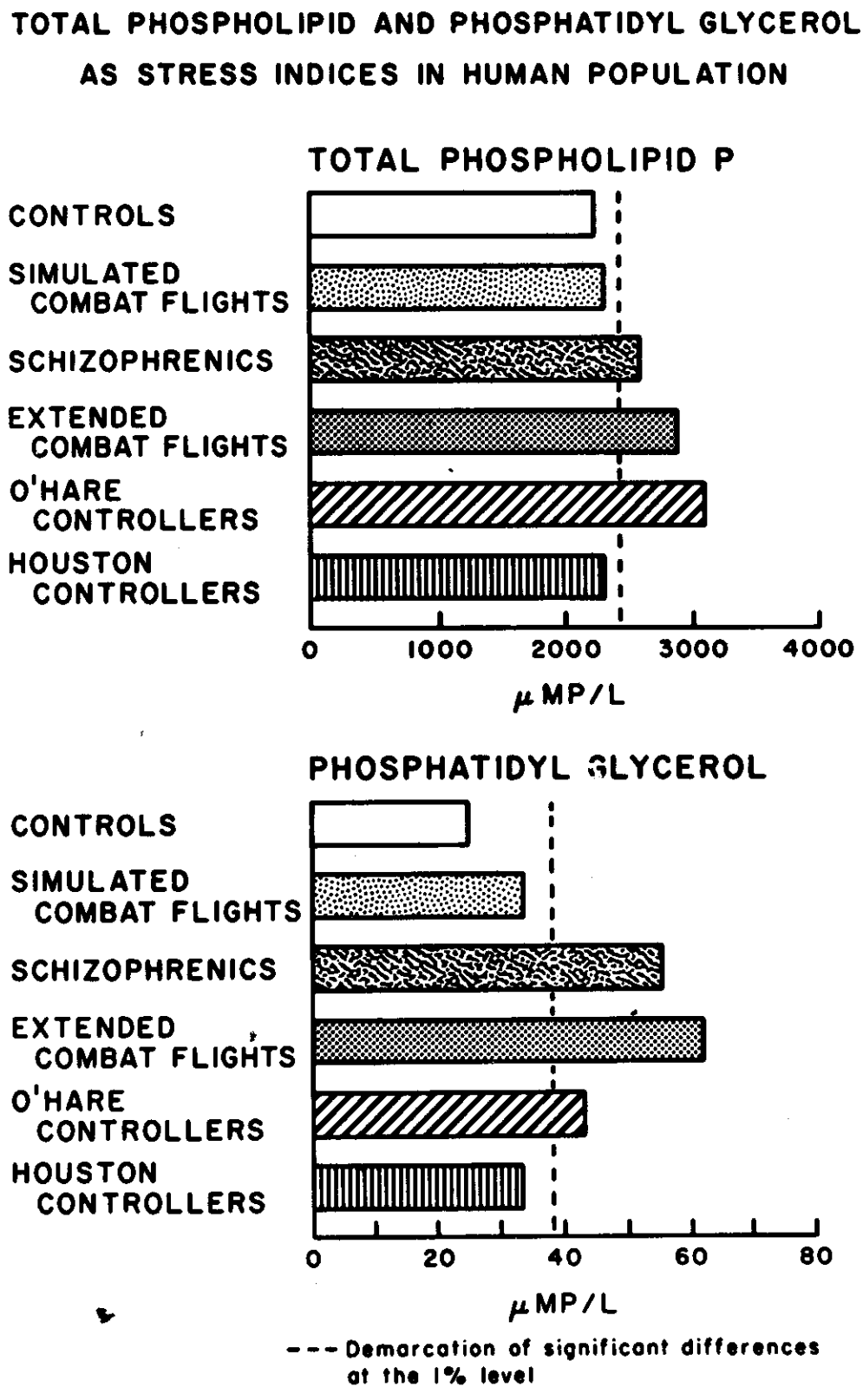

FIGURE 1. Comparison of plasma phospholipid levels in various human groups.

gard to total phospholipids and exceeds control (unstressed) groups, including Houston controllers, on the basis of phosphatidyl glycerol. The Houston controllers as a group do not differ significantly from control groups (Figure 1). When the two groups' individual phospholipid levels are normalized as percent of total phospholipid, it is apparent that their amplitudes of change in total phospholipid and phosphatidyl glycerol as a function of work load are about the same (Table XI). The Houston group exhibits a significantly lower percentage of phosphatidyl ethanolamine, cardiolipin, and phosphatidic acid. The conclusion to be derived from these observations on the normalized data is that both groups were adapted to about the same extent to the long-term stress, except that the O'Hare group was operating at a higher level of stress than was the Houston group.

The mid-shift at Houston *per se* does not appear to be particularly stressful as judged by the measures used in this study. O'Hare and Houston controllers differ in this regard only with respect to catecholamine excretion. Generally, O'Hare controllers excreted a significantly greater amount of catecholamine on the mid-shift than did Houston controllers, a reflection, probably, of the greater traffic load at O'Hare. While mid-shift work itself must be considered light in terms of numbers of aircraft at both facilities, it exacts a penalty from the controllers in the form of inadequate off-duty rest. This conclusion is reached to some extent from controllers' verbalizations but, more objectively, from their group biochemical profile which shows that in both groups catecholamine and steroid excretion during day sleep were either greater than or not significantly different from levels of those compounds in on-duty speciments.

It can be generally concluded that the level of stress at the Houston Intercontinental Airport Tower is significantly lower than it is at the O'Hare Airport Tower. The reasons appear to be related to the lighter traffic and the superior facilities at Houston. Such being the case, the data support controllers' practice of moving from high-density, high-stress locations to lower-density facilities when either air safety or the employee's health is jeoparized.

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TABLE I

COMPARISONS OF MEAN HEART RATES ON MID-SHIFT AND DAY SHIFT

Tower Position	Mid-Shift	Day Shift	Significance Level
Radar Positions			
Approach control	75	84	0.01
Departure control	80	88	*
Supervisor Tracon	77	82	*
Coordinator	83	87	*
Cab Positions			
Local control	77	78	*
Ground control	80	80	*
Data positions	77	81	N.S.
Supervisor	72	85	*

*Insufficient mid-shift data for statistical comparison.

TABLE II

TABLE II

COMPARISONS BETWEEN ACTIVITIES
(Houston)

First Activity	Average Heart Rate	Second Activity	Average Heart Rate	Significance Level***
Mid-Shift Radar	76	Mid-Shift Cab	79	.05
Mid-Shift Radar	71	Mid-Shift Supv.	76	**
Mid-Shift Cab	73	Mid-Shift Supv.	76	**
Day Shift Radar	84	Day Shift Cab	81	N.S.
Day Shift Radar	84	Day Shift Supv.	86	N.S.
Day Shift Cab	81	Day Shift Supv.	85	**
Mid-Shift Radar	75	Day Shift Radar	85	.01
Mid-Shift Cab	76	Day Shift Cab	81	N.S.
Mid-Shift Resting	80	Day Shift Resting	84	N.S.
Mid-Shift (0200 to 0600)	73	Days Off Physical Activity	85	.01
Mid-Shift (0200 to 0600)	73	Days Off Sedentary	80	.01
Day Shift (1000 to 1400)	84	Days Off Physical Activity	85	N.S.
Day Shift (1000 to 1400)	84	Days Off Sedentary	80	N.S.
$\bar{X}$ Mid-Shift and Day Shift Resting	84	Days Off Sleep	66	.01
Days Off Physical Activity	86	Days Off Sedentary	80	N.S.
Days Off Sedentary	80	Days Off Sleep	67	.01

**Data not sufficient to make a statistical test.
***Wilcoxon matched pairs signed rank test.

TABLE III

COMPARISONS BETWEEN HOUSTON AND O'HARE HEART RATES

Activity	AVERAGE HEART RATE Houston	O'Hare	Significance Level*
Mid-Shift (0200 to 0600)	72	77	N.S.
Day Shift (1000 to 1400 Houston) vs (1700 to 2100 O'Hare)	83	90	.05
Mid-Shift			
CAB Position	78	81	N.S.
Radar Position	75	78	N.S.
Supervisor Position	76	76	N.S.
**Pre-work	80	86	.05
Day Shift			
CAB Position	81	95	.002
Radar Position	84	87	N.S.
Supervisor Position	86	90	N.S.
**Pre-work	84	95	.01

*Mann-Whitney U Test

**One-minute heart-rate determination at the time of instrumentation.

TABLE IV

EPINEPHRINE EXCRETION - HOUSTON CONTROLLERS

	μg/100 mg Creatinine	S.D.
Day - First Half (D-1)	1.56	0.95
Day - Last Half (D-L)	1.36	0.68
Night Sleep (P-D-N)	0.26	0.11
Mid-Shift - First Half (M-1)	0.61	0.31
Mid-Shift - Last Half (M-L)	0.86	0.53
Mid-Shift - Post Work (M-P) Day Sleep	0.66	0.55

	t*	Significance Level
D-1 vs D-L	2.09	N.S.
D-1 vs M-1	4.74	.01
D-1 vs M-L	4.06	.01
D-1 vs M-P	5.20	.01
D-1 vs P-D-N	6.05	.01
D-L vs M-1	5.68	.01
D-L vs M-L	4.11	.01
D-L vs M-P	5.04	.01
D-L vs P-D-N	7.35	.01
**M-1 vs M-L	-3.28	.01
M-1 vs M-P	-0.54	N.S.
M-1 vs P-D-N	5.36	.01
M-L vs M-P	2.76	.05
M-L vs P-D-N	5.15	.01
M-P vs P-D-N	3.43	.01

*Correlated t test - listed are the t-values for the various comparisons. (N=16)

**Negative values mean that the second variable is higher than the first.

TABLE V

NOREPINEPHRINE EXCRETION - HOUSTON CONTROLLERS

	μg/100 mg Creatinine	S.D.
Day - First Half (D-1)	3.74	1.00
Day - Last Half (D-L)	3.92	0.99
Post Day - Night Sleep (P-D-N)	2.44	1.06
Mid - First Half (M-1)	2.76	0.41
Mid - Last Half (M-L)	2.96	0.73
Mid - Post Work (M-P) Day Sleep	2.66	0.72

	t*	Significance Level
D-1 vs D-L	-0.76**	N.S.
D-1 vs M-1	4.44	.01
D-1 vs M-L	3.88	.01
D-1 vs M-P	4.36	.01
D-1 vs P-D-N	8.09	.01
D-L vs M-1	5.58	.01
D-L vs M-L	4.58	.01
D-L vs M-P	5.45	.01
D-L vs P-D-N	6.78	.01
M-1 vs M-L	-1.66	N.S.
M-1 vs M-P	.0.63	N.S.
M-1 vs P-D-N	1.38	N.S.
M-L vs M-P	2.12	N.S.
M-L vs P-D-N	2.79	.05
M-P vs P-D-N	0.99	N.S.

*Correlated t test - listed are the t-values for the various comparisons. (N=16)

**Negative values mean that the second variable is higher than the first.

TABLE VI

17-KETOGENIC STEROID EXCRETION - HOUSTON CONTROLLERS

	μg/100 mg Creatinine	S.D.
Day - First Half (D-1)	1541.04	481.04
Day - Last Half (D-L)	1348.00	464.55
Post Day - Night Sleep (P-D-N)	832.92	261.90
Mid - First Half (M-1)	735.96	205.68
Mid - Last Half (M-L)	1018.09	309.95
Mid - Post Work (M-P)	1299.70	381.71

	t*	Significance Level
D-1 vs D-L	2.91	.05
D-1 vs M-1	7.29	.01
D-1 vs M-L	4.22	.01
D-1 vs M-P	1.60	N.S.
D-1 vs P-D-N	6.76	.01
D-L vs M-1	5.49	.01
D-L vs M-L	2.69	.05
D-L vs M-P	0.38	N.S.
D-L vs P-D-N	4.58	.01
M-1 vs M-L	-5.51	.01
M-1 vs M-P	-5.23	.01
M-1 vs P-D-N	-1.24	N.S.
M-L vs M-P	-2.43	.05
M-L vs P-D-N	1.85	N.S.
M-P vs P-D-N	4.11	.01

*Correlated t test - listed are the t-values for the various comparisons. (N=16)

**Negative values mean that the second variable is higher than the first.

TABLE VII

URINARY EXCRETION PRODUCTS EXPRESSED
AS PERCENT OF BASELINE VALUES

O'HARE VS HOUSTON*

	Epi	Norepi	Corticosteroid
D-1	-1.04 N.S.**	0.31 N.S.	1.39 N.S.
D-L	1.85 N.S.	2.43 ≤ .05	2.40 ≤ .05
M-1	4.20 ≤ .01	1.84 N.S.	-0.16 N.S.
M-L	4.56 ≤ .01	5.15 ≤ .01	-1.30 N.S.
M-P	2.42 ≤ .05	3.53 ≤ .01	1.05 N.S.

*t test of a difference between two sample means. The chart is a list of t-values, followed by level of significance.

**Negative numbers mean that O'Hare values are lower than Houston values.

See Tables IV, V, and VI for key to symbols in column 1.

TABLE VIII

SODIUM EXCRETION - HOUSTON CONTROLLERS

	mEq/100 mg Creatinine	S.D.
Day - First Half (D-1)	10.43	2.94
Day - Last Half (D-L)	9.46	1.92
Post Day - Night Sleep (P-D-N)	6.99	2.02
Mid - First Half (M-1)	7.48	2.17
Mid - Last Half (M-L)	7.76	2.23
Mid - Post Work (M-P)	8.41	2.74

	t*	Significance Level
D-1 vs D-L	1.45	N.S.
D-1 vs M-1	3.25	.01
D-1 vs M-L	2.67	.05
D-1 vs M-P	1.94	N.S.
D-1 vs P-D-N	4.65	.01
D-L vs M-1	3.40	.01
D-L vs M-L	2.72	.05
D-L vs M-P	1.24	N.S.
D-L vs P-D-N	3.50	.01
M-1 vs M-L	-0.57**	N.S.
M-1 vs M-P	-1.09	N.S.
M-1 vs P-D-N	0.68	N.S.
M-L vs M-P	-0.93	N.S.
M-L vs P-D-N	0.89	N.S.
M-P vs P-D-N	1.73	N.S.

*Correlated t test - listed are the t-values for the various comparisons. (N=16)

**Negative values mean that the second variable is higher than the first.

TABLE IX

POTASSIUM EXCRETION - HOUSTON CONTROLLERS

	mEq/100 mg Creatinine	S.D.
Day - First Half (D-1)	2.85	0.80
Day - Last Half (D-L)	2.18	0.74
Post Day - Night Sleep (P-D-N)	1.25	0.50
Mid - First Half (M-1)	1.83	0.72
Mid - Last Half (M-L)	1.97	0.79
Mid - Post Work (M-P)	1.95	0.69

	t*	Significance Level
D-1 vs D-L	4.11	.01
D-1 vs M-1	4.81	.01
D-1 vs M-L	4.45	.01
D-1 vs M-P	3.20	.01
D-1 vs P-D-N	7.28	.01
D-L vs M-1	1.97	N.S.
D-L vs M-L	1.34	N.S.
D-L vs M-P	0.97	N.S.
D-L vs P-D-N	3.71	.01
M-1 vs M-L	-0.86**	N.S.
M-1 vs M-P	-0.61	N.S.
M-1 vs P-D-N	3.00	.01
M-L vs M-P	0.07	N.S.
M-L vs P-D-N	2.87	.05
M-P vs P-D-N	2.94	.05

*Correlated t test - listed are the t-values for the various comparisons. (N=16)

**Negative values mean that the second variable is higher than the first.

S.D.
0.80
0.74
0.50
0.72
0.79
0.69

Significance Level
.01
.01
.01
.01
.01
N.S.
N.S.
N.S.
.01
N.S.
N.S.
.01
N.S.
.05
.05

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TABLE X

PLASMA PHOSPHOLIPID LEVELS IN HOUSTON CONTROLLERS

μ Moles Phosphorous/Liter

	Total Lipid Phosphorus			Phosphatidyl Glycerol		
Subject#	Mid	Day *	Day Off	Mid	Day	Day Off
1	2175	2232	2191	42.27	47.76	38.18
2	2832	2875	2970	31.77	31.91	32.22
3	2385	--	2479	29.91	--	31.69
4	2266	2254	2180	24.06	30.29	29.53
5	2316	2180	2060	29.57	31.00	29.25
6	2237	2423	2356	32.46	40.59	43.69
7	2207	--	2204	43.30	--	39.66
8	2132	2115	2111	32.05	33.48	31.30
9	2213	2214	2186	28.51	29.26	31.84
10	2570	--	2584	31.12	--	34.15
11	2497	2482	2508	33.05	34.68	31.55
12	2541	2527	2468	30.03	33.35	32.20
13	2746	2730	2669	33.32	35.54	31.18
14	2465	2491	2512	34.20	34.00	32.01
15	2506	2489	2557	28.05	37.18	35.10
16	2567	2612	2599	35.51	36.26	34.38
$\bar{X}$	2416 ± 73	2432 ± 76	2415 ± 87	32.45 ± 0.97	35.02 ± 1.22	33.62 ± 1.22

	t	p		t	p
Mid vs Day Shift	-0.5097	N.S.	Mid vs Day Shift	-3.60	<0.01
Mid vs Day Off	0.0555	N.S.	Mid vs Day Off	-1.14	N.S.
Day vs Day Off	-1.1784	N.S.	Day vs Day Off	-2.02	N.S.

TABLE XI

PLASMA PHOSPHOLIPIDS IN μM P/LITER
HOUSTON VS O'HARE CONTROLLERS AND CONTROLS

	TOTAL LIPID PHOSPHORUS	LECITHIN	PHOSPHATIDYL ETHANOLAMINE	CARDIOLIPIN	PHOSPHATIDIC ACID	PHOSPHATIDYL GLYCEROL	NUMBER OF SUBJECTS	NUMBER OF DETERMINATIONS
O'Hare Air Controllers (1969)	3128*	2144*	55.1*	32.2*	20.7*	44.4*	21	40
S.E.	±67	±55	±2.0	±1.4	±.7	±1.7		
Houston Air Controllers (1970)	2412	1676	32.6	21.5	11.5	33.8	19	53
S.E.	±28	±25	±.6	±.3	±.3	±.6		
Navy Normal Population	2237	1557	40.5	29.2	13.4	26.	37	37
S.E.	±68	±58	±2.0	±1.1	±.8	±1.7		
PLASMA PHOSPHOLIPIDS IN % DISTRIBUTION								
O'Hare Air Controllers (1969)		68.4	1.77*	1.04*	0.67*	1.43	21	40
S.E.		±.5	±.06	±.04	±.02	±.05		
Houston Air Controllers (1970)		69.4	1.35	0.90	0.48	1.41	19	53
S.E.		±.3	±.02	±.02	±.02	±.03		
Navy Normal Population		69.2	1.80	1.32	0.61	1.21	37	37
S.E.		±.7	±.07	±.05	±.03	±.07		

* $P_{(t)} < .001$ O'Hare vs Houston

TABLE XII

COMPARISON OF CATECHOLAMINE, SODIUM, AND POTASSIUM EXCRETION

OF O'HARE CONTROLLERS, HOUSTON CONTROLLERS, AND VARIOUS OTHER GROUPS

Data Source	E*	NE*	Na**	K**
O'Hare (Mid-shift, Last Half)[8]	2.05	6.30	11.1	3.8
Houston (Mid-shift, Last Half)	0.86	2.96	7.8	2.0
O'Hare (Night Sleep)[8]	0.59	2.59	6.6	2.1
Houston (Night Sleep)	0.26	2.44	7.0	1.3
O'Hare (Day Sleep)[8]	1.12	4.68	10.8	4.0
Houston (Day Sleep)	0.66	2.66	8.4	2.0
O'Hare (Day Shift - First Half)[8]	1.30	3.87	13.0	4.8
Houston (Day Shift - First Half)	1.56	3.74	10.4	2.9
Helicopter Crew (10 hr. transatlantic flight)[5]	2.15	4.80	9.4	1.7
Untrained men (10 hr. simulator test)[4]	1.84	5.40	13.0	3.4
C-135 Crew (10 hrs. flight)[3]	1.36	4.47	9.2	2.7
C-130 Crew (New Zealand flight)[3]	1.09	3.62	7.4	2.1
Scientists - (Off Duty)[3]	0.88	3.18	9.9	4.6
Controls (Night Sleep)[3]	0.56	2.93	6.0	2.0
Controls (Day Work)[3]	0.74	2.85	8.7	5.2
Aircraft Mechanics (Day Work)[3]	0.74	2.43	11.3	4.0

*μg/100 mg. creatinine

**mEq/100 mg. creatinine

* $P_{(t)}$ < .001 O'Hare vs Houston