ADRENALIN, NORADRENALIN AND PERFORMANCE IN A VISUAL VIGILANCE TASK

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ABSTRACT

An experiment was undertaken to determine the relationship between signal detection performance and plasma concentrations of adrenalin and noradrenalin in adult male observers undertaking a visual vigilance task.

Signal difficulty level was equated for each observer in a preliminary experiment and each individual was then classified as either a decrementing or non-decrementing observer on the basis of his performance on a conventional visual vigilance task.

In the subsequent experiment, six decrementing and three non-decrementing observers undertook a conventional visual vigilance task. Seven other decrementing observers served as controls and viewed movies under otherwise identical conditions. Blood samples were drawn from the observers periodically during the vigilance task and these were analyzed fluorometrically for adrenalin and noradrenalin.

It was concluded that the level of circulating adrenalin declines in decrementing observers during a conventional vigilance task in a manner positively related to their performance on the task. The data also suggest that the amount of circulating adrenalin is differentially affected in decrementing and non-decrementing observers.

No conclusions were reached regarding the observers' noradrenalin production during the vigilance task. Remarkable elevations of some observers' noradrenalin levels were seen in both experimental and control conditions, but this finding was not consistent throughout the group.

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ADRENALIN, NORADRENALIN AND PERFORMANCE IN A VISUAL VIGILANCE TASK

For over twenty years it has been known that the longer human observers attend to a monotonous environment for the purpose of detecting low-intensity, infrequent and temporally unpredictable signals, the less vigilant they become; i.e., progressively fewer signals are detected.*

Although much psychological research effort has been expended to explore this "vigilance decrement," very little is yet known about the physiological process which is presumed to underlie it.

Occasionally investigators have attempted to explain the facts of vigilance in neurophysiological as well as in psychological terms. One description of a central arousal system which could account for the ability to anticipate and to respond to signals in vigilance tasks has been offered by Hebb (1955). Hebb postulated that the ascending reticular activating system (ARAS: elaborated by Moruzzi and Magoun, 1949) is responsible for maintaining the general level of cortical activity. He further hypothesized that this system serves a "vigilance function" and as such is responsible for arousing the cortex, making it generally responsive to neural "cues" or signals as they arrive in cortical projection areas via the classical sensory tracks. According to Hebb, humans cannot maintain vigilance without a relatively high input from reticular formation to cortex. This is not an all-or-nothing effect: as cortical activity decreases from an optimal level so also, Hebb believes, does vigilance.

The thesis that alertness as measured by performance on a vigilance task is related to cortical arousal has recently been supported by evidence from Haider et al. (1964). These experimenters

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*For reviews of this area of research, see Frankman and Adams, 1962; McGrath et al., 1959; and Bergum and Klein, 1961.

demonstrated that observers' cortical arousal level, as inferred from repeatedly evoked potentials, declined simultaneously with signal detection performance in a visual vigilance task.

There appears to be little doubt of the importance that the reticular formation plays in cortical arousal and, therefore, in the maintenance of vigilance. Lindsley (1960) concluded his review of the literature by stating that:

> Wakefulness is maintained by excitation of the reticular formation and the ARAS through collaterals from all sensory pathways, by corticofugal impulses originating in various regions of the cortex and by humoral factors which affect particularly the rostral portions of the reticular formation. Increased activity in the ARAS through any of these sources of excitation acts upon the cortex by changing the pattern of its electrical activity from the slow waves and spindle bursts of sleep, or the alpha waves of relaxed wakefulness to a pattern of low voltage fast waves commonly referred to as activation. Electrocortical activation is accompanied by behavioral arousal and by alertness and attention.

If there are, as Lindsley suggests, three physiological processes which activate the reticular formation, one could infer that the activity of any or all of these declines over the course of watchstanding, thus decreasing cortical arousal and resulting in poorer performance.

One humoral factor which Lindsley considers is circulating adrenalin. Bonvallet, Dell, and Hiebel (1954) originally demonstrated that intravenous injections into animal preparations of minute amounts of adrenalin (e.g., 5 μg/kg) apparently have a stimulating effect upon the mesencephalic reticular formation that results in cortical arousal. Rothballer (1956) has confirmed this result by demonstrating that the adrenalin-sensitive area of the caudal mesencephalon is activated by local micro-injection, again causing cortical arousal. Finally, Cordeau et al. (1963) have described how unanesthetized cats were awakened from sleep by the

local central stimulating action of micro-injections of adrenalin, following which they behaved in a manner described as indicating "arousal" or "exploration."

Catecholamines, adrenalin and noradrenalin, are hormones differentially produced within individuals as a response to sympathetic nervous activity. Adrenalin is the chief constituent of catecholamines secreted by the adrenal medulla and is generally distributed throughout the body by circulation of the blood. Noradrenalin is principally released at the post-synaptic nerve endings of the sympathetic nervous system (von Euler, 1956).

The catecholamines were once thought to be released in the body only under conditions of physiological or psychological stress, and then to function as mobilizing or stimulating agents in the organism's adjustment to stress. However, von Euler (1961) has recently interpreted the literature to indicate that "the excretion of adrenalin in urine by man even during the night, although the amounts are minute, suggests a small but continuous secretion" (p. 575). And again, ". . . noradrenalin (and probably adrenalin also) can be regarded as always occurring in the blood" (p. 526).

It is believed, then, that endogenous adrenalin is usually present in the blood as a result of sympathetic nervous activity, and has the potentiality of evoking a central arousal response. It has also been shown that adrenalin (but not noradrenalin) is related to degree of alertness in man. Renton and Weil-Malherbe (1956) measured the difference in adrenalin and noradrenalin levels between samples taken from humans during sleep and ten minutes after awakening and found a significant 40 per cent increase of the level of adrenalin in plasma. These experimenters concluded that there exists ". . . a general correlation between the level of plasma adrenalin and the degree of mental activity." Furthermore, it has been shown that exogenous adrenalin increases alertness. Frankenhaeuser and Jarpe (1963) gave evidence that the human ability to perform a tedious computational ("concentration") task is significantly

enhanced by simultaneous infusion with adrenalin.

It still remains to be shown that the endogenous adrenalin level controls central arousal, vigilance and related behavior, though Dell (1958) concluded that such is indeed the case: "this heightened level of epinephrine [adrenalin] activates the reticular systems and produces an intensification of the vigilance, the consequence of which is exploratory behavior" (p. 377).

The purpose of the present investigation was to examine the relationship between catecholamines, adrenalin and noradrenalin, and the maintenance of an alert state. These experiments were undertaken to determine endogenous levels of adrenalin and noradrenalin in human peripheral plasma during the course of a vigilance task.*

GENERAL METHOD

The general method called for two experiments with each observer participating in both. A preliminary experiment was undertaken in order that the difficulty of detecting signals could be equated for each observer in the subsequent vigilance tasks and also to permit the classification of observers on the basis of their performance on a vigilance task. In the subsequent main experiment serial blood samples were drawn from each observer under either an experimental or a control condition.

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*Catecholamine estimations were made from plasma rather than urine since it has been shown by Axelrod (1959) that probably only a small proportion (less than five per cent) of the active hormones are eliminated in the urine as free amines. Furthermore, as Vogt (1960, p. 594) has pointed out, the estimation of urinary excretion of catecholamines does not reflect rapid changes in secretory activity. Together these facts appear to indicate that urinary analysis would be relatively insensitive to extremely small or rapid changes which may occur in the circulatory levels of the catecholamines during watchstanding. On the other hand, direct estimates of plasma adrenalin and noradrenalin from blood samples drawn serially over the course of the watch should indicate a trend in their levels if this does, in fact, exist.

The Laboratory

Two adjoining rooms served as a laboratory. One room contained the watchstanding booth while the other was the experimenter's station.

The dimensions of the watchstanding booth were 4' x 4' x 8' in height. Considerable sound insulation was achieved by acoustical tile on the walls and ceiling and carpet on the floor.

Depending upon the condition employed, the booth contained either the visual display used in the preliminary experiment and in the experimental condition or a rear projection screen used in the control condition. These were mounted in one corner four feet from the floor and four feet from the center of the observer's chair in the opposite corner of the booth.

The visual display consisted of a small black box having a 1-1/8" circular aperture. The aperture was covered with ground glass which could be illuminated from behind by a 50-watt projection lamp. The 8" x 10" rear projection screen was used in conjunction with a motion picture projector placed outside the booth.

The booth also contained a speaker, an intercom, a signal response button mounted in a hand-held 35mm film cassette, and an enclosed shelf-like arm rest designed to accommodate the observer's left forearm in the horizontal position. This last feature was accessible from the outside through a 1' x 3' hatch and to the inside through a cloth sleeve which came to the shoulder when the observer's arm was inserted. This arm rest was easily accessible to the experimenter through the hatch but, owing to the sleeve, the arm was not visible to the observer.

The booth was ventilated and the temperature within was maintained at 78°F. Ambient illumination was supplied by an overhead 15-watt bulb and a white noise broadcast over the speaker masked external sounds. Observers were allowed to smoke and a cup of water

was placed at their disposal when they were in the booth.

The Observers

Twenty-eight paid male laboratory assistants and college students between the ages of 21 and 34 volunteered to participate as observers (Os) in the experiment. All were task naive but all had experienced venipuncture prior to the experiment. Each was medically examined and judged physically fit to participate in the experiment.

The Experimental Task

The task, used in previous experiments (Baker and O'Hanlon, 1963), was to detect a change in the brightness of the circular aperture in the display. The brightness was continuously cycled from dim to brighter every three seconds. A dim "heater" brightness endured for two seconds while the greater "background" brightness endured for the remaining second. Occasionally a "signal" was generated at a still greater brightness during the one-second portion of the cycle. When this occurred it was the O's task to depress the response button and the response was recorded on a pen recorder at the experimenter's station.

THE PRELIMINARY EXPERIMENT

Method

In the preliminary experiment each O undertook both a psychophysical and a watchstanding test. The purpose of the psychophysical test was to determine, for each O, the brightness of a signal which elicited a response to 90 per cent of the signal presentations under alerted conditions. The method used involved presenting a series of seven trials, each being a three-minute sample of the experimental task. During each trial ten signals were given at variable intervals. Signal brightness varied between trials within a range that had elicited from 50 to 100 per cent detections from Os

in previous vigilance experiments. The signal brightness that generated a detection response in 90 per cent of the presentations by each O under these alerted conditions constituted the signal brightness for that O during the watchstanding test.

After a 15-minute rest period each O undertook the second part of the preliminary experiment, which was to perform the watchstanding test consisting of a main watch, and four-minute pre- and post-tests under alerted conditions. Within the main watch the signal frequency was 24 in the hour, 6 in each 15-minute interval. Intersignal intervals was chosen from a rectangular distribution, the shortest being nine seconds and the longest, five minutes.

The general procedure was to give an O an alerted pre-test during which 12 signals were presented. Following this the apparatus was turned off for a minute and then the light resumed flashing, signifying to the O that the main watch had begun. At the end of the main watch the apparatus was again turned off for one minute and then on again for a four-minute alerted post-test containing 12 more signals.

The results of the preliminary experiment were used to dichotomize Os on the basis of their detection performances in the watchstanding test. Each was classified either as a Decrementing Observer (D) if his performance in the main watch was significantly* poorer than that attained under alerted pre- and post-test conditions, or as a Non-Decrementing Observer (N) if his performances were statistically indistinguishable. Four Ns (or 14.3 per cent of all Os) were discovered in the preliminary experiment.

Results

Figure 1 shows the watchstanding performance of 16 Os in the preliminary experiment. It can be seen that the performances of the two groups of six and seven Ds, who later served under experimental

*$P < .01$ when tested by an adaptation of the binomial.

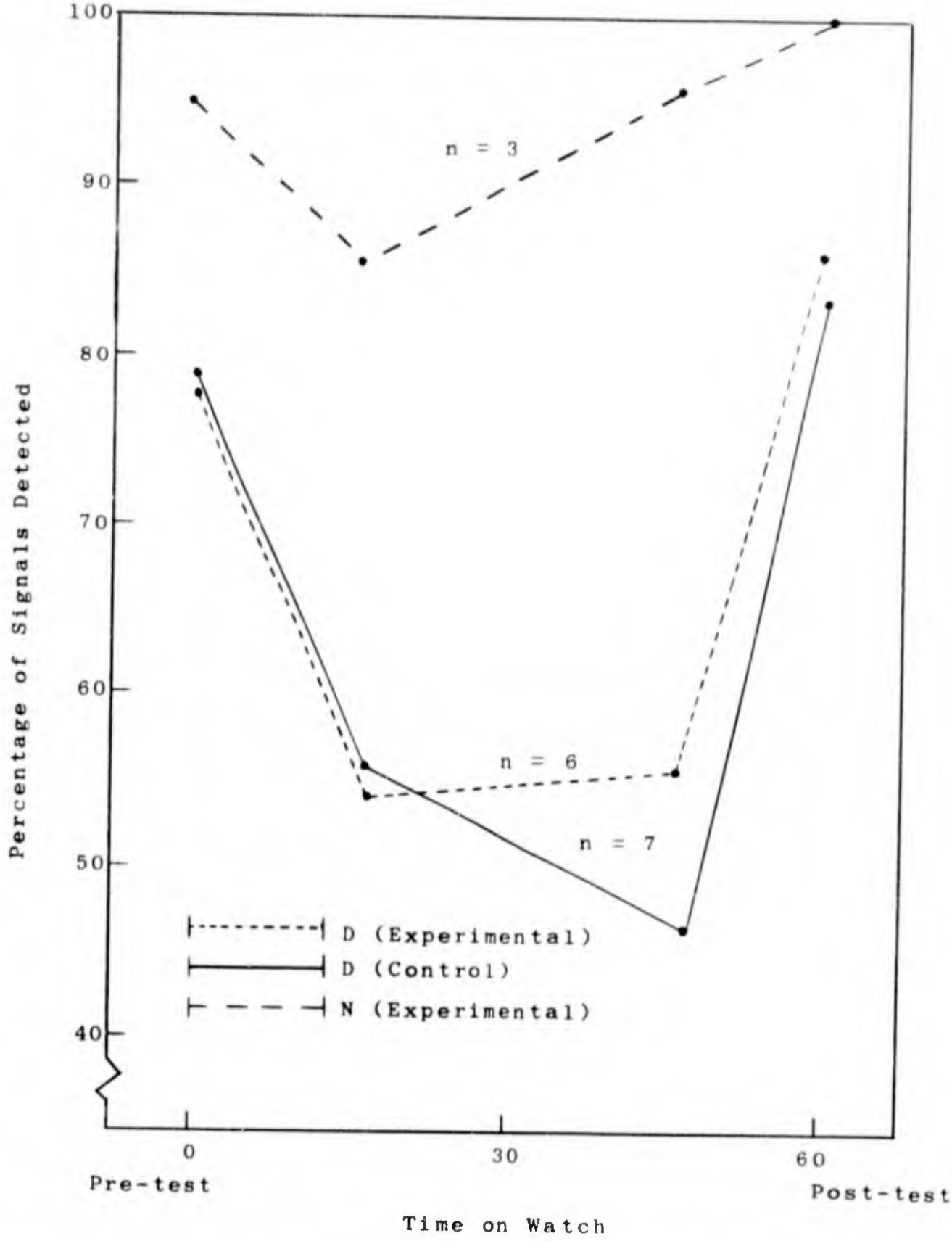

Figure 1. Showing the performances of three groups on the pre-test, main watch (in half-hour intervals) and post-test in the preliminary experiment.

and control conditions respectively in the main experiment, were very similar. Both groups sharply declined in performance from pre-test to the main watch and returned to a high level in the post-test. On the other hand, the three Ns* who later served as Os in the experimental condition showed little decrease in signal detection efficiency from pre-test to main watch and correspondingly little improvement in the post-test.

THE MAIN EXPERIMENT

Method

Six Os and three Ns were successfully tested in the experimental condition.* When seated in the booth the O inserted his left arm through the cloth sleeve and onto the enclosed arm compartment. Novocain (2 per cent solution) was then administered subdermally over an antecubital vein. Following this, venous congestion was achieved and a 2 1/2", 16-gauge plastic intravenous catheter** was introduced into the selected antecubital vein via a 19-gauge needle.

The catheter was joined to an 18" plastic extension tube with a 3mm lumen. This tube was taped to the O's arm, passed through a hole in the hatch and then taped again to the exterior of the booth. Finally, a plastic stopcock was fixed to the free end of the tube.

After insertion of the catheter the O was allowed to rest in the booth until such time as a series of pulse and blood pressure observations indicated that pre-established, normal, stable levels had been regained. This period lasted at least half an hour.

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*Considerable technical difficulty due to inadequate veins and clotting was encountered in achieving venipuncture and maintaining the free flow of blood from some Os in the main experiment. Consequently, adequate blood samples were not obtained from every O. There was no reason to suspect that this attrition tended to bias the results obtained from the remaining Os.

**Deseret Angio-Cath #1962.

Following the stabilizing period each O undertook a pre-test, three-hour main watch, and post-test of the types employed in the preliminary experiment. Blood samples (30cc each) were drawn through the catheter-tube-stopcock system during the pre- and post-tests and at half-hour intervals throughout the main watch beginning 15 minutes after the watch began. Blood which had been allowed to stand in the system between samples was discarded.

It was determined in a pilot study involving two Os, that the Os were not aware when samples were drawn, nor did any O experience localized pain from the catheter in situ. Some did report that their arms became uncomfortable as the result of movement being restricted and a few reported a dull, aching sensation from their left arms; but all these Os agreed that the sensations were transient and were not a major source of concern.

The Control Condition

Seven other Ds performed in the control condition. The control condition was similar to the experimental except that the visual display was removed and the rear projection screen was substituted. In this condition the Os viewed a connected series of 12, 15-minute silent motion picture features with topics including travel, westerns, sports, and comedy. To ensure that the Os would watch the films they were instructed to press the response button whenever a caption appeared. There were two breaks of approximately three minutes each during the otherwise continuous movies to allow for changing of film reels. During these periods the Os viewed a blank screen.

Blood samples were drawn both after 2 and 140 minutes had elapsed from the time the movie watch began. These sample times were analogous to the first and the last times at which a complete set of six samples was obtained from all the Ds participating in the experimental condition. During the interim between samples in the control condition, amounts of blood were drawn and discarded

that were equal in total volume to those drawn in the experimental condition during the same period.

For practical reasons (i.e., the cost of chemical analyses) fewer blood samples were obtained for analysis from the control group than from the experimental group. However, any progressive trend in the data should be revealed as a difference between terminal measurements. Therefore, knowledge of both differences shown by the experimental and control groups between these measures allows for comparison of the progressive effects of both conditions.

Chemical Procedures

Plasma concentrations of adrenalin and noradrenalin were estimated by the fluorometric method of Weil-Malherbe (1961).* In this method strongly fluorescent condensation products were formed from the respective catecholamines and ethylenediamine. The fluorescence of these compounds was read in a Turner Fluorometer (#110). The activating beam was set at 420 mμ and readings were taken at 510 and 580 mμ. The sets of filters used to isolate these spectral lines consisted of Turner Filters 405A and 65A and 2A plus 47B and 2A15, respectively.

Results

The Ds: Plasma catecholamines in the experimental condition.

Results from the estimation of plasma catecholamines in the sample drawn from the six Ds in the experimental condition are shown in

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*The complete specificity of this method has been challenged by several authors whose criticisms are summarized by von Euler (1961) and Vogt (1960). It should be understood, therefore, that estimations reported here are taken from the fluorescence of adrenalin-like and noradrenalin-like substances measured in the observers' plasma. In view of these criticisms it was deemed advisable to investigate the reliability and, indirectly, the validity of the chemical procedures. This was done and is reported in Appendix A.

Table 1.

Table 1

Estimations of Plasma Adrenalin and Noradrenalin from 6 Ds in the Experimental Condition*

Adrenalin (µg/L)

Time (Minutes)

OD	Pre-test	15	45	75	105	135	165	Post-test
TP	.9	<.1	<.1	.2	.5	.2	**	<.1
GB	1.5	.4	1.5	.4	<.1	<.1	<.1	**
HR	1.7	1.3	1.2	1.0	**	1.3	1.9	1.7
AO	1.8	2.7	.9	.9	1.5	1.6	<.1	**
FH	1.0	<.1	1.5	<.1	<.1	<.1	<.1	.7
LW	1.8	1.3	1.8	1.5	1.1	.9	1.3	1.4
Mean	1.45	.97	1.16	.68	.64	.68	.67	.96
σ	.36	.93	.55	.50	.58	.63	.77	.62

Noradrenalin (µg/L)

Time (Minutes)

OD	Pre-test	15	45	75	105	135	165	Post-test
TP	2.1	2.2	5.4	1.9	2.2	1.9	**	2.7
GB	1.7	.5	1.8	3.0	10.0	12.3	6.2	**
HR	2.2	7.4	8.7	11.5	**	1.0	2.0	3.5
AO	5.8	1.4	5.5	11.7	2.4	4.1	8.7	**
FH	3.0	5.8	1.7	5.2	5.2	4.0	4.5	3.0
LW	2.9	2.5	4.2	3.0	2.0	1.3	2.0	3.8
Mean	2.95	3.30	4.55	6.05	4.36	4.10	4.86	3.25
σ	1.35	2.47	2.40	3.68	3.66	3.86	2.40	.43

*For purposes of analysis it was assumed that the true adrenalin level in samples which yielded estimates of <.1 were evenly distributed between 0 - .1. Therefore, the mean of this distribution, or .05, represents the "best guess" for estimates of <1 and was substituted in the statistical analysis for each estimate of <.1.

**These samples were lost in the process of drawing or in the chemical analyses.

It can be seen in Table 1 that there was a drop in the mean adrenalin level and an increase in the variability of individual responses from the pre-test to the main watch. The average adrenalin level showed a downward trend which appeared to approach asymptote after about one hour of the main watch had elapsed. During the final two hours of the main watch, the Ds' mean adrenalin remained at a stable level that was less than 50 per cent of their average pre-test concentration. Finally, there was a suggestion in the data of a rise of adrenalin in these individuals during the post-test.

Noradrenalin, on the other hand, tended to increase in the Ds from pre-test to the main watch. The variability of individual noradrenalin responses also increased during the vigilance task. However, it must be noted that the increasing mean and variability of noradrenalin in the Ds were disproportionately influenced by strong, irregular responses from GB, HR, and AO, and might not be representative of all Ds. Finally, the average noradrenalin level in the post-test was lower than in the main watch and was approximately equal to that in the pre-test.

The declining trend of the Ds' adrenalin level during the pre-test and main watch and the simultaneous rising trend of their noradrenalin level were tested for significance with analyses of variance for components of trend.* The results of these analyses are summarized in Tabl 2.

Table 2 shows that the downward linear trend of the mean level of adrenalin in the Ds from the pre-test to, and subsequently during, the main watch was statistically significant beyond the .025 level. There were no significant trends found in the Ds' mean levels of noradrenalin over the same period.

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*The post-test data were omitted from all analyses due to their incompleteness--see Table 1.

Table 2

Analyses of Components of Trend of Mean Adrenalin and Noradrenalin from Successive Samples in the Pre-test and During the Main Watch

(Unweighted Means Adjustment)

Adrenalin (µg/L) Summary

Source (Trend)	df	MS	F	≥P
Linear	1	2 40	7 27	025
Quadratic	1	41	1 24	NS
Higher Order	4	14	42	NS
Error	28	33		

Noradrenalin (µg/L) Summary

Source (Trend)	df	MS	F	≥P
Linear	1	10 42	1 00	NS
Quadratic	1	9 59	92	NS
Higher Order	4	5 5	5	NS
Error	28	10 42		

As mentioned there was a suggestion from some Ds' data that their noradrenalin levels may have varied nonsystematically between sample times. This tendency would decrease the statistical reliability of repeated measurements relative to the average trend over time on watch. Analyses of variance were undertaken, therefore, to determine if there was evidence for significant reliability of repeated measures of adrenalin and noradrenalin from Ds in the vigilance task. These analyses were performed upon pre-test and the main watch data and are shown in Table 3.

Table 3 shows that while the inter-individual variability of adrenalin was significantly greater than the adjusted intra-individual variability, the same did not prove true of noradrenalin. According to McNemar (1959) these results can be interpreted to mean that repeated estimations of adrenalin were significantly

Table 3

Analyses of Variance to Determine the Reliability of Repeated Catecholamine Estimations in the Pre-test and the Main Watch

(Unweighted Means Adjustment)

Adrenalin (µg/L) Summary

Source	df	MS	F	≥p
Inter-individual	5	2.19	6.64	.001
Intra-individual (Adjusted for temporal effect)	28	.33		

Noradrenalin (µg/L) Summary

Source	df	MS	F	≥p
Inter-individual	5	12.24	1.17	NS
Intra-individual (Adjusted for temporal effect)	28	10.42		

reliable over time on watch relative to the groups' trend but that estimations of noradrenalin were not. In other words, individual Ds tended significantly to maintain their adrenalin (but not noradrenalin) levels in a consistent manner relative to those of the other Ds over time on watch.

The Ds: Plasma catecholamines in the control condition. Results from seven Ds in the control condition are shown in Table 4.

It is apparent from Table 4 that there was no detectable difference in the control Ds' mean adrenalin levels between samples drawn after 2 minutes and 140 minutes had elapsed from the beginning of the movie watch. Similarly, the difference between the mean noradrenalin levels for the same sample times was not found to be significant ($t = .16$).

Table 4

Estimates of Plasma Adrenalin and Noradrenalin from 7 Ds in the Control Condition

	Adrenalin (µg/L)		Noradrenalin (µg/L)	
	Time (Minutes)			
	2	140	2	140
DB_i	.3	.3	9.8	6.5
TO	.1	.1	10.4	13.7
HS	1.0	.9	2.1	1.7
DT	.9	1.3	3.9	4.4
CG	.9	1.0	2.3	2.9
JB	1.7	1.3	4.1	3.4
DB_o	$<.1$	$<.1$	1.5	2.5
Mean	.71	.71	4.87	5.01
SD	.55	.51	3.43	3.83

The Ds: Comparison of plasma catecholamines between control and experimental groups. The control data were compared with the results from the experimental condition in the following manner:

a. The control Ds' mean catecholamine levels in the two-minute sample were compared by *t* test to those levels obtained from the experimental Ds at the corresponding time, i.e., during the pre-test. The results are summarized in Table 5.

b. The control Ds' mean catecholamine levels in the 140-minute sample were compared by *t* test to those levels obtained from the experimental Ds at the corresponding time, i.e., after 135 minutes of the main watch. The results are summarized in Table 6.

c. The changes shown by the control Ds' catecholamine levels between the two sample times were compared by *t* test with the changes shown by the experimental Ds between the corresponding sample times. The results are summarized in Table 7.

Table 5

Comparison of Mean Levels of Adrenalin and Noradrenalin Between Control and Experimental Groups

(First Control Sample Time)

Adrenalin (µg/L) Summary

	M	SE	df	t	≥P
Control	.71	.28	11	2.64	.025
Experimental	1.45				

Noradrenalin (µg/L) Summary

	M	SE	df	t	≥P
Control	4.87	1.63	11	1.18	NS
Experimental	2.95				

Table 6

Comparison of Mean Levels of Adrenalin and Noradrenalin Between Control and Experimental Groups

(Second Control Sample Time)

Adrenalin (µg/L) Summary

	M	SE	df	t	≥P
Control	.71	.35	11	.86	NS
Experimental	.68				

Noradrenalin (µg/L) Summary

	M	SE	df	t	≥P
Control	5.01	2.34	11	.39	NS
Experimental	4.10				

Table 7

Comparison of Mean Changes of Adrenalin and Noradrenalin Between Control and Experimental Groups

Adrenalin (µg/L) Summary
(Group Change)

	M	SE	df	t	≥P
Control	0.00	.21	11	3.67	.001
Experimental	-.77				

Noradrenalin (µg/L) Summary
(Group Change)

	M	SE	df	t	≥P
Control	.14	1.76	11	.57	NS
Experimental	1.15				

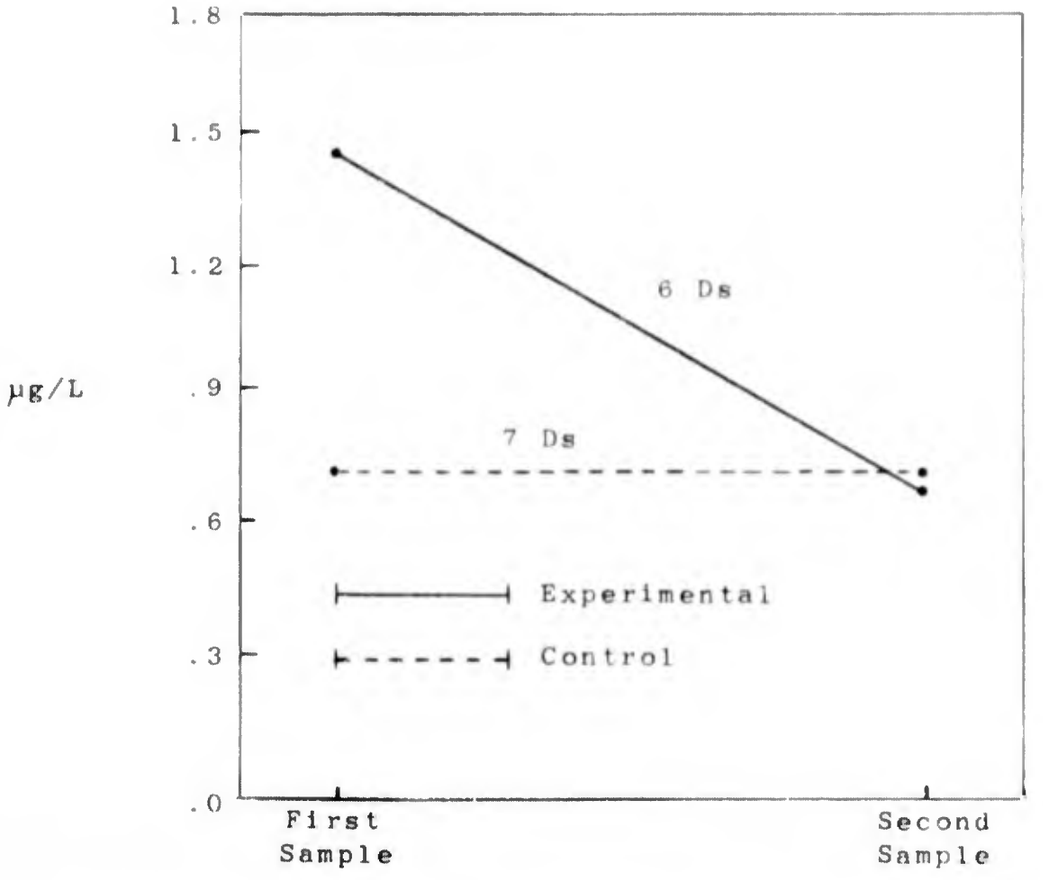

Figure 2. Showing mean levels of plasma adrenalin from experimental and control groups and in samples taken at analogous times during both conditions.

As an aid to interpretation of the preceding comparisons, Figure 2 was prepared showing the groups' mean adrenalin levels as a function of time on watch in control and experimental conditions.

The significant difference (α = .025) between the groups' first sample means is readily apparent from Figure 2. Indeed, the level of plasma adrenalin is approximately twice as high in Ds performing at the onset of the vigilance task than at the analogous time in Ds watching movies. At the second sample time, however, the difference between the adrenalin levels in the two groups was virtually abolished. The adrenalin drop experienced by the experimental group between sample times was found to be very significant (α = .001) relative to the change (or lack of it) which occurred in the control group over the same period.

There were no significant differences between or within the groups with respect to noradrenalin.

The Ds: Relationships between plasma catecholamines and performance on the vigilance task in the experimental condition. Figure 3 shows the mean adrenalin level and mean percentage signal detections as a function of time on watch for six Ds in the experimental condition. Figure 4 shows, in a similar manner, noradrenalin and performance.

It is clear from Figure 3 that the Ds justified their preclassification by showing a marked decrement in performance during the main experiment and that the mean decline in plasma adrenalin closely paralleled this performance. The coefficient of correlation between the Ds' mean adrenalin levels and mean performance from samples in the pre- and post-tests and from half-hour intervals during the main watch was determined to be $r = .84$. The relationship was found to be positive and significant ($t_6 = 3.82$) beyond the .01 level.

Mean plasma noradrenalin appeared to be inversely related to the Ds' mean performance on the vigilance task. This relationship is shown in Figure 4 and was found to yield a coefficient of correlation of $r = -.81$. This correlation was also found significant ($t_6 = 3.37$) beyond the .02 level.

The correlation between the Ds' means for the two catecholamines was $r = -.62$ and was not significant.

The Ns: Performance on the vigilance task. The Ns performed the task as expected, i.e., none showed evidence of a decrement in performance and all detected at least 94 per cent of the signals presented in the pre- and post-tests as well as each half-hour of the main watch. The mean percentage of signals detected during the course of the vigilance task by the three Ns is given in Table 8.

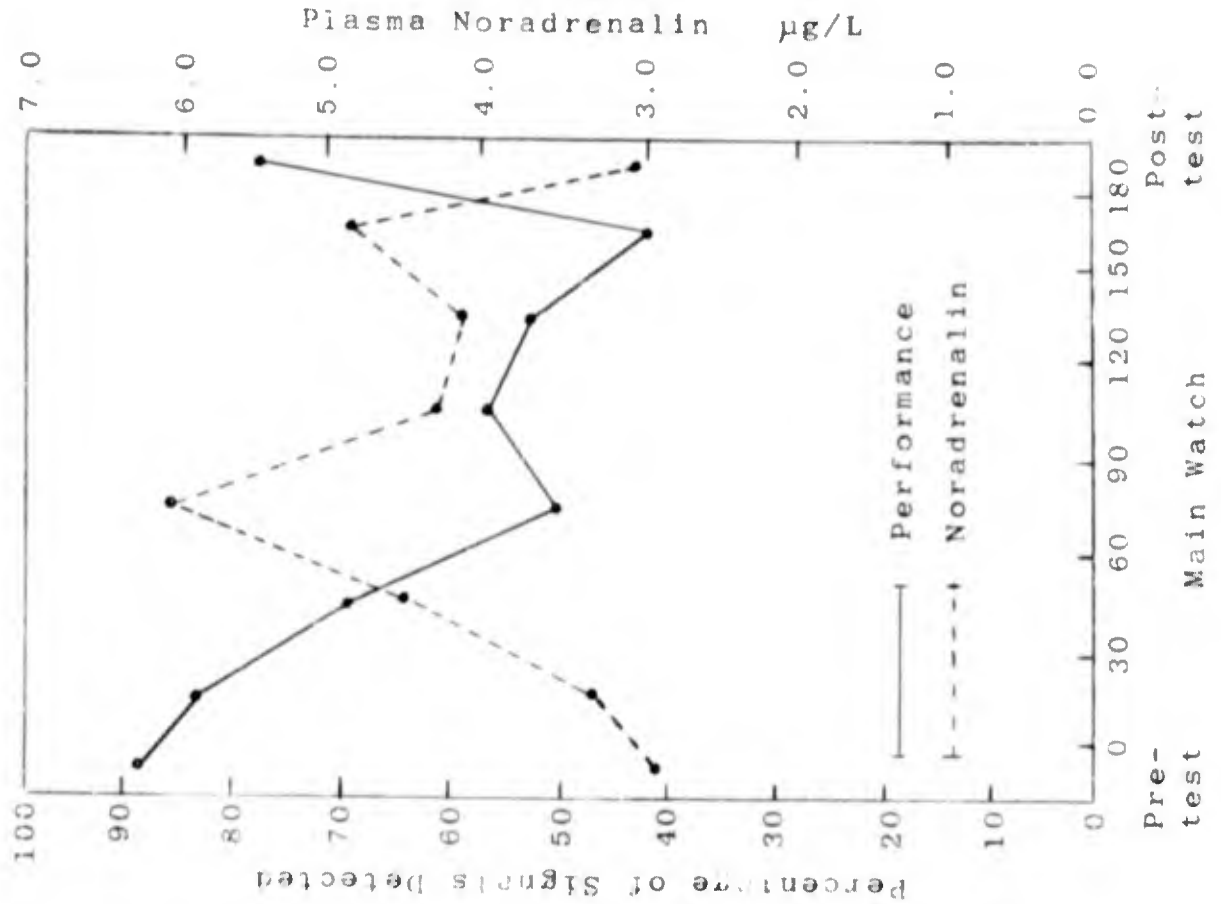

Figure 4. Showing the means for percentage of signals detected and plasma noradrenalin level as a function of time on watch for six Ds.

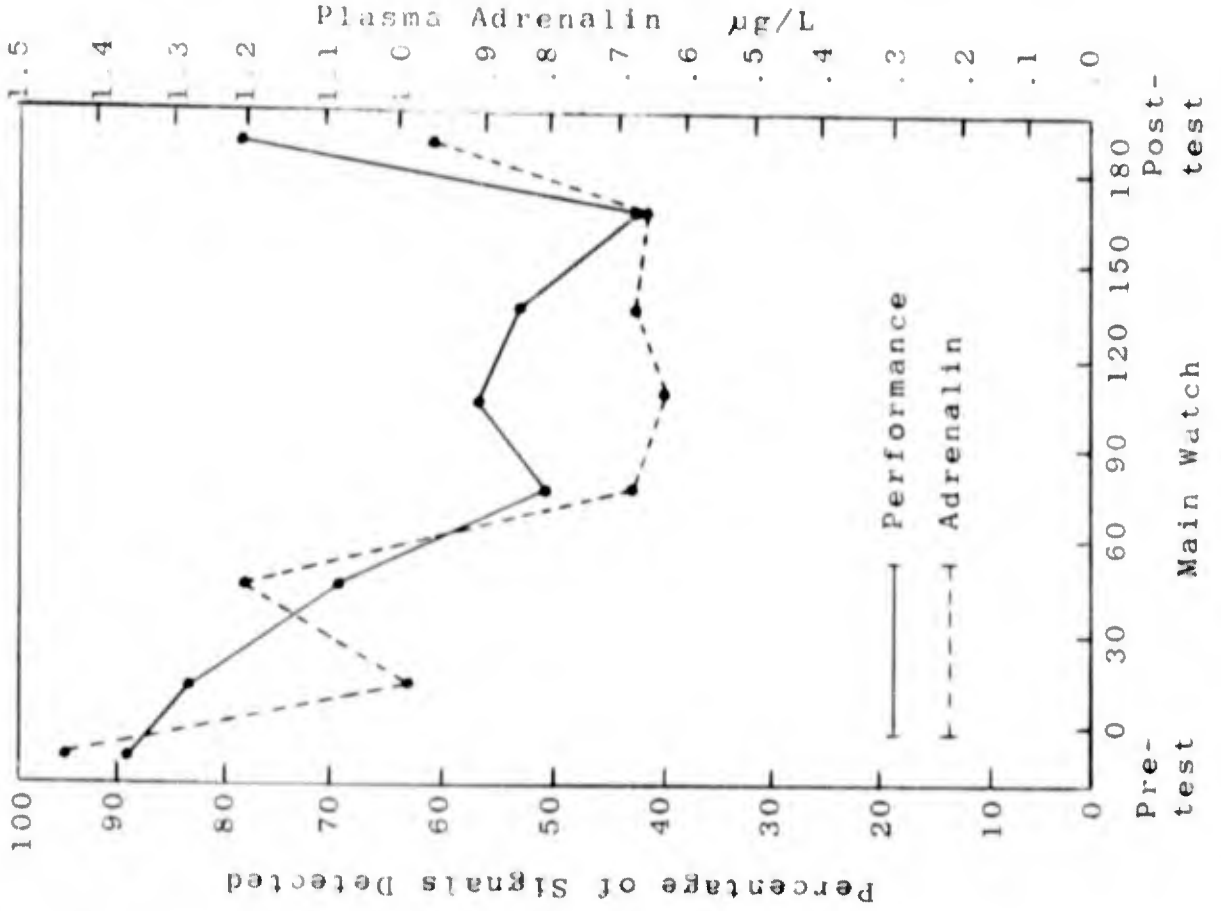

Figure 3. Showing the means for percentage of signals detected and plasma adrenalin level as a function of time on watch for six Ds.

Table 8

Mean Percentage of Signals Detected in the Pre-test, Post-test and During the Main Watch in Half-hour Intervals

	Pre-test	Main Watch (in half-hour intervals) 1	2	3	4	5	6	Post-test
% Signals Detected	97	97	94	97	97	100	97	100

The Ns: Plasma catecholamines in the experimental condition and comparison with the Ds. Results from the estimation of plasma catecholamines in samples drawn from Ns in the experimental condition are shown in Table 9.

Table 9

Estimations of Plasma Adrenalin and Noradrenalin from 3 Ns in the Experimental Condition

Adrenalin (µg/L)

	Pre-test	15	45	75	105	135	165	Post-test
DS	.6	1.0	.7	.6	.8	1.3	1.0	.6
JS	.1	.8	.7	.8	1.0	.9	<.1	**
JL	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Mean	.25	.62	.48	.48	.62	.75	.36	.22

Noradrenalin (µg/L)

	Pre-test	15	45	75	105	135	165	Post-test
DS	4.7	3.8	5.2	3.8	5.0	4.0	4.5	4.0
JS	5.6	3.5	5.0	3.5	10.6	8.1	4.3	**
JL	<.1	2.8	1.1	1.1	<.1	4.5	.3	<.1
Mean	3.45	3.37	3.77	2.80	5.23	5.53	3.03	2.02

**Lost as described.

It can be seen from Table 9 that there were both similarities and differences between the results from the Ns and those from the Ds in the experimental condition.

The Ns' noradrenalin responses during the vigilance task were very similar to the Ds'. The Ns showed a rise of the average noradrenalin level during the task and it can be seen that this average was again biased by extremely high measurements, this time from a single individual, J.S.

The Ns' adrenalin responses contrasted sharply with those of the Ds' In fac., the Ns possessed the lowest adrenalin levels recorded from within the pre-test. Two Ns gave evidence for a general increase in plasma adrenalin from pre-test to main watch while adrenalin in samples from the other N, J.L. never attained a level which could be measured by the chemical analysis. These results were again quite different from those shown by the experimental Ds, each of whom demonstrated a fall of adrenalin from the pre-test to the average main watch samples

DISCUSSION

The experiments described here have shown that the plasma adrenalin level generally declined within the Ds during the vigilance task. Each D evidenced a drop from pre-test to the average level of adrenalin measured during the main watch and the general decline was characteristic of every D. By contrast, the adrenalin level in the control Ds remained stable as was shown by measurements taken at the beginning of the movie watch (two minutes) and measurements made after 140 minutes of movie watching.

The experimental Ds' vigilance, as inferred from their signal detection performance, declined progressively from the pre-test to, and subsequently during, the main watch. After about an hour of the main watch had elapsed, performance stabilized at a relatively low level of detection efficiency. Performance abruptly returned to a high level of efficiency in the post-test. The Ds' average level of plasma adrenalin paralleled their average signal detection performance on the task. The correlation between the means for adrenalin and performance was substantial ($r = .84$)

There are two points of contrast in these results which bear discussion. First, the experimental Ds' initial level was twice that found in the controls'. Second, the fall of adrenalin experienced by the experimental Ds between the pre-test and the main watch (135 minutes) was not shown by the controls between analogous sample times in the movie watch.

With respect to the first, it is suggested that the experimental condition stimulated the physiologic production of adrenalin in the Ds to a greater extent than did the control condition. Perhaps the anticipation of a difficult vigilance task was stressful to the Ds and resulted in an increase of their adrenalin production. This suggestion is not without precedent. Frankenhaeuser et al. (1961) arrived at a similar conclusion after noting that their subjects' rates of noradrenalin and particularly adrenalin excretion were considerably increased while undergoing psychological tests. Likewise, Goodall and Berman (1960) believed that anticipation of centrifugation was the factor responsible for more than doubling their subjects' normal rate of adrenalin excretion. Whatever the cause, the heightened concentration of circulating adrenalin could serve an adaptive purpose of facilitating the Ds' abilities to concentrate on the monotonous vigilance task, as shown in the study by Frankenhaeuser and Jarpe (1963) mentioned earlier

Concerning the second point, it appeared as if the experimental Ds did not maintain the alert and anticipatory state responsible for their high initial level of adrenalin. Rather, their adrenalin level declined progressively during the task until it approximated the controls' level. This fall presumably reflected decreasing activity within the sympathetic control centers of the posterior hypothalamus and could have been brought about by a process of central habituation to the monotonous watchstanding situation. The controls, on the other hand, did not show a fall of adrenalin during the movie watch and it is assumed that habituation did not occur in this condition Whether or not these events were concomitant to the degree of arousal within the reticulo-cortical system is

unknown. A causal relationship has not been established but remains an intriguing possibility.

Similarly, any causal relationship between circulating adrenalin and performance on the vigilance task remains a matter for speculation. If the measurements were valid, if the peripheral adrenalin concentration is related to that within the reticular formation and if, as believed, endogenous adrenalin is a reticular stimulant, then the decline of the Ds' adrenalin level over time on watch could have been partially responsible for their vigilance decrement.

Due to the paucity of data obtained from the Ns, little can be stated about their adrenalin response to the vigilance task, other than to note that the Ns appeared to respond differently than did the Ds. In general, the Ns appeared to have lower initial (pre-test) levels of adrenalin. Whether or not this means that the Ns did not respond to anticipation of the task in the same manner as the Ds is unknown. The Ns did not show a general decline in adrenalin during the main watch. On the contrary, both Ns who yielded measurable quantities showed an increase of adrenalin from the pre-test to the average of samples from the main watch. However, it will be recalled that estimations from one N showed his production of adrenalin to be the slowest of all observers tested. It may be, therefore, that a high level of circulating adrenalin is conducive to but not necessary for the maintenance of good vigilance.

Noradrenalin production was shown to increase (though not significantly) within the Ds and Ns from the pre-test to, and during, the main watch in the experimental condition. This tendency was not shown by every observer. Some gave evidence of marked increases of their production of noradrenalin from one sample time to the next, but others maintained relatively stable levels throughout the task.

There were no significant differences found between the noradrenalin measurements from the experimental Ds and from the control Ds. It is difficult, therefore, to see how the observers' production of noradrenalin could have been affected by performing the vigilance task. On the other hand, it is possible that the stress of catheterization and/or those of isolation and restraint were responsible for the unusually high concentration of noradrenalin found in some individuals in every group. Furthermore, the effects of these stresses upon some observers' noradrenalin production may have been cumulative over time on watch, as indicated by the significant negative correlation ($r = -.81$) found between the experimental Ds' averages for noradrenalin and performance. However, in view of the variability encountered in measuring noradrenalin it is apparent that data must be obtained from a larger sample than employed here to determine if the effects which are suggested by these results do, in fact, exist.

MAIN CONCLUSION

It is concluded that the level of circulating plasma adrenalin declines in Ds during a conventional visual vigilance task in a manner positively related to their performance on the task.

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APPENDIX A

EVALUATION OF THE CHEMICAL METHOD

Six recovery studies were made in which .01 µg adrenalin and .03 µg noradrenalin were added to 10 ml. plasma. The simultaneous recoveries of adrenalin and noradrenalin were .0120 µg ±.0018 µg and .0297 µg ±.0071 µg (or 120% ±18% and 99% ±24%).

The absolute random measurement errors of the two catecholamines were judged tolerable for experimental purposes but should be borne in mind (particularly that for noradrenalin) when evaluating the experimental results. A positive constant error was indicated in the recoveries of adrenalin but this should not affect the relative inter- or intra-subject comparisons made in the experiment since all estimations would presumably be affected by this type of error to the same degree.