AMRL-TR-67-233

AD 668758

THE RELATIONSHIP BETWEEN STIMULUS-ORIENTED CHANGES IN HEART RATE AND DETECTION EFFICIENCY IN A VIGILANCE TASK

AUSTIN W. KIBLER, MAJOR, USAF

FEBRUARY 1968

DDC
RECEIVED
MAY 9 1968
C

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

73

NOTICES

Federal Government agencies and their contractors registered with Defense Documentation Center (DDC) should direct requests for copies of this report to:

DDC
Cameron Station
Alexandria, Virginia 22314

Non-DDC users may purchase copies of this report from:

Chief, Storage and Dissemination Section
Clearinghouse for Federal Scientific & Technical Information (CFSTI)
Sills Building
5285 Port Royal Road
Springfield, Virginia 22151

Organizations and individuals receiving reports via the Aerospace Medical Research Laboratories' automatic mailing lists should submit the addressograph plate stamp on the report envelope or refer to the code number when corresponding about change of address or cancellation.

Do not return this copy. Retain or destroy.

900 - April 1968 - CO455 - 31-664

UNCLASSIFIED

AD 668 758

THE RELATIONSHIP BETWEEN STIMULUS-ORIENTED CHANGES IN HEART RATE AND DETECTION EFFICIENCY IN A VIGILANCE TASK

Austin W. Kibler

Aerospace Medical Research Laboratories
Wright Patterson Air Force Base, Ohio

February 1968

AMRL-TR-67-233

THE RELATIONSHIP BETWEEN STIMULUS-ORIENTED CHANGES IN HEART RATE AND DETECTION EFFICIENCY IN A VIGILANCE TASK

AUSTIN W. KIBLER, MAJOR, USAF

FOREWORD

This study was accomplished as part of the research program of the Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The study was conducted under Project 7183, "Psychological Research on Human Performance," Task 718302, "Fundamental Parameters in Perception," with Dr. M. J. Warrick as the Project Scientist. The study was initiated in June 1965 and completed in June 1967. The report of this research was submitted by the author to the University of Michigan in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
Behavioral Sciences Laboratory
Aerospace Medical Research
Laboratories

ABSTRACT

This study was designed to assess the relationship between detection efficiency and beat-to-beat changes in heart rate around task stimuli in a vigilance task. Thirty-six subjects, instrumented for continuous recording of EKG and respiration, individually stood a 96-minute vigil. They monitored a light which flashed on (stimulus event) for 500 ms once every 6.0 seconds and were to report the occasional brighter flashes (signals). Half of the subjects (high signal density group) received 240 signals; the remaining eighteen subjects (low signal density group) received but sixteen signals. By urging the subjects to do their best, a motivational condition was induced in a six-minute post-test.

As expected, detection efficiency was higher and better sustained by the high signal density group. Detection efficiency of the low signal density group decayed appreciably over time. In the motivational post-test condition the performance of both groups improved significantly.

Measures of changes in heart rate, analyzed both in terms of overall shifts in heart rate over the vigil and beat-to-beat changes in heart rate around each stimulus event, revealed: (1) The median heart rate in succeeding quarters of the vigil, did not differ significantly with changes in detection efficiency. (2) Heart rate preceding a stimulus event decelerated. Changes in the magnitude of the stimulus-oriented cardiac deceleration showed a low but significant relationship to changes in the percentage of signals detected. (3) In the post-test the significant recovery in detection efficiency was accompanied by an increase in the magnitude of stimulus-oriented cardiac deceleration and by a decrease in overall heart rate.

TABLE OF CONTENTS

Page

CHAPTER

APPENDIX

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

BLANK PAGE

SECTION I

INTRODUCTION

The research to be presented in the following pages was designed to explore a possible physiological correlate of detection efficiency in a vigilance task. Specifically, using recent work by Lacey and Lacey (1964) and by Obrist (1963) as a point of departure, this study focuses on the relationship between beat-to-beat changes in heart rate and detection efficiency in a vigilance task.

The desirability of establishing correlates of alertness which can serve, independent of signal detection measures, as indices of alertness in vigilance tasks has been recognized for some time (Buckner and McGrath, 1963; Haider, Spong, and Lindsley, 1964; Jerison and Pickett, 1963; Travis and Kennedy, 1947). In long-term perspective such measures might eventually serve a most valuable purpose of monitoring observers in critical, real watch keeping tasks. More immediately, a valid physiological correlate of detection efficiency would provide a valuable tool to those interested in studying human attentive behavior. A physiological measure (or measures) which co-varies with detection efficiency would enhance the efficiency of vigilance research by providing a continuous indication of the temporal course of alertness, as opposed to the discrete and infrequent sample of attentive behavior presently afforded by signal detection measures. Furthermore, extending the data base of vigilance findings from the behavioral to the organismic level would be a step toward developing the broad set of relationships necessary to understand the dynamics of human alertness.

A data base extended to include physiological findings is particularly desirable in the vigilance area since a loosely applied arousal hypothesis based on physiological activation theory constitutes a leading theory of vigilance at the present time. The arousal theory of vigilance (suggested by Scott, 1957) stems from Hebb's (1955) concept of a dual function of stimuli: a cue function in controlling goal oriented behavior, and a general arousal function maintaining responsiveness or "readiness" on the part of the organism. Scott's review of performance deterioration in repetitive tasks (including vigilance tasks) led him to conclude that the uniformity of the stimulus environment which generally accompanies such tasks is the major contributor to the usual loss of efficiency noted. Scott suggested that the arousal or non-specific function of stimuli are lost with continued exposure to a relatively uniform stimulus environment through "sensory habituation".

There is a large body of behavioral and neurophysiological data which lends support to the arousal function of stimulation (e.g., Lindsley, 1957; Samuals, 1959), and an array of measurable changes in physiological variables have been depicted as indices of "level of arousal", changes in heart rate, blood pressure, EEG activity, and palmar conductance being among these. The current convention in activation theory holds that a shift from a resting state to a higher level of arousal will be accompanied by an increase in heart rate, blood pressure, and palmar conductance and a reduction or disappearance of the resting 8-12 CPS alpha activity. Physiological activation theory further holds that there is a continuum of behavioral arousal and an associated spectrum of physiological responses whose magnitude reflects the intensive dimension of behavior.

Lacey (1965), however, reviewed a large number of experimental results which are not in accord with a unidimensional concept of activation and argued convincingly that behavioral arousal, electrocortical arousal, and autonomic arousal are probably different forms of arousal and that these activation processes do not reflect just the intensive dimension of behavior but also the intended aim or goal of the behavior. Among the studies cited by Lacey, his own recent work (Lacey and Lacey, 1964) and that of Obrist (1963), demonstrating situational stereotypy in somatic response patterns, are particularly relevant here and constitute the point of departure for the experiment to be reported.

In a series of experiments, Lacey and his co-workers established that subjects required to attend to the external environment (e.g., to respond to a flash of light or an auditory stimulus) will show a rather pronounced deceleration in heart rate upon being cued to attend, whereas subjects performing internalized tasks (e.g., problem solving) tend to show a cardiac acceleration in conjunction with such activity. In experiments in which reaction time was used as an index of the subjects' readiness-to-respond, a pronounced beat-by-beat cardiac deceleration was noted beginning with the foreperiod cue, reaching a nadir at the onset of the stimulus, then recovering after the stimulus to the pre-foreperiod level. A low (-.27) but significant inverse correlation was established between the magnitude of the cardiac deceleration and reaction time--a relationship contrary to that predicted by activation theory.

In light of the extreme requirement in vigilance tasks for detailed attentiveness to the external environment, the potential of the cardiac deceleration measure as a possible correlate of detection efficiency is obvious. In a suitably structured vigilance task in which a subject must make periodic observations of a recurrent stimulus event, it follows from Lacey's work with reaction time measures that an attentive subject should show a beat-by-beat cardiac deceleration progressing from some time period in advance of the periodic stimulus. It also seems reasonable to expect that, as vigilance performance decays from an early state of efficiency (and to the extent that the decrement in performance is attributable to inattentiveness), the cardiac deceleration in advance of stimulus events for periods of relatively poor detection efficiency should tend to be smaller than those obtained early in the watch when detection efficiency is high.

To explore the possible relationship between stimulus-oriented cardiac deceleration and detection efficiency, a vigilance task similar to that used by Buckner, Harabedian, and McGrath (1960) was devised. Subjects were required to monitor a regularly recurring flash of light which appeared as a small circular lighted area on a frosted glass surface. Their task was to report detection of those occasional flashes of light which were brighter than the standard flashes. The interval between the onset of succeeding light flashes (stimulus events) was set at 6.0 seconds. This relatively long inter-stimulus interval permitted analysis of changes in beat-to-beat heart rate prior to, at, and subsequent to each stimulus event.

Since the principal concern in this study was to test for possible relationships between detection efficiency and changes in heart rate around stimulus events, it was deemed advisable to use a previously studied independent variable which would predictably produce differences in detection efficiency between two different levels of that variable. It was also desirable to select one level of that variable which would result in a decrement in performance over time. With this in mind, signal density (i.e., the probability of a signal given a stimulus event) was selected as the main independent variable[1] and an experimental procedure similar to that used by Mackworth (1948) was employed.

Two groups of twenty subjects each were used. One group of subjects (condition high) received 240 signals in a 96 minute vigil during which 960 stimulus events were presented (signal density 240/960 = .25). The second

---

[1] The effect of different levels of signal density (often referred to as signal frequency) on detection efficiency in vigilance tasks has been frequently studied with fairly consistent results (e.g., Deese and Ormond, 1953; Jenkins, 1958; Nicely and Miller, 1957). In general, detection efficiency is usually higher and better sustained over time in high signal density tasks than in low signal density tasks.

group of subjects (condition low) received but 16 signals in the same time period (signal density 16/960 = .016). Immediately upon conclusion of the 96 minute vigil for each subject, E called the subject on an interphone and urged the best possible performance in a final six minute post-test. In the post-test, consisting of 60 stimulus events, the subjects serving in the high signal density condition received 15 signals, those in the low signal density condition, one signal, thus maintaining through the post-test the same signal density as presented in the vigil.[1]

Within the framework of this experimental design it was specifically hypothesized that:

1. Detection efficiency in terms of the percentage of signals detected would be higher and better sustained over time for the high signal density group as opposed to the low signal density group. Such a result would be expected from previous research manipulating the same independent variable.
2. A recovery in detection efficiency would be obtained under the motivational condition characterizing the post-test. This would be in accord with results previously reported by Mackworth (1948).
3. The temporal course of heart rate around the stimulus events will show a deceleratory trend in advance of the stimulus events and a recovery (acceleratory trend) following presentation of the stimulus.
4. The relative magnitude of the stimulus-oriented cardiac deceleration effect (as in #3 above) should be positively related to detection efficiency.

---

[1] The signal schedules are presented in Appendices A and B.

SECTION II

APPARATUS AND PROCEDURE

APPARATUS

The flashing light which the subject was to observe appeared in the center of a 10 cm. by 6 cm. frosted glass screen centrally mounted on a 1 m. by 1 m. gray plywood panel. The light was 5 mm. in diameter and in its standard condition had an intensity of 11.5 ml. In the signal condition the light was of the same diameter but had an intensity of 18.6 ml. The spot of light was produced by energizing a three-volt incandescent bulb mounted behind the frosted glass window. A metal mask, interposed between the bulb and the frosted glass window, permitted only the circular spot of light to appear to the subject's view.

The duration of the light flash (500 ms.) and the regular interval between flashes was controlled by two Hunter interval timers. Parallel circuits from the Hunter timers simultaneously fed the signal and standard stimulus information to the recording equipment.

The recording equipment consisted of a Brush eight channel oscillograph with associated amplifiers and a Mnemotron seven channel analog data tape recorder. Five channels of information were recorded on the Brush oscillograph for visual reference and analysis. These consisted of continuous electrocardiogram (EKG), cardiotachometer output, respiration, stimulus event, and signal-response information. The EKG, stimulus, and signal-response channels were also simultaneously recorded on the analog data tape recorder for subsequent computer analysis. The respiration information was not recorded on magnetic tape since the apparatus at hand could not present respiration information in a manner suitable for convenient analog to digital conversion. Cardiotachometer information, recorded in graphic form for visual reference, was not duplicated on magnetic tape since the computer could more accurately derive this information directly from the recorded EKG.

PROCEDURE

Upon arrival at the experimental area, each subject was briefly advised of the general purpose of the experiment and of the importance to the experiment of doing his best. In the course of the general briefing, surface electrodes serving as EKG pickups and a respiration transducer (a mercury-filled tube) were applied to the subject. The subject was then moved into an 8' X 10' booth which served as the experimental area, seated in the chair in front of the display, and instructed to rest quietly for approximately three minutes while the recording apparatus was checked and calibrated. At the conclusion of this time period, the subject was read detailed instructions for his task (Appendix C).

The display circuitry was then activated and the subject was given a manual control switch with which he could introduce signals at his own volition. He was instructed to vary the display between the standard stimulus and signal condition and to carefully study the difference in appearance between the signal stimulus and standard stimulus. Following three minutes of practice, the control switch was taken from the subject. He was then told to rest quietly (but remain awake) while a six minute record of his resting EKG and respiration was taken. During the rest period, the subject's display was turned off but the stimulus programming equipment continued to operate feeding event information corresponding to the onset of each stimulus, to the recording equipment. This event information during the rest period, when in fact no stimuli were being presented to S, was necessary to permit direct comparisons on an identical time frame of cardiac activity during the "rest" and "monitor" portions of the experiment.

At the conclusion of the rest period, the subject was advised by interphone to monitor the display. Then, for a two minute time period, E presented signals to S and furnished S knowledge of results as to his accuracy in detecting the signals. After this brief practice period, the 96 minute vigil was begun. At the conclusion of the vigil, S was again called on the interphone, told that he had about six more minutes of monitoring (post-test) and was further advised that it was extremely important that he be as accurate as possible during that time period. Following the post-test, the subject's display was turned off and S was instructed to rest quietly for an additional five minutes while terminal resting records were made of EKG and respiration. Throughout the two rest periods, the vigil, and the post-test, continuous analog records were made of EKG, respiration, and stimulus events. During the vigil and post-test portions, signal and response information were recorded as well.

SUBJECTS

The subjects were male University of Dayton students serving as paid volunteers. Subjects were tested individually and served in either the high or low signal density group depending on their order of arrival for testing. Their ages ranged from 18 to 24 years.

DATA PROCESSING

The principal data analyses performed in this experiment were accomplished by digital computers from the real-time analog data recorded on magnetic tape. Analog to digital conversion was accomplished on the PDP-1 computer and the resulting digital information further reduced on the IBM 7094-II. In the analog to digital conversion, the following operations were accomplished:

1. The time interval between each succeeding R wave (R-R interval) was measured and translated into digital form.
2. Each R-R interval in which a stimulus event occurred (i.e., each R-R interval which bracketed the onset of a non-signal stimulus light) was identified by appropriate digital information.
3. Each R-R interval in which a signal event occurred (i.e., the brighter flashes of light to which the subject was to respond) was uniquely identified digitally and further digital information indicated whether the subject did or did not report detection of that signal.

4. Each R-R interval in which a false positive response occurred was also uniquely identified in digital form.

The digital operations performed on these data by the IBM 7094-II were basically as follows:

1. The duration of each R-R interval was converted into a rate value in beats-per-minute.
2. For each subject, the rate value for each R-R interval which bracketed the onset of a stimulus (or event mark) was identified. The median and first and third quartiles of the distribution of rate-at-stimulus-values (R_s) were obtained for the initial rest period, succeeding quarters of the vigil, the post-test, and final rest period. The same descriptive measures were independently obtained for each of the distributions of heart rate values immediately preceding and following R_s by one, two, and three rate values (R_{s-1}, R_{s-2}, R_{s-3} and R_{s+1}, R_{s+2}, R_{s+3}).
3. Although the information derived from step #2, above, served to describe the temporal course of stimulus-oriented heart rate, a unitary measure was required which would more definitively indicate the direction and magnitude of change in heart rate around each stimulus event. Pilot experimentation had revealed that the low point of the stimulus-oriented heart rate function occurred at R_{s+1} and that the R_{s-2} value did not overlap with any of the three post stimulus rates of the immediately preceding stimulus. Accordingly,

the magnitude and direction of the difference between each R_{s+1} value and the corresponding R_{s-2} value was used to quantify changes in stimulus-oriented heart rate. For every stimulus within each of the seven experimental segments, the R_{s+1} value was subtracted from the R_{s-2} value and the Wilcoxon matched-pairs signed-ranks test was performed on the resulting distributions of difference scores. This permitted statistical assessment of the significance of temporal shifts in heart rate from R_{s-2} to R_{s+1}. In addition, the median and first and third quartiles of the distribution of difference scores thus obtained were determined for each of the seven experimental segments and printed out for later reference in compiling the results across subjects.

4. Steps 2 and 3 above were also individually accomplished for detected signals, missed signals, stimulus events one subsequent to detected signals, and for all stimuli to which a false positive response was made.

5. In addition to the foregoing steps which were directed principally at isolating any stimulus-oriented temporal shift in heart rate around the periodic stimuli, overall median heart rate figures were obtained for each of the seven experimental segments for each subject.

6. An index of cardiac lability was calculated for each of the seven experimental segments for each subject. The lability index was calculated as follows: starting with the first recorded heart rate

value in the series of heart rate values for a given experimental segment, succeeding rate values were searched until a reversal in the direction of change in rate was noted. The rate value which defined the end of a trend (analgous to either a peak or trough in the cardiotachometer record) was retained and the search continued for the next reversal in the direction of change in rate values. Again, the rate value which defined the end of this trend was retained and the difference between the first value and the second was obtained and stored. Then the third such trend change value was obtained and subtracted from the second, the fourth obtained and subtracted from the third, etc. The resulting distribution of difference scores reflected the magnitude of acceleratory and deceleratory shifts in heart rate which occurred. The median of this distribution of difference scores yielded an index of cardiac lability for each experimental segment for each subject.

To minimize the possibility of movement and electrical noise artifacts contaminating the EKG data, the range of valid heart rates for each subject was obtained from the graphic EKG records where most artifacts are readily apparent. The valid high and low rates for each subject were used as gate values for the computer. Any heart rate values obtained in the machine processing which fell outside the gate values for a given subject were cast out as artifacts and not included in the computations.

The respiratory data were reduced manually from the oscillograph records by noting whether the respiratory phase was inspiratory or expiratory at the onset of each stimulus. The obtained respiratory data were useful only for determining respiratory phase and could not be used to derive reliable information as to inspiratory/expiratory magnitude. The respiratory transducer used in this experiment (a mercury-filled tube secured around the subject's chest) is very sensitive to movement artifacts which can (and did) produce transient shifts and changes in the base line as the subject moved or altered his sitting posture. These shifts in base line make interpretation of respiratory magnitude extremely difficult if not meaningless. Valid data on respiratory magnitude would probably require the wearing of a face mask instrumented to measure the volume of air inspired and expired. Such instrumentation, which would have added a physical discomfort factor to an already tedious task, was not deemed advisable.

SECTION III

RESULTS

The analog records of two subjects in each experimental group could not be processed because of a recording error. The gain on the EKG channel was apparently set too high when recording these subjects' data with the result that both the R and T waves of the EKG were identified as R waves by the analog to digital converter. Consequently, the data to be reviewed here are based on an N of 18 in each of the two groups.

VIGILANCE PERFORMANCE

The results in terms of the percentage of signals detected and the number of false responses for each subject in succeeding quarters of the vigil and the post-test are presented in Tables 1 through 4. Group performance in terms of the percentage of signals detected is presented graphically in Figure 1. It can be seen that the subjects performing in the high signal density condition showed only a slight decrease in detection efficiency over the 96 minute vigil. The percentage of signals detected by the group declined from a first half average of approximately 88% of the signals detected to a second half average of 84% detection efficiency. As expected, however, the group serving in the low signal density condition showed a substantial decline in detection efficiency. As a group, they

TABLE 1

PERCENT SIGNALS DETECTED, LOW SIGNAL DENSITY CONDITION

Subject #	Quarters of Vigil				
	1st	2nd	3rd	4th	Post test
L-1	100	75	50	75	100
L-2	75	75	100	100	100
L-3	100	100	50	100	100
L-4	100	100	75	75	100
L-5	75	50	25	100	100
L-6	75	50	50	75	100
L-7	75	75	75	100	100
L-8	75	25	0	25	100
L-9	100	75	50	75	0
L-10	50	0	0	25	100
L-11	100	100	100	75	100
L-12	75	50	50	50	100
L-13	50	50	25	50	100
L-14	100	100	75	75	100
L-15	100	75	75	25	0
L-16	50	25	50	75	100
L-17	75	50	25	50	100
L-18	100	100	100	100	100
Group Percentage	81.9	65.3	54.2	69.4	88

TABLE 2

PERCENT SIGNALS DETECTED, HIGH SIGNAL DENSITY CONDITION

Subject #	Quarters of Vigil 1st	2nd	3rd	4th	Post test
H-1	83.3	78.3	85.0	71.6	86.6
H-2	91.6	96.6	85.0	86.6	93.3
H-3	98.3	100.0	100.0	98.3	93.3
H-4	86.6	88.3	80.0	81.6	80.0
H-5	91.6	95.0	88.3	93.3	93.3
H-6	65.0	85.0	73.3	75.0	53.3
H-7	96.6	85.0	86.6	83.3	100.0
H-8	95.0	96.6	81.6	86.6	93.3
H-9	98.3	95.0	93.3	93.3	100.0
H-10	90.0	83.3	90.0	78.3	93.3
H-11	96.6	96.6	96.6	93.3	100.0
H-12	91.6	90.0	96.6	96.6	86.6
H-13	93.3	95.0	95.0	93.3	100.0
H-14	81.6	75.0	70.0	55.0	100.0
H-15	91.6	86.6	73.3	75.0	80.0
H-16	50.0	68.3	46.6	91.6	100.0
H-17	85.0	85.0	71.6	73.3	93.3
H-18	98.3	95.0	98.3	93.6	100.0
Group Percentage	88.0	88.6	84.0	84.4	91.5

TABLE 3

FALSE RESPONSES, LOW SIGNAL DENSITY CONDITION

Subject #	Quarters of Vigil				
	1st	2nd	3rd	4th	Post-test
L-1	22	0	0	0	0
L-2	3	2	0	0	0
L-3	26	7	7	8	4
L-4	5	0	0	2	2
L-5	2	0	3	3	1
L-6	4	5	2	7	0
L-7	5	6	6	9	8
L-8	3	0	1	2	3
L-9	0	0	1	2	0
L-10	1	0	0	0	0
L-11	57	21	12	11	5
L-12	5	3	2	7	4
L-13	1	2	3	1	1
L-14	8	1	1	0	2
L-15	9	5	8	6	3
L-16	2	8	10	15	4
L-17	7	0	0	1	6
L-18	12	16	25	22	8
$\bar{X}$ False Responses	9.5	4.2	4.5	5.3	2.8

TABLE 4

FALSE RESPONSES, HIGH SIGNAL DENSITY CONDITION

Subject #	Quarters of Vigil				
	1st	2nd	3rd	4th	Post-test
H-1	3	5	1	5	1
H-2	44	43	29	31	14
H-3	5	8	5	5	6
H-4	4	8	4	5	0
H-5	4	2	7	7	1
H-6	6	5	4	2	1
H-7	16	11	7	13	8
H-8	10	3	5	14	9
H-9	4	2	4	1	0
H-10	15	4	5	5	1
H-11	31	20	25	30	2
H-12	7	12	13	3	8
H-13	4	8	2	2	0
H-14	4	6	2	3	2
H-15	8	4	2	0	0
H-16	8	2	1	6	2
H-17	4	3	1	0	1
H-18	7	7	10	8	1
$\bar{X}$ False Responses	10.2	9.5	7.0	7.7	3.2

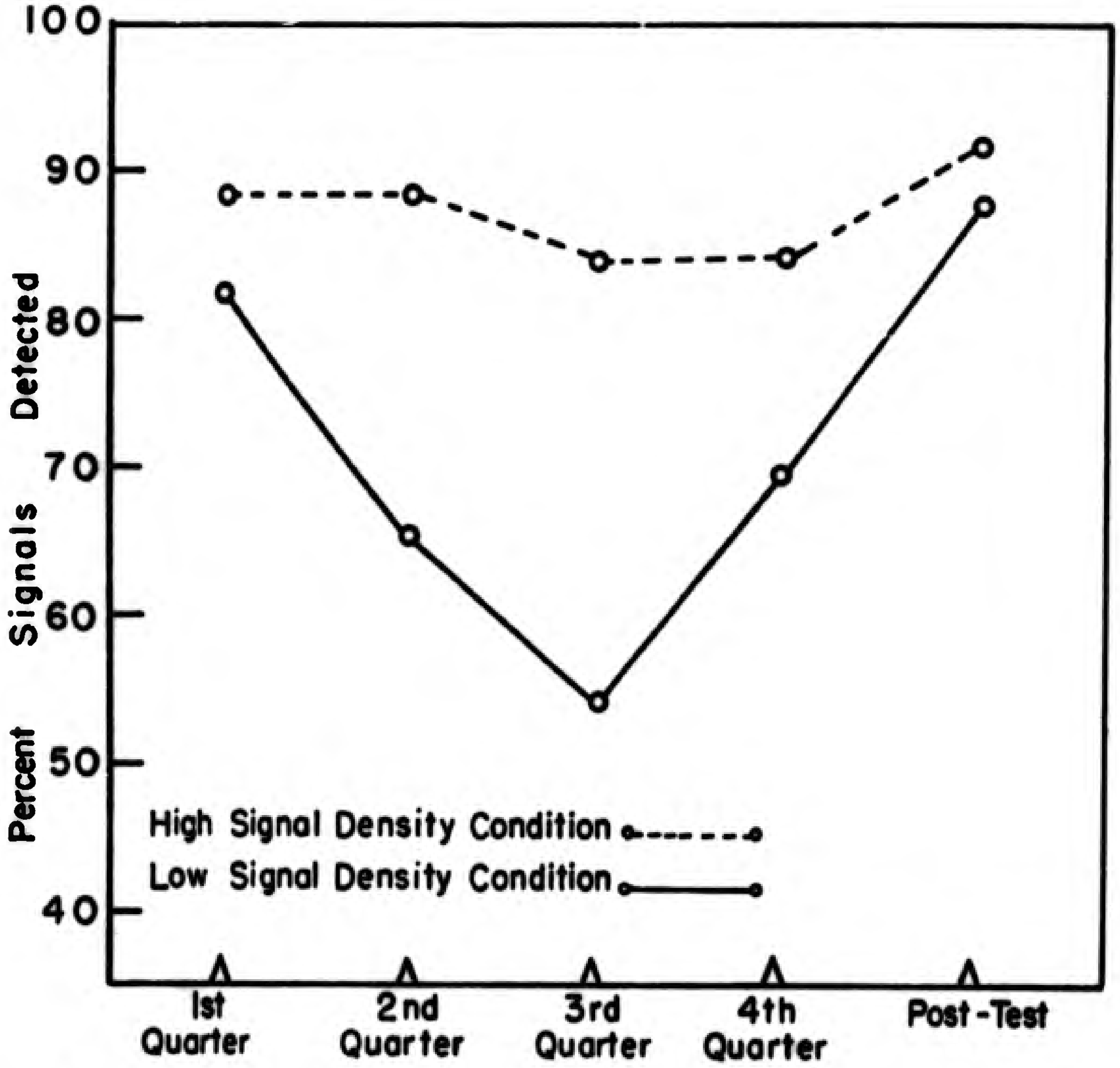

Figure 1. Percentage of signals detected by the high and low signal density groups in succeeding quarters of the vigil and the post-test.

detected 82% of the signals in the first quarter of the watch, 65% of the signals in the second quarter, 54% in the third quarter, followed by a partial recovery in the fourth quarter to 69% of the signals detected. In both groups, a full recovery in performance was obtained in the post-test following instructions urging the best possible performance.

In the low signal density condition, the shift in detection efficiency from the first quarter of the vigil, wherein 82% of the signals were detected, to the third quarter level of 54% is significant ($p = .048$) as tested by the Sign test. The same test applied over the equivalent points in condition high was not significant ($p = .119$). The difference in detection efficiency between the two groups in third quarter performance was also significant ($p < .01$ by the Median test). These results are in accord with previous research manipulating the same independent variables (signal density and motivation) and are of little direct interest except as a vehicle in this study for the assessment of the relationship between stimulus-oriented changes in heart rate and detection efficiency.

To derive indices of vigilance performance which incorporate false response as well as detection rates, the measure d' and β as employed in the theory of signal detectability (Swets, 1964) were computed from the false response and signal detection data of each group. The results of this analysis are shown in Figure 2. As can be seen, the two groups differ principally in terms of β . Substantially higher β values were obtained throughout the vigil by the low signal density group. Furthermore, it is

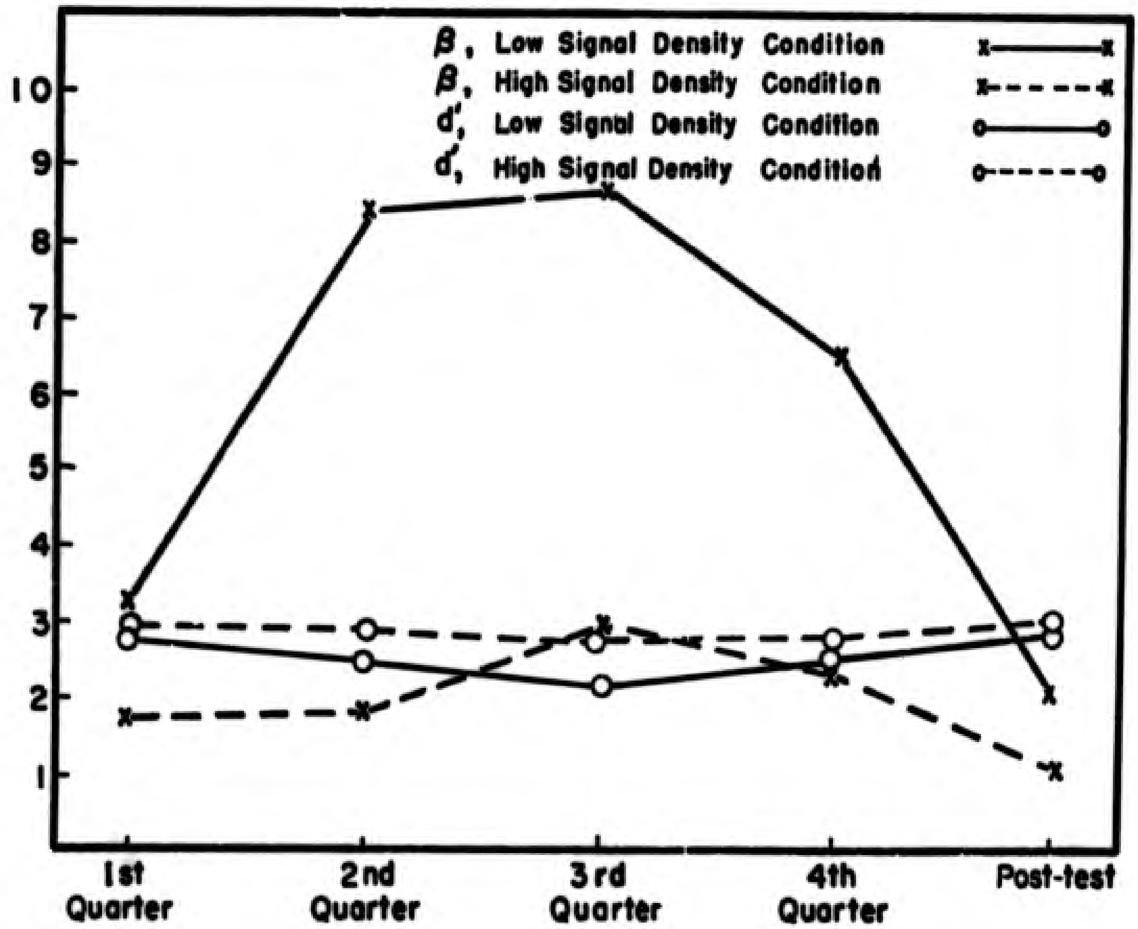

Figure 2. Values of d' and β over the vigil and post-test.

apparent that the shifts in performance which occurred over time in the low signal density condition are reflected largely by changes in β .

The relative constancy of d' and the fluctuations in β suggest that the obtained performance changes were not due to changes in sensory characteristics but rather to changes in one or more possible components of the β measure. In keeping with the position of Jerison, Pickett, and Stenson (1964), increases in β are interpreted as reflecting increases in "non-alert" observing.

RESTING CARDIAC ACTIVITY

Cardiac data obtained in the initial rest period were analyzed in terms of overall median heart rate, and in terms of the magnitude of cardiac lability manifested by each subject. These data for the initial rest period are presented in Table 5. As tested by the Median test, the small difference evident between the high and low signal density groups in median lability and median heart rate are not statistically significant. It can then be assumed that the samples comprising the two groups do not constitute a source of experimental bias.

STIMULUS-ORIENTED CHANGES IN HEART RATE

Figure 3 shows the average of the median heart rate values obtained for the subjects in the low signal density condition at the onset of the stimulus events (R_s) and at one, two, and three rate values preceding and subsequent to the stimuli. Similar values for the high signal density condition are shown in Figure 4. It can be seen that in the initial rest and terminal rest

TABLE 5

MEDIAN HEART RATE AND CARDIAC LABILITY OBTAINED IN THE INITIAL REST PERIOD

Subject #	Lability		Rate	
	Cond. High	Cond. Low	Cond. High	Cond. Low
1	5.8	8.2	70.8	62.1
2	3.2	10.5	92.7	72.5
3	5.5	8.8	80.3	90.3
4	8.2	12.2	58.0	88.2
5	6.1	4.6	60.4	79.5
6	7.1	4.4	69.9	66.5
7	5.3	4.5	82.1	77.6
8	14.8	4.7	68.3	63.4
9	3.5	3.8	46.4	70.4
10	11.8	5.1	64.2	66.2
11	6.6	15.8	69.4	58.3
12	13.8	4.6	67.7	102.2
13	3.9	7.3	82.9	61.1
14	5.3	5.1	55.4	61.3
15	4.0	6.1	69.8	92.3
16	14.2	8.4	79.7	61.1
17	3.6	3.7	66.2	87.0
18	5.5	5.4	57.9	66.8
Mean	7.1	6.8	69.0	73.7
Median	5.7	5.3	68.8	67.6
SIQR	3.0	2.0	10.1	12.9

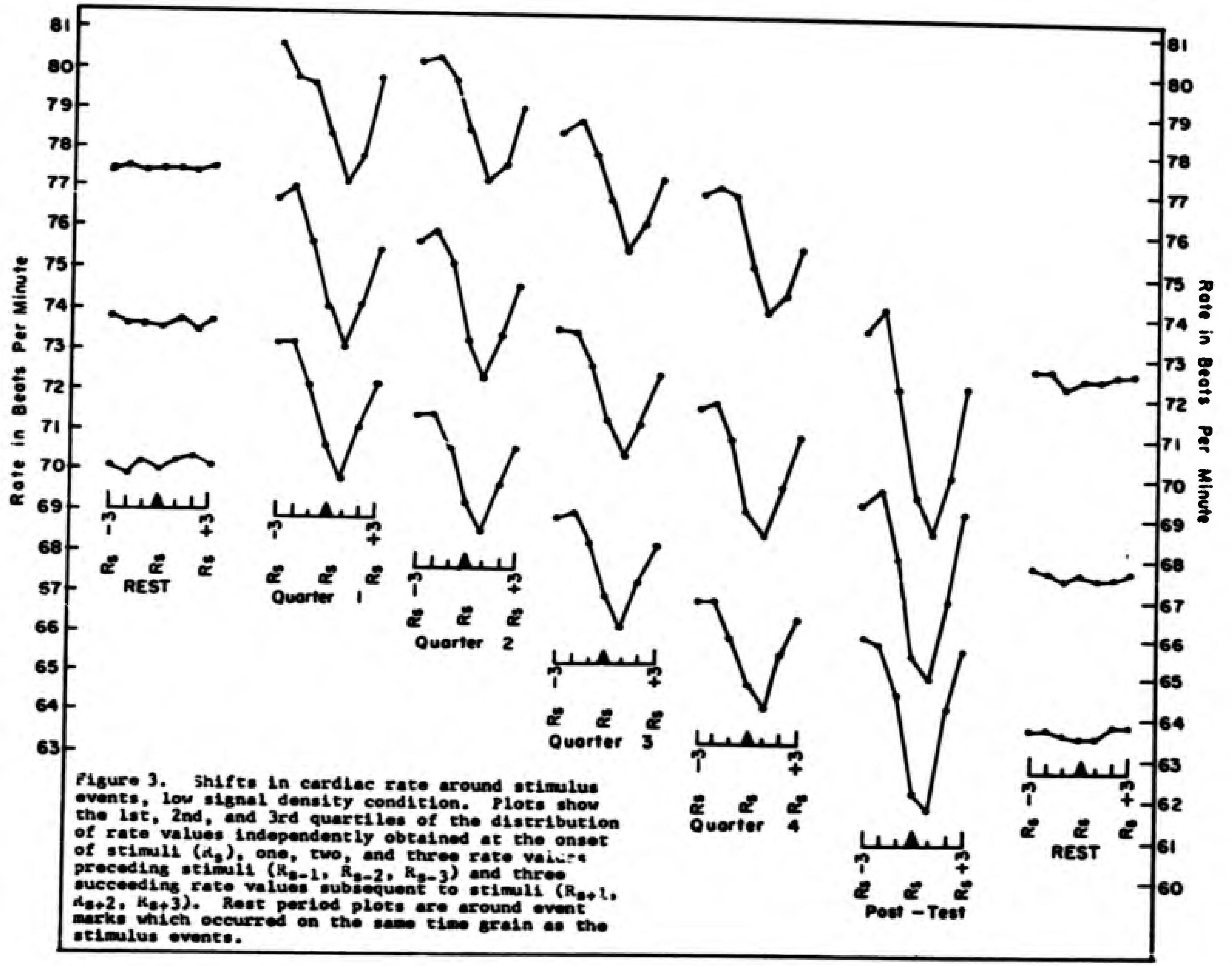

Figure 3. Shifts in cardiac rate around stimulus events, low signal density condition. Plots show the 1st, 2nd, and 3rd quartiles of the distribution of rate values independently obtained at the onset of stimuli (R_s), one, two, and three rate values preceding stimuli (R_{s-1}, R_{s-2}, R_{s-3}) and three succeeding rate values subsequent to stimuli (R_{s+1}, R_{s+2}, R_{s+3}). Rest period plots are around event marks which occurred on the same time grain as the stimulus events.

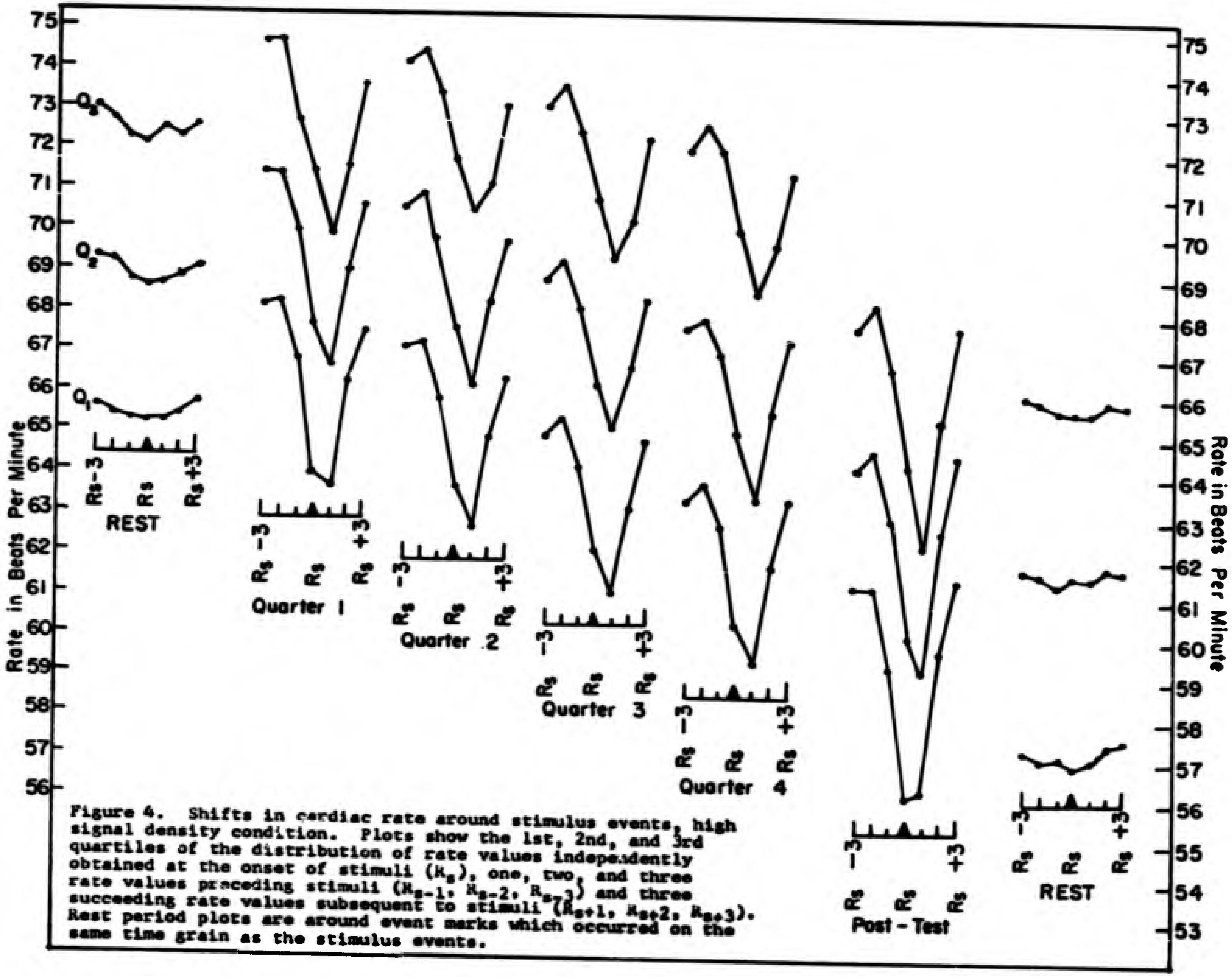

Figure 4. Shifts in cardiac rate around stimulus events, high signal density condition. Plots show the 1st, 2nd, and 3rd quartiles of the distribution of rate values independently obtained at the onset of stimuli (R_s), one, two, and three rate values preceding stimuli (R_{s-1}, R_{s-2}, R_{s-3}) and three succeeding rate values subsequent to stimuli (R_{s+1}, R_{s+2}, R_{s+3}). Rest period plots are around event marks which occurred on the same time grain as the stimulus events.

portions, the heart rate recorded around the event marks showed little or no temporal shift. It will be recalled that during these rest periods, the subject was in position in the experimental setting, but his display was not energized and he had no repetitive observations to make. When the subject's display was activated and he was instructed to observe the display to detect the brighter flashes of light, a slowing of heart rate in advance of the repetitive stimuli was noted. This cardiac deceleration in advance of the stimulus and the beat-by-beat recovery in heart rate after the stimulus, is evident in the plots in Figures 3 and 4 for each of the four quarters of the vigil.[1] In the post-test which immediately followed the instructions urging the best possible performance, the magnitude of the cardiac deceleration in advance of stimulus events is even more pronounced.

The absence of a beat-by-beat change in heart rate around the event marks during resting periods, and the noted beat-by-beat slowing and recovery of heart rate around the stimulus events during the vigil are not fragile artifacts of data grouped over subjects. As can be seen in Tables 6 and 7, a deceleratory trend in heart rate was universally apparent for all subjects in all portions of the monitoring session, low signal density condition and for 17 of the 18 subjects in the high signal density condition.

---

[1] It will be noted that in all cases the nadir of the deceleratory function occurred at R_{s+1}. This does not necessarily mean that the nadir was reached after stimulation. The R_s point was defined as the R-R interval which bracketed the onset of the stimulus. Since the stimulus was 500 ms. in duration, either R_s or R_{s+1} could be concurrent with a portion of the stimulus presentation time period.

TABLE 6

MEDIAN MAGNITUDE CARDIAC DECELERATION ($R_{s-2} - R_{s+1}$), CONDITION LOW

Subject #	Quarters of Vigil				
	1st	2nd	3rd	4th	Post test
L-1	3.008	3.466	1.472	2.894	5.930
L-2	3.111	3.103	3.301	3.864	5.098
L-3	7.983	7.254	6.070	4.043	7.006
L-4	3.752	2.227	2.306	2.613	2.775
L-5	2.084	2.171	1.557	2.010	1.854
L-6	3.240	2.681	3.079	3.705	4.894
L-7	2.575	2.152	2.276	1.728	2.406
L-8	0.965	0.889	0.943	1.414	2.354
L-9	2.533	2.029	1.025	1.714	3.844
L-10	7.464	2.764	3.293	4.612	9.963
L-11	2.466	1.885	1.352	0.558	3.090
L-12	0.266	0.541	0.460	0.492	0.094
L-13	1.224	1.152	1.676	1.438	1.644
L-14	4.182	3.384	2.142	1.436	5.044
L-15	2.609	1.578	1.414	1.330	1.130
L-16	3.190	1.897	3.520	5.024	1.875
L-17	2.748	0.989	2.289	2.304	5.831
L-18	2.753	2.137	2.307	1.741	2.862
Mean	3.12	2.34	2.23	2.35	3.76
Median	2.75	2.14	2.20	1.87	2.98
SIQR	.38	.59	.83	1.13	1.61

TABLE 7

MEDIAN MAGNITUDE CARDIAC DECELERATION ($R_{s-2} - R_{s+1}$), CONDITION HIGH

Subject #	Quarters of Vigil				
	1st	2nd	3rd	4th	Post test
H-1	2.885	3.440	3.204	5.091	6.257
H-2	1.157	0.848	0.590	0.535	0.418
H-3	3.463	3.571	4.027	4.648	3.978
H-4	6.307	5.990	3.051	4.157	6.008
H-5	2.717	3.305	3.269	3.944	2.448
H-6	4.891	3.942	3.653	3.399	5.684
H-7	0.000	0.700	0.000	0.603	1.600
H-8	12.916	9.991	10.350	11.721	15.784
H-9	1.557	1.828	0.243	0.244	0.000
H-10	8.216	7.432	7.818	6.530	4.767
H-11	2.671	4.097	3.001	3.882	4.582
H-12	5.892	4.829	5.289	3.771	4.258
H-13	5.495	4.158	4.193	3.154	9.670
H-14	1.589	2.135	1.926	1.671	2.041
H-15	3.332	3.193	3.386	4.242	5.833
H-16	0.886	1.993	1.864	2.308	2.490
H-17	2.658	1.587	1.361	1.322	2.112
H-18	5.986	6.164	7.115	6.407	9.633
Mean	4.03	3.85	3.71	3.70	4.87
Median	3.10	3.50	3.23	3.82	4.42
SIQR	2.15	1.92	1.13	1.49	1.95

Furthermore, the deceleration in heart rate was statistically significant ($p < .01$) in 87 of the 90 data points (18 Ss X 5 monitor segments per S) in the high signal density condition, and in 85 out of 90 data points in the low signal density condition. In the initial and end rest periods, only one subject of the 36 total subjects (72 data points) showed a significant change in heart rate around the event mark--and this significant change was in an acceleratory direction.

It is thus a reasonably firm conclusion that in a monitoring task of this nature wherein regularly repeated observations of a stimulus are required of Ss, the Ss show, as a statistical rule, a slowing of heart rate as the time of stimulus presentation approaches followed by a recovery in heart rate after the stimulus. Subjects in the same posture and experimental setting except for the absence of regularly recurring stimuli to be observed show no systematic stimulus-oriented change in heart rate even though their heart rate is sampled on the same time grain as used when stimuli are presented and S is required to observe.

RELATIONSHIP OF CARDIAC DECELERATION TO DETECTION EFFICIENCY

In Figure 5, the detection efficiency curves for the two groups of subjects are reproduced along with the functions depicting the mean of the 18 median cardiac deceleration values obtained over corresponding time periods for each group of subjects. For the group performing under the low signal density condition, the significant decay in detection efficiency from

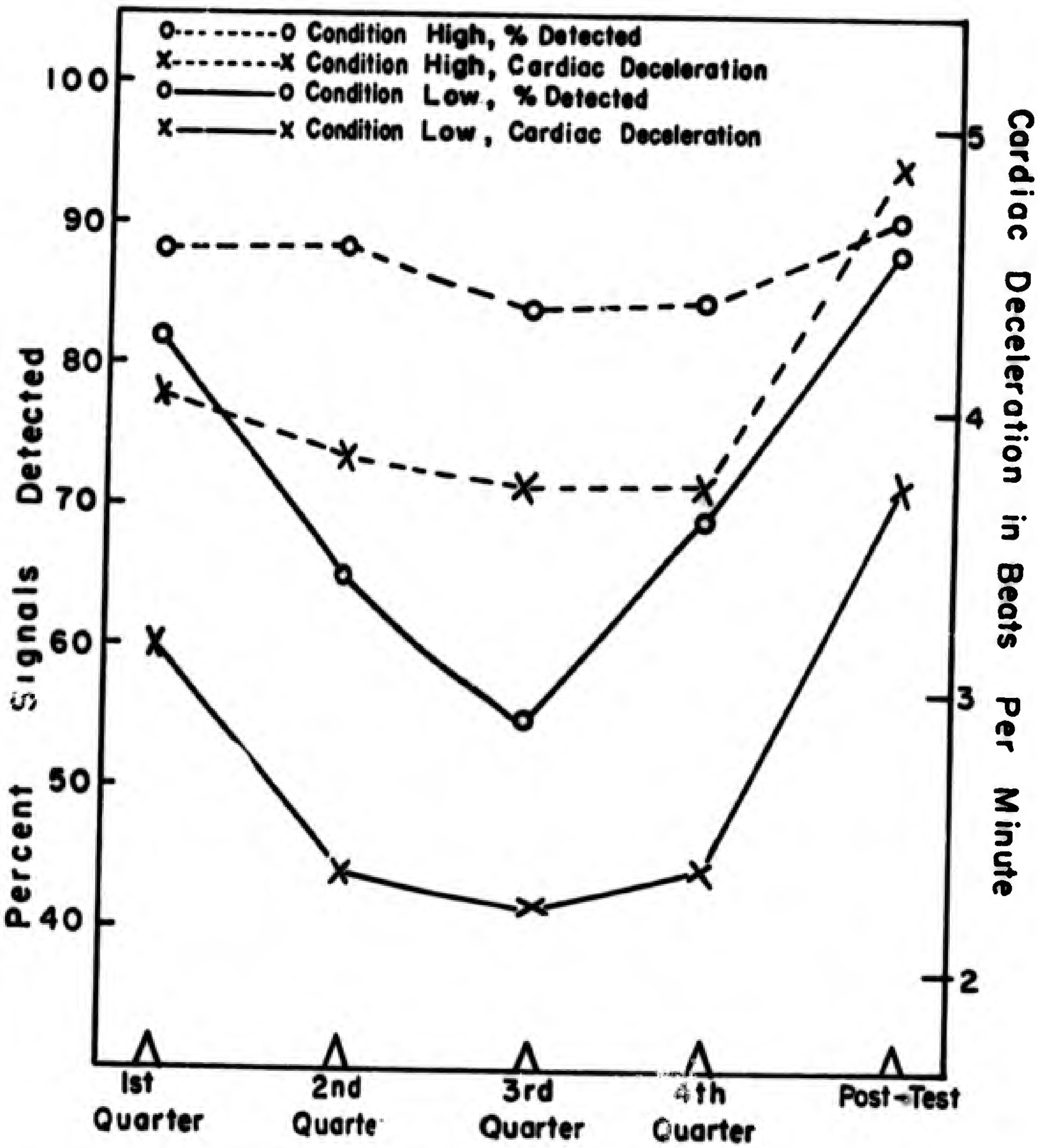

Figure 5. Percentage of signals detected and the mean of median cardiac deceleration values ($R_{s-2} - R_{s+1}$) for the high and low signal density conditions in succeeding quarters of the vigil and the post-test. The percentage of signals detected is plotted against the left ordinate, the mean of median cardiac deceleration values against the right ordinate.

the first to the third quarter of the vigil was accompanied by a significant decrease ($p < .01$) in the median cardiac deceleration values as tested by the Ranked-sums signed-ranks test. The difference between the two groups in the third quarter of the vigil in terms of the obtained magnitude of cardiac deceleration was also significant ($p < .05$) as tested by the Median test.

The Spearman rank order correlation (corrected for ties) between changes in detection efficiency, first quarter to the third quarter of the vigil, low signal density condition, and the changes in the median cardiac deceleration between the same periods was $r_s = +.43$, $p < .05$ one tail. On a broader data base, the rank order correlation between changes in the same two variables between the first half and second half of the vigil was $r_s = .49$, $p < .05$. Similarly obtained rank order correlations for the relatively invariant high signal density condition were $r_s = .40$, $p < .05$ (changes from the first to the third quarter) and $r_s = -.02$ (changes from the first half to the second half). The scatter plots of the data from which the two significant correlations for the low signal density condition were derived are presented in Figures 6 and 7.

It is also interesting to note in Figure 5 the increase in the magnitude of stimulus-oriented cardiac deceleration evidenced by both groups in the post-test. In the low signal density group, this motivational condition resulted in a significant recovery in detection efficiency and a concomitant increase in the magnitude of stimulus-oriented cardiac deceleration. An increase in the median magnitude of cardiac deceleration in the post-test

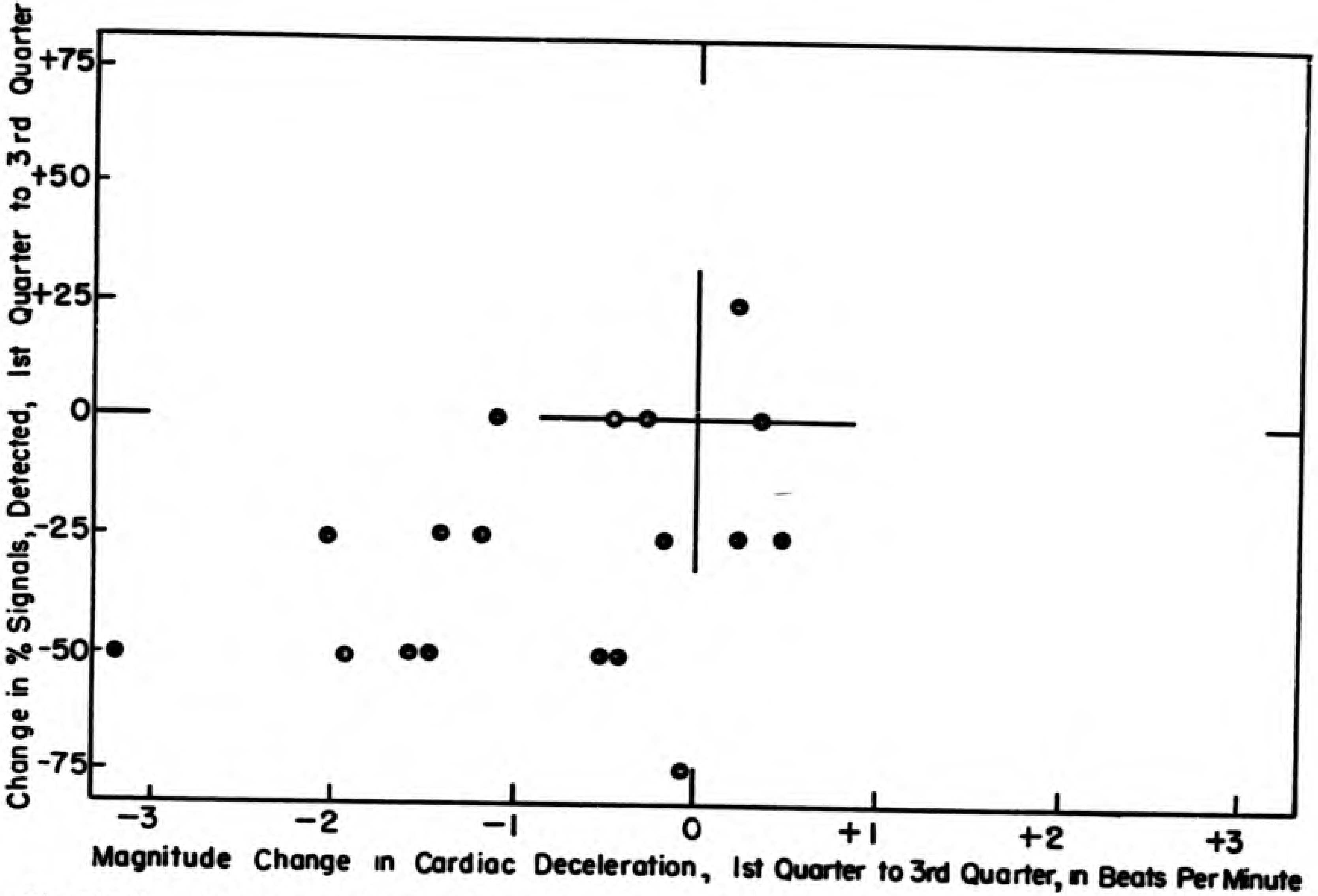

Figure 6. Scatter plot showing the relationship of changes in the magnitude of median cardiac deceleration from the 1st to the 3rd quarter of the vigil to changes in the percentage of signals detected between the same two time periods.

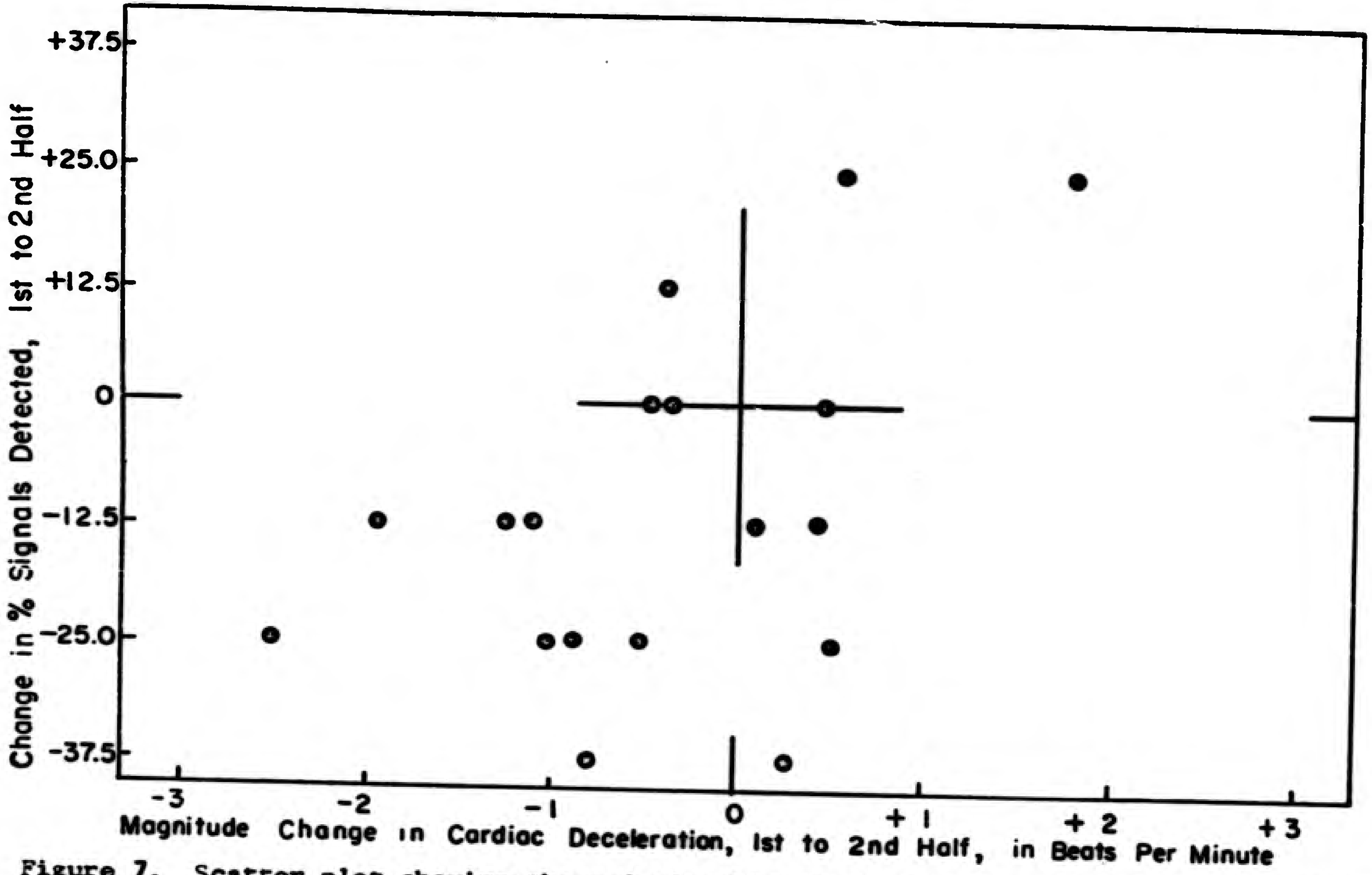

Figure 7. Scatter plot showing the relationship of changes in the magnitude of median cardiac deceleration from the 1st half to the 2nd half of the vigil to changes in the percentage of signals detected between the same two time periods.

over the equivalent cardiac deceleration value obtained in the fourth quarter of the vigil was evident in 14 of 18 subjects in the low signal density condition. In the high signal density condition, 13 of the 18 subjects ($p = .048$) showed an increase in median stimulus-oriented cardiac deceleration in the post-test as opposed to their fourth quarter median deceleration values. These findings are in agreement with those obtained by Lacey and Lacey (undated). In that experiment, an increase in the magnitude of cardiac deceleration and a corresponding performance improvement in response to a motivating condition was found in a reaction time context.

INFLUENCE OF RESPIRATORY SINUS ARRHYTHMIA

In light of the known relationship between heart rate and respiratory phase (heart rate tends to increase on inspiration, decrease on expiration) and since the regular periodicity of the task employed could be conducive to a respiratory "lock-on", the respiratory data were analyzed to determine the degree of involvement of respiratory sinus arrhythmia. To quantify the analog respiratory records obtained, the respiratory phase (inspiratory or expiratory) at the onset of each stimulus event was determined and the percentage of stimulus events in each of the seven experimental segments accompanied by an expiratory phase was calculated. These percentages for the subjects in each of the two groups are shown in Table 8 (low signal density condition) and Table 9 (high signal density condition). In Figure 8, the shift in the percentage of stimulus events associated with expiratory phase over each of the seven experimental segments is plotted for each of

TABLE 8

PERCENT STIMULUS EVENTS ASSOCIATED WITH EXPIRATORY PHASE, CONDITION LOW

Subject #	Quarters of Vigil						
	Rest	1st	2nd	3rd	4th	Post test	Rest
L-1	71.1	71.1	73.0	63.0	66.2	69.1	66.6
L-2	54.1	55.8	57.3	60.0	57.5	61.9	63.9
L-3	57.6	75.8	75.7	73.7	69.9	67.2	67.7
L-4	78.3	75.2	70.1	66.6	67.0	58.3	76.5
L-5	56.6	53.8	57.8	64.6	65.9	63.3	61.8
L-6	63.3	65.0	66.6	67.5	72.1	65.0	56.6
L-7	89.6	65.8	64.1	62.5	71.1	58.9	73.9
L-8	66.1	66.9	69.3	71.6	62.1	62.7	76.9
L-9	68.8	75.6	77.1	67.2	62.0	84.5	50.8
L-10	62.9	64.7	64.2	48.8	67.4	66.1	57.9
L-11	52.5	63.2	61.9	52.5	43.5	50.8	52.6
L-12	77.6	75.6	68.1	65.7	65.9	76.4	69.6
L-13	64.4	63.8	63.6	59.2	56.3	62.7	64.3
L-14	62.1	68.7	70.2	70.6	78.1	83.3	56.9
L-15	57.8	64.6	65.7	54.8	64.1	68.3	58.8
L-16	57.1	64.0	62.8	67.5	69.0	64.8	70.9
L-17	----	----	-- no data --		----	----	----
L-18	57.6	66.4	72.3	69.2	68.5	54.4	68.4
% Events Expiratory	64.5	66.8	67.0	59.7	65.1	65.7	64.3

TABLE 9

PERCENT STIMULUS EVENTS ASSOCIATED WITH EXPIRATORY PHASE, CONDITION HIGH

Subject #		Quarters of Vigil					
	Rest	1st	2nd	3rd	4th	Post test	Rest
H-1	63.8	59.0	55.9	54.0	60.6	58.9	69.5
H-2	55.3	56.8	71.1	62.7	72.1	65.0	----
H-3	69.2	58.5	44.7	53.7	33.0	45.7	73.0
H-4	66.6	73.6	68.0	70.2	72.2	67.3	65.0
H-5	66.6	65.1	65.8	68.1	69.0	72.4	53.2
H-6	70.2	63.2	60.1	56.1	62.4	66.0	63.3
H-7	61.1	63.4	59.9	54.5	61.2	59.3	72.6
H-8	80.0	84.0	86.3	57.9	56.9	69.5	66.6
H-9	66.6	62.0	55.9	50.2	62.0	42.6	54.2
H-10	60.0	72.1	70.7	64.0	66.4	69.5	63.3
H-11	65.3	60.1	59.0	51.8	50.9	50.9	67.5
H-12	57.6	72.7	66.3	68.9	65.0	50.0	58.3
H-13	64.5	57.7	55.0	65.1	66.1	46.7	57.8
H-14	48.5	53.4	51.1	54.0	59.6	47.3	59.6
H-15	55.2	69.4	43.8	55.2	48.4	47.9	32.2
H-16	60.3	59.8	63.0	61.9	61.4	71.6	57.1
H-17	59.3	65.8	63.0	59.9	64.6	62.7	61.6
H-18	54.6	59.7	59.7	54.7	63.7	59.3	63.3
% Events Expiratory	62.5	64.2	61.1	59.4	60.8	58.5	61.1

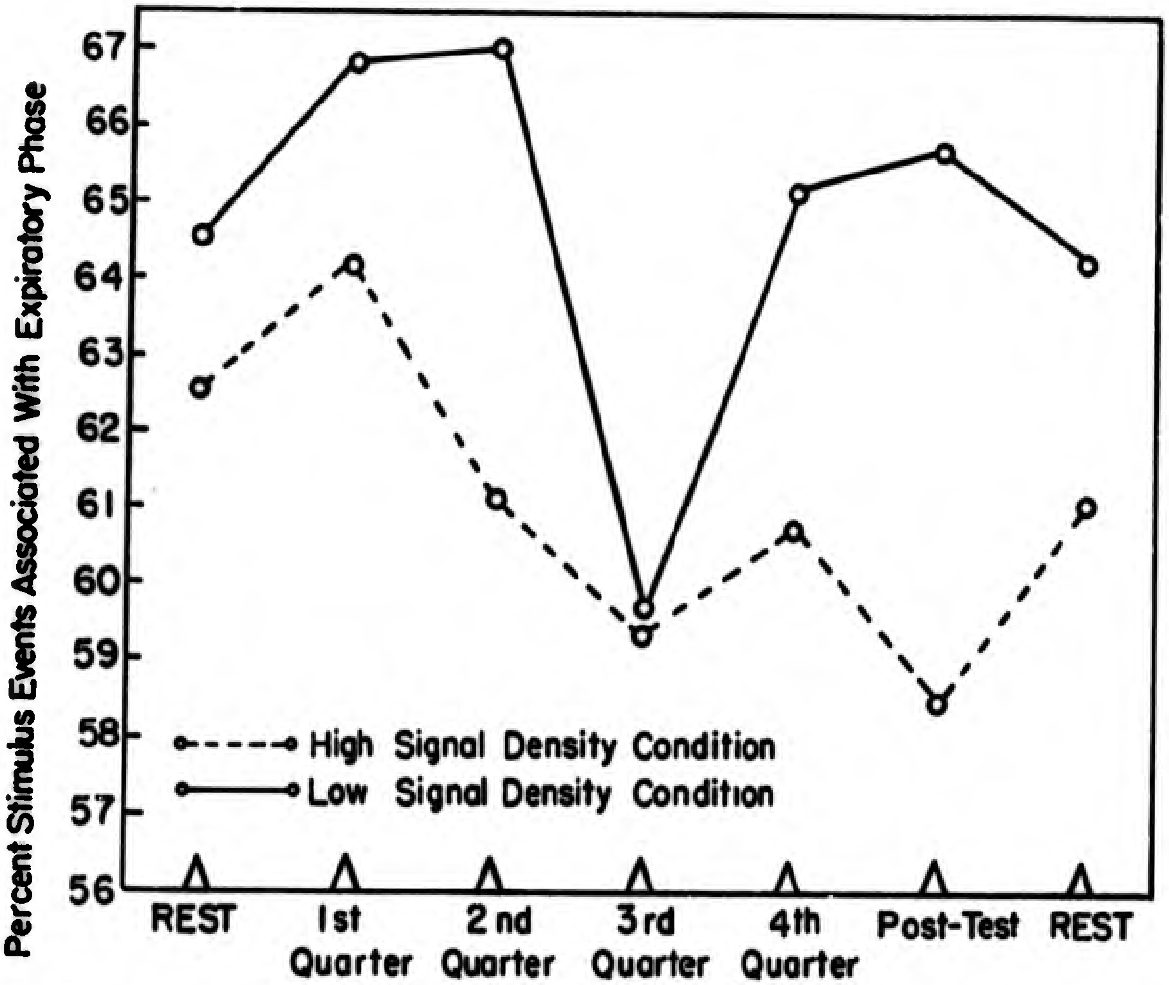

Figure 8. Percentage of stimulus events accompanied by expiratory phase for the high and low signal density conditions in each of the seven experimental segments.

the two groups. If respiratory sinus arrhythmia and changes over time in the probability of S being in an expiratory phase at the time of stimulus presentation were significantly involved in the stimulus-oriented cardiac deceleration effects noted, then at least some of the following relationships should be evident:

1. The high signal density group, which showed larger stimulus-oriented cardiac decelerations than the low signal density group, should show a higher percentage of stimulus events accompanied by expiratory phase.
2. There should be a positive rank order correlation between the proportion of stimulus events associated with expiratory phase and the magnitude of stimulus-oriented cardiac deceleration.
3. The rank order correlation relating changes in the magnitude of cardiac deceleration to changes, between various parts of the vigil, in the percentage of stimulus events associated with expiratory phase should show a significant positive correlation.

Tests for the relationships postulated above do not substantially implicate respiratory sinus arrhythmia as a major factor underlying the obtained cardiac deceleration phenomena. The high signal density group, which showed the largest stimulus-oriented cardiac deceleration effect, had a lower percentage of stimulus events accompanied by expiratory phase than did the low signal density group. Over subjects, the rank order correlation between the magnitude of cardiac deceleration and the probability of a stimulus event being associated with expiratory phase was $r_s = .21$, $p > .05$ for condition low, and $r_s = .44$, $p > .05$, condition high. Further, the rank order correlation between the magnitude of change in the probability of expiratory phase at the onset of stimulus events and the magnitude of change in median cardiac deceleration between the first and third quarter of the vigil, condition low was $r_s = -.28$, $p > .05$. The same statistical treatment relating the same change values between the first and second half of the vigil for the low signal density condition did not reach significance, $r_s = -.017$, $p > .05$.

It would be premature, however, to judge on the basis of the foregoing data that respiratory sinus arrhythmia was not at least a partial contributor to the relationship between detection efficiency and the cardiac deceleration effects which were obtained. As was pointed out previously, the instrumentation used in this study did not permit quantitative analysis of changes in respiratory magnitude. Inasmuch as the magnitude of change in heart rate is also related to the magnitude of the respiratory cycle, it must be borne in mind that changes in respiratory magnitude and the associated changes in the magnitude of change in heart rate may at least partially underlie the obtained relationships. It would require more sophisticated respiratory instrumentation than used in this study to fully analyze respiratory involvement.

CARDIAC DECELERATION FOR DETECTED SIGNALS, MISSED SIGNALS, AND FALSE RESPONSES

In the relationships reported earlier in this paper between changes in detection efficiency and changes in the magnitude of stimulus-oriented cardiac deceleration, the cardiac deceleration measure represented data pooled over all stimulus events within a given time period irrespective of the signal or non-signal property of the stimuli or of the nature of the response (detection, missed signal, false positive response). Consequently, the reported shifts in the magnitude of cardiac deceleration relate to long term shifts in vigilance performance for each group. They do not define a specific relationship between the magnitude of change in heart rate in advance of a given stimulus event and the probability of that stimulus event being detected or missed (if a signal event), or a false response rendered in the case of a non-signal event.

To determine if the general group relationships could be generalized to the intra-subject case and, further, to determine if reliable differences existed for each group between the pattern of cardiac activity obtained for detected signal events, missed signal events, and events to which false responses were rendered, the changes in heart rate in advance of each stimulus event in each of these three event-response classes were independently obtained for the 96 minute vigil.

In the comparison of changes in heart rate in advance of detected signal events with those obtained for missed signal events, meaningful comparisons were possible only in the high signal density group. In the low signal density group, and for one subject in the high signal density group, the number of signals missed by each subject was too small to permit meaningful statistical assessment.

In keeping with the general relationships reported earlier, it would be expected that the magnitude of stimulus-oriented cardiac deceleration obtained for detected signal events should be greater than that obtained for missed signal events. This expectation was not borne out, however. As tested by the Wilcoxon matched-pairs signed-ranks test,[1] only one significant intra-subject difference was obtained. In that single case, the magnitude of cardiac deceleration was larger for the detected signal events than for the missed signal events. Testing the trend of the differences across subjects by the Sign test likewise failed to indicate any significant difference between the median magnitude of cardiac deceleration obtained for detected and missed signal events. Of the 17 subjects, 9 showed a greater magnitude of cardiac deceleration for detected signal events and the remaining 8 subjects exhibited a larger deceleration on missed signal events. Thus, no evidence can be offered from this study which would justify generalizing to the intra-subject or event class level the previously reported low relationships between the magnitude of cardiac deceleration and detection efficiency.

---

[1] The required pairs were formed by matching the deceleration score ($R_{s-2} - R_{s+1}$) obtained on the first missed signal event with the deceleration score obtained on the first detected signal event, the second missed signal with the second detected signal, etc., until the distribution with fewer N (in this case, missed signal events) was exhausted.

With the same statistical treatment, the data also failed to differentiate the magnitude of cardiac deceleration obtained on false response events from that obtained on detected signal events. These results were again restricted to the high signal density condition. Intra-subject comparisons revealed only three differences significant at the .05 level. In each of these three cases, the magnitude of cardiac deceleration was greater on the false response events than on the detected signal events. For the group, 11 of the 18 subjects showed a greater median cardiac deceleration for false response events than for detected signal events. For the remaining 7 subjects, the median cardiac deceleration was larger for the detected signal events.

In addition to these independent analyses, the pattern of stimulus-oriented changes in heart rate was also isolated for all events one subsequent to a detected signal event exclusive of any such stimulus events to which false positive responses were rendered. This analysis was performed to determine if the act of signal detection (or reporting detection) had an effect on the pattern of cardiac activity recorded on the subsequent event. It has been variously argued in the vigilance literature that signal detection is rewarding (Mackworth, 1948), or that subjects are less likely to critically observe immediately after reporting signal detection because of a reduced expectancy that the next stimulus event will be a signal (Baker, 1959). Additionally, motor activity (pressing a key) is required to report a detection. Although the effect of most of these factors on the specific pattern of stimulus-oriented cardiac activity around the subsequent event cannot be predicted with any certainty, significant differences in the magnitude of cardiac deceleration obtained around detected signal events and events one subsequent to detected signal events would at least indicate that the cardiac deceleration measure might be reflecting other factors than anticipatory attentive effort.

Comparison of the median cardiac deceleration obtained for detected signal events and events one subsequent to detected signal events revealed that 11 of the 18 subjects tended to show greater cardiac deceleration on the events immediately following detected signal events. This directional trend as tested by the Sign test is not significant, $p = .48$ (two tail). Thus, these data are not indicative of significant post-detection effects on the cardiac measure.

CARDIAC LABILITY

The cardiac lability index was obtained for several reasons. In addition to serving as a relevant measure for testing the approximate equality of the two groups of subjects in terms of their resting cardiac activity, the cardiac lability measure was obtained to investigate possible relationships between cardiac lability and false response rates, and cardiac lability and detection efficiency. In an earlier work by Lacey and Lacey (1958), evidence was presented linking cardiac lability to motor impulsivity. The more labile subjects, serving in a complex reaction time experiment in which certain of the stimuli were not to be reacted to, tended to make faster responses and more false positive responses than those lower on the lability scale. Lacey's findings suggest that in a vigilance context a positive relationship might be found between resting cardiac lability and, (a) false response rates, and (b) the percentage of signals detected.

To test for these suggested relationships, the number of false responses and the number of correct signal detections made by each subject within each of the two experimental groups was determined, and rank order correlations relating each subject's initial resting cardiac lability index to these values were calculated. For false responses, the rank order correlations for the high and low signal density conditions respectively were $r_s = +.66$, $p < .05$, and $r_s = +.21$, $p > .05$. The rank order correlation between resting cardiac lability and the number of signals detected was $r_s = -.14$ for the high signal density condition, and $r_s = +.12$ for the low signal density condition, neither of which reached significance at the .05 level.

In the case of the correlations between false responses and resting cardiac lability, the relationships are in the direction that would be predicted from Lacey's previous work. The fact that a higher relationship was obtained between resting lability and false responses in the high signal density condition possibly reflects a greater response set based on a high subjective expectancy of signal occurrence on any given event. Such an expectancy factor would constitute an adequate condition for tendencies toward motor impulsivity (inability to inhibit a response) to operate. In the low signal density condition, the very low rate of occurrence of signal events would contribute to a low subjective expectancy of signal occurrence and would thus tend to minimize a response inhibition factor. The fact that the false response rate tended to be lower in the low signal density condition is in accord with such a position.

The divergent, low, and insignificant correlations obtained between detection efficiency and resting cardiac lability are not surprising. The relationships previously established by Lacey between cardiac lability and reaction time were also extremely low, but consistently negative. He found that these low negative relationships were secondary ones which resulted from a positive relationship between cardiac lability and the magnitude of stimulus-oriented cardiac deceleration, which in turn was negatively correlated with reaction time. In the context of this study it would be difficult to isolate such a secondary effect in light of the relatively small sample obtained.

Having programmed to obtain the resting cardiac lability index, it was a simple matter to extract the same measure over the vigil, post-test, and final rest portions of the experiment as well. These data permit assessment of the temporal course of cardiac lability during task performance. In Figure 9, the median of the distribution of cardiac lability scores for the 18 subjects in each of the two groups is plotted. It can be seen that median cardiac lability increased throughout the vigil. Although a small but consistent trend toward higher cardiac lability for the low signal density group is apparent, the inter-group differences are not statistically significant.

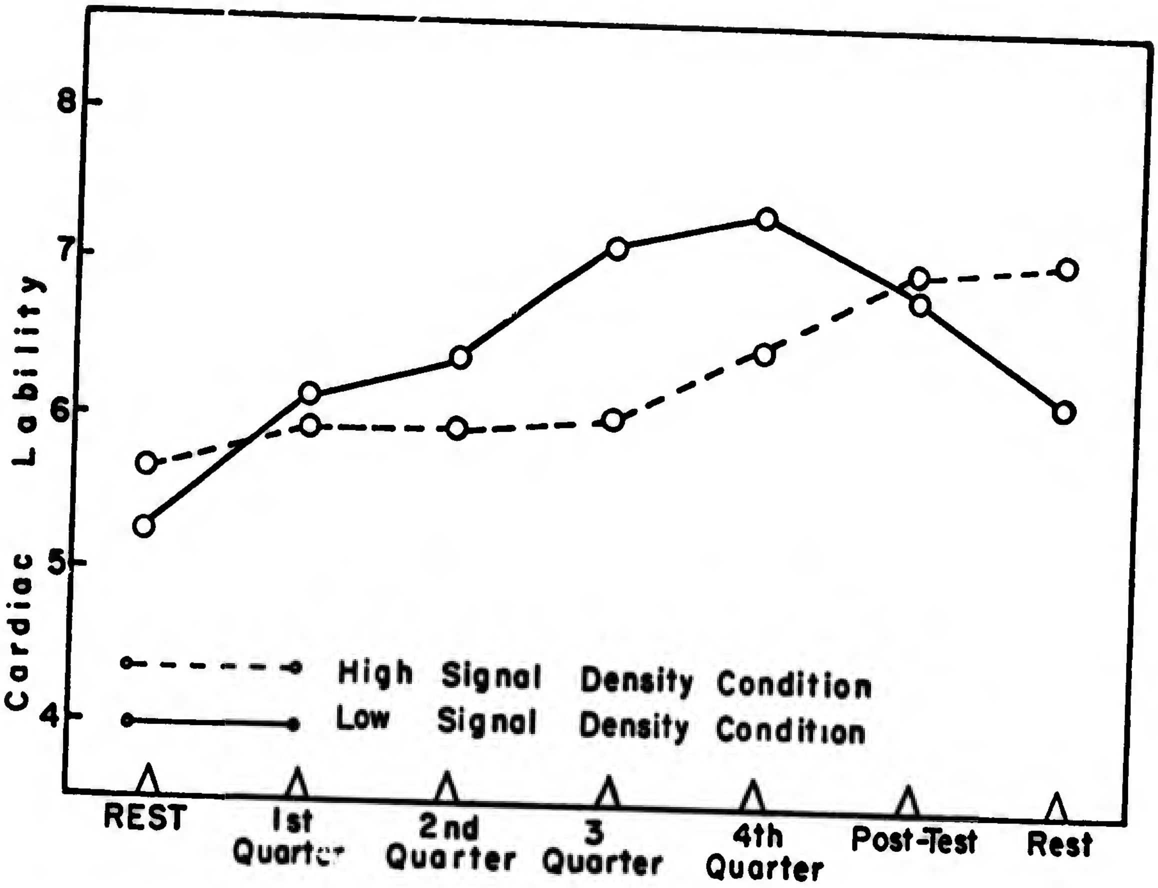

Figure 9. Median cardiac lability.

CHANGES IN MEDIAN HEART RATE

The temporal changes in median overall heart rate for each group of subjects in the seven successive experimental segments are plotted in Figure 10. As tested by the Median test, none of the differences in median heart rate between the high and low signal density conditions are significant.

The rank order correlation relating the changes in median overall heart rate to changes in detection efficiency from the first half of the vigil to the second, for the high signal density group, was not significant, $r_s = -.128$, $p > .05$. For the low signal density group, the same statistical treatment similarly yielded an insignificant rank order correlation of $r_s = +.317$, $p > .05$. It is of particular interest to note that the heart rate function showed a disproportionate decrease between the last quarter of the vigil and the post-test. It will be recalled that the motivational condition of the post-test resulted in a significant recovery in detection efficiency. In this case, the recovery in performance (behavioral arousal) was accompanied by a relatively large decrease in median heart rate and, as previously discussed, by a significant increase in the magnitude of stimulus-oriented cardiac deceleration.

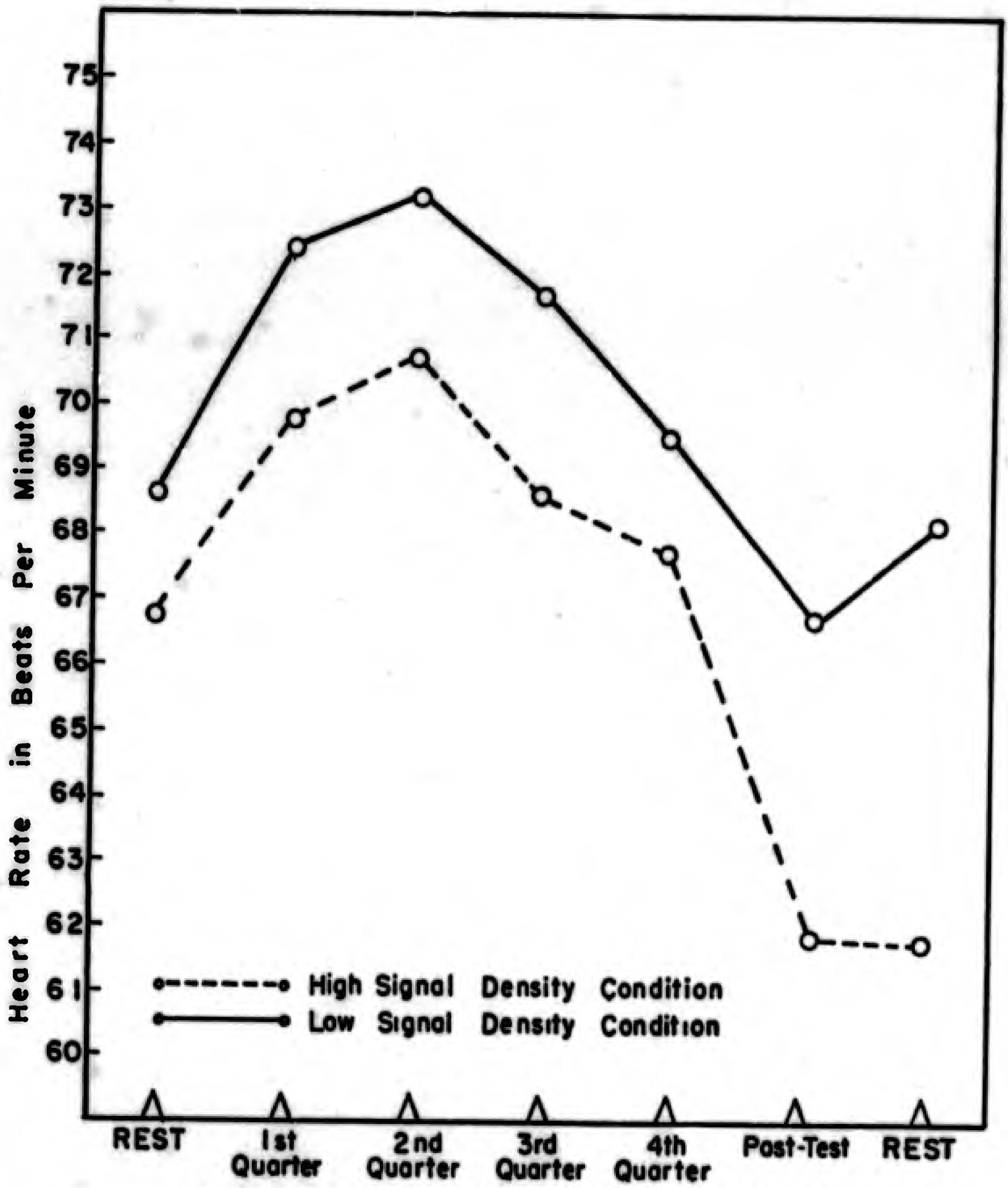

Figure 10. Median of median heart rates.

SECTION IV

DISCUSSION AND CONCLUSIONS

In this study it has been seen that detection efficiency was significantly influenced by two independent variables: signal density which differentiated the two groups of subjects employed, and a motivational variable applied as a post-test to both groups. The effects of these variables, yielding a positive relationship between detection efficiency and signal density and a recovery in detection efficiency in response to the motivating condition, have been previously demonstrated (Mackworth, 1948) and interpreted by some writers (Scott, 1957; Frankman and Adams, 1960) in terms of activation theory.

Conventional activation theory would predict that those conditions showing higher or better sustained detection efficiency (behavioral arousal) should be accompanied by high levels of physiological activity. In this study, heart rate, expressed as the median overall rate obtained in succeeding quarters of the vigil, failed to differentiate the two signal density conditions which produced significant differences in detection efficiency. The rank order correlations relating changes in detection efficiency to changes in median heart rate were low and insignificant.

In rather sharp contrast to the predictions of activation theory, it was found that:

1. The time period in advance of the repetitive stimuli which Ss were to observe was accompanied by a cardiac deceleration (stimulus-oriented cardiac deceleration).
2. In the low signal density condition, wherein significant changes over time occurred in both detection efficiency and the magnitude of stimulus-oriented cardiac deceleration, significant positive rank order correlations were obtained between changes in the percentage of signals detected and changes in the magnitude of stimulus-oriented cardiac deceleration.
3. The motivational condition of the post-test yielded a significant recovery in detection efficiency, a concomitant increase in the magnitude of stimulus-oriented cardiac deceleration, and a <u>decrease</u> in median heart rate.

These findings demonstrate deceleratory responses in heart rate under conditions normally associated with behavioral arousal (e.g., readiness to observe). They further demonstrate a positive relationship between the relative magnitude of the deceleratory responses and objective measures of arousal (e.g., percentage of signals detected). As such, these data extend the recent findings of Lacey and his co-workers which demonstrate deceleratory cardiac responses in other experimental situations requiring attentiveness to external stimuli. This study lends at least partial support to Lacey's position which holds that in situations requiring attentiveness to the external environment, deceleratory responses have a facilitory effect on performance.

It should be borne in mind that these data relating changes in detection efficiency to changes in the magnitude of stimulus-oriented cardiac deceleration were obtained over all stimulus events across subjects. The data failed to show a significant difference between the magnitude of stimulus-oriented cardiac activity for detected signal events, and missed signal events, either on an intra-subject basis or across subjects. Thus, it cannot be asserted that the magnitude of change in heart rate in advance of a stimulus event is specifically predictive of a subject's momentary attentiveness to that stimulus event. Rather, the data indicate that the aggregate of the subjects' anticipatory cardiac responses to stimulus events over a period of time are related to the subjects' detection efficiency during that time period. The fact that shifts in the magnitude and direction of change in stimulus-oriented cardiac deceleration are positively related to changes in detection efficiency suggests that the cardiac deceleration measure may reflect attentive effort on the part of the subject. This conjecture gains some support from the finding that the motivational condition characterizing the post-test resulted in concomitant increases in the magnitude of stimulus-oriented cardiac deceleration and detection efficiency..

From the standpoint of providing an independent measure of attentive behavior, the relationships obtained, although considered promising, are weak.

They are further hindered by the absence of evidence differentiating the magnitude of cardiac deceleration for missed and detected signal events either on an intra-subject basis or across subjects. In addition to the relatively small sample size obtained, particularly on an intra-subject basis in the low signal density condition, the failure of the cardiac measure to differentiate missed and detected signal events might be a result of the inter-stimulus interval employed. From the data plotted in Figures 3 and 4, it is evident that the stimulus-oriented heart rate function tended to reach a zenith two beats prior to the onset of stimuli, and that the trend in heart rate from the third to the second beat preceding stimulation was acceleratory. This indicates that the third rate value prior to stimulation was reflecting the end of the post stimulus acceleratory trend in heart rate from the preceding stimulus. In light of this, it is possible that the inter-stimulus interval was not sufficiently long to exploit the full dynamic range of the cardiac response. Such a range limitation could well have hindered the sensitivity of the measure. This reasoning also suggests that the cardiac deceleration measure might fail entirely as a correlate of detection efficiency in vigilance situations employing inter-stimulus intervals appreciably shorter than the six second interval used in this study. The assessment of changes in the patterns of stimulus-oriented cardiac activity and the relationship of that measure to detection efficiency under conditions of different inter-signal intervals merits further research attention.

The lack of correspondence between the behavioral-physiological relationships obtained in this study and the relationships which would have been predicted by physiological activation theory is not necessarily an indictment of the arousal theory of vigilance. It may be that the phenomena which underlie changes in detection efficiency in a vigil are, as suggested by Scott, similar to those which neurophysiological and psychophysiological evidence has linked to changes in electro-cortical arousal. If this is the case, then the findings in this study, which show stimulus-oriented decreases in heart rate and a positive relationship between the magnitude of change in cardiac deceleration and detection efficiency, are indicative of an inadequate elaboration of the physiological mechanisms which underlie behavioral arousal. The mass of evidence cited by Lacey (1965) certainly indicates that a reappraisal of physiological activation theory is in order.

SUMMARY

This study has demonstrated significant, low, positive relationships between changes in the magnitude of stimulus-oriented cardiac deceleration and changes in detection efficiency obtained in the course of a protracted vigil. Conventional indices of heart rate expressed as a median rate per unit time did not significantly relate to detection efficiency. These results which contradict conventional activation theory lend additional support to Lacey's contention that in tasks requiring attentiveness to the external environment deceleratory cardiac responses have a facilitory effect on behavior.

The relationships obtained are considered as a useful step toward developing an independent measure of alertness in vigilance situations. It was suggested that the relatively short inter-stimulus interval in this task may have artificially restricted the range of response of the cardiac measure and thus contributed somewhat to the low sensitivity of the measure.

APPENDIX A

SIGNAL SCHEDULE,
HIGH SIGNAL DENSITY CONDITION

NUMBERS IDENTIFY THE STIMULUS EVENTS WHICH WERE SIGNALS IN THE SERIAL SEQUENCE OF EVENTS FROM 0 THROUGH 1020

5
11
13
16
21
24
26
31
33
39
41
45
49
56
59
67
73
75
78
80
82
85
88
94
97
104
106
110
114
118
120
124
130
132
136
138
144
150
157
159
163
168
171
183
187
189
193
197
201
206
208
212
215
220
224
228
231
233
237
240
247
250
252
255
258
261
269
276
279
281
283
285
294
296
299
301
307
311
318
320
324
326
332
335
338
340
346
349
351
363
368
371
376
380
383
385
391
394
397
400
403
407
412
414
419
421
425
432
436
441
443
446
453
455
460
466
469
472
475
480
485
491
493
496
501
504
506
511
513
519
521
525
529
536
539
547
553
555
558
560
562
565
568
574
577
584
586
590
594
596
600
604
610
612
616
618
624
630
637
639
643
648
651
663
667
669
673
677
681
686
688
692
695
700
704
708
711
713
717
720
727
730
732
735
738
741
749
756
759
761
763
766
774
776
779
781
787
791
798
800
804
806
812
815
818
820
826
829
831
843
848
851
856
860
863
865
871
874
877
880
883
887
893
896
899
901
905
912
916
921
923
926
933
935
940
946
949
952
955
957

Post test

965
971
973
976
981
984
986
991
993
999
1001
1005
1009
1012
1016

APPENDIX B

SIGNAL SCHEDULE,
LOW SIGNAL DENSITY CONDITION

NUMBERS IDENTIFY THE STIMULUS EVENTS WHICH WERE SIGNALS IN THE SERIAL SEQUENCE OF EVENTS FROM 0 THROUGH 1020

5
94
167
202
263
320
399
465
485
574
647
682
743
800
879
945

Post
test

1001

APPENDIX C

INSTRUCTIONS

The experiment you are about to participate in is designed to obtain information about physiological changes which might occur in protracted watch-keeping tasks. There are many tasks in both civil and military activities which require sustained attention for long periods of time. In the military, radar and sonar operations are famous examples. In civilian activities, many assembly line tasks, inspection jobs and the tasks of those who must keep track of the operating status of automated equipment are additional examples.

Your task today is to watch the small spot of light which you see appearing before you. Occasionally the light will flash a little brighter than it did before. It will be your job to watch the flashing light and to press this key as soon as you think you see one which appears brighter than the others. (Demonstrate brightness difference between standard and signal stimulus.)

Other than the two brightness levels of the light you have seen, there are no gradations in the brightness of the spot which will appear. It will be either one of the two levels of intensity that I just showed you. The brighter flashes of light which you are to report will occur randomly. There is no "system" that will tell you when a bright flash will occur.

As you can see, your task today is extremely simple. Because of its extreme simplicity you will probably find it to be rather tedious. In spite of this, it is extremely important that you do your very best and stay awake. If you fall asleep or quit trying to detect the bright flashes of light, your data will be of little use.

The experiment will be broken into the following parts. First, I will ask you to sit quietly for five minutes while I record your resting heart and respiration activity. During this rest period your display will be turned off and there will be no flashing to watch. At the end of the rest period I will call you on the intercom and ask you to watch the flashing light which I will then turn on. Watch for the brighter flashes of light and press your key whenever you think you see one. I will tell you whether you were right or wrong. That practice period will last about two minutes. When it is over, I will again call you on the intercom and tell you that the main part of the experiment will now begin. This part will last an hour and thirty minutes, and in that time period I will not tell you whether or not your responses were correct. You will be entirely on your own. When the hour and thirty minute session is over, I will again call you and ask you to rest quietly while a final six minute resting record of your heart and respiratory activity is made.

Throughout the experiment, it will be important that you minimize your body movements. If you fidget or move around a great deal, the physiological data I am recording is disturbed and may not be useable. You will probably find it necessary, however, to shift your position from time to time. By all means, feel free to do so. I only ask that when you must move, get yourself readjusted comfortably and then try to remain still. An occasional movement is much better than continual fidgeting.

You may better familiarize yourself with the difference between the bright and the dim flashes of light. If you press this switch, the next flash of light to appear will be a bright one. By using this switch, alternate the flashing light from bright to dim and study the difference. You may work with the display controlling it yourself for the next several minutes.

START OF VIGIL: That concludes your practice period. The main portion of the experiment will now begin. Remember, do the best you can and stay awake.

POST-TEST: You have just six more minutes to go. In this last six minutes it is extremely important that you be as accurate as you possibly can.

REST: That concludes your test period. Now rest quietly for five more minutes while I make a final record of your heart and respiratory activity.

REFERENCES

Baker, C. H., Towards a theory of vigilance. *Canad. J. Psychol.*, *13*, 35-42, 1959.

Bradley, J. V., *Distribution-free statistical tests*. WADD Technical Report 60-661, (AD 249 268), Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, August 1960.

Buckner, D. N., Harabedian, A., and McGrath, J. J., *A study of individual differences in vigilance performance*. Technical Report 2, Human Factors Research, Inc., Contract Nonr 2649(00) NR 153-199, 1960.

Buckner, D. N., and McGrath, J. J., *Vigilance: a symposium*. New York: McGraw-Hill, 1963.

Deese, J., and Ormond, E., *Studies of detectability during continuous visual search*. WADC Tech. Report 53-8, (AD 24 214), Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1953.

Frankman, Judith P., and Adams, J. A., *Theories of vigilance*. Air Force Command and Control Development Division. Technical Note 60-25 (AD 245 063), L. G. Hanscom Field, Mass., April 1960.

Haider, M., Spong, P., and Lindsley, D. B., Attention, vigilance, and cortical evoked potentials in humans. *Science*, 180-182, 1964.

Hebb, D. O., Drives and the conceptual nervous system. *Psychol. Rev.*, *62*, 243-253, 1955.

Jenkins, H. M., The effect of signal rate on performance in visual monitoring. *Am. J. Psychol.*, *71*, 647-661, 1958.

Jerison, H. J., and Pickett, R. M., Vigilance: a review and re-evaluation. *Human Factors*, *3*, 211-238, 1963.

Jerison, H. J., Pickett, R. M., and Stenson, H. H., The elicited observing rate and decision processes in vigilance. *Human Factors*, *7*, 107-128, 1965.

Lacey, Beatrice C., and Lacey, J. I., *Change in cardiac response and reaction time as a function of motivation*. Fels Research Institute, Yellow Springs, Ohio. Undated publication.

Lacey, Beatrice C., and Lacey, J. I., Cardiac deceleration and simple visual reaction time in a fixed foreperiod experiment. Paper delivered at meetings of the Society for Psychophysiological Research, 1964.

Lacey, J. I., Somatic response patterning and stress: some revisions of activation theory. Paper delivered at a symposium on "Issues in Stress", held at York University, Toronto, Canada, May 10-12, 1965.

Lacey, J. I., and Lacey, Beatrice C., The relationship of resting autonomic activity to motor impulsivity. Res. Publ. Assn. Res. Nerv. and Ment. Dis., 36, 144-209, 1958.

Lindsley, D. B., Psychophysiology and motivation. In M. R. Jones (Ed.) Nebraska symposium on motivation. University of Nebraska Press, 44-105, 1957.

Mackworth, N. H., The breakdown of vigilance during prolonged visual search. Quart. J. Exp. Psychol, 1, 6-21, 1948.

Nicely, P. E., and Miller, G. A., Some effects of unequal spatial distribution on the detectability of radar targets. J. Exp. Psychol., 53, 195-198, 1957.

Obrist, P. A., Cardiovascular differentiation of sensory stimuli. Psychosom. Med., 25, 450-469, 1963.

Samuals, Ina, Reticular mechanisms and behavior. Psychol. Bull., 56, 1-25, 1959.

Scott, T. H., Literature review of the intellectual effects of perceptual isolation. Def. Res. Bd. Rep., No. HR 66 (Canada). 1957.

Siegel, S., Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill, 1956.

Swets, J. A. (Ed.), Signal detection and recognition by human observers. New York: John Wiley, 1964.

Travis, R. C., and Kennedy, J. C., Prediction and control of alertness. J. Comp. Physiol. Psychol., 40, 457-462. 1947.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
AEROSPACE MEDICAL RESEARCH LABORATORIES,
AEROSPACE MEDICAL DIVISION, AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AFB, OHIO 45433

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
THE RELATIONSHIP BETWEEN STIMULUS-ORIENTED CHANGES IN HEART RATE AND DETECTION EFFICIENCY IN A VIGILANCE TASK

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report, June 1965 - June 1967

5. AUTHOR(S) (First name, middle initial, last name)
AUSTIN W. KIBLER, MAJOR, USAF

6. REPORT DATE
February 1968

7a. TOTAL NO. OF PAGES
62

7b. NO. OF REFS
24

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 7183

c. Task No.: 718302

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AMRL-TR-67-233

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES
Dissertation for Doctor of Philosophy, University of Michigan, 1967.

12. SPONSORING MILITARY ACTIVITY
AEROSPACE MEDICAL RESEARCH LABORATORIES, AEROSPACE MEDICAL DIVISION, AIR FORCE SYSTEMS COMMAND, WRIGHT-PATTERSON AFB, OHIO 4543

13. ABSTRACT

This study was designed to assess the relationship between detection efficiency and beat-to-beat changes in heart rate around task stimuli in a vigilance task. Thirty-six subjects, instrumented for continuous recording of EKG and respiration, individually stood a 96 minute vigil. They monitored a light which flashed on (stimulus event) for 500ms. once every 6.0 seconds and were to report the occasional brighter flashes (signals). Half of the subjects (high signal density group) received 240 signals; the remaining 18 subjects (low signal density group) received but 16 signals. By urging the subjects to do their best, a motivational condition was induced in a six minute post-test.

As expected, detection efficiency was higher and better sustained by the high signal density group. Detection efficiency of the low signal density group decayed appreciably over time. In the motivational post-test condition the performance of both groups improved significantly.

Measures of changes in heart rate, analyzed both in terms of overall shifts in heart rate over the vigil and beat-to-beat changes in heart rate around each stimulus event, revealed: 1. The median heart rate in succeeding quarters of the vigil, did not differ significantly between the two groups. Nor did changes in overall heart rate correlate significantly with changes in detection efficiency. 2. Heart rate preceding a stimulus event decelerated. Changes in the magnitude of the stimulus-oriented cardiac deceleration showed a low but significant relationship to changes in the percentage of signals detected. 3. In the post-test the significant recovery in detection efficiency was accompanied by an increase in the magnitude of stimulus-oriented cardiac deceleration and by a decrease in overall heart rate.

DD FORM 1 NOV 65 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cardiac Lability						
Detection Efficiency						
Heart Rate						
Signal Density						
Vigilance						

Security Classification