ESD-TDR-63-605

SENSORY ALTERNATION AND PERFORMANCE IN A VIGILANCE TASK

TECHNICAL DOCUMENTARY REPORT ESD-TDR-63-605
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Alin Gruber

DECISION SCIENCES LABORATORY
DEPUTY FOR ENGINEERING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
L. G. Hanscom Field, Bedford, Massachusetts

(Prepared under Contract AF19(628)-1654 by Dunlap & Associates, Inc., 429 Atlantic Street, Stamford, Connecticut)

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FOREWORD

This study was initiated and conducted by the Human Factors Department of Dunlap and Associates, Inc., Stamford, Connecticut. Dr. Alin Gruber, Senior Psychologist, was the principal investigator. The project was supported in part by the USAF Electronic Systems Division, and in part by Dunlap and Associates, Inc. Dr. Richard L. Sulzer, formerly of the Air Force Systems Command, was project officer.

The author wishes to acknowledge the encouragement and support received from Dr. Jerome H. Ely, late Vice-President and Director of the Human Factors Research Division at Dunlap and Associates.

Mr. Edward S. Rosenbluh and Mr. James Seeley of the University of Bridgeport, Bridgeport, Connecticut served as experimental assistants. Their help in preparing the apparatus and conducting a preliminary investigation was invaluable.

The author would also like to thank Dr. Charles R. Kelley, Chief Scientist and formerly Laboratory Director at Dunlap and Associates, Dr. Norman H. Mackworth, formerly Chief Scientist at Dunlap and Associates, and Mr. Barry Gruber, Laboratory Technician at Dunlap and Associates for their counsel and/or support at various stages of this study.

ABSTRACT

The effects of four experimental conditions on performance in a vigilance task were studied using eight subjects in a repeated measurements design. The four conditions were: visual detection alone; auditory detection alone; combined (redundant) visual and auditory detection; and alternating, in 30-minute periods, auditory and visual detection. Subjects were required to detect .1-second, aperiodic interruptions in either or both a visually displayed horizontal line or a 1000 cps tone. The intensities of both signals were adjusted to near-threshold levels against constant noise backgrounds. Data were collected on the number of signals detected, the number of false responses, and response times during the two-hour testing session. It was found that: (1) sensory alternation was an effective means of maintaining alertness; (2) redundant, dual sense monitoring resulted in significantly fewer false responses; (3) there were no differences between the four conditions with respect to median response times; and (4) response times did increase with the length of the watch over the four conditions.

REVIEWED AND APPROVED FOR PUBLICATION

for James S. Duva

ANTHONY DEBONS
Colonel, USAF
Director
Decision Sciences Laboratory
Deputy for Engineering and Technology

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Sensory Alternation and Performance in a Vigilance Task

The published literature (Mackworth, 1948, 1950; Broadbent, 1958; Deese, 1953; Bakan, 1955; Baker, C.H., 1958, 1959, 1960, 1961; Adams, 1956; Jerison, 1957, 1958, 1959; Colquhoun, 1961; and Baker, R.A., 1962) has established that the deterioration of human performance in the course of sustained monitoring for fleeting, infrequent and unpredictable signals can be arrested through: a) frequent changing or rotation of operators; b) multiple (redundant) monitors working independently; c) increasing signal duration; d) increasing signal density (occurrence frequency over time); e) increasing signal intensity or contrast; f) the use of drugs such as benzedrine; g) providing an operator with knowledge of the results of his performance (i.e., indicating to an operator what his level of alertness is); and h) providing "false" or synthetic signals which appear as real signals and to which an operator must respond as though they were real (related to "d", increasing signal density). Recent research (Buckner and McGrath, 1961; and Osborn, Sheldon and Baker, 1963) verify that a dual-sense, redundant signal presentation will also result in improved detection performance.

Still another possible means of arresting a vigilance decrement, and the condition of primary interest in the present study, is the periodic alternation of the sensory input channel to the human. Sensory alternation[1] is the term that will be used to refer to this condition of signal presentation.

That sensory alternation might be anticipated to be an effective means of helping to sustain alertness finds theoretical support from two sources: the "filter theory" hypothesis discussed by Broadbent (1958); and Frankmann's and Adams' (1962) treatment of Scott's (1957) review of the evidence deriving from studies of varied (and patternless or deprived) sensory environments. According to the filter theory hypothesis, our perceptual processing, in terms of which signals proceed to awareness, can be described in part in terms of a filter which, as a function of the recent and ongoing level of stimulation, becomes positively biased in favor of those

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[1] "Sensory Alternation" will be used throughout the discussion to refer to the periodic changing of the sensory modality to which the signals to be detected by an operator are presented in a task requiring sustained perceptual alertness.

channels not recently activated. Scott's review, in referring to the arousal and/or motivational properties of stimuli, is interpreted as concluding in part that (Frankmann and Adams, 1962, p. 265):

> ...loss of efficiency (is) directly related to reduction in stimulus variation... The more unchanging are the critical stimuli, the sooner deterioration will occur. Rest periods and... extraneous stimuli... increase the variety of stimulation...

Thus, in the case of sensory alternation, the shift from one sense channel to another might be anticipated to counteract the "sensory habituation" (Scott, 1957) that increases as exposure to the same stimuli is prolonged--especially under the conditions of a homogeneous background or the greatly reduced level of extra-task stimulation characteristic of many monitoring situations.

Since some existing theories would lead one to anticipate a beneficial effect from sensory alternation, it was felt that an examination of sensory alternation--if results were consistent with expectations--would provide further support to the theories.

In selecting the experimental conditions to be studies, a dual-sense, simultaneous presentation of signals to both the visual and auditory channels was also included. The primary reason for including this condition was that, within the context of the experiment to be described in the next section, the dual-sense or redundant presentation condition offered an opportunity to also collect information bearing upon the "activationist hypothesis" (Broadbent, 1958). The activation hypothesis, which seems to have many identities with the varied sensory environment thesis, relates alertness to the stimulation level of the task. When the level of stimulation is decreased (such as in typical vigilance situations) or becomes homogeneous and relatively unchanging, the alertness level of the entire organism degrades. If level of stimulation alone were sufficient to account for performance in a vigilance task, one would expect that a dual-sense or simultaneous presentation of signals to two channels should prove a more effective procedure than sensory alternation. Under the latter condition, the level of stimulation (in terms of the number of signals presented) is one-half that of the redundant, dual-sense mode.

The objectives of the present study were thus to provide information bearing on the following:

1. Is sensory alternation an effective means of arresting the deterioration in detection performance that is characteristic of vigilance tasks?

2. What is the relative advantage (if any) between the simultaneous use of both the visual and auditory channels when compared with the alternating use of these same channels?

It was also anticipated that the present study would provide additional data on the benefits to be expected from the dual-sense or bi-modal, redundant signal input condition.

Method

Design. The study was designed to provide repeated measurements on each test subject over four experimental conditions. The four experimental conditions were:

Condition 1. (V) -- Visual presentation only of the signals to be detected throughout the two-hour watchkeeping period.

Condition 2. (A) -- Auditory presentation only of the signals to be detected.

Condition 3. (R) -- Combined, simultaneous (and redundant) visual and auditory presentation of the signals to be detected.

Condition 4. (V/A) -- Alternation, in 30-minute periods, of auditory presentation alone and then visual presentation alone of the signals to be detected.

The sequence in which subjects performed under each of the experimental conditions was counter-balanced in order to counteract any learning or other effects that might attend the order of testing.

Subjects. The subjects (Ss) were eight (8), volunteer, male high school students with no apparent visual, auditory, or other sensory defects. Their ages ranged from 16 to 18 years, and all were in the college preparatory program. One student was a junior and the rest were seniors. Each student was tested individually for two hours on each of the four experimental conditions. A subject was tested on one condition only on any given day, and most of the subjects completed the schedule within a one-week interval.

Experimental Setting and Apparatus. Testing was performed in two adjoining laboratory rooms occupied respectively by the test subject and the experimenter (E). All equipment except the display apparatus and a response key were located in the experimenter's room.

The visual conditions of signal presentation are illustrated in Figure 1. A subject sat in a straight-back chair facing the display which was located approximately 10 degrees below his standard line-of-sight. The display-to-eye distance was approximately 36 inches; the distance between a plumb line from the face of the display and the front edge of the fixed chair was 26 inches. Subjects were allowed to change their sitting positions in the chair.

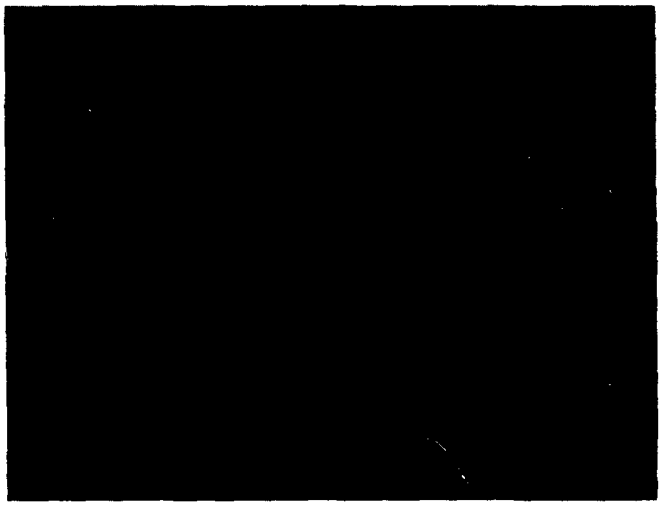

Figure 1. Photograph of the Apparatus Illustrating the Visual Condition of Signal Presentation

The actual display was generated on the 5-1/2 inch screen of a Hewlitt-Packard 122A oscilloscope with P7 phosphor. As may be seen in Figure 1, a special plastic screen was etched with a single, thin, horizontal line. (In order to obtain an acceptable photograph, the intensity of the horizontal line was increased considerably above that needed during the study; hence the noticeable irradiation effect in the photo which makes the line seem thicker than was actually the case.) The horizontal line was 3-1/2 inches long and located 1-1/2 and 1-3/4 inches from the top and bottom respectively of the face of rectangular screen area shown in Figure 1. Opaque black electrical tape was used to demark the 3-1/4 x 3-1/2-inch rectangular boundaries of the display. The intensity of the thin horizontal line was controlled by the voltage applied to the lamps providing edge-lighting to the plastic screen. The intensity of the line could be varied from zero to well above threshold, and control of this feature was remoted from the oscilloscope to the control panel. White noise from a type CAOW-35 ABP Modulation Generator was presented visually on the oscilloscope to form the display background.

The background "noise" continually swept across the display from left to right at the relatively slow sweep rate of 400 milliseconds per centimeter. As the effective width of the oscilloscope was approximately 10 centimeters, it thus required four seconds for the sweep to traverse the display. The background "noise" completely filled the 3-1/4-inch vertical distance of the display, as shown in Figure 1. While no intensity measurements were taken of the scope face, it should be reported that the sweep intensity was adjusted to a comfortable level well above threshold but below the level at which the sweep line starts to "bloom" or irradiate. The intensity of the sweep was fixed at the beginning of the study and remained the same thereafter for all subjects. (The photograph in Figure 1 distorts the actual condition in that no fading of the sweep is shown at the left side of the display.)

Thus, as described above, a visual display was generated which seemed analogous to many radar-type watchkeeping tasks. The pulse sweeping at a rate of 15 sweeps per minute provided a noise background against which the wanted signal was to be detected. As will be described more fully later, the wanted signal was the momentary extinguishing of the horizontal line.

The auditory conditions of signal presentation were designed to be qualitatively analogous to the visual setting. White noise generated from the same CAOW-35 ABP Modulation Generator was presented as a continuous background over a set of Koss SP-3 stereo earphones. The intensity of the white noise remained fixed throughout testing. As measured with a General Radio Type 1551-B Sound-Level Meter, the intensity readings of the white noise taken at the S's position with the meter microphone positioned between the earphones were:

Weighting Scale	db Level (Slow Reading)
A	56-57
B	60-62
C	67-71

Superimposed on the white noise in both earphones was a 1000 cps tone generated by a Heathkit AG-10 Sine-Square Generator. The intensity of this 1000 cps tone could be varied from zero to well above threshold at the E's position. As will be discussed more fully later, the wanted signal in the auditory task was the momentary interruption of the 1000 cps tone.

A signal presentation rate of 20 signals per hour was programmed semi-automatically through the use of a Dual-Trol, Model D. T., Industrial Timer and a Hunter 100B Interval Timer. Signal interruptions of . 1-second duration were controlled by the Hunter Interval Timer. The Dual-Trol permitted individual scheduling of successive signals and also controlled a latching relay which caused a 1/100-second, electric clutch, laboratory timer to continue to run for six (6) seconds following the presentation of a signal.

The signal presentation schedule is shown on the Sample Data Collection Sheet and Stimulus Presentation Schedule in Appendix A. There were 10 signals per half-hour, and the schedule repeated itself for each of the four half-hour testing periods. Within each half-hour period, the inter-signal interval ranged from 1. 5 minutes to 4. 0 minutes in a random sequence which contained two of each of the following intervals: 1. 5, 2. 0, 3. 0, 3. 5, and 4. 0 minutes. The presentation schedule was held invariant for each of the four test periods in order to provide the closest possible control over the signal mix and thus allow subsequent comparison of segments of performance.

In addition to the apparatus already mentioned, a Superior Electric Powerstat 116 variac was used to maintain, as uniform as possible, the power being supplied to the oscilloscope. Several Chicago Standard P-6410 Isolation Transformers were also used to provide electrical independence and uniformity between the audio and visual signal-generating equipment. A Simpson Model 266 Multimeter and a Superior Instruments Model 77 Vacuum Tube Volt Meter were used to monitor the visual and auditory signal levels respectively throughout the testing sessions. As will be described later, these meters were also used in establishing the visual and auditory thresholds of subjects.

The low level, indirect, ambient illumination in the S's room was provided by a single 7-1/2 volt, white, General Electric incandescent lamp. The lamp was contained in a fixture with an opaque shade. Light from the fixture cast upon a crinkled aluminum foil reflector and was diffused toward the ceiling. The source and reflector were located in a position which shielded them from the S's field of view. Measured at a distance of one foot with a Photovolt Model 210 Photometer, the following readings of the intensity of the ambient light source were obtained:

.05 foot-candle -- with the photocell plate positioned parallel to the reflected light rays

.4 foot-candle -- with the photocell plate positioned normal to the reflected light

Procedure. As already described, the visual and auditory tasks were designed to be generally analogous. Both tasks required that a subject detect the aperiodic interruptions of a relatively distinct signal feature displayed against a continuous noise background. In an attempt to generally equate further the auditory and visual tasks, the intensities of both the horizontal signal line and the 1000 cps signal tone were both adjusted to near-threshold values for each subject. Using the continuous adjustment variation of the psychophysical method of limits, a total of 20 series of alternatively ascending and then descending trials were taken for the scheduled test condition on each subject prior to every experimental session. From these data, the signal intensity corresponding to the 75% threshold was established. These near-threshold intensity settings were then made on the apparatus, and each subject was given five (5) practice trials of the .1-second interruptions at this setting. The practice trials were presented randomly but in close succession. If an S missed more than one signal, E told S of his failures and repeated the trials.

Another point seems worthy of mention concerning the use of the near-threshold intensities. In addition to being perhaps one of the few ways of approximately equating the stimulus conditions for the different senses, as shown by Teichner (1962), detection performance during a vigilance task seems directly related to the probability of detection prevailing at the initiation of the task. Thus, matching the visual and auditory tasks on their initial probability of detection also seemed desirable should interpretation of any between sense comparisons be attempted subsequently.

The general procedure used with each S was as follows. After an S arrived for testing, he was allowed 15 minutes to dark adapt, if his schedule trial included the visual detection task. Next, S's threshold(s) were determined as described above. If it was the first test session with a subject, S was next read the standard Instructions to Subjects, contained in Appendix A. Then S was given five practice trials as mentioned above. (E went directly from the threshold determination to the practice trials in subsequent sessions with an S.) Following the practice trials, the two-hour testing session was started during which there was no communication between E and S. As stated in the Instructions to Subjects, S's watch was removed so that distractions from the task would be minimized.

Regardless of whether the test session was visual alone, auditory alone, or alternating, the background sweep on the oscilloscope and the white background noise in the earphones were always presented. That is, the noise backgrounds to both senses were constant for each subject for all of the test sessions. An S wore the earphones and sat before the oscilloscope at all times during each test session. Whether or not the horizontal line (visual signal), 1000 cps tone (auditory signal), or both the horizontal line and 1000 cps tone were present depended upon which test condition S was scheduled to receive.

After each half-hour interval, for all test conditions, E momentarily blinked twice the small 7-1/2 watt light providing ambient illumination in S's area. This was done primarily to facilitate informing an S that E was about to shift channels in the alternating condition. Since it seemed desirable to use this impersonal, visual, signalling system under the alternating condition, the momentary blinking was continued for the other three test conditions in order to keep all conditions constant. (Otherwise, the blinking with the alternating condition would have been added extraneous stimulation.)

With regard to the alternating condition, S's all performed under the following sequence: auditory detection for the first half-hour; visual detection for the second half-hour; then auditory again; and finally visual detection for the last period. When shifting sense channels, E, after blinking, first switched off the previous signal and then switched on the alternative signal. Thus, in going from auditory to visual, the 1000 cps tone was cut-off and the horizontal line switched on.

As described also in the Instructions to Subjects (Appendix A), a monetary schedule of pay and reward was used in order to motivate subjects, maintain their motivation over the four test sessions, and induce them to return for all four of the separate testing sessions. The payment schedule was as follows. A basic hourly rate of $1.25 per hour, or thus $2.50 for each two-hour session, was established consistent with prevailing State law. In addition to the hourly rate, S's were told that they could earn a considerable bonus for good work. They could earn an additional $.10 for each signal that they detected and responded to quickly. However, they were also told that $.10 would be subtracted from their bonus money for each signal that they failed to detect. Further, they were told that $.05 would be subtracted from their bonus money if they responded when no signal had been presented. While the foregoing was perhaps a generous schedule, it did seem to produce the desired results. All subjects returned for all of the test sessions, and all seemed anxious to learn how much bonus money they had earned following each session. (Repeated exposure to two hours of forced concentration in a homogeneous, dim, sensory deprived environment is not the kind of situation most high school boys seek out.) S's were given their earnings immediately following each session in order to closely associate the reward with their effort.

In making a response, S pressed a response key which he held in his hands throughout a test session. The response key consisted of a spring-loaded push-button switch mounted in a hand-sized box. The push-button switch was fitted with a white bar key which was pivoted at one end (on its long axis). The bar key was used to facilitate location and activation of the switch. Operation of the switch caused two actions to occur at E's position: (1) a relay was unlatched which simultaneously stopped the response time clock; (2) a 100 watt incandescent lamp positioned at E's eye level and at a distance of less than two feet was illuminated. Every time S depressed the switch, the 100 watt lamp was energized; the relay could be unlatched only when the clock had been activated via the interval programming timer. The latter concurrently: (a) latched a relay which in turn simultaneously started the response time clock; and (b) also triggered the Hunter stimulus duration timer.

As a final point, it should also be mentioned that E's area was "bathed" in noise as an added safety precaution during the testing. This added precaution was taken to insure that no extraneous cues or distractions could reach S--even though S was required to wear the earphones at all times and the adjacent room in which S was located was fully partitioned. The noise was provided by two exhaust blowers and a radio tuned to an off-channel frequency.

Measures. Data were collected on each of the following performance measures:

- Number of Signals Missed
- Number of False Detections
- Response Time for Each Signal Detected

With regard to the collection of the response time data, it should be mentioned that the response timer could run-on for six seconds following the presentation of the .1-second stimulus. The duration of timer clock run-on was controlled by the second portion of the Dual-Trol interval-timer. The latter automatically opened the latched relay (thus stopping the response timer) if an S failed to respond within six seconds from stimulus presentation. While six seconds is rather long, it avoided any doubt that a signal should be recorded as "missed" if no response was made within this time frame. (In practice, only a few isolated responses occurred at latencies of three seconds.)

False signals were manually recorded by tallying a mark every time the 100 watt lamp in front of E went on when no stimulus signal had been presented.

Results

The results will consider separately the data obtained on each of the performance measures: percentage of signals detected; number of false signals; and response time. As an overview, Figures 2 and 3, and Tables 1 and 2 deal with the percentage of signals detected; Table 3 concerns the number of false signals; and Tables 4 and 5 present the response time data. In Appendix B, Tables 6, 7, and 8 provide additional, detailed data on individual subject performance for each time period under the four experimental conditions for signal detection performance, false signals, and median response time respectively.

Percentage of Signals Detected. Table 1 presents the percentage of signals detected by each subject under each of the four experimental conditions. A Friedman Nonparametric Two-Way Analysis of Variance by Ranks (Siegel, 1956) was performed on these data, and the results are summarized below Table 1. It may be seen that significant differences were found among the experimental conditions. Both the sensory alternating condition and the redundant signal condition resulted in significantly b .tter detection performance than that obtained under the visual or auditory conditions.

Figure 2 presents graphically the percentage of signals detected under each of the conditions by half-hour periods. The data for Figure 2 may be found in Table 6, Appendix B.

The effectiveness of sensory alternation over both the visual condition and the auditory condition is demonstrated even more clearly in Figure 3. In this figure, the dashed "continued" line plots the percentage of signals detected in the corresponding half-hour period with the appropriate sense channel. That is, since the second period under the alternating condition used the visual task, the point used to plot the "continued" line is the percentage of signals detected in the second period taken from the data obtained

Table 1.

Percentage of Signals Detected by Each Subject
Under the Four Experimental Conditions

	V	A	R	V/A	Average for Each S
Subject # 1	92.5	85.0	97.5	100.0	94.0
2	65.0	82.5	72.5	82.5	76.0
3	70.0	60.0	77.5	80.0	72.0
4	65.0	42.5	87.5	65.0	65.0
5	65.0	85.0	87.5	90.0	82.0
6	55.0	60.0	55.0	87.5	64.0
7	65.0	77.5	95.0	90.0	82.0
8	90.0	45.0	82.5	80.0	74.0
Average for Each Condition	70.9	67.2	81.9	84.4	

Summary of Friedman Two-Way Analysis of Variance by Ranks

	V	A	R	V/A
Sum of the Column Ranks (R_j)	25.0	25.5	16.5	13.0

$\chi^2_r = 8.74^*$ $p < .05$

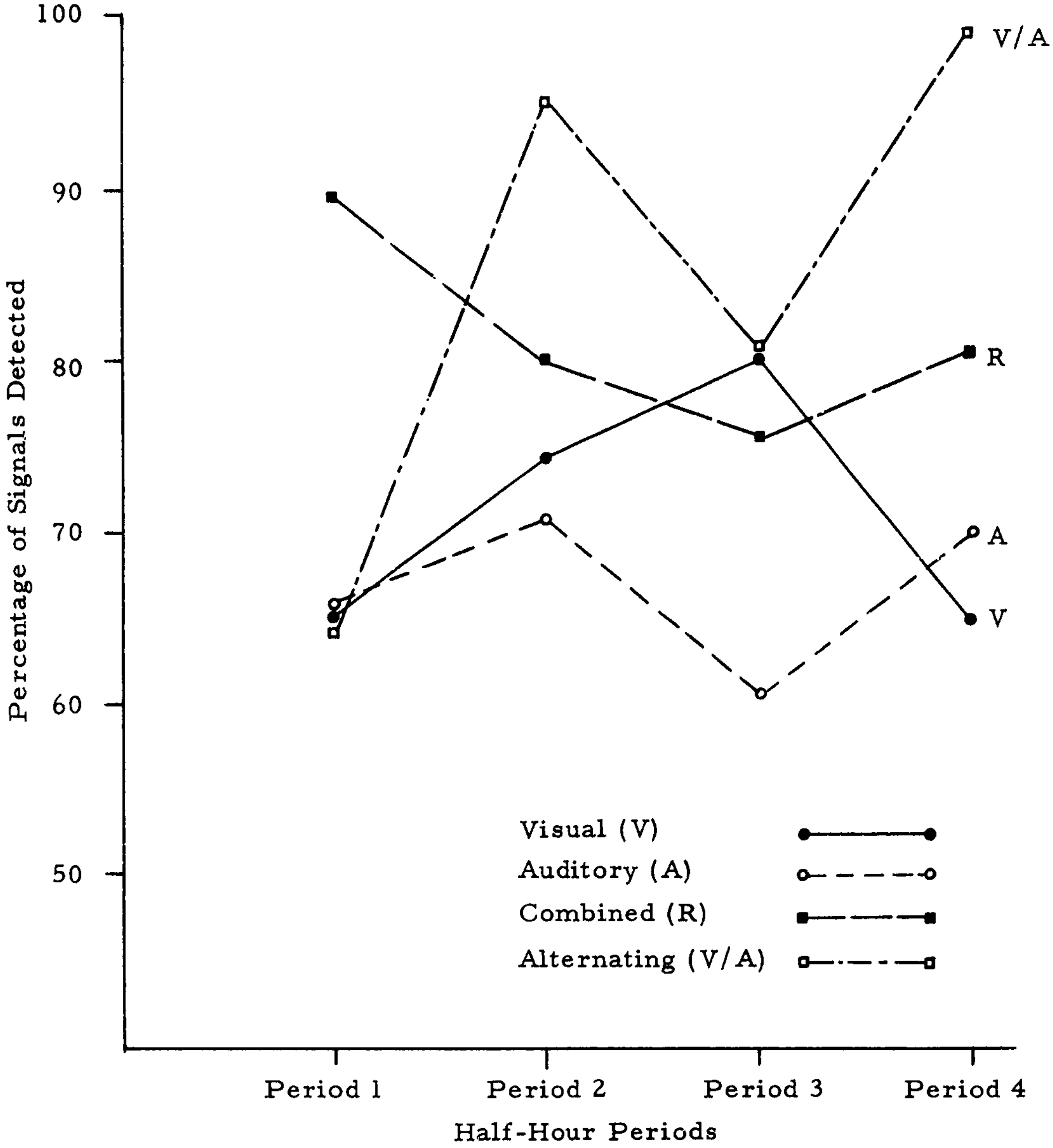

Figure 2. Percentage of Signals Detected in Each Half-Hour Period under the Four Experimental Conditions (N = 8)

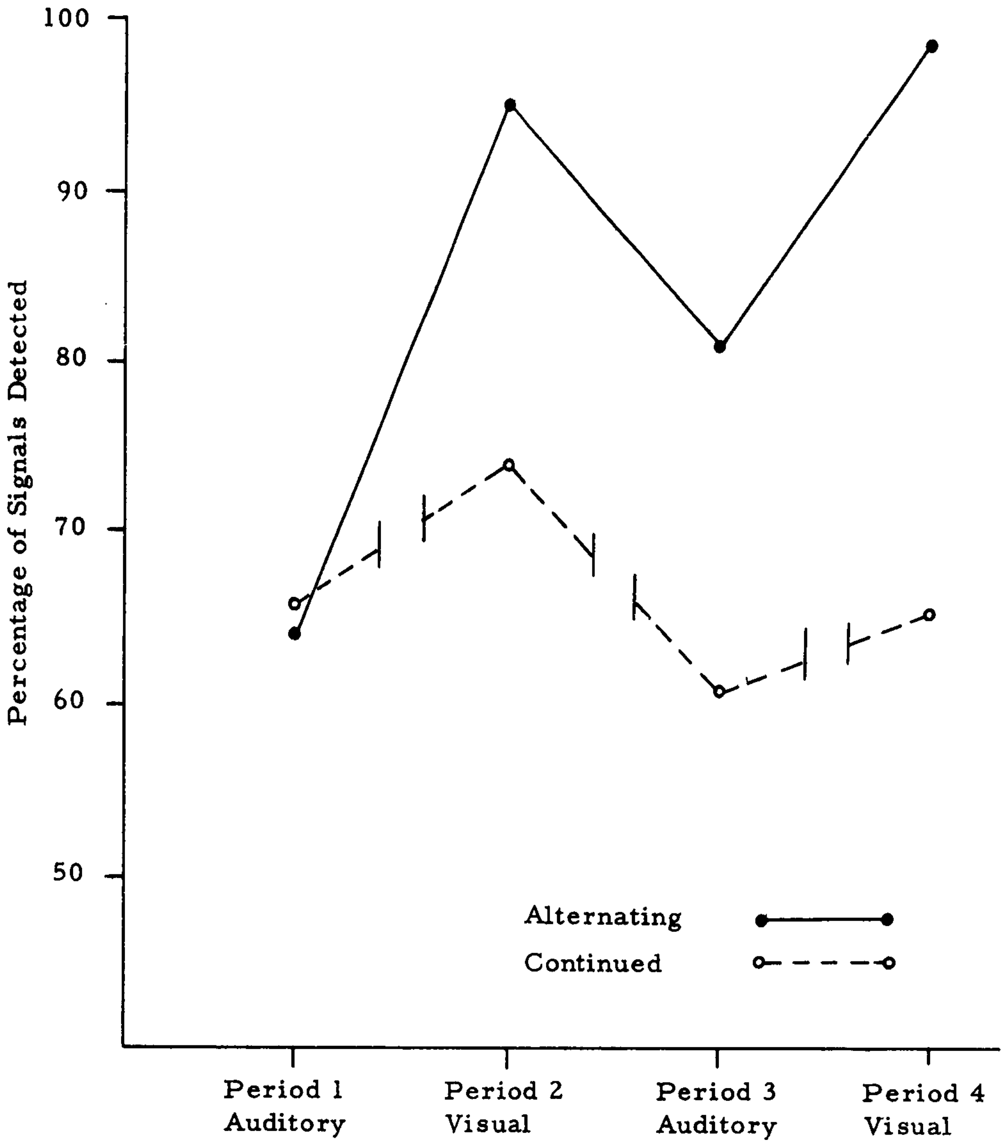

Figure 3. Percentage of Signals Detected in Half-Hour Periods: Sensory Alternation Compared with Performance Obtained in Corresponding Segments under Single Channel, Continued Monitoring (N = 8)

under the visual task condition (V). Most noticeable is the fact that while performance tended to deteriorate under both the visual and auditory conditions, performance actually improved increasingly above its initial level under sensory alternation.

The comparative effectiveness of sensory alternation, as shown in Table 1, was achieved despite the fact that the data from several subjects indicate differences between their visual and auditory performance (see Tables 2 and 6). On the average, alternation was significantly beneficial despite the existence of sensory differences, favoring a particular modality, within some individuals.

Since detection performance was the primary dependent variable and also because the foregoing results were positive, the data on the number of signals detected were also subjected to a parametric analysis of variance in order to examine interaction effects. Table 2 summarizes the results of this analysis. In determining appropriate denominators for the F-tests, Treatment Conditions (C) was considered a fixed factor and Half-Hour Periods (P) and Subjects (S) were considered random factors (Winer, 1962).

Consistent with the nonparametric results already mentioned, treatment conditions (C) was a significant main effect. As is characteristic of the findings in other studies, significant differences were also found among subjects (S). No differences were found among half-hour periods.

Two significant second-order interaction effects were obtained: treatment conditions (C) with subjects (S); and half-hour periods (P) with treatment conditions (C). The significant interaction between conditions and subjects (C X S) confirms the statement made earlier that some subjects tend to display noticeable sensory differences favoring either the visual or auditory modality (see Table 6). The significant interaction between periods (P) and conditions (C) is characteristic of findings in other related studies and also to be expected from an examination of Figure 2. The shape of the curves for each treatment condition not only differed, but as pointed out earlier, under sensory alternation detection performace increasingly improved over the watch period. A general improvement in detection is not characteristic of performance in most vigilance tasks.

Number of False Signals. Table 3 presents the number of false signals reported by each subject under the four experimental conditions. (Table 7 in Appendix B presents similar data broken-out by performance in each half-hour period under the four treatment conditions.) A Friedman Two-Way Analysis of Variance by Ranks was performed on the data in

Table 2.

Analysis of Variance Summary Table of the Number of Signals Detected Under the Four Experimental Conditions

SOURCE	df	MS	F
Half-Hour Periods (P)	3	5.26	
Treatment Conditions (C)	3	21.80	6.39**
Subjects (S)	7	15.14	4.63**
P X C	9	7.35	3.34**
P X S	21	3.27	
C X S	21	5.34	2.43**
Residual (P X C X S)	63	2.20	

* $p < .05$
** $p < .01$

Table 3.

Number of False Signals for Each Subject Under the Four Experimental Conditions

	V	A	R	V/A	Subject Total
Subject # 1	8	27	0	4	39
2	5	0	5	6	16
3	2	4	1	6	13
4	2	18	6	9	35
5	1	1	0	1	3
6	4	6	0	4	14
7	25	3	0	7	35
8	4	19	0	2	25
Total for Each Condition	51	78	12	39	

Summary of Friedman Two-Way Analysis of Variance by Ranks

	V	A	R	V/A
Sum of the Column Ranks (R_j)	21.0	25.0	10.5	23.5

$\chi_r^2 = 9.63^*$ $p < .05$

Table 3, and the results are summarized below the table. Significant differences were obtained among the experimental conditions. As indicated rather clearly by the analysis of variance summary table, significantly fewer false signals were reported under the dual-channel, redundant condition. Over the eight subjects, there were no differences among the visual, auditory, or alternating conditions with respect to the incidence of false signals. All three conditions were inferior to the redundant, dual-channel condition.

Response Times. Table 4 presents the median response times of each subject under the four experimental conditions. (Table 8 in Appendix B presents similar data broken-out further by performance in each half-hour period.) The results of a Friedman Two-Way Analysis of Variance by Ranks are summarized below Table 4. No reliable differences were evidenced among the four experimental conditions.

Table 5 presents the same data broken-out this time for each of the four half-hour periods. The tabled data were obtained by averaging the median response times of the eight subjects for each half-hour period. As indicated by the results of the Friedman Two-Way Analysis of Variance summarized below Table 5, highly significant ($p < .0009$) results were found among the periods. In general, over the four experimental conditions, response time tended to increase as the duration of watchkeeping was prolonged. This finding will be discussed further in the next section.

Discussion

The foregoing results demonstrate quite clearly that sensory alternation is an effective means of maintaining alertness in a vigilance task.

Consistent with recent findings by Osborn, Sheldon and Baker (1963), the dual-sense, redundant condition also resulted in significantly improved detection performance when compared to the pure visual and pure auditory conditions.

The redundant, dual sense condition was also significantly better than the other treatment conditions with regard to the number of false signals reported. The other three treatment conditions (alternation, visual, and auditory) resulted in essentially similar performance in this regard. The higher occurrence of false signals under these conditions might be viewed in a manner similar to the hallucinatory experiences that have been reported in sensory deprivation investigations. As a result of the homogeneous task

Table 4.

Median Response Times for Each Subject Under the Four Experimental Conditions*

	V	A	R	V/A	Average for Each S
Subject # 1	.55	.62	.51	.44	.53
2	.60	.55	.55	.63	.58
3	.70	.65	.73	.66	.69
4	.57	.60	.73	.63	.63
5	1.04	.60	1.19	.85	.92
6	.88	1.13	.99	.75	.94
7	.75	.91	.73	1.13	.88
8	.72	1.01	.78	.77	.82
Average	.73	.76	.78	.73	

*Response time in seconds

Summary of Friedman Two-Way Analysis of Variance by Ranks

	V	A	R	V/A
Sum of the Column Ranks (R_j)	18.0	20.5	22.5	19.0

$\chi_r^2 = 0.86$ (Not Significant)

Table 5.

Averaged Median Response Times for Each Half-Hour Period for the Four Experimental Conditions*

Half-Hour Periods	1	2	3	4
Visual Condition	.68	.73	.75	.76
Auditory Condition	.74	.75	.81	.86
Redundant Condition	.73	.75	.84	.79
Alternating Condition	.70	.74	.76	.78
Grand Averages	.71	.74	.79	.80

*Response time in seconds

Summary of Friedman Two-Way Analysis of Variance by Ranks

Half-Hour Periods	1	2	3	4
Sum of the Column Ranks (R_j)	4	8	13	15

$\chi_r^2 = 11.1$** $p < .00094$

conditions and dim, infrequent signals, the false responses could, in part, be attempts from within the individual to introduce variation in his environment.

With regard to the theoretical considerations mentioned in the introduction, the obtained results (effectiveness of sensory alternation) are consistent with both Broadbent's filter hypothesis and the varied sensory environment thesis of Scott. Since sensory alternation resulted in detection performance equivalent to that obtained with the redundant, dual-sense condition, it seems that a pure level of stimulation concept is not sufficient to explain vigilance performance. It will be remembered that twice as many signals were presented to an S under the redundant condition than with the other three treatments. (It is possible to think that behavior in the redundant condition is actually the result of a selective, internal alternation.) The fewer false signals reported under the dual sense condition may result from the redundant signal acting to permit confirmation of the signal first detected. The latter finding is also consistent with previous findings where redundant signals which aid signal discriminability improve the accuracy of human performance.

Turning finally to the response time results, as Mackworth (1950) has discussed, this measure is rather less sensitive than the others because no data were possible on the missed signals. Notwithstanding the latter fact, significant differences were obtained between half-hour periods when averaged over subjects. The four treatment conditions resulted in virtually identical response time trends: as the duration of the vigil was prolonged, median response times increased. This finding seems contrary to a recent study by Teichner (1962) in which the conclusion is made that speed of response to a detected signal in a vigilance task is independent of the length of the watch. No explanation seems to suggest itself for this contradiction.

Conclusions

The obtained data support the following conclusions:

(1) Sensory alternation is an effective means of arresting the performance decrement characteristic of vigilance tasks.

(2) Where the task conditions require the detection of fleeting, near-threshold signals, sensory alternation and dual-channel or redundant sensory monitoring are equally effective in avoiding a decrement in

detection performance. The redundant condition is superior from the standpoint of accuracy of performance, as reflected by the infrequent occurrence of false responses.

(3) The speed of response, as reflected by the median response time for those signals which are detected, tends to increase with the length of the watch.

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APPENDIX A

INSTRUCTIONS TO SUBJECTS

(After determining necessary thresholds, the following is to be read to each subject:)

The purpose of the experiment in which you are about to participate concerns how well people can detect signals in a monitoring or surveillance situation. The data which we hope to collect from you and other subjects will be useful in determining how best to present data to humans to improve the detection of infrequent, random signals. For example, the data may be useful for such situations as: how to present information to humans in our early warning radar installations; or how to design shipboard sonar presentation systems to optimize the role of the human operator.

Your task during the testing session will be to detect the brief interruption of either an auditory signal or a visual signal. In some situations, the signals being interrupted may be presented both auditorily and visually.

The condition under which you will be tested today is (tell subject). The interruption of the signal(s) will be fleeting, as will be demonstrated to you now. (The experimenter should present the interruptions several times to the subject at this point.)

As soon as you perceive that the signal(s) has been interrupted, press this response key as quickly as possible. We will be interested in knowing how quickly you can respond. To repeat, your task is to detect when this (visual, auditory, combined) signal is interrupted and to respond as quickly as possible by pressing the response key.

Do you have any questions?

You will be tested for a total of two hours, during which time you will not be permitted to communicate with the experimenter or to leave your seat in front of the apparatus. We have asked you to leave your watch with the experimenter to avoid any distractions. The experimenter will tell you as soon as the testing session is over.

As you know, you are being paid for participating in this experiment. How much you will be paid is influenced in part by how well you perform during the experiment. We have established a minimum pay of two dollars and fifty cents for the testing session; however, you can earn an amount greater than this two dollars and fifty cents by correctly and quickly detecting each of the interrupted signals that will be presented.

In determining how much you have earned, we have established the following schedule: for every signal which you detect correctly and rapidly, you will receive ten cents; however, for every signal which you miss you will be penalized ten cents; also, if you respond falsely (when the signal has not been interrupted) you will be penalized five cents.

To review then, we want you to be as attentive as you can possibly can. As soon as you detect the interruption of the signal(s), press the response key. Do you have any questions?

(Insure that the subject is ready, then give subject 5 practice trials.)

(If no further questions, start experimental session.)

Sample Data Collection Sheet and Stimulus Presentation Schedule

Subject:________________________ No.: ___________

Date:___________________ Condition: Visual Auditory Combined Alternating (Circle)

Order in which S received this condition 1 2 3 4 (circle)

Period	Signal	Interval	Response Time	False Signals				
	1	3.5						
	2	3.0						
	3	2.0						
	4	2.0						
1	5	1.5						
	6	3.0						
	7	3.5						
	8	4.0						
	9	1.5						
	10	4.0						
	1	3.5						
	2	3.0						
	3	2.0						
	4	2.0						
2	5	1.5						
	6	3.0						
	7	3.5						
	8	4.0						
	9	1.5						
	10	4.0						
	1	3.5						
	2	3.0						
	3	2.0						
	4	2.0						
3	5	1.5						
	6	3.0						
	7	3.5						
	8	4.0						
	9	1.5						
	10	4.0						
	1	3.5						
	2	3.0						
	3	2.0						
	4	2.0						
4	5	1.5						
	6	3.0						
	7	3.5						
	8	4.0						
	9	1.5						
	10	4.0						

APPENDIX B

Table 6.

Number of Signals Detected in Each Half-Hour Period by Each Subject Under the Four Experimental Conditions

	VISUAL				AUDITORY				REDUNDANT				ALTERNATING			
Period	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Subject # 1	9	10	8	10	10	9	6	9	10	10	10	9	10	10	10	10
2	6	5	9	6	8	9	9	7	6	6	8	9	5	9	9	10
3	8	8	6	6	5	7	6	6	10	7	6	8	5	10	7	10
4	5	8	9	4	0	6	4	7	9	9	8	9	3	10	3	10
5	8	6	7	5	10	7	8	9	10	9	8	8	8	9	9	10
6	4	6	7	5	6	6	5	7	7	5	5	5	8	10	9	8
7	3	6	9	8	10	6	6	9	10	10	9	9	9	8	9	10
8	9	10	9	8	4	7	5	2	9	8	7	8	3	10	9	10
Average Per Cent Detection	65	74	80	65	66	71	61	70	89	80	76	81	64	95	81	98

Table 7.

Number of False Signals for Each Half-Hour Period and for Each Subject Under the Four Experimental Conditions

	VISUAL				AUDITORY				REDUNDANT				ALTERNATING			
Period	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Subject # 1	3	3	1	1	24	3	0	0	0	0	0	0	0	3	0	1
2	5	0	0	0	0	0	0	0	2	1	0	2	4	0	2	0
3	0	1	0	1	3	1	0	0	0	0	1	0	5	0	1	0
4	0	0	1	1	6	9	2	1	0	2	2	2	1	0	7	1
5	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
6	1	1	1	1	4	1	1	0	0	0	0	0	2	0	2	0
7	4	1	7	13	0	0	1	2	0	0	0	0	4	1	0	2
8	3	1	0	0	8	4	2	5	0	0	0	0	1	0	1	0
Total	17	7	10	17	45	19	6	8	2	3	3	4	18	4	13	4

Table 8.

Median Response Times for the Signals Detected in Each Half-Hour Period for Each Subject Under the Four Experimental Conditions

	VISUAL				AUDITORY				REDUNDANT				ALTERNATING			
Period	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Subject # 1	.54	.54	.54	.57	.58	.63	.71	.59	.51	.44	.65	.52	.35	.50	.34	.54
2	.71	.64	.52	.66	.61	.56	.52	.55	.53	.51	.52	.71	.54	.79	.63	.58
3	.71	.71	.68	.71	.66	.66	.71	.61	.66	.59	.74	.96	.71	.61	.59	.81
4	.71	.54	.59	.54	--	.56	.51	.71	.71	.71	.61	.81	.76	.61	.71	.58
5	.61	1.21	1.06	1.06	.56	.54	.68	.74	1.31	1.26	1.26	.81	.71	.71	.84	1.01
6	.61	.88	.89	1.06	1.16	1.01	1.31	1.18	.86	.94	1.16	1.04	.73	.71	.84	.71
7	.86	.56	1.01	.71	.90	1.01	.75	1.45	.68	.81	.79	.59	.91	1.28	1.05	1.29
8	.71	.73	.71	.76	.72	1.06	1.26	1.01	.59	.76	.96	.91	.86	.68	1.11	.72
Average for Each Period	.68	.73	.75	.76	.74	.75	.81	.86	.73	.75	.84	.79	.70	.74	.76	.78