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OBSERVING RESPONSES AND DECISION PROCESSES IN VIGILANCE[1]

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Vigilance performance was investigated within the framework of a two-stage model. A direct measure of the first phase, the observing response (OR) stage, was obtained by requiring *S*s to key press to produce the stimulus display containing either a signal or noise. The second phase, the detection-decision stage, was analyzed using both conventional measures and those derived from the theory of signal detection (TSD). Specifically, the effects of time, signal difficulty, and payoffs were investigated. Results indicated that the frequency of ORs increased with time, while vigilance performance decreased. It was suggested that simple frequency of ORs is under the control of variables different from those controlling the decrement function. Reliable estimates of TSD parameters were obtained for the difficult signal condition and were discussed in relation to the OR stage. Payoffs had no effect.

In a recent review, Swets and Kristofferson (1970) have suggested that vigilance tasks be placed more within the context of psychophysical experiments, especially when indexes derived from the theory of signal detection (TSD) are of major interest. Psychophysical analysis within the TSD framework has revealed that one can obtain estimates of two independent parameters: *S*'s sensory acuity (d') and *S*'s willingness to report a signal (his criterion, β) (Green & Swets, 1966). Psychophysical procedures are, of course, highly structured and explicitly designed to maximize *S*'s observation of the display on every trial. Vigilance tasks, on the other hand, are generally characterized, among other things, by the lack of an explicitly defined correspondence between *S*'s observing behavior and the occurrence of stimulus events. In fact, it is this latter relationship that is most often under investigation in vigilance tasks (Jerison, 1970).

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A two-stage model of vigilance behavior proposed by Jerison and Pickett (1963), if directly applied, most closely approximates a psychophysical procedure. The first stage consists of *S*'s decision of whether or not to observe the display and is a function of the costs and values associated with the response outcomes, as well as the a priori probability of signal occurrence. If, as in a psychophysical task, an observing response (OR) occurs, then the second stage, the analysis of the sensory information or detection-decision phase, is presumed to follow. Although Jerison (1970) further indicates that a TSD analysis is appropriate for the second stage, he has continued to elaborate upon and emphasize the importance of the observing response stage (Jerison, 1970; Jerison, Pickett, & Stenson, 1965). Holland (1958) has also suggested that vigilance data can be most readily understood in terms of observing responses in that the probability of detecting a signal depends on the rate of emission of ORs. To study the frequency of observing responses, Holland devised a technique which requires *S*s to make an overt OR, generally a key press, in order to briefly illuminate a display, thereby permitting *S*s to determine whether a signal is present. Holland found that ORs, i.e., key presses or eye movements (Schroeder & Holland, 1968), are reinforced by the detection of suprathreshold signals, even in the absence of any other extrinsic reinforcement.

The present experiment was designed to study vigilance performance within the framework of the two-stage model. Specifically, by employing a variation of Holland's technique, OR rate and detection-decision responses (for both conventional measures such as hits and false alarms and the TSD indexes d' and β) were investigated as a function of time, signal difficulty, and payoffs. Below-"threshold" and highly discriminable signals were presented to determine whether uncertainty as to the existence of a signal (given an OR) and the occurrence of false alarms (FAs) affect the distribution of ORs over time. To facilitate this evaluation, the occurrence of false alarms was made more likely by including a payoff matrix which increased the value of a hit and the cost of a miss. In addition, with respect to the payoff factor, the role of extrinsic reinforcement provided in the form of points associated with a financial reward for the possible response outcomes was investigated. Research involving this variable has produced ambiguous results for conventional measures (Weiner, 1969). With regard to TSD indexes, Davenport (1968, 1969) in both auditory and vibrotactile tasks, and Levine (1966) in an auditory task, found d' to be invariant with time and costs for misses and false alarms. These experiments also indicated that β was higher for high costs than for low costs and increased with time on task, whereas positive values associated with hits had no effect.

Method

Subjects.—Twelve students, obtained from an introductory psychology *S* pool served as *S*s. Each was paid $2.50/hr for participation. An additional incentive of $25.00 was paid to that *S* who achieved the highest point total.

Apparatus.—The stimuli consisted of 35-mm. slides of two vertical lines projected (Lafayette Model, KT-800) on a rear projection screen from an adjacent control room to the *S* room. Nonsignal or "noise" stimuli were defined as two vertical lines identical in height. A signal stimulus was one in which the upper segment of the right-hand member of the pair of lines was slightly longer than the left-hand member. For *S* to determine whether a trial contained a signal or noise, he needed only make a pair comparison on that trial.

The *S* was comfortably seated approximately 1.2 m. from the screen in a normally illuminated room. An easily grasped hand switch was placed in his left hand. Depression of this switch (OR key) briefly illuminated the display. Response buttons marked "yes" (indicating he believed a signal to be present) and "no" (indicating no signal present) were located on the extended right arm of the chair. White noise presented via a speaker (approximately 75 db.) from a Grason-Stadler (Model 901B) white-noise generator was used to mask extraneous sounds. All events were automatically controlled by the appropriate electromechanical programming and recording apparatus located in the adjacent control room.

Procedure.—Each *S* was scheduled for 10 sessions (only 1 session per day), with each session lasting 60 min. Care was taken to schedule each *S* at approximately the same time each day. Pilot investigations using the Yes–No (Y–N) psychophysical procedure (Green & Swets, 1966) provided the basis for the selection of two classes of stimuli: (*a*) An "easy" signal yielded 99.75% hits and no more than .2% false alarms. In practice, virtually all *S*s achieved 100% hits and 0% false alarms under these alerted conditions for the easy signal. (*b*) A "difficult" signal was defined as any combination of hits and false alarms that generated a d' value range of 1.5–2.5. In all sessions, the sequence of events required *S*s to first depress the hand switch, which after a 1.5-sec. delay was followed by a 200-msec. exposure of the stimulus event. The *S* was then required to press either the Yes or No key. A Y–N response was required on every trial and the OR key remained inoperative until the response occurred.

The first two sessions were devoted to instructions, training, and practice within the Y–N psychophysical procedure. After *S* became familiar with the task requirements, the sequence of events, and the slide stimuli, he was informed of the possible outcomes of his behavior as related to the occurrence of a signal or noise event, including an explanation of hits, misses, false alarms, and correct rejections. This was accomplished by first presenting a card consisting of the four-celled, stimulus–response matrix and then relating the matrix to *S*s' actual performance. Appropriately labeled feedback lights provided both information as to *S*s' accuracy as well as demonstrating the response outcome possibilities. When this was clear, the payoff matrix was introduced. The *S*s were told that we had found it worthwhile in the past to provide points for each correct response and to subtract points for each incorrect response and that a bonus of $25.00 would be given to the person with the highest point total obtained over the last eight sessions. Two payoff matrices were described. The first was balanced, providing one point for either a hit or correct rejection and subtracting one point for either a miss or a false alarm [1, 1, −1, −1]. The second payoff matrix provided 10 points for a hit and 1 point for a correct rejection and subtracted 10 points for a miss and 1 point for a false alarm [10, 1, −10, −1]. The *S*s were given practice for all four combinations of payoff matrix and signal difficulty using the Y–N psychophysical procedure. Immediate feedback as to *S*s' accuracy was provided and, although *S*s could rest as often as necessary since they initiated each trial by depressing the OR key, frequent rest periods were scheduled by *E*. Signals were programmed to occur randomly on 50% of the trials. The *S*s were given this information along with information regarding the payoff matrix currently in effect.

The remaining eight sessions were vigilance sessions consisting of two consecutive sessions each of the four combinations of payoff matrix and signal difficulty. The order of conditions was random with the restriction that each condition appeared an equal number of times at each position in the sequence. The *S*s were permitted to press the OR key as often as they wanted and told to try to detect as many signals as possible, thereby earning as many points as possible. Of course, no feedback or scheduled rest periods were provided during these 60-min. vigilance sessions, although *S*s were aware of the particular payoff matrix and signal level in effect for that session. Prior to each session, *S*s were informed of total points earned in the previous session and given a brief practice period.

Each vigilance session was divided into three 20-min. segments for programming and analysis purposes. Ten signals occurred within each 20-min. time block. The signal was available on a "limited hold" for 5 sec. Any OR during that time resulted in the presentation of a signal as well as terminating the limited hold. If the signal was not observed during this 5-sec. period, it was replaced by a nonsignal slide. The signal schedule was obtained by selecting randomly from a rectangular distribution of intersignal intervals, with the restriction that no intersignal interval be more than 240 sec. (twice the average interval) or less than 20 sec. This schedule was repeated three times throughout the session. Only the data from the second session of each payoff-matrix signal level combination was used for analysis.

Results

Percent hit data were arc sine transformed and an analysis of variance carried out on the transformed scores. Hits, misses, false alarms, and correct rejections were calculated only for those occasions when an OR occurred. A "miss" could also occur by simply not making an OR within 5 sec.; however, this information was treated separately.

The percent hits decreased significantly over the three time blocks, F (2, 22) = 7.26, $p < .005$, as illustrated in Fig. 1. The effect of signal difficulty was also

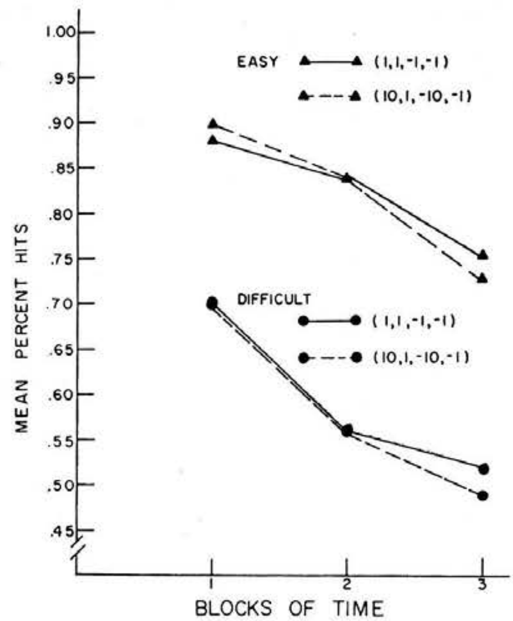

FIG. 1. Mean percentage of hits for each condition as a function of time.

significant, F (1, 11) = 81.71, $p < .001$; however, neither the interactions nor the effects of the payoff variable reached significance.

For the Difficult Signal condition only, an analysis of variance was applied to the arc sine transformed percent false-alarm data. A significant decrease in the percent false alarms as a function of time was obtained, F (2, 22) = 3.53, $p < .05$, but no other effects were significant. For the Easy Signal condition, percent false-alarm data were analyzed using nonparametric tests (Siegel, 1956), since these data were markedly skewed. A Friedman two-way analysis of variance was carried out separately for each of the payoff conditions to assess the effects of time. Neither the [1, 1, −1, −1] nor the [10, 1, −10, −1] matrix produced a significant effect. A comparison between the two payoff conditions was also not significant (Wilcoxon test, $p > .05$). Finally, the percent false alarms for each *S* was much higher in the Difficult Signal condition than in the Easy Signal condition, with no overlap between the distributions.

The frequency of observing responses in-

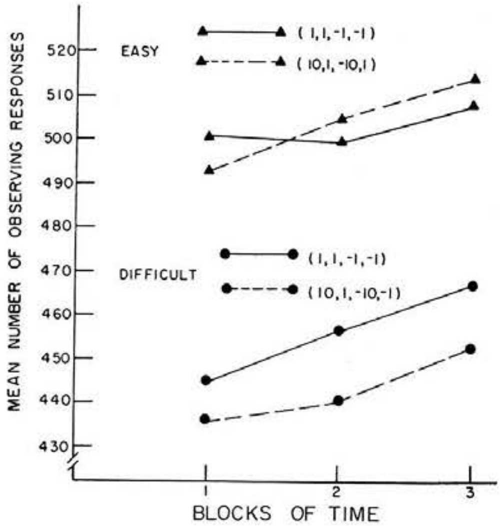

FIG. 2. Mean number of observing responses for each condition as a function of time.

creased significantly over time, F (2, 22) = 7.32, $p < .005$ (see Fig. 2), and a substantially larger OR rate resulted during the Easy Signal conditions than during the Difficult Signal conditions, F (1, 11) = 13.49, $p < .005$. The payoff variable again had no effect and none of the interactions approached significance.

The TSD measures, d' and β (see Table 1) were obtained from each condition from the hit and false-alarm data for each S for each of the three time blocks using Freeman's (1964) tables. However, TSD measures were derived for the Difficult Signal conditions only, for two reasons. First, the generally low rate of FAs that occurred in the Easy Signal condition does not permit

Table 1

MEAN THEORY OF SIGNAL DETECTION (TSD) MEASURES AS A FUNCTION OF PAYOFF MATRIX AND TIME ON TASK

Payoff matrix	Blocks of time		
	1	2	3
(1,1,−1,−1):			
d′	2.11	1.77	1.75
log β	.3731	.4521	.5784
(10,1,−10,−1):			
d′	2.06	1.61	1.59
log β	.2548	.3903	.5819

reliable estimates of the detection theory parameters (Swets & Kristofferson, 1970). Second, a straightforward application of the TSD model to data including the frequent occurrence of either 100% hits and/or 0% FAs (as occurred in the Easy Signal conditions in this experiment) has been objected to on both theoretical and empirical grounds (Jerison, 1970; Jerison et al., 1965; Swets & Kristofferson, 1970). In the few instances in which this did occur in the Difficult Signal condition, an interpolation procedure following Loeb and Binford (1968) was employed.

An analysis of variance revealed that d' decreased significantly over time, F (2, 22) = 3.64, $p < .05$, with no other variable or interaction significant. A similar analysis carried out on the log β values indicated a significant increase in those values over time, F (2, 22) = 7.76, $p < .005$, also with no other variables or interactions approaching significance.

The OR rates, even under the Difficult Signal conditions, were sufficiently high that most signals were observed during the 5-sec. limited hold. Although more signals tended to be missed in the Difficult Signal condition, the difference was quite small.

DISCUSSION

The frequency of observing responses increased with time, whereas vigilance performance decreased. For the Easy Signal condition, this latter fact is reflected by the progressive reduction in percent hits as a function of time (vigilance decrement), a result reported by a majority of such studies (see Jerison & Pickett, 1963; Mackworth, 1970). With respect to the increased rate of ORs, using a variation of Holland's technique in which ORs were defined as button presses to illuminate neon bulbs and the failure of a bulb to light constituting a signal, Broadbent (1963) found that the number of ORs increased with time, as did Holland (1958), at least for those Ss in Holland's study who rarely missed a signal. In addition, most Ss in the present study often observed the signal, as measured by key depressions, but failed to report its existence. Similar results have been reported by Broadbent and found in studies using eye fixations as the OR measure (Baker, 1960; Mackworth, Kaplan, & Metlay, 1964; Schroeder & Holland, 1968). Furthermore, as illustrated in Fig. 1, this tendency increased over time, an effect also noted by Broadbent and Schroeder and Holland.

All of the research discussed above employed signals readily detectable by an alert *O*. The present study has extended this work to include difficult signals, thereby permitting additional analyses using TSD indexes. For the Difficult Signal conditions, the percentage of hits decreased with time at a rate very similar to the Easy Signal conditions. However, this reduction in hits was not totally due to the fact that *S*s increased their criterion, β, since the sensitivity parameter, d', also decreased as a function of time. The OR rate was substantially lower for the Difficult than for the Easy Signal condition, primarily due to the increased decision time required by *S*s during the Difficult Signal sessions.

The design of this study was formulated in terms of a two-stage model of vigilance behavior described earlier. Jerison has further suggested (Jerison, 1970; Jerison et al., 1965) that the observing stage can be classified into at least three types of observing behavior: (*a*) alert, (*b*) blurred, and (*c*) nonobservation, and that vigilance data, including TSD measures, mainly reflect different proportions of time *S* spends observing in each of these response modes. The technique employed in this study provided direct information with regard to the occurrence or nonoccurrence (nonobservation) of an OR. In addition, given that a key press produces some mode of observing, the decrease in d' as the session progresses apparently reflects an increase in the proportion of blurred as opposed to alert observing (Jerison et al., 1965). In any event, at least for the Difficult Signal condition, it is assumed that the d' parameter reliably reflects sensitivity changes, whether due to different observing modes or to other processes. Furthermore, criterion changes can be identified.

The use of an observable and independent measure of ORs here has provided data that suggest that, in this situation, the simple occurrence or nonoccurrence of an OR is under the control of variables different from those controlling the decrement function, since these two measures were unrelated. The similarity of the forms of the OR curves over time for all conditions suggests that the OR function is not closely related to the level of signal difficulty (with associated properties such as a feedback function for easy signals not totally shared by difficult signals), the percentage of false alarms, or other characteristics intrinsic to the signal detection situation. Rather, factors such as the overall payoff may determine the distribution of ORs over time. However, when signal detections are the only specified goal, as in tasks such as Holland employs (Holland, 1958; Schroeder & Holland, 1968), signal detections may indeed serve as reinforcers for ORs and control their frequency of occurrence.

The Easy Signal condition yielded an extremely low rate of false alarms with many *S*s not producing any at all. The closeness to the lower limit of 0% may have prevented the normally obtained result in vigilance studies, a decrease in false alarms as a function of time, from occurring. In the Difficult Signal condition, however, as usual, the percentage of FAs decreased and the criterion β increased as a function of time. The general explanation for these changes is that *S*s have rather high expectations initially regarding signal probability and adjust their criterion appropriately as the session progresses (Colquhoun & Baddeley, 1964; Williges, 1969). The fact that the OR rate increased over time in this experiment suggests an additional possibility. As a consequence of the increased OR rate, *S*s in this experiment were experiencing increasing numbers of nonsignal trials, which effectively reduced the a priori probability of signal occurrence. This situation generally produces an increase in *S*'s response criterion (Baddeley & Colquhoun, 1969).

It was anticipated that by increasing the value of a hit and the cost of a miss, a lower β value would result, if *S*s were attempting to maximize the expected value of their point total (Green, 1960). Although the trend was in the right direction, especially for the first two time periods, a statistically reliable effect was not obtained. In fact, the payoff variable did not have a detectable effect on any of the dependent variables. Perhaps applying costs directly to false alarms or increasing the amounts of differential costs and values will affect, not only TSD parameters, but the observing response stage as well.

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