Variation in performance on auditory and visual monitoring tasks as a function of signal and stimulus frequencies[1]

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Observers were required to detect double jumps of a diffuse light spot jumping in a circular pattern and more intense noise pulses in a pulse train. Seven groups performed at different combinations of stimulus and signal frequencies, higher signal frequency/stimulus frequency ratios, and lower stimulus frequencies. Stimulus frequency was a more potent determiner of performance than signal frequency, and performance was not invariant within a given signal frequency/stimulus frequency ratio. Correlations of dependent measures were also examined. Results are discussed with reference to various theories of vigilance behavior.

Usually experimenters manipulating signal rate in vigilance experiments have reported less decrement and generally improved performance at higher signal rates (Jenkins, 1958; Kappauf & Powe, 1959; Smith, Warm, & Alluisi, 1964). Colquhoun and Baddeley (1964) reported that the principal effect is on average detection level rather than decrement and is heavily dependent on expectations regarding signal frequency established during pretraining. Recently researchers have concentrated less on signal frequency and more on the matrix of stimuli in which signals occur. Colquhoun (1961) and Jerison, Pickett, and Stenson (1965) have reported that detections decrease as the number of total stimulus events (signals plus nonsignals) per unit time increases. Johnston, Howell, and Goldstein (1966) have manipulated the number of signals and the size of the spatial matrix in which they occur and reported that variation of detections with signal frequency occurred only at high stimulus densities and variation with stimulus density only at low signal frequencies.

Colquhoun (1961) indicated that performance is determined not by signal rate alone but rather the ratio of signal to stimulus or event rate (i.e., signal probability). A similar suggestion was made by Jerison and Pickett (1963). Their data were analyzed in terms of the theory of signal detectability (TSD) (Swets, 1964) and in terms of a complex "decision" model for observing behavior. The former model assumed that observed decrements in detections and false alarms are attributable to changes in observers' criteria for responding. The latter model advanced by Jerison and Pickett assumes that detections of signals represent values associated with good or "alert" observing and that observations of nonsignal stimuli are costs which increase inefficient observing strategies. In a later article by Jerison, Pickett, and Stenson (1965), signal frequency appeared to have little, if any, effect, while detections decreased as event rate increased. In this paper the emphasis was on the cost of observing, and it was shown that spurious estimates of TSD indices (especially β, often interpreted as an index of conservatism) will be obtained if they are computed over periods involving several observing strategies.

False alarms (FA) generally have not been tabulated in relation to signal and carrier rate, possibly because FA rate was usually quite low. In the experiments of Jerison and his colleagues, FA rate decreased with time on task, but was not systematically related to signal or event rate (Jerison et al, 1965). Taub and Osborne (1968) recently reported that the number of FAs was relatively invariant with event rate and thus percentage FA was inversely related to event rate. Effects on detections were similar to those reported by Jerison et al—i.e., percentage of detections was an inverse function of stimulus (event) rate and not significantly related either to signal frequency or signal probability.

There appears to be sufficient conflicting evidence on the effects of signal frequency, event frequency, and signal probability to warrant further investigation. Moreoever, past experiments have employed only visual displays. Somewhat different results might be expected with auditory displays, as in this case the role of the orienting or observing response should be reduced.

METHOD

Each S served for three sessions, on different days. The preliminary session involved auditory screening and 15 min practice on auditory and on a visual monitoring task with feedback. In subsequent sessions Ss performed on the same auditory and visual monitoring tasks for an hour. Ss were assigned to one of seven groups of 16, each with a unique combination of signal and carrier rates. Six groups were formed by using three event rates—6, 12, and 24 events per min (epm)—and two signal rates—0.5 and 1 signal per min (spm). A seventh performed with a signal rate of 2 spm and an event rate of 12 epm.

Signals were presented randomly with the restrictions that the minimum intersignal interval between them was 10 sec and an equal number occurred within successive 10-min blocks of time. Ss were to respond as rapidly as possible by depressing a key. Responses within 2.5 sec after signal initiation were scored as detections; others, as FAs.

Auditory Task

Ss were seated within a soundproof room and listened to 0.5 sec noise pulses (auditory events) generated by a Grason-Stadler noise generator fed through switching equipment into Telephonics TDH 39 earphones. Nonsignal pulses were 60 dB (SL) in intensity; signal pulses were 61.8 dB.

Visual Task

The visual display, a variation of the Mackworth (1950) clock task, was observed in the same test chamber as the auditory display. It consisted of pilot lights arranged at 15-deg intervals around a 10-in. diam circle approximately an inch in back of a sheet of translucent plastic. These were sequentially illuminated for 0.25 sec at the appropriate event rate, producing the appearance of a diffuse spot of light moving circularly. Nonsignal events were 15-deg jumps; signals were double (30 deg) jumps.

Subjects

All Ss were University of Louisville students recruited without restriction as to age or sex and paid for participating.

RESULTS

Percentages of Detections

Mean percentages of detections (D) on visual and auditory tasks in successive blocks of time for each condition are plotted in Figs. 1a and 1b. The usual decrements appear present for all conditions. Effects of signal and event rates are not as definitive. There appears to be no general tendency for visual Ds to vary systematically with signal rate, but auditory Ds appear to be generally lower at the lowest (0.5/min) signal rate. There seems to be a tendency for Ds to decrease with increasing event rate, especially at the highest rate (24 epm).

Statistical analyses generally confirm these impressions. For D, as well as other measures described below, two kinds of analyses were performed. One was an overall 2 (Signal Rates) by 2 (Event Rates) by 8 (Blocks of Time) with repeated measures on the third factor. The "odd group" (2 spm, 12 epm) was excluded from this "overall" analysis. Another "supplementary" analysis was performed for the three groups performing at 12 epm, including the "odd group."

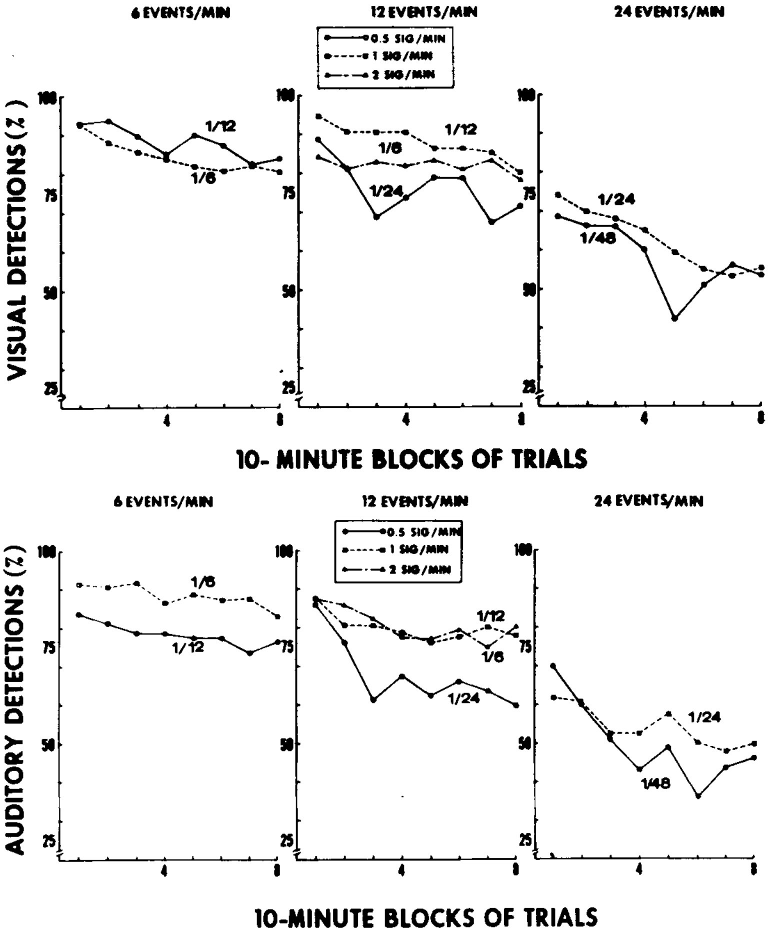

Fig. 1. Percentage detections for the various conditions as a function of time on task. (Numbers on the lines identify signal probability ratios associated with each condition. A signal probability of 1/12, e.g., may be generated by a signal rate of 0.5/min and an event rate of 6/min or by a signal rate of 1/min and an event rate of 12/min.) Above, visual conditions; below, auditory conditions.

The analyses showed variation over Blocks of Time and Event Rate to be significant for both visual and auditory tasks ($p < 0.01$). Variation with Signal Rate was significant on the overall analyses only for the auditory task ($p < 0.05$); with the supplementary analyses the effect of Signal Rate fell short of usually accepted criteria for significance ($.05 < p < .10$, for both tasks).

False Alarms

Mean FA percentages are plotted in Figs. 2a and 2b.

It will be noted that auditory FAs are considerably more numerous than visual FAs. It is also evident that for the visual conditions a decline occurred only for the condition (0.5 spm, 6 epm) with the greatest number of FAs, while FAs declined between the first and last block in six of the seven auditory conditions.

In both visual and auditory conditions FA percentages appear to be greatest at the lowest (6 epm) carrier rate, and there does not appear to be a regular systematic effect attributable to signal rate.

Again, the analyses generally confirmed the impressions gleaned from the curves. Variance attributable to blocks of time was significant only for auditory data ($p < 0.01$). In the overall analyses there was not significant variance attributable to signal rate for either visual or auditory tasks, but the supplementary analysis indicated significant variance with signal rate for visual tasks at the 12 epm carrier rate ($p < 0.05$). (Generally at this event rate FA percentages appear to decline with signal rate, but this effect is not maintained at other event rates.) There were significant interactions of Signal Rate with Blocks of Time as well as Signal Rate, Event Rate and Blocks of Time in the overall analyses of visual and auditory FA percentages ($p < 0.01$). Presumably these reflect differential signal rate effects at different event rates as well as differences in trend for the different conditions.

Analyses in terms of absolute number of FAs rather than FA percentages indicate that there is still significant variance attributable to Event Rate in both tasks ($p < 0.05$). There were also significant interactions of Signal Rate and Blocks of Time for the visual task and Event Rate and Blocks for the auditory, reflecting differential trends for the different conditions ($p < .01$). The mean absolute number of false alarms, unlike per cent FAs, is not highest at the lowest event rate; rather it is highest at the highest rate in the first block of trials but falls more rapidly at this event rate (24 epm).

Signal Probability Analyses: Hits and False Alarms

Another approach to the data is to determine whether performance is a function not of signal or event rate but rather the ratio of the two ("signal probability") as first suggested by Colquhoun (1961). Two of the conditions employed in this experiment had a signal probability of 1/6; two, 1/12; two, 1/24; and one, 1/48. The seven lines representing conditions in Figs. 1a, 1b, 2a, and 2b have been labeled in terms of signal probability (SP). If Colquhoun's hypothesis is correct, mean level of performance should be invariant at a given SP regardless of the signal and carrier rates producing it.

Since for both visual and auditory tasks there were four SPs with a high and a low event rate for three of these, analyses of variance (three-factor, repeated measures) were performed on the data for six of the seven conditions (excluding the signal probability, 1/48, which had only one event rate associated with it). Analyses of visual and auditory per cent detection data in these terms indicated that for both there was significant variance

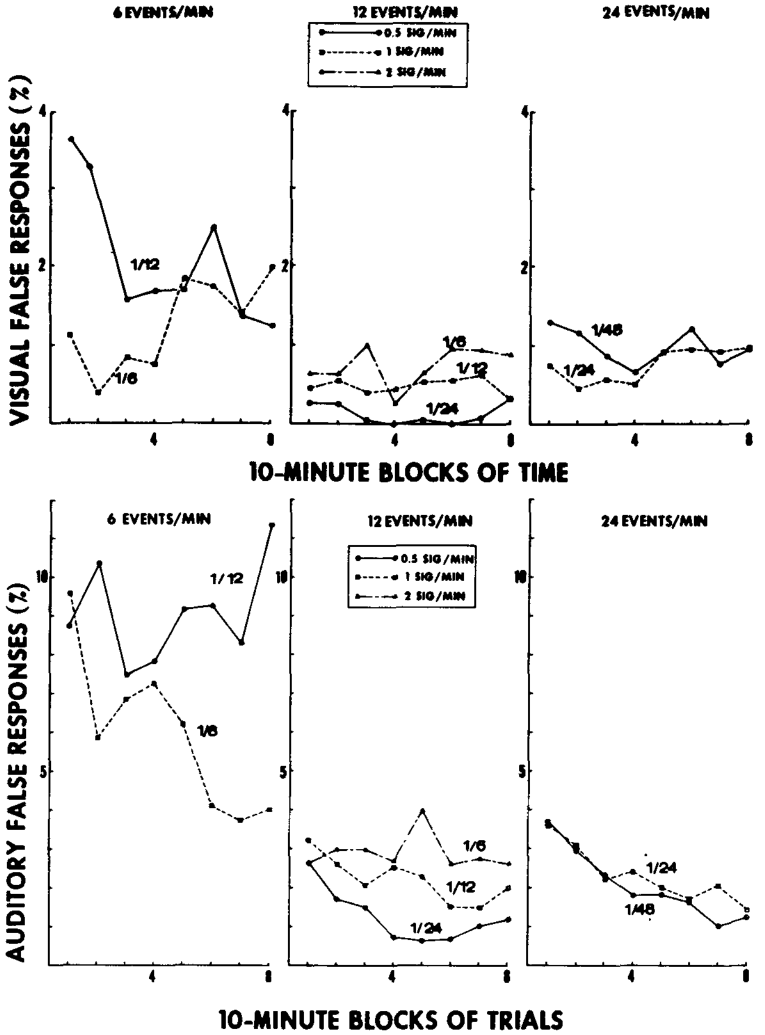

Fig. 2. Percentage false positive responses as a function of time on task. (Numbers on the lines identify signal probabilities.) Above, visual conditions; below, auditory conditions.

attributable to SP with Ds being generally higher at high SPs. However, for the auditory conditions there was also significant variance between event rates within SPs, Ds being higher at the lower event rates for the 1/6 and 1/24 SPs. (At 1/12 the difference between event rates is quite small and in the opposite direction.) No such differences were noted for visual Ds.

For visual FA percentages there was not a significant effect attributable to either SP or Event Rate, but there were significant interactions of SP and Event Rate ($p < .05$) and of SP, Event Rate and Time Blocks ($p < 0.01$). These interactions probably reflect reversals in effect of event rate at the 1/12 and 1/24 SPs and differences in temporal trends for these conditions. (See Fig. 2a.) For auditory FA percentages, there was significant variance attributable to SP, probably due to the generally lower percentage of FAs at the 1/24 SP. However, there are significant interactions of SP and Event Rate ($p < .05$) and of SP, Event Rate, and Time, doubtless reflecting the large differences between event rates at the 1/6 and 1/12 SPs only, with FAs' per cent being higher at the lower event rates within these SPs and trends differing somewhat in different conditions.

Detection Theory Analysis

It was previously indicated that vigilance data may be analyzed in terms of the theory of signal detection (TSD) (Egan, Greenberg, & Schulman, 1961), and several investigators have done so (e.g., Broadbent & Gregory, 1963; J. F. Mackworth & Taylor, 1965; Loeb & Binford, 1964; Jerison et al, 1965). When there are no misses or no Ds or FAs, as happens commonly with monitoring tasks, good estimates of TSD parameters are not possible. Previous investigators have generally computed estimates based on interpolation between the highest (or lowest) observable value and 100% (or 0%). In the present experiment TSD parameters were obtained with the aid of the Freeman tables (Freeman, 1964) for both blocks of trials and for entire sessions, and interpolation procedures were employed where necessary. A detailed description of the interpolation procedures employed and their relative advantages is available (Loeb & Binford, 1968). The indication was that in this experiment variations in procedures in interpolation were not critical in determining differences between conditions.

Mean d' values for each block of time for visual and auditory conditions are plotted in Figs. 3a and 3b, respectively.

Generally visual d' values are higher and this effect is highly significant ($p < 0.01$); it is due to the considerably smaller number of visual FAs. Generally visual d' values appear to be lower at 24 epm than at 6 or 12, and to decline within sessions. Auditory d' values also appear lowest at 24 epm, but no general decline is apparent.

Analyses of variance similar to those employed with Ds and FAs were performed on the TSD data. For visual d' there was significant variance attributable to Event Rate and to Blocks of Time ($p < 0.01$). For auditory d' there was significant variance associated with Event Rate and Signal Rate ($p < 0.05$) but not Blocks of Time; there was also a significant interaction of Signal and Event Rates ($p < 0.01$).

In Figs. 4a and 4b mean log β values for the various visual and auditory conditions are similarly plotted.

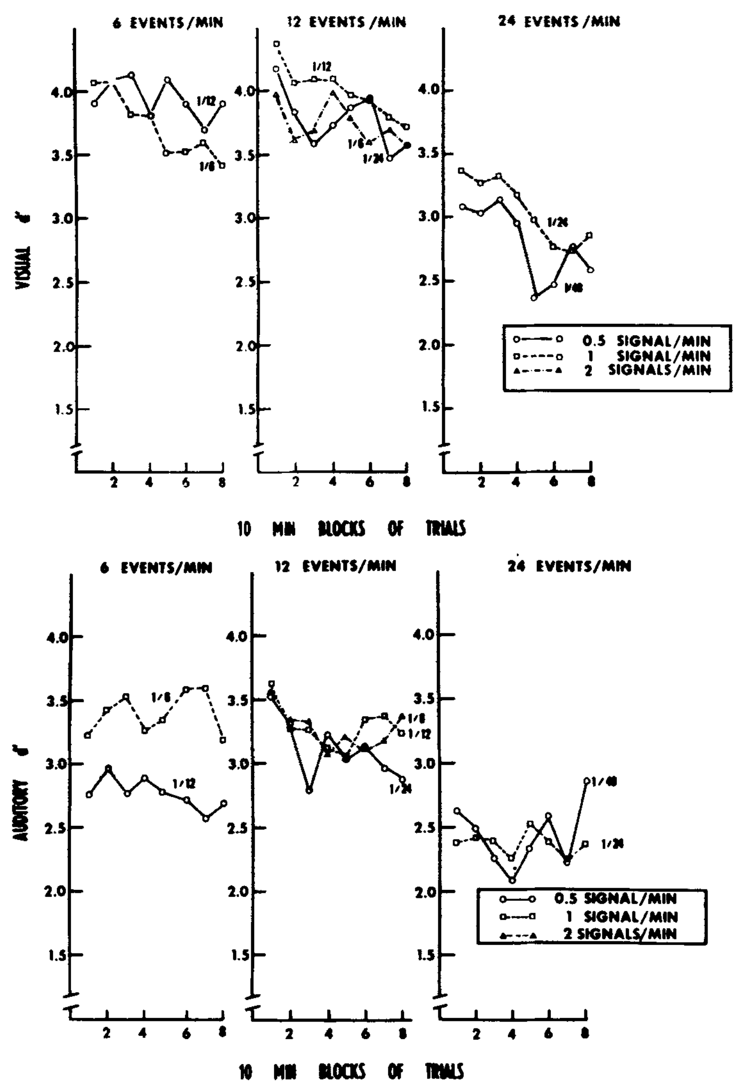

Fig. 3. Estimates of d' for each condition as a function of time on task. (Numbers on lines represent signal probabilities.) Above, visual conditions; below, auditory conditions.

Generally, log β values increase with blocks of trials and with event rate. The analyses of variance indicated that the variance across Blocks is statistically significant ($p < 0.05$ for visual, < 0.01 for auditory) as is the variance across event rates ($p < 0.01$ for both tasks).

Signal Probability Analysis: TSD Indices

The TSD indices were analyzed in terms of signal probability just as were the Ds and FAs. The lines representing individual conditions on Figs. 3 and 4 have been marked in terms of signal probability. Significant variance in d' attributable to SP was found for both conditions. Variance attributable to event rate with signal probabilities was nonsignificant, but the interaction of SPs and Event Rate was significant ($p < 0.05$ for visual, < 0.01 for auditory). Inspection of the relevant figures suggests that d' is appreciably lower at the higher event rate for the 1/24 ratio; in the auditory condition this is also true but there also appears to be a difference in the opposite direction at the 1/12 ratio.

For both auditory and visual tasks log β varied significantly with SP, tending to decrease as SP increased ($p < 0.01$). For the auditory condition only there was a significant SP by Event Rate interaction, apparently due to difference in log β between event levels at lower SPs ($p < 0.05$).

The findings may be somewhat clearer from an inspection of Figs. 5a and 5b, in which mean d' and log β values, respectively, are plotted as a function of SP for both the high and low event rate within each SP and at the 1/48 SP (which has only one event rate).

Values were derived from Ds and FAs for entire sessions rather than individual blocks of time and so there were considerably fewer zero and 100% cases requiring interpolations. Note that while the d' values are similar to those in the block by block analysis, the log β values are generally lower. This suggests that the very high values often obtained in vigilance experiments may reflect interpolation procedures.

The SP data may be summarized by stating there is a tendency for d' to decrease as a function of SP (especially in auditory conditions) and for log β to increase, but that there are differences at a given SP as a function of event rate which seems to be specific to a particular SP.

Correlations

While the present experiment is not primarily concerned with correlations between vigilance tasks, there are data on which such correlations can be based, and the findings should be of interest. Generally performance has been found to be task-specific (Buckner & McGrath, 1963).

Correlations of Ds, FAs, and d' and log β values were computed for every condition. For detections and d' values correlations were low and not significant. For FAs the coefficients ranged from

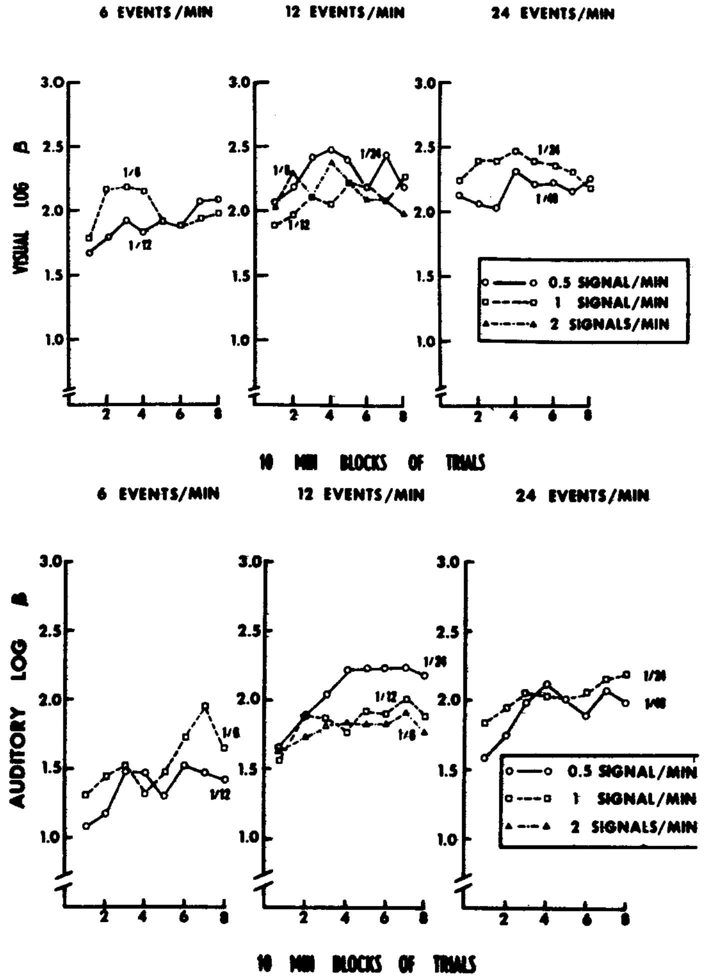

Fig. 4. Estimates of log β as a function of time on task. (Numbers on lines represent signal probabilities.) Above, visual conditions; below, auditory conditions.

−0.03 to 0.84, and the average value (obtained by converting to Fisher zs, averaging, and converting the average z to r) was 0.50, significant at the 0.05 level. For log βs the range was −0.08 to 0.89, averaging 0.56 (significant beyond the 0.05 level). Correlations between measures (hits vs FAs, etc.) generally were nonsignificant.

DISCUSSION

These data suggest that at comparable ratios, signal and event rate both affect performance but the latter variable is more important. It also seems that though signal probability may determine performance, as Colquhoun (1961) and Jerison et al (1965) have suggested, performance is not necessarily invariant at a given probability. More extensive experiments, with a greater number of Ss, a greater number of signal and carrier rate combinations, and various kinds of stimuli and signals, seem necessary.[3]

The decrease in visual d′ within sessions is in accord with results reported by J. F. Mackworth and Taylor (1963). The finding that auditory d′ did not change significantly agrees with previous findings by Loeb and Binford (1964). The data might be interpreted as supporting the position that the visual task, a loosely coupled situation, requires frequent observing responses which extinguish over time, while the auditory task, being closely coupled, does not require such responses, and therefore no change in sensitivity occurs. An interpretation solely in these terms would suggest that there would be more detections and higher sensitivity as signal rate increased for a visual monitoring task, while the same prediction would not necessarily be made for an auditory task. In

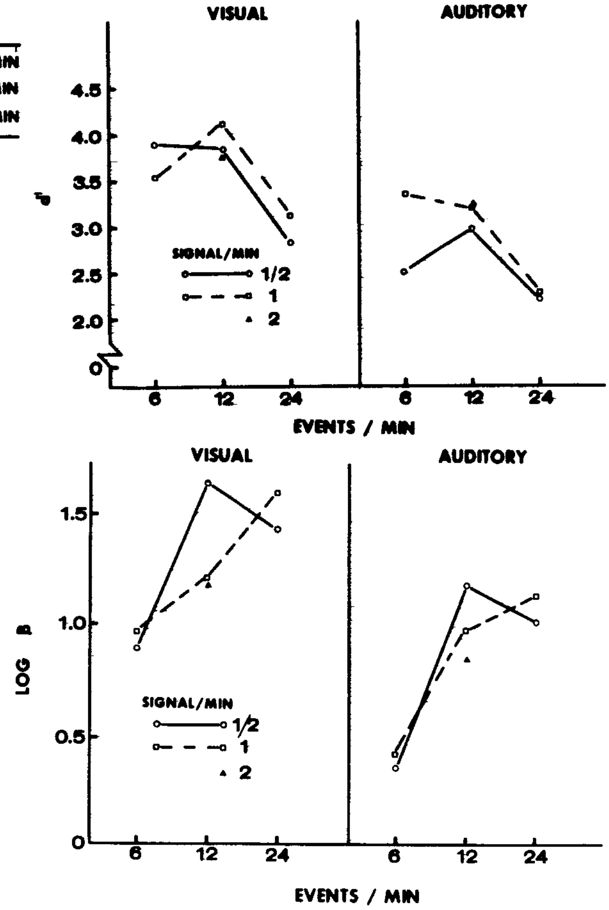

Fig. 5. The relationship between signal probability, relative event rate, and estimates of TSD parameters for entire sessions. (For exact signal and event rate determining each signal probability, refer to Fig. 4.) Above, d′; below, log β.

fact, however, these factors operated in similar ways for both kinds of tasks, with signal rate having more effect on detection rate and sensitivity for auditory tasks than for visual tasks.

Jerison et al (1965) argue that an analysis in TSD terms is misleading, since detection index values (especially β) obtained in vigilance sessions are quite different from those obtained in classical detection experiments. (This may not be a totally valid argument in view of the very low signal density and probability and lack of feedback in vigilance tasks.) They propose that the values obtained reflect mixtures of several modes of attending, (1) "normal, alerted attention," (2) "blurred observing," in which Os are less sensitive but have unchanged response criteria, and (3) "distraction," a condition which might be produced by daydreaming, which results in no detections or FAs. They show that various spurious TSD values could be produced by a mixture of detection and false alarms produced by these three modes of attention in appropriate combinations, and suggest that a mix of observing modes could produce a large apparent increase in β with only a small decrease in d'. It is not clear how one could obtain large increases in β over time accompanied by practically no decrease in d', as in Jerison et al's (1965) investigations and in the auditory conditions of this investigation.

While Jerison and his colleagues' hypotheses that changes in modes of observing occur seem reasonable, other mechanisms may also be operating. At least two studies (Broadbent & Gregory, 1963; Loeb & Binford, 1964) have shown that Os tend to be less certain of their judgments (according to ratings) late within sessions, and it would appear to be inappropriate to exclude the possibility that observers' criteria may truly be growing more stringent.

Trends in false alarms also pose some difficulties for Jerison and his colleagues. In a recent discussion, Jerison (1967b) states (p. 288) that "... the data of vigilance experiments suggest that regardless of when a signal occurs, if the observer's alert, he will not miss it." This is true only if one restricts the usage of "vigilance" to include only monitoring tasks with highly discriminable stimuli, but a number of experiments have employed imperfectly discriminable stimuli in vigilance situations, and many "real-life" situations, including radar, sonar, and inspection tasks, employ imperfectly discriminable signals. Moreover, Jerison et al (1965), reported their greatest number of false alarms in the first time period of their experiment and a significant decline thereafter (as in most vigilance experiments). They suggested that there must be considerable "blurred observing" in the beginning and that "distraction" later preempts time formerly devoted to alert and blurred observing and thus reduces the number of false alarms as well as hits. The "perfectly discriminable" signal, then, must be perfectly discriminable only for brief intervals. It would be interesting to employ fine-grained analyses for false alarms similar to those earlier employed by Jerison (1959) in examining detections, to see when "blurring" first occurs.

Perhaps Os come into experiments with relatively high expectations regarding signal rate and relatively little knowledge as to the differential cues for signals and noise and with time prolonged exposure to the set of stimuli, they realize that some of the stimuli to which they had responded were not signals and modify their expectations and criteria. While this notion does not exclude the possibility that changes in modes of observing also occur, it predicts the observed decrements in detections and false alarms. If both changes in criteria or expectations and changes in modes of observing were operating, one would predict that in a subsequent session, the initial false alarm rate would be down, but the initial detection rate would not. This, in fact, occurs (Binford & Loeb, 1966).

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NOTES

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3. In his most recent publication, Jerison (1967b) argues, on the basis of data shown, that two of the frequently reported vigilance effects—decrements with time and signal frequency effects—occur only at high event rates (e.g.,

30/min). However, in our own laboratory and elsewhere, effects of this kind have been reported both in the apparent absence of nonsignal events and with continuous, unchanging background stimulation, with relatively conspicuous visual signals and with poorly discriminable auditory signals. Obviously, the complex interactions determining signal-event rate interactions are still not well understood.

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