Interaction of signal discriminability and task type in vigilance decrement

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The results of recent studies suggest that perceptual sensitivity may decline over time in high-event-rate vigilance tasks either (1) when signals require successive, rather than simultaneous, discrimination or (2) when signals are difficult to discriminate from nonsignals. The joint effects of these two factors were examined in the present study. Two groups of subjects performed simultaneous- and successive-discrimination vigilance tasks requiring the discrimination of differences in line lengths at each of three levels of signal discriminability—low, moderate, and high. Both tasks lasted 30 min and had a high nonsignal-event rate. Perceptual sensitivity was assessed, using both parametric and nonparametric indices. For moderately or highly discriminable signals, sensitivity declined over time for the successive-discrimination task but not for the simultaneous-discrimination task. For low-discriminability signals, however, a sensitivity decrement was obtained for both tasks. These findings point to the role of the cumulative demand on attentional capacity in determining sensitivity decrement. The results are discussed in terms of attention allocation processes in high-event-rate vigilance tasks.

The types of critical and neutral events that individuals must be vigilant for play a critical role in the determination of performance on vigilance tasks (Davies & Parasuraman, 1982). For example, the processes underlying the vigilance decrement—the deterioration in the signal detection rate over time—are different when signals are presented with a high neutral-event (nonsignal) rate than when they are presented with a low neutral-event rate (Jerison & Pickett, 1964; Parasuraman, 1979; Posner, 1978; Warm & Jerison, 1984). In high-event-rate tasks, the vigilance decrement is primarily associated with a sensitivity decrement over time, with or without a concomitant change in the response criterion (Loeb & Binford, 1968; Parasuraman, 1979; Swets, 1977). When the event rate is low, however, sensitivity generally remains stable and the vigilance decrement is associated with a criterion shift alone (Binford & Loeb, 1966; Broadbent & Gregory, 1963; Parasuraman & Davies, 1975; Williges, 1969). Changes in the event rate also modulate the influence of other factors on vigilance performance (Warm & Jerison, 1984). For these reasons, the event rate has been identified as an important task factor in a *taxonomic* analysis of vigilance (Parasuraman & Davies, 1977).

In this approach, patterns of vigilance performance are differentiated on the basis of the processing demands associated with different categories of vigilance tasks. Apart from event rate, signal discrimination type is proposed as an important task factor. In *successive*-discrimination vigilance tasks, signals have to be distinguished from a nonsignal reference represented in recent memory, be-

cause nonsignal and signal events are presented successively. In *simultaneous*-discrimination tasks, signal and nonsignal features are presented within the same stimulus event. Thus, successive-discrimination tasks impose a greater memory load than do simultaneous-discrimination tasks (cf. Campbell, 1985). Other considerations are (1) whether the discrimination required is sensory or cognitive, (2) whether the sensory modality is visual or auditory, and (3) whether the signals originate from a single source or multiple sources.

The distinction between simultaneous and successive discrimination has resulted in some improved generalizations regarding the mechanisms underlying vigilance—for example, the difference noted earlier between sensitivity and criterion shifts. Parasuraman (1979) reported that the vigilance decrement was associated with a sensitivity shift only for successive-discrimination tasks in which the event rate was high (> 24 events/min). For simultaneous-discrimination and low-event-rate tasks, sensitivity did not decline over time. Criterion shifts over time were found both in the presence and in the absence of a sensitivity decrement. The results were interpreted in terms of the greater memory load associated with the successive-discrimination task, and the sensitivity decrement was attributed to limitations in effortful attention allocation with time (see also Parasuraman, 1985). This view would predict that for signals that do not require effortful processing (e.g., so-called automatic processes), performance should be sustained with little sensitivity decrement over time. This prediction was confirmed in a study by Fisk and Schneider (1981). They tested subjects on prolonged visual discrimination tasks in which signals and responses were either consistently or variably mapped. Sensitivity declined over time only for the variably mapped signals, which required controlled (effort-

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ful) processing and access to working memory, and not for the consistently mapped signals, which could be processed automatically.

Following the study by Parasuraman (1979), other studies providing data pertinent to the successive/simultaneous distinction have been reported. Although a number of supporting results with respect to the level of vigilance performance have been obtained (Davies, Parasuraman, & Toh, 1984; Dember, Joshi, Warm, & Scerbo, 1985; Lanzetta, Warm, Dember, & Berch, 1985), conflicting results have been obtained with regard to sensitivity decrement over time. Nuechterlein, Parasuraman, and Jiang (1983) examined vigilance performance for the discrimination of a single target digit in an intermittent sequence of nonsignal digits presented at a very fast event rate (60/min). Blurring of stimuli and a visual mask were used so that the discriminability of the signal (from nonsignals) was high, moderate, or low. This task qualifies as a high-event-rate simultaneous-discrimination task, and thus should not show a sensitivity decrement over time. Nevertheless, a marked decrement in sensitivity was obtained in this task when signals were poorly discriminable but not when they were moderately or highly discriminable. The task lasted for only 8 min; thus the result could be attributed to the atypically short duration in comparison to most other vigilance tasks, which last 30 min or longer. Furthermore, the event rate was much greater than that in previous studies, in which event-rate effects had been found for rates greater than about 24/min (e.g., Loeb & Binford, 1968; Parasuraman, 1979). However, similar results were found in a subsequent study in which performance on the same task was assessed over 30 min and a high event rate of 30/min was used (Parasuraman, 1985). Dittmar, Warm, and Dember (1985) examined performance on a high-event-rate task requiring discriminations of line length. They found a sensitivity decrement for both successive and simultaneous discrimination. Dittmar et al. speculated that the sensitivity decrement might have occurred in their study because of the low discriminability of the signals, as had been the case in the study by Nuechterlein et al. (1983).

These results suggest that successive discrimination may not be necessary for a sensitivity decrement to occur in high-event-rate vigilance tasks. One possible factor that may account for the discrepant results is the level of signal discriminability. Nuechterlein et al. (1983) found that a sensitivity decrement occurred for a simultaneous-discrimination task only when signals were highly degraded. These findings suggest the need to examine the effects of signal discriminability and signal discrimination type on sensitivity decrement in high-event-rate vigilance tasks. Two hypotheses regarding sensitivity decrement are possible. One is that a sensitivity decrement may occur only for low-discriminability signals, as for the degraded signals in Nuechterlein et al. (1983), irrespective of task type. A second possibility is that there is an interaction between signal discriminability and task type, so that a decrement occurs only for successive-

discrimination tasks at high levels of signal discriminability, but for both successive- and simultaneous-discrimination tasks at low levels of signal discriminability.

METHOD

Subjects

Twenty-four young adults, aged 18 to 29 years (11 males, 13 females), volunteered to participate in the experiment. All subjects reported normal hearing and normal or corrected-to-normal vision.

Tasks

The vigilance tasks used required the discrimination of differences in the lengths of a pair of vertical lines presented briefly (150 msec) on a graphics display at a rate of one pair every 1.5 sec (event rate of 40/min). The stimuli were presented centrally at eye level against a dark background at a luminance of 1.4 cd/m². The standard or nonsignal lines were 36 mm in length, separated by 14 mm. In the simultaneous-discrimination task, one of the lines of the pair was shorter than the standard length. (The left and right lines served as the shorter line equally often, at random.) In the successive-discrimination task, both of the lines were shorter in length than the standard nonsignal lines. The discriminability of the signals was varied over three levels—low, moderate, and high—by varying the extent of the difference in line length. The differences in line length were selected on the basis of pilot studies so that signal discriminability, as indexed by d' , was approximately 2.0, 2.5, or 3.0 under alerted observation for the low, moderate, and high discriminability conditions, respectively, for both the successive- and simultaneous-discrimination tasks. The differences in line lengths needed to achieve this were 1.2, 2.2, and 3.0 mm, respectively, for the simultaneous-discrimination task, and 2.2, 3.4, and 4.3 mm, respectively, for the successive-discrimination task. (Henceforth, the term *signal discriminability* is used to refer to the difference in line length between signal and nonsignal, a small difference implying low discriminability and a large difference implying high discriminability. Observer performance in discriminating signals from nonsignals is referred to as *sensitivity*.)

The vigilance tasks lasted for 30 min, comprising three continuous 10-min periods. Forty signals and 360 nonsignals were presented in a random sequence in each 10-min period, with the restriction that signals never followed one another. The probability of signal occurrence throughout the task was 0.1. The subjects were required to respond to signals by depressing the space bar on a terminal keyboard. Stimulus presentation and response acquisition were controlled by an IBM PC-XT microcomputer.

Procedure

The subjects were divided into two groups of 12 each. Each group of subjects performed one of the vigilance tasks (successive or simultaneous discrimination) at each of the three discriminability levels, in three separate sessions. The order of presentation of discriminability level was counterbalanced between subjects. Each session lasted approximately 1 h and consisted of a training period and a practice period. The practice period lasted 10 min and was an exact replica of one of the 10-min periods of the main vigilance task. Knowledge of results was provided during training and at the end of the practice period. Following a 5-min break, subjects performed the main task uninterruptedly for 30 min.

RESULTS

Table 1 shows the mean percentage of correct signal detection (hits) as a function of 10-min time period, task

type (successive or simultaneous discrimination), and signal discriminability (low, moderate, or high). The hit-rate data were submitted to a $2 \times 3 \times 3$ analysis of variance (ANOVA) with the factors of task type, signal discriminability, and time periods, with repeated measures for the last two factors. (All p values for main or interaction effects involving the two repeated measures factors were computed using the conservative Greenhouse-Geisser method with corrected degrees of freedom). ANOVA gave significant effects for task type [$F(1,22) = 7.31$, $p < .025$], discriminability [$F(1,22) = 43.09$, $p < .001$], time period [$F(1,22) = 43.84$, $p < .001$], and the interaction between discriminability and time period [$F(1,22) = 6.60$, $p < .025$]. As Table 1 indicates, there was a decrease in the hit rate over time periods (the vigilance decrement) in all conditions. Furthermore, the detection rate was higher for the simultaneous-discrimination than for the successive-discrimination task, and increased with signal discriminability. The interaction resulted from a reduced decrement over time periods for the highly discriminable signal, particularly for the simultaneous-discrimination task.

The false-alarm data are shown in Table 2. ANOVA gave significant effects for discriminability [$F(1,22) = 12.51$, $p < .005$] and the interaction between discriminability and task type [$F(1,22) = 11.10$, $p < .005$]. The false-alarm rate remained relatively constant across time periods, suggesting a stable response criterion. Furthermore, there was a progressive decline in the false-alarm rate with increasing discriminability in the simultaneous-discrimination task. For the successive-discrimination task, however, there was an inverted-U relationship between the false-alarm rate and discriminability, with no overall effect of discriminability. Since the hit rate showed a progressive decline over time periods, whereas the false-alarm rate remained stable, these results suggest that perceptual sensitivity declined over time. To examine this possibility, we computed parametric and nonparametric signal-detection-theory measures of sensitivity.

Two indices of sensitivity were computed from the hit and false-alarm data, the parametric index d' and the non-parametric index $P(A)$, which is an estimate of the area under the ROC described by a single hit and false-alarm pair (Pollack & Norman, 1964; see also Davies & Parasuraman, 1982, chap. 3; Swets, 1986). This index is also commonly referred to as A' (Craig, 1979). Figure 1 shows the mean values of d' in each experimental condi-

Table 2
Mean Values of False-Alarm Rate in Consecutive 10-Minute Blocks for Simultaneous- and Successive-Discrimination Vigilance Tasks at Three Levels of Signal Discriminability

Level of Signal Discriminability	10-Minute Blocks					
	Simultaneous			Successive		
	1	2	3	1	2	3
High	.019	.013	.005	.021	.024	.020
Moderate	.028	.021	.020	.036	.040	.040
Low	.045	.046	.041	.033	.025	.020

tion. ANOVA of the d' scores gave significant effects for task type [$F(1,22) = 4.74$, $p < .05$], discriminability [$F(1,22) = 37.70$, $p < .001$], time period [$F(1,22) = 10.38$, $p < .005$], and the interactions between task type and time period [$F(1,22) = 7.33$, $p < .025$] and between discriminability, task type, and time period [$F(1,22) = 4.34$, $p < .05$]. Figure 2 shows the results for A' . ANOVA gave significant effects for discriminability [$F(1,22) = 38.31$, $p < .001$], time period [$F(1,22) = 30.21$, $p < .001$], and the interaction between discriminability and time period [$F(1,22) = 5.36$, $p < .05$].

Figures 1 and 2 show that a sensitivity decrement (as indexed by d' or by A') was obtained for the successive-discrimination task at all three discriminability levels. For the simultaneous-discrimination task, however, sensitivity was stable over time for the moderate and high discriminability levels and declined only for the low discriminability signals. This pattern was confirmed by computing 3×3 (discriminability $\times$ time periods) ANOVAs separately for each task. For the successive-discrimination task, the main effect of time periods was significant [for d' , $F(1,11) = 24.15$, $p < .001$; for A' , $F(1,11) = 36.55$, $p < .001$], whereas the interaction between discriminability and time periods was not ($F < 1$). For the simultaneous-discrimination task, however, there was a significant interaction between discriminability and time periods [for d' , $F(1,11) = 5.50$, $p < .05$; for A' , $F(1,11) = 4.95$, $p < .05$].

The parametric index β is not very stable in vigilance tasks (Davies & Parasuraman, 1982, chap. 3); a suitable nonparametric index is the criterion cutoff, C , which is proportional to the false-alarm probability, results for which are reported above.

DISCUSSION

The results of this study indicate that signal discriminability and task type (successive or simultaneous discrimination) interact in their effects on sensitivity decrement in high-event-rate vigilance tasks. When the discriminability of signals was moderate or high, sensitivity declined over time only for the successive-discrimination task. At low signal discriminability, however, sensitivity decrement occurred for both successive- and simultaneous-discrimination tasks. The results serve to resolve the discrepancy between the previous findings of Parasuraman (1979), who found that sensitivity decrement was re-

Table 1
Mean Values of Hit Rate (Correctly Detected Signals) in Consecutive 10-Minute Blocks for Simultaneous- and Successive-Discrimination Vigilance Tasks at Three Levels of Signal Discriminability

Level of Signal Discriminability	10-Minute Blocks					
	Simultaneous			Successive		
	1	2	3	1	2	3
High	.880	.876	.873	.874	.802	.692
Moderate	.731	.744	.642	.794	.725	.619
Low	.794	.652	.529	.685	.513	.460

Figure 1. Mean values of sensitivity, as indexed by d' , as a function of time on task for successive- and simultaneous-discrimination tasks at three levels of signal discriminability (low, moderate, and high).

stricted to successive-discrimination tasks, and those of Nuechterlein et al. (1983) and Dittmar et al. (1985), who found sensitivity decrements for simultaneous-discrimination tasks with poorly discriminable signals.

High-event-rate vigilance tasks have been shown to be resource consuming (Bowers, 1983; Parasuraman, 1985), and the sensitivity decrement in such tasks has been linked to excessive demands on effortful attention allocation over time (Fisk & Schneider, 1981; Parasuraman, 1979; Swets & Kristofferson, 1970). The results of the present study indicate that the sensitivity decrement may be determined by the total level of resource demand imposed on the subject. This demand is normally greatest when a high event rate is combined with the memory load associated with a successive-discrimination signal. However, if signals are difficult to discriminate from nonsignals, resource demand is increased, and a sensitivity decrement over time may occur even in the absence of a memory load.

The role of resource limitations in vigilance was recently examined in a study reported in Parasuraman (1985). A secondary-task technique was used to assess the resource demand of vigilance tasks at different event rates. Subjects performed the degraded-digit-detection task of Nuechterlein et al. (1983) at either a low (15/min) or a high (30/min) event rate. Auditory probe tones were presented for brief periods at the beginning and toward the end of a 30-min period of continuous performance. Subjects were instructed to give priority to the main vigilance task. Reaction time to the auditory probes was taken as a measure of the primary-task demand. Secondary-task reaction times were significantly longer when the primary-task event rate was high, indicating greater resource demand, than when the event rate was low. Moreover, this difference was found only for probes presented toward the end of the task, when sensitivity on the primary task was reduced, indicating that the sensi-

Figure 2. Mean values of sensitivity, as indexed by A' , as a function of time on task for successive- and simultaneous-discrimination tasks at three levels of signal discriminability (low, moderate, and high).

tivity decrement was associated with an increase in resource demand.

Criterion shifts over time have been found to occur both in the presence and in the absence of a sensitivity decrement (Parasuraman, 1979), and have been linked to changes in the observer's expectancy for critical signals (Parasuraman, 1986; Swets, 1977; Williges, 1969). Such shifts occur ubiquitously (Craig, 1985), but appear to be the primary determinant of performance changes over time in low-event-rate and simultaneous-discrimination tasks. The present finding that the false-alarm rate (and hence the criterion cutoff, C) varied with signal discriminability for the simultaneous-discrimination task but did not do so systematically for the successive-discrimination task is interesting and unexpected. Although specific predictions for criterion shifts were not made in this study, this result indicates that the successive/simultaneous dichotomy may have meaning for criterion shifts as well. In general, the result is consistent with the view that expectancy-linked criterion shifts are more likely to be found in simultaneous-discrimination tasks, whereas performance changes in successive-discrimination tasks are associated more with resource-linked sensitivity changes. Confirmation of this post hoc interpretation in a subsequent study would constitute an important extension of the taxonomic approach.

The present results indicate that the interaction between event rate and the successive/simultaneous dimension does not completely account for the distinction between sensitivity and criterion shifts in vigilance. Nevertheless, the results point to the importance of the successive/simultaneous task dimension for determining vigilance performance, particularly when signal discriminability is taken into account. The joint importance of these two factors is also evident when intertask correlations in vigilance performance are analyzed. Intertask (including intermodality) correlations in vigilance performance are often low, on the order of .1 or .2 (see Davies & Parasuraman, 1982, chap. 6, for a review). These low correlations have led researchers to view vigilance as completely task specific and to question its viability as a unified central construct (Buckner & McGrath, 1963). If vigilance is completely task or modality specific, it should not be possible to predict performance on a combined audiovisual task from a knowledge of performance on the component (auditory and visual) tasks. However, this is not the case. Craig, Colquhoun, and Corcoran (1976) found that bimodal vigilance performance could be predicted from performance on the component unimodal tasks, and that the best predictor was a model assuming partial commonality in auditory and visual detection mechanisms, rather than complete independence. This leads to the view that the performances of the same subjects on different vigilance tasks are correlated and that the degree of correlation increases as the information-processing demands that the tasks share increases. This was confirmed by Parasuraman (1976), who showed that strong intertask correla-

tions emerge when vigilance tasks are matched not only for signal discriminability, but also for the type of signal discrimination—whether successive or simultaneous discrimination. This finding fits well with the results of the present study. Both sets of results indicate that task type and signal discriminability are important determinants of consistencies in vigilance performance.

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