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Effects of the rate and regularity of background events on sustained attention

DAVID O. RICHTER, RODERICK J. SENTER, and JOEL S. WARM
University of Cincinnati, Cincinnati, Ohio 45221

Subjects listened for occasional increments in the intensity of recurrent acoustic pulses. Detection probability varied inversely with the rate of repetition of neutral background events in which critical signals were arrayed (the background event rate). Contrary to expectations derived from a habituation model of vigilance (Mackworth, 1968, 1970), the presentation of neutral events in a temporally irregular manner suppressed rather than enhanced the detection of critical signals and failed to attenuate performance differences associated with variations in background event rate.

Most sustained attention or vigilance experiments make use of dynamic displays in which critical signals for detection are embedded within a matrix of recurrent background events. Although they are neutral in the sense that they usually require no overt response from an observer, the background events are not unimportant. Indeed, they have a considerable influence on the observer's ability to maintain attention to the task at hand. Both the overall speed and the overall accuracy of critical signal detections vary inversely with the frequency of repetition of background events, or the background event rate (Parasuraman, 1979; Parasuraman & Davies, 1976; Warm, 1977). Further, the deterioration of performance efficiency over time that typifies vigilance performance can be amplified or reversed by suitable variations in background event rate (Jerison & Pickett, 1964; Krulewitz, Warm, & Wohl, 1975; Wiener, 1977), and such variations can also modify the effects associated with other psychophysical parameters including the amplitude and probability of critical signals (Krulewitz & Warm, 1977; Metzger, Warm, & Senter, 1974). These results have led to the conclusion that background event rate is a prepotent stimulus factor in sustained attention (Dember & Warm, 1979).

To date, all of the experiments that have focused upon event rate have exposed observers to temporally regular presentations of background events, for example, a slow rate of one event every 12 sec or a fast rate of one event every 2 sec. No effort has been made to assess the consequences of a temporally irregular schedule of background events on vigilance performance. There is, however, theoretical reason to do so.

Mackworth (1968, 1970) has offered a model of vigilance, anchored in the phenomenon of habituation, that incorporates the effects of event rate and time on task within a single explanatory framework. This position maintains that the repetitive stimulation of the recurring background events serves to habituate neurophysiological responses to stimuli from the monitored display. With the build-up of habituation, the observer's ability to discriminate critical signals becomes degraded and his/her performance suffers a decline in efficiency over time. Due to the frequency of repetition, habituation accumulates more rapidly under a fast, relative to slow, event rate, resulting in poorer overall performance under the fast event rate.

An interesting property of habituation, which Mackworth acknowledges (1968, p. 316; 1970, p. 91), is that its development can be arrested when the habituating stimulus occurs in an irregular manner. Therefore, the habituation model of vigilance leads to the expectation that, relative to a temporally regular matrix of background events, a temporally irregular matrix should attenuate performance differences associated with variations in the frequency of background events and enhance the durability of sustained attention. These possibilities were tested in the present study.

METHOD

Forty students, 24 men and 16 women, from the University of Cincinnati served as subjects. They ranged in age from 18 to 40 years, with a mean of 22 years. All of the students were free of any known hearing impairments and took part in order to fulfill a course requirement.

Two levels of background event rate (slow and fast) were combined factorially with two levels of event regularity (regular and irregular). Ten subjects were assigned at random to each of the four factorial combinations of event rate and event regularity.

All subjects participated in a 1-h session, during which they listened continuously for occasional increments in the intensity of a recurrent 1,000-Hz tone. Acoustic stimulation was presented binaurally via headphones. Throughout the session, 250-msec pulses of stimulation with a rise-decay time of 5 msec were presented at an intensity of 54 dBA SPL. These constituted

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nonsignal events, to which no overt responses were required. Critical signals for detection were pulses of 57 dB SPL. Subjects responded to critical signals by depressing a hand-held push-button switch.

The frequency of recurrent stimulation was 5 pulses/min at the slow event rate and 30 pulses/min at the fast event rate. With regular event schedules, these event rates were achieved by presenting pulses once every 12 sec and once every 2 sec, respectively. With irregular event schedules, slow and fast event rates were achieved by varying the interevent intervals (IEIs) as follows. For irregular slow events, the IEIs were 6, 9, 12, 15, and 18 sec (mean = 12 sec). They were distributed in a non-systematic manner in a 300-sec time block that was recycled 12 times during the vigil. For irregular fast events, the IEIs were 1, 1.5, 2, 2.5, and 3 sec (mean = 2 sec). These IEIs were also distributed in a nonsystematic manner. In this case, a 50-sec time block was used that was recycled 72 times during the watch. While the absolute variability of the irregular event schedules differed within the slow and fast event rates, their relative variability was held constant by keeping the coefficients of variation of their distributions equal to .40 sec for each cycle.

The vigil was divided into three 20-min periods of watch. A total of five critical signals was presented during each period under all experimental conditions. The intervals between critical signals were 1.6, 2.4, 4.4, 5.6, and 6.0 min in all conditions. These intervals occurred according to a predetermined random order during each period of watch.

Stimulus event rates, event schedules and the occurrences of critical signals were governed by a KIM-1 microprocessing computer. The computer also recorded the subjects' responses. Those responses appearing within 2.5 sec after the onset of a critical signal were automatically considered correct detections (hits); all others were logged as errors of commission (false alarms). The 2.5-sec cutoff value was based on pilot work with the acoustic task that indicated that if subjects were going to respond to a critical signal at all, they would do so within 2.5 sec of its onset.

Subjects were tested individually in a 1.01 x 1.23 x 1.98 m Industrial Acoustics sound chamber. Ambient illumination within the chamber was provided by a 25-W bulb mounted in a cylindrical wall fixture. Subjects surrendered their watches upon entering the chamber and had no knowledge of the length of the vigil other than that it would not exceed 2 h.

RESULTS

Mean percentages of correct detections and false alarms for all experimental conditions are shown in Table 1. An analysis of variance of an arcsin transformation of the detection scores indicated that critical signals were detected significantly more often in the context of a slow event rate (mean = 81.7%) compared with a fast event rate (mean = 66.7%) $[F(1,36) = 8.58, p < .01]$ and also in the context of a regular event schedule (mean = 79.3%) compared with an irregular schedule (mean = 69.0%) $[F(1,36) = 4.71, p < .05]$. All other sources of variance in this analysis lacked significance ($p > .05$).

A similar analysis of an arcsin transformation of the false alarm data indicated that the percentage of false alarms was greater under the slow event rate (mean = 23.2%) than under the fast event rate (mean = 4.2%) $[F(1,36) = 68.06, p < .001]$. In addition, there was a significant drop in the percentage of false alarms over time $[F(2,72) = 23.00, p < .001]$, which occurred principally in conjunction with a slow event rate $[F(2,72) = 6.00, p < .005]$. Mean percentages of false alarms for the first through the third period of watch were 27.0%, 23.5%, and 19.0%, respectively, under the slow event rate and 4.0%, 5.0%, and 3.5%, respectively, under the fast event rate.

Table 1
Mean Percentages of Correct Detections (Ds) and False Alarms (FAs) and Mean A′ and B″ Values in All Experimental Conditions

	Event Regularity	Measure	Periods of Watch (20 Min) 1	2	3
Slow Event Rate	Regular	D	90	80	90
		FA	30	26	20
		A′	.89	.84	.91
		B″	−.64	−.30	−.52
	Irregular	D	82	76	72
		FA	24	21	18
		A′	.87	.85	.86
		B″	−.35	−.20	−.04
Fast Event Rate	Regular	D	84	68	64
		FA	6	6	4
		A′	.94	.90	.89
		B″	.14	.09	.38
	Irregular	D	58	70	56
		FA	2	4	3
		A′	.87	.90	.82
		B″	.36	.38	.62

Note—Negative B″ values indicate a lenient response criterion, positive values a conservative criterion.

Mean values for signal detection theory indexes of perceptual sensitivity (A′) and response criterion (B″) are also shown in Table 1. Distribution-free measures were employed (cf. Grier, 1971) in response to recent arguments that the assumptions governing the use of parametric measures are usually not met by data gathered in vigilance experiments (Craig, 1979). An analysis of variance of the A′ scores revealed no reliable main effects or interactions ($p > .05$). Thus, none of the variation in the detection of critical signals noted above could be attributed to differences in perceptual sensitivity. A similar analysis of the B″ scores, however, indicated that a significantly more stringent response criterion was adopted by subjects in the context of a fast (mean = +.33) compared with a slow (mean = −.34) event rate $[F(1,36) = 20.77, p < .001]$ and that there was a marginally significant tendency for the response criterion to be more stringent in the context of an irregular (mean = +.13) compared with a regular (mean = −.14) event schedule $[F(1,36) = 3.34, .10 > p > .05]$. No other sources of variance in the analysis of B″ scores were significant ($p > .05$).[1]

DISCUSSION

As in previous experiments, the frequency of critical signal detections in this study varied inversely with the rate of repetition of neutral background events. Furthermore, this result was associated with variations in the subjects' response criterion but not with changes in perceptual sensitivity. While A' remained essentially invariant, the subjects displayed a more stringent response criterion when critical signals were embedded within the context of a fast compared with a slow event rate.

Contrary to expectations derived from Mackworth's (1968, 1970) habituation model, the effects of event rate were not attenuated by presenting neutral events on an irregular schedule. Differences between the two event rate conditions were equally robust under the regular and the irregular event schedules. The sole consequence of introducing an irregular schedule of events was to depress the overall level of detections. The fact that the overall level of signal detections was depressed by an irregular schedule of neutral events is of more than passing significance for the adequacy of the habituation theory of vigilance. If, as Mackworth has suggested, the accumulation of habituation should be retarded when neutral events occur on an irregular basis, one would expect that the irregular schedule would enhance, not depress, performance efficiency. All in all, with respect to event rate, the results of this study not only fail to confirm a prediction derived from the habituation model but also fall in a direction opposite to one that can be encompassed by the model.

Perhaps a more useful framework in which to incorporate the results of this investigation comes from a suggestion by Jerison (1970). He takes the position that increments in event rate increase the demands placed upon the subject in a vigilance task by increasing the pace at which he/she must emit observing responses or "unitary attentive acts" toward the stimuli to be monitored. The result is a decline in the subject's willingness to attend to the task and poorer performance. The present finding that the lower frequency of detections under the fast event rate was accompanied by an elevated response criterion fits easily with Jerison's position if one assumes that increments in B'' reflect a cognitive strategy designed to alleviate the heightened task demand under the fast event rate. Simply stated, when faced with a fast event rate, subjects may have set a high criterion for emitting observing responses and, by so doing, reduced the taxing pace at which they had to emit such responses in search of critical signals. Within this line of reasoning, the higher levels of B'' under the fast event rate may well be a consequence of the casual manner in which the subjects attended to the display in that condition.[2]

The overall effects associated with event regularity may be explained along the same lines. Under the regular schedule, pulses that could contain critical signals appeared in a temporally predictable manner. Subjects could have utilized this predictability to take task-contingent "time-outs" from observing and, thereby, reduce the cost of attending to the display. In contrast, under the irregular event schedule, the time course of pulse appearances that could contain critical signals was less predictable. Consequently, the irregular schedule would require more continuous observing, with a resulting higher overall cost. From Jerison's (1970) point of view, the higher cost of observing under the irregular event schedule could have led to more unwillingness to attend to the task and fewer detections, in comparison with the regular event schedule.

Unfortunately, the present results offer no evidence with which to evaluate Mackworth's (1968, 1970) claim that the decline in vigilance performance over time results from an accumulation of habituation. Although temporal changes in false alarm rates were observed in the present data, such changes were not accompanied by meaningful declines in the percentage of signal detections. Such a result was unexpected, since a decrement in detections over time is one of the most characteristic aspects of behavior in a vigilance task (Dember & Warm, 1979).

The absence of a detection decrement in this study may be linked to a sampling factor. Smith (1966) has noted that there are wide individual differences in the durability of sustained attention, some subjects show a notable performance decrement and others are able to maintain a more stable level of performance throughout the vigil. According to Smith, the former can frequently be characterized as "periodic participators," individuals who are relatively uncommitted to the task at hand, and it is these individuals who are primarily responsible for the performance decrements noted in laboratory vigilance tasks. Along these lines, it must be noted that the task used in this study was quite demanding. Approximately 30% of all subjects who initially appeared in the laboratory were rejected for their inability to discriminate critical signals from neutral events beyond chance expectations under alerted conditions (there was no systematic relation between subject rejection and the event rate/event regularity conditions). Therefore, it is conceivable that the present study included fewer "periodic participators" than is usually the case and that this accounts for the absence of any vigilance decrement. Given the likelihood of such a sampling situation, the fact that significant effects were obtained in this study for event rate and event regularity but not for time on task leads to an intriguing possibility. As implied by Mackworth (1968, 1970), the characteristics of neutral background events may indeed be more potent determinants of sustained attention than time itself.

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NOTES

1. Long and Waag (1981) have provided a cogent argument for caution in the application of the signal detection model to vigilance experiments. They report a significant positive correlation between d′ and β scores in a vigilance task, which implies that the more sensitive subjects were also more cautious. As Long and Waag note, such a correlation makes a strict interpretation of vigilance performance along signal detection theory lines difficult and could result from violations in the assumptions of the model. With this in mind, we compared correlations (rs) between A′ and B″ scores for subjects under the fast and the slow event rates and the regular and the irregular event conditions of the present study. These values were −.30, −.21, −.18 and +.01, respectively. All failed to reach statistical significance ($df = 19$, $p > .05$). In addition, the overall correlation between A′ and B″ across all subjects in this investigation was −.11, a value that also failed to reach significance ($df = 39$, $p > .05$). The absence of significant correlations between A′ and B″ scores, coupled with the fact that the detectability of critical signals was associated only with criterion changes, leads to the conclusion that in this case, the signal detection measures were, as would be expected on the basis of the detection theory model, independent indexes of performance.

2. An account of this sort differs from the usual signal detection theory interpretation of elevations in response criterion. It implies that increased B″ scores may reflect something more than a decrease in the subject's willingness to stipulate that a sensory event was a sample of signal plus noise. Instead, such an elevation may reflect the subject's lack of information about the sensory event requiring a detection decision. Jerison and his co-workers (Jerison, Pickett, & Stenson, 1965) have articulated a similar position for the interpretation of increments in the response criterion in a vigilance setting.

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