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EFFECTS OF NOISE EXPOSURE ON PERFORMANCE OF A SIMULATED RADAR TASK

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16. Abstract

The present study examined the effect of noise (radar control room sounds, 80 dBA) on the ability to sustain attention to a complex monitoring task. The visual display was designed to resemble that of a highly automated air traffic control radar system containing computer-generated alphanumeric symbols. Fifty-six men and women were divided into four equal-sized groups. Each group was assigned to one of four combinations of noise or quiet condition and easy or difficult version of the task. In addition to measuring performance (detection latency to specified changes in the alphanumerics), physiological recordings of heart rate and heart rate variability and subjective measures of attentiveness, fatigue, tension, annoyance, and boredom were also obtained. With the exception of heart rate variability, no significant effects of noise were obtained. Heart rate variability was significantly lower under the noise than under the quiet condition. This suggests that, although performance was unchanged, effort expenditure may have been greater under noise.

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I. Introduction.

While a considerable number of vigilance studies have investigated the effects of noise on performance, surprisingly little useful information has resulted from this research. The findings have ranged from adverse effects through no effects to beneficial effects on performance. (See 1,2,5,10,11,17 for reviews.)

Given this diversity of findings, some have taken the extreme position that noise has little or no effect, not only on vigilance performance, but on mental or motor performance in general (10,16). An alternative view, however, is that noise effects are real but extremely elusive, and that even slight changes in characteristics of the vigilance or monitoring task and/or in characteristics of the noises used may significantly alter the obtained results (12). If one adopts this latter view, then it would behoove the applied investigator to carefully choose noise and task conditions that approximate as closely as possible those of the particular operational situation of interest.

The present study was undertaken with this approach in mind, i.e., the study sought to determine the possible effects of normal radar control room noises on visual monitoring performance using a task designed to simulate the display conditions and functional task requirements of a highly automated air traffic control radar system. In essence, the task required the observer to simply monitor the visual display for infrequent, "critical" changes in alphanumeric symbols. Two conditions of task difficulty were employed. In one condition, a constant, readily identifiable critical stimulus was used, while the more difficult condition required the observer to detect changes in altitude numbers above or below assigned limits. Performance was measured in terms of latency to detect critical stimulus changes. In addition to mean latency measurements, maximum and minimum latencies were also obtained. The results of several previous studies of complex monitoring suggest that maximum latencies reflect lapses of attention or failures to maintain scanning while minimum latencies provide an estimate of the individual's maximum state of alertness at any given period during the course of a monitoring session (8,18,21).

Noise consisted of recordings of sounds obtained from actual radar control rooms. Such noise is a composite of speech sounds, whistles, laughs, coughs,

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telephone bells, etc. The noise varied about a mean level of 78-80 dBA. This level was chosen for two reasons: (i) It approximates the noise levels for large Air Route Traffic Control Center (ARTCC) radar rooms during periods of high activity (14); (ii) 80 dBA is below the level at which one can expect hearing damage even for long-term exposures.

In addition to studying performance effects, we included a number of subjective measures along with measures of heart rate and heart rate variability. These measures were included in order to assess additional effects of noise that might be related to changes in performance.

II. Method.

A. Subjects. Fifty-six men and women were randomly assigned to four groups of equal size: (i) Noise-Low Task Difficulty, (ii) Noise-High Task Difficulty, (iii) Quiet-Low Task Difficulty, and (iv) Quiet-High Task Difficulty. All subjects (Ss) were selected from the general population (e.g., college students, housewives) and were paid for their participation. Their ages ranged from 18 to 29 years. None of the Ss had had prior experience with the task used or previous training in air traffic control.

B. Apparatus and Design. The basic apparatus and task have been described in detail in several previous studies (20,21).

In essence, all task programing and recording of responses were accomplished using a Digital Equipment Corporation PDP-11/40 computer, interfaced with a 17-inch cathode-ray tube that served as the S's display. The stimuli (targets) consisted of small rectangular "blips" representing the locations of given aircraft. Adjacent to each target was an alphanumeric data block, which identified the aircraft and gave its altitude and speed. A simulated radar sweepline made one complete clockwise revolution every 6 seconds. A target was updated as to location and any change in its data block moments after the sweepline passed the target's prior location. Critical stimuli consisted of a sudden change in a data block as follows: For the low difficulty condition, the S simply looked for the appearance of a 999 (signifying a malfunction) in the altitude portion of a data block, while in the high difficulty condition, the S had to search for any altitude whose value exceeded 550 (55,000 ft) or was less than 150 (15,000 ft). For both task conditions, 10 critical stimuli occurred in each half-hour period, 5 in the first 15 minutes and 5 in the second. The S's response to a critical stimulus consisted of pressing a button held in the right hand and then holding a light pen over the critical target. The light pen caused the altitude portion of the data block to revert to its previous value. If the S failed to detect a critical stimulus within 1 minute, the data block automatically reverted to its previous value. Marker channels on a Beckman Dynograph signaled the onset of a critical stimulus and the occurrence of the required button press.

Heart rate was obtained from chest electrodes with the leads connected to the Dynograph. Pulses from a cardiotachometer coupler were used as inputs to the computer for recording heart rate and heart rate variability.

C. Background Stimulation (Noise). As noted previously, the noise condition consisted of tape-recorded sounds obtained from actual radar rooms. The radar rooms used were located in the ARTCCs at Fort Worth, Texas, and Albuquerque, New Mexico. Using the recordings from both rooms, a single 30-minute tape segment was made by mixing these separate recordings. The purpose of using this composite was to mask virtually all intelligible speech. Additional editing removed all recognizable words. The 2-hour recording used for the noise condition consisted of this 30-minute segment repeated four times without any noticeable interruption. Repeating the same segment in this manner insured a relatively uniform level and quality of background noise throughout the experimental session.

The amplified noise was led to an Acoustic Research (AR2a) speaker located 6 feet behind the S at head height. Average noise level at the S's head location was 78-80 dBA (re 20 $\mu N/m^2$) as measured with a sound level meter. Ambient noise in the room (quiet condition) was measured at the same location and found to average approximately 57 dBA.

D. Procedure. The S was seated at a simulated air traffic control console, which contained the visual display. Chest electrodes were attached and the task instructions administered. If the S was one assigned to the noise condition, he/she was told that a continuous recording of actual radar control room sounds would be played during the task session. The Ss were instructed to try to ignore the noise as much as possible, since they were told that would be what an actual controller would tend to do. A 9-point subjective rating scale was then administered dealing with present feelings of attentiveness, fatigue, tension, annoyance, and boredom, followed by a 4-minute practice period containing six critical stimuli.

After the 2-hour task session, the S completed a second form of the subjective rating scale. This form was identical to the first except that the S was asked to rate each item on the basis of how the S felt near the end of the test period just completed.

E. Measurement of the Performance and Physiological Data. Performance data were computer processed and the following measures were obtained on each S for each 30-minute period (all latency measures refer to the time from critical stimulus onset to the button press):

(i) Mean response latency to critical stimuli correctly identified.

(ii) Single longest latency to a correctly identified critical stimulus.

(iii) Single shortest latency to a correctly identified critical stimulus.

(iv) Number of critical stimuli missed.

The computer program described in a previous study (19) was used to obtain the mean and standard deviation of heart rate for each successive 5-minute period. These were then averaged to give values for the four 30-minute periods.

III. Results.

Figure 1 shows mean, maximum, and minimum detection latencies for the two levels of task difficulty under noise and quiet conditions. Analyses of variance revealed significant differences between task difficulty levels for mean, $F(1,52) = 45.29$, $p < .01$; maximum, $F(1,52) = 48.26$, $p < .01$; and minimum, $F(1,52) = 15.64$, $p < .01$ detection latencies. Likewise, there were significant main effects for 30-minute periods for all three response measures.

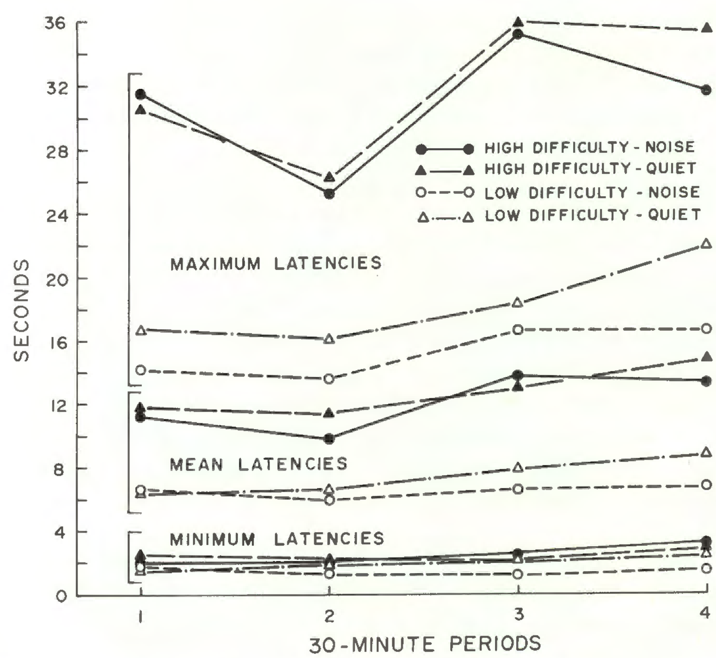

FIGURE 1. Detection latencies for the two levels of task difficulty under noise and quiet conditions.

Obtained values were $F(3,156) = 7.38$, $p < .01$; $F(3,156) = 5.19$, $p < .01$; and $F(3,156) = 3.24$, $p < .05$, for mean, maximum, and minimum latencies respectively. As with our previous studies using this task (18,20,21), performance appears to remain relatively uniform or even improve during the first hour with a general increase in latencies during the second. Although the data in Figure 1 (especially mean and maximum latencies) suggest a slight, general superiority of performance under noise for both levels of task difficulty, none of the main effects for noise were significant, nor were any of the interactions significant ($p > .05$).

With regard to missed stimuli, there was no apparent effect of noise under the low task difficulty condition. Thus, one S under the quiet condition missed a critical stimulus and two Ss each missed one stimulus under noise. For high task difficulty, 10 of the 14 Ss in the quiet condition missed one or more critical stimuli, while only 5 of 14 noise-exposed Ss missed one or more stimuli. A comparison of the number of Ss in the high difficulty noise and high difficulty quiet groups missing no stimuli with those missing one or more yielded a chi-square value of 3.59, df = 1. This value approached ($p < .10$) but did not reach the conventional 5-percent level of statistical significance.

Heart rate data are shown in Figure 2. Analyses of variance revealed a significant decline in heart rate across 30-minute periods ($F(3,156) = 26.08$,

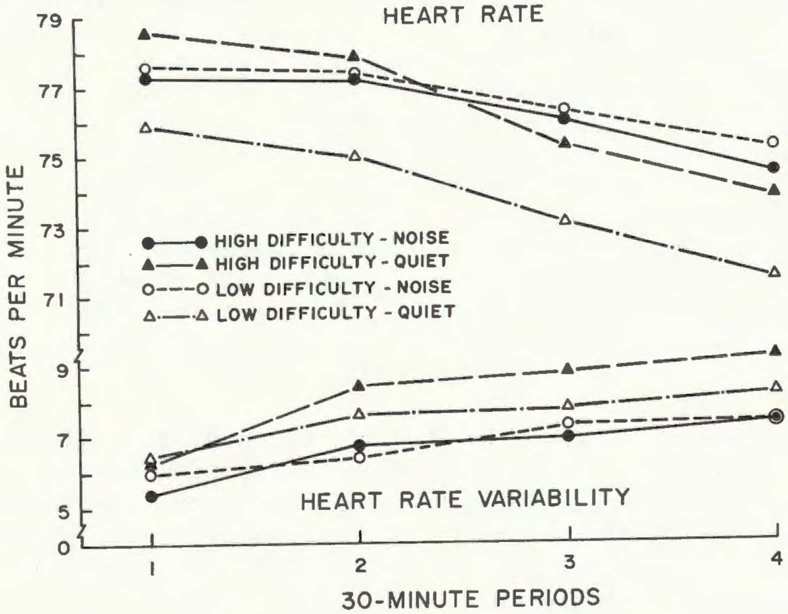

FIGURE 2. Heart rate and heart rate variability under noise and quiet for the two levels of task difficulty.

$p < .01$) and a significant increase in heart rate variability ($F(3,156 = 29.42$, $p < .01$). However, for heart rate variability, there was also a significant main effect for noise ($F(1,52) = 5.28$, $p < .05$). As is evident from the figure, heart rate variability was lower in noise for both levels of task difficulty. There were no other significant main effects for either heart rate or heart rate variability and no significant interactions ($p > .05$).

Analyses of variance were also applied to the subjective rating scale data. Significant differences between measurement periods were obtained for attentiveness ($F(1,52) = 97.63$, $p < .01$), fatigue ($F(1,52) = 82.41$, $p < .01$), annoyance ($F(1,52) = 26.16$, $p < .01$), and boredom ($F(1,52) = 122.04$, $p < .01$). The increase in tension was nonsignificant ($p > .05$). No significant main effects for noise or task difficulty and no significant interactions were obtained for any of the above variables ($p > .05$). Statements on the scales corresponding to the mean ratings at the completion of the task period suggested that the Ss were only slightly bored, were mildly annoyed, felt more tired than usual, and felt themselves to be reasonably attentive. The actual obtained values are not presented because of the lack of significant between-group and interaction effects.

IV. Discussion.

The results of the present study indicate that typical radar control room noise at an average level of 78-80 dBA does not significantly affect monitoring performance. However, although performance was unaffected by noise, heart rate variability was significantly lower under the noise than under the quiet condition. This was true for both levels of task difficulty. Since numerous studies have shown an inverse relationship between measures of heart rate variability and mental load or attentional demands (3,4,7,9,19), the lower heart rate variability under noise suggests that greater effort was required to sustain attention under noise than under quiet conditions. That increasing levels of noise may affect effort expended without affecting performance has recently been reported by Dornic, Sarnecki, Larsson, and Svensson (6). In the four different tasks studied, all of which required concentrated attention, exposure to 70-90 dB of street and office noise significantly increased perceived effort but had no significant effect on performance.

If noise exposure in the present study did indeed affect effort expenditure, it is interesting that none of the subjective rating scale measures differed as a function of noise. Thus, although no specific measure of perceived effort was included, ratings on such seemingly related variables as attentiveness, annoyance, and fatigue did not differ among the noise and quiet groups. Perhaps the relationship of these variables to perceived effort is not that high. Whatever the reasons for the lack of agreement between the physiological, performance, and subjective measures used in this study, such a finding is not uncommon. As Broadbent (1) has noted, these measures frequently do not agree in studies in which noise or some other environmental condition is varied. However, while many noise studies have been conducted in which some combination of two of the above three kinds of measures are compared within a single investigation (15), studies (especially in the area of vigilance research) in which all three are examined in the same experiment are virtually nonexistent. Future studies of noise and vigilance performance should endeavor to include selected physiological and subjective measures in order to enable a more comprehensive assessment of noise effects than is presently available.

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