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RATE OF INITIAL RECOVERY AND SUBSEQUENT RADAR MONITORING PERFORMANCE FOLLOWING A SIMULATED EMERGENCY INVOLVING STARTLE

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16. Abstract The present study employed auditory startle to simulate the principal components (unexpectedness, fear, and physiological arousal) that are common to many types of sudden emergencies and compared performance recovery following startle with recovery following a nonstartling stimulus. The subject's primary task was to monitor a simulated air traffic control radar display. Performance recovery following the emergency (a radar failure signaled by either a loud or low level noise) was assessed in terms of response time and error rate on a secondary information processing (serial reaction) task and also in terms of subsequent performance on the radar monitoring task. Although the high intensity noise was clearly startling, while subjects exposed to the lower intensity noise showed only a surprise reaction, subsequent performance of the two noise exposure groups differed significantly in only two respects: The variance of initial response times was greater in the startled group, and this group had a higher frequency of incorrect responses on the serial reaction task during the first minute following stimulation. A comparison of these findings with those of other studies of simulated emergencies suggests that recovery time for simple perceptual-motor responses during the initial shock phase of an emergency is quite rapid (on the order of 1 to 3 s), and this appears to be independent of whether or not the emergency is startling and emotionally arousing or simply surprising and unexpected. If the shock phase evokes heightened emotional-physiological arousal as in the case of startle, information-processing ability may be impaired for approximately 30 to 60 s following the stimulus event.

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RATE OF INITIAL RECOVERY AND SUBSEQUENT
RADAR MONITORING PERFORMANCE FOLLOWING
A SIMULATED EMERGENCY INVOLVING STARTLE

In proposed highly automated air traffic control systems of the future, such as the Automated En Route Air Traffic Control (AERA) concept (6), it is anticipated that the controller will become less involved in manual control operations and will become more of a systems monitor or systems manager. Such a shift in role is not unique to air traffic control; it is becoming common to all automated systems as computer technology rapidly advances. In some areas, such as nuclear control room operation, these role changes are already occurring (13). Operators are being removed from the manual control loop to serve as systems monitors whose primary function is to detect occasional malfunctions or departures from normal limits, and then take corrective action. Thus, in nuclear control rooms and similar highly automated systems, a primary responsibility of the operator is to act as a backup in case of failure.

While it is almost axiomatic that engineers and designers of highly automated systems will attempt to design such systems as fail-safe as possible, it is difficult to anticipate all possible contingencies that may arise. As Lees and Sayers (9) point out, there will always remain "...a residual of events, usually of low probability, against which there is no protection either because they were unforeseen or because their probability was estimated as below the designer's cutoff level" (p. 332). It is the unexpected, low-probability event that the systems monitor is expected to handle. Some of these events will undoubtedly be emergency situations, and the reliability of humans in rapidly resolving unexpected emergencies, such as equipment failures in critical situations, is often stated to be low (9). In proposed highly automated air traffic control systems, it is clearly important to determine how rapidly and effectively controllers can respond to unexpected failure conditions in order to establish redundancy requirements and to determine the extent of automated backup needed.

Although the belief that humans are relatively ineffective in rapidly resolving emergency situations is a common one, relatively few studies of human performance in emergency situations have actually been conducted. Part of this is due to the fact that field data on human reliability in general, to say nothing of human reliability in emergencies, are almost nonexistent (4). Laboratory studies are difficult to conduct because subjects are usually aware that some "emergency" is going to occur and because realistic emergencies are extremely difficult to simulate in a laboratory environment.

Of the field studies dealing with emergency behaviors, the earliest appears to have been conducted by Ronan (cited in Rigby and Edelman (14)). Ronan collected information on 2,790 emergency situations that crew-members of multiengine aircraft had encountered. His data suggest that approximately 16 percent of the critical actions taken to resolve these emergencies either made the situations worse or failed to correct them. Rigby and Edelman (14) selected 32 of the more common emergencies listed by

Ronan and, using a paired-comparison technique, had experienced multiengine crew-members identify the most stress-producing item in each pair. The 32 emergencies were then scaled according to perceived stress, covering a range from mildly stressful to extremely stressful. Since Ronan had listed the frequency of effective and ineffective behaviors for each of these emergencies, Rigby and Edelman obtained an approximate error rate for each emergency by dividing the number of ineffective behaviors by the total number of behaviors reported. From a resulting plot of error rates against perceived stressfulness of the various emergencies, they arrived at error rates ranging from .01 for mildly stressful emergencies to .25 for extremely stressful emergencies. The types of emergencies associated with their lowest stress category (mildly stressful) appeared to differ little from normal behaviors encountered in piloting aircraft. Consequently, they consider an error rate of .01 to be a conservative estimate of task unreliability under reasonably benign operating conditions.

Other studies relating to performance recovery in emergency situations have dealt with simulated nuclear power plant emergencies. Lees and Sayers (9) describe a number of studies carried out by the United Kingdom Atomic Energy Authority over a period of years that ranged from relatively simple laboratory experiments of response times to warning lights, to simulator studies involving response times to realistic fault conditions. Because of the differences between experimental situations, it is difficult to summarize these results. However, it would appear from the simulator data that average response times for the various fault conditions were almost always within allowable response times. Thus, values of actual response times divided by allowable times ranged from .33 to 2.60, with a mean across faults of .87. The mean probability of failing to respond within allowable times was .18. A much lower value of .001 was obtained for failure to respond rapidly enough to a warning light in the simpler laboratory studies, when the allowable response time was 4 s.

The higher probability of failure obtained in the simulator studies was apparently due to the fact that allowable response times were the sum of motor or movement times plus the more variable time that it took the operator to decide that the fault was uncontrollable, requiring that the plant be shut down. In the laboratory studies, decision time was minimal, with a mean time to respond (as estimated from the data given) of approximately 1 s.

The remaining studies to be considered have dealt with driver response-recovery time to unexpected situations. Ziperman and Smith (26) examined driver performance following the unexpected deployment of air bag restraining devices. Although there was some initial lateral deviation in vehicle travel following deployment (the actual duration and extent of deviation were not reported), recovery was quite rapid and no driver's lateral deviation exceeded the limits of the driving lane. In a recently published study, Muto and Wierwille (11) studied the effects of prolonged driving on driver's response time to a simulated emergency. The emergency consisted of a sudden deceleration of the lead vehicle in a car-following scenario. Mean response time to the initial emergency situation following a prolonged driving period was found to be 1.64 s. With repeated practice, response times declined significantly to baseline levels.

From the studies just reviewed, it is apparent that the data on human reliability in emergency situations are both extremely meager and, because of the different methods and approaches used in assessing reliability, are difficult to compare in any meaningful manner. In addition, although investigators generally acknowledge the need to incorporate stress into studies of performance recovery following simulated emergencies (4), it is often very difficult to create in a laboratory the particular perceptual-cognitive events that, because of their meaning or significance to the individual, are the usual triggers for the emotional reactions associated with real-life emergencies. Yet some way of producing emotional stress in simulation studies would appear to be essential if the data are to have relevance.

In an early study by Sternbach (19), it was reasoned that startle resulting from a loud auditory stimulus might be used to approximate the principal components (unexpectedness, fear, and physiological arousal) that are common to many types of sudden emergencies and hence provide a technique for studying the time course of behavioral recovery following traumatic events under laboratory conditions. It is generally accepted that sudden emergencies frequently, if not typically, elicit feelings of fear and anxiety, and a number of studies have clearly demonstrated that startle does evoke an experience, albeit rather transitory, that is most closely identified with fear (2,17). Further, the physiological response to startle, when compared with autonomic response patterns produced by exercise, the cold pressor test, and injections of epinephrine and norepinephrine, has been found to closely resemble the pattern produced by epinephrine injection (18). This latter pattern has been shown to be the characteristic pattern produced by fear-inducing situations (1,15).

Using a pistol shot as the stimulus for a required button press response, Sternbach (19) found that behavioral recovery times ranged from 128 to 3,262 ms with a mean (estimated from the data) of 950 ms. Sternbach's primary concern, however, was not with the establishment of mean values of response-recovery time to an emotionally disruptive stimulus, but rather with investigating psychophysiological correlates of individual differences in response time to such stimuli. In this regard, he found that greater autonomic response to the high intensity noise was associated with slower perceptual-motor recovery from startle. A later study by Thackray (20) compared response times to startle with reaction times to nonstartling auditory stimuli. The intent of this study was to provide baseline data that might be used to establish pilot response times to potentially critical situations, such as unexpected clear air turbulence or a sudden failure in an automatic control system. Mean response-recovery time (893 ms) to the startle stimulus was similar to that obtained by Sternbach, but the principal finding was that response times to startle exaggerated differences between individuals in their reaction times to low intensity tones, i.e., the slow tended to respond slower and the fast responded more rapidly to the startle stimulus.

A subsequent study by Thackray and Touchstone (21) again used startle to simulate a sudden aircraft emergency and examined both the magnitude of initial disruption in psychomotor coordination and the time course of performance recovery. Although tracking performance showed maximum impairment during the first 2 s following startle, significant impairment was still present 10 s following stimulation. Since the total reflex response to startle lasts approximately .3 to 1.5 s (8), it is evident that the obtained impairment in tracking, lasting up to 10 s following startle, clearly extended beyond the initial disruptive effects of the startle reflex itself and would appear to be a manifestation of a longer lasting, more *general physiological-emotional response to the unexpected noise* stimulation.

Other laboratory studies of perceptual-motor recovery following startle, however, have failed to find evidence of impairment lasting this long. Thus, May and Rice (10) and Vlasak (23), using various types of tracking tasks, found that impairment following startle lasted considerably less than 10 s, with significant impairment occurring only during the first 2 to 3 s following stimulation. The longer period of impaired performance found by Thackray and Touchstone (21) may have been due to the use of a more difficult tracking task and/or the use of a more refined measure of tracking error.

Although perceptual-motor recovery following startle appears to be quite rapid, there is evidence that tasks involving decision making or information processing may be impaired for a longer period of time. Thus, Vlasak (23) studied the effects of startle on continuous mental subtraction and found performance to be signficiantly impaired during the first 30 s following stimulation. A similar period of impairment was found by Woodhead (24,25) who obtained decrements on a continuous symbol-matching task lasting from 17 to 31 s after startle.

The fact that impairment on some tasks following startle may last for at least 30 s clearly indicates that startle effects extend beyond the initial period of motor disruption produced by the reflex response itself. Given that startle is unexpected, frequently evokes subjective responses associated with fear, and produces pronounced physiological arousal, it seems reasonable to conclude that startle may indeed provide a laboratory technique for studying recovery of functioning following sudden emergency situations.

In all of the startle studies just reviewed, performance recovery effects were studied only during the first few min following stimulation. While it is entirely possible that performance impairment does not extend beyond this time period, startle is known to be accompanied by rather *massive autonomic (especially cardiovascular) changes, and it is entirely* possible that such changes could have longer-term effects on performance. Thus, a pronounced discharge of the autonomic nervous system might have a long-term activating effect resulting in prolonged performance facilitation, or, conversely, it might produce a period of parasympathetic overcompensation leading to eventual drowsiness and impaired performance.

The present study was conducted to compare both short- and long-term performance recovery effects following a simulated emergency involving startle with recovery following a nonstartling emergency situation. This latter condition was considered to be a control condition for the purpose of establishing a baseline response-recovery pattern to a nonemotional "emergency" situation. The subject's primary task was to monitor a simulated air traffic control (ATC) radar display. Performance recovery following the emergency (a radar failure signaled by either a loud or low level noise) was assessed in terms of response time and error rate on a simple information processing task and also in terms of subsequent performance on the radar monitoring task. In addition to performance, physiological and subjective measures of startle and arousal were also obtained. It was hypothesized that performance following the high intensity noise (expected to elicit a startle reflex) would be significantly impaired relative to performance following the low intensity noise (expected to elicit an orienting type response).

Method

Subjects. Thirty paid university students (16 males and 14 females) were randomly assigned, in approximately equal male-female proportions, to one of two treatment groups. Subjects ranged in age from 19 to 34 (mean = 23.5) and none had prior experience with the tasks used or previous training in air traffic control. All had 20/20 vision, corrected or uncorrected, and all had no reported hearing loss.

Apparatus. Programing and recording of responses for the primary radar task were accomplished using a Digital Equipment Corporation PDP 11/40 computer. The computer was interfaced with a 17 in (43 cm) cathode-ray tube (CRT), which served as the subjects' display. The stimuli (targets) consisted of 16 alphanumeric data blocks that identified the aircraft and gave its altitude and speed. Targets were updated as to location and any change in the alphanumerics in a continuous, clockwise manner, such that a complete update occurred every 6 s. Critical stimuli consisted of a change in a target's displayed altitude to a value greater than 550 or less than 150. Changes occurred randomly, with 10 critical stimuli in each half-hour period. Interstimulus intervals ranged from 1.2 to 7.5 min. Subjects responded to a critical stimulus by pressing a button held in their 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 within-limits value. If a critical stimulus was not detected within 1 min, the altitude change reverted automatically to its previous value.

The secondary information-processing task consisted of a simple self-paced serial reaction (SR) task. The subject's panel contained four lever-actuated microswitches arranged in a row 3 cm apart with a 1.9 cm diameter visual display centrally located over the keys. The visual display presented the numbers 1-4 corresponding to keys 1-4 as numbered from left to right. A tape reader was used to present the numerical stimuli to the subject. Stimuli consisted of a quasi-random series of numbers with the restrictions that no number could occur twice in succession and that each number occur an equal number of times in the series. The series consisted of 300 stimuli and repeated itself automatically.

Each time a given number appeared, the subject attempted to press the corresponding key. If a correct response was made, the tape reader advanced and the cycle continued. If an incorrect response was made, the visual stimulus did not change until the correct key was pressed. Elapsed time between responses as well as incorrect responses were computer recorded.

The noise burst used to signal the onset of the simulated radar failure consisted of a 1 s pulse of amplified white noise produced by a Grason Stadler Noise Generator and delivered through an Acoustic Research (AR2a) speaker located 1.8 m behind the subject at head height. Noise level at the subject's head location was 104 dBA for the high intensity (startle) condition and 67 dBA for the low intensity condition. Ambient room noise was 57 dBA.

Heart rate was obtained from chest electrodes placed at midlateral locations on the rib cage and the leads connected to a Beckman cardiotachometer. Pulses from the cardiotachometer were used as inputs to the computer for processing heart rate. Beckman biopotential electrodes filled with a saline paste and attached to the volar surfaces of the index and middle fingers of the subject's left hand were used for measuring conductance level. Leads from these electrodes led to a Beckman Type 9844 coupler that recorded conductance directly.

The computer and other recording apparatus were located in an adjacent room from which the subject was monitored and video-tape recorded via closed-circuit TV. Indirect lighting was used in the subject's room, and the level of illumination at the display was 21.5 lux. This level approximates that used in operational air traffic control environments.

Procedure. The subject was seated at a simulated air traffic control console containing the visual display, with the SR task located directly to the right of the chair. Electrodes were attached and an orientation tape played. The orientation stated that this was one of a series of studies designed to investigate the role of an air traffic controller in future, highly automated systems, and that in this particular study the intent was to evaluate performance recovery following an emergency condition (a radar failure).

The instructions for the radar task emphasized the necessity of pressing the button immediately upon detection of a critical stimulus. The subject was told that a critical stimulus (any altitude value greater than 550 or less than 150) could occur in any target at any time, regardless of the current altitude values of the targets. It was explained that occasional large changes in altitude would not normally occur in an actual radar system, but that this departure from normal conditions was necessary to insure that all targets would be given equal priority in scanning. A 7-min practice period was then administered.

Instructions for the SR task described the basic nature of the task and emphasized that performance should be as rapid as possible, but not at the expense of accuracy. They were told that a noise from the speaker behind them would always be the signal to begin performing this task. Three 1-min training periods separated by 30-s rest periods were then administered. The noise level signaling the start of each training period was always set at 67 dBA.

Subjects were then reminded that the purpose of this study was to examine performance recovery following an emergency (radar failure) condition. They were told that at some time during the 1 1/2- to 2 1/2-h period of radar performance (the actual duration of radar performance was always 2 h) the targets on the screen would stop moving. At the same time they would hear a noise signal from the speaker and a red indicator light on the console would be illuminated. When this occurred, they were to immediately begin performing the SR task and continue performing it until the red indicator light went off. They were informed that the targets on the radar screen would commence to move again once the red light was extinguished, and they were to resume performance of the radar task at that time. Subjects were told that they had been randomly assigned to different conditions and that the noise signaling the radar failure would be at the same intensity level as used during the practice periods for some subjects, but would be at a louder, possibly startling, level for others.

The radar failure occurred at the end of 1 h of performance on this task. The period of time between the failure and resumption of radar monitoring was 5 min. After the 5-min period of SR performance, subjects resumed radar monitoring for one more hour. At the end of the experiment, all subjects rated the degree of startle elicited by the noise signaling the failure period.

Measurement of the Performance and Physiological Data. For the radar task, mean time for critical stimuli correctly detected and the number of critical stimuli missed were obtained for each subject for each successive 30-min of the task. Heart rate was computer processed and the mean rate determined for each 30-min period. Conductance level was measured directly from the chart recordings at the beginning and end of each of these periods.

Our previous study of tracking recovery following startle (21) clearly suggested that maximum performance effects occurred well within the first min following stimulation. Consequently, a fine-line analysis was made of mean SR time during each successive 6-s interval for the first min following stimulation. To determine the magnitude of change in heart rate and skin conductance, as well as the time-course of recovery, maximum heart rate (single fastest beat as measured from the cardiotachometer recording) and maximum skin conductance level were obtained within each 6-s interval. Since it was anticipated that both performance and physiological measures would begin to stabilize after the first min following stimulation, mean values were used for all measures during the subsequent four, 1-min measurement periods of the radar failure period.

Results

Initial Performance and Physiological Response to Noise Stimulation. Figure 1 shows mean response time for SR performance during successive 6-s intervals of the first min following noise stimulation. Also shown are prestimulus levels. (These were obtained from the final min of the initial practice period and did not differ significantly ($t(28)=.18$, $p>.05$)). Relative to prestimulus levels, both noise stimulation groups displayed an increase in response time followed by a return to a level at or below prestimulus values. Surprisingly, the performance trends shown in this figure appear almost identical in the two groups. An analysis of variance of the poststimulus data revealed that, although the periods effect was significant ($F(9/252)=16.17$, $p<.01$), there was in fact no difference between groups and no significant interaction ($F<1.00$ in both cases).

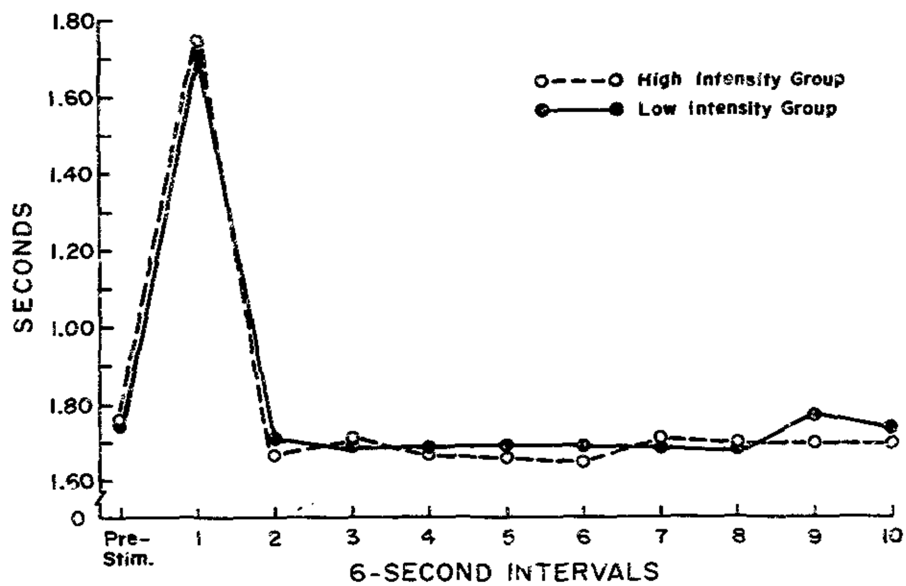

Figure 1. Mean response time for SR performance during successive 6-s intervals of the first min following noise stimulation. Also shown are prestimulus values.

Since this finding was not expected, response times during the first 6-s period were examined more closely. The time from noise stimulation to first response (designated the initial response time) was obtained for each subject in the two groups. These data, plotted on log normal probability paper, are shown in Figure 2.

For the high intensity group, mean initial response time was 2.91 s, while mean time for the low intensity group was 2.84 s. A t test performed on these data revealed no difference between the group means ($t(28)=.24$, p

>.05). Figure 2 suggests, however, a difference in the variability of initial response times in the two groups. Response time variance for the high intensity group was .9916, while for the low intensity group the variance was .3806.

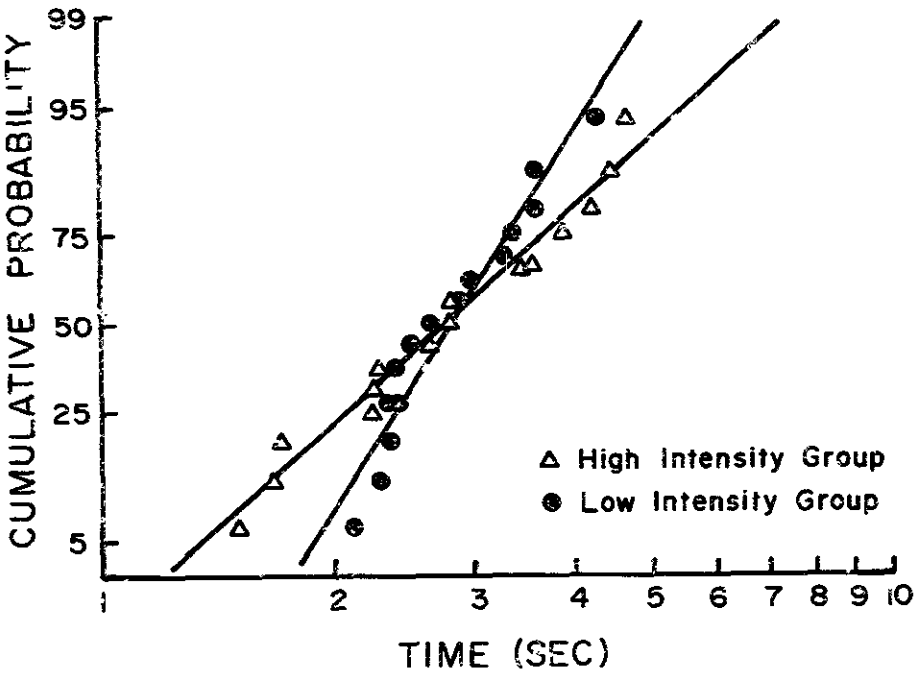

Figure 2. Distribution of time to first SR response following noise stimulation.

This difference was significant ($\underline{F}(14/14)=2.61$, $\underline{p}<.05$). The significant difference in variances was confined only to initial response times. An examination of response time variances during the first 6-s period following stimulation revealed variances of .2869 and .1272 for the high and low intensity groups respectively. The difference between groups was not significant ($\underline{F}(14/14)=2.25$, $\underline{p}>.05$).

In an attempt to clarify the reasons for this lack of difference in initial mean response times accompanied by a significant difference in variability, video-tape recordings taken of each subject's response following noise stimulation were visually analyzed. In the high intensity group, all subjects displayed perceptible movements of the torso, head, and arms in accordance with the classic startle pattern described by Landis and Hunt (8). Reactions subsequent to the reflex response, however, differed markedly among subjects. Some subjects appeared dazed and disorganized by the noise, while others recovered almost immediately and rapidly began performing the SR task. For the group receiving the low intensity noise stimulation, the behavioral response was quite different. There was no evidence of startle and, as expected, the typical reaction resembled an orienting or surprise response. Following the orienting reaction, virtually all subjects in the low intensity group exhibited an almost identical pattern. They slowly and deliberately turned in the chair and, in the same slow manner, began performing the SR task. There was none of the confusion and disorganization displayed by many subjects in the high intensity noise group. Thus, analysis of the video-tape recordings clarified the reasons for the lack of difference between the groups in mean time to first response. The disruptive effect of the loud sound for some subjects combined with the rapid recovery shown by others apparently balanced the generally uniform response of the low intensity group. This also explained the difference in the variance of response times of the two groups.

Other performance data obtained during the first min following stimulation consisted of the mean number of incorrect responses made by each group. The obtained mean value for the high intensity group was 3.14 errors, while the mean for the low intensity group was 1.86. A Mann Whitney $\underline{U}$ test, used because the distributions were highly skewed, revealed this difference to be significant ($\underline{U}$=50, $\underline{p}$ <.05). (There was no difference between the groups ($\underline{U}$=70, $\underline{p}$ >.05) in their frequency of errors during the last min of the initial practice period at the beginning of the experiment. Mean error rates were 2.07 and 1.36 for the high and low intensity groups respectively.)

Physiological changes during the first min following noise stimulation are shown in Figures 3 and 4. Figure 3 shows conductance change and Figure 4 shows heart rate change.

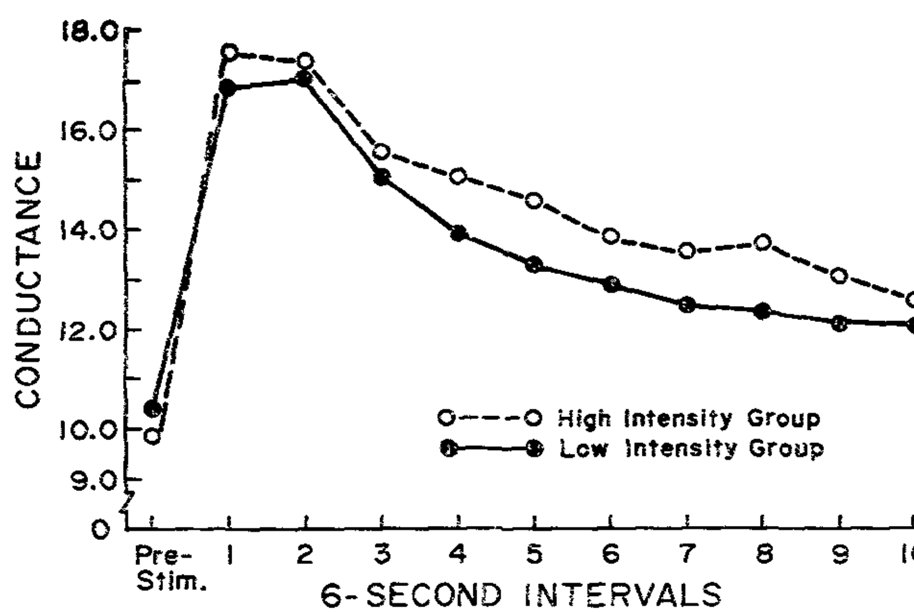

Figure 3. Mean maximum conductance level during successive 6-s intervals of the first min following noise stimulation. Also shown are pre-stimulus values.

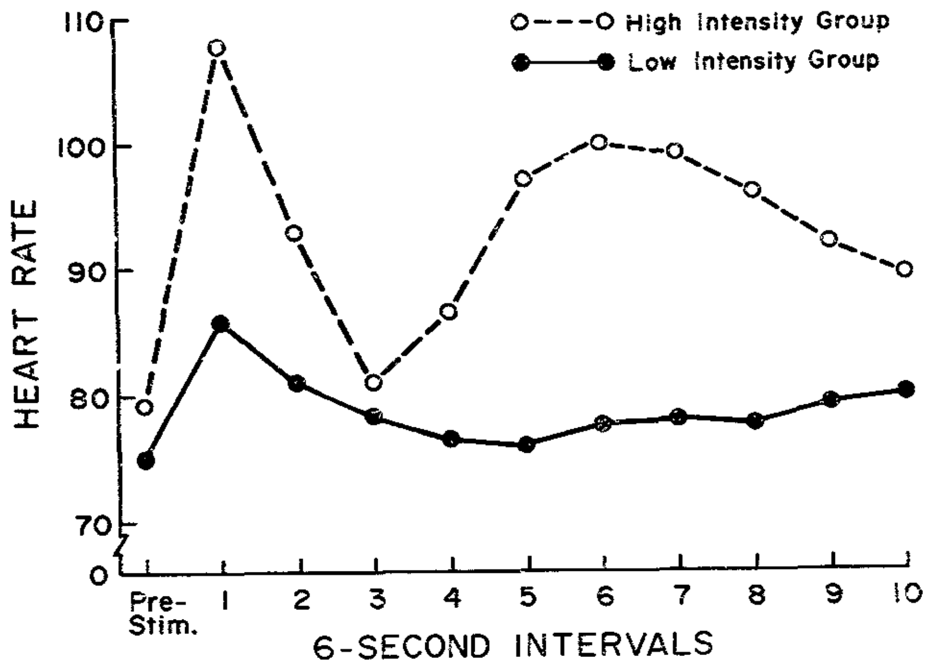

Figure 4. Mean maximum heart rate during successive 6-s intervals of the first min following noise stimulation. Also shown are prestimulus values.

Prestimulus values are also shown in both figures. Separate *t* tests performed on the prestimulus values for heart rate and conductance level revealed no significant differences (p >.05) between groups. Analysis of variance performed on the poststimulus conductance data of Figure 3 revealed a significant periods effect (F(9/252)=75.36, p <.01), but no difference between groups and no interaction effect (F <1.00 in both cases). Quite different results were obtained for the heart rate data, however. The analysis of variance revealed significant differences between groups (F(1/28)=10.42, p <.01), periods (F(9/252)=12.22, p <.01), and a significant interaction effect (F(9/252=6.61, p <.01). Examination of the data for the high intensity group in Figure 4 reveals a typical heart rate response to startle. There is pronounced initial cardiac acceleration followed by an abrupt decline or rebound effect of almost equal magnitude. This is followed by a rather large secondary acceleration and slow deceleration. The data for the low intensity group, on the other hand, show considerably less initial acceleration followed by gradual decline and slow recovery to prestimulus level. To clarify further the differences in heart rate response, beat-by-beat patterns evoked by the two stimulus intensities are shown in Figure 5 as deviations from prestimulus beat 1. Since orienting responses can be differentiated from startle responses by the direction of the initial heart rate change following stimulation (7), only the initial changes were analyzed.

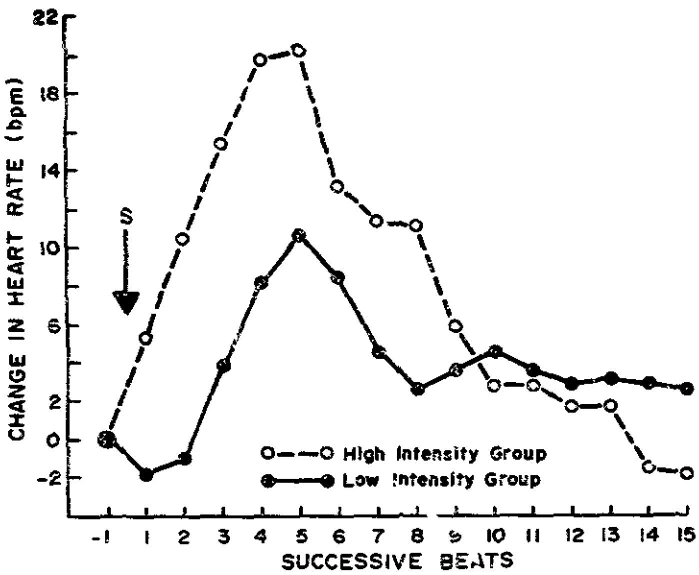

Figure 5. Beat-by-beat changes in mean heart rate from prestimulus beat 1.

Relative to prestimulus rate, heart rate decreased ($\underline{t}(13)=1.82$, $\underline{p}<.05$, one-tailed) in the low intensity group and increased ($\underline{t}(13)=2.71$, $\underline{p}<.01$, one-tailed) in the high intensity group. The direction of these changes is consistent with the expected direction of change for orienting and startle responses respectively (7). The fact that conductance change did not differ in the two groups is not necessarily inconsistent with the heart rate data. Although magnitude of skin conductance change is often found to be proportional to stimulus intensity (3,12), conductance change, being unidirectional, cannot be used to differentiate orienting from startle reactions (7), and orienting reactions of magnitudes comparable to startle responses are often evoked by weak stimulus intensities (5).

Subsequent Performance and Physiological Response to Noise Stimulation. Mean SR response time, heart rate, and conductance level were also obtained for min 2 through 5 following noise stimulation. These data are shown in Table 1. SR performance increased significantly ($\underline{F}(3/84)=3.74$, $\underline{p}<.05$) for both groups during this time frame and probably reflected a fatigue effect. Conductance level also increased ($\underline{F}(3/84)=39.33$, $\underline{p}<.01$), while heart rate showed no change ($\underline{F}(3/84)=1.66$, $\underline{p}>.05$). There were no differences between the groups in serial reaction performance, heart rate, or conductance level, and no significant interaction effects ($\underline{F}<1.00$ in all cases).

TABLE 1. Mean Serial Reaction Time, Heart Rate, and Conductance Level for Minutes 2 Through 5 Following Noise Stimulation

Measure	Groups	Minutes After Noise 2	3	4	5
Serial Reaction (seconds)	High Intensity	.7533	.7393	.7613	.7720
	Low Intensity	.7553	.7440	.7480	.7673
Conductance (micromhos)	High Intensity	11.56	10.56	10.06	9.77
	Low Intensity	11.39	10.70	10.31	10.21
Heart Rate (beats per min)	High Intensity	77.3	77.2	78.4	78.6
	Low Intensity	74.9	75.7	75.7	75.8

Frequency of errors (not shown in Table 1) for the serial reaction task was summed across min 2 through 5 and divided by 4 to give the mean number of incorrect responses per minute of each group. The obtained means were 2.70 and 2.62 for the high and low intensity groups respectively. A Mann Whitney *U* test revealed no difference between the groups (U=82, p >.05).

Mean performance on the radar task across the 2-h session is shown in Figure 6.

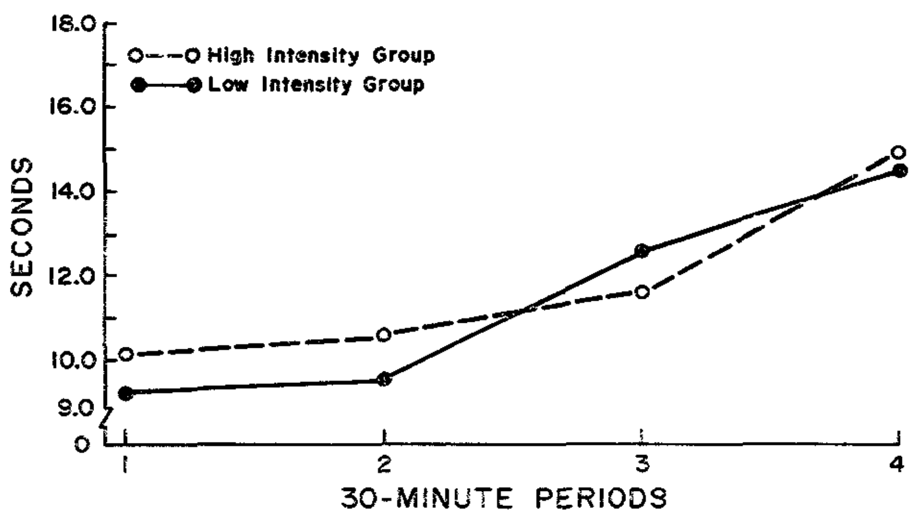

Figure 6. Mean target detection time on the radar monitoring task across the 2-h session.

The general increase in detection time, common to both groups across the session, is a typical pattern that has been found in all of our previous studies with this task, e.g., Thackray & Touchstone (22). An analysis of variance showed this period's effect to be significant ($F(3/84)=13.02$, $p <.01$). However, there was no difference between groups ($F <1.00$) and, more importantly, there was no significant interaction of groups by periods ($F <1.00$). With regard to omission errors, five subjects in each group missed one or more critical stimuli during the first hour of radar performance. During the second hour, seven subjects in the high intensity and five subjects in the low intensity group missed one or more stimuli. A chi-square analysis revealed this difference between groups during the second hour to be nonsignificant ($p >.05$). Thus, the different noise intensities to which the two groups were exposed had no differential effect on either mean performance or omission errors during subsequent radar monitoring.

Mean heart rates and conductance levels across the 2-h radar monitoring session are shown in Table 2.

TABLE 2. Mean Heart Rate and Conductance Level During Each 30 Minute Period of Radar Monitoring

Measure	Group	30 Minute Periods 1	2	3	4
Conductance (micromhos)	High Intensity	9.46	9.23	8.58	8.13
	Low Intensity	10.14	9.87	9.48	8.80
Heart Rate (beats per min)	High Intensity	80.61	79.53	76.13	75.02
	Low Intensity	78.34	76.13	73.65	72.76

Analyses of variance revealed a significant decline in heart rate ($F(3/84=41.31$, $p <.01$) and in conductance level ($F(3/84)=18.31$, $p <.01$). There were no significant interaction effects for either variable and no differences between groups in either heart rate or conductance level ($F <1.00$ in all cases).

Subjective Response to Noise Stimulation. Subjective ratings of startle, obtained at the completion of the experiment, appeared clearly different among the groups. The mean value for the high intensity group was 6.9 (corresponding to a rating of "very startled"), while for the group receiving the low intensity noise, the mean value was 2.9 (corresponding to a rating of "only slightly startled"). A t test performed on these data revealed the difference to be significant ($t(28)=6.56$, $p <.01$).

Discussion

Video-tape recordings, heart rate response, and subjective ratings of startle were consistent in demonstrating that the high intensity noise signal was clearly startling to subjects assigned to this group. Conversely, the group exposed to the low intensity noise exhibited no behavioral evidence of startle, and the direction of initial heart rate change was consistent with the expectation that this level of noise would produce only an orienting or surprise reaction. In spite of these differences, however, at no time during the first min following the noise signaling a radar failure did response times on the secondary SR task differ in the two groups.

At first glance, this lack of any difference between the startled and nonstartled groups in mean performance during the first min following stimulation would appear to be inconsistent with the findings of other startle studies reviewed earlier. Previous studies of perceptual-motor recovery following startle have found a period of impaired performance lasting from 1 to 10 s following intense noise stimulation. It should be noted, however, that in all of these studies startle was introduced during the performance of some form of continuous tracking task and that the period of maximum impairment was always confined to the first 1 to 3 s following startle. In the present study, the noise used constituted a signal that a radar failure had occurred requiring a transition from the primary monitoring task to the secondary SR task. Mean time to make this transition was 2.91 s in the startled group, a value clearly within the period of maximum tracking impairment reported in the earlier studies. Consequently, it would appear that the primary disruptive effects of startle occurred during, or were confined to, the time period from stimulation to the first SR response (the task transition period), and it is thus not too surprising that no differences were found between the groups in mean SR performance during the first min following noise exposure. Interestingly enough, however, task transition time was found to be no greater in the startled than in the nonstartled group. As discussed earlier, analysis of the video-tape recordings taken during noise stimulation revealed the reason for the lack of difference. In the group receiving the nonstartling noise signal, behavior following stimulation was extremely uniform; subjects slowly turned in the chair and began performing the SR task. In the startled group, there were pronounced individual differences following stimulation with some subjects appearing dazed and confused by the noise while others recovered almost immediately and rapidly began performing the task. The extreme reactions to the high intensity noise were apparently balanced out by the far more uniform behavioral reaction to the low intensity noise resulting in a difference between groups in the variance of initial response times, but not in mean values.

Although mean response times were not adversely affected by startle, frequency of errors on the SR task was significantly greater in the startled than in the nonstartled group during the first min following stimulation. This finding is in general agreement with the findings of Vlasak (23) and Woodhead (24, 25) reported earlier, that information processing may be impaired during recovery from startle for periods ranging from 17 s to over 30 s.

There was no evidence that startle affected frequency of errors or mean performance on either the SR task or the radar task subsequent to the first min following stimulation. Since neither heart rate nor conductance level differed among the groups during these subsequent periods of SR and radar performance, it would appear that the physiological and performance effects of startle are quite transitory and are largely confined to the first min following the startling event.

It would be desirable to compare laboratory findings of recovery from startle with the time course of performance recovery following other forms of simulated emergencies. Unfortunately, few such comparisons can be made because of the paucity of published findings. Of the studies that have been reported, the most comparable appear to be those dealing with driver reactions to sudden emergencies or startling events. As previously noted, Ziperman and Smith (26) found that explosive deployment of air bag restraining devices caused only momentary disruption of vehicle travel, and Muto and Wierwille (11) found that mean initial braking time to an unexpected driving emergency, presented after a prolonged period of uneventful driving, was 1.64 s. Other relevant studies have dealt with simulated nuclear power plant emergencies. In these studies, process operators in nuclear control rooms were instructed to make a pushbutton response as rapidly as possible to simulated emergencies signalled by audible alarms and visual indicators. With signal rates of .35 to 1.35 per hour, response times (estimated from the data given) were quite short and ranged from less than 1 s to approximately 2.5 s (9).

Laboratory studies of performance recovery following startle are not completely analogous to studies of simulated nuclear power plant emergencies or even driver response to unexpected situations. Yet, all of these studies suggest that performance following unexpected, and often traumatic, situations is not nearly as disrupted as is frequently believed, with initial recovery of perceptual-motor functioning typically occurring within the first few s following the emergency or unexpected event.

In evaluating these findings with regard to their applicability to emergency behaviors in real-life situations, it is important to recognize that unexpected emergency situations in real life may involve at least two phases of behavioral response. The initial phase, which could be termed a "shock phase," is one in which the individual attempts to react to the unexpected situation as rapidly as possible with immediate behaviors designed to cope with or rectify the unexpected event. It is during this phase that emotional-physiological reactions to the emergency may produce behavioral disruption or even temporary immobility. In some emergencies, the shock phase is followed by a second phase which could be termed an "evaluative phase." This phase occurs if the emergency situation has not been resolved during the initial shock phase and is characterized by an emerging perception or evaluation of the situation in terms of the individual's ability to cope with the emergency. If it becomes apparent that there is no satisfactory means of coping with the situation, panic may occur.

It is evident that findings of studies of performance disruption following startle, such as the present one, would be relevant only to the initial recovery period or shock phase of a sudden emergency event. This would seem to be the case also with the studies simulating nuclear control room emergencies and driver response to unexpected situations that were cited earlier. Taken together, these studies suggest that perceptual-motor disruption immediately following a simulated emergency or startling event is relatively short-lived; task relevant responses are generally initiated or completed within 1 to 3 s following onset of the event, and there is little or no evidence of significant perceptual-motor impairment beyond this period (9, 10, 11, 19, 20, 23, 26). There is suggestive evidence, however, that cognitive behaviors may be impaired for a longer period of time, since several startle studies, including the present one, have found impairments in information processing lasting from 17 to 60 s following a startling event (23, 24, 25).

If it is accepted that the emotional-physiological response to auditory startle can serve to at least approximate the shock-phase reaction normally triggered by particular perceptual-cognitive events in real-life emergencies, then the use of startle may prove to be a relatively simple laboratory technique for studying performance disruption and rate of recovery on a wide variety of tasks. In addition, studies of individual differences in response-recovery from startle could assist in our understanding of some of the extreme reactions displayed by individuals in real-life emergencies. In natural disasters, for example, about 12 to 25 percent of individuals remain completely "cool and collected" during the initial response phase, while about the same percentage show maladaptive responses such as confusion, paralyzing anxiety, and hysterical reactions (16). As noted earlier, previous laboratory studies have isolated several individual difference variables (autonomic reactivity and simple reaction time) that appear to be correlated with response-recovery from startle (19, 20, 21, 23). Such variables suggest the existence of inherent, constitutional factors that may be related to the ability to respond rapidly and effectively to real-life sudden stress situations. Further research is needed, however, to determine the extent to which such variables, uncovered in laboratory studies of startle, can serve as useful predictors of performance recovery following simulated ATC emergencies that closely approximate real-life situations.

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