4

AD

AD-A217 106

Technical Memorandum 18-89

THE ACOUSTIC STARTLE RESPONSE AND DISRUPTION OF AIMING: I. EFFECT OF STIMULUS REPETITION, INTENSITY, AND INTENSITY CHANGES

John A. Foss
Argus Research Laboratories
Horsham, Pennsylvania

James R. Ison
University of Rochester
Rochester, New York

James P. Torre, Jr.
Samuel Wansack
Human Engineering Laboratory
Aberdeen Proving Ground, Maryland

DTIC
ELECTE
JAN 26 1990
S E D

November 1989
AMCMS Code 611102.74A0011

U.S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland 21005-5001

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
Technical Memorandum 18-89

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Human Engineering Laboratory

6b. OFFICE SYMBOL *(If applicable)*
SLCHE

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State, and ZIP Code)*
Aberdeen Proving Ground, MD 21005-5001

7b. ADDRESS *(City, State, and ZIP Code)*

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
6.11.02	1L161102B74A		

11. TITLE *(Include Security Classification)*
The Acoustic Startle Response and Disruption of Aiming: I. Effect of Stimulus Repetition, Intensity, and Intensity Changes

12. PERSONAL AUTHOR(S)
(see reverse side)

13a. TYPE OF REPORT
Final

13b. TIME COVERED
FROM ________ TO ______

14. DATE OF REPORT *(Year, Month, Day)*
1989, November

15. PAGE COUNT
12

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
05	08	
23	02	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
acoustic startle,
acoustic startle and disruption of aiming,
aiming and acoustic startle

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Three experiments examined the disruption of perceptual motor performance by intense noise bursts. Subjects aimed a rifle at a fixed target for 15-s periods separated by 15 s of rest. This cycle was repeated 30 times in each of two series separated by a 15-min rest, each series containing five noise bursts. The noise bursts disrupted aiming for 1-2 s, an effect that increased with sound pressure level for 110, 120, and 130 dB stimuli. There was no difference between stimuli with energy centered on 250 Hz as opposed to 800 Hz. The effect diminished over the five bursts within the first series (but not to zero) and did not recover in the 15-min rest period. Some subjects received three days of testing; in these cases the effect of the noise bursts partially recovered after rest intervals of 24 hrs and then seven days. Other subjects received 15 trials with 110-dB stimuli, then five more trials with 130-dB stimuli. The disruption of aiming by 130 dB stimuli was not reduced by prior exposure to 110-dB stimuli.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Technical Reports Office

22b. TELEPHONE *(Include Area Code)*
301-278-4478

22c. OFFICE SYMBOL
SLCHE-SS-IR

12.

John A. Foss
Argus Research Laboratories
Horsham, Pennsylvania

James R. Ison
University of Rochester
Rochester, New York

James P. Torre, Jr.
Samuel Wansack
Human Engineering Laboratory
Aberdeen Proving Ground, Maryland

AMCMS Code 611102.74A0011 Technical Memorandum 18-89

THE ACOUSTIC STARTLE RESPONSE AND DISRUPTION OF AIMING: I. EFFECT OF STIMULUS REPETITION, INTENSITY, AND INTENSITY CHANGES

John A. Foss
Argus Research Laboratories
Horsham, Pennsylvania

James R. Ison[1]
University of Rochester
Rochester, New York

James P. Torre, Jr.
Samuel Wansack
Human Engineering Laboratory
Aberdeen Proving Ground, Maryland

November 1989

APPROVED: John D. Weisz
JOHN D. WEISZ
Director
Human Engineering Laboratory

---

[1] Requests for reprints should be addressed to James R. Ison, Department of Psychology, Meliora Hall, University of Rochester, River Campus Station, Rochester, NY 14627.

Approved for public release;
distribution is unlimited.

U.S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland 21005-5001

HUMAN FACTORS, 1989, 31(3), 307–318

The Acoustic Startle Response and Disruption of Aiming: I. Effect of Stimulus Repetition, Intensity, and Intensity Changes

JOHN A. FOSS, *Argus Research Laboratories, Horsham, Pennsylvania,* JAMES R. ISON,[1] *University of Rochester, Rochester, New York, and* JAMES P. TORRE, Jr., *and* SAMUEL WANSACK, *Aberdeen Proving Ground, Maryland*

Three experiments examined the disruption of perceptual motor performance by intense noise bursts. Subjects aimed a rifle at a fixed target for 15-s periods separated by 15 s of rest. This cycle was repeated 30 times in each of two series separated by a 15-min rest, each series containing five noise bursts. The noise bursts disrupted aiming for 1–2 s, an effect that increased with sound pressure level for 110, 120, and 130 dB stimuli. There was no difference between stimuli with energy centered on 250 Hz as opposed to 800 Hz. The effect diminished over the five bursts within the first series (but not to zero) and did not recover in the 15-min rest period. Some subjects received three days of testing; in these cases the effect of the noise bursts partially recovered after rest intervals of 24 hrs and then seven days. Other subjects received 15 trials with 110-dB stimuli, then five more trials with 130-dB stimuli. The disruption of aiming by 130 dB stimuli was not reduced by prior exposure to 110-dB stimuli.

INTRODUCTION

Sudden and intense acoustic stimuli elicit startle reflexes in humans and in other animals (Landis and Hunt, 1939). In addition, these stimuli or the responses they elicit disrupt or inhibit ongoing performance. Simple reaction-time or tracking tasks can be interrupted for several seconds by a noise burst (May and Rice, 1969; Thackray and Touchstone, 1983; Vlasek, 1969), whereas complex perceptual-motor tasks (Thackray and Touchstone, 1970) or cognitive tasks (Vlasek, 1969; Woodhead, 1958, 1959) can be affected for up to 30 s following the stimulus. The deleterious effects of startle stimuli can have important practical implications for human performance, particularly in situations that require accurate motor reactions or rapid mental computation. Although considerable research has focused on the startle response itself, there has been little systematic study of the performance decrements that these stimuli engender. In particular only a few studies have examined how adaptation to intense stimuli might alleviate their deleterious effect on motor performance (Lukas and Kryter, 1968; May and Rice, 1969).

The present experiments were intended to

---

[1] Requests for reprints should be addressed to James R. Ison, Department of Psychology, Meliora Hall, University of Rochester, River Campus Station, Rochester, NY 14627.

characterize these disruptive effects. The first experiment examined the importance of the strength of a brief noise and its spectral characteristics in affecting the performance of a simple aiming task. In addition, it determined whether the performance disruption that might be induced by the startle stimulus would decline with repeated exposure to the noise (habituation) and then recover following a rest period (spontaneous recovery). Each of these four variables has been reported to be important in determining the vigor of the acoustic startle reflex, and the question of interest was whether the variables might also affect the severity of the performance disturbance resulting from the startle stimulus.

EXPERIMENT 1

Method

Subjects. Research participants (all male, *N* = 82) were recruited from introductory psychology classes or through ads posted on campus. Hearing was tested before and after the experiment with a Bausch and Lomb Audio-Rater audiometer following the PEST procedure described by Taylor and Creelman (1967). Subjects with a threshold over 20 dB (SL) for either ear at any frequency between 500 Hz and 4 kHz were disqualified from the experiment.

Stimulus generation. The eliciting stimuli were produced by a noise generator and passed through a filter (24 dB/octave) to an electronic switch and a zero-crossing gate. The latter, in combination with a bank of timers, controlled operation of the electronic switch and delayed the closing and opening of the switch until the signal was at zero potential. The electronic switch was set for its minimum rise time (0.5 ms), and the nominal duration of the eliciting stimulus was set for 50 ms (the actual duration could vary by several ms depending on the time of zero crossing). A manual attenuator after the electronic switch controlled stimulus intensity, the output going to a power amplifier. The output of the amplifier went into a relay controlled by the timers. The relay eliminated the combination of amplifier noise and leakage from the electronic switch and was set to close less than 1 ms before the stimulus onset and to open just after the stimulus. The output of the relay was fed into a set of matched TDH 39 earphones (± 1 dB at 1000 Hz).

Measurements were made with a B&K acoustic coupler (Model 4152) and a B&K Model 2203 sound level meter using a Model 4131 microphone. The output of the sound level meter was monitored with a digital oscilloscope, and the largest positive peak for a stimulus was translated into dB SPL. Approximately 15 measurements were taken at each attenuator setting to determine the mean peak sound pressure level.

Two frequencies of noise were used in this experiment: a "low-frequency" stimulus consisting of an approximate octave band of noise centered at 250 Hz (cutoffs at 179 Hz and 350 Hz) and a "high-frequency" stimulus consisting of an approximate one-third octave band centered at 800 Hz (cutoffs at 700 Hz and 900 Hz). The stimuli used in this experiment had peak sound pressure levels of 110, 120, 130, and 135 dB. The standard deviation of the peak levels in a sample of 15 measurements was 1.2 dB for the 135 dB stimulus.

Some discussion may be useful concerning the safety of the stimuli used in these experiments on the acoustic startle reflex. No damage risk criteria are currently available to rate the potential hazard to hearing of impulse noise stimuli. The various industrial criteria (see Eldredge, 1976) are intended to prevent hearing loss resulting from prolonged exposure to steady noise based on an eight-hour working day. For example, in 1974 the Occupational Safety and Health Administration (OSHA) proposed recommending a limit of 90 dB (A-scale) with higher sound pressure levels permitted for shorter periods of time, 5 dB for each halving of the duration. That year, the Environmental Protection Agency (EPA) proposed a limit of 74 dB, with higher intensities permitted as long as the total energy in the eight-hour period was not exceeded. The OSHA recommendations would allow exposure to 135 dB for 56 s; the EPA recommendations, for 25 ms.

More pertinent to the present investigations, Price (1981) has argued that there is a critical sound level beyond which intense noise stresses the physical structure of the ear and that calculating time/intensity tradeoffs is not appropriate for assessing the risks attendant on impulse noise. He hypothesizes that hearing loss resulting from a sudden mechanical displacement of the inner ear is not predictable from the presumed metabolic effects of prolonged weaker stimuli that summate over time. Price calculated that the "median" critical level was 140 dB at 3 kHz, with a standard deviation of 8 dB; at this frequency, where the human ear is most sensitive to mechanical stress, an estimated 95% of the population would find 126.8 dB to be safe (G. R. Price, personal communication, 1984). For the present experiment, because the critical level declines at 6 dB per octave below 3 kHz, the stimulus at 250 Hz was comfortably away from this region of maximal sensitivity and the 135 dB stimulus was well within the 95% safety margin. In contrast, the higher-frequency stimulus was only about two octaves removed from the region of greatest sensitivity, and therefore a narrower band of frequencies was used here.

Approximately 2% of the Experiment 1 and 2 subjects were found to experience temporary threshold shift following exposure to these stimuli. A total of 241 subjects participated in the entire series of experiments on the acoustic startle reflex (in this series and in Foss, Ison, Torre, and Wansack, 1989). Threshold shifts of 10 dB or more were seen only at the 500 Hz test stimulus, in each instance following exposure to the low-frequency eliciting stimulus: at 130 dB for three subjects (with losses of 22, 12, and 11 dB) and at 110 dB for one subject (followed by a loss of 11 dB). These four subjects received an additional hearing test 24 hours later, by which time their sensitivity had returned to normal.

Aiming performance. The subjects stood with one elbow resting on a sandbag, aiming a demilitarized M16 rifle at a notch cut in a black rectangle set against a brightly lit white background (the notch was 1.2 cm × 0.75 cm, and the rectangle was 3.5 cm × 3.0 cm). The rifle tip was 5.5 m from the target. A solid-state video camera on the rifle barrel presented an image of the target to a tracking and measuring system that computed the horizontal and vertical deviations from the initial "on-target" position. The deviations were recorded at 5-ms intervals on two channels of the digital oscilloscope, and the digitalized traces were stored for later analysis.

Procedure. Each subject performed two series of 30 aiming trials, the second series following the first by a rest period of 15 min. On each trial the subject was told to pick up the rifle and aim at the target and to continue aiming until told to put the rifle down. When the subject's aim was on target, he so informed the experimenter, who then activated the tracker to begin a 15-s aiming period. After the aiming period the subject was told to put the rifle down and to rest for 15 s while still standing. The intense noise burst occurred on five occasions within each of the two series, on average every six trials and when the trial had been running for between 5 and 10 s. Five other trials within each series provided the control data for aiming accuracy in the absence of the noise burst.

Analysis. The mean of the deviations from target in the 5-s period before the stimulus defined the baseline and was subtracted from each value in the prestimulus and poststimulus period. Only deviations in the azimuth plane were examined in the first experiment. The mean absolute deviations were computed for 500-ms intervals from 1.5 s before the stimulus to 3.0 s after the stimulus. When reactions to the noise were so extreme that the tracking device was unable to follow the target, the missing data were replaced by the maximum error values on adjacent segments. The data were analyzed using the 2V program of the BMDP statistical software (Dixon, 1983), the dependent variable for the analysis being the maximum among the mean absolute deviations for the poststimulus interval. Given that temporal factors often produce violations of the symmetry assumptions of repeated-measures designs, the degrees of freedom in tests involving within-subjects factors were reduced using the Huynh-Feldt adjustment.

Results

The number of trials when subjects responded so vigorously that the tracking machinery could not follow the resulting excursion of the rifle barrel provided an unexpected dependent variable for the effects of the stimuli on performance. Respectively, 4, 10, 13, and 15 subjects (of 20, 20, 22, and 20) had these extreme reactions on one or more trials at 110 dB, 120 dB, 130 dB, and 135 dB. This difference was significant across stimulus intensity, with $\chi^2(3, N = 82) = 12.64, p < 0.01$. Four subjects gave an especially notable reaction to their first noise burst: they disregarded instructions to continue aiming until the trial was over and followed a vigorous startle reaction by turning away from the target and putting the rifle down.

The frequent occurrence of such trials was a major practical problem with the most intense stimuli. Data from the 135-dB groups were not subjected to the more quantitative analyses because 60 trials contained estimated values. Data from the remaining groups are given in Figure 1, which provides the mean absolute deviation in milliradians for 500-ms segments before and six segments after the noise burst, across the 10 startle trials, as a function of stimulus intensity. (The spectral composition of the noise bursts was not a significant factor in any analysis and so is not shown in this figure. It should also be noted that tonal frequency was not a factor in determining the number of subjects who lost the target in the preceding analysis.)

Three major effects can be noted in the succession of graphs. First, the startle stimuli disrupted the subject's aim for a period of 1–2 s. Over all groups combined, on the first trial the average maximum perturbation was 3.71 mrad compared with a spontaneous maximal deviation of 1.70 mrad on blank control trials. Second, the more intense stimuli had a greater effect on performance, but their distinctive influence was seen primarily in the earlier trials. Third, in general the effect of the noise declined over the series of trials. Thus on the first noise trial the amplitudes of the perturbation were 2.7 mrad, 3.2 mrad, and 5.1 mrad for the 110, 120, and 130 dB groups, respectively, whereas on the tenth trial the corresponding values were 2.6, 1.9, and 2.5 mrad. The effect of the noise declined considerably in the first series of five trials (from 3.71 mrad overall to 2.51 mrad) and did not recover any of its original strength following the 15-min rest period (the mean error was 2.54 mrad on the first trial of the second series). Finally, however, the effect of the noise at the conclusion of the day's testing was still considerable. Considering the six groups of subjects as a whole, on the tenth trial the maximum perturbation was 0.50 mrad greater than the maximum recorded on the comparable blank trial, $t(60) = 3.17, p < 0.01$.

These data were subjected to an analysis of variance in which the dependent variable

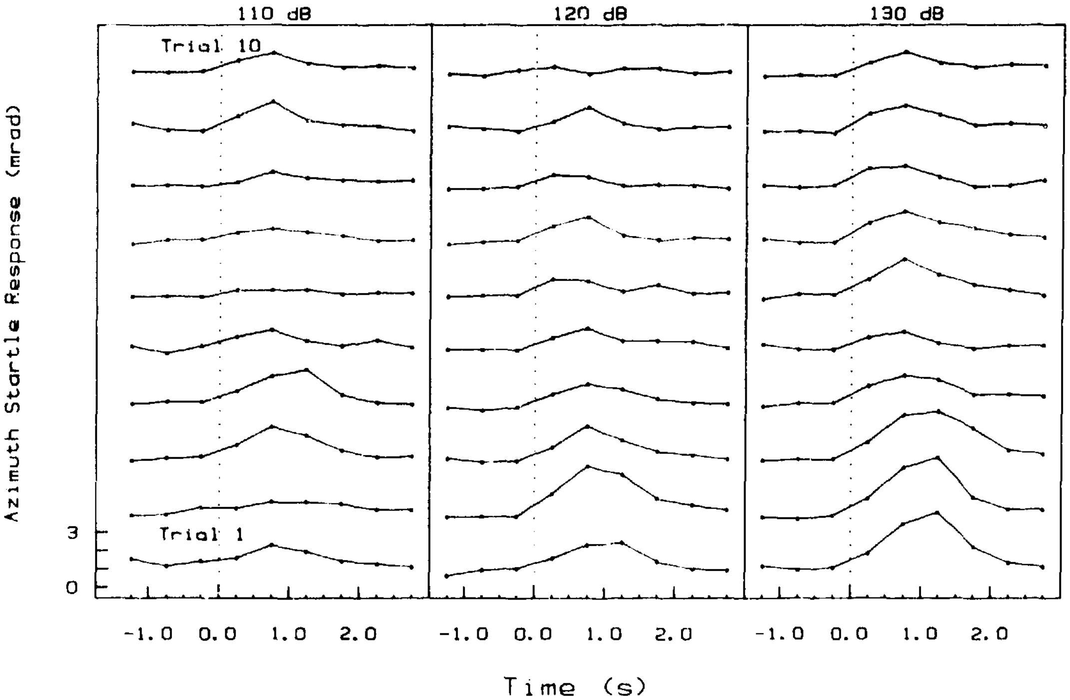

Figure 1. *Mean absolute deviations from target over trials as a function of noise intensity. The stimulus was delivered at 0.0.*

was the maximum of the mean absolute deviations in the four half-second intervals that followed the stimulus. The analysis considered the factors of stimulus intensity, tonal frequency, period (before and after the 15-min rest), and trials (five within each period). It also showed that the deviations from target were reliably smaller in the second half of the experiment—for periods, $F(1,56) = 17.3, p < 0.001$—and that they declined across the five trials within periods: for trials, $F(4,224) = 4.29, p < 0.01$. The drop across trials occurred primarily in the first period—for the Trial × Period interaction, $F(4,224) = 4.88, p < 0.01$—and with more intense stimuli—for the Trial × Intensity interaction, $F(8,224) = 3.91, p < 0.01$.

Discussion

This experiment showed that noise bursts momentarily disrupt subjects' ability to maintain aim on a stationary target, with the size of this effect determined by stimulus strength and prior exposure to the stimuli. The effect itself and its initial duration (subjects required about 1 to 2 s to recover on-target aim) are consistent with the findings of May and Rice (1969), Thackray and Touchstone (1970), and Vlasek (1969) on the disruptive effect of intense acoustic stimuli on simple perceptual-motor tasks. Previous experiments had found that the perceived intensity of a loud noise was reduced following stimulus repetition (May and Rice, 1969) and that stimulus repetition reduced the amplitude of the startle reflex seen in the trapezius muscle (Lukas and Kryter, 1968). However, in neither of these earlier reports were these noted effects of stimulus repetition accompanied by any significant improvement in motor performance. In the present experiment, in contrast, the subjects were better able to maintain their aim on the target following adaptation to the stimuli, although the degree of adaptation was not sufficient to entirely eliminate the effect of the noise.

Tonal frequency was not a factor in determining the magnitude of performance disruption, which is perplexing because the 800-Hz stimulus seemed markedly louder than the 250-Hz stimulus. This finding and that of May and Rice (1969) suggest that motor reactivity may be related less to the perceived loudness of the startle stimulus than to its physical characteristics, such as sound pressure level or stimulus bandwidth.

EXPERIMENT 2

In Experiment 1 the beneficial effect of adaptation to the stimuli that took place within the first five trials of the experiment persisted across the 15-min rest. Studies of the startle reflex itself typically find that the response recovers at least partly with time since the last exposure to the stimulus (e.g., Hoffman and Searle, 1968). In Experiment 2 we examined performance across three sessions to study the persistence of adaptation across a 24-hr period and then a one-week break in training.

Method

Subjects. Ten additional male subjects recruited as before, were paid for their participation in the experiment. The selection procedures and general treatment were the same as in the earlier experiment.

Apparatus. The 130-dB high-frequency stimulus of the previous experiment was used in this study, as were the aiming task and performance monitoring equipment. However, rather than considering only deviations in the azimuth plane, we averaged the magnitudes of the vector sums of the deviations in azimuth and elevation over the 500-ms intervals.

Procedure. The general procedure and conditions in the initial session for these subjects replicated those of the first experiment. The sequence of control and stimulus trials was altered when the subjects returned for testing on the next day and then seven days later, but the basic pattern of two periods separated by a 15-min rest, each with 30 aiming trials and five noise trials, remained the same.

Results

Figure 2 shows means of the absolute deviations from the target in the three segments before and the six segments after the stimulus. The dependent measure for the analysis of variance was again the maximum mean error in the first four 500-ms intervals after the stimulus. As was seen previously, the errors were smaller in the second half of each day—for the effect of period, $F(1,9) = 5.88, p < 0.05$—and declined across trials within each period—for the Trial × Period interaction, $F(4,36) = 3.92, p < 0.05$, with a significant quadratic trend, $F(1,9) = 5.96, p < 0.05$. Although the beneficial effect of stimulus repetition was again apparent in these subjects, it was not as powerful in the second experiment. A comparison of the two groups that had received the same noise stimulus (and using the same combined azimuth and elevation error for both groups) showed a significant difference in the extent to which their responses declined over the five trials in each part of the session, $F(4,76) = 3.37, p < 0.05$. There is no evident reason for the presence of this reliable but unexpected difference between the two groups.

As was seen previously, the noise stimulus did not recover its initial impact following the 15-min rest period (over the three days combined, the mean perturbation was 3.64 mrad on the last trial before the rest and 3.61 mrad on the first trial after the rest). The evidence for persistence of adaptation over the longer intervals of 24 hrs and seven days was less impressive. The average error taken across the 10 trials of each day declined from

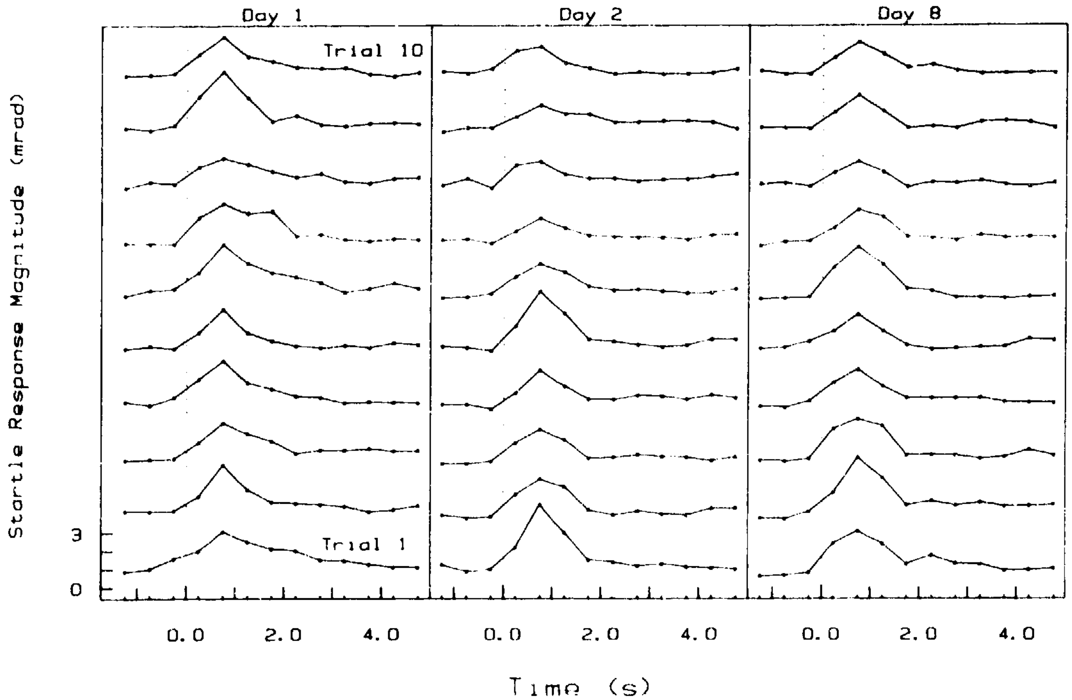

Figure 2. *Mean absolute deviations from target over three test days, given one and then seven calendar days apart. The stimulus was delivered at 0.0.*

3.62 mrad on Test Day 1 to 3.19 on Test Day 2, $t(9) = 3.02, p < 0.02$, indicating that habituation at least partially persisted across the 24-hr period. However, the effect of the stimulus had recovered on the third test one week later. On Test Day 3 the mean deviation was 3.45 mrad—significantly greater than the mean on Test Day 2, $t(9) = 2.27, p < 0.05$ and not reliably reduced compared with the errors recorded on Test Day 1.

Discussion

The second experiment, like the first showed that adaptation to the noise bursts was successful in reducing their disruptive effect on aiming performance and that this beneficial effect persisted over a 15-min rest period. However, the longer-term persistence of adaptation, and thus the relatively permanent benefit of prior experience with the disruptive stimuli that might be hoped for, was not impressive. Though reliable, the difference in the effect of noise on aiming performance between the first and second days was not large, and the benefit of two days of exposure to the stimuli had substantially diminished one week later. In this regard the presumably secondary effect of noise bursts in disrupting ongoing performance shares the phenomenon of spontaneous recovery, the recovery of response potential with the passage of time which is characteristic of direct measures of the startle reflex elicited by these stimuli (Thompson and Spencer, 1966).

EXPERIMENT 3

The final experiment again examined performance within a single day's session. The primary intent of this experiment was to determine whether adaptation to a relatively low-intensity stimulus would generalize so as to reduce the disruptive effect of a more intense stimulus on subsequent test trials. The possibility of the transfer of adaptation from one noise intensity to another in the context of perceptual-motor performance has practical significance. If adaptation to a less intense noise burst does reduce the disruptive influence of more intense stimuli, then it might be possible to design an adaptation experience with relatively innocuous stimuli that would help to protect against more intense stimuli.

The amplitude of the eye-blink reflex to the intense noise burst was also measured in this experiment, this being the most sensitive component of the startle reflex pattern (Landis and Hunt, 1939). The intent was to correlate the amplitude of the disruption in aiming performance and the size of the immediate reflexive consequence of the noise bursts. The findings of the first two experiments on habituation of the performance effects of intense noise bursts were similar to those that describe habituation of the reflexes elicited by such stimuli. A correlational analysis of performance disruption and reflex expression within the same context might reveal that both consequences of startle stimulation shared a common relationship, suggesting, for example, that the motor jerk or flinch associated with the startle reflex threw off the aim.

Method

Subjects. Male subjects ($N = 20$) were recruited from introductory psychology classes and from ads posted on campus. Their general treatment was the same as in the earlier experiments.

Apparatus. The aiming task and performance monitoring equipment were as before, and the aiming measure was the combined vector score in azimuth and elevation. Eye blinks were measured by electromyography. Recording electrodes with adhesive collars were fixed over each subject's inferior portion of the orbicularis oculi muscle on the side used for sighting. One electrode was placed at the lateral canthus and the other in a medial position. The reference electrode was placed on the temple along the zygomatic arch. The impedances between electrodes were always less than 20 kOhms. The EMG was conditioned by an FET preamplifier and then amplified by a differential amplifier. The signals were rectified and sent to an analog integrator, which summed the response during the period from 30 to 90 ms after onset of the stimulus. This interval captures the main component of the blink to intense noise bursts.

Procedure. Two groups of subjects first received a total of 15 sound bursts at either 110 dB or 130 dB using the low-frequency stimulus of Experiment 1. Startle and blank control trials were alternated in this sequence, so on average the stimuli were given approximately one minute apart. Then both groups were given five further trials with 130-dB stimuli interspersed in an irregular pattern among 11 control trials, the intent being to ensure that both groups experienced some change in their experimental condition from one condition to the next. The two series were contiguous, and the subjects were not told that the intensity of the stimuli might change during the experiment. Thus they could not anticipate that the intensity of the stimulus had changed until after the first test trial had occurred, but they could detect that there had been a change in the pattern of trials.

Results and Discussion

The maximum mean error in aiming performance in the four 500-ms segments following the stimulus is described in Figure 3, and eye-blink reactions are shown in Figure 4. As was seen in Experiment 1, habituation was most apparent in the early trials and among subjects receiving the more intense stimulus. Errors in aiming performance were greater with this stimulus in the first three trials, but

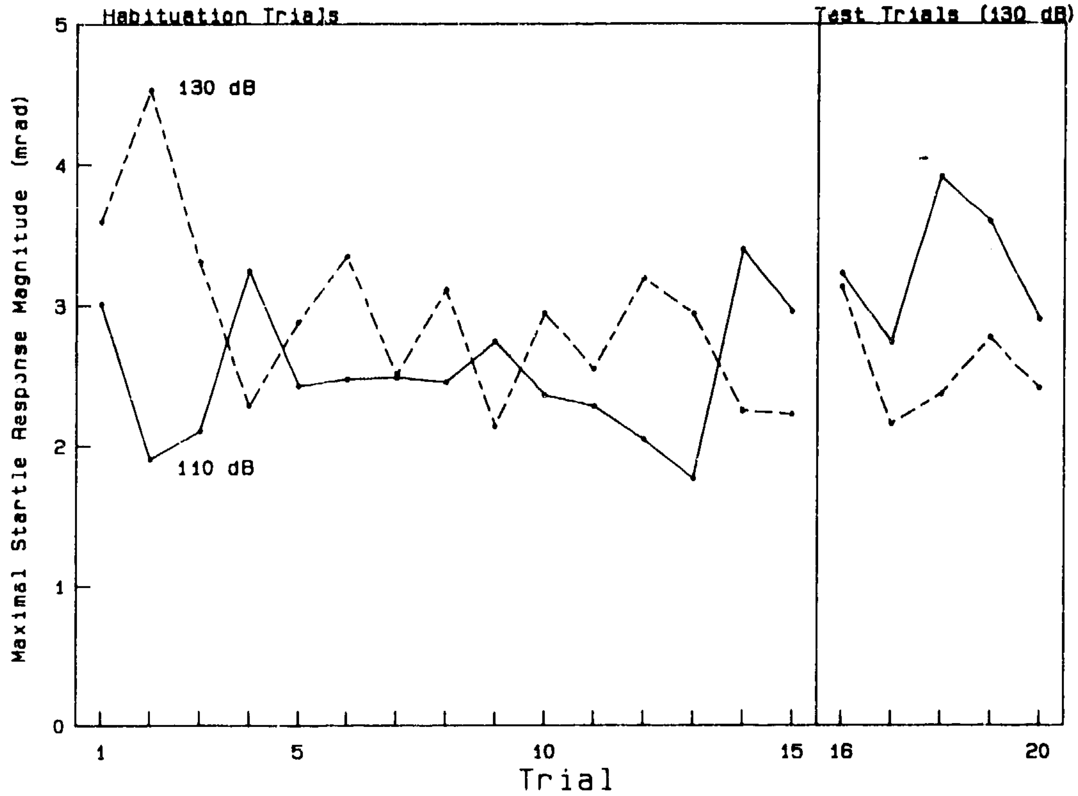

Figure 3. *Maximal deviation in aim following a 130 dB or 110-dB stimulus over 15 trials, followed by 5 trials at 130 dB for both groups.*

thereafter the two groups responded at about the same level. Eye-blink reactions in the group that received the 130-dB stimulus also showed their greatest change within the first three trials, but here the more intense stimulus continued to elicit larger responses throughout the remainder of the first stage of the experiment. No systematic changes across the 15 trials were seen in either measure in the group given 110 dB, though the responses elicited by the noise burst tended to be greater than the spontaneous responses recorded on blank control trials: for aiming, $t(9) = 2.09, p < 0.05$, one-tailed; for EMG, $t(9) = 2.32, p < 0.05$.

These data were subjected to a combined analysis of variance following a translation to standard scores in order to eliminate differences in the unit of measurement. This analysis confirmed that the more intense stimulus was more effective in disrupting performance and in eliciting eye-blink activity, $F(1,18) = 6.97, p < 0.05$; that the effect of the stimulus declined over trials, $F(14,252) = 2.86, p < 0.01$; and that this trials effect was greater with the high-intensity stimulus, $F(14,252) = 4.14, p < 0.01$. The overall interaction between measures and stimulus intensity was of marginal significance, $F(1,18) = 3.04, p < 0.10$, and no other contrast of performance errors and the eye-blink response approached significance. Thus it may be concluded that reflex responses and performance disruptions occasioned by the noise were affected by repeated exposure to these stimuli in substantially the same way, though there

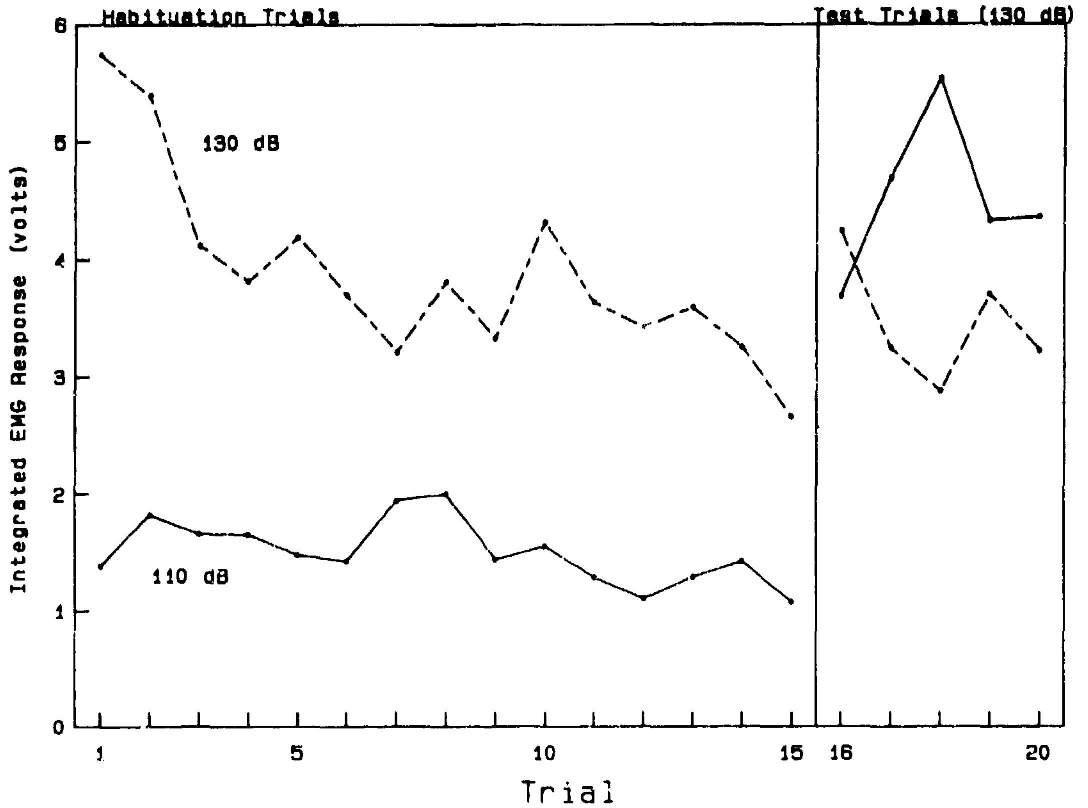

Figure 4. *Integrated EMG in the eye-blink elicited by a 130-dB or 110-dB stimulus in 15 trials, followed by 5 trials at 130 dB for both groups.*

was a tendency for the eyelid reflex to be more sensitive to variation in stimulus intensity.

Trial 16 occurred in an unexpected position, and thereafter the noise stimulus was presented in an irregular pattern, which replaced the alternating pattern of the first series. The effect of the 130-dB noise stimulus was greater in each group on Trial 16 compared with Trial 15 for both performance errors and for the amplitude of the eye-blink reflex: for the 110–130-dB crossover group, $F(1,9) = 7.68$, $p < 0.05$; for the group maintained on 130 dB, $F(1,9) = 16.91$, $p < 0.01$. The increase in the group maintained on 130 dB could have resulted only because of the change in the expected stimulus pattern from Trial 15 to Trial 16, and it seems to indicate that the subjects had learned to expect startle stimuli on a particular schedule of presentation and were surprised by the shift in conditions.

The crossover group maintained its response level over the next four trials, whereas the group that had been kept at 130 dB fell to the preshift level of responding. (The one-trial enhancement of behavior in this group is characteristic of dishabituation effects that result from changes in stimulus context; see Thompson and Spencer, 1966.) Over the postshift period the interaction between trials and groups was significant, $F(4,72) = 3.65$, $p < 0.01$. The crossover group had a mean error deviation of 3.28 mrad on the performance measures of Trials 16–20, its first five trials with 130 dB after the series of trials with 110 dB. This value was very close to the mean of 3.32 mrad obtained by the other group on its five initial trials in the experiment, which began with 130 dB with no prior experience. By contrast, the latter group, trained and then maintained on 130 dB, had a mean error of only 2.56 mrad over the five final trials. In this group adaptation to the 130-dB stimulus was significant, $t(9) = 2.41$, $p < 0.05$.

The eye-blink analyses were very similar to the results obtained with the performance data. On the last five trials (16–20) the crossover group had a mean score of 4.52 units, which was about the same as the mean of 4.65 for the first five trials (1–5) for the group that began the experiment at 130 dB. The latter group had a mean response of 3.46 on the last five trials. This decline, again about 25% from the first five to the last five trials, was significant, $t(9) = 1.97$, $p < 0.05$, one-tailed, indicating that habituation had occurred. These findings indicate that adaptation and training with the 110-dB stimulus transferred minimally, if at all, to the 130-dB stimulus. The data are consistent with a report by Davis and Wagner (1968), who showed that habituation of the acoustic startle reflex in the rat was more profound following exposure to strong rather than weak eliciting stimuli. The implication of these data is that adaptation training intended to reduce the disruptive effect of intense noise bursts on later test performance must be given at the stimulus intensities that will be encountered during the test.

A question of some potential relevance for understanding the cause of the performance disruption produced by noise bursts was whether the size of the performance disruption correlated with the size of the eye-blink reflex either across subjects or across trials within subjects. Positive correlations would be expected if the two behavioral effects shared a common process that, as it varied from trial to trial or subject to subject, would affect both measures in tandem. However, all of the correlations between these two measures approximated zero. The failure to find any evidence of commonality did not occur because of any intrinsic unreliability in the two measures: odd-even reliability estimates using the Spearman-Brown formula were $r = 0.95$ for aiming and $r = 0.98$ for the eyelid EMG.

CONCLUSIONS

In general outline these experiments supported prior findings (e.g., May and Rice, 1969; Thackray and Touchstone, 1970; Vlasek, 1969) in demonstrating that skilled performance is disrupted for approximately 1–2 s by intense noise bursts. They extended the earlier results in three ways. First, they showed that the amplitude of the performance disruption was greater with stronger stimuli. Second, they demonstrated that intense stimuli lost some effectiveness with repetition but recovered in substantial measure following a long rest interval. Third, they showed that experience with a weak stimulus did not reduce the disruptive effect of a more intense stimulus.

It could be expected that the benefits of adaptation would have been greater had the noise bursts been closely massed in time rather than being separated by several minutes, as was mostly the case in these experiments. However, the reflex literature (Davis, 1970a, 1970b) reveals that experience with eliciting stimuli should be widely distributed in time if habituation is to be retained, a characteristic that habituation shares with other forms of learning (Hovland, 1951). This literature suggests that the several examples of persistent adaptation found over a 15-min interval, and at least partially over a 24-hr interval, would not have been observed if the noise bursts had been presented just seconds rather than minutes apart.

The absence of correlation between the eye-blink reflex, a direct measure of the startle reflex, and the performance disruption produced by a noise burst argues against the simple notion that the subject's aim was thrown off the target by reflexive activity in the muscles responsible for maintaining aim on the target. (This conclusion is appropriate if it can be assumed that the startle reflex measured in the eyelid is a valid indicator of the vigcr of a more general startle pattern.) Other data show that motor interference can be only part of the explanation, especially demonstrations that on complex tasks the effects may persist for 15 or 30 s after the stimulus (Thackray and Touchstone, 1970; Vlasek, 1969; Woodhead, 1958, 1959). This period far outlasts the somatic motor consequences of the startle stimulus.

In a related observation Thackray and Touchstone (1983) reported that some subjects who were supposed to respond selectively to a noise burst instead appeared to be "dazed and disoriented" by a 1-s, 104-dB noise. The behavior of a small number of the subjects in the present experiment on their initial exposure to the intense stimulus could be similarly described. Thus to some extent performance disruption produced by startle-eliciting stimuli seems to involve a more cognitive deficit than would be expected of simple motor interference. Overall, however, changes in the disruptive effects of intense acoustic stimuli on perceptual motor tasks following exposure to the stimulus conditions are consistent with the phenomena of simple reflex behavior.

ACKNOWLEDGMENTS

The authors thank Alice Eastwood for her excellent technical assistance. This work was supported by Contract No. DAAK11-84-K-0016 from the U.S. Army Human Engineering Laboratory. Computational resources were provided by EY-01319 to the Center for Visual Science at the University of Rochester.

REFERENCES

Davis, M. (1970a). Interstimulus interval and startle response habituation with a "control" for total time during training. *Psychonomic Science, 20,* 39-40.

Davis, M. (1970b). Effects of interstimulus interval length and variability on startle-response habituation in the rat. *Journal of Comparative and Physiological Psychology, 72,* 177-193.

Davis, M., and Wagner, A. R. (1968). Startle responsiveness after habituation to different intensities of tone. *Psychonomic Science, 12,* 337-338.

Dixon, W. J. (Ed.). (1983). *BMDP statistical software.* Los Angeles: University of California Press.

Eldredge, D. H. (1976). The problems of criteria for noise exposure. In D. Henderson, R. P. Hamernik, D. S. Dosanjh, and J. H. Mills (Eds.), *Effects of noise on hearing* (pp. 3-20). New York: Raven Press.

Foss, J. A., Ison, J. R., Torre, J. P., Jr., and Wansack, S. (1989). The acoustic startle response and disruption of aiming: II. Modulation by forewarning and preliminary stimuli. *Human Factors, 31,* 319-333.

Hoffman, H. S., and Searle, J. L. (1968). Acoustic and temporal factors in the evocation of startle. *Journal of the Acoustical Society of America, 43,* 269-282.

Hovland, C. I. (1951). Human learning and retention. In S. S. Stevens (Ed.), *Handbook of experimental psychology* (pp. 613-689). New York: Wiley.

Landis, C., and Hunt, W. A. (1939). *The startle pattern.* New York: Farrar and Rinehart.

Lukas, J. S., and Kryter, K. D. (1968). *A preliminary study of the awakening and startle effects of simulated sonic booms* (Report NASA-CR-1193). Washington, DC: NASA.

May, D. N., and Rice, G. (1969). *Startle due to pistol shots—Effects on control precision performance* (Report ISVR-TR-26; NTIS N71-20799). Southampton, England: University of Southampton Institute of Sound and Vibration Research.

Price, G. R. (1981). Implications of a critical level in the ear for the assessment of noise hazard at high intensities. *Journal of the Acoustical Society of America, 69,* 171-177.

Taylor, M. M., and Creelman, C. D. (1967). PEST: Efficient estimates on probability functions. *Journal of the Acoustical Society of America, 41,* 782-785.

Thackray, R. I., and Touchstone, R. M. (1970). Recovery of motor performance following startle. *Perceptual and Motor Skills, 30,* 279-292.

Thackray, R. I., and Touchstone, R. M. (1983). *Rate of initial recovery and subsequent radar monitoring performance following a simulated emergency involving startle* (FAA report AM-83-13; NTIS AD-A133 602). Washington, DC: Federal Aviation Administration.

Thompson, R. F., and Spencer, W. A. (1966). Habituation: A model phenomenon for the study of the neural substrates of behavior. *Psychological Review, 73,* 16-43.

U.S. Department of Labor, Occupational Safety and Health Administration. (1974). *Occupational noise exposure, proposed requirements and procedures* (29 CFR Part 1910 Docket No. OSH-11). *Federal Register, 39*(207), 37773-37778.

U.S. Environmental Protection Agency. (1974). *Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety.* (Report 550/9-74-004). Washington, DC: Author.

Vlasek, M. (1969). Effect of startle stimuli on performance. *Aerospace Medicine, 40,* 124-128.

Woodhead, M. M. (1958). The effects of bursts of loud noise on a continuous visual task. *British Journal of Industrial Medicine, 15,* 120-125.

Woodhead, M. M. (1959). Effect of brief loud noise on decision making. *Journal of the Acoustical Society of America, 31,* 1329-1331.