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THE EFFECTS OF AIRBLAST ON DISCRIMINATED AVOIDANCE BEHAVIOR IN RHESUS MONKEYS

V. Bogo, R. A. Hutton, and A. Bruner



HEADQUARTERS

Defense Nuclear Agency
Washington, D.C. 20305

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Lovelace Foundation
for

Medical Education and Research
Albuquerque, New Mexico

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**Technical Progress Report
on
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FOREWORD

The work covered by this report was carried out at the Lovelace Foundation for Medical Education and Research. It was supported by the Defense Nuclear Agency of the Department of Defense under Contract No. DA-49-146-XZ-372.

ABSTRACT

Eighteen monkeys, trained to perform auditory and visual discrimination avoidance tasks, were exposed to a reflected shock-tube airblast of 30, 40, or 50 p. s. i. Results indicated that: (1) immediate but transient performance decrement occurred; (2) latency was more affected than accuracy, particularly for the 50-p. s. i. group; (3) performance decrement was mild and recovery time brief (usually under 4 hours) despite frank physical injuries; and (4) auditory discrimination underwent more decrement than visual, with eardrum injury occurring frequently.

The experimental work discussed in this manuscript was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences-National Research Council.

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THE EFFECTS OF AIRBLAST ON DISCRIMINATED AVOIDANCE BEHAVIOR IN RHESUS MONKEYS

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INTRODUCTION

Airblast overpressures produced by nuclear and other explosions are of current concern for their injury and incapacitation potential to personnel surviving the blast and having missions to complete. The few studies assessing blast effects on performance capability have primarily emphasized the behavioral decrements associated with hearing loss induced by weapon blast, engine noise, and other intense noise sources.^{3, 5, 8, 9, 13, 14, 15} One shortcoming of importance has been the failure to employ a blast source which accurately simulates the shock front created by a nuclear detonation, in terms of rise-time, duration, and overpressure. Thus, the present study attempted to evaluate the performance alterations in primates resulting from exposure to blast overpressure from an air-driven shock tube, a device which produces a long-duration shock wave similar to that of a nuclear weapon.

METHODS

Subjects

The subjects were 18 rhesus monkeys (Macaca mulatta), weighing between 2.5 and 4.8 kg. Two additional monkeys were used as replacements for two which died immediately following blast exposure.

Apparatus

The apparatus employed in this study has been described previously,¹ but a brief description will be given here. Training and testing were conducted with the unrestrained monkey in a 2-foot cubical chamber, one wall of which served as the stimulus-response panel. Two sets of panel manipulanda were used; two levers and two disc-shaped plastic keys, conveniently located for height and right- or left-hand response choices. A ground glass window was located just above each of the two levers. Two speakers were at the top of the panel (Figure 1).

A shock generator delivered either of two shock intensities, as selected, between the grid floor of the test chamber and a neck leash. The stronger shock (3 to 14 ma.) was adjusted to produce vigorous escape and other emotional reactions, while the weaker shock (1 to 7 ma.) was adjusted to suppress extraneous responses without producing strong emotional concomitants. Both shocks were 1 second in duration.

Procedure

Training. The training procedures for the two tasks used in this study have been described in detail elsewhere.¹ Training was accomplished using standard operant-shaping techniques, and all monkeys were trained to perform the visual task before the auditory task was introduced.

Visual Discrimination Task. This was a simple "go, no-go" avoidance task involving red or white transillumination of the ground glass windows. Only one window was lighted per trial with one of the two colors (randomly alternated). On white-light trials ("go"), the animal had to press the lever just below the lighted window within 5 seconds or else receive the strong shock. A correct

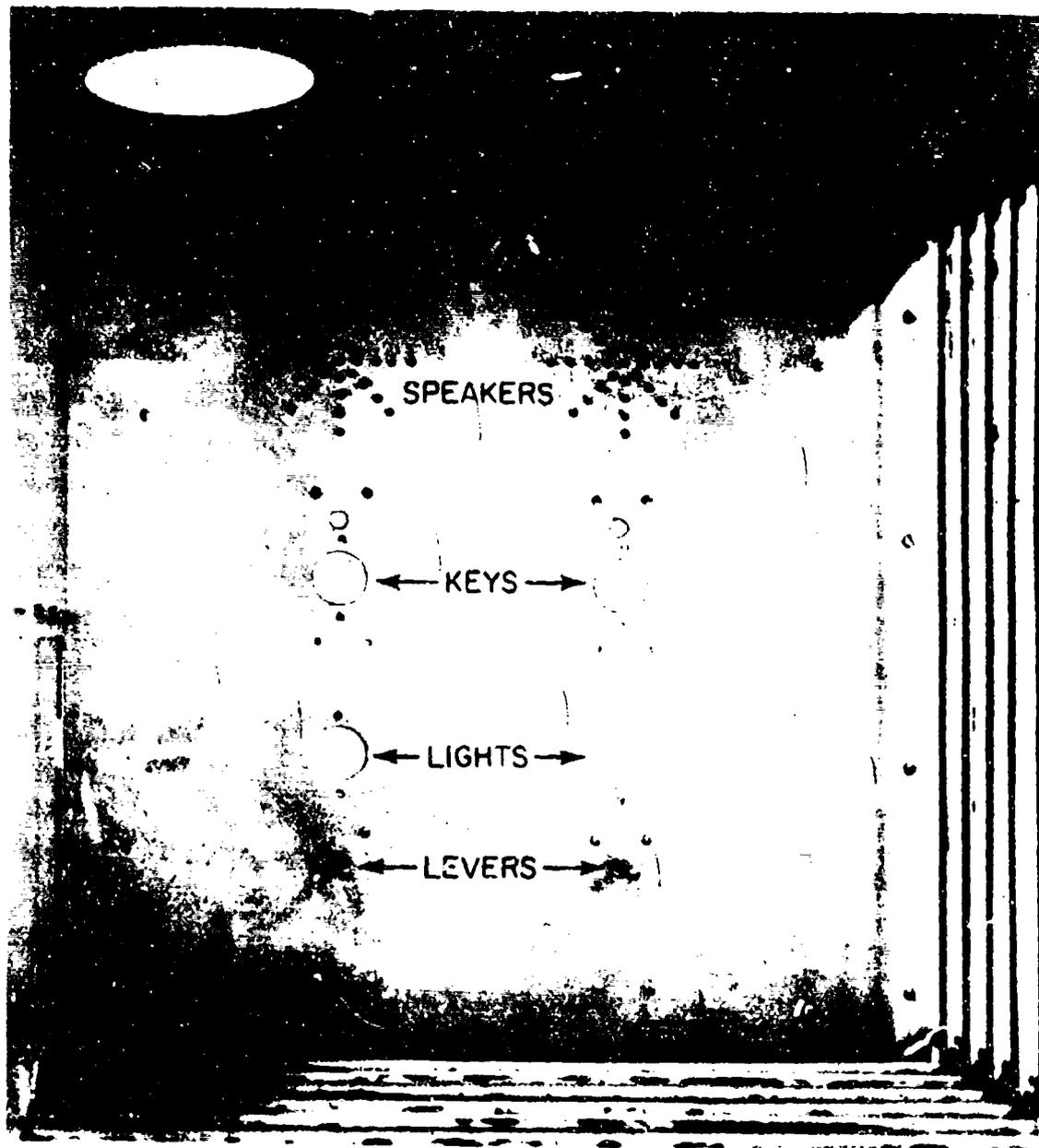


Figure 1. --View of Stimulus-Response Panel.

press avoided the shock, terminated the white light, and initiated a 5-second timeout (T.O.). An incorrect press (below the unlighted window) was punished immediately with the weak shock. Red-light trials ("no-go") required the withholding of lever responses for 5 seconds. Red-light responses did not terminate the light and were punished with the weak shock. Red-light trials were also followed by a 5-second T.O. Additionally, all lever presses during T.O.'s were shocked (weak). The start of this task was signalled by onset of the chamber light and a white masking noise (90 db, .0002 ref.).

Auditory Task. Onset of the auditory avoidance task was signalled by turning on the chamber light only. A right-side key press was required when either a 1,000- or 3,000-Hz (75 db) tone was presented (in random alternation). This press terminated the tone and initiated a 5-second T.O. Failure to respond within 5 seconds resulted in delivery of the strong shock. Responses on the left key or responses made during T.O. resulted in delivery of the weak shock. Since apparatus clicks were audible, "blank" trials were presented at random on 10 percent of the auditory trials; the equipment was cycled, but no tones were given. A weak shock resulted when any responses were made during blank trials.

Before exposure to blast, subjects were trained until achieving 95-percent correct choices on both visual and auditory tasks for five consecutive sessions. Achieving this criterion required from 52 to 138 sessions (mean = 95), for all subjects. The duration of each task was always 10 minutes with a 1-minute separation between tasks. This duration normally allowed for 85 auditory and 75 visual trials.

Blast Exposure. Six monkeys were randomly assigned to each of three blast-dose groups: 30, 40, and 50 p. s. i. (Table I). The only assignment restriction was that the groups were equated for males (10) and females (8). Within each dose group, the monkeys were divided and assigned to an auditory-visual (A_1V_2) or a visual-auditory (V_1A_2) order of task presentation.

Exposure to blast was administered on the day following completion of the 5-day stabilization criterion. After 16 hours without food, each monkey was mounted on the endplate of the shock tube in a special nylon-mesh restraint suit

TABLE I
SEX, BLAST DOSE, AND TASK ORDER

Subject No.	Sex	Reflected Blast (psi)	Task Order
<u>30 Psi Group:</u>			
279	F	30.0	AV*
453	F	31.8	AV
435	F	27.5	VA
613	M	27.9	VA
626	M	30.2	AV
627	M	30.0	VA
<u>40 Psi Group:</u>			
439	F	40.5	AV
466	M	41.2	VA
581	M	41.2	VA
622	F	39.7	AV
617	F	40.0	VA
631	M	40.0	AV
<u>50 Psi Group:</u>			
451	M	48.0	AV
445	F	48.8	AV
455	F	53.0	AV
460	F	50.3	AV
619**	F	51.2	VA
634**	M	52.0	VA
628+	M	47.0	VA
630+	M	45.8	VA

* A = auditory; V = visual task
 ** Died before post-test
 + Replacements

as illustrated in figure 2. This suit secured the animal flush against the endplate without cutting off limb circulation and without measurably decreasing the airblast dose. Some head movement was possible, however. The initial four monkeys participated in a sham procedure at least 1 week before exposure, simulating all conditions except the actual blast. This procedure failed to produce any significant changes for either task and was subsequently discontinued.

Shock Tube. The 42-inch-diameter shock tube employed for exposing the monkeys to airblast has been described previously.¹¹ The shock tube was a 140-foot-long cylinder divided by a rupturable diaphragm into a 15-foot-long compression chamber and a 125-foot-long expansion chamber (Figure 3). Air pumped into the compression chamber to a predetermined level explosively ruptured the diaphragm and projected a shock front down the expansion chamber similar to the front generated by a nuclear blast.¹⁰ The end of the expansion chamber was closed so that when the shock-front pulse struck the endplate it was rapidly reflected, increasing the pressure. Relief vents in the tube served to bleed off the reflected front and to control the duration (approximately 120 msec.) of overpressure.

Pressure-time measurements for the reflected airblast were recorded from piezoelectric transducers mounted close to the restrained monkey. The high-frequency output response of these transducers was amplified and displayed on a cathode-ray oscilloscope. A detailed explanation of the recording components involved here can be found in a report by Richmond.¹¹

Normally, the time-to-death of animals exposed to high levels of airblast is very brief.^{10, 12} As post-exposure performance was of chief interest, only sublethal overpressures were used; i. e., below the dose at which death ultimately occurs in 50 percent of the subjects (LD₅₀). The LD₅₀ for the monkey in this shock tube is approximately 58 p. s. i., while the LD₁ and LD₉₉ are 47 and 67 p. s. i., respectively.² In view of this narrow range of blast effectiveness, the three dose groups selected were 30, 40, and 50 p. s. i. (Table I), in an attempt to reveal a dose-response effect related to overpressure.

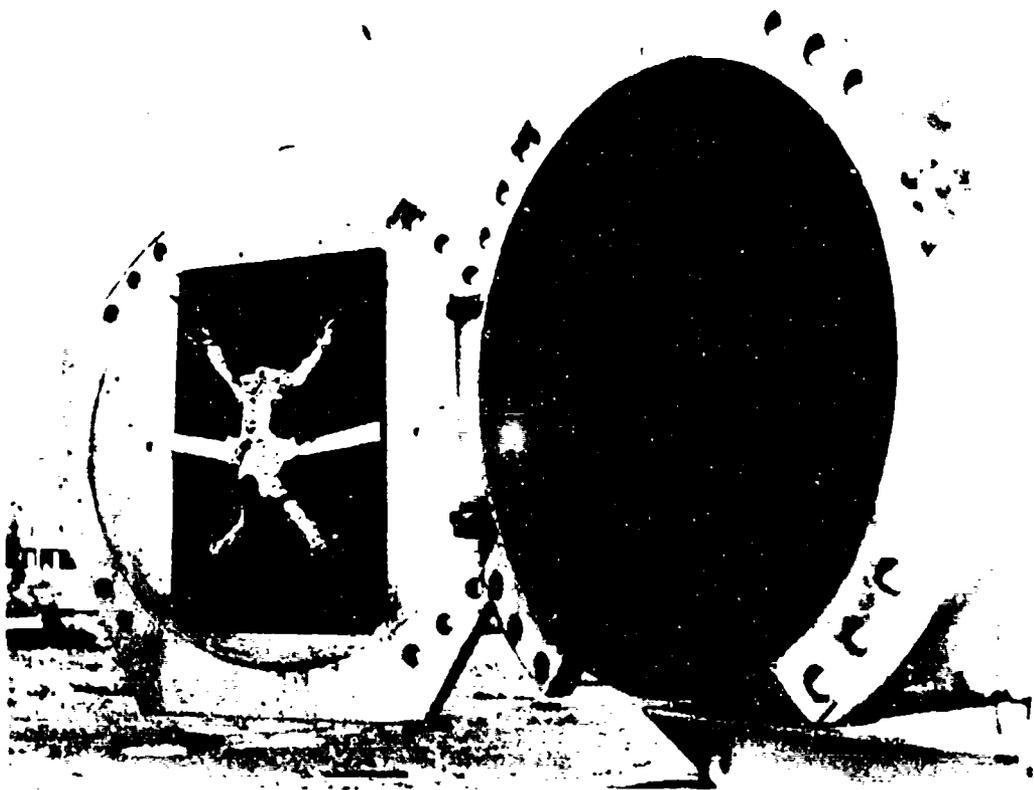


Figure 2. -- Monkey Mounted on Opened Endplate of the 42-Inch-Diameter Shock Tube.

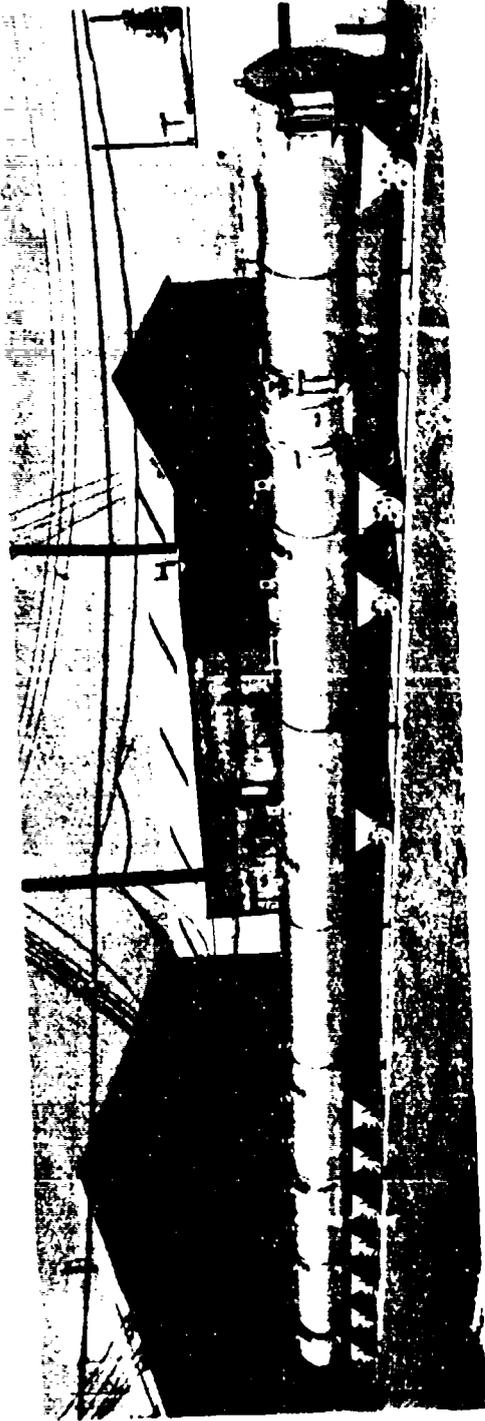


Figure 3. --The 42-Inch-Diameter Shock Tube (Closed Endplate).

Response Measures. For each task, percentage-correct responses and latency were examined for the final five pre-exposure sessions (baseline) and also at 5 minutes, 2 hours, and 7 days following blast. All surviving monkeys were tested regularly every 48 hours following exposure in order to preserve performance at high levels. In some instances, 4-hour and 30-day post-blast tests were also secured. As the data of the seventh post-blast day was found to adequately represent late effects, the intervening 48-hour observations, and 30-day tests were not plotted. In addition, nonperforming subjects' data was excluded from all statistical analyses.

Percentage correct in both tasks was calculated by the formula:

$$\text{Percentage-Correct Responses} = \frac{\text{NCIR}}{\text{NT}} \times 100$$

Where: NCIR = the number of correct initial responses (beginning from each trial's start) and

NT = the number of trials.

Initial responses on an inappropriate lever or key were counted as errors and were shocked. Corrections by the animal were then allowed, but these were not counted in the determination of percentage-correct tasks. On 50 percent of the visual trials, no response was required (red-light trials). At least one correct response (to the white light) had to be made before the above formula was applied. As it turned out, errors of commission (lever pressed to the red light) were rare. Therefore, the percentage correct was almost always over 50, reflecting, primarily, only errors of omission (failure to respond to the white light).

X-ray Examinations. Gross autopsies were performed on the first seven subjects. In these animals, no consistent dose-related injuries (especially of the ears or lungs) could be discerned. Since from 7 to 30 days had elapsed between the time of blast exposure and death, it was felt that sufficient healing could have occurred to have obscured the extent of injury visible at autopsy. Therefore, no additional autopsies were done.

Subsequently, a new procedure was carried out on the next 11 monkeys. At 24 hours before and 4 hours after blast, lateral and ventral-dorsal lung X-rays

were obtained. These were rated for degree of damage by two veterinarians unaware of the overpressure dose.

RESULTS

Auditory Task Percentage-Correct

The pre- and post-exposure mean percentage-correct responses of the 30-, 40-, and 50-p. s. i. dose groups are shown in figure 4, with the mean of the last five pre-exposure sessions representing baseline. The three groups did not have an equal number of post-blast sessions due to varying survival times or times of no performance.

It is evident from figure 4 that only the 50-p. s. i. group exhibited an early, pronounced decrement, falling to 60-percent correct responses at the 5-minute observation point. After 2 hours, both the 30- and 50-p. s. i. groups performed at an accuracy of about 80 percent in contrast to their 98-percent baseline. Not responding to the tone stimuli was the primary form of decrement. In figure 4, all three groups are shown as recovered to their pre-exposure baseline by 24 hours. Recovery was probably even earlier, however, as 4-hour post-blast tests administered to 10 selected animals (3, 4, and 3 monkeys, respectively, in the 30-, 40-, and 50-p. s. i. groups) indicated that for these animals recovery to baseline was achieved by 4 hours.

A repeated measures analysis-of-variance (ANOVA)¹⁶ was performed on the auditory percentage-correct scores of the three dose groups over the baseline and four post-blast sessions of figure 4. There was a significant effect for sessions, but not for dose or interaction (Table II). To specifically determine where the sessions' factor varied, the Newman-Keuls procedure¹⁶ was applied, and only the 5-minute session was found to differ from all other sessions.

For each dose group, *t*-tests⁶ were used to contrast the four combined post-exposure sessions. It can be seen from table III that only the 30- vs. 50-p. s. i. and the 40- vs. 50-p. s. i. comparisons differed significantly. In addition, since group decrement occurred only during the first two post-blast observations, *t*-tests were applied contrasting the 5-minute and 2-hour sessions of each dose group. The 30- vs. 50-p. s. i. and 40- vs. 50-p. s. i. 5-minute session comparisons differed significantly as did the 30- vs. 40-p. s. i. and 40- vs. 50-p. s. i. 2-hour session comparisons (Table IV). Baseline and post-blast performance

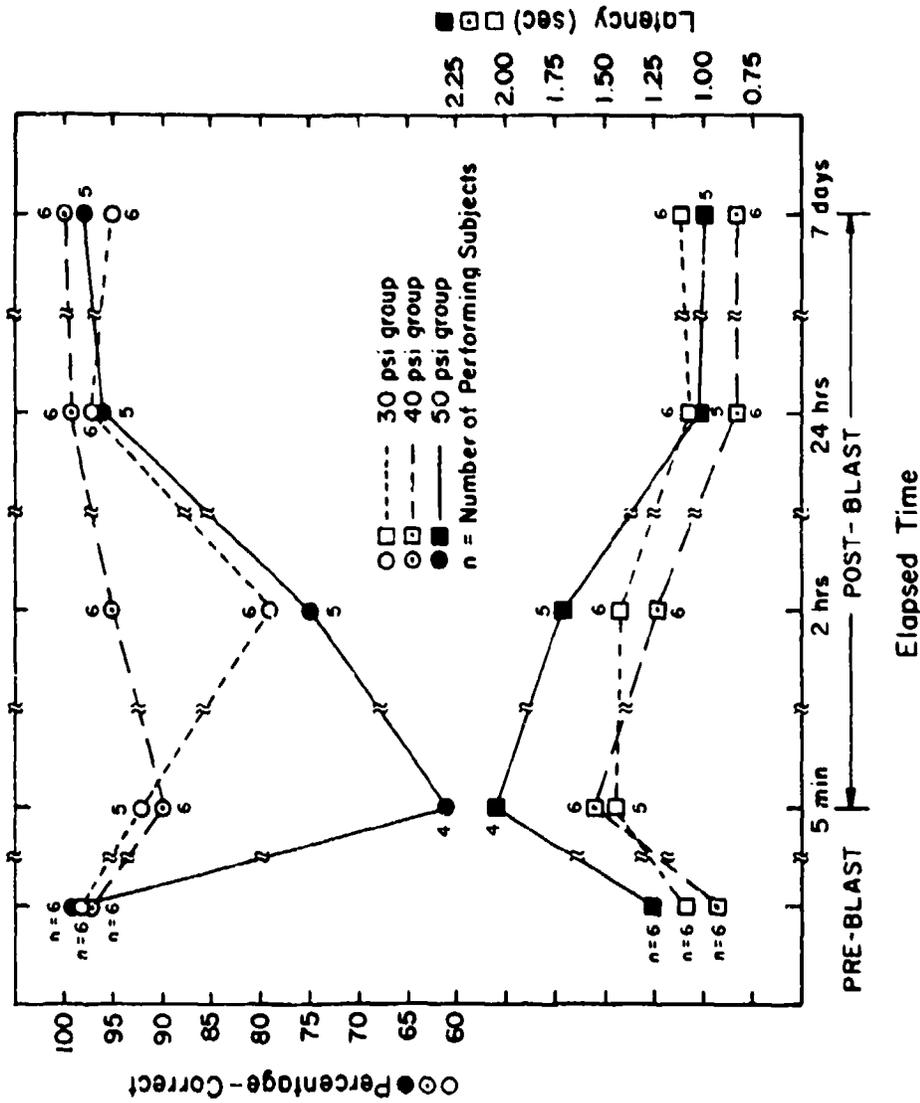


Figure 4. --Auditory Task Percentage-Correct (Upper Curves and Left Ordinate) and Latency (Lower Curves and Right Ordinate) for the 30-, 40-, and 50-p. s. i. Groups.

TABLE II
ANALYSIS OF VARIANCE SUMMARY TABLE FOR
PERCENTAGE CORRECT AND LATENCY FOR THE
AUDITORY TASK

	Percentage-Correct			Latency		
	Degrees of Freedom	Mean Square	F-ratio	Degrees of Freedom	Mean Square	F-ratio
Between Subjects	17			17		
Dose Groups (A)	2	897.0	1.92	2	1.16	1.58
Subject Within Groups	15	467.0		15	.73	
Within Subjects	72			72		
Testing Sessions (B)	4	1056.5	3.79 ^a	4	1.39	17.38*
AB	8	272.0	.98	8	.05	
B x Subjects Within Groups	54	278.6		54	.08	

* $p < .01$

TABLE III
DOSE-GROUP COMPARISONS (*t*-TESTS) FOR THE
FOUR COMBINED POST-EXPOSURE SESSIONS

	30 vs. 40 Pal	30 vs. 50 Pal	40 vs. 50 Pal
Auditory Percentage-Correct	$t = 1.94, NS^*$	$t = 2.15, p < .05$	$t = 4.17, p < .001$
Auditory Response Latency	$t = .29, NS$	$t = .32, NS$	$t = .65, NS$
Visual Percentage-Correct	$t = .17, NS$	$t = .61, NS$	$t = .75, NS$
Visual Response Latency	$t = .28, NS$	$t = .49, NS$	$t = .41, NS$

* NS = nonsignificant

TABLE IV
DOSE-GROUP COMPARISONS (*t*-TESTS) FOR THE
5-MINUTE AND 2-HOUR SESSIONS

Post-Blast Session	30 vs. 40 Psi	30 vs. 50 Psi	40 vs. 50 Psi
<u>Auditory Percentage-Correct</u>			
5 Min	<i>t</i> = .79, NS*	<i>t</i> = 6.40, <i>p</i> < .01	<i>t</i> = 5.46, <i>p</i> < .01
2 Hr	<i>t</i> = 3.94, <i>p</i> < .01	<i>t</i> = .74, NS	<i>t</i> = 4.56, <i>p</i> < .01
<u>Auditory Response Latency</u>			
5 Min	<i>t</i> = .16, NS	<i>t</i> = .78, NS	<i>t</i> = .64, NS
2 Hr	<i>t</i> = .34, NS	<i>t</i> = .29, NS	<i>t</i> = .72, NS
<u>Visual Percentage-Correct</u>			
5 Min	<i>t</i> = .91, NS	<i>t</i> = 1.89, NS	<i>t</i> = .76, NS
2 Hr	<i>t</i> = .15, NS	<i>t</i> = .13, NS	<i>t</i> = .10, NS
<u>Visual Response Latency</u>			
5 Min	<i>t</i> = .59, NS	<i>t</i> = .84, NS	<i>t</i> = .12, NS
2 Hr	<i>t</i> = .14, NS	<i>t</i> = .65, NS	<i>t</i> = .49, NS

* NS = nonsignificant

profiles showing the extent of individual subject impairment in auditory percentage-correct are presented in table V.

Analyses of the auditory data (ANOVA's) done to determine if there was differential decrement for the 1,000- and 3,000-Hz tones failed to yield any significant frequency differences for the three dose groups.

Auditory Response Latency

The mean auditory-response latencies of the 30-, 40-, and 50-p. s. i. groups are also shown in figure 4, demonstrating the same immediate decrement as the percentage correct. In this figure, none of the latency curves returned fully to pre-exposure levels until the 24-hour session. However, among the selected subjects tested at the fourth hour (data not plotted), only the 50-p. s. i. monkeys were not fully recovered by 24 hours. The ANOVA revealed a significant effect for sessions but not for dose groups or interaction (Table II). The Newman-Keuls ordered-means procedure indicated that the significant sessions effect was due to slower latencies during the 5-minute and 2-hour sessions. The additional between-group and between-session *t*-test outcomes are presented in tables III and IV, none of which were significant for latency.

As was true for the auditory percentage-correct data, the 1,000- and 3,000-Hz tones produced no differential effects on latency. Individual auditory latency data are presented in table VI, which indicates that somewhat greater variability was shown among individual subjects' auditory response latencies than occurred for the percentage-correct measure.

Visual Discrimination Percentage-Correct

Figure 5 depicts the mean percentage-correct color-discrimination curves for the three groups. During the 5-minute session, only the 50-p. s. i. group demonstrated decrement, with recovery complete by 2 hours. Failure to respond to the white light was the primary form of decrement in the visual task. The ANOVA on these data yielded a significant sessions effect only (Table VII). The Newman-Keuls analysis indicated that the 5-minute session was significantly different from the other sessions. None of the additional group analyses yielded any significant variances (Tables III and IV).

TABLE V
AUDITORY TASK PERCENTAGE-CORRECT FOR
30-, 40-, and 50-P. S. I. SUBJECTS

Subject	Pre-Exposure	Post-Exposure			
		5 min	2 hr	24 hr	7 day
<u>30 Psi</u>					
279	96	97	96	99	96
453	95	75	77	88	91
435	99	94	96	96	90
613	98	96	96	98	91
626	100	NP*	7	98	100
627	100	100	100	100	100
<u>40 Psi</u>					
439	96	96	86	99	99
466	98	98	99	100	100
581	98	94	93	97	99
622	93	52	94	100	100
617	97	98	100	100	100
631	96	100	98	100	100
<u>50 Psi</u>					
451	98	NP	91	83	93
445	98	93	97	100	100
455	97	3	81	96	96
460	98	NP	NP	100	100
628	100	61	4	Dead	
630	100	86	100	100	100

* NP = subject did not perform.

TABLE VI
AUDITORY TASK LATENCY (SEC) FOR
30-, 40-, AND 50-P. S. I. SUBJECTS

Subject	Pre-Exposure	Post-Exposure			
		5 min	2 hr	24 hr	7 day
<u>30 Psi</u>					
279	.63	1.05	.73	.80	.56
453	1.23	2.16	2.32	1.57	1.50
435	.78	1.13	1.23	.71	.76
613	1.61	1.86	1.68	1.07	1.24
626	1.24	NP*	1.75	1.39	1.59
627	.93	.99	.87	.75	1.04
<u>40 Psi</u>					
439	.92	2.17	1.28	.74	.93
466	.98	1.62	1.69	.80	.86
581	1.35	1.65	1.13	.81	.99
622	.75	1.97	1.15	.80	.61
617	.82	1.00	1.01	.89	.76
631	.74	.89	1.13	.87	.73
<u>50 Psi</u>					
451	1.45	NP	1.78	1.40	1.05
445	1.88	2.29	1.45	1.35	1.31
455	.84	2.50	1.36	.90	.76
460	.68	NP	NP	.62	.70
628	1.68	2.38	2.84	Dead	
630	.94	1.00	1.04	.92	1.13

* NP = .subject did not perform.

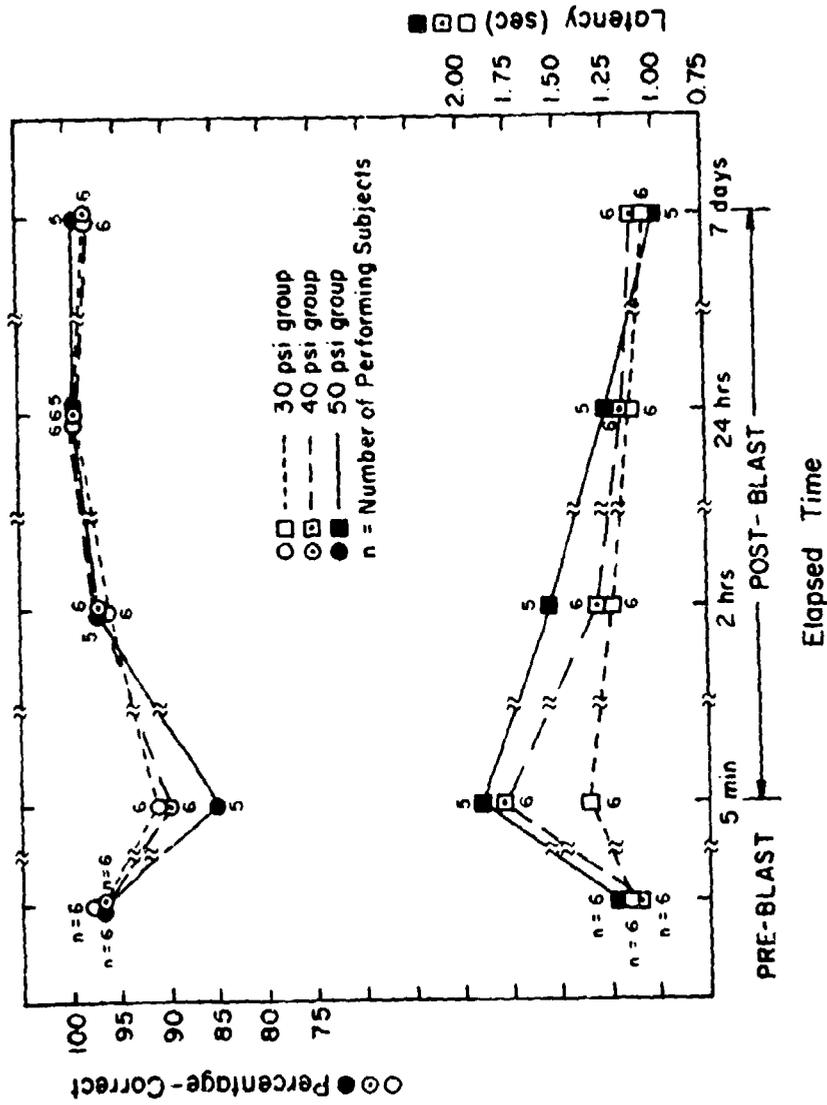


Figure 5. --Percentage-Correct Visual Discriminations (Upper Curves and Left Ordinate) and Latency (Lower Curves and Right Ordinate) for the 30-, 40-, and 50-p. s. i. Groups.

TABLE VII
ANALYSIS OF VARIANCE SUMMARY TABLE FOR
PERCENTAGE CORRECT AND LATENCY FOR
THE VISUAL TASK

	Percentage Correct			Latency		
	Degrees of Freedom	Mean Square	F-ratio	Degrees of Freedom	Mean Square	F-ratio
Between Subjects	17			17		
Dose Groups (A)	2	8.0	.16	2	.26	.50
Subjects Within Groups	15	48.5		15	.52	
Within Subjects	72			72		
Testing Sessions (B)	4	298.8	9.96*	4	1.09	12.11*
AB	8	13.3	.44	8	.11	1.22
B x Subjects Within Groups	56	30.0		56	.09	

* $p < .01$

The individual visual percentage-correct data are shown in table VIII. It was noteworthy that monkey No. 628 performed the visual task at 92-percent accuracy during the 2-hour session. This subject died while performing the subsequent auditory task of the same session minutes later.

Visual Response Latency

The mean visual response latencies for the three dose groups are illustrated in figure 5, which mainly reflects a transient increase in latency immediately after exposure. Except for the 50-p. s. i. group, visual latency was fully recovered by 2 hours. Baseline level of performance was not achieved by the 50-p. s. i. group until 24 hours. Again, only the sessions factor was significant (Table VII), and the Newman-Keuls analysis showed that these effects occurred at the 5-minute session. None of the additional between-group and between-session comparisons yielded any significant differences (Tables III and IV). Individual response latencies for the baseline and post-blast sessions are presented in table IX.

Additional tests were conducted to determine if within-session recovery occurred during the 5-minute post-blast test by dividing the session into ten 1-minute segments. The first 2 minutes for each response-measure were compared by *t*-tests against the last 2 minutes. These tests failed to yield any significant differences.

Task Presentation Order

The auditory and visual data were combined irrespective of dose group and examined for differences associated with task presentation order, comparing all subjects receiving the A₁V₂ order to those receiving the V₁A₂ order. Figure 6 shows the regrouped percentage-correct and latency difference data (baseline minus 5-minutes post-blast) plotted as a function of presentation order. It is apparent that subjects receiving the auditory task first displayed greater early post-blast decrement (5-minutes) relative to preblast than subjects receiving the visual task first. This is confirmed in table X, where significant *t*-test values were obtained between the A₁ and V₁ percentage-correct and latency difference scores, but not between the V₂ and A₂ scores.

TABLE VIII
PERCENTAGE-CORRECT VISUAL DISCRIMINATIONS
FOR 30-, 40-, AND 50-P. S. I. SUBJECTS

Subject	Pre-exposure	Post-Exposure			
		5 min	2 hr	24 hr	7 day
<u>30 Psi</u>					
279	97	99	97	100	100
453	99	100	100	100	99
435	99	77	90	100	99
613	95	88	94	96	89
626	97	86	96	99	100
627	96	95	97	99	100
<u>40 Psi</u>					
439	98	96	100	99	100
466	96	88	96	99	99
581	98	90	90	99	90
622	96	67	97	99	99
617	98	99	100	100	100
631	97	100	100	100	100
<u>50 Psi</u>					
451	98	97	99	96	100
445	96	66	97	100	99
455	100	74	96	97	100
460	97	NP*	NP	97	96
628	98	88	92	Dead	
630	100	99	100	100	100

* NP = subject did not perform.

TABLE IX
VISUAL RESPONSE LATENCIES (SEC) FOR
30-, 40-, AND 50-P. S. I. SUBJECTS

Subject	Pre-exposure	Post-Exposure			
		5 min	2 hr	24 hr	7 day
<u>30 Psi</u>					
279	.70	.88	.65	.67	.57
453	1.38	2.06	1.89	1.78	2.21
435	.88	1.42	1.15	.82	.56
613	1.57	1.38	1.73	1.46	1.09
626	1.24	1.44	1.06	1.00	1.03
627	1.21	1.00	.92	1.03	.92
<u>40 Psi</u>					
439	.77	1.43	1.21	.83	.70
466	1.51	1.80	1.42	1.53	1.33
581	1.17	1.30	1.06	.90	1.33
622	1.49	3.50	1.92	1.49	.97
617	1.00	1.81	1.11	1.32	1.08
631	.74	.88	.95	.88	1.10
<u>50 Psi</u>					
451	1.09	2.28	1.75	1.02	1.05
445	1.31	1.82	1.22	1.11	.95
455	1.22	2.19	1.68	1.46	1.00
460	1.48	NP*	NP	1.63	.69
628	.95	1.67	1.89	Dead	
630	1.18	1.44	1.22	1.00	1.26

* NP = subject did not perform.

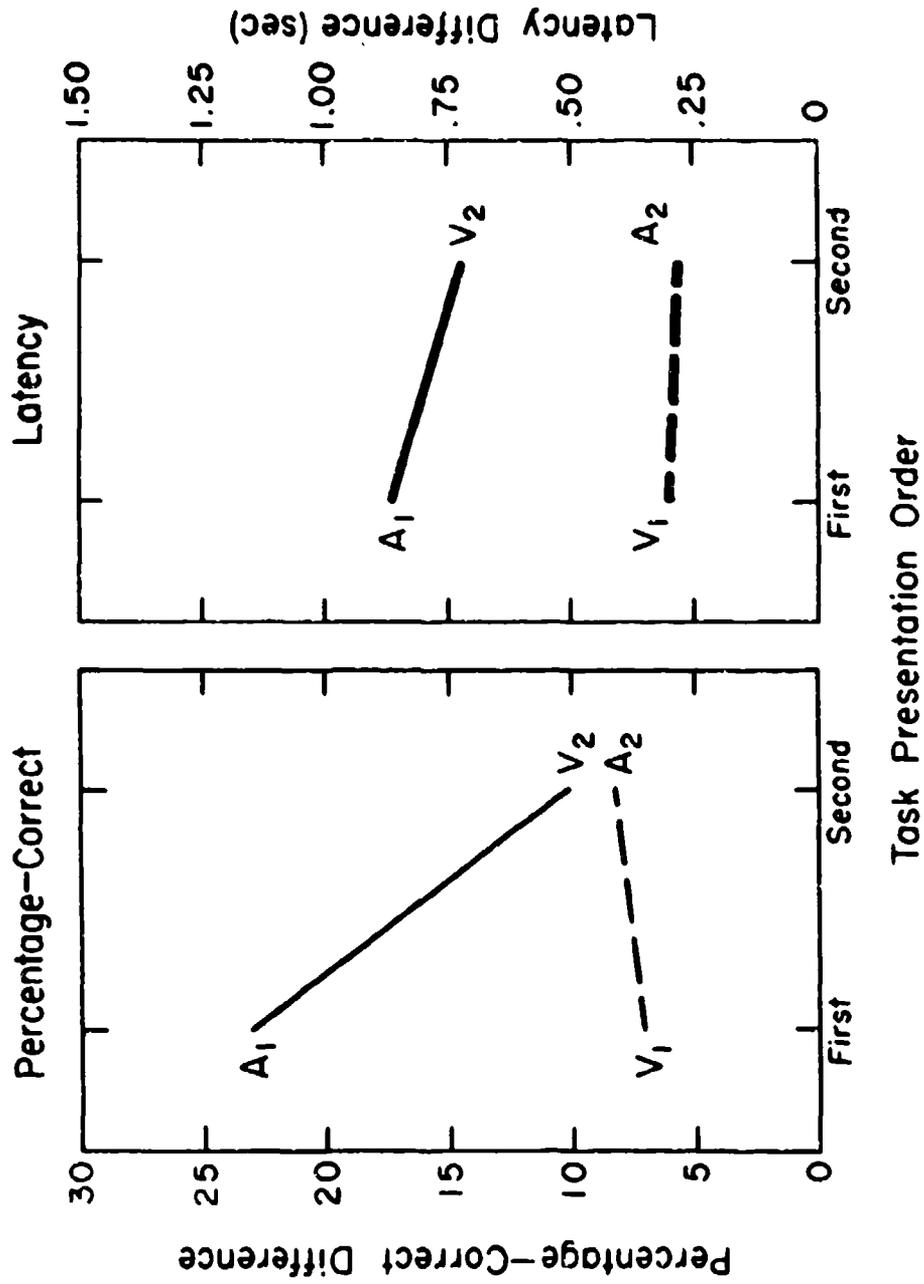


Figure 6. --Auditory and Visual Task Percentage-Correct and Latency Difference Scores (Baseline Minus 5-Minute Session) for the Three Dose-Groups Combined Comparing Task Presentation Order.

TABLE X
TASK-PRESENTATION-ORDER COMPARISONS (t-TESTS)
FOR THE 5-MINUTE SESSION

	Percentage-Correct	Latency
Auditory 1 vs. Visual 1	$t = 2.58, p < .05, (n = 15)$	$t = 2.04, p < .05, (15)$
Visual 2 vs. Auditory 2	$t = .71, NS^*, (17)$	$t = .46, NS, (17)$

* NS = nonsignificant.

Sex Comparisons

An analysis was done to determine if there was a differential blast effect related to sex. For those subjects performing after exposure, there was no significant effect related to sex for any of the response measures; however, it should be noted that the three post-exposure subjects which did not perform were all males.

Error Performance

For all but one monkey, T. O. responses increased from virtually zero pre-blast to about four per session post-blast. One subject made initial responses to the left press key (responses were correct only on the right press key) during the 5-minute post-blast auditory session. No responses were ever made on the levers while performing the auditory task or on the keys when performing the visual task, and no increase in error-rate was made to the auditory "dummy-click" trials.

General Post-Exposure Behavior

Seven monkeys assumed new postural orientations relative to the stimulus-response panel following exposure. In four cases, this posture may have interfered with discrimination accuracy or latency. Four subjects showed less general post-exposure activity compared with their preblast behavior; e. g., during preblast T. O. 's, some subjects moved restlessly around the chamber, and another subject performed a "superstitious" pacing during the red-light trials. Heavy breathing or blood around the mouth and nose were noted in six subjects during the 5-minute, post-blast session. Two subjects did not eat fruit put in the chamber after the 5-minute test. One subject had to be awakened for the 2-hour post-test, while another subject could not walk back to the living cage after the 4-hour session. These physical debilities were most apparent during the early post-blast hours and disappeared within a day. They seemed roughly related to the dose-level received. Six subjects remained outwardly unchanged following exposure to blast.

X-ray Evaluations of Lung Damage

The lung X-rays of 11 monkeys were judged "blind" as to extent of lung damage by two veterinarians. Based on chi-square analysis,⁴ the two judges were able to differentiate the baseline and post-blast X-rays appropriately ($\chi = 4.46$, $p < .05$). The X-rays of Nos. 613 and 626 were excluded from analysis due to the post-exposure films being overexposed. The interjudge reliability for ranking severity of lung damage was tested (rank-order correlation) and found to be significant ($\rho = .95$, $p < .01$). The combined-judge X-ray rankings of severity of lung damage were significantly correlated with the reflected overpressures received by each monkey ($\rho = .64$, $p < .05$).

The X-ray rank evaluations were also correlated against each performance-response measure. As can be noted from table XI, all lung damage and performance-measure correlations were significant.

TABLE XI

RANK-ORDER (ρ) CORRELATIONS BETWEEN X-RAY
EVALUATIONS OF LUNG DAMAGE AND RESPONSE
MEASURES ($n = 9$) AT 5-MINUTE POST-BLAST

X-Ray vs Auditory Percentage-Correct	$\rho = .90, p < .01$
X-Ray vs Auditory Response Latency	$\rho = .77, p < .01$
X-Ray vs Visual Percentage-Correct	$\rho = .78, p < .01$
X-Ray vs Visual Response Latency	$\rho = .70, p < .02$

DISCUSSION

The comparisons made between auditory and visual performance indicate that more prominent blast-related decrement occurred for the former. This was indicated in several ways. First, auditory percentage correct was the only measure to reflect a dose-response effect, and this was most apparent in the high-dose subjects immediately following exposure. For the visual task, only the 50-p. s. i. group demonstrated percentage-correct decrement on the 5-minute post-blast session. (In both tasks, decrement was mainly a failure to respond.) Second, the auditory latencies of all three groups were affected (increased) 5 minutes post-blast, while for visual-task latency, only the high and medium dose-groups reflected early decrement. Finally, it was clear that immediately after blast exposure, performance was more impaired when tones were presented as the first post-blast stimuli (A₁V₂) than in the case of the lights (V₁A₂). Additionally, three A₁V₂ monkeys did not respond at all during the auditory trials directly after blast, although all of the V₁A₂ animals responded.

Greater decrement in the auditory task compared to the visual task reflects the fact that ear damage was produced by the airblast, while no detectable injuries to the eyes were observed. It has been shown that air-containing organs, such as the ears, are more prone to overpressure damage,^{10, 12} than are organs, such as the eyes. In the seven autopsied monkeys exposed to from 30 to 50 p. s. i., the area of eardrum rupture ranged from 0 to 66 percent in the worst ear. In a review of overpressure effects on the ear,⁷ it was reported that 30 p. s. i. produces about 60-percent eardrum perforation in the monkey. The lesser degree of rupture and the variability seen in the present study is likely due to the fact that some freedom of head movement was allowed by the restraint suit employed. Consequently, head orientation relative to the shock front was allowed to vary, increasing the variability of the degree of ensuing rupture.

The findings of the auditory- and visual-task comparisons for the present study are interesting with respect to a previous investigation,¹ in which similarly trained, radiation-exposed subjects showed comparatively more decrement on the visual task. Furthermore, in the radiation study, auditory percentage-correct was unaffected; while in the present study, the opposite results were found.

In general, the individual-subject performance fluctuations were not extensive in this study in contrast to those observed in the radiation study.¹ In most cases, airblast decrement occurred immediately and was usually transient, with stable responding thereafter. In the radiation study, session-to-session variability was much more prominent, implying that such variability may be a characteristic radiation effect rather than inherent to these particular behavioral measurement techniques.

The X-ray procedure of this study proved to be exceptionally fruitful, as it facilitated good rank-order correlations with performance and blast dose. Future work in this area would probably be benefitted by the use of this procedure.

The present investigation has shown that airblast-produced decrement is not extensive and behavioral recovery time is not long following 30- to 50-p. s. i. exposures, even though such overpressures are adequate to produce clear evidence of damage to the ears and lungs. Only 17 percent of the subjects were not able to work immediately after exposure, while the remainder were able to perform optimally either immediately or within 24 hours post-blast.

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