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# POTENTIAL FOR INTERACTION OF LOW-LEVEL IMPULSE AND CONTINUOUS NOISE


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AFAMRL-TR-80-68

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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FOR THE COMMANDER

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The purpose of the experiments described in this report was to establish whether a synergistic interaction occurs between relatively low levels of continuous and impulse noise to produce an increased hearing loss and cochlear pathology. Twenty-three monaural chinchillas were used as experimental subjects. The animals were divided into six groups. Each group was exposed 8 hours per day for 8 weeks to various combinations of impulse and continuous noise presented at various levels. Using behavioral conditioning techniques, hearing thresholds were measured before, during, and after noise exposure. After a minimum of 30 days post-exposure the animals were killed and their cochleas were analyzed using the surface preparation technique. Histological results were quantified in the form of a cochleagram. In contrast to earlier findings the results of this study found no evidence of a synergistic interaction when the animals were exposed to a combination of continuous (between 75-85 dB SPL) and impulse (103 dB SPL peak exposure) noise.

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# PREFACE

This effort was performed under contract F33615-78-C-0513 with Syracuse University for the Air Force Aerospace Medical Research Laboratory (AFAMRL), Wright-Patterson Air Force Base, Ohio. Dr. Thomas J. Moore of the Biological Acoustics Branch, Biodynamics and Bioengineering Division, served as the technical contract monitor in support of work unit 2312V314, "Research on Function Changes in Auditory System."

The authors acknolwedge the technical assistance of John Perry, Donald Coling, Mary Cuomo-Benzo and Gary Pavek for their assistance in the animal conditioning, noise calibration and histology.

## TABLE OF CONTENTS



## LIST OF ILLUSTRATIONS

# LIST OF TABLES

# INTRODUCTION

Military personnel are often exposed to noises that include continuous and impulsive components. Separate Damage Risk Criteria (DRC) exist for each type of noise, but present operating procedures do not include provisions for evaluating the combined effects of impulse and continuous noise. Moreover, research on animal models (chinchilla) has shown that exposure to combinations of high level impulse (158 dB p.e. SPL) and high level continuous noise (85 dB SPL 2-4 KHz OBN) can produce greater hearing loss and cochlear damage than would be expected from the sum of the effects of exposure to each noise alone (Hamernik et al., 1974, and Hunt et al., 1976).

A practical issue in the studying the relationship between noise exposure and hearing loss is deciding on the parameters of noise that lead to a just measurable temporary threshold shift (TTS). Some have assumed if a noise does not lead to a measurable TTS then the noise will be safe for long term exposures; conversely, others have hypothesized the amount of TTS after 8 hours of noise exposure may be equal to the Permanent Threshold Shift (PTS) that can be expected after years of exposure to the same noise. The actual exposure threshold for the beginning of noise-induced hearing loss is difficult to determine because of the extreme amounts of variability. For example, one source of variability may be related to the concept that individuals have some unique critical level (McRobert and Ward, 1973). Noises above this level cause hearing loss, whereas noises below the level do not cause hearing loss, regardless of the duration of the exposure. Traditionally, attempts to determine the threshold of hearing damage have either been retrospective demographic studies of noise-exposed populations or controlled laboratory studies that created mild temporary threshold shifts.

This report summarizes the results of an experimental program directed toward measuring the potential for synergistic interactions of continuous and impulse noise at moderate to low levels of exposure. The experiments were done on chinchilla because it is possible to get reliable measures of hearing function from this animal. Also, we probably have a better understanding of how noise affects the chinchilla than any other animal model. The noise exposure was patterned to mimic a work-week, i.e., an exposure of 8 hours per day for 5 days for 8 weeks. The noises were "pink noise" and impact noise set at levels that would produce reliable but relatively low threshold shifts. The results of such experiments may be useful in setting guidelines for limiting exposure in the work environment

# METHODS

## SUBJECTS

Twenty-three adult chinchillas were used as subjects. All animals were made monaural by surgical destruction of the left cochlea under a sodium pentobarbital anesthesia (50 mg/kg, I.P.). The animals were divided into six groups, with four-five animals per group as shown in Table 1.

## APPARATUS

*Behavioral testing*

Behavioral testing is based upon traditional shock-avoidance conditioning principles. The animal is placed in a restraining device and is held in a standing position in the sound field. The chinchilla's reflexive tendency to jump when shocked on the tail is used as the avoidance response. Figure 1 shows the animal in the restrainer which positions the animal's head 9 in. above the floor and 25 in. directly below the loudspeaker (Dynaco A-25). Responses of the animal were recorded by means of a microswitch which registered upward movement (approx. 0.5 in.) of the restraining yoke. Shock was delivered to the animal's shaved tail by means of two disk electrodes taped to the tail with a separation of approximately 2 in. Electrode paste was used under the electrodes to insure good conduction to the skin. Electric shock was produced by a constant-current, 60-Hz shocker at a level of 5 mA for all animals and conditions. A safety signal, which indicated successful shock avoidance to the animal, was a 40-W light mounted on the wall of the sound booth facing the animal. The audiological test environment consisted of a single-walled sound booth (IAC 400) with 3-in. foam (Soundfoam) on the floor. The sound field was calibrated with a 1-in. condenser microphone positioned (at normal incidence) at a point approximating the center of the animal's head.

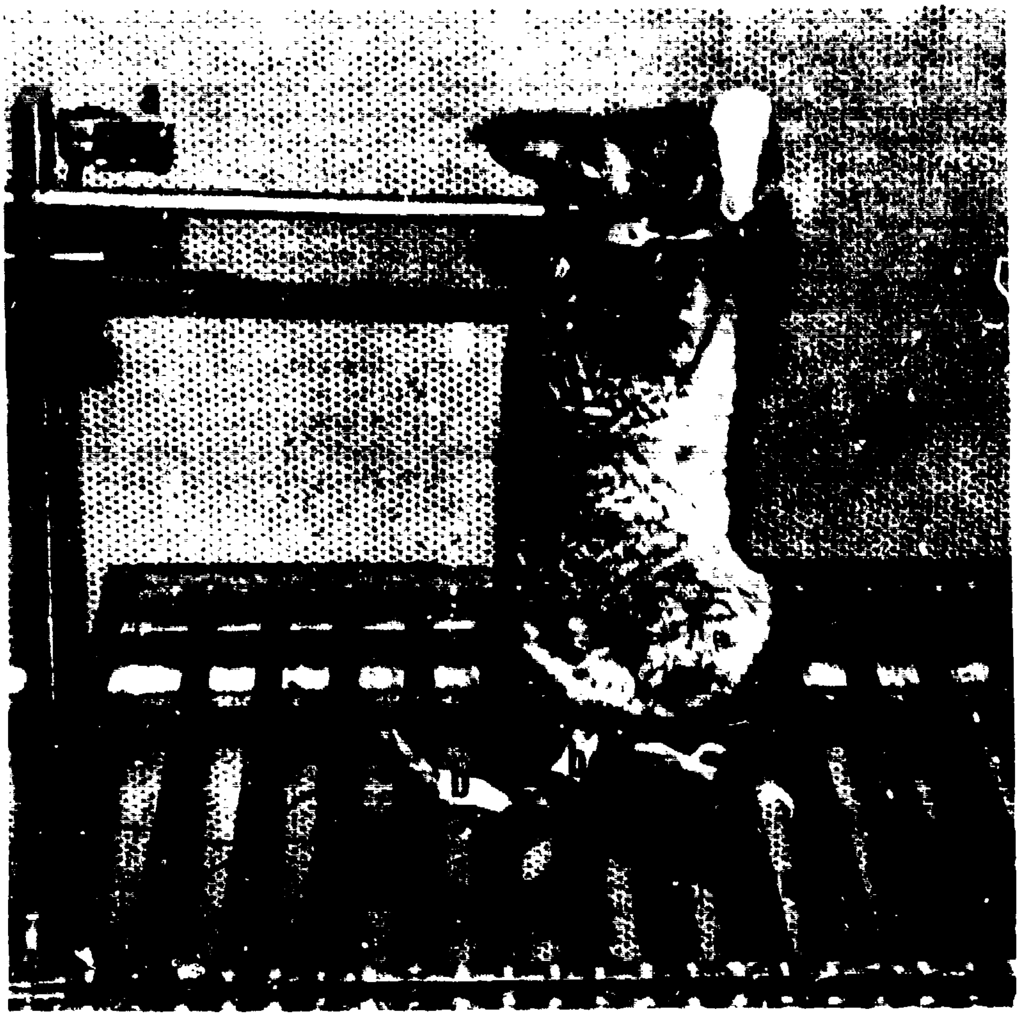

Figure 1. A View Within the Sound Booth of a Chinchilla Restrained by the Jump-Stand Conditioning Apparatus Showing: (a) Microswitch for Detecting Responses; (b) Electrodes Attached to Tail with Tape; (c) Support Grid.

Signals were generated by standard audio equipment consisting of an oscillator, electronic switch, amplifier, attenuator, impedance-matching transformer, and loudspeaker. Tone bursts were gated with a 5-ms rise-fall time. The attenuator was checked for linearity at low signal levels by means of a wave analyzer and was found to be correct with ± 1 dB for the entire range of required attenuation. The harmonic content of the loudspeaker was also checked and for all test frequencies, the levels of the harmonics were found to be at least 40 dB below those of the fundamentals. Timing and control of the test sequence was provided by solid-state programming equipment.

***Exposure:***

**An outline of the noise exposure protocol for each animal is given in Table 1. Each animal was exposed to a noise environment for 8 hours per day; 5 days per week for 8 weeks. For all six groups the impulse noise was the same. i.e.: 103 dB p.e. SPL ± 2 dB presented at the rate of 1 per sec. The impulse pressure-time profile and spectrum is shown in Figure 2. The continuous noise varied from group to group as indicated below. The specific expoure protocol for each group was as follows:**

- **Group 1:** **Weeks 1-4 impact noise exposure at 103 dB p.e. SPL. Weeks 5-8 85 dB SPL continuous noise exposure combined with the 103 dB impact noise. The continuous noise had the spectrum shown in Figure 3.**
- **Group 2:** **Continuous noise alone at 85 dB for weeks 1-4. A spectrum of this continuous noise is shown in Figure 3. The intensity of the continuous noise was varied in an attempt to produce a stable level of threshold shift. On days 1 through 10 the level was 75 dB SPL; days 11 through 13 the level was increased to 80 dB SPL; and on day 14 through to the end of the group 1 exposure the level was kept at 85 dB. During weeks 5-8 the exposure was a combination of the 103 dB p.e. SPL impulse plus the 85 dB SPL continuous noise.**
- **Group 3:** **Weeks 1-4 continuous noise exposure at 85 dB SPL using the spectrum shown in Figure 3. Weeks 5-8 a combination of 85 dB continuous noise and 103 dB p.e. SPL impact noise.**
- **Group 4:** **Weeks 1-4 impact noise exposure at 103 dB p.e. SPL. Weeks 5-8 a combination of 76 dB SPL continuous noise and 103 dB p.e. SPL impact noise. The continuous noise spectrum was changed from that used for groups 1-3, to the more nearly "pink noise" spectrum shown in Figure 4.**
- **Group 5:** **Weeks 1-4, impact noise exposure at 103 dB p.e. SPL. Weeks 5-8, a combination of the 76 dB SPL continuous noise and the 103 dB p.e. SPL impact noise. The 76 dB SPL continuous noise spectrum was evened out using a B & K spectrum equalizer. The new spectrum is shown in Figure 5.**
- **Group 6:** **Weeks 1-4, continuous noise exposure at 76 dB SPL having the spectrum shown in Figure 5. Weeks 5-8, a combination of the 76 dB SPL continuous noise and the 103 dB p.e. SPL impact noise.**

**Figures 6 and 7 illustrate the noise generation and measurement set-ups.**

## TABLE 1

## AN OUTLINE OF THE NOISE EXPOSURE PROTOCOL FOR FACH EXPERIMENTAL GROUP

| Group | Chinchilla No. | Continuous Noise[a] | Impulse Noise | Exposure *Week 1-4* | *Week 5-8* |
|---|---|---|---|---|---|
| 1 | 703, 706, 754, 756 | 85 dB SPL (77 dBA) | 103 ± 2 dB p.e. SPL | Impulse | Impulse & Cont. |
| 2 | 840, 758,* 757, 841* | 75-85 dB SPL** (69-dBA) | 103 ± 2 dB p.e. SPL | Continuous | Impulse & Cont. |
| 3 | 839, 846, 853, 857, 856* | 85 dB SPL 77 dBA) | 103 ± 2 dB p.e. SPL | Continuous | Impulse & Cont. |
| 4 | 881, 891, 893, 904, 908 | 76 dB SPL (70 dBA) | 103 ± 2 dB p.e. SPL | Impulse | Impulse & Cont. |
| 5 | 758, 841, 952, 956 | 76 dB SPL (70 dBA) | 103 ± 2 dB p.e. SPL | Impulse | Impulse & Cont. |
| 6 | 995, 997, 998, 856 | 75 dB SPL (70 dBA) | 103 ± 2 dB p.e. SPL | Continuous | Impulse & Cont. |

* These animals were used in groups 5 or 6 also (See page 12).

(a) The spectra of the continuous noise for groups 1-3 differed from that of grups 4-6 (See page 8-9).

** This was the first group of animals exposed to the continuous noise. During the first four weeks the noise was adjusted from 75 dB SPL (weeks 1-3) to 85 dB SPL for the fourth week and all other times.

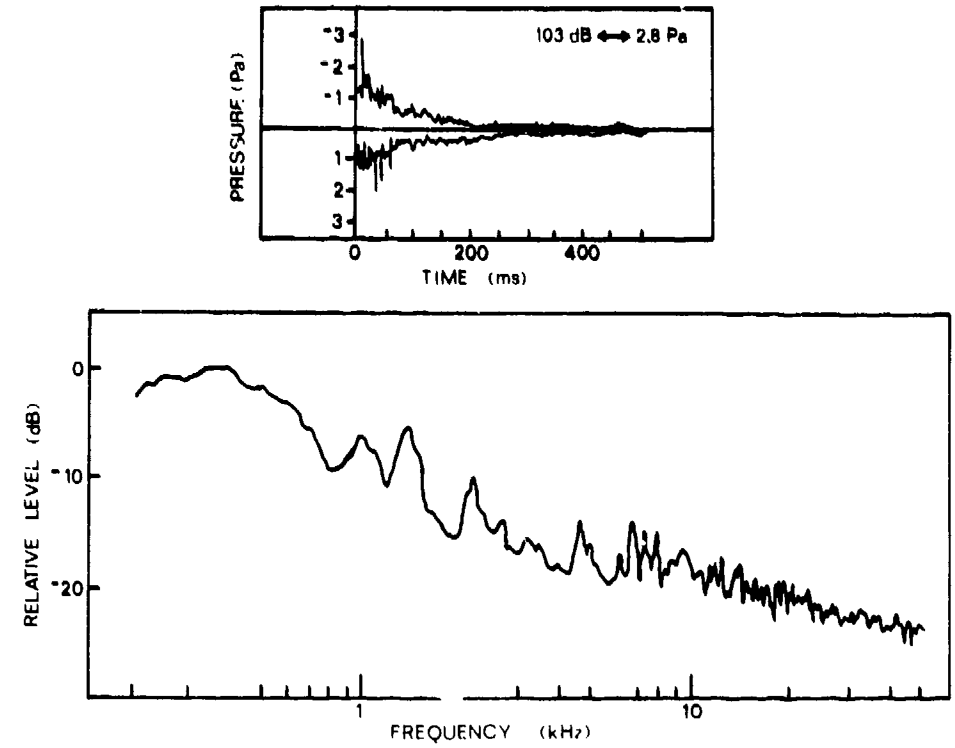


**Figure 2. The Impact Noise Pressure - Time Trace and the Relative Spectrum Level**

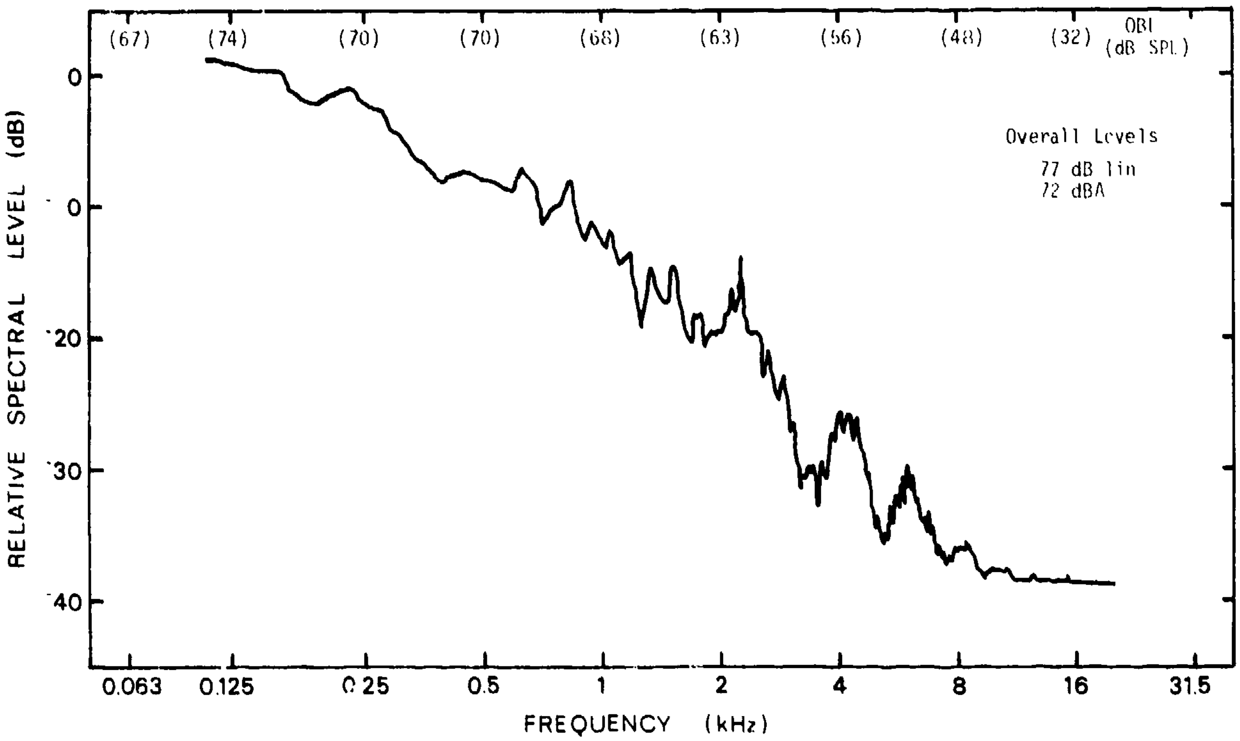


**Figure 3. Relative Spectrum Level of the Continuous Noise Used in the Exposure of Groups 1-3. The noise had a band level of 85 dB during the exposure, but the spectrum was computed at a band level of 77 dB to facilitate comparison with the noise used in Groups 4, 5 and 6.**

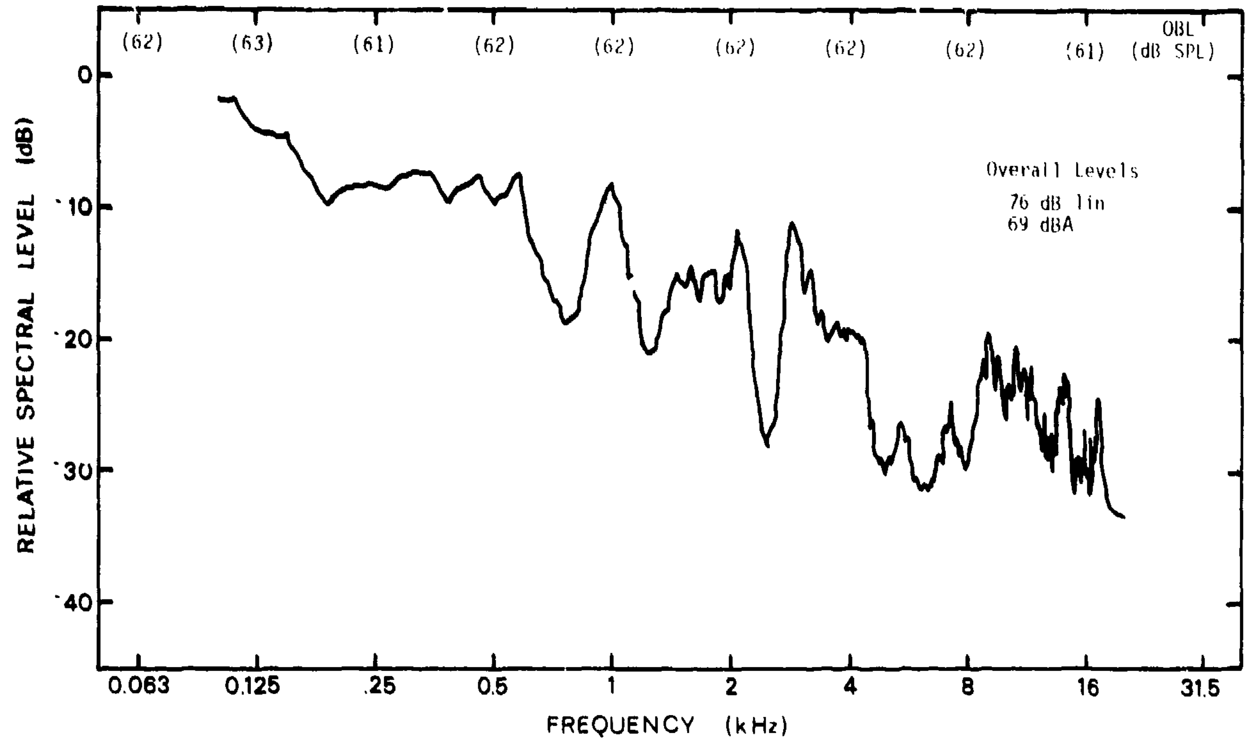


**Figure 4. Relative Spectrum Level of the Continuous Noise Used in the Exposure of Group 4.**

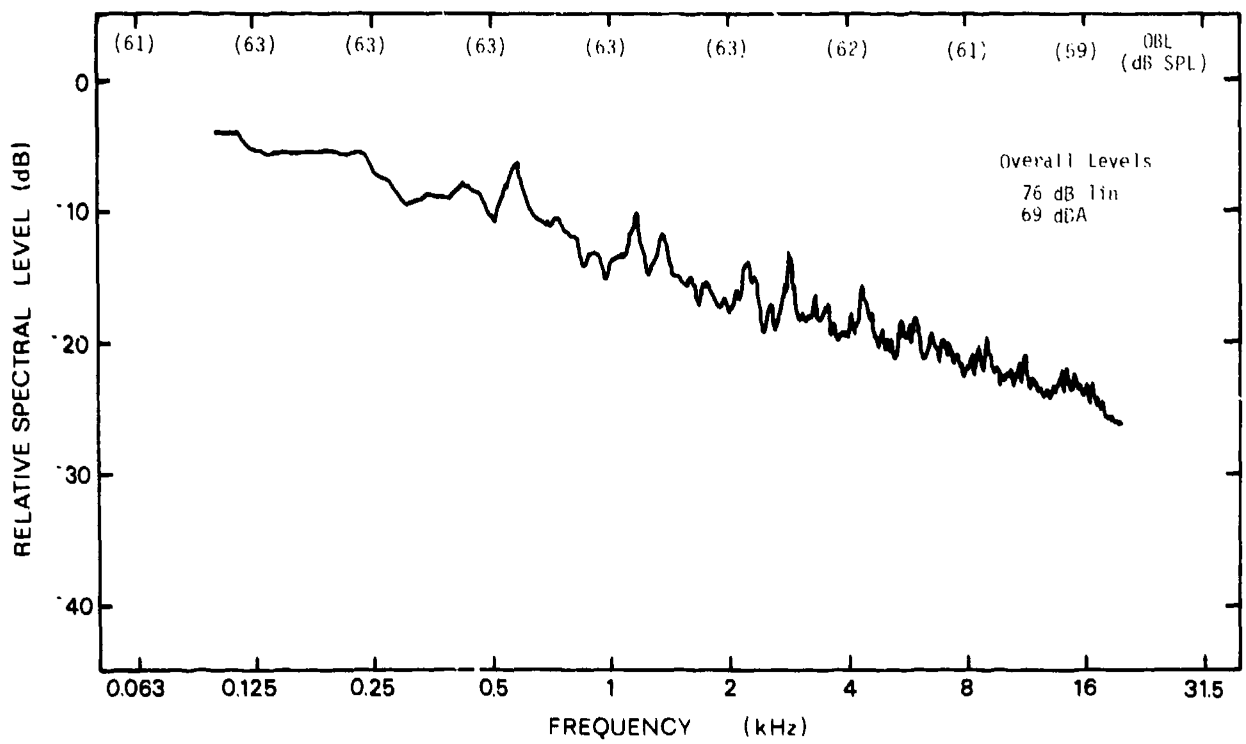


**Figure 5. Relative Spectrum Level of the Continuous Noise Used in the Exposure of Groups 5 & 6.**

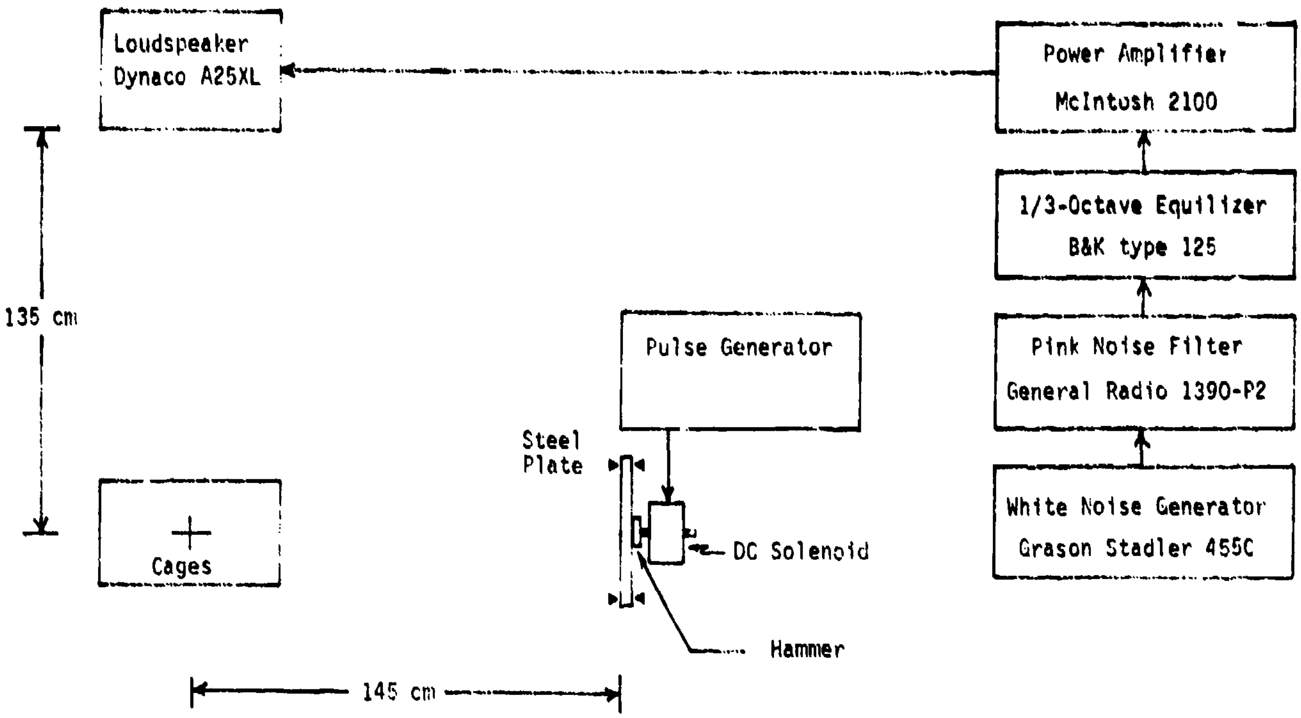


Figure 6. Schematic of the Impulse & Continuous Noise Generation Systems

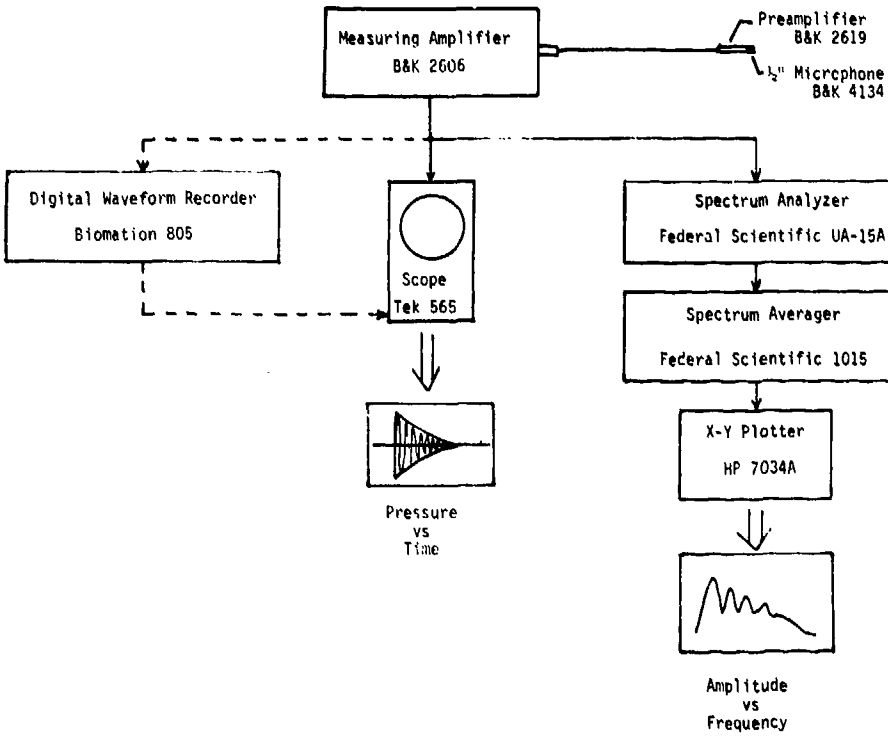


Figure 7. Schematic of the Acoustic Measurement System

# PROCEDURE

## INITIAL TRAINING

During the first adaption session, the animal was placed in the restraining apparatus and allowed to stand for 30 min. At the end of this session the [illegible] was shaved. During the second adaptation session, the animal was again placed in the restrainer, this time with electrodes in [illegible] the tail. On the third day, the animal was placed in the restrainer, electrodes were attached and ten trials with an in[illegible]terval of 1 min. were presented. A trial consisted of a train of eight tone bursts (500 ms on, 500 ms off, 5-ms rise-fall, [illegible] threshold ( 60dB SPL) intensity. At the onset of the sixth tone burst, pulsed shock was delivered to the tail (5 m[illegible] ms off). At the end of the 8-tone burst, the shock was terminated. If the animal responded during the first 5-tone [illegible] successfully avoided shock, the signals were terminated, and the safety signal was turned on for 20 s. If the animal responded during the shock period (last three tone bursts), the signals were terminated and it escaped further shock. Once the animal avoided for a total of five trials, frequency was randomized, followed by gradual randomizations of intensity. The fourth and fifth training sessions consisted of 25 trials each, during which the chinchillas were trained with correction procedures to make avoidance responses for signals (approximately 20-80 dB SPL in 10-dB steps). When the animal learned to avoid shock during trials with ran[illegible]ized frequency and intensity, the paradigm was changed. Instead of five warning signals, the animal received only two signals before the onset of shock. Training was conducted with this paradigm until nearly perfect performances were obtained (errors less than 5%). The entire training procedure required from five to seven 30-min sessions after which the animal was ready for threshold testing.

## PRE-EXPOSURE THRESHOLD TESTING

The psychophysical method used in threshold testing was a modified method of limits, similar to that used by Miller (1970). At each frequency to be tested, testing commenced at a high intensity (approximately 60-80 dB SPL) and after each successful avoidance, the intensity was lowered by 20 dB. When the animal failed to avoid, the intensity was raised by 10 dB. Threshold was defined as halfway between the lowest intensity at which the animal avoided and the highest intensity at which it failed to avoid. The intertrial interval (ITI) was randomly varied between duration of 30-90 s. The shock was turned off approximately 20 dB above the expected threshold. No secondary reinforcer, such as a buzzer, was used and the animal was never intentionally shocked at or near threshold. The animal was allowed one false response during each ITI. If the animal responded twice during the ITI, the automated interval timer was shut off and the experimenter waited until a period of 30 s without responding passed before initiating another trial. This insured a false response level of less than 6.7%. False response level is defined as the ratio of the time interval for a possible avoidance (2 s) over the entire period in which false responses can be made (30 s, as a minimum).

Auditory thresholds were measured at five frequencies: 0.5, 1, 2, 4, and 8 kHz. The order in which these frequencies were run each day was randomized and the initial signal level at which testing commenced was varied. Twelve measurements were made at each frequency. Using a unit attenuator (0-9 dB in 1-dB steps) in series with the main attenuator (0-100 dB in 10-dB steps), the attenuation values used each day were randomly incremented by from 0-9 over the ten days of testing. This presumably moved the 10-dB threshold "window" about the "true" threshold and was intended to provide a better estimate of threshold. In the manner of Miller (1970), when the chinchilla failed to respond at a signal level more than 20 dB above the estimated threshold (in the range where shock would be given), that trial was run again. The results of the second run were always accepted. Thresholds from the first 2 days of testing were not used. The results of the following 8 days of testing were averaged regardless of any particular threshold's divergence from the expected value. Figure 8 shows the mean pre-exposure audiogram for each of the six experimental groups and for all 23 chinchillas.

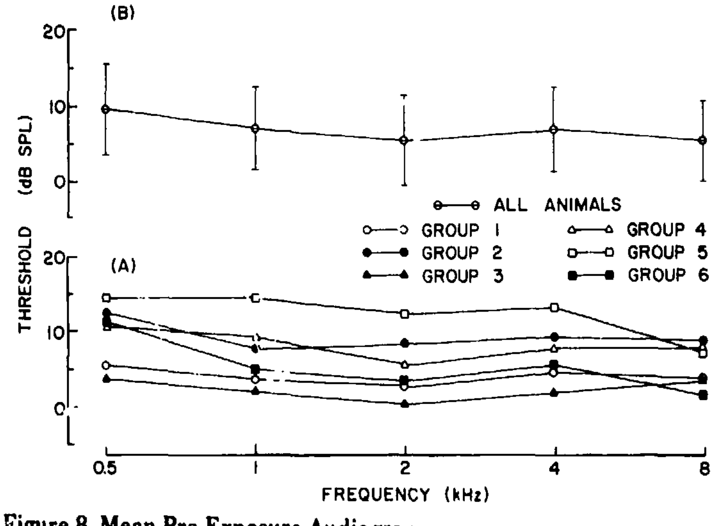


Figure 8. Mean Pre-Exposure Audiograms
(A) Group Means
(B) Mean Audiogram From all Experimental Animals (N=23)

## EXPOSURE AND TTS MEASUREMENT

After the pre-exposure thresholds were obtained the animals were exposed to noise for 8 weeks. At the end of each day exposure thresholds were measured twice at 4.0 kHz. The mean of these two measures was accepted as a measure of the effect of the noise exposure. During the 4th week and 8th week (i.e. days 15-20 and 35-40) thresholds were measured daily at 0.5, 1, 2, 4 and 8 kHz. After the 8th week of exposure the animals were allowed to recover for 30 days, at that time thresholds were again measured eight times in each animal at 0.5, 1, 2, 4 and 8 kHz.

## HISTOLOGY

After the final 30 day post-exposure thresholds were obtained each animal was killed by decapitation. The right bulla was removed and opened widely on its ventral and lateral surface to expose the cochlea. The cochlea was perfused through the round window with a 2.5% gluteraldehyde solution in 0.1 M $PO_4$ buffer (pH of 7.3). The stapes was removed and additional fixative was perfused through the oval window for 5 min. The cochleas were left in the fixative, refrigerated for at least 12 hours, then washed in $PO_4$ buffer and postfixed in 1% $OsO_4$ (in $PO_4$ buffer) for ½ hour. The cochleas were washed in buffer and dehydrated to 70% ETOH. The entire sensory epithelium was dissected from the cochlea, mounted in glycerine, and counts of hair cells present or absent were made using a light microscope. Cochleagrams were plotted using average hair cell populations over 0.4-mm segments of the organ of Corti. A hair cell was counted as present if the cell-body cuticular plate complex was intact.

# RESULTS

## PRE-EXPOSURE AUDIOGRAMS

Figure 8 illustrates the average pre-exposure audiograms for each of the six groups and the overall mean audiogram for the 23 experimental animals along with the standard deviations. The pre-exposure audiogram was defined for an individual animal as the average audiogram obtained from 10 days of consecutive testing. Tabulated thresholds for individual animals and the six groups is presented in Tables 2 and 3.

The variability across groups is quite small i.e. group thresholds ranged from 0-15 dB SPL. The individual audiograms, also were quite consistent and the standard deviations were approximately 6 dB across the whole frequency range tested. Furthermore, the group audiogram agrees closely with the normative data for the chinchilla published by Miller (1970).

Three of the animals (758, 841 and 856) were used in two groups (see Table 1). Before inclusion into the second group, their thresholds were tested and found to be within experimental error. Consequently, the group audiogram is based on an N=23, but the total number of subjects in all of the experimental groups equals 26.

TABLE 2

GROUP MEAN PRE-EXPOSURE THRESHOLDS — dB SPL

| | FREQUENCY · | 0.5K | 1K | 2K | 4K | 8K |
|---|---|---|---|---|---|---|
| GROUP 1 | $\overline{X}$ | 5.2 | 3.5 | 2.5 | 4.5 | 3.8 |
| N=4 | $\sigma$ | 8.1 | 4.8 | 7.7 | 7.0 | 5.4 |
| GROUP 2 | $\overline{X}$ | 12.2 | 7.5 | 8.2 | 9.2 | 8.8 |
| N=4 | $\sigma$ | 4.2 | 6.0 | 4.0 | 1.5 | 3.9 |
| GROUP 3 | $\overline{X}$ | 3.4 | 1.6 | 0.2 | 1.8 | 3.4 |
| N=5 | $\sigma$ | 2.2 | 1.1 | 2.6 | 3.5 | 3.8 |
| GROUP 4 | $\overline{X}$ | 10.4 | 9.0 | 5.4 | 7.6 | 7.6 |
| N=5 | $\sigma$ | 4.1 | 3.2 | 4.9 | 7.4 | 6.5 |
| GROUP 5 | $\overline{X}$ | 14.2 | 14.2 | 12.2 | 13.2 | 7.2 |
| N=4 | $\sigma$ | 5.7 | 4.1 | 5.0 | 2.8 | 3.3 |
| GROUP 6 | $\overline{X}$ | 10.8 | 4.8 | 3.2 | 5.5 | 1.5 |
| N=4 | $\sigma$ | 4.9 | 2.5 | 1.7 | 2.4 | 7.6 |
| ALL GROUPS | $\overline{X}$ | 9.2 | 6.6 | 5.1 | 6.8 | 5.4 |
| N 26 | $\sigma$ | 6.0 | 5.4 | 5.8 | 5.7 | 5.5 |
| N=23 | $\overline{X}$ | 8.5 | 6.2 | 4.7 | 6.4 | 5.0 |
| | $\sigma$ | 5.9 | 5.6 | 5.7 | 5.9 | 5.6 |

## TABLE 3

## INDIVIDUAL MEAN PRE-EXPOSURE THRESHOLDS - dB SPL

| Animal No. | Group 1 | | | | Group 2 | | | | Group 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 703 | 706 | 754 | 756 | 757 | 758 | 840 | 841 | 839 | 846 | 853 | 856 | 857 |
| Freq. kHz | | | | | | | | | | | | | |
| 0.5 | 0 | 16 | 7 | −2 | 18 | 12 | 11 | 8 | 7 | 2 | 2 | 2 | 4 |
| σ | 3 | 11 | 8 | 7 | 4 | 6 | 6 | 6 | 1 | 2 | 3 | 3 | 6 |
| 1 | 1 | 7 | 8 | −2 | 14 | 6 | 10 | 0 | 2 | 3 | 0 | 2 | 1 |
| σ | 5 | 4 | 8 | 8 | 6 | 4 | 3 | 10 | 4 | 5 | 3 | 4 | 5 |
| 2 | −2 | 10 | 8 | −6 | 13 | 10 | 6 | 4 | 3 | −3 | 2 | 1 | −2 |
| σ | 7 | 7 | 8 | 9 | 6 | 6 | 6 | 10 | 3 | 7 | 5 | 3 | 2 |
| 4 | −1 | 11 | 10 | −2 | 11 | 10 | 8 | 8 | 8 | 0 | 0 | 1 | 0 |
| σ | 7 | 6 | 7 | 9 | 9 | 3 | 6 | 5 | 6 | 5 | 3 | 1 | 2 |
| 8 | 2 | 4 | 11 | −2 | 11 | 11 | 10 | 3 | 9 | 5 | 3 | −1 | 1 |
| σ | 8 | 5 | 8 | 9 | 7 | 4 | 4 | 8 | 4 | 7 | 4 | 2 | 2 |

| Animal No. | Group 4 | | | | | Group 5 | | | | Group 6 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 881 | 891 | 893 | 904 | 908 | 758 | 841 | 952 | 956 | 995 | 997 | 998 | 856 |
| 0.5 | 6 | 17 | 9 | 11 | 9 | 17 | 9 | 10 | 21 | 6 | 12 | 8 | 17 |
| σ | 5 | 7 | 4 | 6 | 6 | 6 | 4 | 4 | 6 | 11 | 7 | 6 | 4 |
| 1 | 5 | 11 | 13 | 9 | 7 | 13 | 9 | 17 | 18 | 4 | 5 | 2 | 8 |
| σ | 6 | 6 | 5 | 3 | 5 | 8 | 4 | 4 | 5 | 8 | 7 | 5 | 4 |
| 2 | −1 | 12 | 8 | 4 | 4 | 16 | 5 | 13 | 15 | 1 | 4 | 3 | 5 |
| σ | 7 | 4 | 5 | 4 | 4 | 6 | 5 | 5 | 4 | 12 | 6 | 9 | 6 |
| 4 | −2 | 18 | 8 | 10 | 4 | 10 | 12 | 16 | 15 | 4 | 7 | 3 | 8 |
| σ | 4 | 8 | 5 | 3 | 5 | 8 | 6 | 5 | 8 | 3 | 11 | 4 | 5 |
| 8 | 3 | 18 | 5 | 10 | 2 | 12 | 5 | 5 | 7 | 9 | −6 | −4 | 7 |
| σ | 7 | 11 | 4 | 3 | 5 | | 0 | 3 | 8 | 6 | 13 | 9 | 5 |

## DAILY MEASURES OF TTS AT 4 kHz

Figures 9 through 14 illustrate the daily magnitude of the median threshold shift and the range measured at 4 kHz over the course of the 40 days of noise exposure. On the figures, the daily noise exposures are numbered consecutively 1-40. However, remember that the animals are being exposed on a "work week" schedule; thus after every 5th day, there are two days without an exposure or threshold test. Tables 4 and 5 summarize the individual animal 4 kHz threshold shifts as well as the group median shifts. The table below summarizes the mean threshold shift at 4 kHz for the six exposure groups.

| Group | $\overline{TTS}_{20}$ | $\overline{TTS}_{40}$ | Group | $\overline{TTS}_{20}$ | $\overline{TTS}_{40}$ |
|---|---|---|---|---|---|
| 1 | 12 | 32 | 4 | 11 | 10 |
| 2 | 5 | 29 | 5 | 32 | 28 |
| 3 | 26 | 34 | 6 | 16 | 21 |

$\overline{TTS}_{20}$ = mean temporary threshold shift at 4 kHz for the first 20 days of exposure

$\overline{TTS}_{40}$ = mean temporary threshold shift at 4 kHz for days 21 through 40.

The average additional threshold shift incurred during the combination exposure (days 20 through 40) is about 17 dB for groups 1-3 while it is about 0 dB for groups 4-6.

On the basis of the results of groups 1-3, it appears that the final threshold shift for the combination exposure reflects the sum of the threshold shifts from the continuous noise and the impulse noise. However, for groups 4-6 the situation is quite different. The effect of combining the impulse and continuous noise does not significantly change the $\overline{TTS}_{20}$. If anything, it appears as if the final level of $\overline{TTS}_{40}$ is determined by the noise exposure that produces the largest shift. The differences between groups 1-3 and groups 4-6 may reflect the different spectra and levels of the continuous noise that was used. See Figures 2 through 4.

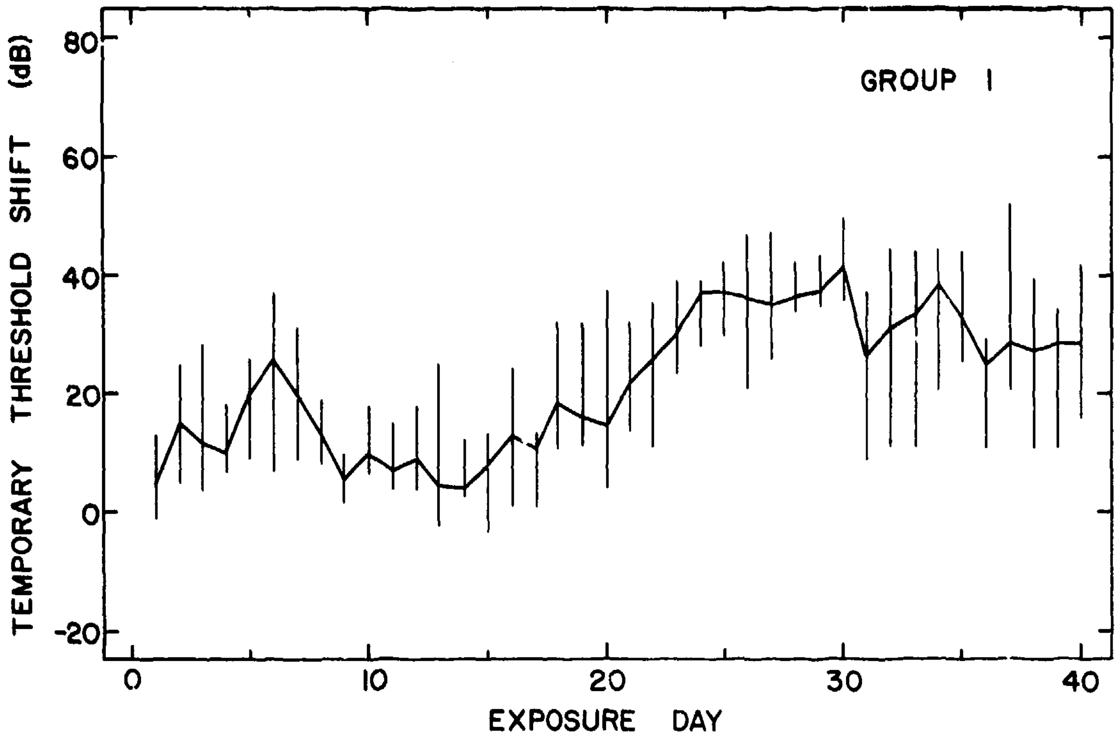


**Figure 9. Median and Range of the Daily Threshold Shift Measured at 4 KHZ for Group 1.**

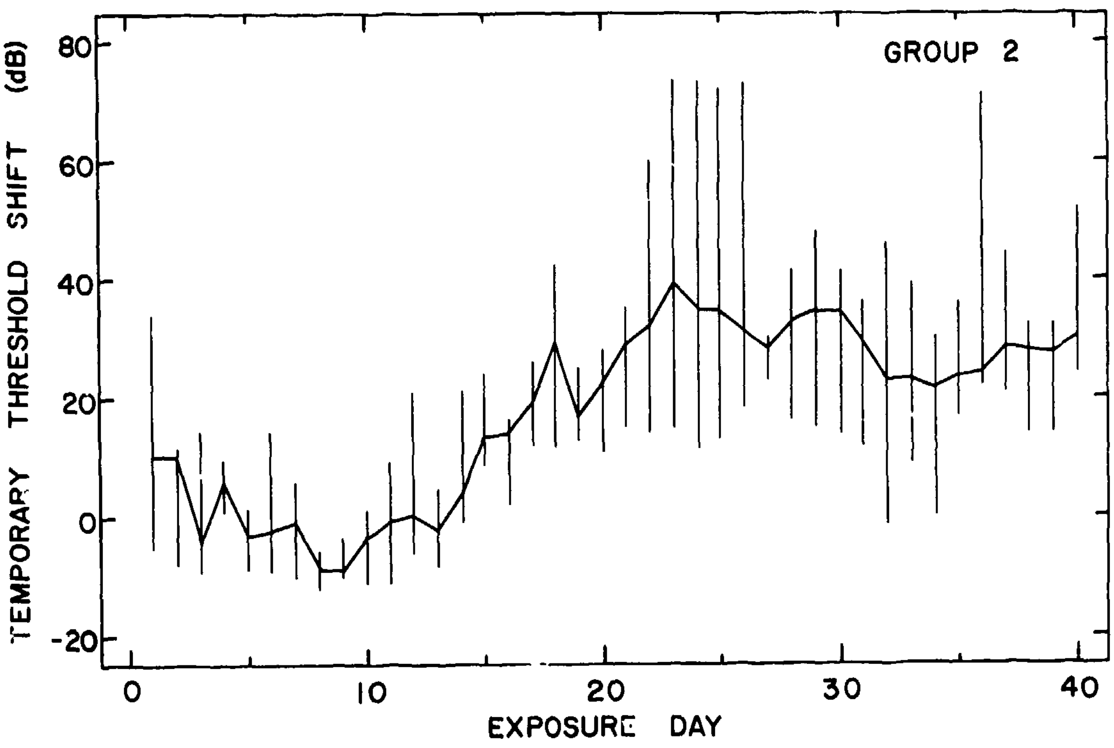


**Figure 10. Median and Range of the Daily Threshold Shift Measured at 4 KHZ for Group 2.**

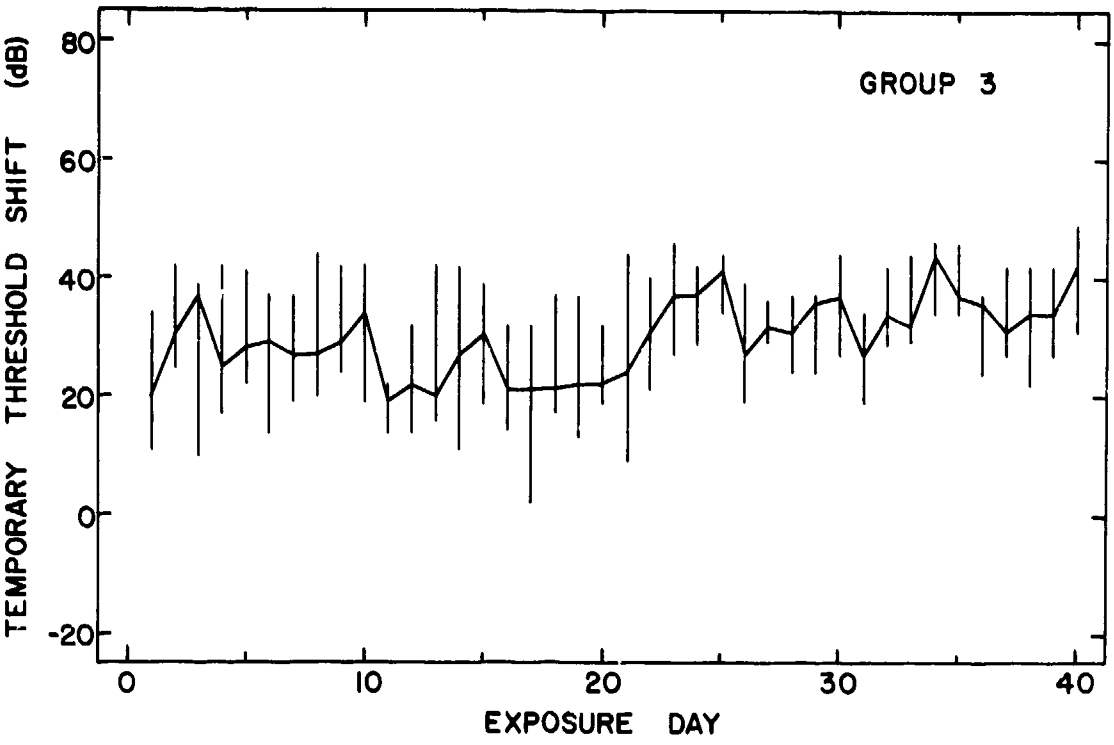


Figure 11. Median and Range of the Daily Threshold Shift Measured at 4 KHZ for Group 3.

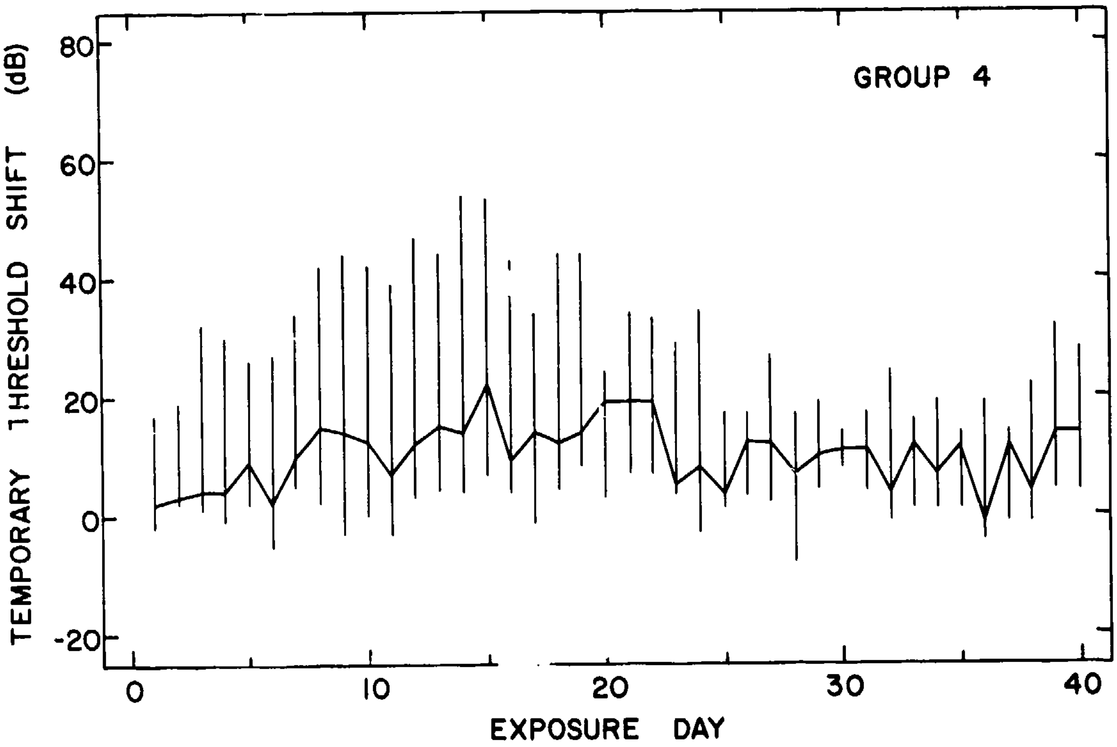


Figure 12. Median and Range of the Daily Threshold Shift Measured at 4 KHZ for Group 4.

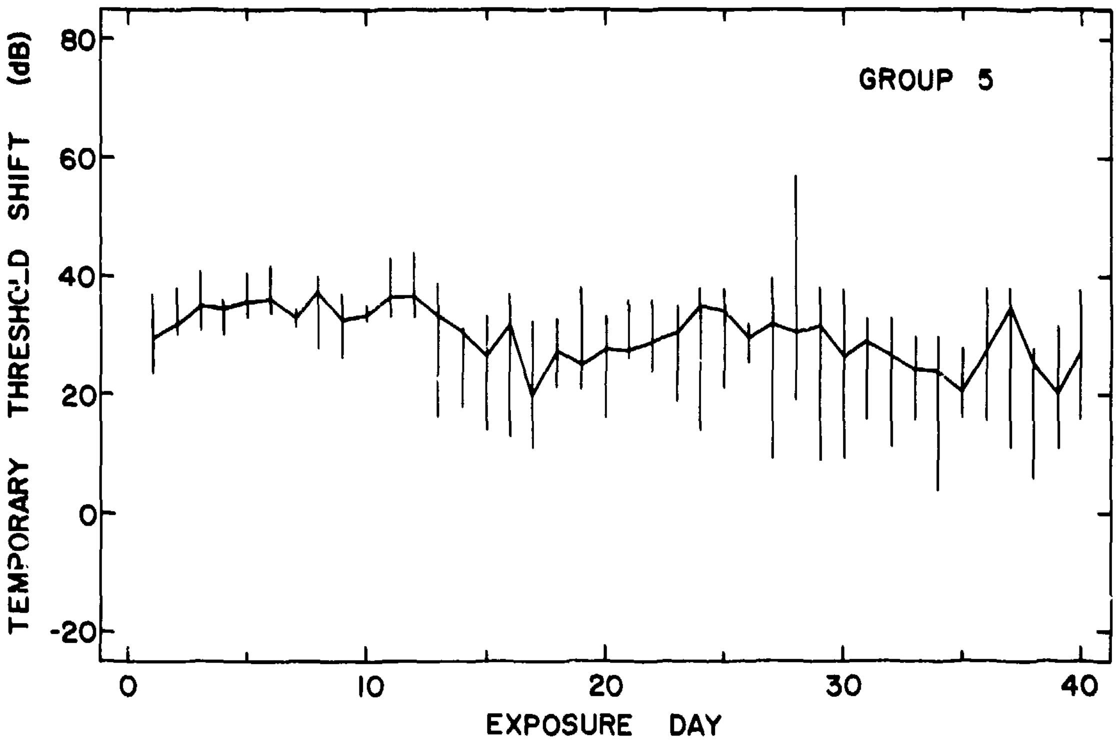


Figure 13. Median and Range of the Daily Threshold Shift Measured at 4 KHZ for Group 5.

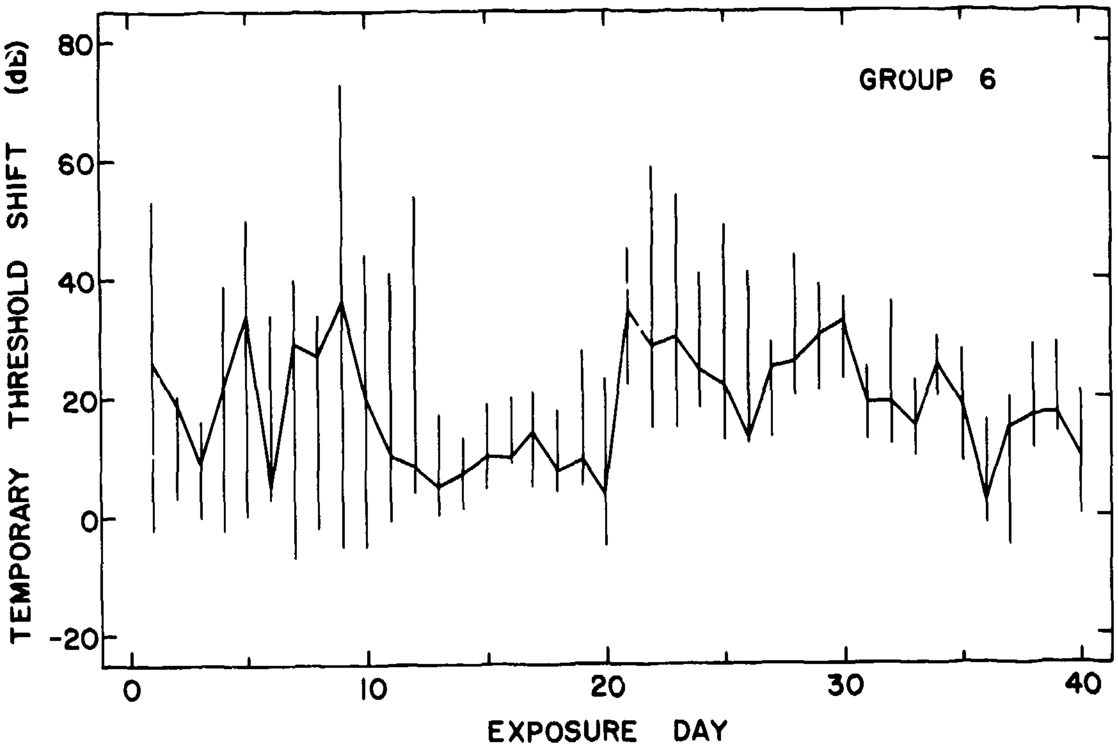


Figure 14. Median and Range of the Daily Threshold Shift Measured at 4 KHZ for Group 6.

# TABLE 4

## MEDIAN THRESHOLD SHIFTS AT 4 KHz (DAYS 1-20)
## (dB)

| DAY | GROUP 1 | GROUP 2 | GROUP 3 | GROUP 4 | GROUP 5 | GROUP 6 |
|---|---|---|---|---|---|---|
| 1 | 4.5 | 10 | 20.5 | 2 | 29.5 | 26 |
| 2 | 15 | 10 | 30 | 3 | 32 | 19 |
| 3 | 12 | -4.5 | 37 | 4 | 35 | 9 |
| 4 | 10 | 5.5 | 25 | 4 | 34.5 | 21 |
| 5 | 20 | -3.5 | 27 | 9 | 35.5 | 34 |
| 6 | 26 | -2.5 | 29 | 2 | 36 | 5 |
| 7 | 20 | -1 | 27 | 10 | 33 | 29 |
| 8 | 13 | -9 | 27 | 15 | 37.5 | 27 |
| 9 | 5.5 | -9 | 29 | 14 | 32.5 | 36.5 |
| 10 | 10 | -3.5 | 34 | 12 | 35.5 | 19.5 |
| 11 | 7 | -1 | 19 | 7 | 36.5 | 10 |
| 12 | 9.5 | 0 | 22 | 12 | 36.5 | 8 |
| 13 | 4.5 | -2.5 | 20 | 15 | 33 | 5 |
| 14 | 4 | 3.5 | 27 | 14 | 30.5 | 7 |
| 15 | 8 | 13 | 30 | 22 | 26.5 | 10 |
| 16 | 13 | 14 | 21 | 9 | 32 | 10 |
| 17 | 10.5 | 19 | 21 | 14 | 20 | 14.5 |
| 18 | 18.5 | 29.5 | 21 | 12 | 27.5 | 7.5 |
| 19 | 16 | 17 | 22 | 14 | 25 | 9.5 |
| 20 | 14.5 | 22.5 | 22 | 19 | 27.5 | 1.5 |
| $\bar{X}$ | 12 | 5 | 26 | 11 | 32 | 16 |

## TABLE 4 (cont'd)

## MEDIAN THRESHOLD SHIFTS AT 4 KHz (DAYS 21-40) (dB)

| DAY | GROUP 1 | GROUP 2 | GROUP 3 | GROUP 4 | GROUP 5 | GROUP |
|---|---|---|---|---|---|---|
| 21 | 22 | 29.5 | 24 | 19 | 27.5 | 34.5 |
| 22 | 26 | 32.5 | 31 | 19 | 29 | 28.5 |
| 23 | 30 | 39 | 37 | 5 | 30.5 | 30 |
| 24 | 37 | 35 | 37 | 8 | 35 | 24.5 |
| 25 | 37 | 34.5 | 41 | 3 | 34 | 22 |
| 26 | 36 | 31 | 27 | 12 | 29.5 | 13.5 |
| 27 | 35 | 28.5 | 32 | 12 | 32 | 25 |
| 28 | 36.5 | 32.5 | 31 | 7 | 30.5 | 26 |
| 29 | 37.5 | 34.5 | 36 | 10 | 31.5 | 30.5 |
| 30 | 41.5 | 34 | 37 | 11 | 26.5 | 33 |
| 31 | 26 | 29 | 27 | 11 | 29 | 19 |
| 32 | 31 | 23 | 34 | 4 | 26.5 | 19 |
| 33 | [illegible] | 23 | 32 | 12 | 24.5 | 15.5 |
| 34 | 38.5 | 21.5 | 44 | 7 | 23 | 25.5 |
| 35 | 33.5 | 23.5 | 37 | 12 | 20.5 | 18.5 |
| 36 | 25 | 24 | 36 | -1 | 27.5 | 2.5 |
| 37 | 28.5 | 28.5 | 31 | 12 | 35 | 15 |
| 38 | 27.5 | 20 | 34 | 4 | 25 | 17.5 |
| 39 | 28.5 | 27.5 | 34 | 14 | 20.5 | 18 |
| 40 | 28.5 | 30 | 42 | 14 | 27.5 | .5 |
|  | 32 | 29 | 34 | 10 | 28 | 21 |

## TABLE 5

## INDIVIDUAL THRESHOLD SHIFTS AT 4 KHz (DAYS 1-20) (dB)

| | Group 1 Animal No. | | | | Group 2 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|
| DAY | 703 | 706 | 754 | 756 | 757 | 758 | 840 | 841 |
| 1 | 13 | -1 | 5 | 4 | 34 | 5 | 4 | 16 |
| 2 | 16 | 14 | 5 | 25 | 11 | -8 | 11 | 9 |
| 3 | 28 | 14 | 10 | 4 | 1 | -8 | 14 | -9 |
| 4 | 18 | 13 | 7 | 7 | 1 | 2 | 9 | 9 |
| 5 | 26 | 18 | 22 | 9 | 1 | -8 | 1 | -9 |
| 6 | 18 | 34 | 37 | 7 | 1 | -6 | 14 | -9 |
| 7 | 28 | 31 | 12 | 9 | 1 | -3 | 6 | -11 |
| 8 | 8 | 14 | 12 | 19 | -11 | -6 | -9 | -9 |
| 9 | 10 | 4 | 7 | 2 | -9 | -10 | -4 | 9 |
| 10 | 18 | 11 | 7 | 9 | -4 | -3 | 1 | -11 |
| 11 | 8 | 6 | 15 | 4 | -4 | 2 | 9 | -11 |
| 12 | 15 | 4 | 18 | 4 | 21 | 6 | 4 | 4 |
| 13 | 5 | -2 | 25 | 4 | 1 | -8 | 4 | -6 |
| 14 | 3 | 4 | 12 | 4 | 21 | 3 | 4 | -1 |
| 15 | 13 | 9 | -3 | 7 | 24 | 10 | 16 | 9 |
| 16 | 18 | 1 | 8 | 24 | 16 | 2 | 14 | 14 |
| 17 | 13 | 1 | 12 | 9 | 26 | 12 | 24 | 14 |
| 18 | 13 | 11 | 32 | 24 | 24 | 35 | 12 | 12 |
| 19 | 13 | 11 | 32 | 19 | 25 | 21 | 13 | 13 |
| 20 | 18 | 11 | 37 | 4 | 28 | 19 | 11 | 26 |

## TABLE 5 (cont'd)

## INDIVIDUAL THRESHOLD SHIFTS AT 4 KHz (DAYS 21-40) (dB)

| | Group 1 Animal No. | | | | Group 2 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|
| DAY | 703 | 706 | 754 | 756 | 757 | 758 | 840 | 841 |
| 21 | 25 | 14 | 32 | 19 | 35 | 29 | 30 | 15 |
| 22 | 18 | 16 | 35 | 34 | 60 | 29 | 14 | 36 |
| 23 | 25 | 24 | 35 | 39 | 73 | 36 | 42 | 15 |
| 24 | 28 | 36 | 38 | 39 | 73 | 37 | 33 | 12 |
| 25 | 30 | 36 | 38 | 42 | 72 | 36 | 33 | 13 |
| 26 | 30 | 21 | 42 | 47 | 73 | 39 | 23 | 18 |
| 27 | 28 | 26 | 12 | 47 | 30 | 29 | 28 | 23 |
| 28 | 36 | 34 | 35 | 42 | 41 | 37 | 28 | 16 |
| 29 | 43 | 36 | 35 | 39 | 48 | 39 | 30 | 15 |
| 30 | 43 | 36 | 40 | 49 | 41 | 37 | 31 | 14 |
| 31 | 23 | 9 | 37 | 29 | 29 | 12 | 29 | 36 |
| 32 | 25 | 11 | 44 | 37 | 46 | 12 | 31 | 1 |
| 33 | 28 | 11 | 44 | 39 | 34 | 12 | 39 | 9 |
| 34 | 38 | 21 | 44 | 39 | 21 | 22 | 30 | 0 |
| 35 | 28 | 26 | 44 | 39 | 21 | 17 | 36 | 26 |
| 36 | 28 | 11 | 22 | 29 | 71 | 22 | 24 | 24 |
| 37 | 23 | 21 | 52 | 34 | 21 | 22 | 35 | 44 |
| 38 | 23 | 11 | 32 | 39 | 16 | 32 | 24 | 14 |
| 39 | 28 | 11 | 34 | 29 | 26 | 32 | 29 | 14 |
| 40 | 28 | 16 | 42 | 29 | 31 | 32 | 29 | 24 |

## TABLE 5 (cont'd)

## INDIVIDUAL THRESHOLD SHIFTS AT 4 KHz (DAYS 1-20) (dB)

| | Group 3 Animal No. | | | | | Group 4 Animal No. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAY | 839 | 846 | 853 | 856 | 857 | 881 | 891 | 893 | 904 | 908 |
| 1 | 19 | 34 | 22 | 11 | . | 17 | -1 | 4 | 2 | -2 |
| 2 | 25 | 42 | 34 | 26 | . | 7 | 2 | 19 | 2 | 3 |
| 3 | 24 | 37 | 39 | 37 | 10 | 7 | 4 | 32 | 2 | 1 |
| 4 | 25 | 42 | 19 | 41 | 17 | 9 | 4 | 30 | -1 | 1 |
| 5 | 24 | 32 | 27 | 41 | 22 | 9 | 24 | 26 | 2 | 8 |
| 6 | 14 | 37 | 29 | 37 | 22 | -5 | 27 | 14 | 2 | -2 |
| 7 | 19 | 37 | 27 | 31 | 27 | 9 | 34 | 34 | 10 | 5 |
| 8 | 20 | 44 | 27 | 26 | 32 | 7 | 27 | 42 | 2 | 15 |
| 9 | 24 | 42 | 29 | 24 | 40 | 14 | 38 | 44 | -3 | 11 |
| 10 | 19 | 42 | 34 | 19 | 42 | 12 | 19 | 42 | 0 | 11 |
| 11 | 19 | 22 | 14 | 16 | 22 | 7 | 7 | 39 | -3 | 3 |
| 12 | 14 | 32 | 22 | 19 | 30 | 12 | 22 | 47 | 4 | 3 |
| 13 | 19 | 42 | 27 | 16 | 20 | 14 | 27 | 44 | 4 | 15 |
| 14 | 11 | 42 | 32 | 26 | 27 | 14 | 17 | 54 | 4 | 5 |
| 15 | 19 | 39 | 34 | 26 | 30 | 22 | 29 | 54 | 7 | 8 |
| 16 | 14 | 32 | 17 | 21 | 22 | 9 | 4 | 44 | 12 | 8 |
| 17 | 19 | 32 | 22 | 21 | 2 | 14 | -1 | 34 | 17 | 8 |
| 18 | 19 | 37 | 37 | 21 | 17 | 19 | 4 | 44 | 12 | 8 |
| 19 | 13 | 32 | 37 | 21 | 22 | 9 | 14 | 44 | 22 | 8 |
| 20 | 19 | 27 | 32 | 21 | 22 | 19 | 24 | 19 | 22 | 3 |

## TABLE 5 (cont'd)

## INDIVIDUAL THRESHOLD SHIFTS AT 4 KHz (DAYS 1-20) (dB)

| | Group 3 Animal No. | | | | | Group 4 Animal No. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAY | 839 | 846 | 853 | 856 | 857 | 881 | 891 | 893 | 904 | 908 |
| 21 | 9 | 19 | 24 | 44 | 27 | 7 | 19 | 27 | 34 | 11 |
| 22 | 31 | 21 | 29 | 39 | 40 | 7 | 24 | 19 | 16 | 33 |
| 23 | 34 | 27 | 37 | 46 | 42 | 4 | 29 | 4 | 7 | 5 |
| 24 | 34 | 29 | 42 | 41 | 37 | 14 | 34 | -3 | 3 | 8 |
| 25 | 44 | 34 | 42 | 41 | 37 | 9 | 2 | 1 | 17 | 3 |
| 26 | 19 | 24 | 29 | 39 | 27 | 12 | 17 | 9 | 12 | 3 |
| 27 | 31 | 29 | 34 | 36 | 32 | 14 | 12 | 2 | 27 | 3 |
| 28 | 29 | 24 | 32 | 31 | 37 | 12 | 7 | -8 | 17 | 3 |
| 29 | 26 | 24 | 37 | 36 | 37 | 4 | 14 | 29 | 10 | 8 |
| 30 | 34 | 27 | 42 | 44 | 37 | 12 | 14 | 8 | 10 | 11 |
| 31 | 19 | 29 | 27 | 34 | 22 | 7 | 17 | 4 | 12 | 11 |
| 32 | 29 | 34 | 42 | 41 | 32 | 24 | 2 | -1 | 4 | 8 |
| 33 | 29 | 32 | 42 | 44 | 30 | 12 | 9 | 16 | 12 | 1 |
| 34 | 34 | 44 | 44 | 46 | 37 | 7 | 19 | 4 | 9 | 1 |
| 35 | 34 | 37 | 44 | 46 | 37 | 14 | 9 | 14 | 12 | 1 |
| 36 | 19 | 27 | 37 | 36 | 37 | 19 | -1 | -1 | 4 | -4 |
| 37 | 29 | 27 | 42 | 31 | 32 | 14 | -1 | 14 | 12 | 8 |
| 38 | 34 | 22 | 42 | 36 | 22 | 4 | 14 | -1 | 22 | 3 |
| 39 | 34 | 27 | 42 | 36 | 32 | 14 | 4 | 14 | 32 | 8 |
| 40 | 49 | 32 | 42 | 31 | 42 | 14 | 4 | 4 | 22 | 28 |

## TABLE 5 (cont'd)

## INDIVIDUAL THRESHOLD SHIFTS AT 4 KHz (DAYS 1-20) (dB)

| | Group 5 Animal No. | | | | Group 6 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|
| DAY | 758 | 841 | 952 | 956 | 995 | 997 | 998 | 856 |
| 1 | 34 | 24 | 37 | 25 | 9 | 34 | 53 | -2 |
| 2 | 38 | 34 | 30 | 38 | 19 | 19 | · | 3 |
| 3 | 41 | 31 | 32 | 38 | 9 | 16 | · | 0 |
| 4 | 36 | 36 | 30 | 33 | 39 | 21 | · | -2 |
| 5 | 33 | 36 | 35 | 41 | 37 | 31 | 50 | 0 |
| 6 | 36 | 34 | 42 | 36 | 5 | 34 | · | 3 |
| 7 | 33 | 34 | 32 | 33 | 22 | 36 | 40 | -7 |
| 8 | 28 | 39 | 40 | 36 | 27 | 34 | · | -2 |
| 9 | 26 | 34 | 37 | 31 | 27 | 46 | 73 | -5 |
| 10 | 33 | 34 | 35 | 33 | 29 | 44 | 10 | -5 |
| 11 | 43 | 36 | 37 | 33 | -1 | 41 | 15 | 5 |
| 12 | 36 | 44 | 37 | 33 | 4 | 54 | 8 | 8 |
| 13 | 36 | 39 | 30 | 26 | 17 | · | 5 | 0 |
| 14 | 31 | 31 | 30 | 18 | 7 | · | 13 | 1 |
| 15 | 33 | 14 | 30 | 23 | 19 | · | 10 | 5 |
| 16 | 33 | 31 | 37 | 13 | 9 | · | 20 | 10 |
| 17 | 33 | 11 | 27 | 13 | 9 | 21 | 20 | 5 |
| 18 | 33 | 21 | 27 | 28 | 4 | 18 | 10 | 5 |
| 19 | 38 | 21 | 22 | 28 | 14 | 28 | 5 | 5 |
| 20 | 33 | 16 | 27 | 28 | -1 | 23 | 10 | -5 |

## TABLE 5 (cont'd)

## INDIVIDUAL THRESHOLD SHIFTS AT 4 KHz (DAYS 21-40)
(dB)

| | Group 5 Animal No. | | | | Group 6 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|
| DAY | 758 | 841 | 952 | 956 | 995 | 997 | 998 | 856 |
| 21 | 36 | 26 | 27 | 28 | 22 | 39 | 45 | 30 |
| 22 | 36 | 24 | 30 | 28 | 39 | 59 | 15 | 18 |
| 23 | 33 | 19 | 35 | 28 | 37 | 54 | 23 | 15 |
| 24 | 38 | 14 | 37 | 33 | 29 | 41 | 18 | 20 |
| 25 | 38 | 21 | 37 | 31 | 29 | 49 | 13 | 15 |
| 26 | 31 | 26 | 32 | 28 | 12 | 41 | 15 | 13 |
| 27 | 36 | 9 | 40 | 28 | 27 | 29 | 23 | 13 |
| 28 | 38 | 19 | 57 | 23 | 29 | 44 | 23 | 20 |
| 29 | 38 | 9 | 30 | 33 | 39 | 21 | 33 | 28 |
| 30 | 38 | 9 | 25 | 28 | 37 | 31 | 35 | 23 |
| 31 | 31 | 16 | 27 | 33 | 22 | 16 | 25 | 13 |
| 32 | 33 | 11 | 25 | 28 | 12 | 36 | 20 | 18 |
| 33 | 28 | 16 | 30 | 21 | 17 | 14 | 23 | 10 |
| 34 | 28 | 4 | 30 | 18 | 27 | 24 | 30 | 20 |
| 35 | 28 | 16 | 27 | 16 | 9 | 19 | 28 | 18 |
| 36 | 38 | 16 | 27 | 28 | −1 | 16 | 0 | 5 |
| 37 | 38 | 11 | 32 | 38 | 19 | 11 | 20 | −5 |
| 38 | 23 | 6 | 27 | 28 | 29 | 11 | 20 | 15 |
| 39 | 13 | 11 | 32 | 28 | 29 | 16 | 20 | 15 |
| 40 | 33 | 16 | 22 | 38 | 19 | 21 | 0 | 0 |

## 4TH AND 8TH WEEK AUDIOGRAMS

Hearing thresholds were measured in each animal at 0.5, 1, 2, 4 and 8kHz daily during the 4th and 8th week. Figures 15 through 20 illustrate the 4th and 8th week median audiograms for each experimental group. Threshold shift data for the individual animals and median data for the six groups are tabulated in Tables 6 and 7.

The audiograms of group 1-3, show that, on the basis of the group 1 animals, the impulse noise exposure for days 1-20 produced a relatively flat median threshold shift of about 10-15 dB across the 0.5-8.0 kHz test frequency range. Adding the continuous noise background to the group 1 animals causes a 15-20 dB increase in threshold shift across the entire frequency range. The 8th week audiogram for the group 1 animals looks very similar (except at high frequencies) to the 4th week audiograms from groups 2 and 3. The continuous noise exposure during days 1-20 in groups 2 and 3 causes a threshold shift of around 30-35 dB between 0.5 and 2.0 kHz and a smaller but a more variable shift at 4 and 8 kHz. In groups 2 and 3 the addition of the impulse noise during weeks 5-8 does not appreciably affect the shape of the audiogram between 0.5 and 4 kHz, however, there is an average increase in the threshold shift of about 15 dB at 8 kHz. Thus on the basis of the 4th and 8th week audiograms, the noise causing the greatest shift dominates the final pattern of hearing loss across the 0.5-8 kHz frequency range.

For groups 4-6, median threshold shifts were less consistent and variability was greater. Groups 4 and 5, in particular, had the same sequence of exposures. Group 4 had less than 10 dB losses from 0.5-8 kHz while group 5 had from 20-30 dB losses. Group 6 was in between with 5-20 dB losses. During the last 20 days, on the average, no discernable effect was seen in the audiograms when the animals were exposed to the combination environment.

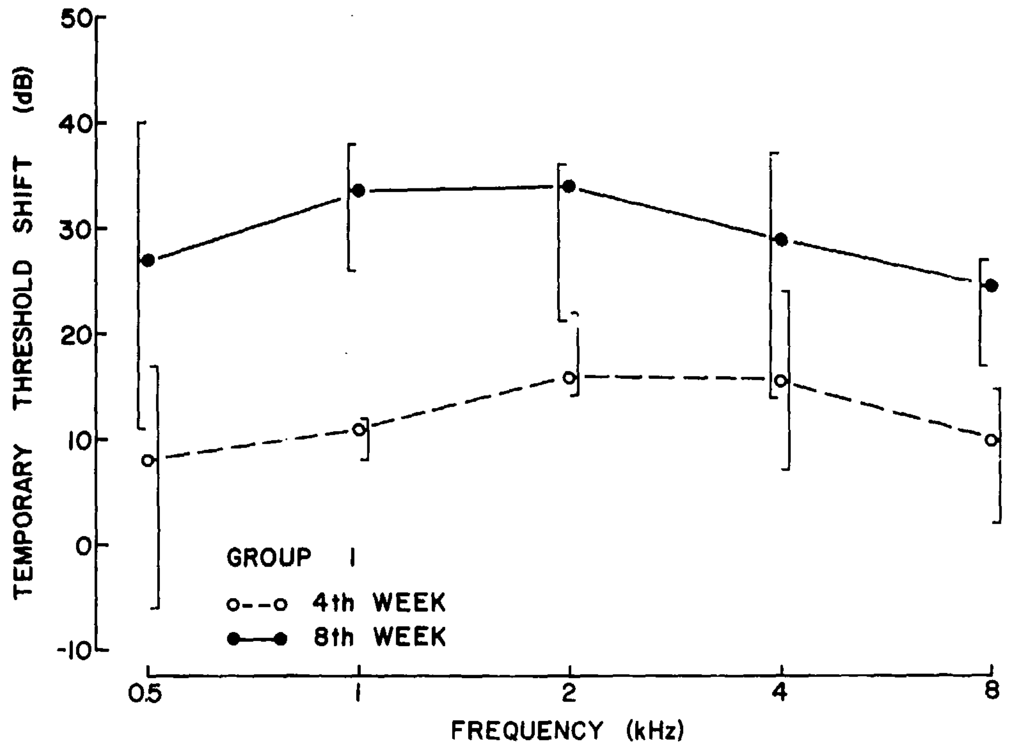


**Figure 15.** Group 1 Median 4th and 8th Week Temporary Threshold Shifts. Medians were calculated from the mean values of the individual animal data measured over 5 days during the 4th and 8th week of exposure (bars indicate the range).

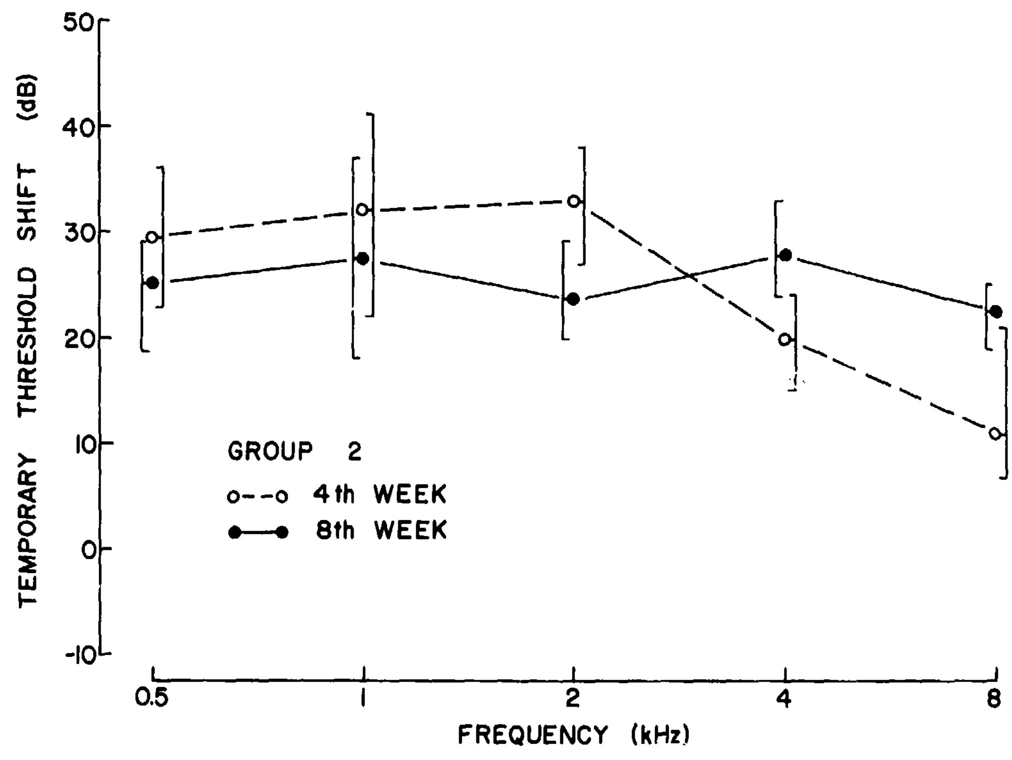


**Figure 16.** Group 2 Median 4th and 8th Week Temporary Threshold Shifts. Medians were calculated from the mean values of the individual animal data measured over 5 days during the 4t/· and 8th week of exposure (bars indicate the range).

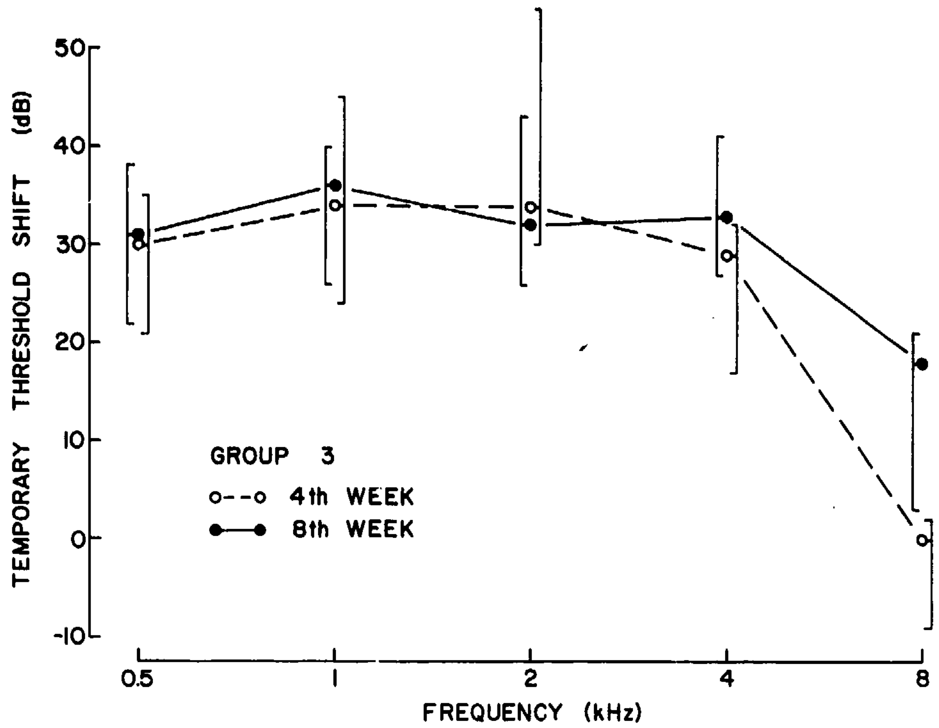


Figure 17. Group 3 Median 4th and 8th Week Temporary Threshold Shifts. Medians were calculated from the mean values of the individual animal data measured over 5 days during the 4th and 8th week of exposure (bars indicate the range).

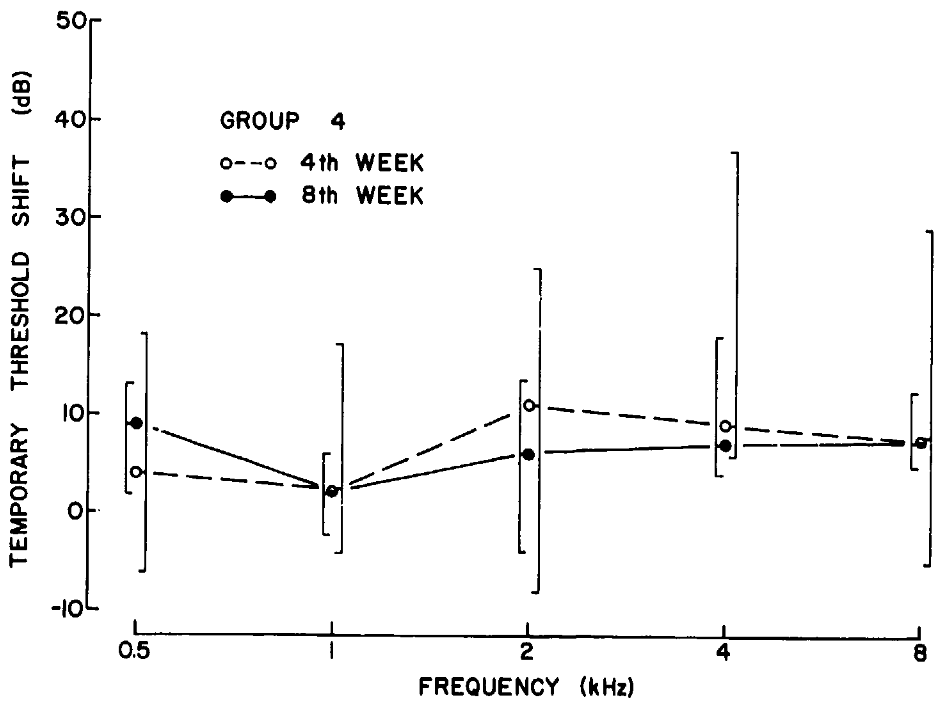


Figure 18. Group 4 Median 4th and 8th Week Temporary Threshold Shifts. Medians were calculated from the mean values of the individual animal data measured over 5 days during the 4th and 8th week of exposure (bars indicate the range).

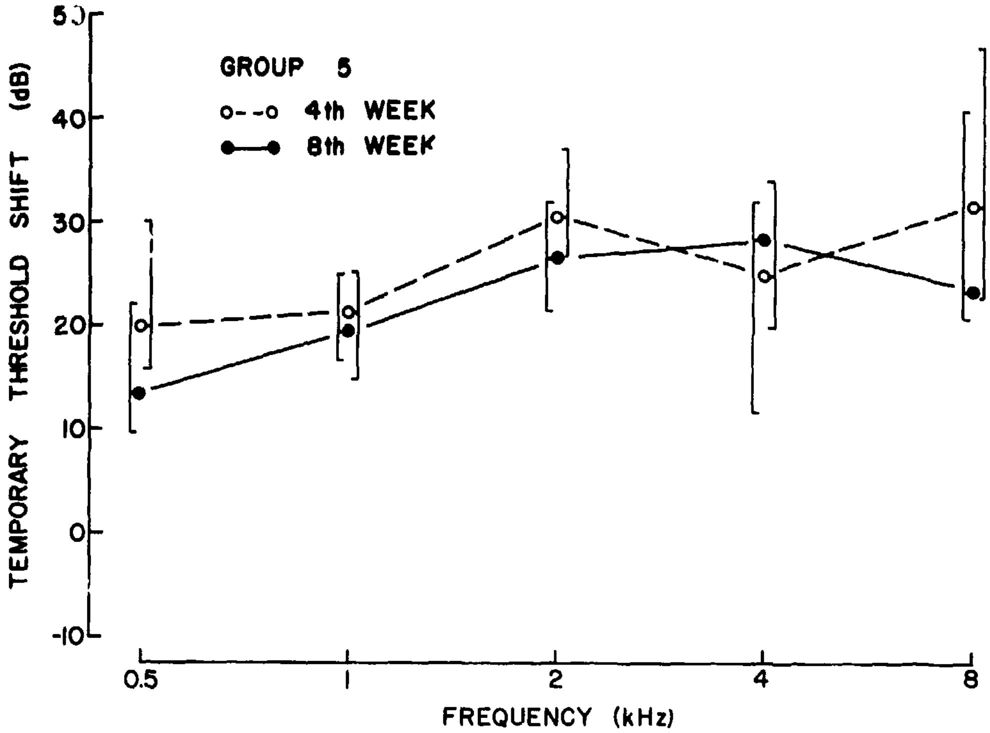


Figure 19. Group 5 Median 4th and 8th Week Temporary Threshold Shifts. Medians were calculated from the mean values of the individual animal data measured over 5 days during the 4th and 8th week of exposure (bars indicate the range).

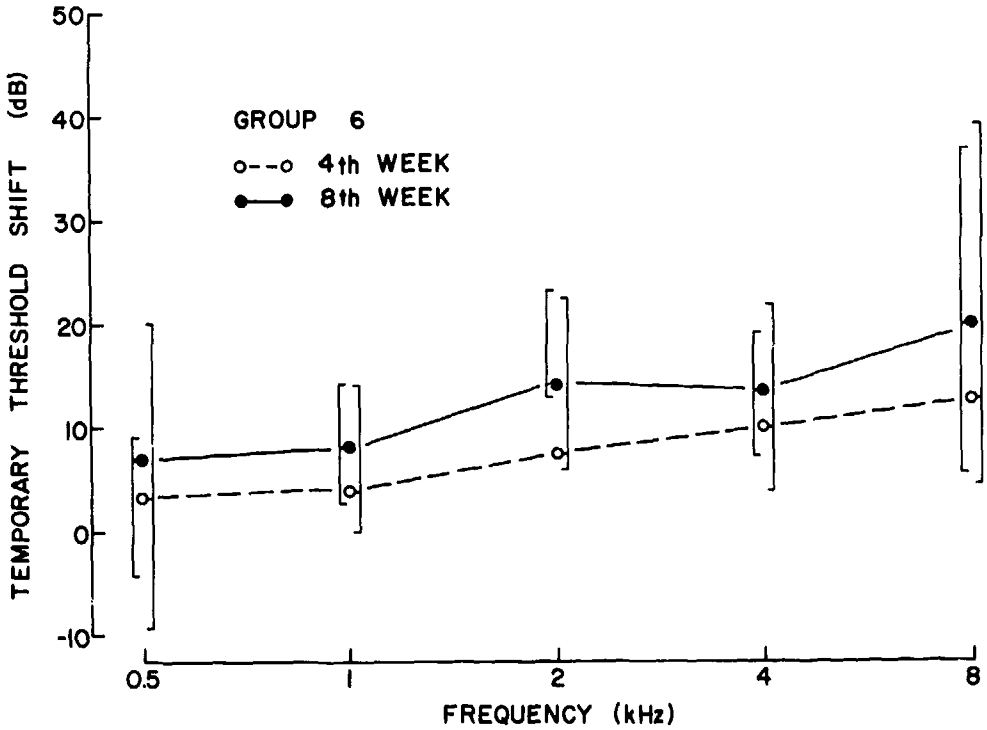


Figure 20. Group 6 Median 4th and 8th Week Temporary Threshold Shifts. Medians were calculated from the mean values of the individual animal data measured over 5 days during the 4th and 8th week of exposure (bars indicate the range).

# TABLE 6

## THE MEAN AND THE GROUP MEDIAN THRESHOLD SHIFTS MEASURED DURING THE 4TH EXPOSURE WEEK

### GROUP 1

Animal No.

| kHz | | 703 | 706 | 754 | 756 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 11 | −6 | 17 | 5 | 8 | −6 17 |
| | σ | 7 | 3 | 9 | 5 | | |
| 1 | $\overline{X}$ | 12 | 8 | 12 | 10 | 11 | 8 12 |
| | σ | 5 | 3 | 7 | 2 | | |
| 2 | $\overline{X}$ | 15 | 22 | 14 | 17 | 16 | 14 22 |
| | σ | 7 | 6 | 14 | 3 | | |
| 4 | $\overline{X}$ | 15 | 7 | 24 | 16 | 15.5 | 7 24 |
| | σ | 3 | 5 | 12 | 8 | | |
| 8 | $\overline{X}$ | 15 | 2 | 12 | 8 | 10 | 2 15 |
| | σ | 8 | 4 | 5 | 8 | | |

### GROUP 2

Animal No.

| kHz | | 757 | 758 | 840 | 841 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 23 | 26 | 36 | 33 | 29.5 | 23 36 |
| | σ | 6 | 2 | 6 | 4 | | |
| 1 | $\overline{X}$ | 22 | 39 | 25 | 41 | 32 | 22 41 |
| | σ | 6 | 5 | 8 | 4 | | |
| 2 | $\overline{X}$ | 32 | 34 | 27 | 38 | 33 | 27 38 |
| | σ | 6 | 6 | 6 | 6 | | |
| 4 | $\overline{X}$ | 24 | 18 | 15 | 22 | 20 | 15 24 |
| | σ | 4 | 11 | 5 | 12 | | |
| 8 | $\overline{X}$ | 21 | 7 | 9 | 13 | 11 | 7 21 |
| | σ | 10 | 9 | 11 | 19 | | |

## TABLE 6 (cont'd)

## THE MEAN AND THE GROUP MEDIAN THRESHOLD SHIFTS MEASURED DURING THE 4TH EXPOSURE WEEK

GROUP 3

Animal No.

| kHz | | 839 | 846 | 853 | 856 | 857 | MED | RANGE |
|---|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 33 | 27 | 30 | 35 | 21 | 30 | 21 35 |
| | $\sigma$ | 7 | 5 | 6 | 6 | 2 | | |
| 1 | $\overline{X}$ | 34 | 45 | 43 | 34 | 24 | 34 | 24 45 |
| | $\sigma$ | 7 | 4 | 5 | 7 | 17 | | |
| 2 | $\overline{X}$ | 31 | 54 | 46 | 34 | 30 | 34 | 30 54 |
| | $\sigma$ | 5 | 2 | 4 | 2 | 3 | | |
| 4 | $\overline{X}$ | 31 | 32 | 29 | 21 | 17 | 29 | 17 32 |
| | $\sigma$ | 7 | 3 | 8 | 0 | 8 | | |
| 8 | $\overline{X}$ | 2 | 0 | 2 | −3 | −9 | 0 | −9 2 |
| | $\sigma$ | 7 | 18 | 3 | 4 | 2 | | |

GROUP 4

Animal No.

| kHz | | 881 | 891 | 893 | 904 | 908 | MED | RANGE |
|---|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 4 | 2 | 18 | 1 | −6 | 4 | −6 18 |
| | $\sigma$ | 6 | 9 | 12 | 10 | 2 | | |
| 1 | $\overline{X}$ | 2 | 11 | 17 | 2.2 | −4 | 2.2 | −4 17 |
| | $\sigma$ | 4 | 11 | 13 | 5 | 4 | | |
| 2 | $\overline{X}$ | −8 | 11 | 25 | 11 | 0 | 11 | 8 25 |
| | $\sigma$ | 4 | 12 | 12 | 4 | 5 | | |
| 4 | $\overline{X}$ | 6 | 9 | 37 | 17 | 7 | 9 | 6 37 |
| | $\sigma$ | 4 | 1. | 11 | 5 | 2 | | |
| 8 | $\overline{X}$ | −5 | 7.4 | 29 | 4 | 13 | 7.4 | 5 29 |
| | $\sigma$ | 8 | 8 | 19 | 15 | 6 | | |

## TABLE 6 (cont'd)

## THE MEAN AND THE GROUP MEDIAN THRESHOLD SHIFTS MEASURED DURING THE 4TH EXPOSURE WEEK

### GROUP 5

| kHz | | Animal No. 758 | 841 | 952 | 956 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 16 | 30 | 19 | 21 | 20 | 16 30 |
| | $\sigma$ | 5 | 10 | 8 | 5 | | |
| 1 | $\overline{X}$ | 24 | 25.2 | 15 | 19 | 21.5 | 15 25.2 |
| | $\sigma$ | 5 | 11 | 7 | 5 | | |
| 2 | $\overline{X}$ | 32 | 27 | 29 | 37 | 30.5 | 27 37 |
| | $\sigma$ | 10 | 9 | 7 | 4 | | |
| 4 | $\overline{X}$ | 34 | 20 | 28 | 22 | 25 | 20 34 |
| | $\sigma$ | 2 | 7 | 5 | 8 | | |
| 8 | $\overline{X}$ | 25 | 47 | 40.4 | 23 | 32.7 | 23 47 |
| | $\sigma$ | 8 | 6 | 8 | 7 | | |

### GROUP 6

| kHz | | Animal No. 995 | 997 | 998 | 856 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 6.6 | 20 | .25 | -9 | 3.4 | -9 20 |
| | $\sigma$ | 9 | 15 | 2 | 4 | | |
| 1 | $\overline{X}$ | 3 | 14 | 5 | 0 | 4 | 0 14 |
| | $\sigma$ | 6 | 13 | 10 | 4 | | |
| | $\overline{X}$ | 8 | 22.5 | 7 | 6 | 7.5 | 6 22.5 |
| | $\sigma$ | 4 | 5 | 4 | 9 | | |
| 4 | $\overline{X}$ | 7 | 21.8 | 13 | 4 | 10 | 4 21.8 |
| | $\sigma$ | 6 | 5 | 7 | 5 | | |
| 8 | $\overline{X}$ | 8.6 | 39.2 | 17 | 4.6 | 12.8 | 4.6 39.2 |
| | $\sigma$ | 4 | 18 | 13 | 16 | | |

**TABLE 6 (cont'd)**

**THE MEAN AND THE GROUP MEDIAN THRESHOLD SHIFTS MEASURED DURING THE 8TH EXPOSURE WEEK**

**GROUP 1**

Animal No.

| kHz | | 703 | 706 | 754 | 756 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 27 | 11 | 40 | 27 | 27 | 11 40 |
| | σ | 4 | 4 | 10 | 13 | | |
| 1 | $\overline{X}$ | 38 | 26 | 34 | 33 | 33.5 | 26 38 |
| | σ | 3 | 2 | 6 | 9 | | |
| 2 | $\overline{X}$ | 35 | 21.2 | 33 | 36 | 34 | 21.2 36 |
| | σ | 0 | 4 | 5 | 7 | | |
| 4 | $\overline{X}$ | 26 | 14 | 37 | 32 | 29 | 14 37 |
| | σ | 3 | 4 | 11 | 4 | | |
| 8 | $\overline{X}$ | 22.4 | 17 | 27 | 27 | 24.7 | 17 27 |
| | σ | 1 | 9 | 10 | 6 | | |

**GROUP 2**

Animal No.

| kHz | | 757 | 758 | 840 | 841 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 19 | 25 | 25 | 29 | 25 | 19 29 |
| | σ | 6 | 4 | 7 | 4 | | |
| 1 | $\overline{X}$ | 18 | 35 | 20 | 37 | 27.5 | 18 37 |
| | σ | 5 | 2 | 3 | 4 | | |
| 2 | $\overline{X}$ | 20 | 29 | 21 | 26.2 | 23.6 | 20 29 |
| | σ | 7 | 8 | 2 | 5 | | |
| 4 | $\overline{X}$ | 33 | 28 | 28 | 24 | 28 | 24 33 |
| | σ | 22 | 5 | 4 | 12 | | |
| 8 | $\overline{X}$ | 19 | 21 | 24 | 25 | 22.5 | 19 25 |
| | σ | 10 | 15 | 10 | 8 | | |

## TABLE 6 (cont'd)

## THE MEAN AND THE GROUP MEDIAN THRESHOLD SHIFTS MEASURED DURING THE 8TH EXPOSURE WEEK

**GROUP 3**

**Animal No.**

| kHz | | 839 | 846 | 853 | 856 | 857 | MED | RANGE |
|---|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 35 | 30 | 38 | 31 | 22 | 31 | 22 38 |
| | σ | 5 | 4 | 8 | 2 | 4 | | |
| 1 | $\overline{X}$ | 31 | 37 | 40 | 36 | 26 | 36 | 26 40 |
| | σ | 7 | 3 | 3 | 4 | 7 | | |
| 2 | $\overline{X}$ | 26 | 43 | 41 | 32 | 26 | 32 | 26 43 |
| | σ | 7 | 3 | 6 | 4 | 2 | | |
| 4 | $\overline{X}$ | 33 | 27 | 41 | 34 | 33 | 33 | 27 41 |
| | σ | 11 | 4 | 2 | 3 | 7 | | |
| 8 | $\overline{X}$ | 14 | 3 | 18 | 21 | 20 | 18 | 3 21 |
| | σ | 3 | 8 | 4 | 5 | 10 | | |

**GROUP 4**

**Animal No.**

| kHz | | 881 | 891 | 893 | 904 | 908 | MED | RANGE |
|---|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 9 | 8 | 9 | 13 | 2 | 9 | 2 13 |
| | σ | 4 | 8 | 7 | 14 | 5 | | |
| 1 | $\overline{X}$ | 0 | 4 | 2 | 6 | −2 | 2 | −2 6 |
| | σ | 4 | 6 | 4 | 7 | 4 | | |
| 2 | $\overline{X}$ | 0 | −4 | 8 | 13.4 | 6 | 6 | −4 13.4 |
| | σ | 7 | 5 | 4 | 16 | 8 | | |
| 4 | $\overline{X}$ | | 4 | 6 | 18 | 9 | 7 | 4 18 |
| | σ | 5 | 6 | 8 | 11 | 11 | | |
| 8 | $\overline{X}$ | 5 | 5 | 12.4 | 7.4 | 12 | 7.4 | 5 12.4 |
| | σ | 6 | 4 | 10 | 6 | 4 | | |

## TABLE 6 (cont'd)

## THE MEAN AND THE GROUP MEDIAN THRESHOLD SHIFTS MEASURED DURING THE 8TH EXPOSURE WEEK

GROUP 5

Animal No.

| kHz | | 758 | 841 | 952 | 956 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 14 | 22 | 13 | 10 | 13.5 | 10 22 |
| | $\sigma$ | 8 | 11 | 5 | 10 | | |
| 1 | $\overline{X}$ | 25 | 21 | 17 | 18 | 19.5 | 17 25 |
| | $\sigma$ | 11 | 8 | 8 | 5 | | |
| 2 | $\overline{X}$ | 32 | 21.6 | 30.2 | 23.2 | 26.7 | 21.6 32 |
| | $\sigma$ | 7 | 7 | 10 | 6 | | |
| 4 | $\overline{X}$ | 29 | 12 | 28 | 32 | 28.5 | 12 32 |
| | $\sigma$ | 11 | 4 | 4 | 5 | | |
| 8 | $\overline{X}$ | 21.4 | 26 | 41 | 21 | 23.7 | 21 41 |
| | $\sigma$ | 13 | 6 | 4 | 15 | | |

GROUP 6

Animal No.

| kHz | | 995 | 997 | 998 | 856 | MED | RANGE |
|---|---|---|---|---|---|---|---|
| 0.5 | $\overline{X}$ | 9 | 7 | 7 | -4 | 7 | -4 9 |
| | $\sigma$ | 8 | 6 | 10 | 2 | | |
| 1 | $\overline{X}$ | 14.2 | 3 | 5 | 11 | 8 | 3 14.2 |
| | $\sigma$ | 9 | 4 | 6 | 8 | | |
| 2 | $\overline{X}$ | 15 | 13 | 23.2 | 13.6 | 14.3 | 13 23.2 |
| | $\sigma$ | 2 | 3 | 10 | 8 | | |
| 4 | $\overline{X}$ | 19 | 15 | 12 | 7.2 | 13.5 | 7.2 19 |
| | $\sigma$ | 12 | 4 | 11 | 10 | | |
| 8 | $\overline{X}$ | 5.6 | 23 | 37 | 17 | 20 | 5.6 37 |
| | $\sigma$ | 7 | 4 | 3 | 5 | | |

# TABLE 7

## INDIVIDUAL ANIMAL THRESHOLD SHIFT DATA MEASURES AT 5 FREQUENCIES DURING THE 4th EXPOSURE WEEK (dB)

| | | Group 1 Animal no. | | | | Group 2 Animal no. | | | |
|---|---|---|---|---|---|---|---|---|---|
| kHz | day | 703 | 706 | 754 | 756 | 757 | 758 | 840 | 841 |
| 0.5 | 16 | 12 | -9 | 5 | -2 | 14 | 25 | 46 | 29 |
| | 17 | 12 | -4 | 10 | 4 | 24 | 25 | 36 | 29 |
| | 18 | 22 | -9 | 20 | 14 | 29 | 28 | 36 | 39 |
| | 19 | 7 | -4 | 30 | 4 | 29 | 25 | 36 | 34 |
| | 20 | 2 | -4 | 20 | 4 | 21 | 28 | 26 | 34 |
| 1 | 16 | 10 | 10 | 4 | 9 | 13 | 36 | 32 | 47 |
| | 17 | 5 | 5 | 14 | 9 | 18 | 31 | 22 | 37 |
| | 18 | 20 | 5 | 4 | 9 | 20 | 41 | 27 | 42 |
| | 19 | 10 | 10 | 20 | 9 | 28 | 41 | 32 | 37 |
| | 20 | 15 | 10 | 19 | 14 | 23 | 44 | 12 | 42 |
| 2 | 16 | 15 | 13 | -5 | 14 | 30 | 23 | 27 | 44 |
| | 17 | 10 | 18 | 5 | 14 | 30 | 33 | 37 | 29 |
| | 18 | 20 | 21 | 20 | 19 | 35 | 40 | 27 | 44 |
| | 19 | 5 | 28 | 15 | 19 | 25 | 33 | 27 | 38 |
| | 20 | 25 | 28 | 35 | 19 | 42 | 40 | 17 | 39 |
| 4 | 16 | 18 | 1 | 7 | 24 | 16 | 2 | 14 | 14 |
| | 17 | 13 | 1 | 12 | 9 | 26 | 12 | 24 | 14 |
| | 18 | 13 | 11 | 32 | 24 | 26 | 35 | 14 | 44 |
| | 19 | 13 | 11 | 32 | 19 | 26 | 22 | 14 | 14 |
| | 20 | 18 | 11 | 37 | 4 | 26 | 17 | 9 | 24 |
| 8 | 16 | 23 | 1 | 4 | 2 | 24 | 4 | 5 | -3 |
| | 17 | 3 | 1 | 14 | 17 | 4 | 4 | 30 | -3 |
| | 18 | 13 | -4 | 14 | -3 | 34 | 24 | 5 | 34 |
| | 19 | 13 | 6 | 9 | 17 | 24 | -1 | 5 | -3 |
| | 20 | 23 | 6 | 19 | 7 | 19 | 4 | 0 | 39 |

## TABLE 7 (cont'd)

## INDIVIDUAL ANIMAL THRESHOLD SHIFT DATA MEASURED AT 5 FREQUENCIES DURING THE 4th EXPOSURE WEEK (dB)

| | | Group 3 Animal No. | | | | | Group 4 Animal No. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kHz | Day | 839 | 846 | 853 | 856 | 857 | 881 | 891 | 893 | 904 | 908 |
| 0.5 | 16 | 21 | 26 | 25 | 40 | 18 | -3 | -5 | 8 | -4 | -7 |
| | 17 | 36 | 21 | 20 | 45 | 23 | 2 | -10 | 8 | 6 | -7 |
| | 18 | 31 | 36 | 35 | 30 | 23 | 2 | 5 | 18 | -9 | -7 |
| | 19 | 41 | 26 | 35 | 30 | 18 | 7 | 10 | 18 | 16 | -2 |
| | 20 | 36 | 26 | 35 | 30 | 23 | 12 | 10 | 38 | -4 | -7 |
| 1 | 16 | 36 | 44 | 37 | 35 | 36 | 1 | 16 | 9 | 3 | -5 |
| | 17 | 31 | 44 | 42 | 40 | -9 | -4 | 6 | 9 | 3 | -10 |
| | 18 | 46 | 39 | 42 | 35 | 31 | 6 | -4 | 9 | -6 | -5 |
| | 19 | 31 | 49 | 42 | 20 | 31 | 1 | 11 | 39 | 3 | 0 |
| | 20 | 26 | 49 | 52 | 40 | 31 | 6 | 26 | 19 | 8 | 0 |
| 2 | 16 | 40 | 51 | 40 | 32 | 30 | -9 | 1 | 25 | 9 | -6 |
| | 17 | 30 | 56 | 45 | 37 | 30 | -4 | 1 | 25 | 9 | -6 |
| | 18 | 30 | 56 | 45 | 37 | 25 | -9 | 11 | 15 | 9 | 4 |
| | 19 | 25 | 56 | 50 | 32 | 30 | -14 | 11 | 45 | 19 | 4 |
| | 20 | 30 | 51 | 50 | 32 | 35 | -4 | 31 | 15 | 9 | 4 |
| 4 | 16 | 19 | 32 | 17 | 21 | 22 | 3 | 4 | 44 | 12 | 8 |
| | 17 | 34 | 32 | 22 | 21 | 2 | 8 | -1 | 34 | 17 | 8 |
| | 18 | 29 | 37 | 37 | 21 | 17 | 13 | 4 | 44 | 12 | 8 |
| | 19 | 39 | 32 | 37 | 21 | 22 | 3 | 14 | 44 | 22 | 8 |
| | 20 | 34 | 27 | 32 | 21 | 22 | 3 | 24 | 19 | 22 | 3 |
| 8 | 16 | -9 | -10 | 2 | -1 | -6 | -7 | 2 | 20 | -5 | 8 |
| | 17 | 1 | -10 | -3 | -1 | -6 | -7 | -3 | 0 | -10 | 8 |
| | 18 | 6 | -5 | 2 | -1 | -11 | -7 | 7 | 40 | 25 | 13 |
| | 19 | 1 | -10 | 7 | -1 | -11 | -12 | 14 | 50 | 15 | 23 |
| | 20 | 13 | 35 | 2 | -11 | -11 | 8 | 17 | 35 | -5 | 13 |

## TABLE 7 (cont'd)

## INDIVIDUAL ANIMAL THRESHOLD SHIFT DATA MEASURED AT 5 FREQUENCIES DURING THE 4th EXPOSURE WEEK (dB)

| | | Group 5 Animal No. | | | | Group 6 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|---|
| kHz | day | 758 | 841 | 952 | 956 | 995 | 997 | 998 | 856 |
| 0.5 | 16 | 12 | 23 | 17 | 16 | −4 | · | −1 | −15 |
| | 17 | 12 | 18 | 12 | 16 | 6 | 20 | · | −10 |
| | 18 | 22 | 38 | 17 | 26 | 16 | 25 | −1 | −5 |
| | 19 | 22 | 43 | 32 | 26 | 16 | 0 | −1 | −10 |
| | 20 | 12 | 28 | 17 | 21 | −1 | 35 | 4 | −5 |
| 1 | 16 | 24 | 18 | 15 | 14 | −2 | · | 20 | −1 |
| | 17 | 19 | 18 | 5 | 19 | 3 | 29 | · | −6 |
| | 18 | 19 | 23 | 15 | 24 | −2 | −1 | 0 | 4 |
| | 19 | 29 | 44 | 28 | 24 | 13 | 19 | 0 | −1 |
| | 20 | 29 | 23 | 15 | 14 | 3 | 9 | 0 | 4 |
| 2 | 16 | 19 | 30 | 22 | 35 | 4 | · | 2 | 0 |
| | 17 | 24 | 15 | 32 | 30 | 9 | 25 | · | 0 |
| | 18 | 39 | 35 | 32 | 40 | 9 | 15 | 7 | 20 |
| | 19 | 39 | 35 | 22 | 40 | 4 | 25 | 7 | 10 |
| | 20 | 39 | 20 | 37 | 40 | 14 | 25 | 12 | 0 |
| 4 | 16 | 33 | 31 | 37 | 13 | 9 | · | 20 | 10 |
| | 17 | 33 | 11 | 27 | 13 | 9 | 18 | 20 | 5 |
| | 18 | 33 | 21 | 27 | 28 | 4 | 18 | 10 | 5 |
| | 19 | 38 | 21 | 22 | 28 | 14 | 28 | 5 | 5 |
| | 20 | 33 | 16 | 27 | 28 | −1 | 23 | 10 | −5 |
| 8 | 16 | 23 | 45 | 30 | 13 | 6 | · | 29 | −4 |
| | 17 | 13 | 40 | 50 | 18 | 14 | 37 | 29 | −4 |
| | 18 | 23 | 55 | 40 | 28 | 6 | 27 | 9 | −12 |
| | 19 | 33 | 45 | 47 | 28 | 6 | 27 | −1 | −2 |
| | 20 | 33 | 50 | 35 | 28 | 11 | 66 | 19 | −17 |

## TABLE 7 (cont'd)

## INDIVIDUAL ANIMAL THRESHOLD SHIFT DATA MEASURED AT 5 FREQUENCIES DURING THE 8th EXPOSURE WEEK (dB)

| | | Group 1 Animal No. | | | | Group 2 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|---|
| kHz | day | 703 | 706 | 754 | 756 | 757 | 758 | 840 | 841 |
| 0.5 | 36 | 32 | 17 | 30 | 34 | 9 | 20 | 26 | 24 |
| | 37 | 22 | 12 | 40 | 19 | 19 | 25 | 36 | 29 |
| | 38 | 27 | 7 | 30 | 9 | 24 | 30 | 21 | 29 |
| | 39 | 27 | 12 | 50 | 39 | 24 | 25 | 21 | 34 |
| | 40 | 27 | 7 | 50 | 34 | 19 | 25 | 21 | 29 |
| 1 | 36 | 40 | 25 | 29 | 24 | 9 | 31 | 22 | 37 |
| | 37 | 35 | 25 | 29 | 44 | 19 | 36 | 22 | 32 |
| | 38 | 40 | 25 | 34 | 34 | 19 | 36 | 17 | 37 |
| | 39 | 40 | 30 | 34 | 39 | 19 | 36 | 17 | 42 |
| | 40 | 35 | 25 | 44 | 24 | 24 | 36 | 22 | 37 |
| 2 | 36 | 35 | 14 | 25 | 44 | 30 | 23 | 22 | 20 |
| | 37 | 35 | 23 | 35 | 39 | 10 | 18 | 22 | 24 |
| | 38 | 35 | 23 | 35 | 29 | 20 | 33 | 22 | 24 |
| | 39 | 35 | 23 | 35 | 39 | 20 | 33 | 17 | 29 |
| | 40 | 35 | 23 | 35 | 29 | 20 | 38 | 22 | 34 |
| 4 | 36 | 28 | 11 | 22 | 29 | 71 | 22 | 24 | 24 |
| | 37 | 23 | 21 | 52 | 34 | 21 | 22 | 34 | 44 |
| | 38 | 23 | [illegible] | 32 | 39 | 16 | 32 | 24 | 14 |
| | 39 | 28 | 11 | 37 | 29 | 26 | 32 | 29 | 14 |
| | 40 | 28 | 16 | 42 | 29 | 31 | 32 | 29 | 24 |
| 8 | 36 | 20 | 11 | 19 | 22 | 10 | 4 | 10 | 12 |
| | 37 | 23 | 6 | 14 | 27 | 10 | 14 | 35 | 22 |
| | 38 | 23 | 16 | 34 | 37 | 15 | 14 | 25 | 22 |
| | 39 | 23 | 26 | 34 | 27 | 30 | 34 | 20 | 27 |
| | 40 | 23 | 26 | 34 | 22 | 30 | 39 | 30 | 22 |

## TABLE 7 (cont'd)

## INDIVIDUAL ANIMAL THRESHOLD SHIFT DATA MEASURED AT 5 FREQUENCIES DURING THE 8th EXPOSURE WEEK (dB)

| | | Group 3 Animal No. | | | | | Group 4 Animal No. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kHz | Day | 839 | 846 | 853 | 856 | 857 | 881 | 891 | 893 | 904 | 908 |
| 0.5 | 36 | 30 | 30 | 50 | 30 | 28 | 12 | 20 | 3 | 1 | 3 |
| | 37 | 35 | 25 | 30 | 30 | 18 | 12 | 0 | 8 | 1 | 3 |
| | 38 | 40 | 30 | 35 | 30 | 18 | 7 | 5 | 13 | 11 | 8 |
| | 39 | 30 | 30 | 35 | 30 | 23 | 12 | 5 | 18 | 16 | -7 |
| | 40 | 40 | 35 | 40 | 35 | 23 | 2 | 10 | -2 | 36 | 3 |
| 1 | 36 | 25 | 34 | 42 | 35 | 36 | -4 | -4 | 4 | -2 | -5 |
| | 37 | 25 | 39 | 42 | 40 | 26 | 6 | 6 | -1 | 3 | 5 |
| | 38 | 30 | 34 | 37 | 40 | 26 | 1 | 11 | -1 | 3 | -5 |
| | 39 | 35 | 39 | 42 | 35 | 26 | 1 | 6 | -1 | 13 | 0 |
| | 40 | 40 | 39 | 37 | 30 | 16 | -4 | 1 | 9 | 13 | -5 |
| 2 | 36 | 25 | 41 | 41 | 32 | 25 | -9 | -9 | 10 | -1 | 4 |
| | 37 | 20 | 41 | 46 | 32 | 30 | 1 | 1 | 0 | -1 | -1 |
| | 38 | 20 | 41 | 46 | 37 | 25 | -4 | -4 | 10 | 9 | 4 |
| | 39 | 30 | 46 | 31 | 32 | 25 | 6 | 1 | 10 | 31 | 4 |
| | 40 | 35 | 46 | 41 | 27 | 25 | 6 | -9 | 10 | 29 | 19 |
| 4 | 36 | 19 | 27 | 37 | 36 | 37 | 13 | -1 | -1 | 2 | -2 |
| | 37 | 29 | 27 | 42 | 31 | 32 | 8 | -1 | 14 | 12 | 8 |
| | 38 | 34 | 22 | 42 | 36 | 22 | -2 | 14 | -1 | 22 | 3 |
| | 39 | 34 | 27 | 42 | 36 | 32 | 8 | 4 | 14 | 32 | 8 |
| | 40 | 49 | 32 | 42 | 31 | 42 | 8 | 4 | 4 | 22 | 28 |
| 8 | 36 | 1. | -5 | 17 | 16 | 19 | 13 | 2 | 10 | 15 | 8 |
| | 37 | 16 | 5 | 22 | 21 | 9 | 3 | 2 | 0 | 5 | 8 |
| | 38 | 16 | -5 | 22 | 26 | 24 | 8 | 7 | 15 | 5 | 13 |
| | 39 | 11 | 5 | 12 | 26 | 14 | -2 | 2 | 27 | 12 | 13 |
| | 40 | 16 | 15 | 17 | 16 | 34 | 3 | 12 | 10 | 0 | 18 |

## TABLE 7 (cont'd)

### INDIVIDUAL ANIMAL THRESHOLD SHIFT DATA MEASURED AT 5 FREQUENCIES DURING THE 8th EXPOSURE WEEK (dB)

| | | Group 5 Animal No. | | | | Group 6 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|---|
| kHz | Day | 758 | 841 | 952 | 956 | 995 | 997 | 998 | 856 |
| 0.5 | 36 | 2 | 8 | 7 | 11 | 11 | 0 | 24 | -5 |
| | 37 | 12 | 18 | 17 | -4 | 1 | 5 | 4 | -5 |
| | 38 | 12 | 18 | 17 | 6 | 21 | 10 | 4 | 0 |
| | 39 | 22 | 28 | 17 | 16 | 6 | 5 | 4 | -5 |
| | 40 | 22 | 38 | 7 | 21 | 6 | 15 | -1 | -5 |
| 1 | 36 | 24 | 18 | 10 | 14 | 13 | -3 | 5 | 9 |
| | 37 | 39 | 18 | 10 | 14 | 13 | 2 | 15 | 14 |
| | 38 | 9 | 13 | 15 | 14 | 29 | 7 | 0 | 4 |
| | 39 | 24 | 33 | 25 | 24 | 8 | 2 | 0 | 4 |
| | 40 | 29 | 23 | 25 | 24 | 8 | 7 | 5 | 24 |
| 2 | 36 | 39 | 28 | 20 | 18 | 14 | 16 | 32 | 0 |
| | 37 | 39 | 20 | 20 | 18 | 19 | 11 | 27 | 15 |
| | 38 | 29 | 10 | 32 | 20 | 14 | 11 | 12 | 20 |
| | 39 | 29 | 25 | 42 | 30 | 14 | 11 | 32 | 15 |
| | 40 | 24 | 25 | 37 | 30 | 14 | 16 | 13 | 18 |
| 4 | 36 | 38 | 16 | 27 | 28 | -1 | 16 | 0 | 5 |
| | 37 | 38 | 11 | 32 | 38 | 19 | 11 | 20 | -5 |
| | 38 | 23 | 6 | 27 | 28 | 29 | 11 | 20 | 18 |
| | 39 | 13 | 11 | 32 | 28 | 29 | 16 | 20 | 18 |
| | 40 | [illegible] | 16 | 22 | 38 | 19 | 21 | 0 | 0 |
| 8 | 36 | 33 | 20 | 45 | 8 | -4 | 21 | 34 | 18 |
| | 37 | 15 | 20 | 40 | 38 | 11 | 21 | 34 | 18 |
| | 38 | 3 | 25 | 35 | 3 | 14 | 21 | 39 | 8 |
| | 39 | 23 | 30 | 40 | 28 | 6 | 21 | 39 | 18 |
| | 40 | 33 | 35 | 45 | 28 | 1 | 31 | 39 | 23 |

## PERMANENT EFFECTS

Mean permanent threshold shifts (PTS) for each of the six groups are shown in Figures 21 through 26. The audiograms from groups 1-3 were generally flat with a consistent 5-10 dB PTS at each frequency tested. Representative cochleagrams for seven of the chinchilla from groups 1-3 are shown in Figures 27 through 29. The cochleagrams were variable, but the animals generally had a low-level outer hair cell loss throughout the extent of the cochlea. Losses amounted to only around 10% with some animals showing small lesions of up to 50% outer hair cell loss. Three of the animals from these groups are still alive (no. 758, 841, 853) while the remaining three animals whose cochleagrams are not shown were essentially normal (no. 754, 840, 839). Overall, the cochleagrams are reasonably conistent with the 10 dB PTS measured across the test frequency range.

Groups 4-6 received a somewhat milder continuous noise exposure, which is reflected in the final audiograms for these groups shown in Figures 24 to 26. Groups 4 and 6 showed virtually no permanent effects, in fact the group 6 post-exposure thresholds show improvements by as much as 10 dB. This improvement is difficult to explain considering that the pre-exposure thresholds for group 6 animals are reasonably low and well within acceptable limits. Cochleagrams for groups 4 and 6 show little ( < 5%) loss except for a single animal (no. 891) that showed a basal lesion of outer hair cells (Figure 29). The relatively normal appearance of the organ of Corti in groups 4 and 6 is typified by the cochleagram of animal 995 shown in Figure 29.

The four animals in group 5 showed a 5-10 dB permanent threshold shift. All four animals in group 5 are still alive, and are being used for further psychophysical experiments, thus cochleagrams are not available.

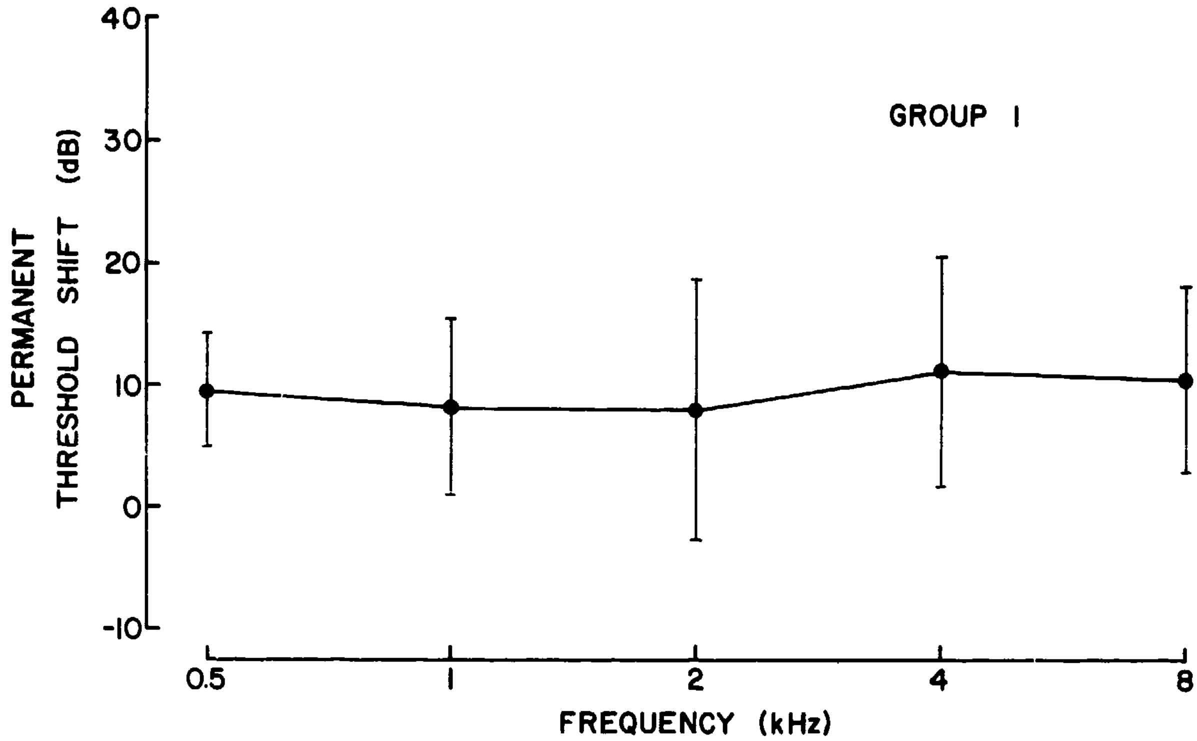


Figure 21. Group 1 Mean Permanent Threshold Shifts Measured 30 Days Post-Exposure
The bar indicates ± 1 S.D.

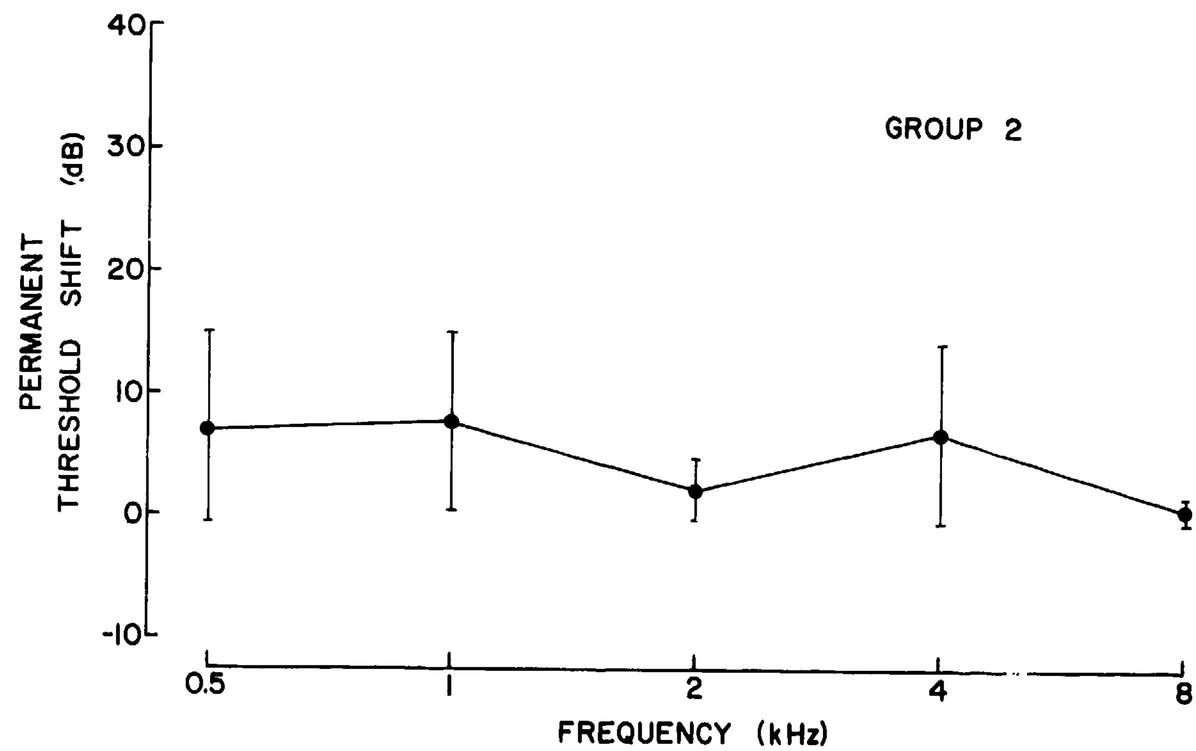


Figure 22. Group 2 Mean Permanent Threshold Shifts Measured 30 Days Post-Exposure
The bar indicates ± 1 S.D.

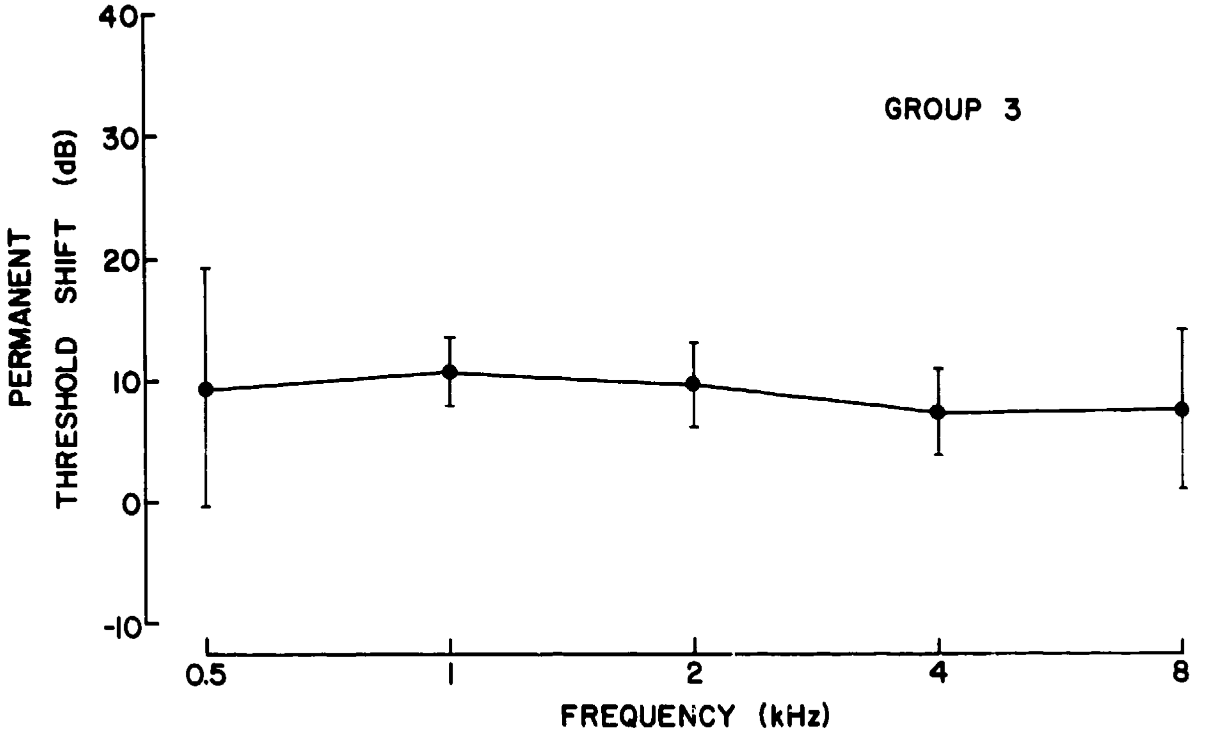


Figure 23. Group 3 Mean Permanent Threshold Shifts Measured 30 Days Post-Exposure
The bar indicates ± 1 S.D.

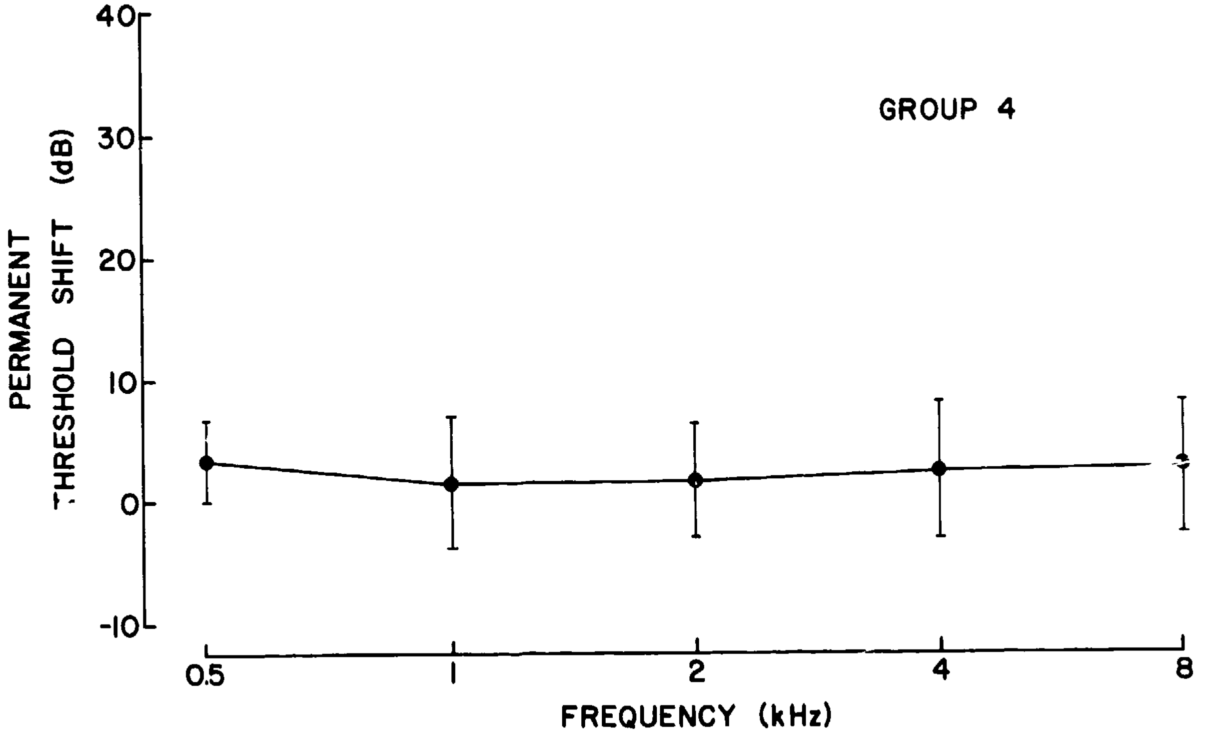


Figure 24. Group 4 Mean Permanent Threshold Shifts Measured 30 Days Post-Exposure
The bar indicates ± 1 S.D.

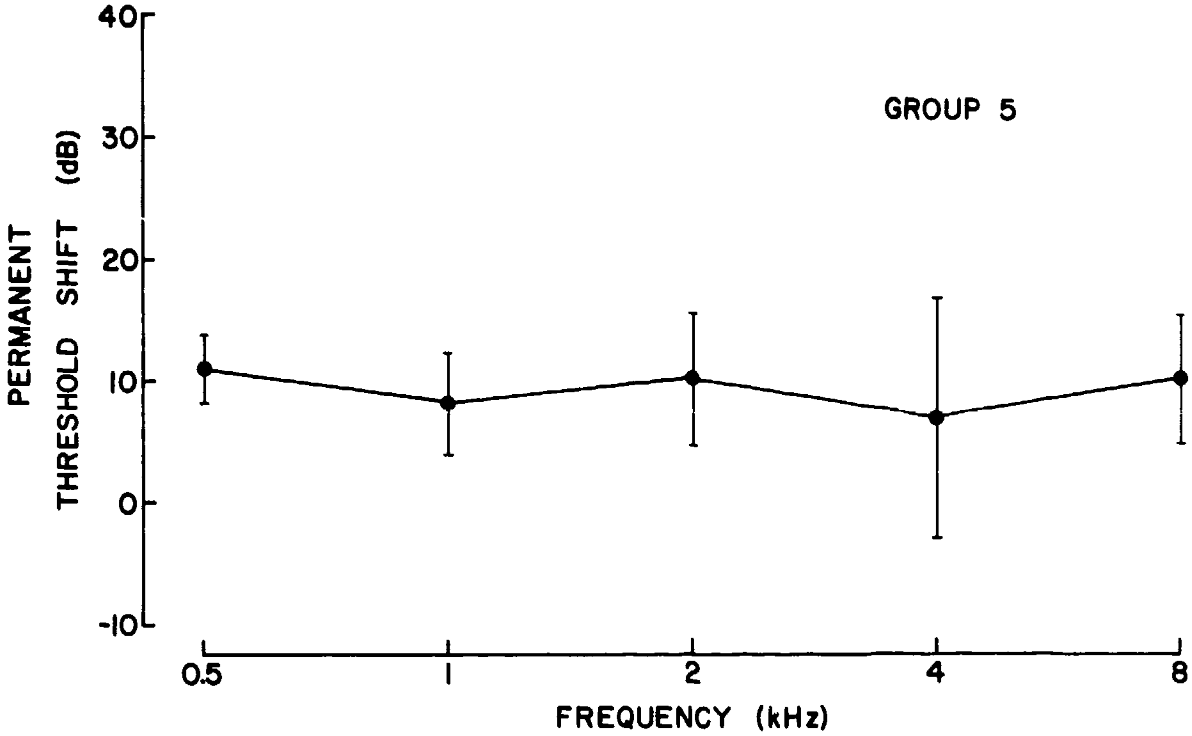


Figure 25. Group 5 Mean Permanent Threshold Shifts Measured 30 Days Post-Exposure
The bar indicates ± 1 S.D.

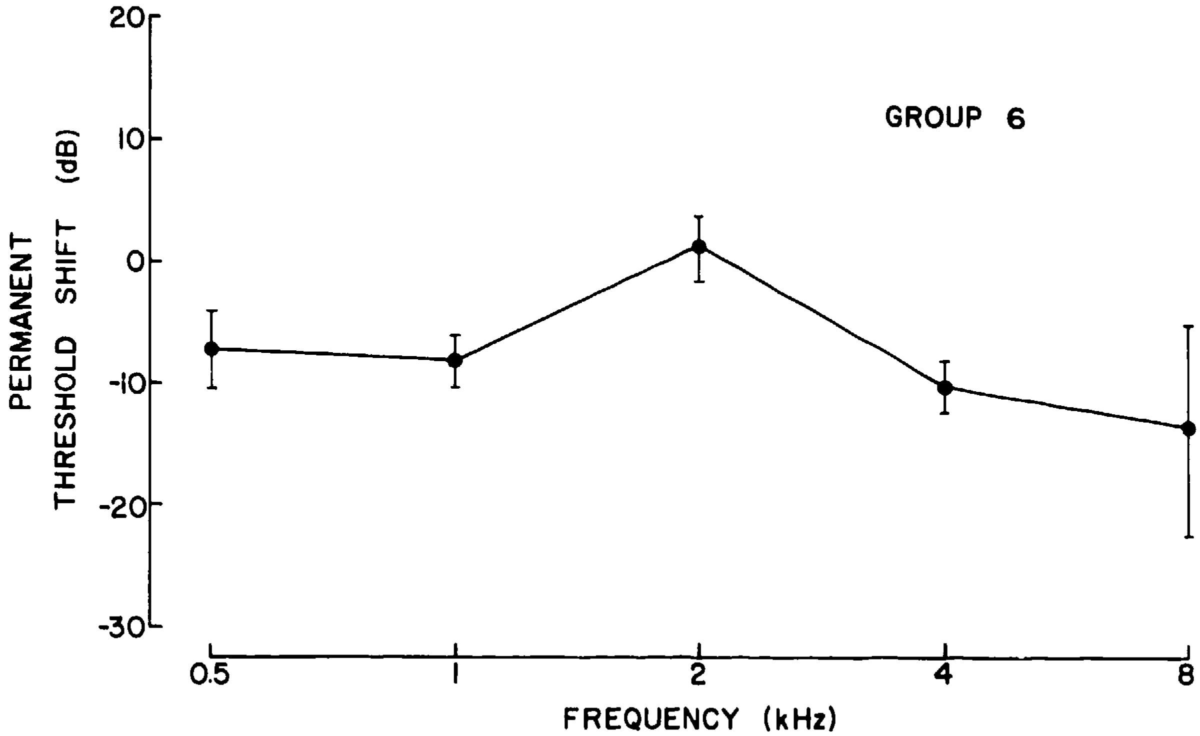


Figure 26. Group 6 Mean Permanent Threshold Shifts Measured 30 Days Post-Exposure
The bar indicates ± 1 S.D.

## TABLE 8

### GROUP MEAN 30-DAY POST-EXPOSURE THRESHOLDS (db-SPL) and PTS (dB) FOR FIVE FREQUENCIES

| | FREQUENCY - | 0.5K | 1K | 2K | 4K | 8K |
|---|---|---|---|---|---|---|
| GROUP 1 | $\overline{X}$ | 11.8 | 12.0 | 10.5 | 15.8 | 14.2 |
| N=4 | $\sigma$ | 7.7 | 9.8 | 15.0 | 10.8 | 10.6 |
| GROUP 2 | $\overline{X}$ | 19.5 | 15.2 | 10.5 | 9.2 | 9.2 |
| N=4 | $\sigma$ | 11.1 | 11.1 | 4.2 | 1.5 | 3.1 |
| GROUP 3 | $\overline{X}$ | 12.8 | 12.2 | 9.8 | 9.2 | 11.0 |
| N=5 | $\sigma$ | 8.3 | 2.4 | 4.1 | 2.7 | 6.4 |
| GROUP 4 | $\overline{X}$ | 13.8 | 10.6 | 7.0 | 10.0 | 10.2 |
| N=5 | $\sigma$ | 1.8 | 3.4 | 3.5 | 4.6 | 5.0 |
| GROUP 5 | $\overline{X}$ | 25.2 | 22.5 | 25.0 | 20.2 | 17.5 |
| N=4 | $\sigma$ | 6.7 | 4.1 | 10.5 | 10.4 | 5.7 |
| GROUP 6 | $\overline{X}$ | 3.5 | -3.5 | 4.2 | -5.0 | -12.5 |
| N=4 | $\sigma$ | 5.2 | 4.0 | 3.5 | 3.4 | 5.6 |

30 day post-exposure thresholds - dB SPL

| | FREQUENCY - | 0.5K | 1K | 2K | 4K | 8K |
|---|---|---|---|---|---|---|
| GROUP 1 | $\overline{X}$ | 9.5 | 8.2 | 8.0 | 11.2 | 10.5 |
| N=4 | $\sigma$ | 4.7 | 7.1 | 10.7 | 9.5 | 7.6 |
| GROUP 2 | $\overline{X}$ | 7.2 | 7.8 | 2.2 | 7.0 | 0.8 |
| N=4 | $\sigma$ | 7.8 | 7.2 | 2.6 | 7.3 | 1.0 |
| GROUP 3 | $\overline{X}$ | 9.4 | 10.6 | 9.6 | 7.4 | 7.6 |
| N=5 | $\sigma$ | 9.8 | 2.9 | 3.5 | 3.6 | 6.6 |
| GROUP 4 | $\overline{X}$ | 3.4 | 1.6 | 1.6 | 2.4 | 2.6 |
| N=5 | $\sigma$ | 3.4 | 5.4 | 4.8 | 5.6 | 5.4 |
| GROUP 5 | $\overline{X}$ | 11.0 | 8.2 | 10.2 | 7.0 | 10.2 |
| N=4 | $\sigma$ | 2.9 | 4.1 | 5.4 | 9.9 | 5.3 |
| GROUP 6 | $\overline{X}$ | -7.2 | -8.2 | 1.0 | -10.5 | -14.0 |
| N=4 | $\sigma$ | 3.2 | 2.1 | 2.7 | 2.1 | 8.6 |

Permanent threshold shift - dB

# TABLE 9

## MEAN INDIVIDUAL ANIMAL 30-DAY POST-EXPOSURE THRESHOLDS (dB SPL) and PTS (dB) (FOR FIVE FREQUENCIES)

| | Group 1 Animal No. | | | | Group 2 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|
| | 703 | 706 | 754 | 756 | 757 | 758 | 840 | 841 |
| 0.5k | 6 | 10 | 23 | 8 | 33 | 12 | 24 | 9 |
| σ | 5 | 4 | 10 | 4 | 9 | 4 | 4 | 4 |
| PTS | 6 | 6 | 16 | 10 | 15 | 0 | 13 | 1 |
| 1k | 4 | 11 | 26 | 7 | 31 | 6 | 15 | 9 |
| σ | 7 | 3 | 12 | 4 | 8 | 4 | 4 | 4 |
| PTS | 2 | 4 | 18 | 9 | 17 | 0 | 5 | 9 |
| 2k | -3 | 12 | 31 | 2 | 15 | 10 | 12 | 5 |
| σ | 6 | 3 | 15 | 6 | 4 | 6 | 6 | 5 |
| PTS | 1 | 2 | 23 | 8 | 2 | 0 | 6 | 1 |
| 4k | 10 | 10 | 32 | 11 | 28 | 10 | 15 | 12 |
| σ | 3 | 6 | 16 | 5 | 7 | 3 | 4 | 6 |
| PTS | 11 | -1 | 22 | 13 | 17 | 0 | 7 | 4 |
| 8k | 13 | 4 | 29 | 11 | 12 | 11 | 10 | 5 |
| σ | 6 | 3 | 14 | 9 | 11 | 4 | 3 | 0 |
| PTS | 11 | 0 | 18 | 13 | 1 | 0 | 0 | 2 |

| | Group 3 Animal No. | | | | | Group 4 Animal No. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 839 | 846 | 853 | 856 | 857 | 881 | 891 | 904 | 893 | 908 |
| 0.5k | 2 | 21 | 6 | 17 | 18 | 14 | 16 | 14 | 14 | 11 |
| σ | 7 | 6 | 5 | 4 | 4 | 7 | 9 | 6 | 9 | 5 |
| PTS | -5 | 19 | 4 | 15 | 14 | 8 | -1 | 5 | 3 | 2 |
| 1k | 13 | 13 | 13 | 8 | 14 | 15 | 9 | 12 | 6 | 11 |
| σ | 5 | 5 | 5 | 4 | 7 | 6 | 3 | 9 | 5 | 4 |
| PTS | 11 | 10 | 13 | 6 | 13 | 10 | -2 | -1 | -3 | 4 |
| 2k | 13 | 6 | 14 | 5 | 11 | 9 | 12 | 6 | 3 | 5 |
| σ | 7 | 8 | 4 | 6 | 7 | 8 | 6 | 7 | 7 | 5 |
| PTS | 10 | 9 | 12 | 4 | 13 | 10 | 0 | -2 | -1 | 1 |
| 4k | 11 | 7 | 13 | 8 | 7 | 9 | 18 | 6 | 8 | 9 |
| σ | 8 | 4 | 4 | 5 | 5 | 6 | 4 | 4 | 3 | 6 |
| PTS | 3 | 7 | 13 | 7 | 7 | 11 | 0 | -2 | -2 | 5 |
| 8k | 9 | 22 | 6 | 7 | 11 | 12 | 18 | 8 | 5 | 8 |
| σ | 7 | 8 | 5 | 4 | 5 | 8 | 5 | 5 | 8 | 6 |
| PTS | 0 | 17 | 3 | 8 | 10 | 9 | 0 | 3 | -5 | 6 |

| | Group 5 Animal No. | | | | Group 6 Animal No. | | | |
|---|---|---|---|---|---|---|---|---|
| | 758 | 841 | 952 | 956 | 995 | 997 | 998 | 856 |
| 0.5k | 24 | 20 | 22 | 35 | -4 | 7 | 4 | 7 |
| σ | 6 | 16 | 5 | 10 | 7 | 7 | 3 | 3 |
| PTS | 7 | 11 | 12 | 14 | 10 | -5 | -4 | -10 |
| 1k | 26 | 18 | 20 | 26 | -7 | -3 | -6 | 2 |
| σ | 13 | 7 | 4 | 8 | 11 | 11 | 10 | 3 |
| PTS | 13 | 9 | 3 | 8 | -11 | -8 | -8 | -6 |
| 2k | 33 | 11 | 23 | 33 | 3 | 6 | 0 | 8 |
| σ | 12 | 7 | 10 | 15 | 10 | 6 | 4 | 3 |
| PTS | 17 | 6 | 10 | 18 | 2 | 2 | -3 | 3 |
| 4k | 21 | 9 | 17 | 34 | -7 | -6 | -7 | 0 |
| σ | 16 | 4 | 7 | 12 | 9 | 4 | 7 | 4 |
| PT | 11 | -3 | 1 | 19 | -11 | -13 | -10 | -8 |
| [illegible] | 20 | 9 | 21 | 20 | -16 | -10 | -18 | -6 |
| σ | 15 | 6 | 9 | 5 | 9 | 5 | 6 | 5 |
| PTS | 8 | 4 | 16 | 13 | -25 | -4 | -14 | -13 |

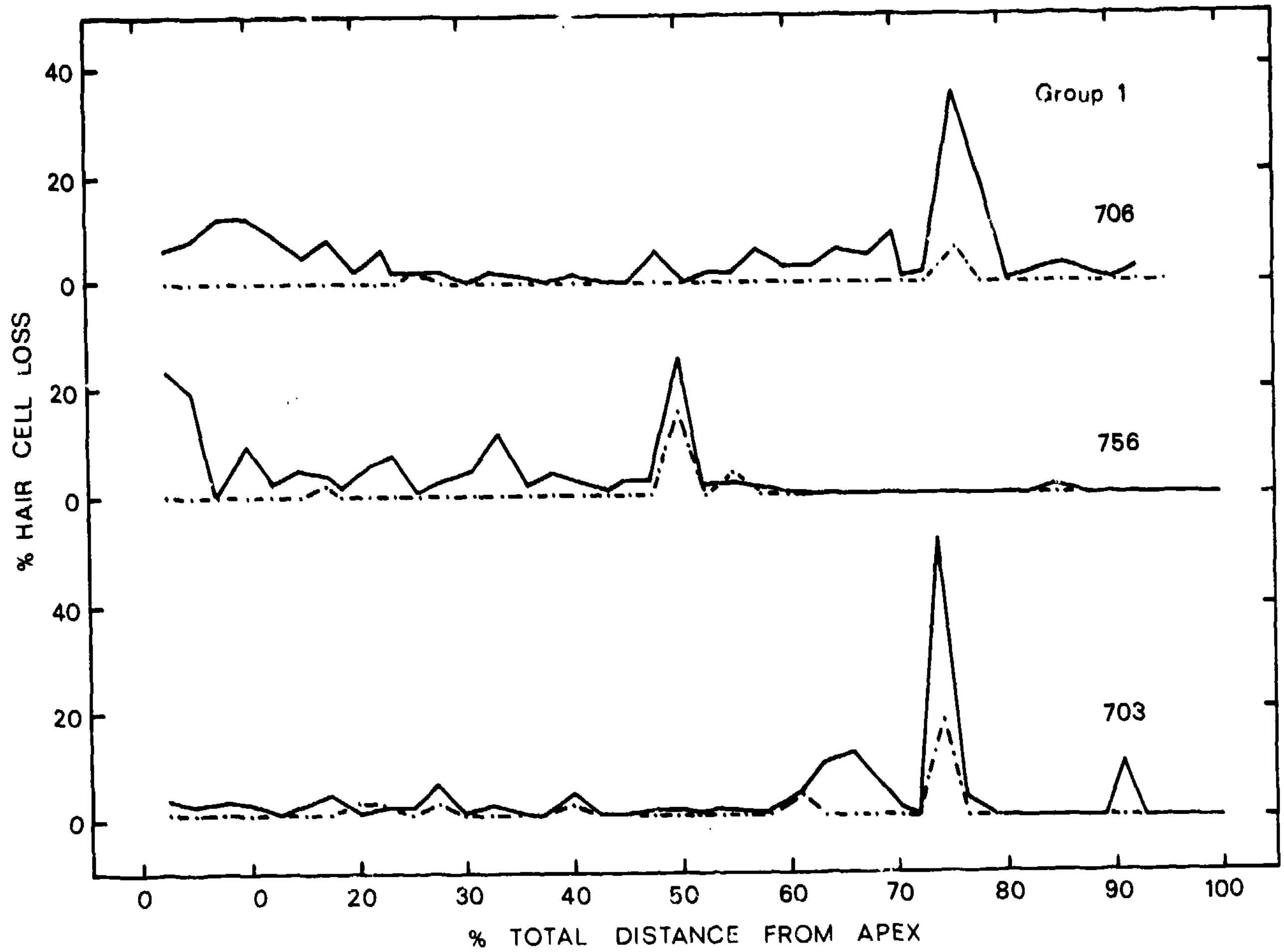


Figure 27. Typical Cochleagrams for the Group 1 Animals

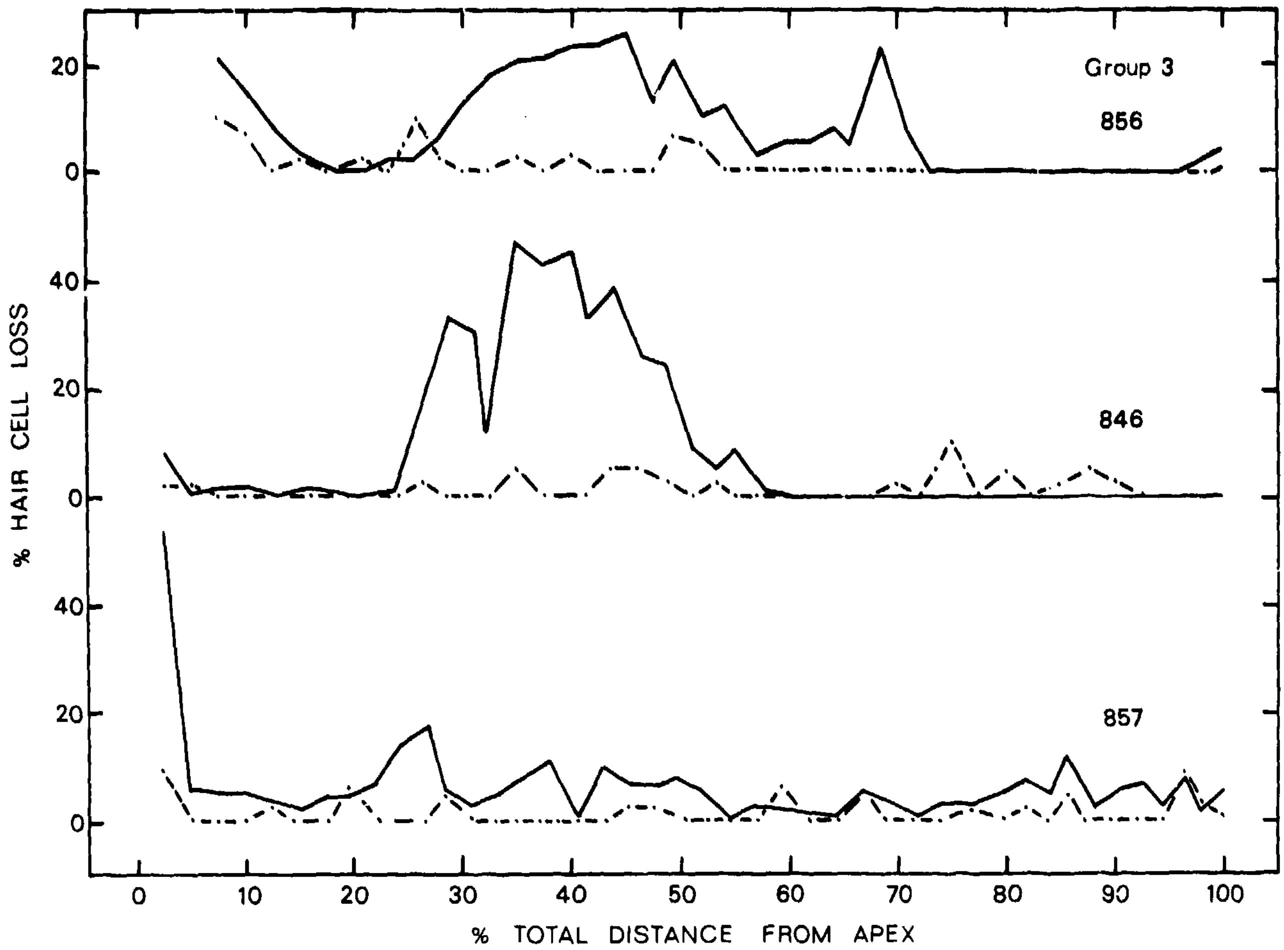


Figure 28. Typical Cochleagrams for the Group 3 Animals

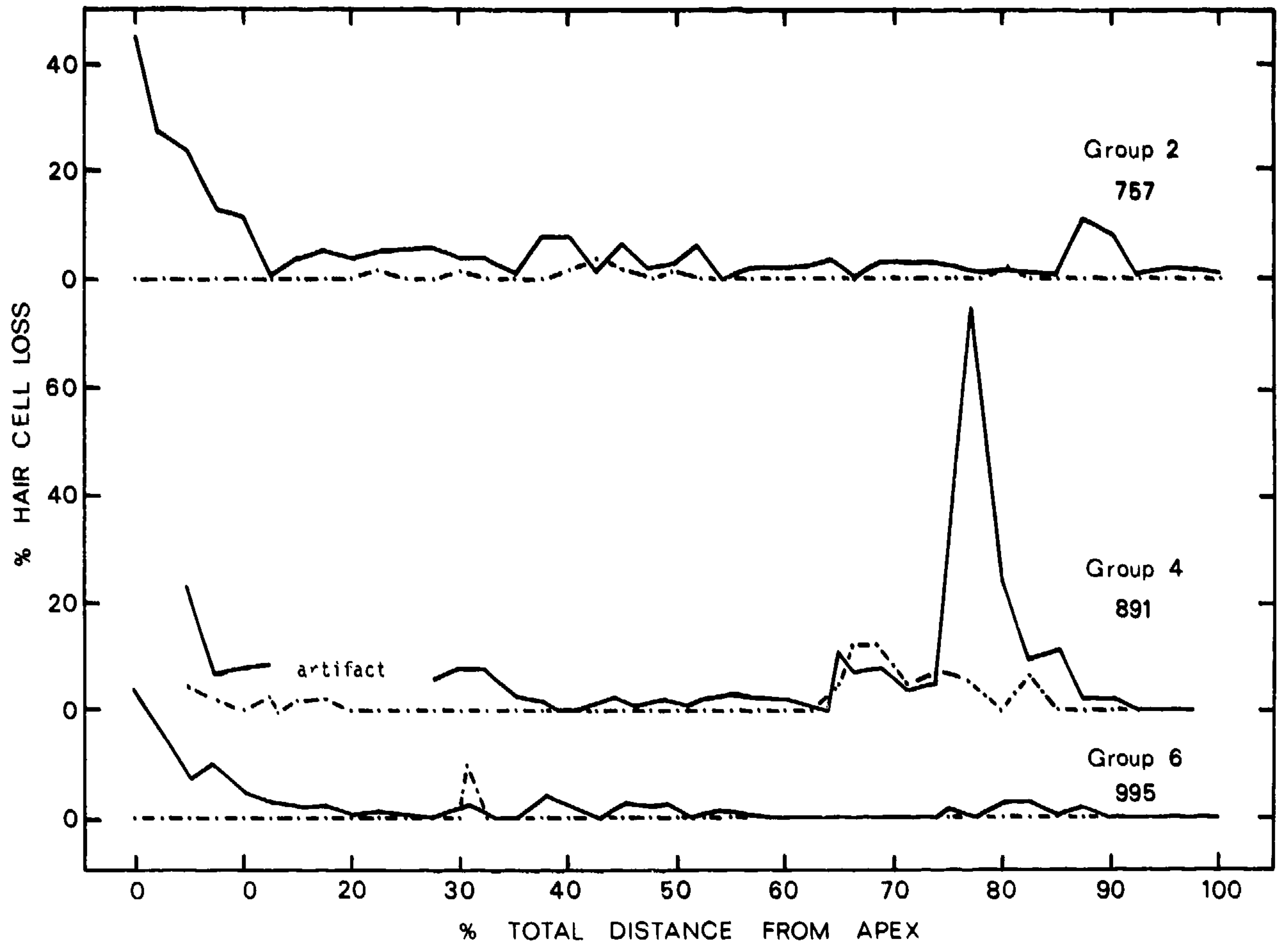


Figure 29. Typical Cochleagrams for the Group 2, 4 and 6 Animals

# DISCUSSION

## PRE-EXPOSURE

The pre-exposure thresholds were homogenous across the 23 chinchillas. Furthermore, the thresholds were in good agreement with estimates of the audibility curve of the chinchilla published by other laboratories (Miller, 1970). The relatively small inter- and intrasubject variability (across 10 days of testing) provided a measure of confidence when testing each of the animals during and after the noise exposure. Also, as a corollary, when there is significant variability in thresholds during and after the noise exposure, the variability can be assumed to be a consequence of individual differences in susceptibility to noise rather than a problem in measurement.

## INTERACTION OF CONTINUOUS AND IMPULSE NOISE

The primary aim of this study was to learn if there is an interaction between continuous and impulse noise when both noises alone produce only minor threshold shift (TTS < 20 dB). There are essentially two sets of results because the continuous noise for groups 1, 2 and 3 was set at 85 dB SPL and the continuous noise for groups 4, 5 and 6 was set at 76 dB SPL. However, both groups received the same impulse noise which produced only 12-15 dB TTS across all the frequencies tested; in the same period group 1 received the 103 dB impulse noise which produced only 12-15 dB TTS across all the frequencies tested; in the same period groups 2 and 3 received the continuous noise which produced 30 dB TTS for low and mid-frequencies. In the last 4 weeks when all the animals were exposed to the combination of continuous and impulse noise they developed a pattern of TTS that was the same as the TTS from the continuous noise alone. One interpretation of the results for weeks 5-8 is that the level of TTS is simply determined by the continuous noise that is the most traumatic agent and there is no interaction between the effects of the two noises.

For groups 4, 5 and 6 the situation is somewhat different. The continuous noise was lowered from 85 dB to 76 dB. During weeks 1-4, group 6 was exposed to the continuous noise and developed 10-15 dB TTS across all frequencies. The pattern of TTS during weeks 1-4 for group 6 was essentially the same as the pattern of TTS produced by impulse noise along (weeks 1-4 for groups 1 and 4). During weeks 5-8, when all the animals of groups 4, 5 and 6 were exposed to a combination of impulse and continuous noise, the pattern of TTS did not reflect any interaction.

The lack of any interaction between the continuous and impulse noise in these six groups is in contrast with other studies of combinations of impulse and continuous noise (Hamernik et al., 1979, Hunt et al., 1976), thus it would be instructive to compare conditions in the exposures that show interactions and those that don't. In the first study to show interaction effects (Hamernik et al., 1974), the impulse was a blast wave with a 40 usec initial over pressure and a peak equivalent SPL of 158 dB. The background noise was an octave band of noise (2-4 kHz) set at 95 dB SPL. Both the impulse and continuous noise alone produced a TTS of 30 dB or more at the high and mid-frequencies; however in the present experiment both controls produced less than 30 dB of TTS. Also, the actual modus operandi of the impulse noise is probably different in the two experiments.*

It has been hypothesized that the cochlea is damaged by excessive metabolic activity when stimulated by continuous noise. However, with high levels of impulse noise the cochlea is probably damaged by mechanical or inertial forces, as well as by exhaustive metabolic processes. Thus, in a study by Hamernik et al., the chinchillas were stressed both metabolically and mechanically. In the present study, the levels of TTS were lower for both types of noise and it is not likely that the peak level of the impulse was high enough to inflict direct mechanical damage.

Spectral considerations may be another reason that there is no interaction in the present experiment. In the Hamernik et al. (1974) experiment both the impulse and continuous noise overlapped in the 2 to 4 kHz range. In the present experiment, both the impulse and continuous noise have a maximum in their spectra at low frequencies (~500 Hz) and a gradual attenuation with higher frequencies (~ dB/octave). It is possible that the interaction effect seen by Hamernik et al. may be a consequence of localizing acoustic energy to the basal regions of the cochlea, rather than spreading it throughout the cochlea, as was done in the present experiment.

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*Luz and Hodge (1970) hypothesized that impulse noise damages the cochlea by direct mechanical destruction as well as from excessive metabolic demands. They base their hypothesis on the non-linear recovery curve often found after exposure to impulse noise. Frequently, after a period of recovery of sensitivity there is a large rebound to a higher level of hearing loss about 3-8 hours post-exposure. Luz and Hodge suggest that the delayed reaction is consistent with the time course seen in the edementous reaction of soft tissue following concussion. Histological studies (Spoendlin) give further support to the position that impulse noise destroys the cochlea by direct mechanical disruption.

## PRIORITIES FOR FUTURE RESEARCH

The lack of an interaction in the present experiment and the robust interaction found in other experiments dictates that further research be done to determine the boundary conditions leading to synergistic interaction between the continuous and impulse noise. In the present experiment we use broad band stimuli with the intent of mimicking real life exposures. The desire to create real life situations in the laboratory has a certain face validity, but may complicate the data to the point that it is difficult to get a perspective on the phenomenon in question. Consequently a first priority would be to conduct experiments using simpler acoustic conditions, e.g., narrow band noises and impulses consisting of either Friedlander waves or damped sinusoids.

The amplitudes of these simpler signals could be adjusted so that they cause either metabolic or mechanical damage. It would then be desirable to use these signals in long term exposures that lead to stable levels of ATS and low variability. Systematic investigations could then be carried out to determine whether the interaction is based upon either a reaction at localized region in the cochlea or some generalized response.

## ASYMPTOTIC THRESHOLD SHIFT (ATS) FROM BROAD BAND NOISE

The phenomenon of asymptotic threshold shift is interesting and potentially useful. It is interesting that with continuous exposure, threshold shifts stabilized rather than continue to grow as would be predicted by a Total Energy Model. The condition of ATS is potentially useful because the level of ATS has been hypothesized to represent the eventual PTS that could be expected with years of exposure to a given noise. The ATS phenomenon is also very orderly. Recently, a quantitative relationship was described between the maximum ATS resulting from continuous exposure to octave band noise and the level and spectrum of that noise (e.g., Mills, 1979). Saunders (1977) extended the Mill's prediction to cover intermittent exposures. He reported that 8-hour (daily) exposures for several days produce a form of ATS, but at alower level than would continuous exposure to the same noise. He suggested that the maximum ATS is a simple function of the equivalent power of noise exposures.

The long term, 8 hour per day exposures to broad band noise used in the present experiments would be expected to produce a condition of ATS. Therefore, it might be interesting to extrapolate from Saunder's suggestion and determine if the threshold shifts produced by octave bands contained within the broad band noise used here are consistent with those which would be predicted to occur from exposure to the octave bands alone.

Comparisons of predicted and obtained "ATSs" for the three groups (no. 2, 3 and 6) are shown in Table 10. (The rationale for the listed predictions is explained in the caption.) The two sets of values do not generally agree. For groups 2 and 3 the smallest difference between predicted and obtained values is about 5 dB (for the 4kHz octave band noise). For group 6 (for the same noise exposure) the difference is larger and in the opposite direction.

These experiments were not designed specifically to test or expand upon Saunders' hypothesis, but the comparisons of the experimental data with the predictions which can be made indicates that either the assumptions used to predict ATS in the current study are erroneous, or that ATS at a given frequency varies in level depending on whether the appropriate octave band is imbedded in a wider band of noise or stands alone.

## TABLE 10

## COMPARISON OF THE PREDICTED AND OBTAINED THRESHOLDS

| GROUP | Noise Exposure Octave Band Center Freq. (kHz) | Octave Band Level (dB SPL) | Intercept Critical Level C* (dB) | Slope* (dB) | Predicted ATS @ ½ Octave above Noise CF (dB) | Observed** ATS |
|---|---|---|---|---|---|---|
| 2 | 0.5 | 70 | 65 | 1.7 | 7.0 | 31 |
| | 1 | 68 | 64 | 1.7 | 5.8 | 32 |
| | 4 | 56 | 48 | 1.7 | 11.2 | 16 |
| 3 | 0.5 | 70 | 65 | 1.7 | 7 | 32 |
| | 1 | 68 | 64 | 1.7 | 5.8 | 34 |
| | 4 | 56 | 48 | 1.7 | 11.2 | 17 |
| 6 | 0.5 | 63 | 65 | 1.7 | 0.1 | 3 |
| | 1 | 63 | 64 | 1.7 | 0.8 | 5 |
| | 4 | 62 | 48 | 1.7 | 20.6 | 11 |

The predicted ATS values were derived from the equation:

$$ATS = 1.7\left[10 \log_{10} \frac{I_e + I_c}{I_c}\right]$$

$I_c$ = Intensity of the intercept Critical Level
$I_e$ = Intensity of the Noise Exposure Band

Since this equation predicts ATS for a continuous noise exposure, a correction was made to account for the intermittent nature of the exposure in these experiments. Saunders (1977) suggested that the ATS for intermittent exposures will be lowered by:

$$10 \log_{10}\left({}^{T_e}/_{T_i}\right)$$

where $T_e$ is the duration of the exposure (8 hours) and $T_i$ is the period of integration for the effects of the noise. Saunders observed the closest fit between predicted and obtained values when $T_i$ was assumed to be 18 hours, so that value has been used here with the result that the ATS listed values are reduced by approximately 3.5 dB relative to those predicted for continuous exposures.

* From Mills et al., 1979

**Note that the maximum ATS occurs about 0.5 octave above the noise band center frequency, so the "observed" threshold elevations listed had to be interpolated from the obtained threshold measures.

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