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Wright-Patterson Air Force Base, Ohio

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The effects on hearing sensitivity of 24 hour monotic exposures to a narrow band noise with the center frequency at 1000 Hz at sound intensities of 80, 85, and 90 dB(A) were evaluated. Automatic audiometry was used to assess changes in hearing from baseline levels for six test frequencies during exposure and during subsequent recovery. Among the results (1) TTS growth and recovery was present for 1000, 1500, and 2000 Hz test frequencies only, (2) TTS reached a maximum or asymptote between 8 and 16 hours exposure, (3) TTS

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) induced by the 85 and 90 dB(A) exposure levels exceeded the limits specified by CHABA damage risk criteria and (4) long duration exposures of 85 and 90 dB(A) require at least 24 hours of rest prior to subsequent exposure.

SUMMARY

A study of the effects on hearing of 24-hour monotic exposures to a narrow band noise with center frequency at 1000 Hz, at levels of 80, 85, and 90 dB(A) was conducted. Subjects were interrupted (i) for brief hearing test batteries at the 8 and 16 hour points during exposure or uninterrupted (u) with no tests during exposures. Bekesy-type audiometric tracings were used to estimate changes in hearing threshold from baseline levels for six audiometric frequencies during exposure and during subsequent recovery. General findings included the following:

(1) Generally, no TTS was observed for the 500, 4000, and 8000 Hz test frequencies. Positive TTS was measured for 1000, 1500, and 2000 Hz, as expected. Discussion of TTS growth and recovery concern only these three frequencies.

(2) TTS at 8 hours was 4 to 18 dB greater than baseline and was directly related to (a) magnitude of the exposure, and (b) test frequency. Magnitude of TTS rank ordered with exposure level with the highest TTS produced by 90 dB(A) and the lowest by 80 dB(A). TTS was greatest for the 1500, 2000, and 1000 Hz signals, in that order.

(3) The increase in TTS at 16 hours over the levels at 8 hours ranged from zero to a maximum of 4 decibels. The average TTS at 24 hours exposure was no more than 1 decibel greater than the TTS at 16 hours (exceptions at 1500 Hz during 80 and 90 dB(A) exposures). TTS had reached its maximum growth by 8 hours for some of the conditions and 16 hours for all conditions tested. This is interpreted as cessation of measurable TTS growth with continued exposure or asymptote.

(4) Although baseline hearing sensitivity differed for the two groups, average TTS at 24 hours exposure was higher for the "u" group by as much as 8 decibels over that of the "i" group.

(5) Comparison of the TTS data with the CHABA damage risk criteria revealed that effects of the 80 dB(A) exposure did not exceed the limits. TTS induced by the 85 and 90 dB(A) levels clearly exceeded the limits indicating that daily exposures to these levels would put the ear at risk.

(6) Recovery of baseline hearing required only a couple of hours following exposures at 80 and 85 dB(A) while recovery periods of 8 to 24 hours were required following exposures at 90 dB(A). Rest periods from noise of at least 24 hours duration are required for long duration exposures of 85 to 90 dB(A).

(7) Recovery of baseline hearing appeared to involve a three phase pattern consisting of the initial rapid phase, a plateau or period during which recovery temporarily ceased, and a final slow recovery phase to baseline values.

No attempt was made to relate recovery to asymptotic TTS.

PREFACE

This study was accomplished by the Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, under a joint program with the United States Environmental Protection Agency. The research was conducted by Capt David W. Krantz, Lt Col Daniel L. Johnson, and Charles W. Nixon under Project 7231 "Biomechanics of Air Force Operations," Task 723103 "Effects of Operational Noise On Air Force Personnel," Work Unit 016 "Auditory Responses to Acoustic Energy in Air Force Activities and under Interagency Agreements EPA-IAG-0181(D) and EPA-IAG-D4-0376 on Noise Effects Research."

Acknowledgement is made of the assistance provided by H. C. Sommer and W. C. Sears of the Biological Acoustics Branch.

HUMAN TEMPORARY THRESHOLD SHIFT

AND

RECOVERY FROM 24 HOUR ACOUSTIC EXPOSURES

INTRODUCTION

Bioacoustics research continually examines and interprets the relationship between temporary auditory threshold shift (TTS) and short term noise exposure. Permanent threshold shift (PTS) from daily occupational noise exposures occurring over many years is assumed to be related to TTS in a sufficiently logical manner that PTS is estimated from TTS data. This relationship continues to be used as one of the bases for development of allowable noise dosages of up to eight hours duration. These allowable exposures (criteria) indicate the combinations of noise intensity, spectra and duration which, for designated portions of the population, will produce either no TTS, TTS presumed to thoroughly recover on a daily basis or an estimated amount of PTS following many years of daily exposure. The stipulated combinations of stimulus factors assume that recovery occurs (e.g. after an 8-hour work day) during the long period of reduced noise level prior to any subsequent exposure. This assumption is not applicable to military aircraft, submarine and spacecraft environments which provide virtually continuous noise exposures for more than 8 hours, even for days and weeks. Patterns of many civilian noise exposures are also often greater than 8 hours, with the rise of second jobs, recreational vehicle noise, proximity of housing to various environmental noise sources, and industries such as some textile mills which may operate for 12 hour shifts, all of which involve long duration noise exposure.

The extent to which present noise exposure criteria can be directly extrapolated with validity for these longer duration exposures is not known although some agencies have adopted the practice of reducing the permissible exposure level by 3 to 5 dB for each doubling of exposure time up to about 16 hours. A clearer picture of the nature of temporary threshold shift growth and recovery patterns resulting from long term exposures is a prerequisite to the establishment of long term exposure guidelines. The objective of the present study has been to obtain additional information on TTS growth and recovery patterns for noise exposures of 24 hour durations. Of specific interest are determinations of average and maximum TTS magnitudes as a function of exposure level, the rate of TTS growth with time, rate of TTS recovery to baseline with time and distribution of these findings in a population of subjects.

The number of previous experimental investigations exploring the relationship between TTS and noise exposures greater than 8 hours duration has been small. In general, they have demonstrated similar findings in terms of TTS magnitudes, but often have not been concerned with the acquisition and recovery of TTS as they might apply to hearing damage risk criteria. Briefly summarizing these:

(1) Yuganov et al (1967) during a simulated space mission with an ambient noise of about 75 dB, found TTS values of 10 to 20 dB after 24 hours exposure with recovery in 1-2 hours.

(2) Smith, et al, (1970) exposed groups of men for about 25 hours to a 70 Hz tone at 112.8 dB SPL and to a 300 Hz tone at 113.4 dB SPL. In general, measured TTS ranged from zero to a maximum of 15-20 dB at some frequencies.

(3) Mills (1970) exposed himself to a 93 dB SPL signal for about 30 hours and measured about 25-27 dB TTS which required 2-4 days for total recovery.

(4) Melnick (1972) exposed subjects for 16 hours to a 300-600 Hz octave band of noise at 90 dB SPL and again found maximum TTS to be 15-20 dB. Recovery was complete within 10 hours postexposure.

(5) In Aerospace Medical Research Laboratory pilot studies (unpublished data); (a) 24 hour exposure to 75, 80, 85 dB(A) via portable oscillators and (b) 24 hour group exposures to 75, 80, 85 dB(A) via loudspeakers, produced maximum TTS values of 15-25 dB with recovery within 24 hours.

The purpose of the present investigation was to explore the growth and recovery of TTS produced by 24-hour exposures to a narrow band of noise at various sound levels. A one-third octave band pass of noise with center frequency at 1000 Hz was used as the exposure stimulus at sound levels of 80, 85, and 90 dB(A). Monaural threshold of hearing for test frequencies of 500, 1000, 1500, 2000, 4000 and 8000 Hz were recorded prior to, during and following exposure of the test ears of the subjects. Deviations in hearing levels from preexposure values were attributed to the noise exposure and were defined as the criterion measures.

PROCEDURE

EQUIPMENT

The experimental facility and equipment used to measure hearing thresholds and to produce the noise exposures are shown in Figures 1 and 2. The experimental test suite consisted of separate control, noise exposure, and audiometric test rooms. The exposure room was a large reverberation chamber, which contained bunk beds, a table, chairs, a refrigerator, banks of loudspeakers and basic sanitary facilities. An observation window and intercommunication system allowed visual observation and communication contact with the subjects.

A white noise source (General Radio type 1382 random noise generator) provided a signal to a band-pass filter (General Radio Universal filter type 1952), which shaped the noise to a ⅓ octave band centered at 1 KHz. A precision decade attenuator (Hewlett-Packard type 350C) was used to set the input level for an Altec type 351C amplifier, which fed three Jensen Model LM1 125 12 inch loudspeakers positioned in the exposure room as shown in Figure 1.

The sound field in the exposure room was measured and continuously monitored with a 1 inch condenser microphone (Bruel and Kjaer Type 4145) with type 2619 cathode follower connected to a B & K type 2112 audio frequency spectrometer. The B & K sound level meter with 1 inch condenser microphone type 4131 was used to periodically spot check the sound level in

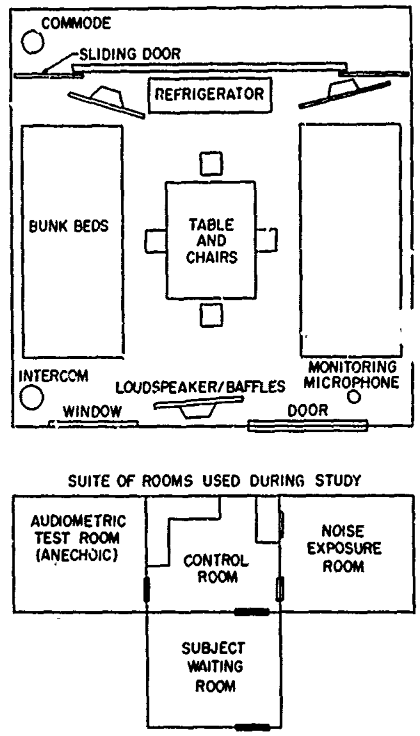

Figure 1. Noise Exposure Room (not to scale)

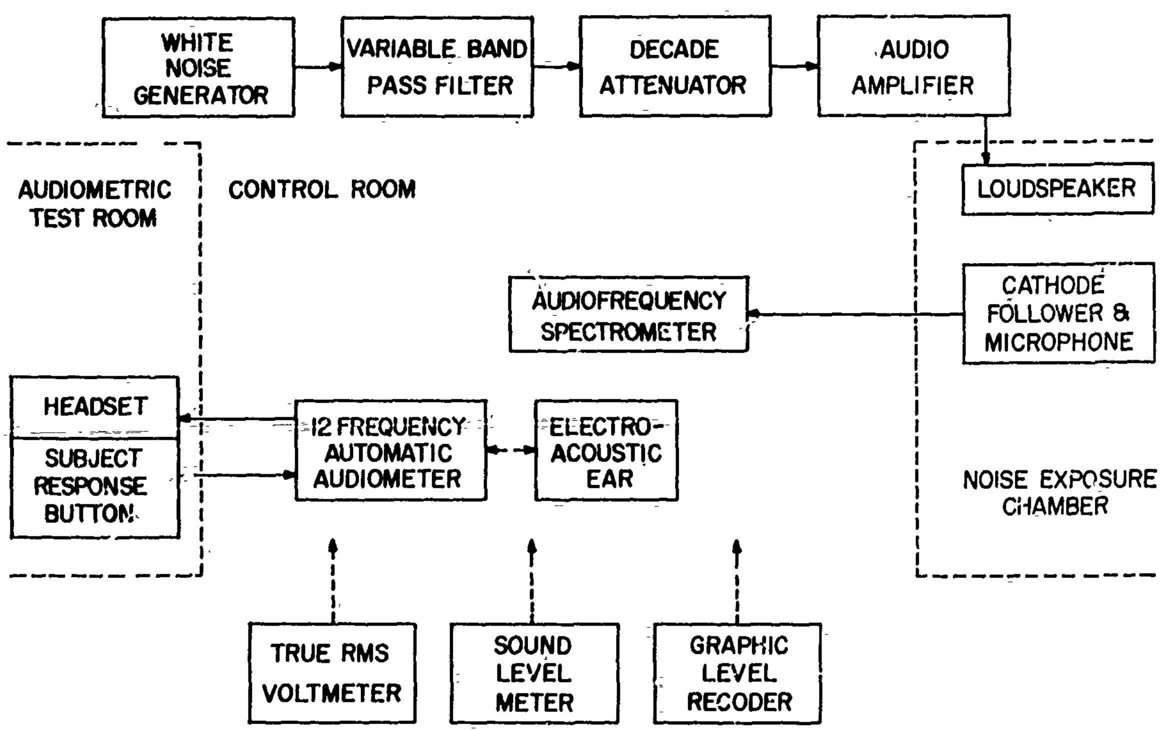

Figure 2. Instrumentation Block Diagram

the exposure room at subject positions. Print-outs of the spectra of background noise in the chamber and the exposure noise were obtained with a General Radio Graphic Level Recorder type 1523 (Table 1). The sound field at the various subject locations was uniform to within less than plus or minus 2 dB. The exposure room's ventilation system and occasional auxiliary fan did not measurably increase the sound level readings obtained. The subject waiting area, used prior to and after exposure, was a fourth laboratory room adjacent to the experimenter's control area. Normal background noise levels in this waiting area were about 60-64 dB(A).

Hearing threshold levels were measured in the anechoic chamber of the test suite with a Rudmose ARJ-6A automatic audiometer. The audiometer was calibrated to ANSI 1969[ref. 2]. Subjects controlled a motor-driven attenuator, which varied the magnitude of the test signals at the ear and simultaneously recorded them on audiogram cards. Each test tone was tracked for 30 seconds during each set of threshold determinations. The test tones were interrupted at a rate of 2.5 pulses per second and were varied in amplitude at a rate of 5 dB per second. The output of the audiometric test earphone (TDH-39) was calibrated using a Bruel and Kjaer sound level meter type 2203 and octave filter set type 1613, with a 6 cc coupler and 1 inch condenser microphone type 4132. During the experiments, the audiometer headset output was monitored for stability using a Rudmose RA 106A Electro-Acoustic Ear. Band-pass settings for the exposure noise filter were established following calculations derived from ASA Standard, Sl. 11–1966. Octave, Half-Octave, and Third-Octave Band Filter Sets.

VOLUNTEERS

Twelve college age males volunteered to participate in the study. Hearing threshold levels of the subjects were no greater than 20 dB (ANSI 1969) at the audiometric test frequencies.

HEARING THRESHOLD MEASUREMENTS

Threshold hearing levels used as the baseline for TTS magnitude measurement were averages of five sets of preexposure threshold data, with two sets taken on the day each exposure began. Figure 3 illustrates the time history of the paradigm employed in the study.

The twelve volunteers formed three teams of 4 subjects each. Three of the four members of each team left the exposure chamber at the 8- and 16-hour points during the noise exposure for hearing threshold measurements at the six test frequencies in the quiet audiometric test suite. Approximately 45 seconds elapsed in transferring to the quiet room from the noise chamber prior to the first audiometric test tone presentation on each of these occasions. Adding this to the 3 minutes of threshold testing and the transit time back to the noise chamber constituted a "rest" period for these subjects of approximately 4½ minutes on each 8- and 16-hour testing occasion. The total duration of the noise exposure was not itself lengthened by any correction factor, i.e., a subject entering the noise chamber originally at 8:00 AM emerged at 8:00 AM the following day. The fourth member of each subject team experienced an uninterrupted 24-hour exposure, i.e., growth of TTS was not measuresd.

Hearing thresholds were tested for all subjects immediately following the conclusion of the

ONE THIRD OCTAVE BAND CENTER FREQUENCY	NOISE EXPOSURE (dB re 20μPa)	BACKGROUND NOISE LEVELS (dB re 20μPa)
125	39	39
160	40	39
200	41	39
250	43	40
315	47	39
400	53	39
500	63	40
630	73	39
800	82	39
1000	86	39
1250	82	39
1600	73	40
2000	62	39
2500	56	39
3150	49	39
4000	43	39
5000	41	39
6300	40	40
8000	40	40
10000	40	40

Table 1. One Third Octave Band Levels of the Noise Exposure Sound Field

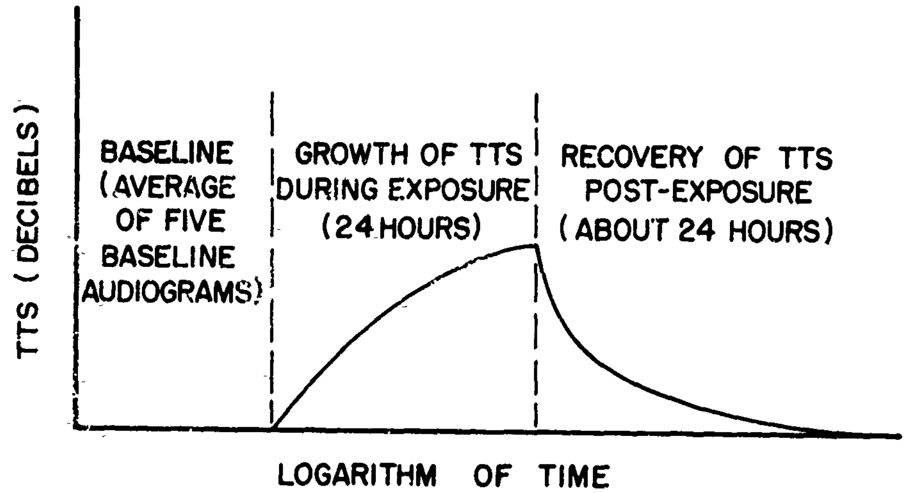

Figure 3. Time History of Paradigm Used in Study

24-hour exposures (the 45-second transfer time applies), again 8 to 10 minutes after the end of the exposure, then 1, 2, and 3 hours postexposure and at various additional postexposure times as conditions demanded and permitted, out to (on a few occasions) 32 hours postexposure.

Noise Exposure. Subjects remained in the noise exposure room throughout the entire 24-hour exposure period (with the exception of the previously mentioned threshold testing for 9 of the 12 subjects at the 8- and 16-hour points). Subjects read, played board games or cards, studied school work and slept much of the time. Each subject was exposed in one ear only, with the other ear being fitted with a commercial ear plug. Care was taken to insure that subjects kept the test ear fully exposed to the noise and did not inadvertently cover it while resting or sleeping.

RESULTS AND DISCUSSION

The threshold shift data contained in the accompanying figures and discussion sections below are tied to the procedural time frame of the data collection periods. Threshold estimations for each audiometric test frequency can be considered to have a time base of the form TTS_{15} sec. number of preceding test frequencies times 30 second. Therefore the following threshold estimates would be approximately correct: 500 Hz—$TTS_{0:45}$, 1000 Hz—$TTS_{1:15}$, 1500 Hz—$TTS_{1:45}$, 2000 Hz—$TTS_{2:15}$, 4000 Hz—$TTS_{2:45}$, and 8000 Hz—$TTS_{3:15}$. As it turns out the common measure of TTS_2 is roughly bracketed by the 1500 Hz and 2000 Hz estimation intervals, and these regions are where much of the larger threshold changes occurred for the 1000 Hz narrow band noise exposures used in this experiment.

GENERAL FINDINGS FOR BASELINE (PREEXPOSURE) THRESHOLDS

The average preexposure hearing threshold levels used as baseline for each subject from which TTS growth and recovery were calculated, are shown in Tables 2 and 3. Five measurements were averaged to determine a single baseline value presented in the tables. Two of the five measures were taken on the day of the particular exposure with the three most recent previous baseline measurements also included. No changes in baseline hearing level either upward or downward as a function of additional exposures emerged as a trend. In the figures and text hereafter, the three subjects whose exposures were uninterrupted for threshold tests during the noise exposure phase are designated as "u" subjects; the remaining nine subjects whose exposures were briefly interrupted for 8- and 16-hour exposure audiometric tests are designated as "i" subjects.

Most subjects at most test frequencies showed baseline thresholds better than clinical audiometric zero hearing threshold level (ANS–1969). The averages at the various frequencies for the three "u" subjects differ from those of the "i" subjects by about 5-6 decibels. Particularly at 1000 and 1500 Hz, where much of the threshold shift activity to be reported was observed, the averages for the "u" group show better sensitivity.

GENERAL FINDINGS FOR TTS GROWTH DURING EXPOSURE

The incidence of TTS across different audiometric test frequencies for the two populations "u" and "i," for the three noise exposure levels is summarized in Table 4. For all three exposure levels, 80 dB(A), 85 dB(A), and 90 dB(A), a relatively unambiguous split in the distribution of average positive TTS was seen. Little or no average TTS for 500 Hz, 4000 Hz, and 8000 Hz test tones emerged for the "i" subjects at any of the exposure levels. This was true for the "u" subjects as well, except that at the highest exposure level these subjects did show an average TTS for the 4000 Hz tone. This allows the discussion to basically center on the remaining three frequencies of 1000 Hz, 1500 Hz, and 2000 Hz in this experiment since average positive TTS of important magnitude was prevalent here for three exposure levels.

The average temporary threshold shift growth and recovery data are summarized for all relevant conditions in Table 5. The magnitude of TTS increased with higher exposure levels. The shifts at the individual test frequencies, in order of decreasing amount, are 1500 Hz, 2000 Hz, and 1000 Hz. The average threshold shifts at 16 and 24 hours of exposure are equal to within ±1.5 dB, strongly suggesting that an asymptote had been reached. This is more clearly visible in the TTS growth curves plotted in Figure 4.

The average hearing levels for the 1000 Hz, 1500 Hz, and 2000 Hz test frequencies were used to construct the nominal growth curves for the 80 dB(A), 85 dB(A), and 90 dB(A) noise

		TEST FREQUENCY (Hz)					
SUBJECT	EXPOSURE LEVEL	500	1000	1500	2000	4000	8000
1	PRE 80 dB(A)	-5	-11	-6	4	7	-6
	PRE 85 dB(A)	-4	-11	-7	3	7	-6
	PRE 90 dB(A)	-6	-11	-6	5	7	-8
2	PRE 80 dB(A)	-7	-12	-11	-12	-15	-6
	PRE 85 dB(A)	-10	-13	-10	-11	-12	-7
	PRE 90 dB(A)	-4	-11	-11	-12	-13	-6
3	PRE 80 dB(A)	-6	-12	-10	-9	2	-4
	PRE 85 dB(A)	-6	-11	-11	-10	4	-6
	PRE 90 dB(A)	-6	-13	-11	-10	2	-3
AVERAGE FOR 3 SUBJECTS		-6	-12	-9	-6	-1	-6

Table 2. Baseline Average Hearing Threshold Levels for "u.' Subject Population

		TEST FREQUENCY (Hz)					
SUBJECT	EXPOSURE LEVEL	500	1000	1500	2000	4000	8000
1	PRE 80 dB(A)	4	-3	8	-1	-3	-4
	PRE 85 dB(A)	2	-5	9	-2	-5	-7
	PRE 90 dB(A)	4	-3	9	1	-4	-3
2	PRE 80 dB(A)	-2	-6	-8	-12	0	11
	PRE 85 dB(A)	-2	-10	-8	-12	0	7
	PRE 90 dB(A)	-1	-8	-9	-12	-1	9
3	PRE 80 dB(A)	-5	-11	1	-9	-9	1
	PRE 85 dB(A)	-4	-11	0	-9	-8	1
	PRE 90 dB(A)	-6	-11	2	-8	-9	-1
4	PRE 80 dB(A)	-3	-11	-8	-8	-4	-4
	PRE 85 dB(A)	-1	-10	-8	-9	-7	-3
	PRE 90 dB(A)	-4	-8	-7	-7	-6	-5
5	PRE 80 dB(A)	3	5	8	14	7	10
	PRE 85 dB(A)	4	5	8	13	8	10
	PRE 90 dB(A)	0	2	6	14	7	10
6	PRE 80 dB(A)	-6	-11	-1	-1	-1	-2
	PRE 85 dB(A)	-7	-13	0	-2	-3	-3
	PRE 90 dB(A)	-3	-10	0	-2	0	-5
7	PRE 80 dB(A)	* 6	2	2	10	4	1
	PRE 85 dB(A)	* 5	0	-1	9	5	0
	PRE 90 dB(A)	-8	-8	-9	-2	-6	6
8	PRE 80 dB(A)	-1	-10	-12	-12	-2	-8
	PRE 85 dB(A)	1	-9	-11	-11	-2	-10
	PRE 90 dB(A)	-1	-11	-13	-10	-2	-6
9	PRE 80 dB(A)	-2	-8	-11	-6	-13	-3
	PRE 85 dB(A)	-3	-8	-11	-5	-13	-5
	PRE 90 dB(A)	-3	-8	-11	-6	-13	-4
AVERAGE FOR 9 SUBJECTS		-2	-7	-3	-4	-4	0

* EAR CANAL PARTIALLY OBSTRUCTED WITH CERUMEN

Table 3. Baseline Average Hearing Threshold Levels for "i" Subject Population

FINDINGS	SUBJECTS	EXPOSURE LEVEL	500	1000	1500	2000	4000	8000
			TEST FREQUENCY (Hz)					
POSITIVE TEMPORARY THRESHOLD SHIFT	i	80dB(A)	—	O	O	O	—	—
		85dB(A)	—	O	O	O	—	—
		90dB(A)	—	O	O	O	—	—
	u	80dB(A)	—	O	O	O	—	—
		85 dB(A)	—	O	O	O	—	—
		90dB(A)	—	O	O	O	O	—

O Some TTS was measured

Table 4. Incidence of TTS among Test Conditions

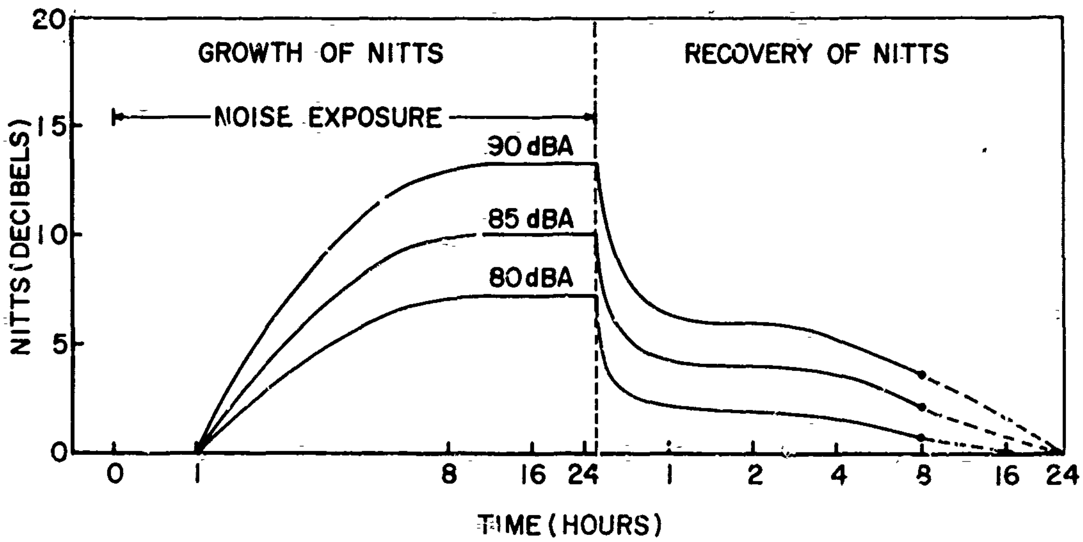

Figure 4. Noise Band (1/3 Octave) Centered on 1000 Hz

DATA: Average Hearing Levels at 1000 Hz, 1500 Hz, and 2000 Hz
Test Frequencies Measured at Times Marked on
Abscissa

exposures. TTS appears to progressively increase until sometime during the period of from 8 to 16 hours of the noise exposure. Within this time frame, from onset of noise, the progression appears to cease and no additional TTS is accrued during the remainder of the exposure. This is additional confirmation that a given moderate noise exposure produces a maximum amount of TTS that is not exceeded during continued exposure of at least up to 24 hours.

NOISE LEVEL	SUBJECTS	TEST SIGNAL (Hz)	EXPOSURE			POST EXPOSURE (HRS)						
			8	16	24	8mins	1	2	3	4	8	24
80 dB(A)	i	1000	4	5	5	1	2	1	1	1	1	0
		1500	7	6	7	3	2	2	2	0	0	0
		2000	6	6	5	3	2	2	1	0	2	0
		AVE	6	6	6	2	2	2	1	0	1	0
	u	1000	–	–	6	3	4	3	0	0	0	0
		1500	–	–	9	5	1	2	0	-1	-1	0
		2000	–	–	7	5	3	3	-1	0	0	0
		AVE	–	–	7	4	3	3	0	0	0	0
85 dB(A)	i	1000	6	10	7	3	1	3	4	–	4	0
		1500	10	13	13	7	7	6	7	–	4	0
		2000	8	11	10	6	5	3	4	–	2	0
		AVE	8	11	10	5	4	4	5	–	3	0
	u	1000	–	–	9	7	5	5	3	–	4	0
		1500	–	–	18	14	10	8	6	–	5	1
		2000	–	–	10	7	4	5	4	–	5	0
		AVE	–	–	12	9	6	6	4	–	5	1
90 dB(A)	i	1000	8	10	9	8	4	5	4	3	3	0
		1500	18	16	17	12	10	8	9	6	6	0
		2000	12	12	10	8	5	6	6	4	4	0
		AVE	13	13	12	9	6	6	6	4	4	0
	u	1000	–	–	12	9	7	8	4	5	5	0
		1500	–	–	22	16	13	12	7	7	7	1
		2000	–	–	18	15	10	9	6	4	4	0
		AVE	–	–	17	13	10	10	6	5	5	0

Table 5. Average Temporary Threshold Shift Growth and Recovery

Inspection of the average TTS values measured for the "i" group compared to those of the "u" group (Figure 5) indicates that small but clearcut differences have emerged. The "i" group, which experienced two 5 minute rest periods from the noise at 8 and 16 hours, shows less threshold shift. These differences are essentially negligible for the 80 dB(A) condition but increase to from 3 to 8 dB for the 90 dB(A) exposure. An argument might be made that these differences simply reflect the "rest" effects operating for the "i" subjects during hearing tests at 8 and 16 hours. This argument might be supported by the concept in Figure 5, which asserts that the uninterrupted growth of TTS reaches a higher level at 24 hours than exposures interrupted at 8 hours and 16 hours. A counterpoint is that the growth rate has slowed sufficiently at 8 and 16 hours that a brief rest will have little or no effect on TTS at 24 hours.

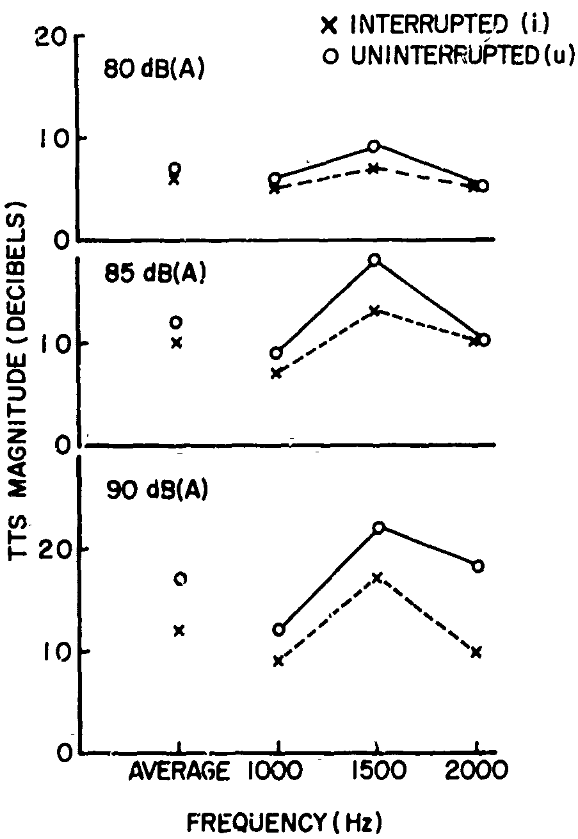

Figure 5. Average TTS Values for the "i" Group Compared to Those of the "u" Group

The concept that slight recovery from TTS occurs each time the exposure is interrupted for audiometric tests is illustrated in Figure 6. Although the data in Figure 5 appears to support this concept another possible explanation exists for the case in point. The baseline hearing threshold levels of the "u" group were much more sensitive than for the "i" group. Consequently the "u" subjects were compared only to the "i" subjects whose baseline hearing was similar (Table 6). Inspection of the average data for the 4 "i" subjects and the "u" subjects shows good similarity. The test interruption effects tending to reduce final TTS magnitudes are not clearcut. It is unfortunate that the design of the present study did not run the same subjects

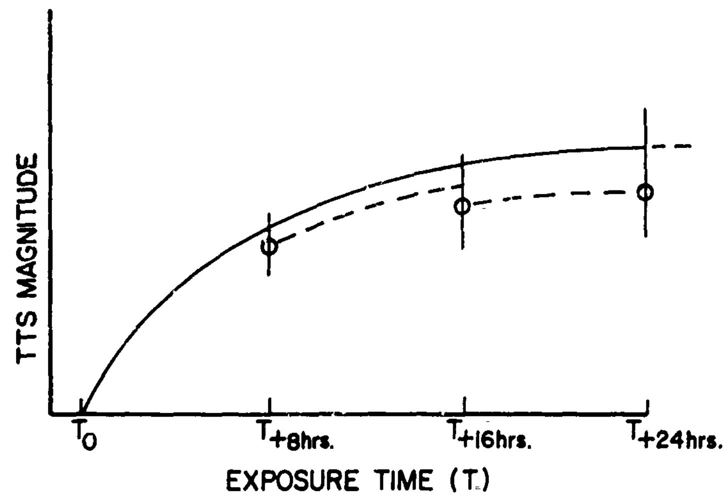

Figure 6. Hypothetical Curve showing TTS Growth as a Function of Interruptions of the Noise Exposure Solid line represents theoretical maximum TTS due to a particular exposure condition. The symbol 0 represents measured behavioral thresholds which have experienced slight recovery each time exposure is interrupted for audiometric tests. Assertion is that threshold at 24 hours exposure for ears interrupted for test is better (less TTS) than for uninterrupted exposures or the theoretical curve. The question is open.

		TEST FREQUENCY (Hz)			
SUBJECTS	EXPOSURE LEVEL	1000	1500	2000	AVERAGE
4	80 dB(A)	15	17	9	14
	85 dB(A)	19	27	19	22
	90 dB(A)	16	26	16	19
6	80 dB(A)	3	8	10	7
	85 dB(A)	7	19	19	15
	90 dB(A)	5	19	14	13
b	80 dB(A)	4	9	11	8
	85 dB(A)	6	16	15	12
	90 dB(A)	16	29	26	24
9	80 dB(A)	4	3	1	3
	85 dB(A)	-3	3	-3	-1
	90 dB(A)	4	17	11	11
AVERAGE ORIGINAL 9 SUBJECTS	80 dB(A)	5	7	5	6
	85 dB(A)	7	13	10	10
	90 dB(A)	9	17	10	12
AVERAGE 4 SUBJECTS INCLUDED ABOVE	80 dB(A)	7	9	8	8
	85 dB(A)	7	16	13	12
	90 dB	10	23	17	17
AVERAGE FOR "u" SUBJECTS	80 dB(A)	6	9	7	7
	85 dB(A)	9	18	10	12
	90 dB(A)	12	22	18	17

Table 6. Average TTS at 24 Hours Exposure for 4 "i" Subjects Whose Average Baseline Hearing Levels are Comparable to Three of the "u" Group

in both the "i" and "u" configurations, because the average baseline hearing level contrast problem just discussed prevents resolution of one of the questions originally of interest, namely, whether any differences in TTS magnitude between "i" and "u" subjects seen after

24 hours of exposure could be attributed to resting or recovery effects created by the interruptions for audiometric testing of the "i" group at the 8 and 16 hour point.

The threshold shift results of this study are compared to the NAS-NRC CHABA* hearing damage risk criteria[ref. 4]. Maximum permissible TTS values of the criteria are 10 dB at 1000 Hz and below, 15 dB at 2000 Hz, and 20 dB at 3000 Hz and above. Table 7 tabulates those instances for which the criteria were exceeded by the TTS experienced in this study. Clearly, the exposures used bracket a transitional range for TTS growth patterns relative to the CHABA limits. Little TTS of CHABA limit magnitude is seen at the 80 db(A) exposure level whereas at 85 dB(A) a substantial number of subjects exceed or press against the limits. At the 90 dB(A) exposure level, the speech range frequencies are strongly implicated.

EXPOSURE LEVEL	SUBJECT	TEST FREQUENCY (Hz)					
		500	1000	1500	2000	4000	8000
80 dB(A)	i						
	u						
85 dB(A)	i		○	●			
	u		○	●			
90 dB(A)	i		○	●	●		
	u		●	●	●		

○ AVERAGE TTS IN EXPERIMENT APPROACHES CHABA LIMIT BUT DOES NOT EXCEED IT.

● AVERAGE TTS IN EXPERIMENT EXCEEDS CHABA LIMIT.

Table 7. Comparison of TTS Measured in this Study with CHABA Damage Risk Criteria

Typical variations in individual sensitivity or susceptibility to noise induced by TTS are clearly illustrated by the data on TTS after 24 hours exposure in Table 8. No subjects incurred more than 20 dB TTS following the 80 dB(A) exposure. Three subjects displayed more than 20 dB TTS from the 85 dB(A) exposure as well as following the 90 dB(A) exposure with one subject showing a TTS greater than 30 dB. Carder and Miller's[ref. 3] work with chinchillas shows that asymptotic TTS values of 30 dB or less follow similar recovery curves regardless of the length of the noise exposure required to produce the shift (1-7 days). Asymptotic TTS values greater than 30 dB resulted in more widely varying recovery patterns and are believed by many to approach the region of possible acoustic trauma. Asymptotic TTS greater than 55 dB, also from chinchilla studies. is considered to be very hazardous as recovery does not return to zero TTS[ref. 7]. Although direct extrapolation to man may be questionable, it is believed that long term noise exposures that will cause TTS much greater than 30 dB should not be allowed. The range of asymptotic TTS between 30 and 55 dB is a grey area which

*National Academy of Sciences, National Research Council, Committee on Hearing, Bioacoustics and Biomechanics it is believed should not be called safe until proven to be so. It has been common, in the past, to consider any one-time exposure that causes TTS less than 40 dB to be safe.

	80 dB(A)			85 dB(A)			90 dB(A)		
SUBJECT	1k	1.5k	2k	1k	1.5k	2k	1k	1.5k	2k
1	4	3	1	-3	3	-3	4	17	11
2	4	9	11	6	16	15	16	29	26
3**	-	-	-	-	-	-	8	11	2
4(u)	8	8	1	·10	11	3	10	14	11
5	3	8	-3	10	19	19	5	19	14
6	4	4	4	7	9	7	8	9	6
7	15	17	9	19	27	19	16	26	16
8(u)	12	8	11	13	21	6	13	18	12
9	3	5	0	8	15	13	12	15*	16
10	1	2	1	5	0	-2	7	12	-1
11	6	9	6	11	8	12	11	15	4
12(u)	-1	12	9	5	23	20	12	33	30

* First Test Showed (-5).

** Subject #3 did not run at 80 dB(A) and data was unacceptable at 85 dB because of ear wax problem.

Table 8. TTS after 24 Hours of Noise Exposure (TTS Values Greater than 20 dB Are Circled)

Considering this position, it is clear with our limited number of subjects, that the 90 dB(A) exposure to the narrow band of noise is not safe. The 85 dB(A) exposure appears to be marginally safe, although certainly a few individuals are likely to exceed a TTS of 30 dB. TTS greater than 20 dB was not experienced by any of the subjects following the 80 dB(A) exposure.

GENERAL FINDINGS FOR TTS (POSTEXPOSURE) RECOVERY TO BASELINE LEVELS

In the examination of postexposure hearing threshold data questions of interest include (a) how is recovery of hearing levels at the termination of exposure related to exposure level and to frequency of test tone, (b) what is the shape of the recovery function, and (c) is the rate fast enough to allow complete recovery in less than one additional 24-hour period. Also of interest were individual differences and possible effects on recovery of interruptions (rest periods) during acoustic exposure for audiometric testing.

The distribution of times following termination of exposure at which recovery to baseline occurred is shown in Table 9. Data are plotted only for the three "speech range" frequencies for each of the exposure levels. The tallies are somewhat misleading for recovery times greater than 8 hours, because the entries represent the next available testing period instead of actual recovery time. This problem was especially acute for the 85 dB(A) data which, as a result, shows a spurious loading at hour 32. The 80 dB(A) and 90 dB(A) recovery data were more tightly controlled and are more reliable. In spite of the high probability that many of the entries belong in earlier time blocks, the number of subjects recovering to baseline after the most intense exposure was virtually 100% by the end of the 24th hour following exposure. Consequently, question 3 can be answered affirmatively that the rate of recovery for these exposures is fast enough to allow return to baseline in 24 hours following termination of the exposure.

EXPOSURE LEVEL	TEST SIGNAL	TIME AT WHICH RECOVERY TO BASELINE WAS MEASURED (HOURS POST-EXPOSURE)								
		1	2	3	4	8	12	16	24	32
80 dB (A)	1000 Hz	○○○○○○●		●●					○	
	1500 Hz	○○○○○●●	○	○●						○
	2000 Hz	○○○○○●●	○	●					○○	
*85 dB (A)	1000 Hz	○○○○●							○●●	○○○
	1500 Hz	○○●				○			○○○	○○●●
	2000 Hz	○○●	○			○			○○	○○●●
90 dB (A)	1000 Hz	○	○○	○●		○	●	○	○●●	○
	1500 Hz			○	○○	○○	●	○	○○○●●	
	2000 Hz	○○			○	○	●	○○	○○○●●	

○ i SUBJECTS

● u SUBJECTS

* FOLLOWING THE 85 dB (A) EXPOSURE, NUMEROUS AUDIOMETRIC TESTS WERE NOT TAKEN AT THE 16 AND 24 HOUR PERIODS. AS A CONSEQUENCE THE 32 HOUR DATA ARE "LOADED", RECOVERY SHOULD OCCUR EARLIER FOLLOWING THE 85 dB (A) EXPOSURE THAN FOR THE 90 dB (A) EXPOSURE

Table 9. Distribution of Times at Which Recovery to Baseline Occurred Following Termination of Exposure

The 80 dB(A) to 90 dB(A) exposure level region seems to be a transition zone for the distribution of recovery times vs exposure level. At 80 dB(A) few recoveries exceeded 1 hour, and very few exceeded 3 hours. At 90 dB(A) very few recoveries occurred in a time as short as 1 hour and the majority needed 4 to 8 hours or more. The longest recovery times for the experimental exposure stimuli are shown to be 32 hours or less. The shortest was less than one hour (although not shown in the figure) but this region was not quantified thoroughly because of testing schedule constraints. Occasionally a subject showed a touchdown to baseline 8 minutes after the end of the exposure, but was lumped in the 1-hour postexposure recovery category because of the confirmation provided by this second test. Such very short returns to baseline were not seen for any subjects in the 1000-2000 Hz test frequencies after the 90 dB(A) exposure.

Reference to Table 5 shows tabulations of average residual TTS magnitudes for the speech range frequencies for the various time points after the exposure. While some of the numerical values contrast somewhat at any particular point in time for the "u" and "i" populations, generally the points at which the averages for the two groups return to baseline are about the same. The average maximum TTS for the two groups is not always the same at the beginning of recovery, but the total amounts of time needed for recovery to baseline levels are similar. Recovery of hearing levels is directly related to exposure level. At the lowest levels, recovery occurs within minutes or hours. At the highest level of 90 dB(A), recovery times were measured to be as long as 24 hours postexposure.

These same average data (Table 5) are plotted in Figure 4 using a logarithmic time base. The steep decline in the beginning hour or two of recovery tends to flatten out thereafter, with data points falling around a relatively horizontal imaginary line through them for a few hours, after which a resumption of decline in TTS occurs. This recovery curve plateau was rather unexpected. Although longer recovery times were predicted for longer duration exposures a two-phase recovery pattern was anticipated with a rapid initial rate and a slower continuing rate to recovery. Instead, a three phase pattern is observed in which the initial rapid phase was followed by the plateau which was maintained for a few hours before the slow phase recovery was completed. This plateau pattern is not typical of short duration noise exposures. Additional experience with long duration exposures will be helpful in determining the mechanism or mechanisms involved.

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