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THRESHOLD SHIFTS IN CHINCHILLAS EXPOSED TO OCTAVE BANDS OF NOISE CENTERED AT 63 AND 1000 Hz FOR THREE DAYS

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Threshold shifts in chinchillas exposed to octave bands of noise centered at 63 and 1000 Hz for three days[a)]

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INTRODUCTION

While there have been many studies on the effects of noise on hearing, little has been done with noises dominated by low-frequency energy. The emphasis of research to date has either been with wide bands of noise or octave bands of noise with center frequencies of 500 Hz and above. There are several reasons, however, why the effects of noise bands having center frequencies below 500 Hz should be studied.

First, all damage-risk criteria (DRC) are currently expressed in terms of dBA levels rather than unweighted octave-band levels. The effect of A-weighting is to de-emphasize the levels of low-frequency sounds. Levels are reduced by A-weighting by as much as 70 dB at 10 Hz, to 26 dB at 63 Hz, to as little as 0.8 dB at 800 Hz (ANSI, 1971). By specifying DRC in terms of A-weighted levels, the implicit assumption is that high-level, low-frequency sounds are not as harmful to hearing as are high-level, high-frequency sounds. We know that loudness, annoyance, masking, and speech interference all increase substantially when very low frequencies reach sufficient levels. It seems that the same effect could occur with threshold shifts.

Second, most hearing protectors characteristically provide poor attenuation at low frequencies. Consequently, it is more difficult to protect hearing from high-intensity, low-frequency sounds than from high-intensity, high-frequency sounds.

Third, a dearth of information exists concerning the effects of high-intensity, low-frequency noise on hearing.

The present experiment provides data relevant to these issues.

I. METHODS AND PROCEDURES

A. Subjects

The subjects were eight male, binaural chinchillas that ranged from 11 to 32 months of age at the start of the experiment. The chinchillas were purchased from a local fur rancher.

B. Apparatus

1. Audiometric

Behavioral testing was done in a 1200 Series Industrial Acoustics Company (IAC) sound room. A double grille cage similar to that described by Miller (1970) was located in the center of the room. The cage was constructed of $\frac{1}{4}$-in. (0.64 cm) stainless-steel rod and was 18 in. (46 cm) long, 7 in. (18 cm) wide, and 9.5 in. (24 cm) deep. A barrier 1 in. (2.5 cm) high divided the cage into two compartments. A light bulb mounted in a block of Plexiglas was attached to each side of the barrier. A metal frame supported the cage so that the center of the cage was 30 in. (76 cm) above the floor of the room. On one side of one compartment were mounted three small lights (type 222) and on the opposite side were mounted three photocells. These photocells were used to detect the location of the animal in the cage. A TDH-39 earphone was mounted near the center of the cage and was used to deliver a 250-Hz square wave signal which served as an electronic buzzer. Pure tone test signals were delivered through a cabinet-mounted, 15-in. (38 cm) coaxial loudspeaker (Altec 418B) which was placed on the floor of the room with its diaphragm oriented at a 45° angle to the cage and 36 in. (91 cm) from the cage. This configuration provided the most uniform sound field within the test cage.

[a)]In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals," as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council. These results were presented at the 93rd Meeting of the Acoustical Society of America [J. Acoust. Soc. Am. 61, S 78(A) (1977)].

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A Hewlett-Packard pushbutton oscillator (model 241A), a Hewlett-Packard attenuator (model 350D), and a Crown amplifier (model DC300) were used to generate and adjust the signal level. The signals were exponentially gated by a circuit utilizing an Analog Devices 531L1 multiplier. The control, duration, and sequencing of events, as well as response recording, were accomplished with a ProLog PLS 401 microprocessor. The subjects were observed on closed circuit television.

2. *Exposure*

Broadband noise was generated by a Brüel and Kjær (B & K) random noise generator (type 2402) and passed through an octave-band filter set (B & K type 1612). Levels were controlled by an Altec 1590B amplifier. The level of the noise bands was continuously monitored with a B & K level recorder (type 2305) and the spectra of the noise bands were checked in the sound field at least twice daily by using a time series analyzer (Time Data model 1923A). The subjects were exposed to the noise bands in a 1200 series IAC sound room which had been modified by covering its walls and ceiling with tempered masonite. The noise bands were delivered to the room through four Altec 9844A speaker systems; a total of eight, 15-in. loudspeakers. Four chinchillas were placed in individual compartments of a cage constructed of hardware cloth. The dimensions of each compartment were 12 in. (30 cm) long, 7 in. (18 cm) wide, and 7.5 in. (19 cm) high, and the dimensions of the total cage were 24 in. (61 cm) long, 14 in. (36 cm) wide, and 7.5 in. (19 cm) high.

C. Training and testing procedures

1. *Threshold testing*

Before thresholds were determined, the sound field within the double grille cage was carefully calibrated using an array of four B & K $\frac{1}{2}$-in. condenser microphones (type 4134). The level of each frequency was determined at 36 locations within the cage. The mean and median sound pressure levels for each frequency, as well as the range and the semi-interquartile range are given in Table I. These values are comparable to those reported by Miller (1970).

During the first stage of training the subjects were presented a pure tone with a duration of 3.84 s. If the animal crossed from one compartment to the other during this interval, electric shock was avoided. The execution of an avoidance response resulted in the immediate termination of the signal and the illumination of the lights at the barrier for 1.28 s. If the animal failed to cross from one compartment to the other during the 3.84-s signal presentation, ac shock at a nominal current level of 0.7 mA and buzzer were simultaneously presented until the crossing response (escape response) occurred. The escape response resulted in the immediate termination of shock, buzzer, and the auditory signal, and the 1.28-s illumination of the barrier lights. The subjects received five sessions during this stage of training. Each session consisted of two presentations of each of the eight frequencies for which threshold was to be determined for a total of 16 trials per session. Trials were presented every 60 s on the average (range, 45–75 s). The intensity of the tones was unsystematically varied from trial to trial over a 15-dB range (60–75 dB SPL).

The subjects received five sessions in the next stage of training. The only changes were a gradual reduction of the average intertrial interval from 60 to 20 s and the intensities of the tones varied over a 40-dB range (50–90 dB).

The final training stage consisted of two sessions. The only change was the introduction of pulsed tones. Each trial consisted of three tone pulses with 720-ms on times separated by 560-ms off times. The avoidance response interval elapsed at the onset of the fourth tone pulse which occurred 3.85 s after trial onset. The tone pulse had an exponential rise and decay function with a first time constant (63% full on) of 14 ms.

The frequencies tested were 0.063, 0.09, 0.125, 0.5, 1.0, 1.4, 2.0, and 4.0 kHz. Thresholds for these frequencies were determined using a modified method of limits (Miller, 1970). On the first trial of a threshold determination, the signal was presented at a level of about 70 dB SPL. If the tone was correctly responded to, the level was decreased by 20 dB and another trial was presented. This continued until the subject failed to make an avoidance response. On the trial following a miss, the level of the tone was increased 10 dB and the threshold was taken as the level halfway between the lowest level at which the subject correctly responded and the highest level at which it failed to respond to the signal. After enough data were collected to estimate an animal's threshold, a threshold value which was discrepant from that estimate by 15 dB or more was discarded and a second determination was made. The threshold obtained on the second determination was al-

TABLE I. Means, medians, ranges, and semi-interquartile ranges (SIQRs) of measurements made at 36 locations within the double grille cage. Measurements made with 10-dB attenuation in audiometric circuit.

	Frequency (kHz)										
	0.063	0.09	0.125	0.25	0.5	1.0	1.4	2.0	4.0	5.7	8.0
Median[a]	80.1	97.6	92.1	95.2	102.7	98.2	103.0	108.8	93.1	90.2	68.8
Mean[a]	80.6	97.4	92.1	94.8	102.8	98.0	102.8	108.2	93.2	89.8	68.6
Range[b]	7.1	6.7	7.7	7.7	4.2	12.8	6.8	10.0	14.6	14.4	14.2
SIQR[b]	2.8	1.8	3.5	2.8	1.5	1.1	1.6	2.5	6.0	4.6	5.6

[a]Means and medians are in dB SPL *re* 20 μPa. [b]Range and semi-interquartile range are in dB.

ways accepted. A sham trial always followed the last trial of each threshold determination. This was done to get an estimate of the rate of "spontaneous responding." These trials were identical to regular trials except that the oscillator was unplugged from the circuit and shock and buzzer were turned off.

On those trials near threshold, shock was presented intermittently. However, the buzzer was always presented and appeared to function as a potent secondary reinforcer making it necessary to shock the animals at subthreshold levels only on a small proportion of the trials (5–10%).

2. Exposure conditions

The eight subjects were divided unsystematically into two groups of four animals. One goal of the present experiment was to determine if bands of noise which were nearly equal in *A*-weighted level but had large discrepancies in octave-band level (OBL) would have similar effects on the absolute hearing threshold of the chinchilla. Two octave bands of noise were selected which fulfilled these requirements: an octave band centered at 63 Hz and an octave band centered at 1000 Hz. In the conversion from OBL to *A*-weighted level at 63 Hz, the OBL is reduced by 26 dB, while the OBL and *A*-weighted level at 1000 Hz are equal (ANSI, 1971). Therefore, when these two noise bands are equated in *A*-weighted level they have a 26 dB difference in OBL. The spectral characteristics of the two noise bands as measured in the sound field, are shown in Fig. 1. The highest harmonic of the 63-Hz band occurred at about 200 Hz and was 40 dB down from the peak of the noise. All other harmonics were either 75, 80, or greater than 80 dB down from the peak. The levels of the noise were calibrated at each of the four corners and the center of the exposure cage. The levels of both of the noise bands were uniform ±2 dB across these five locations.

Threshold shift (TS) has been found to grow monotonically during the first 24 h of exposure and to reach a plateau or asymptote shortly thereafter (e.g., Carder and Miller, 1971, 1972; Mills and Talo, 1972; Mills, 1973). Therefore, in order to maximize the possibility that asymptotic threshold shift (ATS) was attained, the exposure durations in this study were all 72 h.

The subjects exposed to the 63-Hz octave-band noise (OBN) were first exposed at a level of 100 dB SPL, then at 110 dB SPL, and finally at 120 dB SPL. The subjects exposed to the 1000-Hz OBN were exposed to successive levels of 75 dB SPL, 85 dB SPL, and 95 dB SPL. During exposure the growth of TS was measured at intervals of 4, 8, 12, 24, 48, and 72 h. At each interval the subjects were removed from the noise for 15 min. During the first 2 min the animal sat in the test cage. Two threshold determinations were then made at the frequency approximately one-half octave above the center frequency of the exposure band (90 and 1400 Hz, respectively). These two measurements were done from minutes 2 to 6 and were averaged to derive a TS_4 measure. During minutes 6–14, one threshold measurement was made at 63, 90, 125, and 500 Hz for the 63-

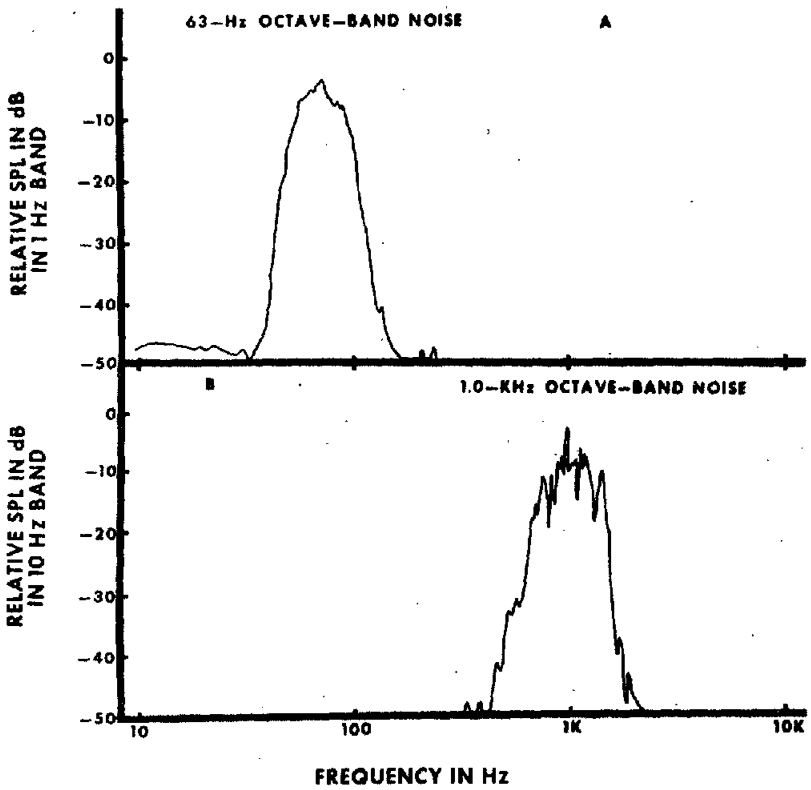

FIG. 1. Power spectrum characteristics of the octave bands of noise used for exposure as measured in the sound field. Panel A depicts the octave band with a center frequency of 63 Hz and panel B depicts the octave band with a center frequency of 1000 Hz.

Hz OBN subjects and at 1.0, 1.4, 2.0, and 4.0 kHz for the 1.0-kHz OBN subjects. These frequencies were tested in random order. The amount of shift at these frequencies was interpreted as TS_{10} (TS an average of 10 min after removal from the noise). The subjects were then returned to the noise during the fifteenth minute of the test period. After the 4-h test the animals were returned to the noise and remained in the noise for four more hours before the 8-h test and so on. The test schedule was adjusted by 15 min each time during exposure so that the animals had received an actual exposure of the stated amount of time. The recovery time given the 63-Hz OBN group between exposures was nine days between 100 and 110 dB, and 77 days between 110 dB and 120 dB. The recovery time given the 1000-Hz OBN group between exposures was 13 days between 75 dB and 85 dB, and 66 days between 85 dB and 95 dB. All four animals in each group were simultaneously exposed in the four compartment exposure cage. The cage was regularly rotated 180° so that the location of the subjects was not fixed throughout the exposure.

3. Recovery conditions

After 72 h the animals were removed from the noise and tested. Thresholds were determined at intervals of 4, 8, 12, 24, 48, and 72 h as well as at regular intervals for longer periods of time as required for either complete recovery or asymptotic recovery to be attained. During the recovery cycle a complete audiogram at all eight frequencies was obtained at each recovery interval.

II. RESULTS

A. Preexposure audiograms

All subjects correctly performed the avoidance response at a level of 90%–100% within four to seven sessions (64–112 trials). This acquisition time is comparable to that reported elsewhere (Saunders, Mills, and Miller, 1977), and again indicates the speed with which the chinchilla learns a shuttle avoidance response.

The amount of TS is each exposure was determined by taking the difference between baseline thresholds and thresholds during exposure and recovery. Baseline thresholds were determined prior to each of the three exposures. This was done to assure adequate representation of the animals' hearing at the successive levels of exposure. The baseline audiogram for the first exposure condition was the average of five audiograms and for the second and third exposures was the average of three audiograms. All baseline audiograms were essentially the same. The audiograms depicted in panels A and B of Fig. 2 are the average thresholds over all of the baseline audiograms. Panel A shows the audiograms for the two groups. Each threshold point in each group is the average of 44 measurements (4 subjects × 11 audiograms). There was essentially no difference between the two groups. The audiogram for all eight subjects combined is shown in panel B of Fig. 2. Each data point is based on 88 threshold measurements. The vertical bars represent one standard deviation above and below the mean. Also shown are the thresholds for monaural chinchillas reported by Miller (1970). The audiogram for the binaural animals of the present study closely resembles that for Miller's monaural animals. The audiogram is also comparable to the average audiogram reported by Miller for two groups of binaural animals. The variability of the present threshold measurements is also comparable to the measurements made by Miller.

The false-alarm rate during the preexposure threshold determinations for the subjects exposed to the 63-Hz noise band was 0.11 and for the subjects exposed to the 1000-Hz noise band was 0.12. Both groups had false-alarm rates of 0.11 during the exposure and recovery phases of the experiment. This indicates that the two groups were comparable in terms of a low-level of spontaneous activity, and that their behavior did not change during the exposure and recovery phases of the study.

B. Exposure to octave-band noise centered at 63 Hz

1. Growth of TS

The growth of TS_4 at 90 Hz for the three exposure levels is shown in Fig. 3. The 100 dB exposure level failed to produce any TS_4 with the maximum shift (TS_{max})

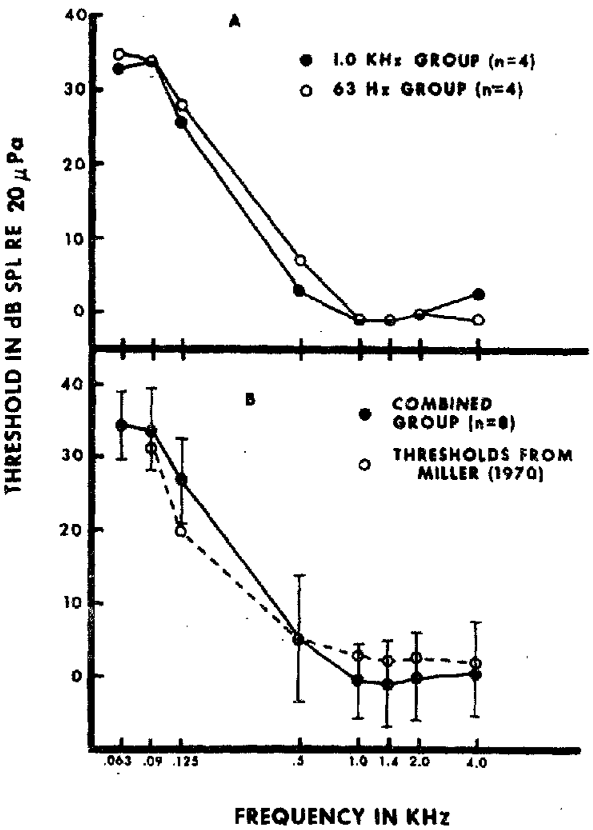

FIG. 2. Preexposure audiograms for binaural chinchillas. Panel A shows the preexposure audiograms for each exposure group. Panel B shows the audiogram for all subjects. The vertical bars indicate one standard deviation above and below these values. Also shown are the thresholds of monaural chinchillas reported by Miller (1970).

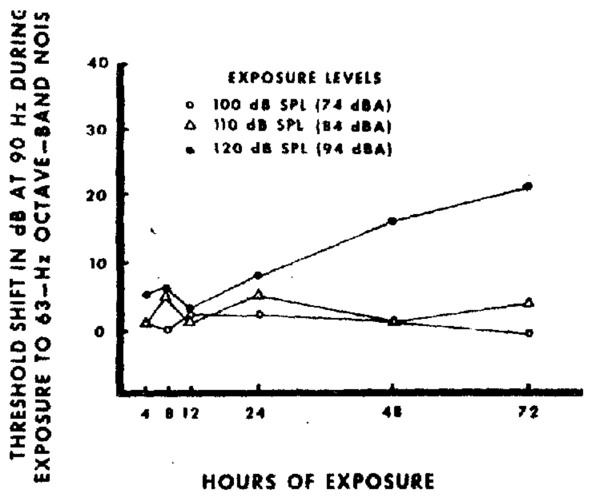

FIG. 3. Growth of threshold shift at 90 Hz during exposure to octave-band noise with a center frequency of 63 Hz at three exposure levels.

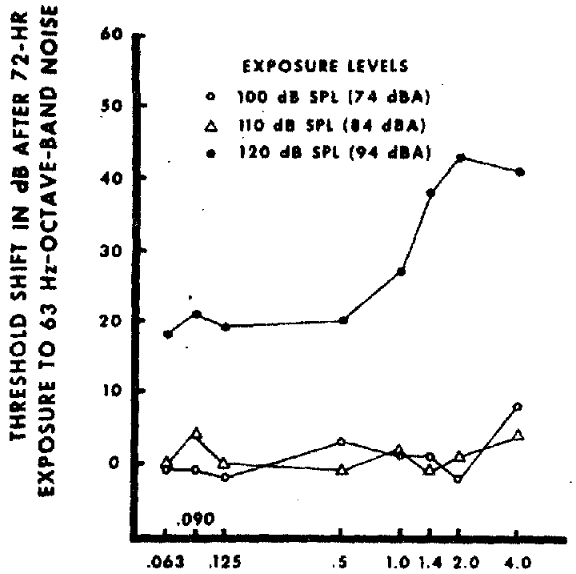

FIG. 4. Threshold shifts between 0.063 and 4.0 kHz after a three-day exposure to octave-band noise with a center frequency of 63 Hz at three exposure levels.

measured being 2 dB. The maximum amount of TS_4 measured for the 110-dB exposure level was 5 dB. Both of these shifts were within the range of measurement error and indicate that essentially no TS_4 occurred at 90 Hz in the 100-dB exposure and that perhaps a very small amount of TS_4 occurred at 90 Hz in the 110-dB exposure. In the 120 dB SPL exposure, 8 dB of TS_4 developed during the first 24 h and 21 dB had developed at 72 h. Unlike TS_4 to higher frequency bands of noise (e.g., Carder and Miller, 1971, 1972; Mills, 1973), asymptotic shift was apparently not reached in 24 h. If the 21-dB shift at 72 h is assumed to be maximum and to reflect the first measurement at asymptote, then the value of the first time constant of the growth of TS_4 is approximately 36 h. If the 21-dB shift is, in fact, below asymptotic level, then the time constant becomes even longer. In either case, the time constant of growth of 36 h is considerably longer than previously reported for the chinchilla (Carder and Miller, 1972). The first time constants of growth and recovery for all conditions showing TSs are given in Table II.

The level of TS at each of the eight frequencies at the termination of the 72 h exposures is shown in Fig. 4. For the 100- and 110-dB exposure levels little TS occurred at any of the eight frequencies tested. The possible exception may have been at 4.0 kHz, but again, only a small TS occurred. On the other hand, the TS produced by the 120-dB exposure level across frequency was large. From the frequencies of 63–500 Hz, the amount of TS was about 20-dB. There was a sharp, unexpected increase in TS at 1.0 to 4.0 kHz with the TS_{max} of 43 and 41 dB at 2.0 and 4.0 kHz, respectively. Unlike any previous findings with the chinchilla that we are aware of, the frequency region of TS_{max} was not found one-half to one octave above the center frequency of the noise band used for exposure. Rather, the frequency region of TS_{max} was five to six octaves above the center frequency of noise.

2. *Recovery from* TS

The recovery curves for 90 Hz at all three exposure levels and for 2.0 kHz at the 120-dB exposure level are shown in Fig. 5. The course of recovery was followed until it appeared to stabilize. All TSs at 90 Hz completely recovered within 48 h postexposure. The time constant for recovery at 90 Hz for the 120-dB exposure

TABLE II. The first time constants in hours for growth and recovery of TS.

	Exposure band					
	63 Hz			1000 Hz		
	Test frequency (kHz)	Exposure level [dB SPL (dBA)]	First time constant (h)	Test frequency (kHz)	Exposure level [dB SPL (dBA)]	First time constant (h)
Growth	0.09	120 (94)	>36	1.4	75 (75)	<4
				1.4	85 (85)	<4
				1.4	95 (95)	<4
Recovery	0.09	120 (94)	12	1.4	75 (75)	12
		120 (94)	72	1.4	85 (85)	24
				1.4	95 (95)	36

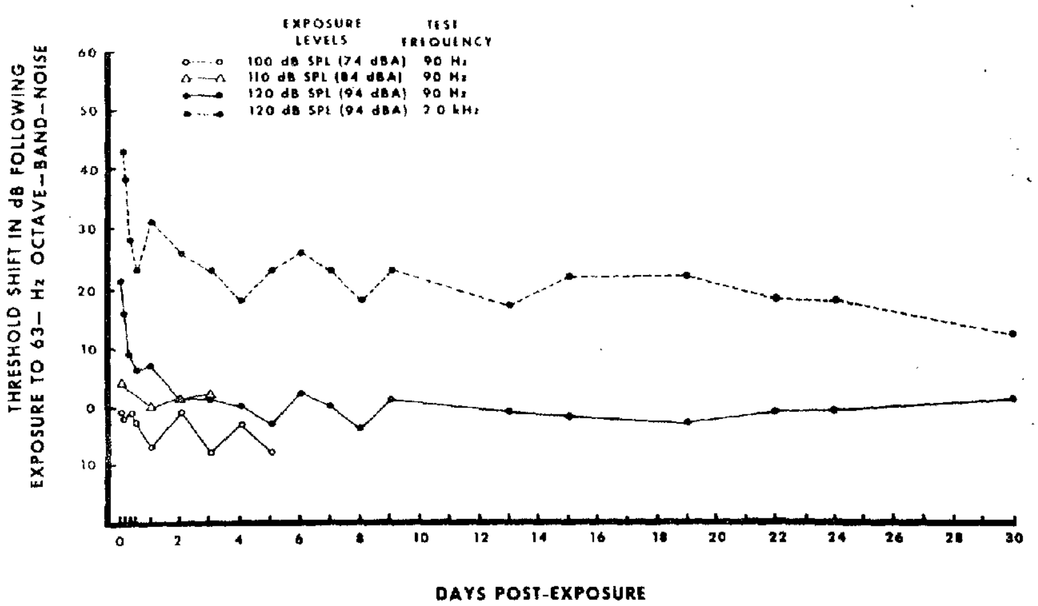

FIG. 5. Recovery of threshold shifts at 90 Hz over the 30-day period following the three-day exposures to octave-band noise with center frequency of 63 Hz at three levels. Recovery at 2.0 kHz is also shown for the highest exposure level.

was about 12 h (see Table II). The average TSs at 1.4 and 2.0 kHz for the 120-dB exposure over the last three data points (days 22, 24, and 26) are given in Table III. These shifts are interpreted as permanent threshold shifts (PTSs). As can be seen, the maximum PTS was 16 dB at 2.0 kHz. The time constant of recovery at 2.0 kHz was about 72 h (see Table II). It is interesting that the time constant for recovery at 2000 Hz was six times larger than at 90 Hz for the same exposure level, indicating a very rapid recovery at the low frequencies. This is particularly interesting considering the very slow growth pattern found at 90 Hz. The thresholds for all other frequencies completely returned to preexposure levels.

TABLE III. Threshold shifts in dB following three days of exposure to octave-band noise centered at 63 Hz at 120 dB SPL (94 dBA) and to octave-band noise centered at 1000 Hz at 95 dB SPL (95 dBA). Each value is the average shift found over the last three days tested, averaged over days 22, 24, and 30 postexposure for the 63-Hz exposure and days 19, 25, and 30 postexposure for the 1000-Hz exposure.

Frequency (kHz)	1.4	2.0
63 Hz		
Exposure band	11	16
1000 Hz		
Exposure band	6	9

C. Exposure to octave-band noise centered at 1000 Hz

1. Growth of TS

The accumulation of TS_4 at 1.4 kHz, one-half octave above the center frequency of the 1.0-kHz band, is depicted in Fig. 6. Both the 75 dB SPL and the 85-dB exposures reached asymptotic levels in about 24 h. Little change was found after the first 4 h of exposure at the 75-dB exposure level while there was a 10-dB increase

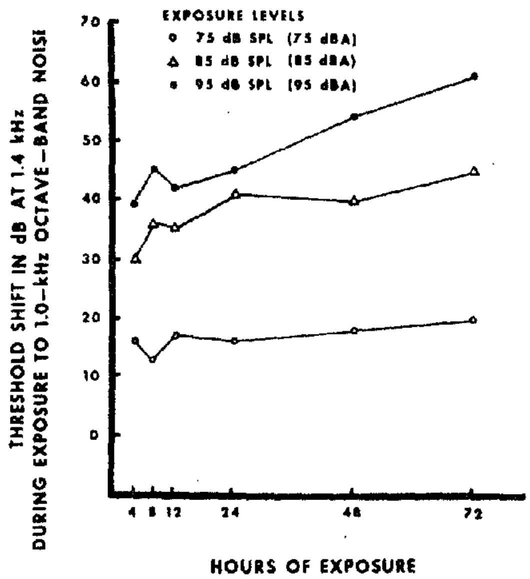

FIG. 6. Growth of threshold shift at 1.4 kHz during exposure to octave-band noise with a center frequency of 1000 Hz at three exposure levels.

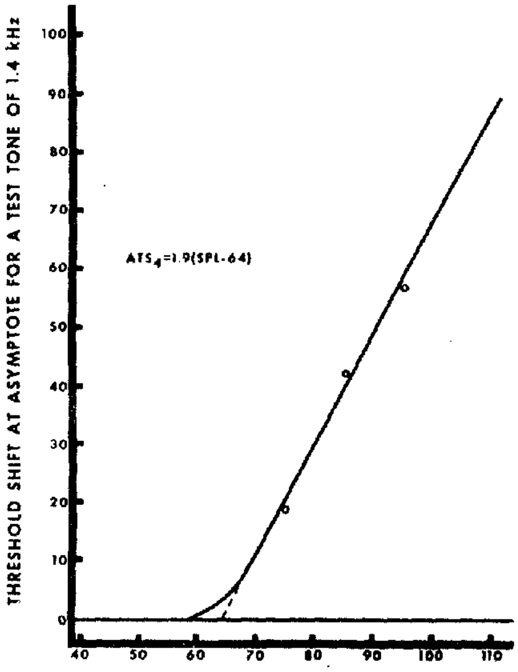

FIG. 7. The relationship between threshold shifts at asymptote for a tone of 1.4 kHz and the level of an octave-band noise centered at 1000 Hz.

in TS_4 between 4 and 24 h at the 85-dB exposure level. The levels at ATS_4 calculated by averaging the TS_4 found at 48 and 72 h was 19.0 dB for the 75-dB exposure condition and 42.5 dB for the 85-dB exposure condition. The time constants for the growth of TS_4 at 1.4 kHz for the 75- and 85-dB exposures were less than 4 h for both exposures (see Table II). Since tests were not done prior to the 4-h exposure time, the exact value of the time constants are unknown. It is not clear whether TS_4 in the 95-dB condition reached asymptote. However, it seemed reasonable to assume that asymptote could be closely approximated by averaging TS_4 for 48 and 72 h. This yielded ATS_4 of 57.5 dB. The time constant for this ATS_4 was slightly less than 4 h (see Table II).

It has been proposed that the level of ATS_4 for the chinchilla grows linearly at a rate of about 1.7 dB for each dB of exposure-band level above a certain frequency dependent level (Carder and Miller, 1971, 1972; Mills, 1973; Mills and Talo, 1972; Mills, Talo, and Gordon, 1973; Saunders, Mills, and Miller, 1977). Fitting a regression line to the three levels found for the 1.0-kHz exposures at 1.4 kHz reveals a rate of growth of 1.9 dB and a subtractive constant of 64 dB. This means that for every dB increase in exposure level above 64 the level at ATS_4 will increase by 1.9 dB. This is shown in Fig. 7. This agrees with the previous data. In fact, a 3-dB increase in the ATS_4 of the 75-dB exposure level (an increase within the measurement error) would produce a constant of 1.7 dB. Although less straightforward, it appears that the shifts at 90 Hz found with the 63-Hz exposures also closely follow these values.

The levels of TS at each of the eight audiogram frequencies after the three 72-h exposures are shown in Fig. 8. The largest shifts were found between 1.0 and 2.0 kHz with the TS_{max} at 1.4 kHz for the 75- and 85-dB exposures and at 2.0 kHz for the 95-dB exposure. There was also more TS at 63 Hz and 90 Hz than at 125 Hz in all conditions. The least amount of TS was shown at 125 Hz in all exposures. The reason for this is unknown. Generally, these data resemble those found by others with exposure noise bands centered at 500 Hz and 4000 Hz (Carder and Miller, 1971, 1972; Mills, 1973).

2. *Recovery from* TS

The course of recovery from ATS_4 at 1.4 kHz is shown in Fig. 9. Thresholds completely recovered in two to five days after termination of the exposure at the 75- and 85-dB levels. At 30 days postexposure there was still TS evident after the 95-dB exposure. There was, as shown in Table III, a PTS of 6 dB at 1.4 kHz and a PTS of 9 dB at 2.0 kHz. The time constants for recovery for the 75-, 85-, and 95-dB exposure levels were 12, 24, and 36 h, respectively (see Table II). A 10-dB increment in exposure level produced a 12-h increment in the time constant for recovery. The level of recovery for the 95-dB exposure was essentially constant after four days.

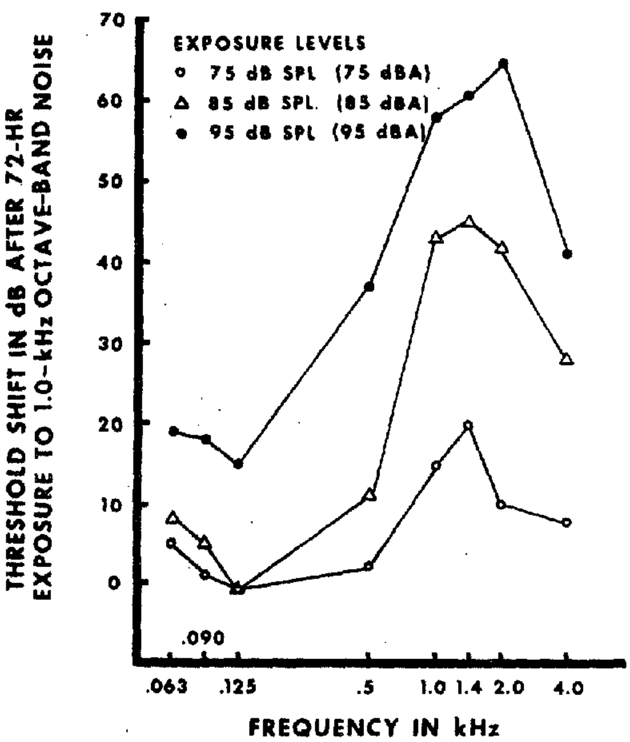

FIG. 8. Threshold shifts between 0.063 and 4.0 kHz after a three day exposure to octave-band noise with a center frequency of 1000 Hz at three exposure levels.

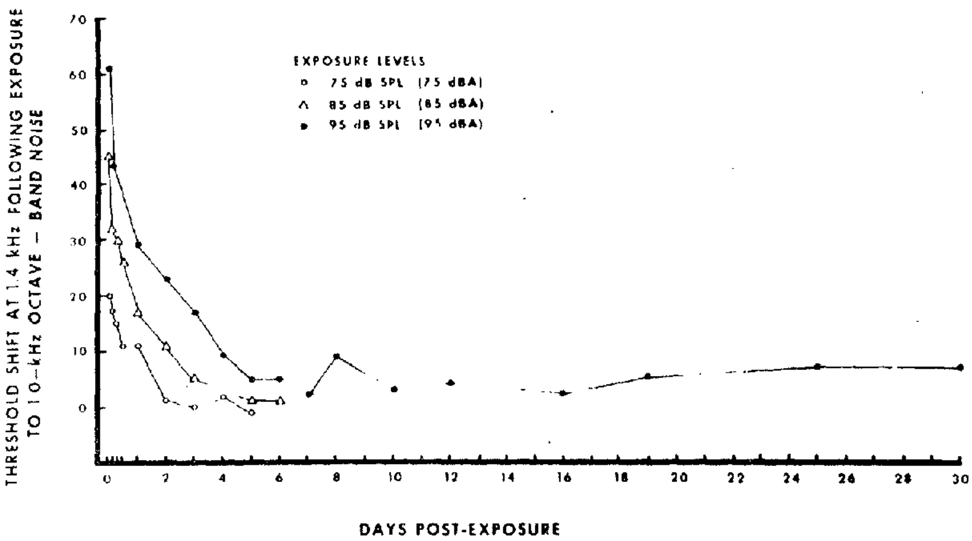

FIG. 9. Recovery of threshold shifts at 1.4 kHz over the 30-day period following the three-day exposures to octave-band noise with a center frequency of 1000 Hz at three levels.

D. Comparison of the two exposure bands

The growth of TS to the 1000 Hz noise band was apparently much more rapid than to the 63 Hz noise band. This was true at least for the development of TS at the half octave above the exposure bands. The time constant for the growth of TS at 90 Hz for an exposure level of 120 dB SPL (94 dB*A*) was more than nine times larger than the time constant at 1400 Hz at 95 dB SPL (95 dB*A*). This is a large unexpected difference for two noise bands having only a 1 dB*A* difference. Unfortunately, the high frequencies were not monitored during the growth phase of the 63-Hz exposures. Consequently, the growth characteristics at these frequencies are not known.

The high-frequency TS produced by the low-frequency exposure was much slower to recover than any of the TSs produced by the high-frequency exposure. The time constant for recovery at 2.0 kHz for the 63-Hz exposure at 120 dB SPL (94 dB*A*) was twice that at 1.4 kHz for the 1000-Hz exposure at 95 dB SPL (95 dB*A*).

With regard to the hearing loss incurred by exposure to the noise bands, little or no TS and no PTS was found for the 63-Hz band exposures at 100 dB (74 dB*A*) and at 110 dB SPL (84 dB*A*). Modest amounts of TS and no PTS were found for the 1000-Hz band exposures at 75 dB SPL (75 dB*A*) and at 85 dB SPL (85 dB*A*). However, TS and PTS were produced by both noise bands at their highest levels. Although the amount of TS at 1.4 and 2.0 kHz produced by the 1000-Hz band was 20 dB greater than that produced by the 63-Hz band, the 63-Hz exposure produced nearly twice the PTS as did the 1000-Hz exposure. (See Figs. 4 and 8, and Table III.)

III. DISCUSSION

The most interesting finding was the high-frequency hearing loss produced by the low-frequency noise. We propose that nonlinearities caused by overdriving one or all of the components of the auditory system (e.g., middle ear, basilar membrane) produced the high-frequency shifts. The exact nature of the mechanism awaits further study. The effect appears to have a rather steep level dependency as evidenced by the almost complete absence of effect at the 100-dB SPL (74 dB*A*) and 110-dB SPL (84 dB*A*) exposure levels and the abrupt TSs and resultant PTSs found with the 120-dB SPL (94 dB*A*) exposure level. These data are quite different from those found by others with bands of noise having higher center frequencies. The data for the three exposures with the noise band centered at 1000 Hz were consistent with previous data. Another interesting finding was that the substantially larger TS produced by the 1000-Hz exposure resulted in a smaller PTS than that produced by the 63-Hz exposure. Further investigation is obviously needed to verify these results and to clarify the growth and recovery characteristics of exposure to high-intensity, low-frequency noise.

The present findings are suggestive of low-frequency noise being an insidious cause of high-frequency hearing loss. This is of particular importance since DRC are specified in *A*-weighted levels. Our results indicate that the use of *A*-weighted levels to prescribe "safe" auditory environments may be inappropriate to areas with intense low-frequency components present. Not only do the present findings indicate a high-frequency hazard from low-frequency noise, but also that the low-frequency noise may be *more hazardous* than high-frequency noise having equal *A*-weighted levels. At the exposure level that produced PTS, the 63-Hz noise band was 1 dB *lower* in level when measured in dB*A* than the 1000-Hz noise band, i.e., 94 versus 95 dB*A* respectively, and the 63-Hz noise band produced nearly *twice* the PTS of the 1000-Hz noise band. This demonstrates that, contrary to the dictates of DRC using *A*-weighted levels, all sounds with equal *A*-weighted levels may not be equally hazardous. The adequacy of the *A*-weighting scheme to depict all noise hazards has also been questioned by Cohen, Anticaglia, and Carpenter (1972) in relation to noises with various sloped spectra.

The argument can be raised that the effects found are appropriate for chinchillas only, and should not be extrapolated to man. Certainly this is true for our results as for any study using an animal model. In terms of low-frequency noise producing high-frequency hearing loss, Jerger *et al.* (1966) exposed humans to tones ranging in frequency from 2 to 22 Hz at levels of 119–144 dB SPL. The subjects received up to seven 3-min exposures separated only by a tracking audiogram taken in the exposure room. Temporary threshold shifts (TTSs) were found in 11 of 19 subjects. All TTSs occurred between 3.0 and 8.0 kHz. This shows that the effect is not confined to the chinchilla but also occurs in man. The question of level cannot be answered as yet. With the exception of one subject, all TTSs found by Jerger *et al.* were produced by levels from 137 to 141 dB SPL. We do not yet know the response of the human ear to the 63-Hz band of noise at the levels used with the chinchillas.

In conclusion, it appears highly probable that high-frequency hearing loss can be produced in man by low-frequency sounds and that the use of *A*-weighted levels to specify DRC for all noise sources may be inappropriate. The present findings raise questions concerning the effects of exposure to high-intensity, low-frequency noise and provide sufficient foundation for further study and concern for the adequate recognition of a potential health hazard.

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