HEARING THRESHOLD SHIFTS TO HIGH FREQUENCY TONAL PULSES

by

J. Donald Harris, Ph. D.

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NUMBER 785

Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF51.524.020-0002BAXI.01

Reviewed and Approved by:

Charles F. Gell

Charles F. Gell, M.D., D.Sc. (Med)
SCIENTIFIC DIRECTOR
NavSubMedRschLab

Approved and Released by:

R. L. Sphar

R. L. Sphar, CDR MC USN
OFFICER IN CHARGE
NavSubMedRschLab

SUMMARY PAGE

THE PROBLEM

This report concerns the effect on hearing of two-hour trains of high-frequency, high-intensity airborne pure-tone pulses at 100 dB sound pressure level (SPL).

FINDINGS

A tentative and non-conservative estimate was made that such pulse trains could be borne indefinitely by 85% of those exposed, only if the SPLs were 90 dB or less, and percentage tone-on time did not exceed 5%.

APPLICATION

The information presented in this report will be useful to physicians and others specifying noise levels in ship compartments, and to engineers involved in meeting such specifications.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit MF51.524.020-0002BAX1. The present report is Number 1 on this work unit. This study was supported in part by the Naval Underwater Systems Center, Project Order Nos. 3-5055 and 3-5066. It was submitted for review on 26 April 1974, approved for publication on 31 May 1974, and designated as NavSubMedRschLab Report No. 785.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

In a study of the effect on hearing of high-frequency, high-intensity, airborne pure-tone sounds, thirteen normal-hearing enlisted men were given 11 two-hour trains of pulses at 3.5 kHz at 100 dB sound pressure level (SPL). Acoustic load was gradually increased from one 0.5-sec pulse every 60 sec to one 0.75-sec pulse every 15 sec, at which point the group temporary threshold shift approached this Laboratory's internal Damage Risk Criteria (DRC) and the experiment terminated. A very tentative and non-conservative estimate was made from these data and from the sparse literature available that the ears of these men could marginally stand such pulses for days on end, only if the SPL were reduced to 90 dB and the percentage on-time did not exceed 5%. More precise damage risk criteria (DRC) must wait upon rather massive data from individual subjects on the time needed for full recovery from single high-intensity pulses.

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INTRODUCTION

A continuing problem exists in hearing conservation for intermittent pure-tone stimulation. National bodies have written damage risk criteria (DRC) for continuous and intermittent noises, both broad-band and narrow-band, but these DRC cannot be applied directly to the case of pure tones, more especially relatively brief pulses. For example, the U.S. Navy Hearing Conservation Instruction makes no mention of the pure tone problem at all, nor, in any detailed way, of noise bursts of duration less than 15 min. The relevant Working Group of the NRC-Armed Forces Committee on Hearing, Bioacoustics, and Biodynamics (CHABA), of which the writer was a member[1] prepared nomographs for bandwidths of 1/3 octave or less, at durations as short as 3 min. These nomographs added the important datum of the recovery, or off-time, that must elapse before another intense, narrow-band noise burst should be allowed.

That these DRC cannot be used for pulsed tones was pointed out by Kryter,[2] who compiled data to show that pure-tone stimulation might produce 10-15 dB more temporary threshold shifts (TTS) than the noise DRC would predict, though he could offer no explanation. Presumably, the energy of a pure tone is, so-to-speak, more concentrated on the organ of Corti than a 1/3-octave band of noise (note that there are several aural "critical bands" within a 1/3-octave frequency range).

Therefore, it seems necessary to examine the pure-tone case itself, and to develop DRC not derived from noise stimulation.

This Laboratory has studied the pure-tone pulse problem previously, both for TTS[3,4,5,6] and for habitability[6,7,8,9]. In these studies a sampling was made of the pulse conditions, with pulse durations restricted to 1/4 sec or less, and listening sessions restricted to 25 min or less (one exception). These reports delineated the separate effects of overall sound pressure level (SPL), pulse duration, and duty cycle (% on-time) for these conditions. Now we wish to extend the data to the case of the longer pulse duration (up to 10 sec), the longer listening session (we concentrate on a 2-hr exposure in this experiment), and the more onerous duty cycles.

EXPERIMENT I: METHOD

As in previous reports[3,4], a group procedure was used. Thirteen enlisted men with normal hearing (no Hearing Level (HL) exceeded 25 dB from .25-8 kHz re ISO 1964 standards) were seated in a large double-wall soundproof chamber provided with seats and sets of closely-matched Permoflux phones in MX cushions, one set for L ears and one set for R ears. The same audiometric tape program as was used earlier[3] provided a pre-exposure audiogram for the test ear at 2.5, 3, 4, 6, and 8 kHz, with 7 estimates of threshold for each frequency in 6 min.

Phones were then removed and an array of 4 loudspeakers turned on for 2 hrs with some pulse train at 3.5 kHz. The SPL throughout the room with the men present was adjusted to an average of 100 dB SPL. During the 2-hr period the men were free to read, nap, play cards, sip coffee, so long as they did not protect the test ear in any way. Just before the last pulse, the men were alerted, and within 6" of the last pulse the audiometric program was presented. The men were given the following 2-hr sessions stretched over 23 days:

Day	3.5 kHz, 100 SPL, 2-Hr Exposure		
	Pulse Duration	Repetition Rate	Duty Cycle
1	1 sec	60 sec	1.7
2	1	30	3.3
3	1/2	60	0.8
4	1/4	30	0.8
5	3	180	1.7
6	1/4	15	1.7
7	1 1/2	30	5
8	1/2	30	1.7
9	1/2	15	3.3
10	2	60	3.3
11	3/4	15	5

These conditions were chosen so as to proceed generally from a less to more acoustic load, though on Day 2 we took advantage of a long weekend recovery. Since this Laboratory feels that a DRC should seek to protect 85% of ears (the most susceptible 15% to be taken care of by selection, monitoring audiometry, protective devices and procedures and, if all fails, VA compensation) we adopted the rule of thumb that we would expose no group to an acoustic load for which the 85th percentile would be likely to exceed a $TTS_{2\ min}$ at 4 kHz of more than 20 dB. As will be seen below, the third largest TTS_2 (this is our best estimate of the 85th percentile) was 14.5 dB for one of the 5% duty-cycle conditions, and we were unwilling to subject this group to a greater load. We had originally proposed that we give this group pulse durations up to 10 sec, and duty cycles as large as 16.7%, but as the data came in and were analyzed daily for the milder conditions, we became reluctant to go beyond the 3-sec pulse and the 5% duty cycle with the fixed SPL and session length of this experiment.

Analysis. The pre- and post-exposure response sheets were compared for every S and his TTS determined for every frequency at 7 points during the 6-min recovery (test) period. These 35 figures were tabulated for each S for every exposure, and for each S a graph was drawn depicting his recovery for the frequencies 4, 6, and 8 kHz separately. The paper used allotted 10 mm/5 dB, and 10 mm/min recovery. The area under the three recovery curves was integrated with a Keuffel and Esser planimeter in square inches. The combined area was taken to represent the fullest estimate of the audiometric shift due to the exposure. Of course, from the 4-kHz curve could also be determined easily the $TTS_{2\ min}$ in dB.

RESULTS AND DISCUSSION

A first approach was to test the equal-energy hypothesis, that is, that the same total acoustic load (i.e., equal duty cycle) over the pattern of pulses would yield the same TTS. Ward et al[10] showed that for intermittent noise pulses down to 1/2-sec duration the TTS_2 at 4 kHz was directly proportional to duty cycle (i.e., a noise "on" only half the time will produce half the TTS_2 of a noise on continuously). However, C. Rol[11] had shown that noise bursts shorter than 1/2 sec created proportionately more TTS.

In our previous data (Ref. 3, Fig. 2) there was no discernible effect of pulse duration between .037 and 0.25 sec, but the effect of duty cycle was relatively constant. Likewise, in the present data, TTS is seen to grow linearly not with pulse duration but with duty cycle. If we take the mean planimeter reading as the best estimate of total effect on the audiogram, Fig. 1 shows that for any duty cycle the effect is relatively constant irrespective of pulse length per se. Thus for these data we corroborate Ward et al.[10] on the primacy of duty cycle.

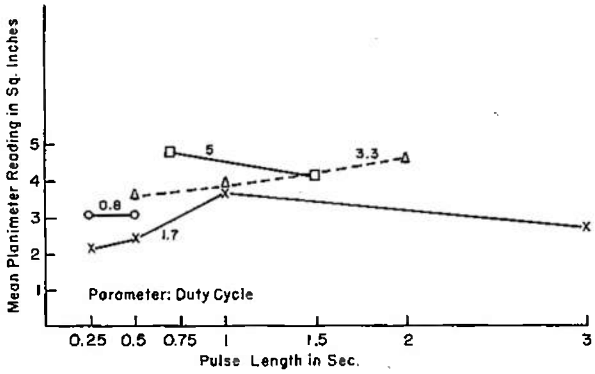

Fig. 1. Effect of Duty Cycle and Pulse Duration.

The linear effect of increasing duty cycle on planimeter readings is seen in Fig. 2: every 1% increase in duty cycle adds about 0.4 sq. inches to the planimeter reading.

It is well to compare the results of Experiment I with those of other studies by examining the more usual index of auditory damage, $TTS_{2\ min}$ at 4 kHz. Fig. 3 gives the 85th percentile TTS: there is a linear rise of 2.4 dB for every 1% increase in duty cycle. Yet Ward's formula for $TTS_{2\ min}$ at 4 kHz for stimulation in the octave band 2.4 - 4.8 kHz:

$$TTS_2 = 0.91\,r\,(S-75)\,(\log_{10} T + 0.19) - 8$$

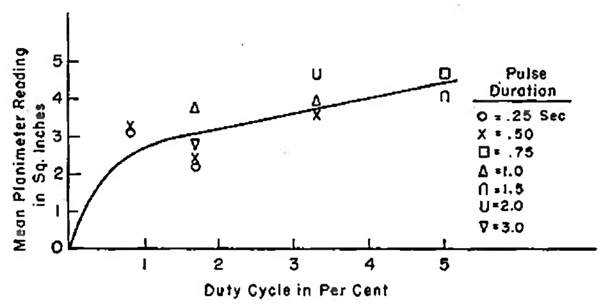

Fig. 2. Shows the Linear Effect of Increasing Duty Cycle.

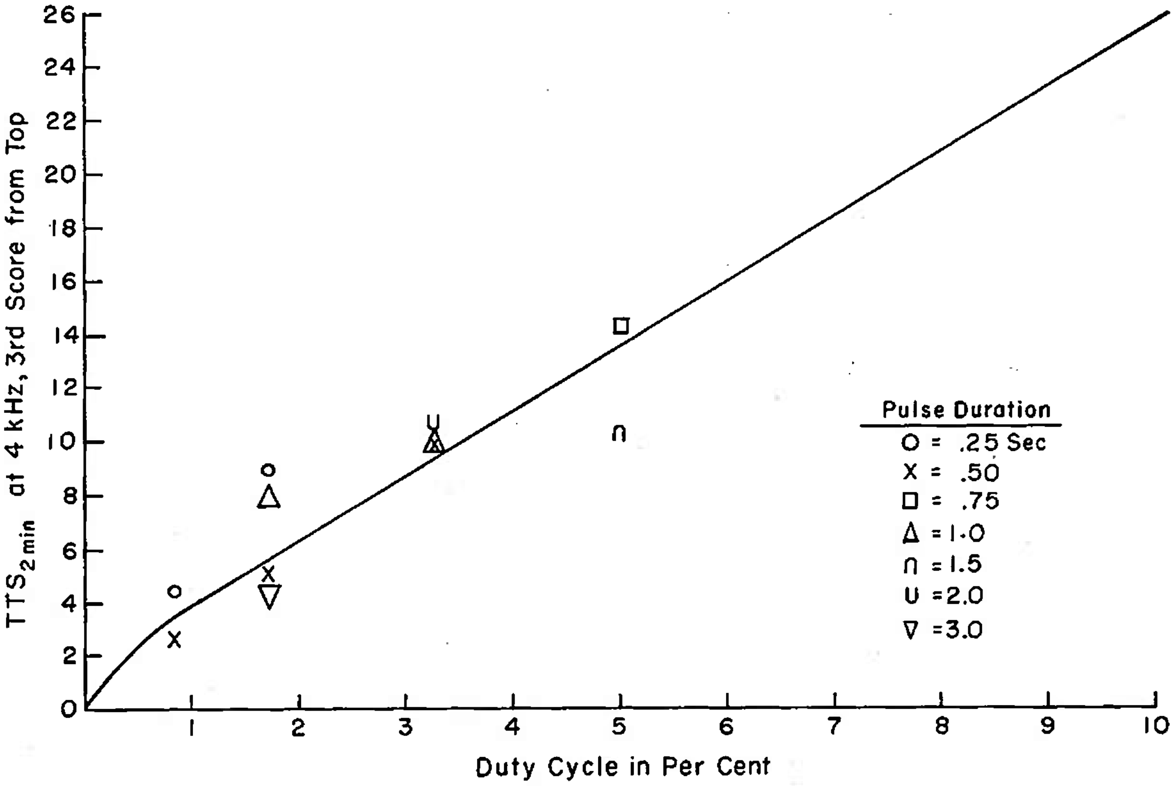

Fig. 3. Effect of Increasing Duty Cycle on TTS$_{2\,min}$ at 4 kHz.

where r = duty cycle, S = SPL, and T = duration in minutes, yields little or no TTS_2 for SPL = 100 dB and T = 120 min, unless the duty cycle is about 20% or more; the inadmissability is evident of using current formulations on noise for predicting TTS in our specific pure-tone conditions.

Although extrapolations are subject to chance with such data, Fig. 3 allows the tentative conclusion that exposure for two hours at 100 dB SPL at a 10% duty cycle would seriously exceed the DRC of 20 dB TTS_2 for the 85th percentile. Lewis (see Ref. 2, p. 209), using 4-kHz pulses 2 sec long, 50 sec off, found a reduction of 14 dB TTS from 95 dB SPL to 85 dB SPL, from which we may estimate in our data that the criterion TTS_2 of 20 dB would have been reached after 2 hrs of stimulation at 10% duty cycle at about 95 dB SPL. Furthermore, also from Lewis (see Ref. 2, p. 211), it can be seen that TTS_2 increases at about 17 dB per log unit of exposure. Applied to our data, this would mean that a TTS_2 of 20 dB would be reached after 1200 min of stimulation at 95 dB at only 3.5% duty cycle, but that if the level were reduced to 90 dB and the duty cycle were only 5%, it could be borne indefinitely.

SUMMARY AND CONCLUSIONS

Thirteen normal-hearing enlisted men were given 11 two-hour exposures, with at least a 22-hour recovery between exposures, to trains of 3.5-kHz pulses at 100 dB SPL. Pulse duration ranged from 1/4 sec to 3 sec, at repetition rates from one pulse every 15 to one pulse every 180 sec. Total acoustic load was increased until we estimated the $TTS_{2\ min}$ for the man at the 85th percentile would exceed 20 dB at 4 kHz. This provisional damage risk criterion (DRC) was approached by pulses of .75-sec duration once every 15 sec (5% duty cycle, or percentage one-time), and we did not subject these men in group fashion to more onerous conditions. TTS in our group was considerably greater than that predicted by Ward for noise bursts of comparable spectral region, SPL, session duration, and duty cycle, and the necessity of setting up DRC independently for pure tone pulses became more apparent.

Within the limitations of our stimulus parameters, the dominant feature contributing to TTS was duty cycle, rather than pulse duration or repetition rate per se, which is predictable from the hypothesis that equal energy yields equal TTS, and corroborates Ward on the strong effect of duty cycle. But indications from the literature and from an inspection of the data for individual Ss in this experiment point to the necessity of further consideration of the interactions between the TTS created by a single high-intensity pulse, however brief, and the time needed by a particular S to recover fully from that pulse.

These data, and extrapolations from an extremely scanty literature, lead to the tentative and not at all conservative estimate that 85% of ears would receive a $TTS_{2\ min}$ at 4 kHz of 20 dB or less, if a train of 3.5-kHz pulses at 5% duty cycle were to continue indefinitely at 90 dB SPL.

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY *(Corporate author)* NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP	
3. REPORT TITLE HEARING THRESHOLD SHIFTS TO HIGH FREQUENCY TONAL PULSES		
4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* Interim report		
5. AUTHOR(S) *(First name, middle initial, last name)* J. Donald Harris, Ph.D.		
6. REPORT DATE 31 May 1974	7a. TOTAL NO. OF PAGES 6	7b. NO. OF REFS 11
8a. CONTRACT OR GRANT NO. b. PROJECT NO. MF51.524.020-0002BAX1 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NSMRL Report Number 785 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	
10. DISTRIBUTION STATEMENT ~~Approved~~ for public release; distribution unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Research Laboratory Box 900 Naval Submarine Base Groton, Connecticut 06340	

13. ABSTRACT

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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0102-014-6600

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Auditory fatigue.						
Damage Risk Criteria for pure tones.						
Temporary Threshold Shift.						