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AUDITORY FATIGUE FOLLOWING HIGH FREQUENCY
PULSE TRAINS

by

J. Donald Harris, Ph.D.

Bureau of Medicine and Surgery, Navy Department,
Research Project NM 22 03 20.02.01

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U. S. Naval Medical Research Laboratory Report No. 306
Bureau of Medicine and Surgery, Navy Department,
Research Project NM 22 03 20.02.01

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SUMMARY PAGE

THE PROBLEM:

To explore temporary threshold shifts and possible auditory damage from high intensity pulse trains at 3.5 kc.

FINDINGS:

The effects of train duration, pulse length, and sound pressure level were investigated. Temporary threshold shifts occurred linearly in response to log duration, duty cycle, and sound pressure level. A level of 90 db could be listened to indefinitely with only negligible after-effects.

APPLICATION:

These data specify the damage risk criteria and levels of ear protection necessary for such auditory situations.

ADMINISTRATIVE INFORMATION

This investigation was undertaken as a part of Bureau of Medicine and Surgery Research Project NM 22 00 00—Psychophysical and Associated Human Engineering Studies in Shipboard and Submarine Operations, under Subtask (2) of Task NM 22 01 20, Psychophysical Studies of Visual and Auditory Factors in Submarine Operation. This report is No. 1 on this subtask and was approved for publication on 21 January 1959.

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ABSTRACT

Large groups of young men were exposed to high intensity pulse trains at 2.5 kc and examined continuously for subsequent acuity changes at 4 kc. Duty cycle varied from 1.4% tone-on to 100%, train length from 1-25 min., and sound pressure level (SPL) from 90-120 db. A new unit, the NOX, representing total cumulative fatigue over a 10-min. interval, was invented to describe the results.

The effect of SPL was linear over the 90-120db range. The effect was linear with log train duration. Equi-noxious contours were drawn stating which combinations of intensity and duration give the same effect. Equal energy input yielded equal fatigue. At the frequency region 2-4 kc and octave band of noise has the same effect as a pure tone about 5 db weaker. For pulses of these durations and intensities a variety of ear protective devices can prevent any possible permanent damage.

Auditory Fatigue Following High Frequency Pulse Trains

INTRODUCTION

This Laboratory has interested itself for some years in the temporary hearing loss suffered by ears exposed in the course of routine operations to rather high noise levels. In an early experiment¹ the losses occasioned by pulses of 300 msec. duration at each octave from 250-8000 cps. were measured; the stimulating tones were set from 20-70 db. over the subject's threshold. Under these conditions, temporary hearing losses of up to 55 db. remain after 80 msec. of recovery, but a subsequent paper² demonstrated that all effects of a single pulse at 70 db. sensation level are dissipated within about a half-second.

At the other extreme, we measured the long-lasting effects of sound pressure levels up to 140 db. for stimulations up to 10 minutes, and wrote equinoxious curves describing the combinations of energy-duration which yield equal damage to the hearing threshold.³ This study was, however, confined to the frequency region 750-1000 cps.

Papers have appeared from several laboratories exploring the question of temporary hearing loss as a function of a variety of parameters, but an inspection of this material reveals that at least one important set of conditions has not been thoroughly studied, namely, the effects of brief repetitive high-frequency pulses. This paper attempts to daub in this area with a few rapid strokes of the Brush.

The closest thing to a definitive study in this restricted area is Rol's thesis⁴ in which he utilized short pulses of broad-band noise at 104 SPL, testing for threshold shifts at 4 kc. With only one noise level, however, it is impossible to extrapolate to higher levels; and in any case the relation between the damaging effect of noise and of pure tone pulses remains to be determined.

Accordingly, it seemed wise to collect data on the fatigability of ears exposed to trains of high tone pulses, varying the

parameters of SPL, duration of exposure, and duty cycle. We used SPLs of 90-120, exposures of 1-25 min, and duty cycles

TABLE I—MEAN FATIGUE IN NOX, BY GROUPS 1 Minute Duration

Pulse Length (msec)	Duty Cycle (%)	100	SPL(db.) 110	120
		Nox Group	Nox Group	Nox Group
5	1.4	2.2 1KL	4.1 1BR	6.5 1IR
37	10.0	3.3 1KR	5.0 2BR	7.9 1LR
70	17.3	4.5 4KR	6.5 3BR	5.1 1GR
250	43.0	7.4 1ER	7.9 1BL	7.1 2FR
			13.0 1ER	
	100.0	7.4 1MR	13.8 1AR	25.4 2MR
			12.8 4BR	26.8 1HR
5 Minutes Duration				
5		3.3 3KR	7.2 2BL	15.4 1IL
37		2.9 2LL	9.6 2KR	17.2 3KL
			7.4 5BR	
70		4.9 2KL	16.9 3BL	12.8 1GL
				22.9 3IR
250	3.3 1DR	10.3 1FR	22.8 6BR	36.2 2FL
		11.5 1ER	27.1 2ER	30.0 2IL
		9.4 2DR		
	100.0	23.0 2LR	31.4 1AL	54.5 5LR
		22.0 1CL	43.8 4BL	33.1 2HR
			38.5 4LR	
			44.4 1CR (Noise)	69.4 2AL (Noise)
			44.8 3LL	"
			43.8 5KL	"
25 Minutes Duration				
5		5.1 1LL	16.1 7BR	18.4 2IR
37		7.7 4KL	28.4 8BR	38.3 6KR
70		10.1 3LR	46.6 6BL	27.2 2GL
250		15.4 1FL	82.6 5BL	103.5 1JR
			50.9 2ER	
	100.0	57.8 5KR	91.7 2AR	101.2 3AL (Noise)
			80.0 9BR	

from 1.4-100%. Stimulation was at 3500 cps, with scattered observations on a noise spectrum of 2400-4800 cps; threshold shift was always studied at 4 kc.

SUBJECTS, APPARATUS AND PROCEDURE

Subjects. A total of 156 young men was utilized in various aspects of this study. These were relieved of more onerous duties around the reservation, were easily induced to listen to the stimuli, were all above average in intelligence, had been screened to be within normal limits at 4 kc. on the audiometer (less than 15 db. loss), and seemed ideal subjects in many ways.

Threshold Testing. Twelve men were seated at a time in a well-ventilated soundproof room and provided with matched monaural

PDR-8 earphones. An Ampex Model 300 tape recorder delivered a sequence of pulses at 4 kc. with saw-tooth frequency modulation $\pm 2\%$, each pulse being .33 sec. long and with .33 sec. silent intervals, in descending intensity steps as follows:

Time after Termination of Stimulation (in Sec.)	Sensation Levels sequence (in db) (0 = audiometric zero at 4 kc.)				
10	40	30	20	10	0
18	35	25	15	5	
26	30	20	10	0	-10
34	25	15	5	-5	
42	30	20	10	0	-10
50	25	15	5	-5	
58	30	20	10	0	-10
66	25	15	5	-5	

At $1\frac{1}{2}$ min. following the termination of stimulation, the last four pulse-sequences were repeated, occupying about $26\frac{1}{3}$ "; this stimulation was repeated at 1-min intervals on the tape for a total of 10 min.

For a first assessment of the group's hearing at 4 kc, the tape was run for 4 min. Subjects during this time listened quietly and marked down on mimeo forms how many pulses they heard in each sequence. They were continuously monitored by the experimenter either in the room or through the triplane window. Papers were then collected and scored by assistants. A quick psychometric graph was drawn for each man and his 50%-detectable level estimated to the nearest 2.5 db.

When it was clear that a reasonably reliable pre-exposure threshold had been obtained for every man, a switch was thrown and the desired fatiguing stimulus was presented. At the conclusion, the Ampex was started and the full 10-min. testing sequence was presented. From a subject's response on a fresh answer sheet, by comparison with the pre-exposure threshold, one can calculate the threshold shift in 8-sec. intervals for the first 68", and (by combining the four pulse-sequences within successive groups) one can calculate the threshold shifts at the nine intervals of $1\frac{1}{4}$, $2\frac{1}{4}$, ..., $9\frac{3}{4}$ min.

Four groups of 12 men each were retained for two full days of testing: Groups A, B, K, and L. In attempting to collect data as quickly as possible, the ears of Group A were stimulated in some cases before every

ear had completely recovered from the previous stimulation, thus bringing "latent damage" as we have named it⁵ into the picture. On later analysis it was found necessary to discard some of the latter results of this group as being contaminated. The B, K, and L 2-day groups were worked considerably slower and no such latent damage could be discerned. The remaining 9 groups had only one or at most two stimulations per ear.

Stimulation Apparatus. A low-distortion oscillator output was led through switching and amplification circuitry to the group phones by way of a DPDT switch alternating at the experimenter's pleasure with the tape output. A group phone was enclosed in a Type 9A 6cc coupler so that the output of a continuous signal could be read directly in SPL. The acoustic pulses as picked up by the W.E. 640AA microphone were examined for duration on a Tektronix scope connected to the SPL meter and the rise-decay time was adjusted to about 0.5 msec. which gave no visible overshoot on the PDR-8 even with the shortest pulse duration of 5 msec.

The fatiguing pulses were either 5, 37, 70, or 250 msec. in all cases. For the durations of stimulation used, these times resulted in duty cycles of 1.4, 10, 17.3, and 43%. Continuous tones (duty cycle 100%) were also employed.

TABLE II—DURATION IN MIN. AT STATED SPL WHICH YIELDS SPECIFIED FATIGUE IN NOX (Data in parentheses indicate the ratio which the duration at any duty cycle is to that at 100%)

SPL(db)	20 Nox Duty Cycle (%)				
	100.0	43.0 (2.3)	17.3 (5.9)	10.0 (10)	1.4 (71.5)
110	1.8	4.1 (2.2)	9.0 (5)	15.5 (8.6)	Did not reach 20 Nox
120	0.9	2.0 (2.2)	3.5 (3.9)	7.0 (7.8)	16.0 (17.8)
130	0.5	1.1 (2.2)	1.7 (3.4)	3.7 (7.4)	5.0 (10)
SPL(db)	30 Nox Duty Cycle (%)				
	100.0	43.0 (2.3)	17.3 (5.9)	10.0 (10)	1.4 (71.5)
110	3.7	7.6 (2.1)	25.0 (6.8)	35.0 (9.5)	Did not reach 30 Nox
120	1.9	4.1 (2.2)	9.1 (4.9)	17.0 (9.0)	"
130	1.1	2.4 (2.2)	4.5 (4.1)	10.0 (9.1)	"
SPL(db)	40 Nox Duty Cycle (%)				
	100.0	43.0 (2.3)	17.3 (5.9)	10.0 (10)	1.4 (71.5)
110	6.0	12.0 (2.0)	40.0 (6.7)	Did not reach 40 Nox	
120	3.1	7.0 (2.2)	20.0 (6.3)	"	
130	1.8	2.9 (1.6)	9.0 (6.1)	"	

Method of Assessing Fatigue. Since one's conclusions on temporary hearing loss will

depend upon the index of fatigue used, we selected a measure of threshold shift with some care. Individuals differ quite widely not only in the absolute value of the shift remaining at any given time after stimulation, but they also differ widely in the shape of the recovery process. Some will return quickly to a value, then stabilize at that loss for some minutes. Some will return almost immediately to normal, then deteriorate appreciably again in the so-called "bounce" described by Bronstein and Churilova⁶ and more recently by Hirsh and Ward.⁷ Other shapes, sometimes rather bizarre, can be found not rarely. In this situation, the best measure is some integration of the total loss up to the time of 100% recovery. This may, however, be hours or even days, making the total loss a wholly unwieldy measure.

We have adopted a short form of the total loss, namely, the total cumulated loss occurring in the first 10 min. of recovery. We have found this index markedly superior to the commonest index now in use, namely, the instantaneous threshold shift after two minutes of recovery. Bounces and other irregularities such as tinnitus and super-normal thresholds ("sensitization") are seen often to occur at about the 2-min. mark, but these very real perturbations of the recovery curve are usually gone before the 10-min. mark; the 10-min. total is thus more highly correlated with ultimate total loss, and has a higher test-retest reliability.

Our technique is to graph an individual's threshold shift in db. (as given by the scored answer sheet minus $\frac{1}{2}$ step-interval, or 2.5 db) against time, where zero threshold shift represents his pre-exposure reading. The area under this curve is then read with a Keuffel and Esser planimeter in square inches. As a convention, we adopt the area representing the least amount of threshold shift we have measured, 2.5 db for 1 min., as 1 "Nox"; dividing this area into the given area furnishes for the 10 min. recovery the auditory fatigue in Nox (plural of Nox).

Dividing this figure by 4 gives the aver-

age instantaneous fatigue in db. over the 10-min. sample.

RESULTS

1. Reliability. In such an experimental design where a single ear cannot undergo all conditions, and comparisons must be made from group to group, the most significant estimate of reliability can be thought to be the repeatability of mean Nox values among groups given identical conditions. This mean value determines, as well, the size of the group which can adequately represent the total population.

Several conditions were given to two or even three groups to investigate this point. It was found that 12 ears were, indeed, just about the minimum required to furnish a mean which would merge with the trend of means from adjacent conditions. For the most part, means from identical conditions were statistically identical. For example, three groups were given a 5 min. exposure at 100 SPL with a 40% duty cycle. Groups DR, ER, and FR yielded mean Nox of 9.4, 11.5, and 10.3 respectively. Again, Groups AL, BL, and LR yielded Nox of 31.4, 43.8, and 38.5 to 110 SPL for 25 min. with a 100% duty cycle. On the other hand, Groups FL, G, and HR give clear evidence of being a bit more resistant than their fellows as shown both by companion groups given identical conditions and by the trends of the data. The fact, however, that these groups can be identified as not having perhaps quite their share of "tender" ears lends support to the firmness of the trends established here. If 12 men did not usually well represent the population, or if group means were not internally stable, such results as from Groups FL, G and HR could not be distinguished from other equally erratic data.

Mean values are in Table I.

2. Effect of SPL. The data are graphed in Fig. 1 to show the effect of SPL upon fatigue. This effect varies with duty cycle, as the figure shows, with duration of stimulation as parameter.

A linear effect of SPL appears in these

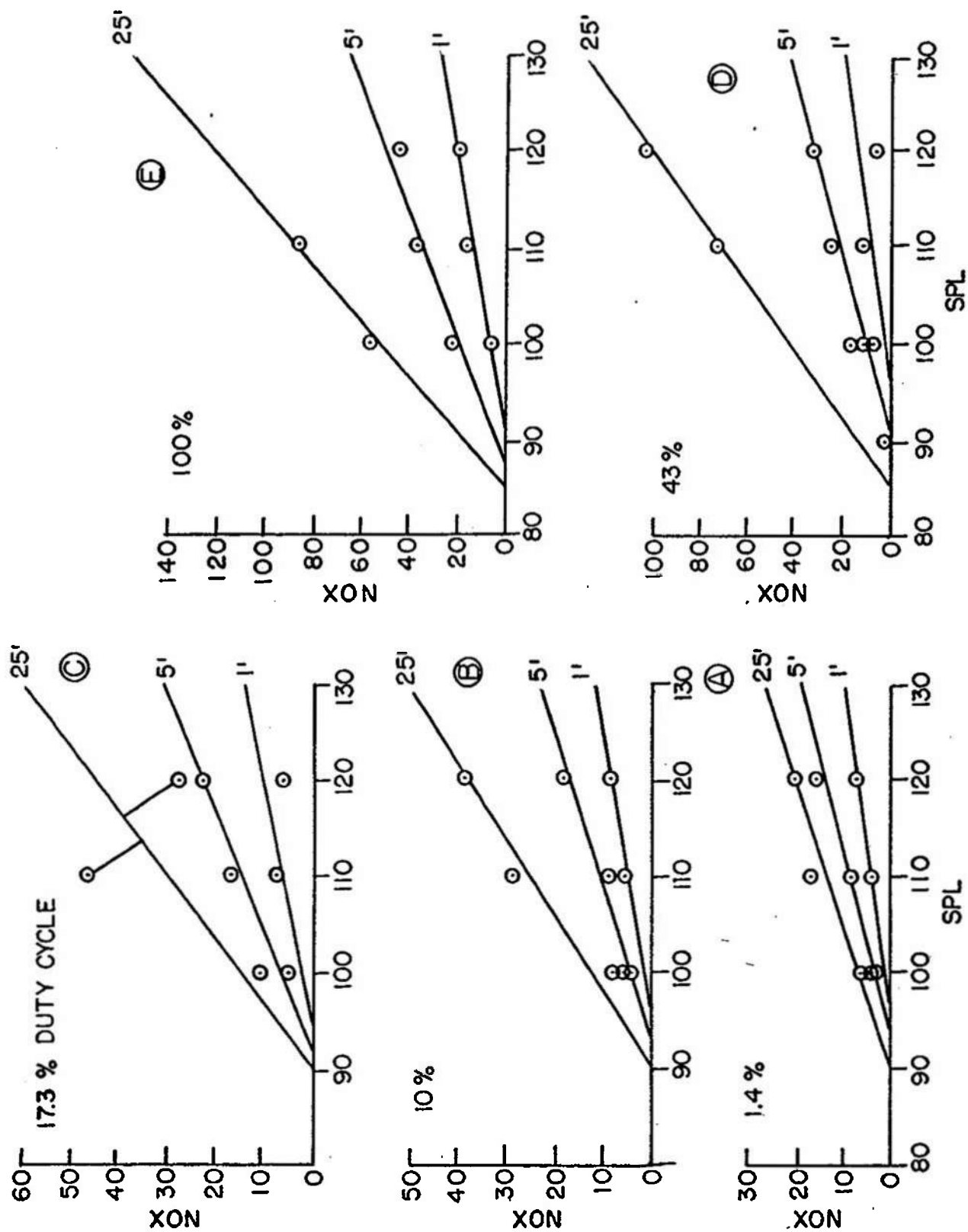


Fig. 1: Effect of SPL on fatigue, duration of stimulation as parameter.

data, as has appeared before in data from this and other laboratories. It would seem to be possible to extrapolate the effect to at least 130 db if not higher.

3. Effect of Duration of Stimulation. These curves can be also read vertically to observe the effect of duration of stimulation. To a first approximation the effect is linear with log duration, as emphasized by Ward* (note that on a log scale, 5 is about half-way between 1 and 25).

4. The Combined Effect of SPL and Duration on Fatigue. Now if we consider for the moment a value of 20 Nox (this effect will be noticeable to most persons, sometimes results in tinnitus, and demands often a couple of hours for complete recovery), it can be seen in Fig. 1A that 5-msec. pulses (1.4% duty cycle) at 120 SPL can last for about half an hour before a fatigue of 20 Nox is occasioned. For a 250-msec. pulse (43% duty cycle), however, this fatigue is reached after only a couple of minutes at 120 SPL.

Other levels of fatigue, for other sets of conditions, can likewise be predicted from Fig. 1.

5. Equinoxious Contours. A more usual way to explore the combined effect of SPL and duration is to re-draw the data of Fig. 1 in so-called equinoxious curves. Figs. 2-6 plot the combinations which yield equal fatigue. Thus, for a 100% duty cycle (see Fig. 2) a fatigue of 30 Nox is caused by a

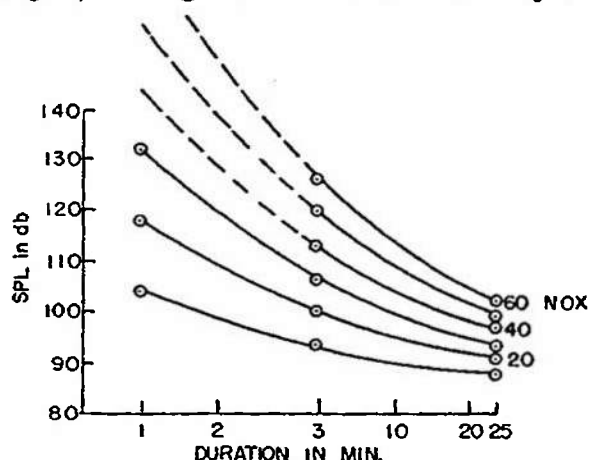


Fig. 2: Equinoxious contours (shows the intensity-time contours which produce various values of fatigue in Nox) for continuous tone of 3500 cps.

train of pulses at 130 SPL for 66 sec., 120 SPL for 2 min, 110 SPL for 5 min., 100 SPL for 10 min., etc.

As a convenience to the reader, a final figure is presented combining the 20-Nox curves from Figs. 2-6. Thus in Fig. 7 one

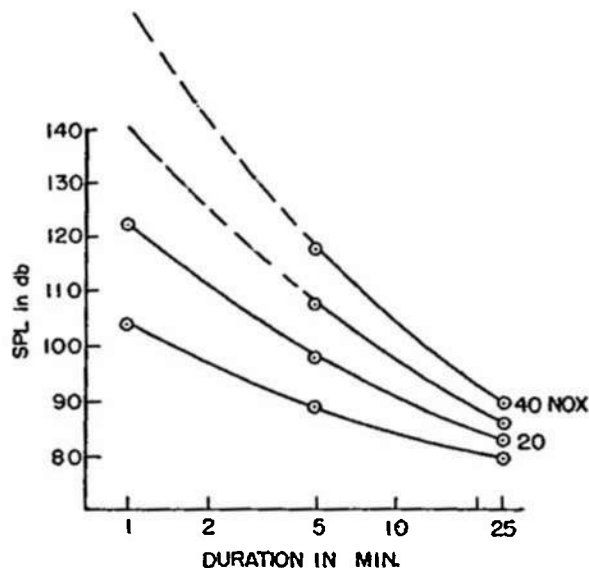
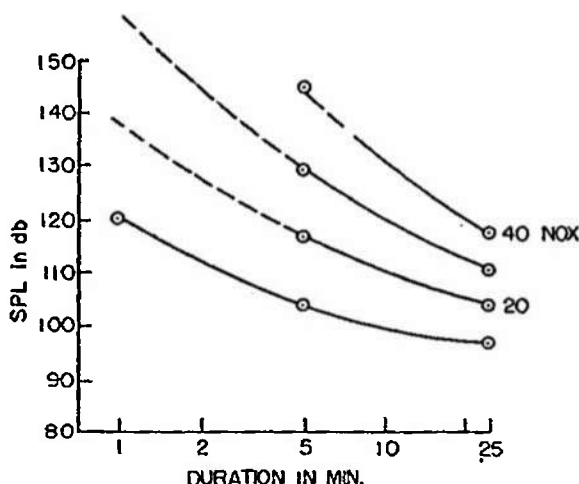


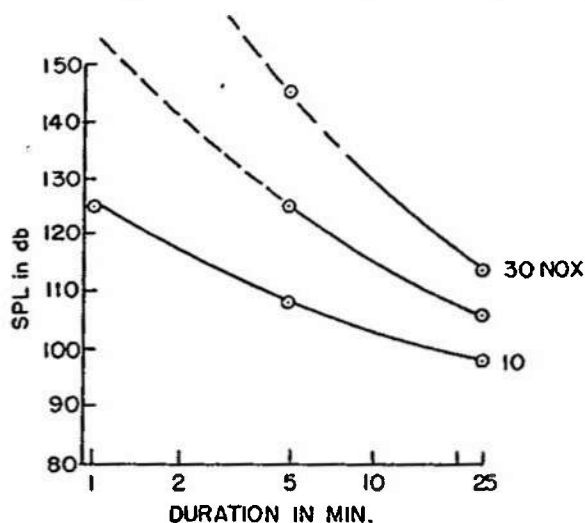
Fig. 3-6: Exactly the same as Fig. 3, for Duty Cycles of 43%, 17.3, 10, and 1.4 respectively.

can determine by interpolation the Intensity-Time combinations for any duty cycle or pulse length which yield noticeable fatigue. (A slight anomaly at the 43% Duty Cycle can perhaps be corrected visually.)

6. The Relation between Total Energy and Fatigue. If we graph the data in a dif-

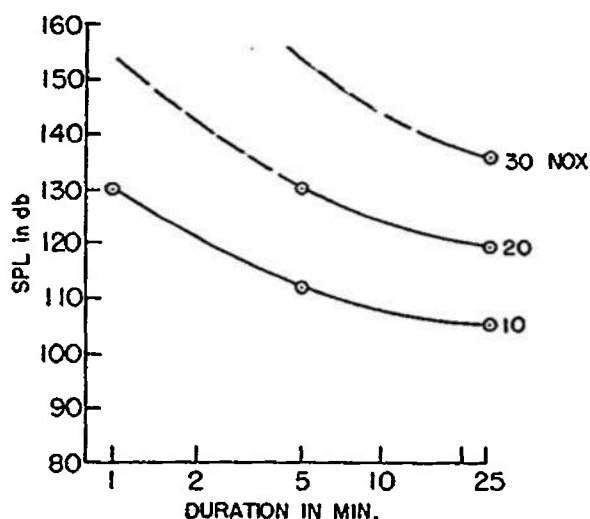


ferent way it is possible to assess whether equal energy yields equal fatigue, irrespective of how the energy is distributed



in time. In the parameters we have chosen, enough energy overlap appears among brief pulses for long durations, and long pulses for short durations, for such an opportunity.

In Fig. 8 we see the relation between total energy (abscissa is simply pulse length x



number of pulses per stimulus duration rather than work in watt-secs.) and fatigue. Curves have been fitted by eye to the data at 100, 110, and 120 SPL. No tendency exists for any pulselength to cause an anomalously large or small fatigue. The implications of this figure is that equal energy yields equal fatigue; for example, 5 minutes of stimulation at 110 SPL will yield 40 Nox, no matter whether this is

the form of continuous stimulation, or 1200 pulses 250 msec. long, or even 60,000 pulses 5 msec. long.

This study did not vary the interpulse

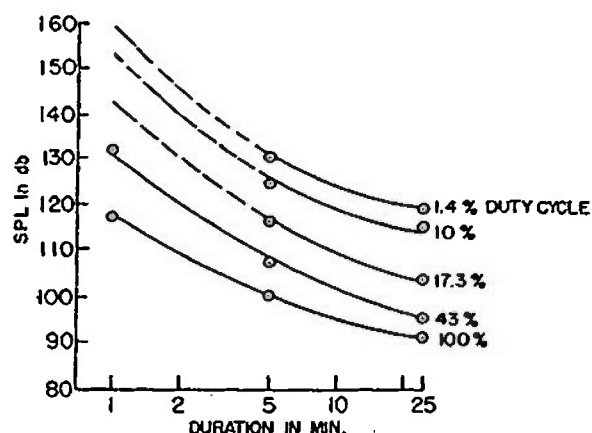


Fig. 7: Exactly as Fig. 3, except the 20-Nox value is graphed from Figs. 2-6.

interval of 333 msec., but it is fairly safe to say on the basis of this Laboratory's experiences with pulses and interpulse intervals of all sorts that within rather wide limits the recovery during the interpulse interval should be negligible, since during the interpulse interval the ear is in a state of quick, complete recruitment.⁹ Further studies will eventually illuminate this point.

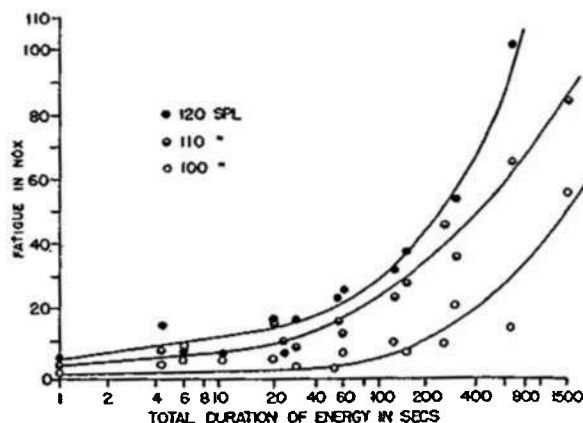


Fig. 8: Shows that equal energy yields equal damage, no matter how it may be distributed in time, written at least the limits of this experiment.

DISCUSSION

A word must be said about the relation of these data to a so-called Damage Risk criterion. A rather generally accepted figure exists of 95 db. per octave band of noise, for wide band noise over 300 cps, as the limit above which long-term exposures should not go. This criterion should be attributed to Kryter¹⁰, with some compromises and extensions by Rosenblith and Stevens¹¹. It was Kryter's conclusion that a safe exposure should not exceed 85 db. SPL for any pure tone or critical band of noise. Rosenblith and Stevens pointed out that sensation level as well as intensity level should be considered, and corrected the baseline, to which 85 db. is added, by up to 10 db. especially at low frequencies. To pass to wideband noise, Rosenblith and Stevens simply add, to the Damage Risk criterion for any frequency, the number of db. by which the frequency-range of the octave exceeds that of the critical band for that frequency. It happens that the width of the critical band varies over frequency in such a way that the Damage Risk criteria for octave-band noise works out to about 95 db. for all octaves down to 300 cps.

Now the 95-db wide-band noise criterion has received strong support, but strictly by coincidence, from large-scale studies of permanent hearing loss in industry, correlated with studies of industrial noises.¹²

Note in Fig. 8 of Ref. 8 that for many years' exposure to a noise in the octave-band 300-600 cps at 95 SPL, ears experience a loss approaching the 15 db level which is included in the National Academy of Sciences' definition of hearing as "Normal". The data on hearing loss at 4 kc. are even more to the present point. See Fig. 7 of Ref. 8. The most debilitating octave-band is 2400-4800 cps. Such a noise at 95 db. for 2 years (we extrapolate here from the data in Fig. 10 of Ref. 8 for the stimulating octave 1200-2400 cps.) will shift threshold at 4 kc. by 15 db., of which about 10 db. must be subtracted to correct for temporary hearing loss, which is admixed into at

least Fig. 10 of Ref. 8. In other words, the ear at 4 kc. begins to break down after 2 years of 95 SPL at 2400-4800 cps.

This correction of 10 db. comes from Fig. 12 of Ref. 8, which in its turn is quoted from a study by Cox, Mansur, and Williams on cotton mill workers' audiograms taken after 15 min. and 2-7 days of recovery. Frequencies of 2 kc. and lower were affected negligibly, but temporary loss at 4 kc. (found in usual industrial audiometry) amounted to 7.5-12.5 db. for two groups.

The writer concludes that the 95-db per octave-band criterion rests upon quite a body of support (and has indeed been incorporated into the U. S. Navy's Bureau of Medicine and Surgery's Instruction No. 6260.6) but that there are almost no data to support the original pure tone criterion! What data we do have cast strong doubt on the validity of the critical-band conversion. While critical-band theory works very well for masking (with only minor corrections) it may not work very well for auditory damage. For example, in the monograph by Davis, et al.,¹³ a pure tone was often seen to have the same fatiguing effect as a broad noise of the same SPL, whereas the Rosenblith-Stevens curves would predict the same effect if the pure tone were about 10 db. weaker.

Data in the present paper are to the effect that in the region of 2-4 kc an octave-band of noise has the same effect as a pure tone about 5 db. weaker, rather than the 12 db. suggested in that region by the Rosenblith-Stevens curves.

The writer would prefer to retain the 95 db. wide-band noise Damage Risk criterion, as validated statistically by Rosenblith and others in the industrial noise area, but to allow these and future experiments to write a new conversion between wide-band noises and line spectra. In this experiment we took the opportunity to present 36 ears with noise for 5' at 110 SPL as measures in the 9A coupler in the octave

region 2400-4800 cps. The average Nox was 44.3 (see Table I). Fig. 1E indicates this 20 Nox value is obtained after 5' of stimulation at 115 SPL, rather than the predicted 122. Again, as indicated in Table I, groups of 12 ears each were exposed to 2400-4800 cps. noise at 120 SPL for 5 and 25 min. respectively. Here Fig. 1E shows the equivalent SPL for a 3500 cps. tone to be 130 SPL (+10 db) and 113 (-7 db) respectively. Here the 5-min. exposure yields approximately the predicted 12 db difference, but the 25-min exposure is even in the opposite direction. It is certain that this figure of -7 db is too low partly because three of the ears in that group (given by far the most noxious stimulus) heard none of the test pulses throughout the whole ten min, but were nevertheless assigned a Nox value as if they could have heard a pulse 5 db louder than was presented. When the mean is used, this convention produces a probably artificially small Nox value.

Confirmation of our suggestion that a 5-db conversion is approximately correct comes from an as-yet unpublished study by Dr. O'Hare of this Laboratory. An octave-band of noise centered at 1 kc at 95, 100, and 105 SPL as measured in a 9A coupler, was presented by PDR-8. earphone to ten subjects individually for 10 minutes. Thresholds were collected at 1.5 kc by the Bekesy technique, and hearing loss for 10 min. was cumulated. Fatigue at the three SPLs exhibited a straight line from 4-19-41 Nox. When 12 men were given a pure tone of 95 SPL at 1 kc instead of the noise band, the mean fatigue was 12 Nox, which corresponds to a noise SPL of 98.5 db. Thus in Dr. O'Hare's study the conversion is 3.5 db.

We conclude that the Damage Risk criterion for pure tones (or critical bands of noise) should be about 5 db weaker than for octave-bands of noise in this frequency region.

Such a position is rather encouraging, since it allows a 3.5 kc tone to be another 7 db louder ($12-5=7$) than would otherwise be the case, before concern is felt for the ear.

We are now, finally, in a position to pass tentatively from temporary hearing loss caused by pulse trains of a 3500 cps pure tone, to permanent damage. Let us further assume not that temporary threshold shift is a definite predictor of permanent damage, but only that the relation between pure tones and noise, as we see it for temporary effects here in this experiment, remains similar for permanent damage in non-laboratory situations. We can then predict that a 3500 cps tone at 90 SPL will have the same permanent damaging effect as a noise of 2400-4800 cps at 95 SPL.

It only remains to pass, if possible, from a continuous tone to a train of pulses of various durations and duty cycles. Figs. 3-7 provide this information.

We can derive the information from Figs. 2-6 that the ear can withstand a pulse train of 250 msec. pulses, with a 43% duty cycle, for about twice as long as if the tone were continuous, before a certain fatigue (damage) is caused. If the pulse is 70 msec. long, with duty cycle of 17.3%, the factor is about 1:6; if the pulse is only 37 msec., duty cycle of 10%, the factor is about 1:10. These statements are supported by the analysis of Table II, in which are entered the durations at various duty cycles and intensities which yield certain Nox values. Also entered are the ratios which the duty cycles are of 100%. As we should expect from Fig. 8, a pulse train duty cycle of 50% can last twice as long as a continuous tone; one of 25% can last four times as long.

(It can be seen that this nice relationship breaks down at a 5 msec. pulse length; this is possibly related more to the absolute length of the pulse than to the 1.4% duty cycle. Such a pulse sounds like a pitchless click. Further data will have to differentiate the two features of pulse length and duty cycle in this region.)

With this information we are furthermore not tied to the data for continuous pure tone stimulations of this study, but can utilize, for example, the stimulations up to 140 db from Ref. 4.

If we can accept our hearing loss measure

and the criterion of a 20-Nox level, which appears in the laboratory to be the minimum which subjects notice, and which certainly cumulates with later stimulation to yield increased fatigue, Fig. 7 then shows us that unless the stimulus is at least 120 db SPL, a 5-msec. pulse can be listened to almost indefinitely, that the asymptote is probably reached at about 115 db for a 37 msec. pulse with 10% duty cycle, and at about 100 db for a 70 msec. pulse, 17.3% duty cycle. In case the pulses are appreciably longer, the level must exceed 90 db before the 20-Nox criteria occurs.

It is probably no coincidence that this 90-db level emerges from our data. Note that this is exactly the figure we derived earlier as the 95-5 = 90 SPL Damage Risk criterion for pure tones. We can, however,

make no more of the coincidence at this time.

Fortunately, even for continuous tones at 3500 cps a variety of ear protective devices, all equally good at this frequency region, are available. Practically all plugs and earmuffs can offer at least 30 db insulation here, so that a workspace containing a long-pulse train of 120 db could be sustained indefinitely with any sort of protective device, while the levels of short-pulse trains could be proportionately louder. The ideal plug for this purpose might be the "Selectone", which passes all frequencies below 1000 cps, thus not affecting conversation in the least. Of course, if men were to work without protective devices, some sort of sound insulation of the higher frequencies would be mandatory under BuMed Instruction 6260.6.

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