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Technical Note 1-72

IMPROVED WEAPON NOISE EXPOSURE CRITERIA

David C. Hodge

February 1972

HUMAN ENGINEERING LABORATORIES

ABERDEEN RESEARCH & DEVELOPMENT CENTER

ABERDEEN PROVING GROUND, MARYLAND

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ABSTRACT

The state of the art in noise-exposure criteria is reviewed and it is suggested that such criteria are in need of revision and extension to meet future operational requirements of the Army. Further, existing noise criteria, expressed in terms of "decibels of hearing loss," should be re-stated in terms of predictions about the performance of military personnel after they have been exposed to noise. Such re-statement in performance terms will significantly improve communication about the risk of noise exposure to people who are in a position to utilize such information but who generally do not comprehend the notation of decibels of hearing loss.

IMPROVED WEAPON NOISE EXPOSURE CRITERIA[1]

INTRODUCTION

At present, assessment of the potential hazards of noise exposure in military environments is made by means of "damage-risk criteria" (DRC). We are beginning to realize that current DRC are deficient for the solution of many human factors problems. New programs of research will be outlined whose purpose is to resolve these deficiencies.

THE STATE OF THE ART IN DAMAGE-RISK CRITERIA

There are two DRC which enjoy wide popularity and application at the present time. They are the DRC for steady-state and intermittent noise (1) and the DRC for impulse noise (2) developed by Working Groups 46 and 57, respectively, of the NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics (CHABA). It would be correct to state that, at least in the United States, practically all recent developments in both military and industrial noise-exposure and hearing-conservation criteria are derived, directly or indirectly, from these two basic DRC.

Figure 1 illustrates one set of damage-risk contours from the CHABA steady-state noise DRC (1). This set of contours is for a single daily exposure to bands of noise. The left-hand ordinate is octave-band sound-pressure level (SPL) in decibels (dB) re 20 $\mu N/m^2$, and the right-hand ordinate is 1/3-octave-band SPL. The abscissa is band-center frequency in Hertz (Hz) -- cycles per second is you are old fashioned! The nine contours show the permissible levels for various exposure times from 1½ minutes to 480 minutes per day. Another set of contours in the DRC expresses these same relationships in such a way that if you knew what exposure time was required to perform a particular job (eight hours or less) you could determine the maximum permissible octave- or 1/3-octave-band SPL. Also, other sets of contours are provided for assessing pure-tone exposures and for various types of intermittent-noise exposure.

Figure 2 illustrates the basic exposure limits for impulse noise. The ordinate is peak pressure level in dB re 20 $\mu N/m^2$ and the abscissa is the duration of a single impulse in milliseconds. The basic DRC assumes exposure to 100 impulses per day with the ear at normal incidence, as shown in the lowest curve. Combining the basic DRC with the correction factors for number of impulses per day and ear orientation permits development of a family of exposure curves as illustrated in Figure 2.

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[1]Based on a talk presented to the Division 21 Symposium, "New Fellows," American Psychological Association, Washington, D. C., 5 September 1971.

Figures 1 and 2 represent only one aspect of DRC — that aspect which relates to limits on physical exposure parameters. The other important aspect of DRC is the amount of change in hearing which is acceptable, i.e., which the user of the DRC is willing to tolerate as an acceptable maximum. The CHABA DRC (1, 2) state hearing loss limits as decibels of temporary threshold shift (TTS) measured two minutes after exposure (TTS_2). The limits are 10 dB at or below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at or above 3000 Hz. The limits apply to 50 percent of ears exposed to intermittent and steady-state noise, and to 95 percent of ears exposed to impulse noise. Less TTS is permitted in the lower frequencies than high, since the primary purpose of current DRC is to preserve man's ability to communicate by speech.

Two additional features of DRC should be mentioned:

1. The actual intent of DRC is to limit permanent hearing loss (i.e., permanent threshold shift — PTS) resulting from years of near-daily exposure. The exact relationship between TTS and PTS is not known, but it is assumed that $PTS_{10\ yr}$ will be equal to or less than $TTS_{2\ min}$.

2. It is implicitly assumed that TTS which is no larger than about 30 dB will recover within 16 hours. More about that later on.

LIMITATIONS OF CURRENT DAMAGE-RISK CRITERIA

Criteria for Long-Term Noise Exposure

For steady-state noise we have no systematic criteria at all for exposures longer than eight hours. This may be a problem for industry as well as the Army, since industry is presently experimenting with a 10-hour work day. In the Army, changes in tactical doctrine are expected to provide for deployment of men and materiel for periods of up to 100 hours continuously. This is the doctrine of "continuous operations."

There has been little investigation of the effects of long-term noise exposure. Some results from a recent study by Mills, et al. (4) are shown in Figure 3. A single subject was exposed to an octave-band of noise centered at 500 Hz. Hearing thresholds were monitored at 750 Hz. Two SPLs were used: 81.5 and 92.5 dB. Both curves in Figures 3 indicate that an asymptote was reached in TTS after about 12 hours of exposure.

Figure 4 shows results from an experiment conducted in the Russian astronautics program and reported by Yuganov, et al. (6). Here, several astronauts were exposed to broad-band noise at 75 dB SPL for 30 days continuously (i.e., 720 hours). The data in Figure 4 are the "average TTS" values reported in Yuganov's paper; they suggest that for a broad-band noise exposure TTS may continue to grow linearly in log time for very long exposures. The contradictory nature of the results from Mills and Yuganov suggest that much further research is needed on the effects of long-term exposure.

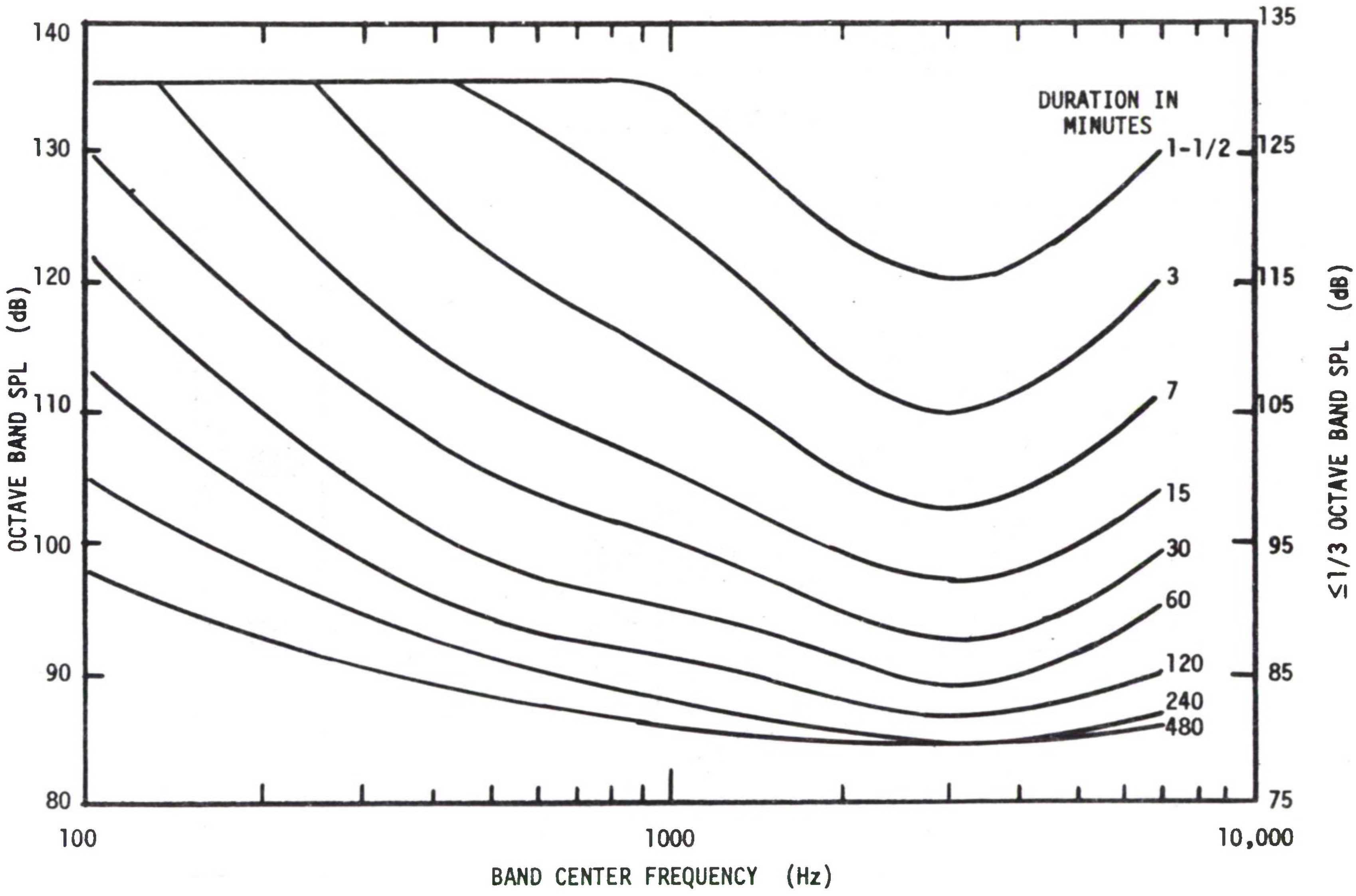

Fig. 1. DAMAGE RISK CONTOURS FOR ONE EXPOSURE PER DAY TO OCTAVE AND ONE-THIRD OCTAVE OR NARROWER BANDS OF NOISE
[This graph can be applied to individual band levels present in broad band noise (From Reference 1.)]

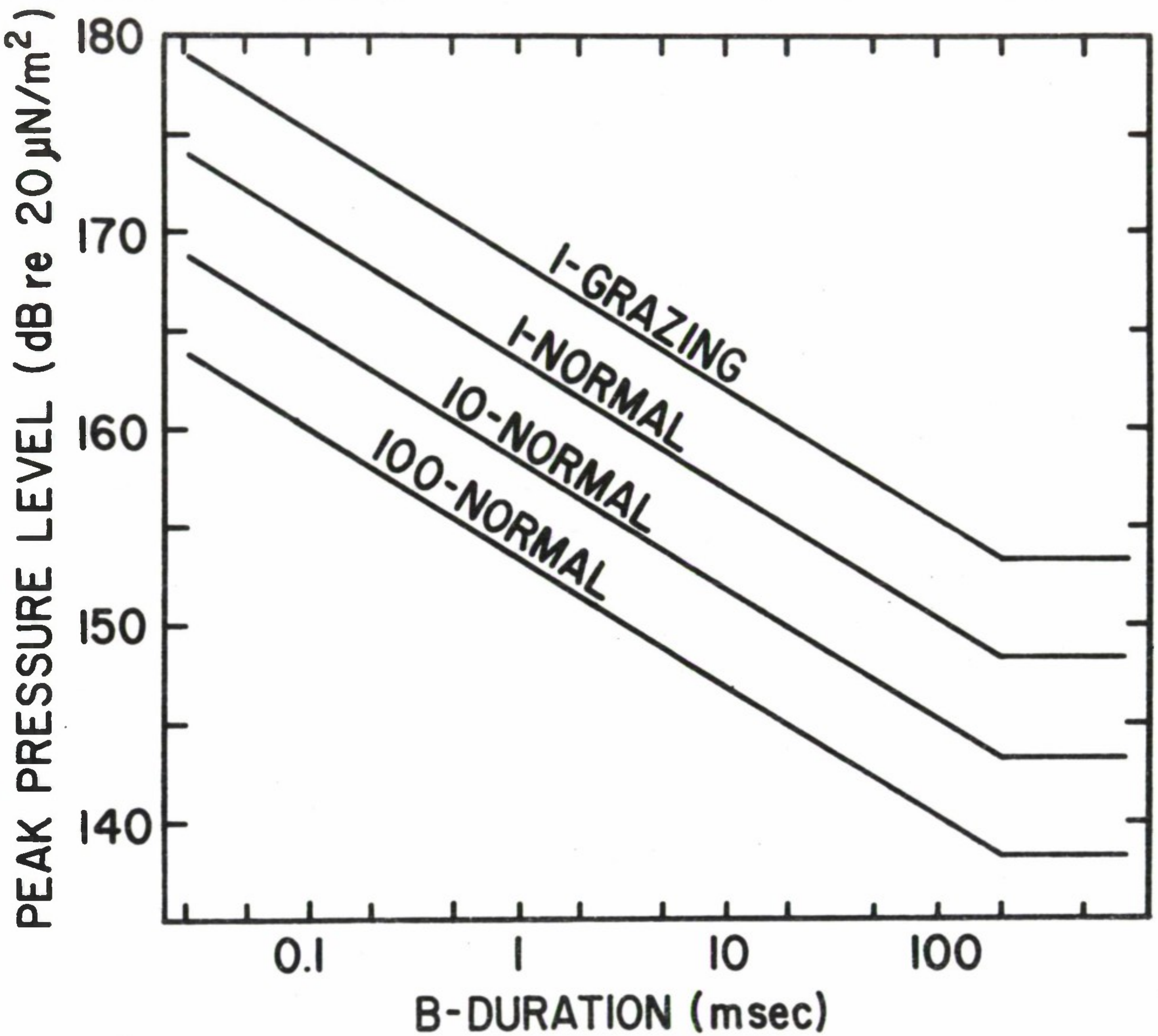

Fig. 2. DAILY EXPOSURE LIMITS FOR IMPULSE NOISE
[Parameters are number of impulses per day and ear orientation.
(From Reference 2)]

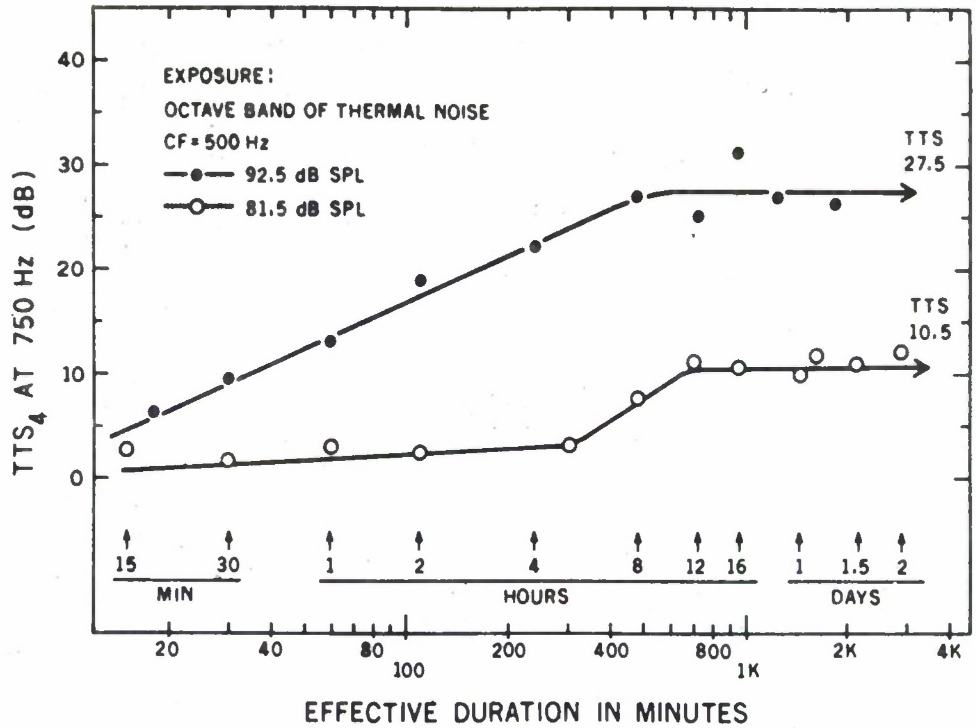

Fig. 3. GROWTH OF TEMPORARY THRESHOLD SHIFT FROM LONG-TERM EXPOSURE TO AN OCTAVE-BAND OF NOISE
(From Reference 4.)

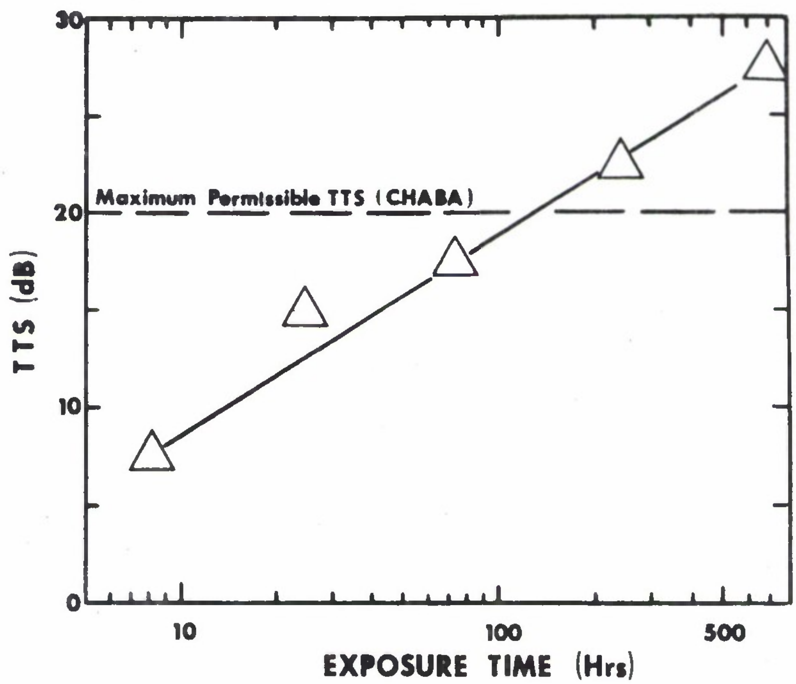

Fig. 4. GROWTH OF TEMPORARY THRESHOLD SHIFT FROM LONG-TERM EXPOSURE TO BROAD-BAND NOISE
(From Reference 6.)

There is another aspect of the long-term exposure problem which should be investigated: the characteristics of recovery from TTS induced by long exposures. Both Mills and Yuganov indicate that recovery took much longer than for the same amount of TTS induced by shorter exposures. Figure 5 shows recovery functions for Mills' one subject. The dashed lines have been added to show the TTS recovery functions implied by the CHABA DRC (1). TTS induced by the lower exposure SPL should have, according to the CHABA DRC, recovered within about 45 minutes; it actually took four days. For the upper curve, recovery should have been complete within about eight hours; it took six days. This matter of recovery requires investigation because one of the most critical questions regarding the whole area of continuous operations is "How long does it take soldiers to recover from long-term performance, including long-term exposure to various environmental pollutants?"

Intermittent Noise Effects

This aspect of current DRC is already receiving attention. Ward (5) has shown that whereas the CHABA DRC (1) accurately predicted the growth of TTS from steady noise exposure, in some cases the recovery was longer than implied by the DRC. The importance of this problem involves the same considerations raised above.

Assumptions of DRC

Two of the fundamental, explicit, assumptions of current DRC should be reconsidered.

1. The concept of 50 percent protection against TTS from steady-state noise needs re-evaluation. For impulse noise it was noted that the DRC provides for 95 percent protection. Current DRC based on 50 percent protection may be inadequately protective from a human factors point of view.

2. Currently, DRC permit twice as much TTS at 3000 Hz and above as they permit at 1000 Hz and below. The notion of placing primary emphasis on preservation of the speech frequencies may need revision. This possibility will be explored further later in the paper.

Impulse-Noise DRC

For impulse noise the current criteria appear to be adequate for the moment. Recent studies have indicated, however, that recovery from impulse-noise-induced TTS varies greatly in the population. Firgure 6 illustrates various recovery-function shapes which have been observed in monkeys and men as reported by Luz and Hodge (3). The upper two curves, labelled "M" and "S," show the recovery functions resulting from two hypothesized TTS mechanisms. The lower four curves show representative examples of recovery functions resulting from combining the two basic mechanisms' functions. All have been observed in experiments on both monkeys and men. These data certainly indicate that we need to examine recovery further. This is particularly true since it was formerly believed that once the value of TTS two minutes after exposure was established the further course of recovery could be predicted with a fair degree of accuracy. This has now been shown not to be necessarily the case.

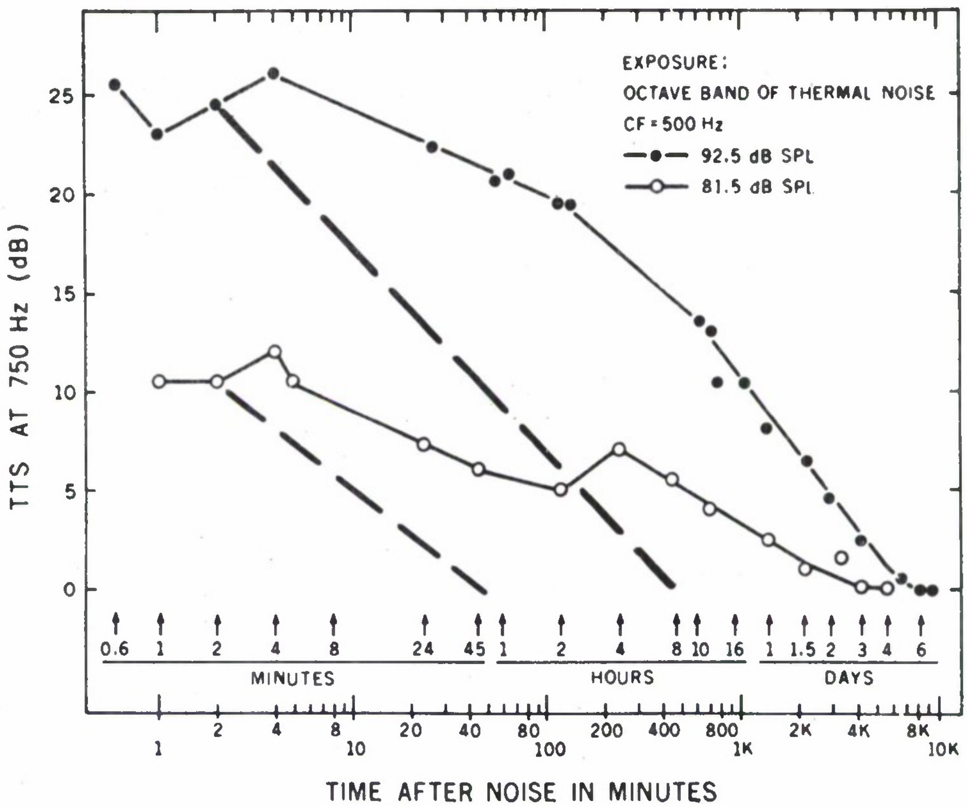

Fig. 5. RECOVERY FROM TEMPORARY THRESHOLD SHIFT INDUCED BY LONG-TERM EXPOSURE (From Reference 4.)
[Dashed lines have been added to show recovery rate implied by CHABA DRC (Reference 1).]

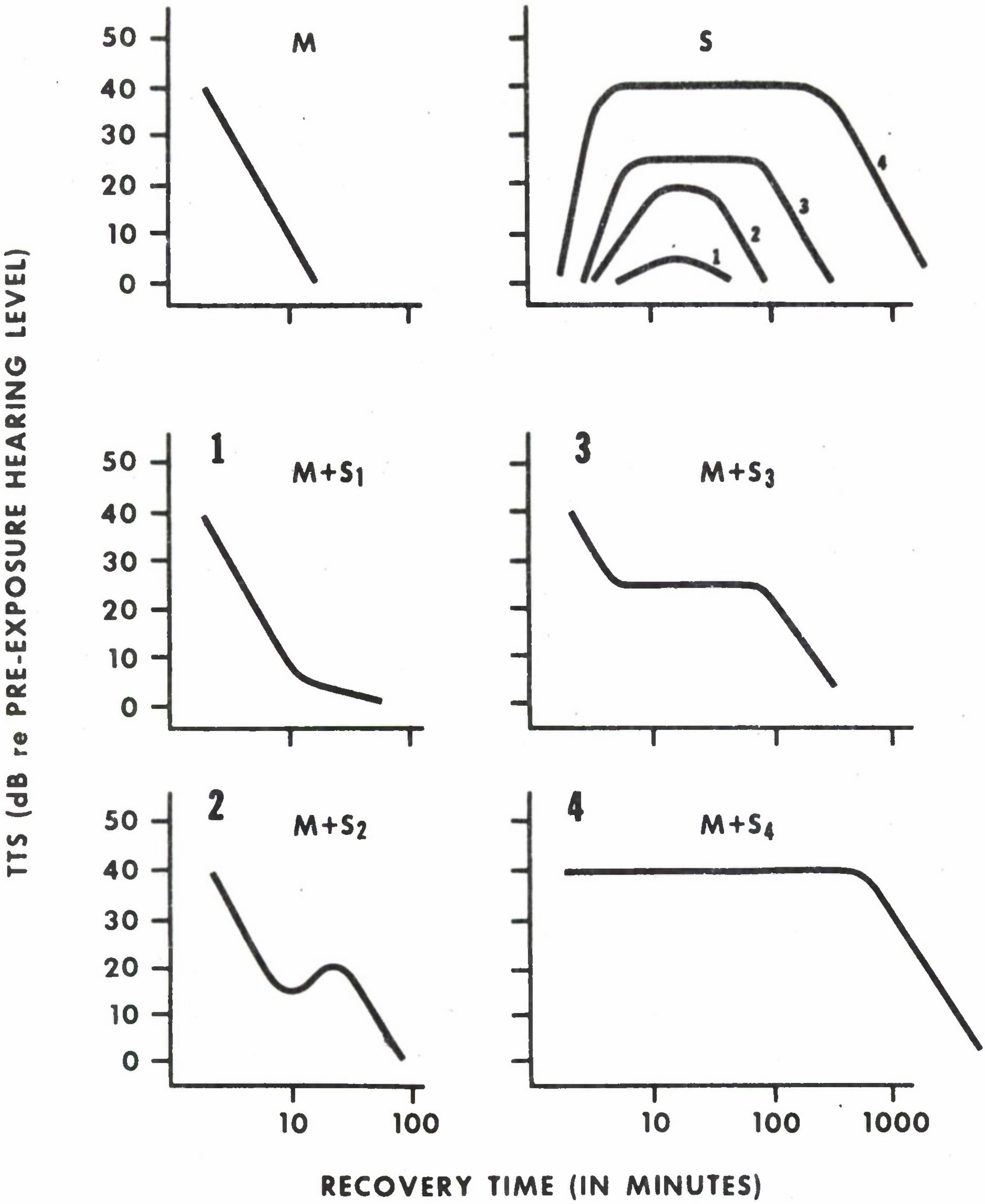

Fig. 6. HYPOTHETICAL RECOVERY FUNCTIONS FOR IMPULSE-NOISE-INDUCED TEMPORARY THRESHOLD SHIFT IN MONKEYS AND MEN (Reference 3)
(The lower four curves have all been seen in both monkeys and human recovery data.)

Inadequacy of DRC Concept

A fundamental defect of all current DRC will not, we feel, be resolved by extending the state of the art as outlined above. The reason is that current DRC are stated in terms of "decibels of hearing loss" at various frequencies in various percentages of the exposed population. Unless one is knowledgeable in this area, such terminology is relatively unintelligible. It would be much better, we feel, if we had "DRC-like" criteria which relate noise exposure parameters to soldiers' performance.

WHY PERFORMANCE CRITERIA ARE NEEDED

We have been able to identify three critical areas in which performance criteria for noise exposure would be extremely helpful. They relate to planning research, designing of new materiel and advising field commanders of the tactical risks of noise exposure.

Research Planning

In designing noise experiments with human subjects, performance criteria are needed for determining when to terminate the exposure. At present, such end-points are derived from humanitarian considerations alone, i.e., we do not want to risk permanent injury to the subjects. Typically, a person is not re-exposed to a larger amount of noise energy once he has shown a TTS of 40 dB or larger at any test frequency. We strongly suspect, however, that performance of tasks requiring acute hearing sensitivity will be significantly degraded long before TTS reaches 40 dB and, if this is so, the experimental noise exposure should be terminated whenever an unacceptable amount of predicted performance decrement has occurred. This will result in more efficient experimental procedures by removing the ambiguity presently involved in setting end-points for exposures.

Equipment Design Criteria

After the need for a new item of materiel has been conceptualized there is a period of time in which various technological approaches to satisfying the concept are weighed against numerious criteria, including effectiveness and compatibility with the human operator. In weapons, for example, some trade-off has to be reached between those features required to deliver a particular projectile to the target and the risk of noise injury to the operator. At present we have engineering models which permit accurate prediction of the noise characteristics of a new weapon from a knowledge of the intended design parameters. But the best available criteria for the effects of impulse noise on man — the CHABA DRC (2) — are expressed in terms of decibels of hearing loss. Few weapon designers really understand hazards expressed in these terms. However, statements like "exposure to the stated noise parameters for one shot per day will render 25 percent of personnel unfit for sentry duty for up to 12 hours" are readily comprehended since they relate to the effectiveness of soldiers in performing their tasks after noise exposure. Performance criteria would thus aid designers in making more informed decisions and trade-offs between weapon effectiveness and maximum acceptable risk of degraded operator performance.

Advice to Military Commanders

In many instances field commanders are presently unable to adequately assess the risks involved in noise exposure because the DRC are expressed in unfamiliar terms. As a result, personnel are not required to utilize hearing protective devices in those tactical situations where such protection is desirable and compatible with operations. I have, for example, talked with several Viet Nam veterans who stated that after a 30-minute helicopter airlift to a combat zone they alighted from the aircraft to discover that they could not understand spoken commands because of the TTS induced by helicopter noise. On the other hand, the flight surgeon responsible for medical planning on the Son Tay prison camp raid insisted that all troops wear ear plugs while being airlifted. The result was that the troops arrived at the prison camp, removed their ear plugs, and found their hearing unimpaired by noise-induced TTS. With performance criteria for noise exposure, we think many more instances of this type would be in evidence.

DEVELOPMENT OF PERFORMANCE CRITERIA

Hearing Loss vs Performance

We have selected two types of performance for initial consideration which are combat-relevant and critical to survival. One of these is communication by speech, and the other is detection and identification of the presence of the enemy.

We already have a substantial body of information relating noise-exposure parameters to the risk of hearing loss. Therefore, our primary focus will be on determining the relation between hearing loss (or, hearing sensitivity) and performance in these tasks. Figure 7 illustrates the frequency spectra of speech and of combat sounds. (The combat sound data are based on our analysis of Device 5H12, Sound Recognition Tape: Night Sounds, prepared by the Training Devices Center, Orlando, Florida.) Note that the peak energy of male speech is at about 400 Hz, whereas, the combat-sound spectra peak generally in the region of 4000 to 8000 Hz. It should be obvious, then, that the understanding of speech and the detection of combat sounds require quite different hearing acuities.

From an extensive literature review and evaluation of our research data on noise exposure, we have concluded that the most pressing problem is that of hearing-loss effects on detection and identification of combat sounds. There are two reasons for reaching this conclusion:

1. The relation between hearing loss and speech reception has been examined closely already, whereas detection of combat sounds has received little attention. Pure-tone audiometry is much simpler to conduct than tests of speech reception, so there has been considerable clinical interest in the prediction of speech reception from pure-tone hearing loss data. Several predictive schemes have been published, and we feel that one or more of these can be used to develop predictive models of hearing loss effects on speech communications.

2. Noise typically affects the upper frequencies of hearing first. Figure 8 illustrates the effect: the TTSs are from the right and left ears of 26 soldiers who fired one shot with the M72 rocket launcher. The TTSs are 95th percentiles: 95 percent of the ears had shifts of this magnitude or smaller, while five percent of the ears had larger shifts. The CHABA DRC limits on 95th percentile TTS are indicated by the dashed line at the bottom of the graph. Comparison of Figures 7 and 8 leads to the conclusion that typical noise-induced hearing loss profiles will more likely affect detection of combat sounds than the understanding of speech.

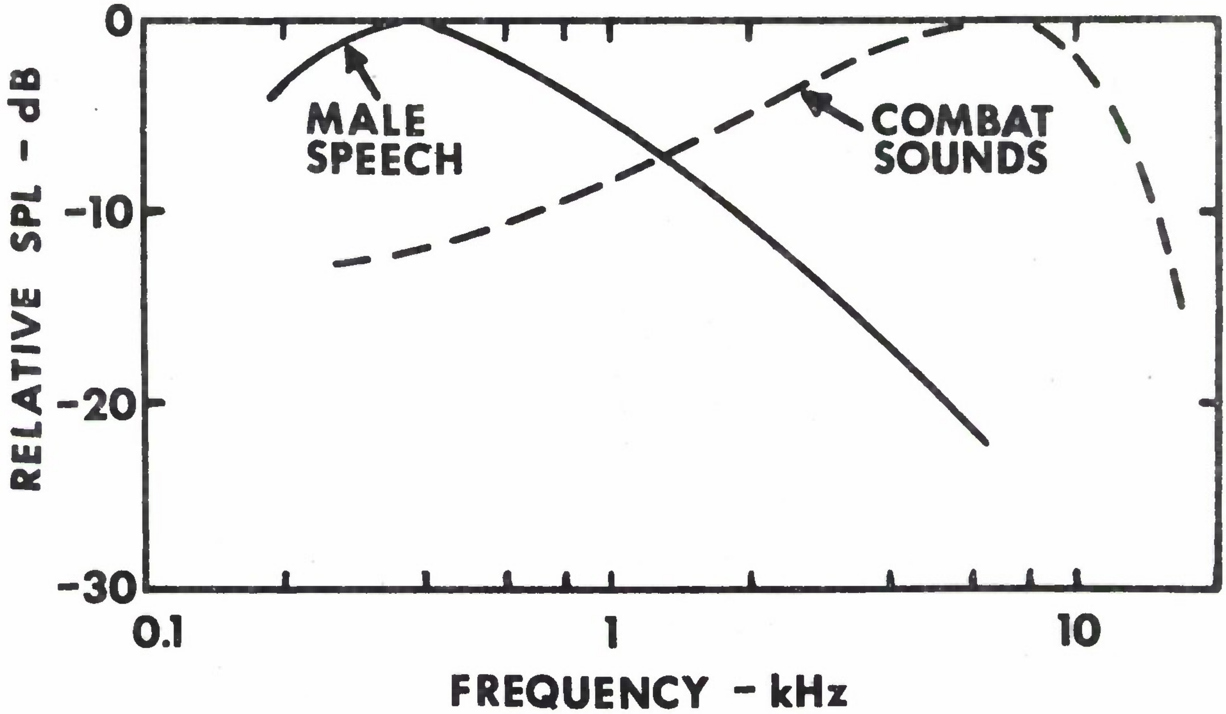

Fig. 7. FREQUENCY SPECTRA OF MALE SPEECH AND COMBAT SOUNDS

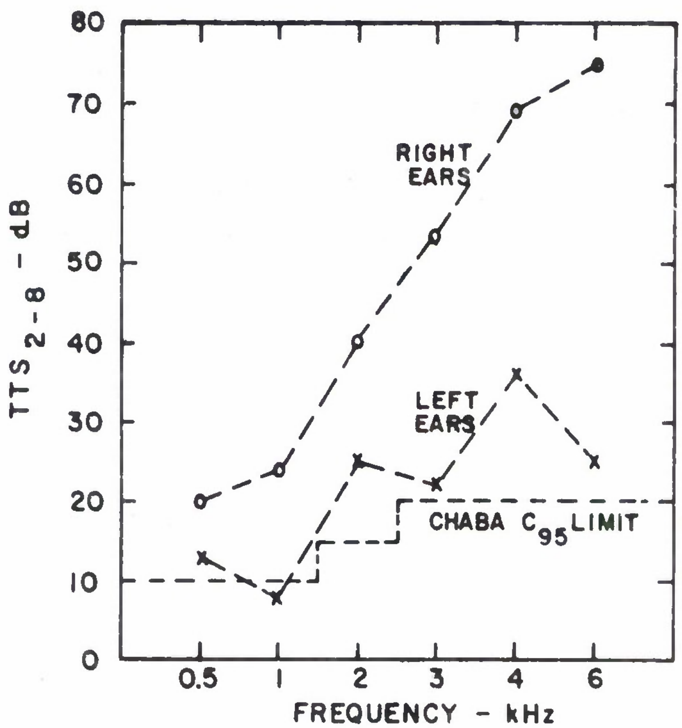

Fig. 8. TEMPORARY THRESHOLD SHIFTS IN RIGHT AND LEFT EARS OF 26 SUBJECTS EXPOSED TO ONE SHOT OF M72 ROCKET NOISE

Tentative Outline of Research Plan

It should be understood that the use of the term "detection" implies and includes the recognition or identification aspect as well. Following is a tentative outline of the steps envisioned to be involved in developing a predictive model of hearing loss effects on detection of combat sounds.

1. An old recipe for rabbit stew starts off: "First you catch a rabbit." The first step in the process is to select a population of combat sounds for use as stimuli in experiments. The population of sounds will likely be developed by reviewing existing documents dealing with combat recognition requirements, including current training plans for Army personnel. An attempt will be made to keep the population definition as broad as possible to assure generality of the empirical data to Army operations under a variety of mission, geographical and terrain situations.

2. In some cases new descriptive parameters must be developed for correlating sound characteristics with detection performance. For some sounds, such as the sound of vehicles operating at great distances, simple octave- or 1/3-octave-band analysis may provide adequate description. In other cases such simple description will not suffice. The masking literature, for example, indicates that sounds of an impulsive character can be detected in steady background noise when the intensity of the signal is below that of the masker. In such instances a more complex form of analysis and description will be required.

3. Instrumentation requirements are being developed. These include instrumentation for recording and playing back stereophonic sounds with minimal distortion. Interfacing requirements to our laboratory programming computer will have to be established.

4. Experimental test procedures may take the form of audiometric-like procedures using real-world sounds. There is little precedent to build on in this area. Rapid testing procedures will be required in some parts of the program.

5. Empirical investigations will include gathering of normative data on subjects having "normal" hearing sensitivity, as well as data from subjects having varying degrees of permanent noise-induced hearing loss. Hypotheses developed from these will be verified with subjects having experimentally-induced TTS. Here, rapid testing methods will be required so detection thresholds can be measured before the TTS recovers.

6. Correlational techniques, among others, will be used to develop predictive models of hearing loss effects on detection of combat sounds.

SUMMARY

Deficiencies in current hearing damage-risk criteria have been identified and discussed, and the research needed to revise these criteria has been outlined.

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13. ABSTRACT

The state of the art in noise-exposure criteria is reviewed and it is suggested that such criteria are in need of revision and extension to meet future operational requirements of the Army. Further, existing noise criteria, expressed in terms of "decibels of hearing loss," should be re-stated in terms of predictions about the performance of military personnel after they have been exposed to noise. Such re-statement in performance terms will significantly improve communication about the risk of noise exposure to people who are in a position to utilize such information but who generally do not comprehend the notation of decibels of hearing loss.

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