NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 1123

HEARING LEVELS OF 416 SONAR TECHNICIANS

by

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Naval Medical Research and Development Command
Research Work Unit M0100.001-5001

Released by:

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Commanding Officer
Naval Submarine Medical Research Laboratory

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SUMMARY PAGE

PROBLEM

To determine whether hearing loss in sonar technicians presents a potential problem for job performance, both for current sonar systems and for future sonar systems incorporating new signal-presentation and signal-processing techniques.

FINDINGS

The hearing threshold levels of sonar technicians were higher (worse) than the International Standards Organization (ISO) norms, which are based on people with no history of noise exposure or otologic disease. The audiometric configuration was consistent with noise exposure. Nevertheless, the hearing levels of most sonar technicians are adequate to perform their job. Hearing levels exceeded the Navy's table of limits, however, in five percent of the sonar technicians.

APPLICATION

Because few sonar technicians have hearing losses great enough to affect performance, auditory sonar channels can be designed independently of hearing levels of the users. Better tests are needed to determine which sonar technicians with hearing loss have decreased job performance. Auditory channels in sonar systems should be designed with high-quality output limiting so that hearing is protected without degradation of the signal.

ADMINISTRATIVE INFORMATION

This research was carried out under Naval Medical Research and Development Command Work Unit 63856N M0100.001-5001, "Auditory Sonar". It was submitted for review on 29 June 1988, approved for release on 19 September 1988, and designated as NSMRL Report Number 1123.

ABSTRACT

Audiograms for 416 sonar technicians were analyzed. Audiometric configurations were consistent with noise exposure. Nevertheless, the hearing of most sonar technicians was adequate for their job. Five percent of the sonar technicians, however, failed the Navy's hearing criteria. As some were fairly young, the hearing losses may have begun prior to their enlisting. More stringent hearing criteria should be required for selection of sonar technicians. An operator with a hearing loss could have an associated impairment in frequency- and temporal-analysis abilities, which could have a large influence on sonar performance. In actual listening situations, experience may help compensate for the loss. The Navy's hearing criteria seem minimally adequate for identifying hearing losses that might lower job performance. Once hearing has exceeded criterion levels, a more direct test of auditory-sonar performance could identify those whose hearing actually does affect job performance. In order to protect the hearing of sonar technicians, better output limiting of auditory-sonar channels should be considered, but a high-fidelity signal must be maintained.

INTRODUCTION

The auditory modality is important to sonar technicians. When advanced visual displays were developed for sonar systems, however, a notion began to take hold among system designers and even some sonarmen that the function of the auditory channel on sonar systems would soon be obsolete. That has proven not to be true (Hanna et al., 1988; Miller, 1987). The importance of auditory channels is again being recognized, with auditory sonar seen as a complement to the visual displays for many tasks, and as a necessity for other tasks, such as rapid classification of transients, discrimination and tracking of multiple close-in contacts on a bearing, and recognition of counter-measures and decoys. Sonar technicians still must have adequate hearing in order to perform their job well. Because supervisors may be required to listen to and make judgments about auditory signals in critical situations, and should at all times monitor the auditory channel over loudspeakers to confirm the judgment of the sonar technician who is listening over headphones, the criteria for their hearing should be no more lenient than for non-supervisors.

One of the requirements for sonar selection and retention is hearing levels for pure-tone stimuli no greater than those specified in the table of limits in Table I. If hearing levels exceed the table of limits in either ear, the sonar technician is disqualified unless a medical waiver is granted. There are no clear-cut criteria for granting a medical waiver at present.

Table I. 1984 table of limits for submarine sonar technicians from Chapter 15: Examinations/ISO Standards of the Manual of the Medical Department.[1] Hearing loss which exceeds these levels at any frequency in either ear is reason for disqualification from the sonar rate. The losses in the manual are in dB HL. The SPL equivalents (for TDH-39 earphones) are given in line 2 of the table.[2]

Frequency in kHz				
Threshold in	0.5	1.0	2.0	4.0
dB HL	35.0	30.0	30.0	40.0
dB SPL	46.5	37.0	39.0	49.5

Disqualifying or retaining a sonar technician on the basis of pure-tone thresholds is questionable because the hearing loss may or may not interfere with his job performance. That is, a sonar technician's job does not involve pure-tone detection at low levels in a quiet environment. Instead, they listen to complex signals at higher intensities in a background of noise. Their task involves not only detection in noise, but also suprathreshold classification of targets and discrimination of changes in target status. Aspects of hearing that are more relevant (but more difficult to test) include auditory filter bandwidths, pitch and spectral shape discrimination, and temporal resolution (Harris, 1957; Howard, 1978; Mackie et al., 1981). Although these auditory processes do worsen with increasing hearing loss, the correlation between any of these processes and amount of hearing loss is far from perfect (Festen and Plomp, 1983). The result is that listeners with similar audiograms (hearing levels across frequencies) may not be similarly impaired at suprathreshold levels (Wightman, 1982).

In addition to the questionable validity of the pure-tone threshold test to assess auditory sonar performance, several other considerations could influence whether a sonar technician should be retained. For example, to what extent does overlearning a task compensate for auditory deficits? Is the sonar technician assigned to a job that does not require good auditory skills (as is the case with many shore assignments)? Is there a shortage of sonar technicians in the fleet?

The purpose of the present study was to describe the hearing levels of submarine sonar technicians. This information is important in order to determine whether deficient auditory skills due to hearing loss present a possible problem to the Navy. It is also important for this laboratory's research on auditory sonar signal-processing and signal-presentation techniques and for the application of that research to the needs of the submarine fleet. That is, the auditory signals in sonar systems should be tailored to provide maximal information to as many sonar technicians as possible. If hearing loss is prevalent, then the losses need to be taken into account in planning signal-processing and signal-presentation strategies.

I. METHOD

We examined pure-tone audiograms for all sonar technicians evaluated from July 1985 through June 1986 at the Navy Regional Hearing Conservation Office of the Naval Hospital Groton. Audiometry was conducted in a four-man testing booth by Navy certified hearing-conservation technicians using Tracor microprocessor 410N audiometers. They measured thresholds at 0.5, 1.0, 2.0, 3.0, 4.0, and 6.0 kHz. For 80% of the sonar technicians, thresholds also were measured at 8.0 kHz. An automated clinical procedure was used. The non-test ear was not masked.

II. RESULTS

A. Hearing Levels of Sonar Technicians

The distribution of hearing levels for the 416 sonar technicians is shown in Figure 1 (8.0 kHz thresholds were measured on 333 of them).[3] Hearing levels are plotted for the 10th, 25th, 50th, 75th, and 90th percentiles. Right and left ears are very similar, although the left-ear thresholds tend to be slightly higher (more hearing loss) at the upper frequencies. The configuration for each of the audiograms (each percentile shown in the figure) is consistent with noise exposure (elevated thresholds in the 3-6 kHz range).

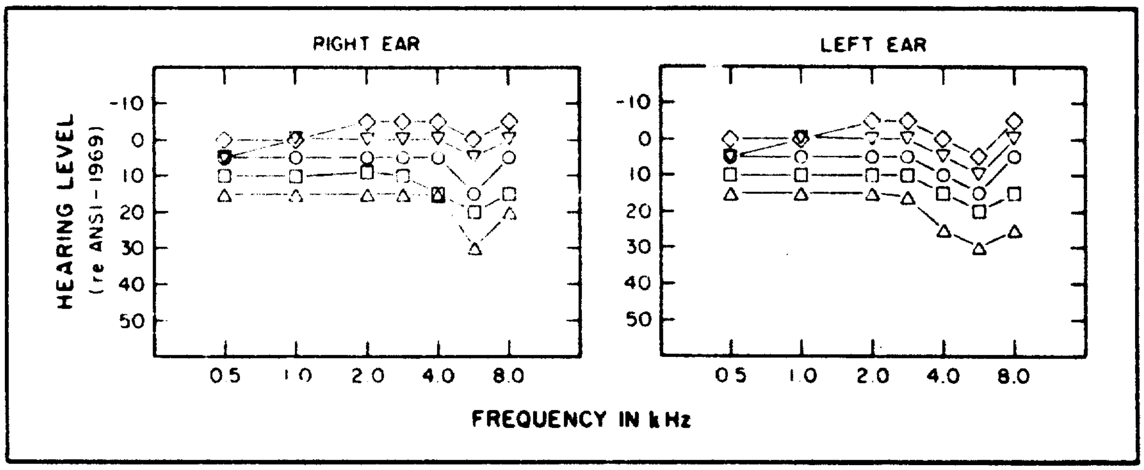

Figure 1. Hearing levels for right and left ears of 416 sonarmen. The ◇, ▽, ○, □, △ and symbols are for the 10th, 25th, 50th, 75th, and 90th percentiles respectively.

Figure 2 shows mean audiograms for 210 sonar technicians from fast-attack submarines and for 174 from fleet-ballistic missile (FBM) submarines. The scale is expanded relative to the previous ones. Thresholds were slightly higher (worse) for the fast-attack group. However, these differences were not significant ($p>.05$) using a Hotelling's T^2 across groups for either the right or left ear.[4] Right and left ears were significantly different ($p<.05$) using a Hotelling's T^2 for the difference between the ears. Post-hoc univariate F-tests showed significant ($p<.05$) differences at 3kHz and 4kHz.

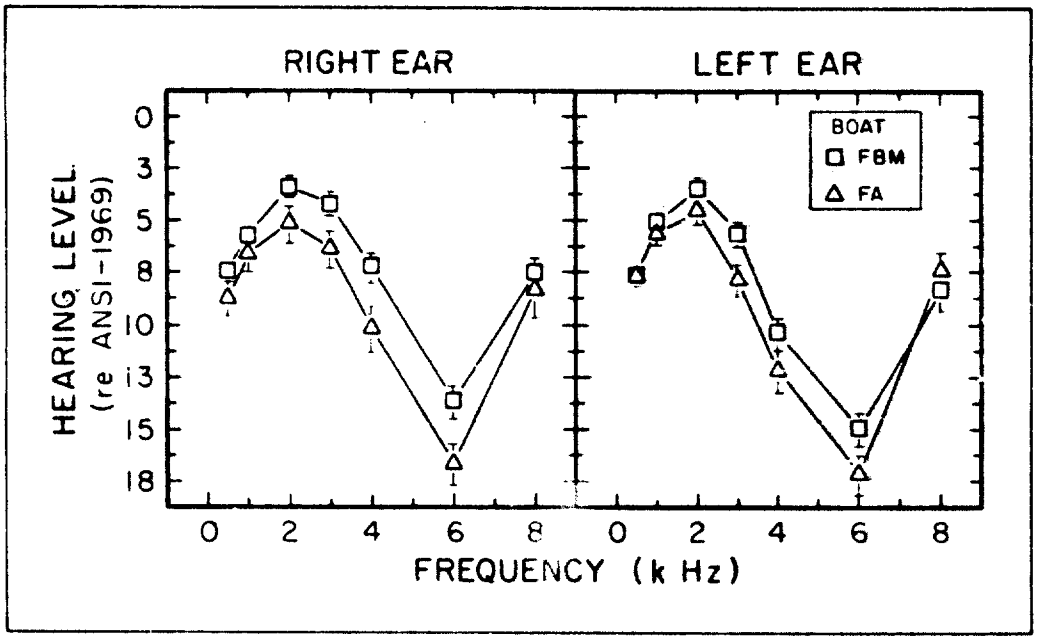

Figure 2. Mean hearing levels for sonar technicians from fast-attack and fleet-ballistic missile submarines. Error bars for the standard error of the mean were not plotted when they were smaller than the symbols or overlapped another symbol.

The effects of noise exposure can best be assessed by comparison to aging norms. Spoor (1967) provided age norms that are used by the International Standards Organization (ISO). The norms are based on a highly screened population of men who were free from otologic pathology and were not exposed to hazardous levels of noise, either at work or outside of work. Figure 3 compares the mean hearing levels of sonar technicians in their 20s (N=328) and 30s (N=83) with the highly screened population. There were too few sonar technicians in their 40s (N=5) to be included in this comparison. The hearing levels of the sonar technicians were higher (worse) than those of the highly screened population. In fact, hearing levels of sonar technicians in their 20s were worse than those for the ISO normative population in their 30s, clearly showing the effects of noise exposure; but the loss could have been incurred either on or off the job.

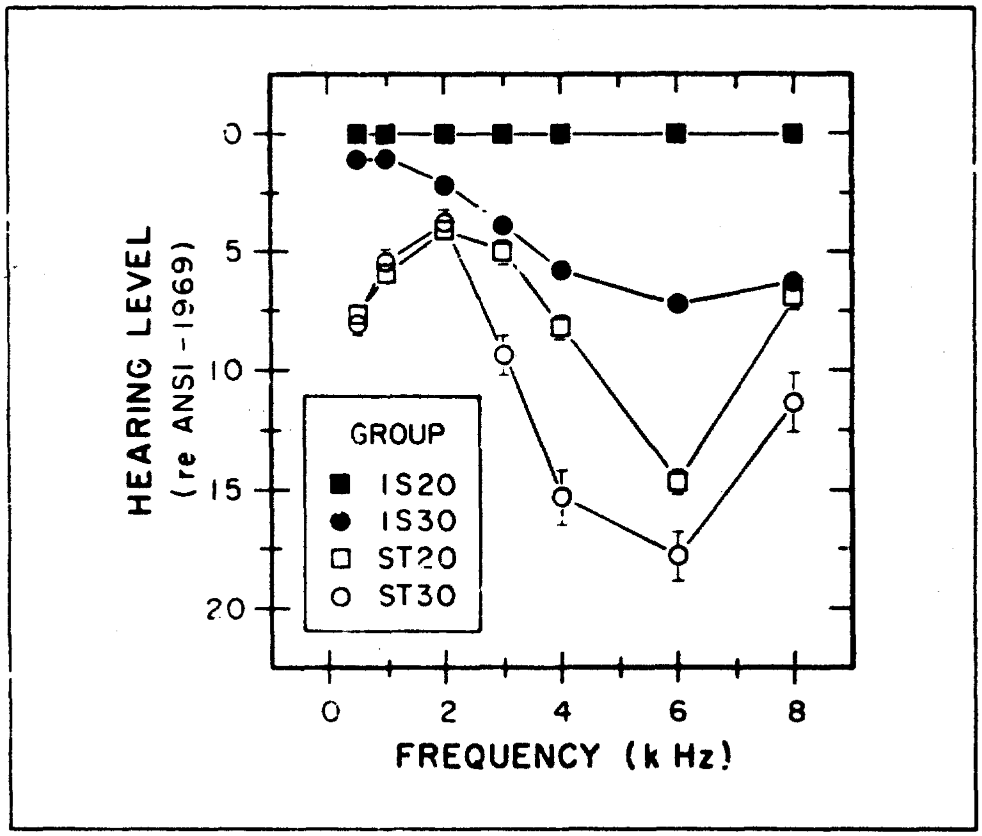

Figure 3. Mean hearing levels of sonar technicians in their 20s and 30s in comparison to a population screened for otologic pathology and noise exposure (ISO norms). The error bars are +- 1 standard error of the mean.

B. Audiograms of Sonar Technicians Failing the Hearing Test

The hearing of 22 sonar technicians did not meet the criteria in the Navy's table of limits. Five were from FBM submarines, sixteen were from fast-attack submarines, and one was on shore duty. We do not know which were later given medical waivers or disqualified.

Two of the sonar technicians failed in both ears. Their audiograms are shown in Figure 4. One had a mild-to-moderate high-frequency hearing loss (left panel). The second had a severe high-frequency loss (right panel). Whether his shore-duty assignment was due to his hearing loss is not known.

The other twenty failed in one ear. Most did not have completely normal hearing in the other ear. Normal hearing is often defined audiologically as hearing levels no greater than 15 dB HL although for research purposes even more stringent criteria are frequently used. With the 15 dB HL criterion, only three of the sonar technicians had normal hearing in one ear. Their audiograms are shown in Figure 5. Because masking was not used, the hearing loss for at least two of the sonar technicians (#121 and #355) may be worse than shown in this figure.

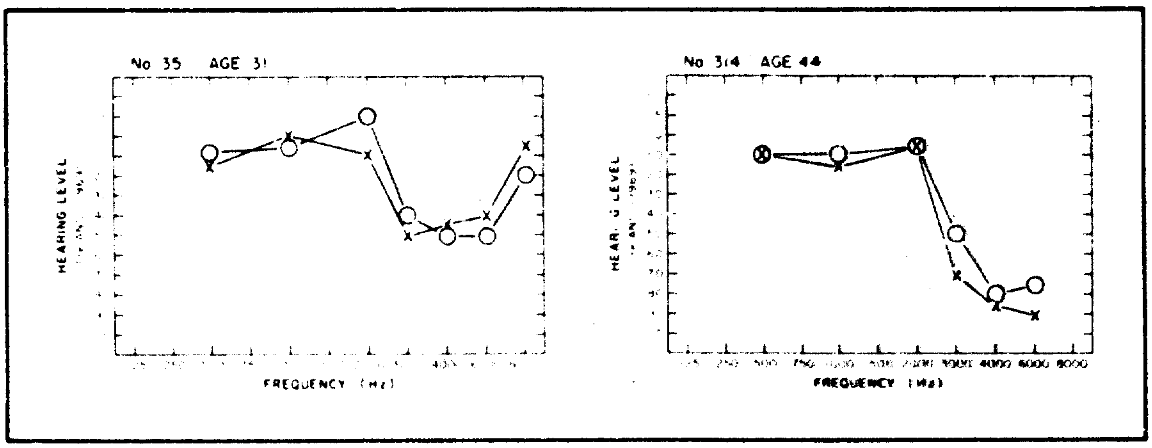

Figure 4. Sonarmen whose hearing exceeded the table of limits in both ears. The O and X symbols are for right and left ears respectively.

Surprisingly, nearly one-third of the sonar technicians who did not meet the hearing criteria were 23 years old or less. The audiograms for two of them are shown in Figure 5; the other five are shown in Figure 6. Due to lack of masking, at least two of the audiograms (#121 in Figure 5 and #343 in Figure 6) may be underestimates of the amount of hearing loss. The audiograms for four of the sonar technicians (the two in Figure 5 and the two on the bottom panels of Figure 6) are consistent with a history of noise exposure. If these losses were incurred during their military service, their hearing-protection program might be questionable. If they had these losses prior to becoming sonar technicians, the hearing criteria for sonar technician assignment are being ignored. The three other sonar technicians are shown in the top two rows of figure 6. Two had fairly flat audiograms (top and middle-left panels), a type not seen with noise exposure. The third gave no indication of hearing in one ear.

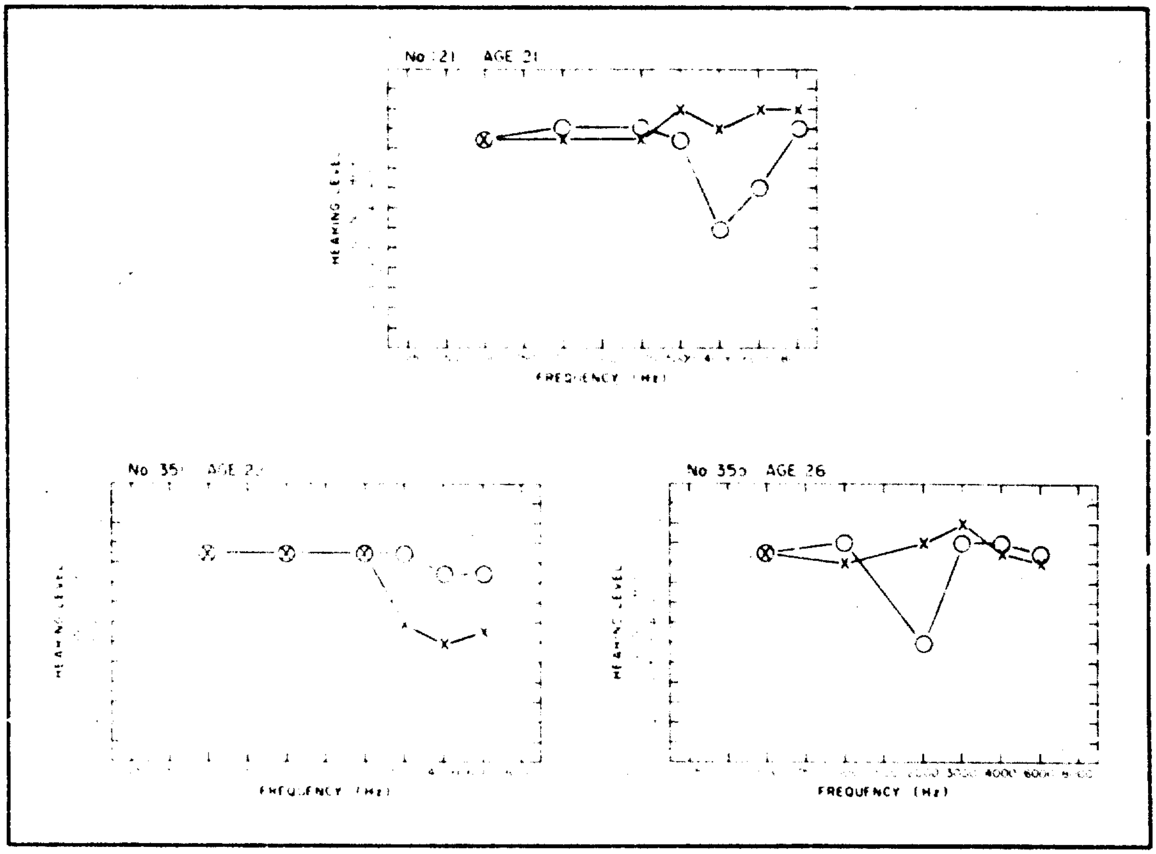

Figure 5. Sonarmen whose hearing exceeded the table of limits in one ear but was audiologically normal in the other ear. The O and X symbols are for right and left ears respectively. The non-test ear was not masked, so hearing loss may have been underestimated for cases #121 and #355.

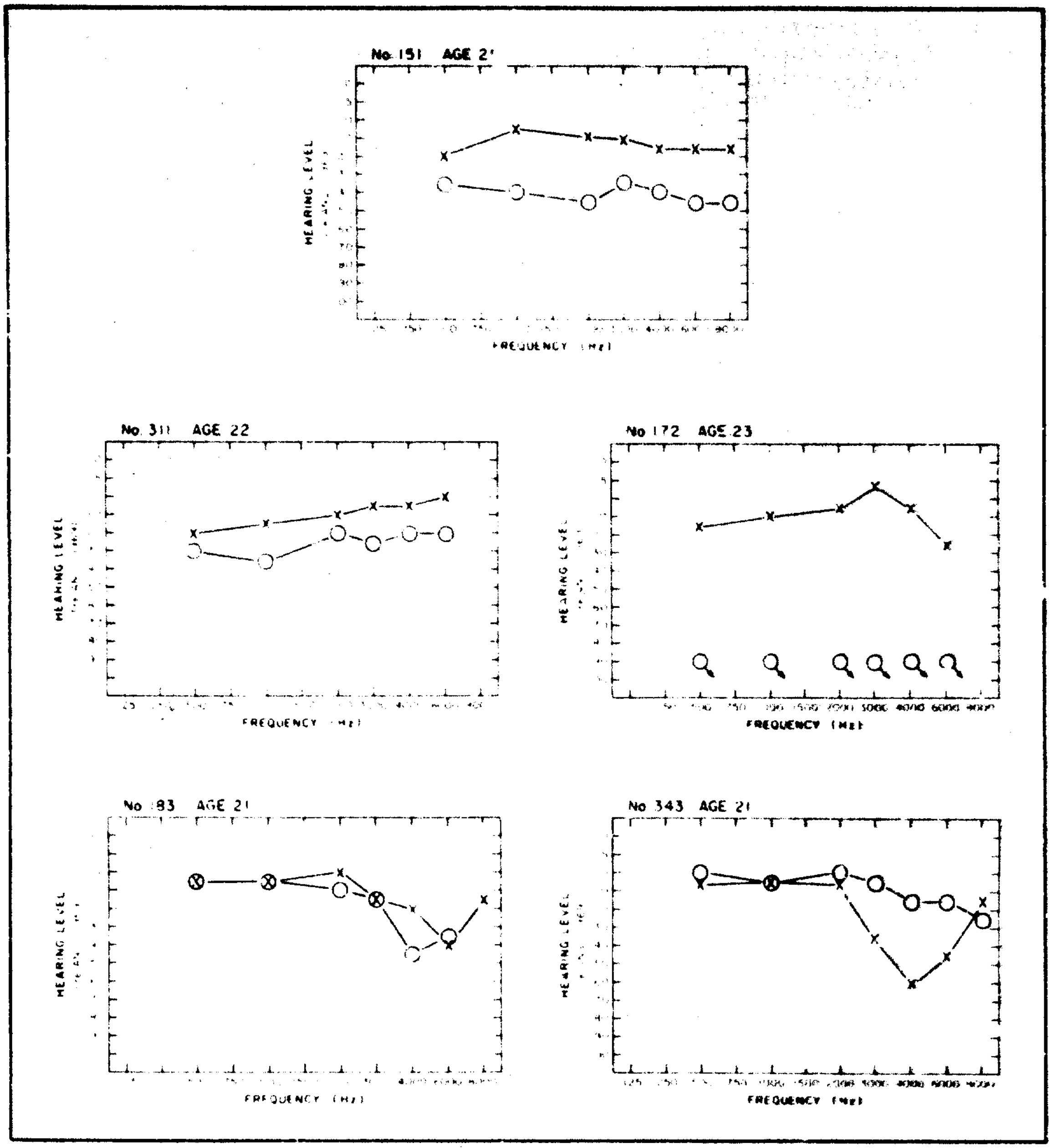

Figure 6. Five of the seven sonarmen whose hearing exceeded the table of limits in one ear and were 23 years old or less. The other two are shown in Figure 5 (left and middle panels). The O and X symbols are for right and left ears respectively. The non-test ear was not masked, so hearing loss may have been underestimated for case #343.

The audiograms of the other 12 sonar technicians are shown in Table II. At least two-thirds of these audiograms may underestimate the amount of hearing loss because masking was not used. Note that some of these losses are quite large given the ages; also note that most of the audiometric configurations are consistent with noise exposure.

Table II. Hearing levels in dB HL of 12 Sonar Technicians whose hearing exceeded the table of limits but are not shown graphically in Figures 4, 5, and 6. For eight of the twelve, hearing levels may be underestimated as masking was not used.

AGE	GRADE	RIGHT EAR (Frequency in kHz)							LEFT EAR						
		0.5	1.0	2.0	3.0	4.0	6.0	8.0	0.5	1.0	2.0	3.0	4.0	6.0	8.0
26	4	-5	5	5	5	20	15	25	0	0	5	50	65	60	35
26	6	0	5	5	15	5	45	10	5	15	-5	5	65	70	45
26	6	-10	20	25	5	5	10	25	10	35	30	0	-10	30	50
30	6	15	15	10	5	10	35	40	10	15	10	15	65	60	25
30	5	10	10	30	50	50	25	10	5	5	5	15	30	10	5
31	6	0	10	10	10	5	20	25	20	35	50	50	45	60	50
32	4	15	20	15	10	20	25	45	15	15	15	50	30	30	15
33	5	10	15	15	20	65	50	--	20	10	15	10	25	45	15
33	6	10	10	0	15	25	15	0	10	15	15	30	50	25	10
33	7	5	5	0	0	5	25	--	10	15	15	35	50	30	--
34	6	10	10	-5	10	50	20	--	15	10	5	20	40	25	-5
39	7	0	-5	0	0	5	20	10	5	-5	0	15	60	60	40

III. DISCUSSION

A. What degree of hearing loss causes problems?

As discussed earlier, suprathreshold hearing is more applicable to sonar performance than is the pure-tone audiogram. In this section, we examine three suprathreshold factors to determine at what level of hearing loss abnormalities are seen and what the correlation is with hearing loss. The three factors are auditory-filter bandwidths, frequency discrimination, and temporal acuity. The data are from psychoacoustics studies on populations that included subjects with noise-induced hearing loss. Data for sonar technicians should be similar. As some of the information presented in this section is fairly technical, readers unfamiliar with psychoacoustic terminology might want to skip directly to the last paragraph in this section.

The widths of the auditory filters are related to detection of speech in noise (Patterson et al., 1982; Festen and Plomp, 1983), and -- as both speech and sonar signals are complex, time-varying signals -- should be important for sonar detection and classification at low signal-to-noise levels. Many measures have been used to infer changes in auditory-filter width: e.g., critical ratios, masking patterns, and psychophysical tuning curves. The most robust measure calculates filter shapes from masked pure-tone thresholds in wideband noise having a notch of variable width centered at the pure-tone frequency and separates the frequency selectivity and efficiency aspects of auditory masking (Patterson and Nimmo-Smith, 1980; Patterson et al., 1982; Glasberg et al., 1984). Glasberg and Moore (1986) found correlations between hearing loss and filter widths obtained with notched-noise maskers of 0.78 and 0.87 for 1.0 and 2.0 kHz respectively. Filter widths remained normal up to thresholds of 40 dB SPL and tended to be broader for greater amounts of loss. Marshall and Jesteadt (1986) demonstrated that detection thresholds for two-interval forced-choice procedures (used by Glasberg and Moore) are 6.5 dB lower than for clinical procedures (used in the Navy's hearing conservation program) -- the equivalent SPL for clinical procedures is 46.5 dB SPL. In dB HL terms (dB relative to normal hearing), these levels are 35, 39.5, 37.5, and 37 dB HL at 0.5, 1.0, 2.0, and 4.0 kHz respectively. The Navy's criteria allow for losses of this magnitude or greater at 0.5 and 4.0 kHz.

Harris (1957) reported that the Sonar Pitch-Memory Test (which measures frequency discrimination for pulsed sinusoids) was the best psychoacoustic predictor of officer ratings of sonarmen. Although there is a large literature on the relation between hearing loss and frequency discrimination, most of it is flawed by not taking into account practice effects, which can be very large (Moore, 1976; Turner and Nelson, 1982). Turner and Nelson measured frequency discrimination for pulsed sinusoids in listeners with high-frequency hearing loss after asymptotic performance had been reached. Abnormal frequency discrimination was seen at 3.0 kHz for listeners with approximately 24 dB SPL hearing loss, measured with a forced-choice procedure (30.5 dB SPL for a clinical procedure) although some listeners with greater amounts of hearing loss had normal frequency discrimination. In dB HL terms, these levels are 19, 23.5, 21.5, and 21 dB HL for 0.5, 1.0, 2.0, and 4.0 kHz respectively. Thus, these effects tend to be seen at hearing levels from 7 to 20 dB lower (less loss) than those required for disqualification.

For ears with high-frequency losses, both auditory bandwidths and frequency discrimination may be affected at lower frequencies where pure-tone thresholds are within normal limits. Abnormally high masked thresholds at mid-frequencies have been seen in these cases (Tyler et al., 1982; Smits and Duifhuis, 1982; Humes, 1983). Humes found that listeners with abnormal frequency resolution (measured with masking patterns and tuning curves) at mid-frequencies also had elevated speech thresholds in noise, while those with normal frequency resolution at the same frequencies had essentially normal speech thresholds in noise. The differences between the two groups of listeners was 3 dB. Abnormal results were seen for hearing levels that would be judged acceptable using the Navy's hearing criteria.

Frequency discrimination shows similar results as auditory-bandwidth measures. Turner and Nelson (1982) found that a hearing loss at high frequencies often resulted in abnormal frequency discrimination at lower frequencies where hearing was normal. Comparisons of histological results with behavioral thresholds in animals have shown that considerable structural damage may occur in the cochlea at mid to low frequencies without threshold elevation (Bredberg, 1968; Stebbins et al., 1979; Eldredge et al., 1973; Henderson et al., 1974).

Examples of fine temporal discrimination are temporal-gap detection (detection of a silent gap in ongoing noise) and temporal modulation transfer functions (TMTFs, thresholds for modulation depth as a function of modulation frequency). Studies using normal-hearing listeners as subjects have shown that loss of high-frequency hearing sensitivity (via low-pass filtering or masking) adversely affects temporal acuity (Patterson et al., 1978; Florentine and Buus, 1984; Bacon and Viemeister, 1985; Formby and Muir, 1988). Listeners with high-frequency hearing losses show the deficits expected due to lack of high-frequency information (Florentine and Buus, 1984; Bacon and Viemeister, 1985); some show an additional deficity, indicating that temporal resolution per se may be affected by the hearing loss (Florentine and Buus, 1984).

Giraudi-Perry et al. (1982) measured temporal-gap detection for chinchillas (whose audiograms and gap-detection thresholds are similar to humans) as the degree of noise-induced hearing loss (asymptotic threshold shift) was systematically varied. The low-frequency noise exposure produced a relatively flat hearing loss, which allowed gap detection to be measured without consideration of whether a reduction in high-frequency information affected the results. When thresholds were elevated by 40 dB (the amount allowed in the Navy's table of limits at 4 kHz), gap-detection thresholds were abnormal, even when the level of the sound was increased to compensate for the hearing loss (i.e., gap detection thresholds were longer than normal both in terms of sound pressure level and sensation level[5]). The chinchillas showed an orderly decrease in temporal resolution with increasing degree of hearing loss, but human listeners do not (Florentine and Buus, 1984). However, the chinchillas all had the same etiology and configuration as well as degree of loss whereas studies using hearing-impaired human listeners used heterogeneous groups.

The role of high frequencies for temporal acuity is more straightforward than is the degree of loss at which abnormalities occur. Recall that sonar technicians have noise-induced hearing losses that begin at frequencies as low as 3 kHz, and that frequencies above 4 kHz need not be considered in disqualification decisions. However, decrements in TMTF detection and temporal-gap detection are clearly seen for low pass cut-offs around 3 kHz, and even though extending the low-pass cut-off to 4 kHz improves detection, it still is worse than either a broad-band or a 4 kHz high-pass filtered stimulus (Patterson et al., 1978; Formby and Muir, 1988). That is, auditory information above 4 kHz is important for temporal resolution.

In summary, abnormalities, both in frequency and temporal domains, are seen with hearing levels that would be acceptable by the Navy's criteria. The psychoacoustic tests discussed in this review are very sensitive indicators of abnormality, however, and frequency-discrimination and temporal-resolution abilities may be better than needed for many auditory sonar tasks. The auditory-filter bandwidth measure no doubt is directly relevant to listening tasks at low signal-to-noise ratios. With increasing degrees of hearing loss, frequency and temporal acuity tend to become worse. We do not yet know how good these abilities must be to have good auditory sonar performance. From our review of frequency- and temporal-domain abnormalities, hearing levels in the table of limits appear to be minimally adequate, at least until more data are available. Objective data relating hearing loss to relevant aspects of job performance would be helpful in determining whether the table of limits is too strict or too lax. Ideally, the table of limits (i.e., audiograms) should be used to identify those sonar technicians who might have problems, and then further testing using suprathreshold tasks would determine whether or not the sonar technician who failed the criteria in the table of limits actually should be disqualified.

B. Difficulty in Devising a Better Test

As hearing loss increases, frequency- and temporal-analysis abilities become abnormal, but individual variability is large -- too large to predict from hearing levels alone. Although frequency-and temporal-analysis abilities could be measured once hearing levels exceeded some criteria (such as the Navy's table of limits), the relationship between these abilities and auditory-sonar performance is not known. It no doubt would be far from perfect. Auditory-sonar performance surely is similar to speech perception in that "top-down processing" (knowledge about the sounds and rules relating to their context) plays a very large role.

The type of test with the best face validity is one which uses simulated situations measuring detection and classification of targets, as well as changes in target status. Numerous problems exist in developing such a test, however. The effects of a high criterion (unwillingness to say that a target is present until very confident) on target detection could be larger than the effects of hearing loss. Classification performance is difficult to assess because classification of targets based on audition alone often is far from perfect (Mecherikoff, 1974). Experience and training play a central role in developing good auditory skills, so less experienced operators usually perform differently from more experienced ones, independent of hearing levels. Individual variability could be quite large even in operators with similar hearing, experience, and training. Moreover, test development for classification abilities would be difficult and time-consuming. First, there are many unknowns about the ways that sonar technicians process auditory sonar information, including which cues are used for various tasks. Second, the stimulus set is not easily defined. Sonar-tape libraries are organized by types of contacts not by types of acoustic cues. Finally, test development would require having many sonarmen available for longer periods of time than most can be.

An alternative test would be one which measures detection using a precise, criterion-free procedure. Test development for a detection test would be fairly straightforward. The test would consist of detection or discrimination thresholds for stimuli (targets) varying in spectra. The test procedure would be an adaptive, forced-choice procedure (Levitt, 1971) with minimal uncertainty of the stimulus and masker so that the test would evaluate any decrements in detection due to the hearing loss, while minimizing cognitive differences among the sonarmen. If a decrement was found in either ear, frequency-selective amplification could be tried. Binaural as well as monaural performance could be optimized in amplification selection. If this amplification put the sonar technician back into the normal range, a personal amplifier could be constructed to plug into the earphone jack.

C. How to prevent hearing loss in submarine personnel

For the year of our sample, five percent of the sonar technicians' hearing levels exceeded the table of limits. Because developing a test to determine which of those five percent actually have problems with auditory sonar tasks is very difficult, every effort should be made to initially select sonarmen with good hearing and then to preserve their hearing.

The hearing-level criteria in the table of limits probably are marginally adequate for sonar retention, but they are much too lax for sonar selection. It doesn't make much sense to select and train individuals whose hearing may soon disqualify them. The group of sonar technicians whose hearing was bad enough to disqualify them included several who were relatively young. It would be interesting to know whether their hearing levels were close to the limits at the time they entered sonar training. In order to determine what the entry criteria should be, longitudinal data on how much loss sonar technicians sustain over the time of their enlistment are needed.

In order to preserve hearing, every effort must be made to minimize noise exposure, both on and off the job. On-the-job noise exposure includes listening on the stack. The worst culprits probably are depth charges and active sonar from a surface ship which is hunting the submarine. Some type of output limiting is necessary. Plomp (1988) has concluded that, for understanding speech, an automatic gain control (AGC) with a relatively slow time constant (0.25-0.5 seconds) is preferable to compression with a fast time constant. Compression time constants (which are less than a few tenths of msec) diminish short-duration spectral and temporal contrasts in the signal. Because AGC does not provide protection from the initial part of loud transients, Plomp suggests that the output of the AGC be peak-clipped. This same approach might well also apply to sonar signals.

Another potential on-board noise problem arises from bunks being next to the speakers used for alarms. These loudspeakers have individual volume adjustments and are not calibrated. Their level may be intense enough to contribute to hearing loss.

Although sonar technicians have been instructed to protect their hearing outside of work, most probably are not careful enough. Loud music in bars, lawn mowers, power tools, chain saws, snowmobiles, and other noises often found in daily life are recognized by sonarmen as being potentially harmful, but seldom do they use ear protection during these noise exposures.

Clinical procedures used for measuring thresholds have fairly large test-retest variability. As a result, criteria for threshold shifts due to noise exposure allow for considerable hearing loss before identifying a significant threshold shift. For example, OPNAVINST 5100.23B defines a significant threshold shift as 15 dB or greater at any frequency from 1.0 to 4.0 kHz, or an average of 10 dB or more at 2.0, 3.0, and 4.0 kHz. A test procedure with smaller test-retest error would allow smaller threshold shifts to be reliably measured. The earlier a permanent threshold shift is detected, the earlier an aggressive plan to prevent further hearing loss can be initiated. Hearing loss should be halted before it begins to approach the values in the table of limits.

D. Should signal-presentation and signal-processing strategies consider the possibility of hearing loss?

Some signal-presentation and signal-processing techniques would not work with hearing-impaired listeners. A hypothetical example is that extending the high-frequency cut-off of a sonar system requires that the listeners have hearing in that region. Because a low percentage of sonar technicians failed the Navy's hearing criteria, we will not pay much attention to the possibility of hearing loss when developing techniques for enhancing performance on sonar systems. The Navy might choose to be concerned, however, about whether inadequate hearing of sonar technicians could sometimes result in decreased operational capability of a submarine.

IV. SUMMARY AND CONCLUSIONS

The audiograms of 416 sonar technicians who were evaluated at the Navy Regional Hearing Conservation Office of the Naval Hospital Groton during one year were analyzed in order to determine whether submarine sonar technicians have hearing losses that could interfere with job performance and with selection of signal-processing and signal-presentation techniques for auditory sonar. The following conclusions were reached:

1. Hearing levels of most sonar technicians (ninety-five percent) meet the Navy's criteria for adequate hearing. Due to the small number who failed to meet the criteria, we will not consider possible hearing losses in our research and for our recommendations on design of auditory-sonar channels.

2. The five percent of sonar technicians whose hearing levels exceed the Navy's table of limits may have abnormal frequency and temporal resolution. Hearing losses of this magnitude may affect job performance.

3. Hearing thresholds are inadequate predictors of whether a sonar technician can still perform his job. Hearing thresholds measure the ability to detect single tones in a quiet background at low overall levels whereas sonar technicians detect complex, noisy signals in a noisy background at much higher overall levels. They also classify suprathreshold sounds such as transients and discriminate changes in target status. Although there is no doubt a relation between hearing levels and the sonar technician's ability to do his job, hearing levels cannot be expected to correlate particularly well with job performance. That is, hearing-impaired individuals with identical audiograms may differ in suprathreshold frequency- and temporal-resolution abilities. Furthermore, learning and training play an important role. A well-learned task is less disrupted by hearing loss than is one with which an individual has less familiarity. Also, people differ cognitively in how well they are able to extract information from minimal acoustic cues.

4. Because it is difficult to predict which sonarmen with hearing losses can still perform their job, it is important to initially select sonar technicians with good hearing and then to insure that their hearing is not damaged. More stringent criteria than those in the Navy's table of limits should be used for selection of sonar technicians.

5. Auditory sonar channels should have well-designed output limiting. Not only does output limiting prevent hearing loss (permanent threshold shift) from noxious noises such as depth charges or active-sonar pulses from surface ships, but it also prevents temporary threshold shifts that may alter the sonar technicians' auditory abilities for the duration of the threshold shift. Poorly designed output limiting, however, can degrade the auditory signal. Future research should specify factors such as the dynamic range for auditory-sonar channels and the time constants for automatic gain control.

FOOTNOTES

1 The table of limits specifies that hearing at 8000 Hz be no worse than 45 dB HL. However, it also states that "Audiometric testing at 6000 Hz may be substituted when testing at 8000 Hz is impractical. The minimum hearing threshold level (HTL) at 6000 Hz should be 40 dB (ISO). When the HTL exceeds 40 dB at 6000 Hz, but is within specifications at all other frequencies, the deficit may be disregarded." (pg. 15-55, 3 Aug 84). In other words, thresholds at 6000 and 8000 Hz are disregarded.

2 Sound pressure level in decibels (dB SPL) is 20 times the logorithmic ratio of the measured sound pressure to a reference sound pressure. The reference in this case is 20 micropascals. It is independent of frequency. Hearing level in decibels (dB HL) is the number of decibels above an average normal threshold for a given signal. Zero dB HL is audiometric zero - the SPL required for detection by normal young adults (with no history of noise exposure or otologic pathology). The SPL required for audibility thresholds of pure tones differs at each frequency, but HL normalizes across frequency relative to normal hearing.

3 Results were essentially unchanged by eliminating those people without 8.0 kHz thresholds.

4 Multivariate tests were used because the variables were correlated. One individual with no hearing at the limits of the audiometer was excluded from the data analysis.

5 Sensation level (dB SL) is the number of decibels above the threshold of audibility for an individual listener or for a specified group of listeners.

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Audiograms of 416 sonar technicians were analyzed. Audiometric configurations were consistent with noise exposure. Nevertheless, the hearing of most sonar technicians was adequate for their job. Five percent of the sonar technicians, however, failed the Navy's hearing criteria. As some were fairly young, the hearing losses may have begun prior to their enlisting. More stringent hearing criteria should be required for selection of sonar technicians; otherwise, new sonar technicians whose hearing is barely adequate to begin with may shortly afterwards have inadequate hearing. An operator with a hearing loss could have an associated impairment in frequency- and temporal-analysis abilities, which could have a large influence on sonar performance. In actual listening situations, experience may help compensate for the loss. The Navy's hearing criteria seem minimally adequate for identifying hearing losses that might lower job performance. Once hearing has exceeded criterion levels, a more direct test of auditory-sonar performance could identify those whose hearing actually does affect

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job performance. In order to protect the hearing of sonar technicians, better output limiting of auditory-sonar channels should be considered, but a high-fidelity signal must be maintained.