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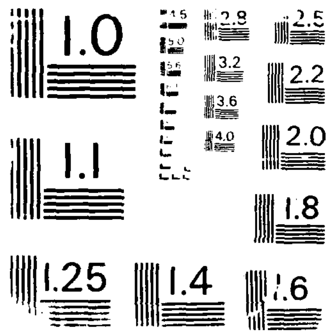
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Technical Memorandum 4-89

THE EFFECTS OF HEARING LOSS ON SPEECH COMMUNICATION AND THE PERCEPTION OF OTHER SOUNDS

Alice H. Suter
Gallaudet University

June 1989
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U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

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Noise-induced hearing loss acts as a low-pass filter for individuals receiving speech sounds or warning signals. These losses can also cause some degree of distortion in the auditory system, necessitating a speech-to-noise ratio of up to 10 dB more favorable to achieve speech recognition comparable to a normal-hearing listener. These distortions may appear in the frequency, intensity, and temporal domains.

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19. (continued)

Hearing in the high-frequency range is important [illegible] speech in noisy conditions, or when speech has been distorted [illegible], reverberation or filtering. Recent research targets the point [illegible] hearing handicap or "low fence" as an average hearing thresh[illegible] between 15 and 30 dB for the audiometric frequencies 1000, 2000, and [illegible] Hz. The effects of hearing impairment on speech may be estimated by various frequency-filter models, which need to be adjusted to account for the distortion component.

There is a lack of data on the ability of hearing-impaired listeners to detect and recognize warning signals, although predictions based on filtering models indicate that differences between normal-hearing and hearing-impaired listeners are small.

The U.S. Department of Defense has hearing threshold level standards for appointment, enlistment, and induction, as do the three individual services. In addition, the U.S. Army and the U.S. Air Force use "H" [illegible] for the initial selection and tenure of certain jobs. [illegible] are either close to the upper limit or exceed the [illegible] researchers as the point of beginning hearing handicap. [illegible] prevalence of hearing handicap in the U.S. Army is [illegible] disruptions of speech communication have serious [illegible] performance.

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Alice H. Suter
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Washington, DC

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Director
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CONTENTS

THE EFFECTS OF HEARING LOSS ON SPEECH COMMUNICATION AND THE PERCEPTION OF OTHER SOUNDS

I. INTRODUCTION

Speech communication is one of the most important activities engaged in by mankind. It is necessary to the proper function of most jobs, as well as to the satisfactory conduct of social and personal relations. Loss of hearing degrades speech communication in these vital functions. The extent to which hearing impairment may degrade performance in military occupations is the subject of this literature review and analysis.

Noise and filtering, which are common in everyday communication situations, have the effect of reducing the natural redundancy in speech. When the listener is hearing-impaired, redundancy is further reduced, to the point where the listener must strain to understand the messages communicated. Depending on the degree of hearing loss and the degradation of the speech signal, messages may be correctly perceived, partly or completely misunderstood, or missed entirely. The consequences of communication failures will range from minor annoyances to disasters.

The causes of hearing impairment among soldiers run the same gamut as they do in the civilian population. They can include impacted earwax, middle ear infections, and inner ear disorders caused by viruses, heredity, or ototoxic drugs. Probably the most common hearing impairment is noise-induced hearing loss, which may result from recreational as well as military and other occupational causes. These losses may be temporary, permanent, or combinations of the two. High-frequency hearing (in the 3000 to 6000 Hz range) is earliest and most severely affected by most noise exposures. Because consonant sounds tend to be high in frequency and low in sound energy, and because they contribute most of the intelligibility to speech, noise-induced hearing loss acts as a very effective filter to remove the intelligibility from speech. When added to the inherent distortion, which is present to some extent in most impaired auditory systems, even mild hearing impairments can place the listener at a disadvantage in certain situations.

For these reasons, all three branches of the military have developed performance criteria for hearing sensitivity. As we shall see, however, these criteria differ among services and among jobs within services (which is reasonable), they are not always enforced, and they do not appear to be based on objective data or principles.

II. EFFECTS OF HEARING LOSS ON SPEECH RECOGNITION

A. Filtering Versus Distortion

Certainly one of the most plausible explanations for the difficulties encountered by individuals with noise-induced hearing loss is that the hearing loss acts as a low-pass filter. This is even born out in the speech of some people who have experienced their hearing losses over a period of years, in that they tend to drop consonants from the ends of words. Because of this filter effect, researchers such as Kryter (1970), Braida et al. (1979), and Skinner and Miller (1983) have proposed corrections for hearing impairment to the Articulation Index (AI).

Levitt (1982) has summarized the filter effect succinctly. For the mildly hearing-impaired individual, most of the weaker consonants, such as sibilants and voiceless stops, will be barely audible or inaudible. This effect will be greater when these phonemes occur in the final position or in blends, where their intensity will be lower. The more severely hearing-impaired person will miss the identifying cues for all voiceless sounds and also many of the weaker voiced consonants, such as voiced stops in the final position.

Although there is still some controversy over the issue of filter versus distortion, there is a mounting body of evidence indicating that filtering is not the only problem for hearing-impaired listeners. Plomp (1978) divides hearing losses into Class A, attenuation, and Class D, which is added distortion. Class D listeners are those who say, "I can hear you talking, but I can't understand what you are saying." Class A individuals have difficulty at low speech and noise levels, but their hearing approaches that of normal listeners at high speech levels, even when the speech is accompanied by high levels of noise. Class D people have minor difficulties in low noise levels but substantial problems in high levels of noise and speech. This difficulty is manifest in the speech recognition function that plateaus or "rolls over" at levels considerably lower than 100% with increasingly higher listening levels. Plomp believes that most actual hearing losses are combinations of Class A and Class D, and as a rule of thumb he estimates that for every 3 dB increase in the speech reception threshold (SRT) for sentences, the distortion or "D" component increases by 1 dB. (One can assume that purely conductive losses would be categorized as Class A only.)

This controversy has been the subject of several investigations over recent years. The earlier studies found few differences between the abilities of subjects with actual hearing losses and those who listened through low-pass filters (Sher and Owens, 1974; Bilger and Wang, 1976; Wang et al., 1978). An exception is an experiment by Chung and Mack (1979), which introduced low-pass filtering with a cut-off at 2000 Hz in an attempt to make the test conditions physically comparable for normal-hearing subjects and those with high-frequency hearing losses. Each subject was tested at 3 speech levels (65, 75, and 85 dB) with 3 different speech-to-noise ratios (+6, +12, and +18 dB). Although the effect was "not as overwhelming" as in some other investigations, the hearing-impaired listeners performed significantly more poorly than their normal-hearing counterparts, especially at higher speech levels and less favorable speech-to-noise ratios.

Walden et al. (1981) used an innovative approach to test the filter versus distortion issue on 14 subjects with unilateral hearing impairments. Using these subjects as their own controls, the investigators compared the consonant recognition ability of the impaired ear to that of the normal ear, listening through a filter shaped to the configuration of the impaired ear. Rather than using the audiometric configuration at threshold, Walden and his

colleagues [illegible]
configuration [illegible]
recognition analy[illegible]
was a mean [illegible]
authors [illegible]
limited number [illegible]
the often-made [illegible]
listening to filter[illegible]
population" (Wa[illegible]

B. Masking

Fabry and Van [illegible] (1986) used masking [illegible] to investigate the question of whether attenuation is the only [illegible] for hearing-impaired listeners. As in the experiment [illegible] et al. (1981), their subjects [illegible] had unilateral, cochlear [illegible] subjects showed better [illegible] masked and [illegible] the impaired ears [illegible] differences among [illegible] subject. The [illegible] error patterns [illegible] people the [illegible] (obviously) [illegible] degree to which [illegible] individuals.

The use of masking in an experiment such as the one [illegible] cited above, [illegible] a logical form of filtering in that it renders part of the speech signal inaudible.

Humes et al. ([illegible]) [illegible] that masking [illegible] cochlear impairment than simple filtering because [illegible] the threshold elevations resulting from masking are [illegible] and that in addition, noise-masked normal listeners [illegible] loudness recruitment (as do individuals with cochlear impair[illegible]). The investigators chose four subjects with bilaterally symmetri[illegible] sensorineural hearing impairments, each of whom was matched with three [illegible] hearing subjects whose noise-masked thresholds were nearly identical [illegible] impaired subject. Recognition [illegible] that under most conditions, the [illegible] or better than the noise-masked [illegible] that if some deficit [illegible] recruitment had been present [illegible] impaired listeners [illegible] normal listeners. [illegible] have these processing deficits, [illegible] speech-recognition performance. [illegible] et al. [illegible] subjects "never performed [illegible]" (p. 772), their data show that [illegible] their normal-hearing counterparts [illegible].

These experiments do not support the [illegible] additional distortion component, [illegible] types of experiments employing masking ... performance of normal listeners and those with ...

Noise masking is a common occurrence in ... Plomp (1978) estimates that 50% of speech ... A-weighted ambient noise levels of 50 dB or ... environments are considerably noisier, and military ... exception.

Presumably because of the distortion ... listeners appear to need more favorable speech-... listeners. According to Plomp (1978), an individual ... hearing impairment needs a speech-to-noise ratio ... than a normal listener would require. Assuming ... are combinations of Class A and Class D, one would ... smaller than 10 dB in real life. Smoorenburg ... sentences in 7 normal-hearing subjects and 22 ... hearing loss in quiet and at A-weighted noise levels ... For 50% correct sentences, the median speech-to-... subjects with normal hearing and -1.8 dB for hearing-... the hearing-impaired subjects needed a speech-to-... dB more favorable than the normal listeners. Although ... a significant increment, it represents a difference ... at 50% (Smoorenburg, 1982).

As the level of a noise increases, its masking ... due to the phenomenon known as the upward spread ... Bess (1983), the popular notion that hearing ... disproportionately affected by the upward spread ... exaggeration. He claims that the actual effect ... effect on normal listeners when the masking stimulus ... sound pressure level for all subjects (presumably ... sensation level). Martin and Pickett (1970) did find ... thresholds for hearing-impaired than for normal ... (e.g., 107 dB), although the actual threshold shift ... found considerable variability among subjects, and ... spread of masking were not strongly related to ... More recently, Picard and Couture-Metz (1985) used ... frequency hearing and losses in the high frequencies. ... masking noise centered at 1000 Hz, the hearing-impaired ... greater spread-of-masking than normal-hearing ... dB and above. This effect occurred despite hearing ... the frequency of the masker.

Gagne (1988) assessed upward spread of masking ... individuals by plotting the level of masked threshold ... level, using only masked thresholds that ... threshold level in quiet. He defined "excess" masking ... between actual and calculated thresholds, the ... of expected values from normal listeners plus ... threshold levels in quiet. The results showed ... masking, which varied according to degree of hearing ... configuration. To assess the validity of his method ... masking, Gagne tested normal listeners with ...

excess masking was [illegible] data of several [illegible] masking [illegible] be quite consistent with [illegible] previously [illegible] methods of [illegible] normal [illegible] [illegible]

C. Distortion

Clinicians have known for many years that [illegible] significantly greater difficulty understanding spe[illegible] their audiometric configurations may be identical. Likewise, [illegible] hearing aid output to mirror the configuration of an audi[illegible] produces unsatisfactory results. Many, if not most, [illegible] sensorineural hearing impairments are affected by some [illegible] dysfunction that renders them somewhat less able to use [illegible] than one would predict from filtering experiments [illegible] literature include [illegible] reduced sensitivity [illegible] frequency [illegible] ability; broader critical bands and poorer ab[illegible] noise, greater spread of masking; non-linear [illegible] reduced linear range of the auditory system (Levitt [illegible] cautions that most of the studies "show correlat[illegible] relationships" and that speech recognition is usually [illegible] other variable, whereas this correlation could be the result of [illegible] correlation with a third, unspecified variable (p. 35). Levitt [illegible] multivariate studies showing that once the degree of [illegible] extracted, the correlation with other psychoacoustic variables [illegible] not eliminated. He emphasizes that the addition of [illegible] the effects of auditory distortion, beyond what one [illegible] proportion of the speech spectrum available to the [illegible]

1. Frequency distortion

In a review entitled "The Input for a Damaged Cochlea", [illegible] describes impairment to frequency coding as a [illegible] tuning curves, a breakdown of the critical band [illegible] one frequency by another. Distant sounds [illegible] (spread of masking) with the result that background [illegible] effectively, and speech sounds mask each other. Stephens [illegible] harmonic distortion as a factor in the impairment of freq[illegible] normal ear begins to produce harmonics at sensat[illegible] While these harmonics are of low intensity at first, [illegible] increases rapidly with increasing intensity of the fundamen[illegible] Impaired cochleas tend to produce harmonics at lower [illegible] therefore, these disruptive harmonics are a more [illegible]

Recent experiments have pointed out the [illegible] psychophysical tuning curves. Salvi **et al.** (19[illegible]) describe a [illegible] curve as a set of frequency-intensity combinations that [illegible] nerve's firing rate to exceed by a fixed am[illegible]

[illegible] (high) frequency, [illegible] progressively lower than [illegible] widened [illegible] is tested with [illegible]. The implication [illegible] broadening the characteristic [illegible], causing masking at lower [illegible] in recognizing speech [illegible].

[illegible] et al. (1983) tested four [illegible] individuals with various [illegible] define frequency sel[ectivity] [illegible] the frequency [illegible] [narro]w-band masking, psycho[physical] [illegible] summation. All four mea[sures] [illegible] of subjects with [illegible] and narrow-band [illegible] and her colleagues [illegible] their data accurately reflect the [illegible] mechanism, [illegible] altered in cochlear [illegible].

[illegible]

[illegible] been the subject of [illegible] distortion, intensity [illegible] speech communication. Perhaps [illegible] the phenomenon known as [illegible] the growth of loudness [illegible] ear perceives [illegible] "catch up" to the normal [illegible] meaning that loudness [illegible] impaired individuals with [illegible] systems, where low-level [illegible] high-level [illegible] individual's tolerance level [illegible].

[illegible] that [illegible] he states [illegible] eliminate [illegible]

[illegible]

[illegible] distortion [illegible] masking. [illegible], meaning that [illegible] duration there must be a 10-dB increase in stimulus level for a [illegible] equally detectable. The ear with a cochlear impairment requires an [illegible] of only 3 to 4 dB. The impaired ear integrates sounds over a short [illegible] (temporal summation), shows greater effects from maskers that precede sign[illegible] in time (forward masking) and maskers that follow signals (backward [illegible] and cannot detect temporal gaps as short as those detected by [illegible] (Stephens, 1976).

Zwicker and Schorn (1982) developed a simplified masking pr[illegible] test temporal resolution in clinical patients. On testing subjects [illegible] normal hearing and several types of hearing impairment, they found [illegible] in the normal listeners, but degraded temporal resolution ability [illegible] hearing-impaired, with more unfavorable speech-to-noise ratios [illegible] greater reductions in temporal resolution. They repeated the tests with normal subjects, this time applying masking to simulate hearing impairment, and found a response pattern that differed considerably from that of the hearing-impaired subjects. Once again it appears that attenuation alone does not explain difficulties in temporal processing.

Tyler et al. (1982) tested several measures of temporal pr[illegible] well as frequency resolution tasks on normal and hearing-impai[illegible] Most hearing-impaired subjects showed poorer results than the norm[illegible] on all tasks, regardless of whether the two groups were compared [illegible] sound pressure levels or sensation levels. Two of the temporal [illegible] effects, increased temporal difference limen (just noticeable differen[illegible] stimulus duration) and longer gap detection thresholds (minimum detectable ga[illegible] durations) correlated significantly with impaired speech recognition ability. These effects persisted even after adjustments had been made for loss of attenuation. The authors conclude that these temporal processing disabilities "may represent the important underlying processes that contribute to the p[illegible] speech perception in the hearing impaired" (p. 750).

D. Binaural Processing and Localization

Hearing-impaired individuals benefit from the effects of binaural hearing, but probably not as greatly as persons with normal hearing (Nabelek and Robinette, 1978). This is especially true in noisy conditions, where they do not benefit as much from the binaural "release from masking" as do their normal-hearing counterparts.

Nabelek and Mason (1981) tested the effect of noise and reverberation [illegible] monaural and binaural word recognition by subjects with various types [illegible] amounts of hearing loss. They found a binaural advantage of 5.9[illegible] in [illegible] environment with a reverberation time of 0.1 second and 7.2[illegible] in reverb[illegible] of 0.5 se[illegible]

With re[illegible] to sound localization, Stephens (1976) cites Florentine [illegible] Scharf (1975) as showing that hearing-impaired subjects exhibit only min[illegible] abnormalities in perceiving sound lateralization and directionality. However, he references Roffler and Butler (1968) and Butler (1970) as showing that subjects with high-frequency hearing losses are unable to identify the direction of sound in the vertical plane (Stephens, 1976).

III. HEARING HANDICAP

Most professionals who work with hearing-impaired individuals would agree that small amounts of hearing loss cause no handicap, and are often not even noticeable to the affected individual. The question is, then, how much hearing impairment can a person acquire before he or she can no longer function adequately in social or occupational settings?

A. Definitions

Three terms, impairment, handicap, and disability are often used interchangeably, but they mean quite different concepts. To confuse the issue further, they are defined differently by different authorities.

In 1965 the American Academy of Ophthalmology and Otolaryngology (AAOO) made the following distinctions (Davis, 1965):

> Impairment: a deviation or change for the worse in either structure or function, usually outside the range of normal.
>
> Handicap: the disadvantage imposed by an impairment sufficient to affect one's personal efficiency in the activities of daily living.
>
> Disability: the actual or presumed inability to remain employed at full wages.

The British Association of Otolaryngologists and the British Society of Audiology (BAOL/BSA, 1983) define impairment similarly, but have reversed the AAOO's definitions of handicap and disability. Accordingly:

> Disability: any lack or restriction (resulting from an impairment) of ability to perceive everyday sounds, either in quiet or a noisy background. It is usually given in a scale of percentages for compensation purposes.
>
> Handicap: the disadvantage for a given individual resulting from impairment or disability that restricts activities that would be expected for that individual.

The World Health Organization defines disability as "any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human body." (Quoted by Robinson, 1994.)

The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA, 1981) adds the concept of "material impairment of hearing", which is somewhere between the AAOO's concepts of impairment and handicap. It is the protection goal for the setting of standards to prevent occupational hearing impairment. OSHA defines it as the point or "fence" beyond which an individual cannot function as well as a normal-hearing person.

The AAOO's use of "handicap" and its attendant meaning is reasonably well understood in the U.S., despite the fact that most state worker compensation laws use the word "impairment" with the AAOO's formula for handicap. Although the British definition is probably more accurate, because the AAOO's use of the word "handicap" is more familiar in the U.S., we will use it for purposes of this report. We do not, however, support the AAOO's audiometric definition of handicap: an average hearing threshold level at 500, 1000, and 2000 Hz that exceeds 25 dB. The reasons for this will [illegible] apparent in the subsequent discussions.

B. Audiometric Thresholds Defining Hearing Handicap

The point of beginning handicap has been the subject of much [illegible] and investigation over recent decades. Early experiments [illegible] relationship between speech recognition and used the term "hearing loss for speech" since the distinctions between impairment, handicap, and disability had not yet been made. The first well known method for assessing hearing loss for speech was developed by Fletcher (1929). Fletcher's time-honored "Point-Eight Rule" divided the entire audible range from 0 to 120 dB (ASA) for the averaged frequencies, 500, 1000, and 2000 Hz into percentage of loss with a slope of 0.8% per decibel. For many years, physicians used Fletcher's [illegible] to calculate compensation for hearing loss, even though it was not meant [illegible] that purpose. Later, the AMA adopted the Fowler-Sabine method [illegible] this method, average hearing threshold level was calculated for the audiometric frequencies 500, 1000, 2000, and 4000 Hz, which were given the weightings 15%, 30%, 40%, and 15%, respectively. The "low fence" or the point of beginning handicap was identified as an average hearing threshold level of 10 dB (ASA, or 20 dB ANSI) (AMA, 1947).

According to Davis (1973), the new formula was too complex, and otologists refused to use it. Accordingly, the AAOO (1959) developed a simple method, which many state statutes still employ today. The new method used the simple average at 500, 1000, and 2000 Hz with a low fence at 15 dB (ASA, or 25 dB ANSI), a high fence (or point of total handicap) at 82 dB, and a growth of handicap of 1-1/2% for each decibel between these points. The AAOO believed that hearing impairment should be evaluated in terms of the ability to hear "everyday speech", and that the ability to hear sentences and repeat them correctly in a quiet environment was satisfactory evidence of good hearing for everyday speech (AAOO, 1959). The AAOO determined that the average hearing level of 16 dB (ASA, or 26 dB ANSI) at 500, 1000, and 2000 Hz was the point at which individuals begin to have difficulty hearing sentences in quiet and seek medical help for their hearing problems. This determination was based on clinical evidence (Davis, 1973).

Over the following two decades, many studies were conducted to discover the audiometric frequencies that best predicted hearing handicap, and the average hearing threshold level at the selected frequencies that [illegible] point of beginning handicap. Many, although not all of the earlier studies, which were conducted in quiet backgrounds, pointed toward the importance of mid-frequency hearing for understanding speech (for example, Harris et al., 1956; Quiggle et al., 1957; and Quist-Hanssen and Steen, 1960). Most later investigations used various types and amounts of noise backgrounds, presumably because noise is characteristic of many everyday listening conditions. Most studies of word recognition in noisy backgrounds have shown the importance of good hearing above 1000 Hz. The same is true with speech distorted by speeding (Harris et al., 1960) and reverberation (Robinson, 1984). Table [illegible] lists many prominent speech recognition/audiometric frequency studies conducted over the past 30 years, showing the audiometric frequencies identified as being most important for understanding speech under various conditions of noise and distortion.

Because of the importance of high-frequency hearing for understanding speech in less than optimal conditions, the American Academy of Ophthalmology (AAO)* decided to include 3000 Hz in the definition of beginning hearing handicap. The low fence remained at 25 dB (AAO, 1979). Many states have changed their worker compensation statutes accordingly in the intervening years.

Other formulas of interest would include the one recommended by the National Institute for Occupational Safety and Health (NIOSH, 1972) and later adopted by OSHA (1981) for purposes of preventive regulation. It identifies material impairment of hearing as an average hearing level of 25 dB or greater at 1000, 2000, and 3000 Hz. The rationale for the inclusion of 3000 Hz and the exclusion of 500 Hz is based on many of the studies listed in Table 1.

The British Association of Otolaryngologists and the British Society of Audiologists have recommended a low fence of 20 dB for the averaged frequencies 1000, 2000, and 4000 Hz, based on studies conducted in the UK, USA, and the Netherlands (BAOL/BSA, 1983).

The exact level of the low fence (or point of beginning handicap) has been the subject of much, and sometimes heated, debate. If the fence is set too high, a series of adverse social consequences will result. Individuals with handicapping hearing loss will be ineligible for compensation. Workers in noisy environments will be denied regulatory protection. Soldiers and aviators will be assigned to jobs in which they are unable to communicate adequately. If the fence is set too low, the opposite set of consequences will prevail. Individuals will be compensated although their losses result either entirely or in part from presbycusis. Regulations will be unnecessarily stringent and expensive. Soldiers and aviators will be disqualified from jobs in which they could have performed satisfactorily.

Recent investigations of the low-fence issue have attempted to pinpoint the hearing threshold level at which persons with mild losses are no longer capable of understanding speech the way normal listeners do. On the basis of her data and those of Acton (1970), Suter estimated the point of beginning handicap occurs at an average hearing threshold of 19 dB at 1000, 2000, and 4000 Hz (Suter, 1978). This point translates to approximately 9 dB at 500, 1000, and 2000 Hz, and 22 dB at 1000, 2000, and 4000 Hz, because most individuals with mild sensorineural impairments have audiometric profiles that slope toward the high frequencies. She observes, however, that the selection of a fence depends upon the definition of hearing handicap and the conditions under which handicap is assessed. As the data in Table 1 indicate, good hearing in the high frequencies becomes increasingly important as listening conditions become increasingly degraded.

---

*By 1979, the AAOO had split into two groups, the ophthalmology group on the one hand, and the otolaryngology/head and neck surgery group on the other.

Table 1

Studies Showing the Relationship of Audiometric Frequency to Word Recognition Ability in Hearing Impaired Individuals

Source	Speech Material	Environment	Frequencies Most Important for Speech Recognition	Comments
Harris, Haines, and Myers, 1956	Harvard PB Monosyllables (50% Correct)	Quiet	av. 500, 1000, 2000 Hz	
Mullins and Bangs, 1957	Harvard PB Monosyllables	Quiet	2000, 3000 Hz	
Quiggle, Glorig, Delk, and Summerfield, 1957	Spondees	Quiet	av. 500, 1000, 2000 Hz	
Quist-Hanssen and Steen, 1960	Norwegian Monosyllables, Disyllables, Digits, and "Context" Speech	Quiet	av. 500, 1000, 2000 Hz	
Kryter, Williams, and Green, 1962	Harvard PB Monosyllables and Sentences	Quiet, Noise, and Low-Pass Filtering	2000, 3000, 4000 Hz	
Ross, Huntington, Newby, and Dixon, 1965	CID W-22 PB Monosyllables	Quiet and Noise	2000, 4000 Hz	Speech materiels presented at 40 dB above SRT.

Table 1 (continued)

Source	Speech Material	Environment	Frequencies Most Important for Speech Recognition	Comments
Acton, 1970	Fry's PB Monosyllables	Quiet (S/N[1] +20) and Pink Noise	2000 Hz	Subjects with mild high-frequency losses (above 2kHz) performed better than normal-hearing controls.
Elkins, 1971	MRT	Quiet and Noise	2000, 3000, 4000 Hz in quiet, but no significant correlations in noise	Speech materials presented at at 40 dB above SRT.
Lindeman, 1971	Dutch Monosyllables	"Cocktail Party" Noise	2000 Hz	
Aniansson, 1973	Swedish PB Monosyllables	9 Different "Everyday Milieu" (Traffic Noise, Competing Speech and Mild Reverberation)	3000 and 4000 Hz just as important as 500 and 1000 Hz	
Kuzniarz, 1973	Polish Monosyllables and Sentences	Quiet, White and Low-Frequency Noise	500, 1000, 2000 Hz in quiet, and 3000, 4000 Hz in noise	Recommended av. 1000, 2000, 4000 Hz to Polish Ministry of Health.
Suter, 1978	MRT and CID Sentences	Quiet and Speech Babble Noise (plus Mild Reverberation)	av. 1000, 2000, 4000 Hz in quiet; av. 2000, 3000, 4000 Hz in noise	

Table 1 (continued)

Source	Speech Material	Environment	Frequencies Most Important for Speech Recognition	Comments
Smoorenburg, 1982	SRT for Dutch Sentences	Quiet and 4 Levels of Speech-Shaped Noise	500 Hz in quiet, 2000-3000 Hz in	Pilot study - only 22 hearing impaired subjects.
Robinson, 1984	1. Simulated Social Gathering: Names, Addresses and Phone Numbers	1. Speech Babble, Jazz Music		Also included self-assessment questionnaires and tests of frequency and temporal processing.
	2. P.A. Announcement in Railway Station	2. Railway Station Noise (plus Reverberation)	av. 3000, 4000, 6000 Hz	
	3. Telephone Listening	3. Noise at 2 dB S/N[1]		
	4. Sound Field Speech Audiometry - CVC Words	4. Speech Babble at 2 dB S/N[1] (plus Mild Reverberation)	av. 1000, 2000, 3000 Hz	
Smoorenburg, 1986	SRT for Dutch Sentences	Quiet and 4 Levels of Speech-Shaped Noise	250-1000 Hz in Quiet, 2000, 4000 Hz in Noise	200 hearing-impaired subjects. Frequencies above 1000 Hz show better correlation with speech recognition even in noise levels as low as 35 dB(A).

[1]S/N = speech-to-noise ratio

Smoorenburg (1982 and 1986) has also studied the question of the low fence. He defines the "onset of handicap" as the amount of hearing loss where an individual first begins to notice a handicap in everyday (meaning somewhat noisy) situations (Smoorenburg, 1986). Because hearing sensitivity at 2000 and 4000 Hz correlates so well with speech recognition in noise, Smoorenburg (1986) defines the "target SRT" as that point where SRT begins to turn significantly upward as a function of average hearing level at 2000 and 4000 Hz. On the basis of data from 400 ears, he identifies this point as a mean SRT of -4.6 dB, which corresponds to an average hearing level of 10 dB at 2000 and 4000 Hz (a level that would be considered well within the range of normal hearing). Smoorenburg then identifies the level at which the SRT increases significantly at the 0.05 level of confidence, which is an SRT of -2.8 dB, corresponding to an average hearing threshold level of 24 dB at 2000 and 4000 Hz, or 15 dB at 1000, 2000, and 3000 Hz. SRT increases significantly at the 0.01 level of confidence at -2.0 dB, which corresponds to an average hearing threshold level of 32 dB at 2000 and 4000 Hz, and 22 dB at 1000, 2000, and 3000 Hz. Smoorenburg believes this (the 0.01 level) is an unacceptable hearing handicap.

In one of the most extensive investigations of this issue, Robinson et al. (1984) tested 20 normal-hearing and 24 hearing-impaired individuals in a variety of listening tasks, which included a simulated social gathering, public address announcements recorded in the Waterloo railway station, and a telephone listening situation where speech and noise were mixed, all at a speech-to-noise ratio of 2 dB. They also administered CVC monosyllables in the sound field at several levels of speech and noise. The results showed large differences between the normal and hearing-impaired groups, but there were also large differences within groups and even within the same subject's responses across tests. Average hearing threshold level at 3000, 4000, and 6000 Hz correlated most highly with performance on the three simulations, and the average at 1000, 2000, and 3000 Hz correlated best with the speech audiometric tests.

Robinson and his colleagues concluded that they could not identify the threshold of disability (what we call handicap) on the basis of a discontinuity in the performance curve because this point is entirely dependent upon the difficulty of the test. "There are as many potential 'disabilities' as there are activities." (Robinson et al., 1984, p. 103) They decided that the function of the low fence is not to distinguish between circumstances but between people. They found that the 2nd percentile of performance by normal subjects (on the poor performance end of the scale) corresponded to hearing threshold levels at 1000, 2000, and 3000 Hz in the impaired group ranging from 27 to 34 dB for all of the tests. Because the performance of individuals with hearing threshold levels in this range was less dependent on particular tasks, they chose an average hearing level of 30 dB at 1000, 2000, and 3000 Hz as the threshold of disability.

Robinson and his colleagues make a very important point when they observe that the onset of handicap (disability in their words) varies according to task, so that the selection of any one set of conditions for the definition of beginning handicap is necessarily arbitrary. However, their selection of the 2% performance level of normal listeners is also somewhat arbitrary. It is based on a limited total number of subjects (20 normals and 24 hearing-impaired), and only one speech-to-noise ratio (2 dB). Only [illegible] subjects had hearing impairments as great as the [illegible] at 1000, 2000, and 3000 Hz. The shape and [illegible] produced different results had there been [illegible]

In the final analysis, it appears that the [illegible] always involved some degree of subjectivity. [illegible] the SRT increases at the 5% or 1% level of signi[illegible] normal performance, or an estimated difference [illegible] normally or subnormally on speech recognition tasks, [illegible] is involved. Fortunately, these recent experiments have narrowed [illegible] beginning handicap to between about 15 and 30 dB [illegible] The only way to narrow it further would be to take [illegible] listening conditions in the specific jobs or life [illegible] which the assessment of handicap is needed. One must also remember that this 15-30 dB range applies to the recognition of everyday speech. Special circumstances, such as sentry duty in quiet areas, may very well require more sensitive hearing if the listener needs to detect faint or high-frequency sounds.

IV. PREDICTING COMMUNICATION AS A FUNCTION OF [illegible]

Some interesting schemes for predicting [illegible] communication losses have been developed by Kryter [illegible] one scheme he borrowed a graph from Stevens and Davis [illegible] Figure 1, from Stevens and Davis, shows an estimate [illegible] number of distinguishable tones in the auditory area. These estimates were made by holding intensity constant to find the difference limen (DL) for frequency (based on the work of Shower and Biddulph, 1931), and then by holding frequency constant to find intensity difference limens (based on the work of Riesz, 1928). Stevens and Davis plotted on the area of audibility for normal listeners the number of discriminable units in squares 1/2 octave wide by 10 dB high. The upper left number in each cell gives the DLs for intensity, the upper right number gives the DLs for frequency, and the lower number gives their product, the total number of DLs in each cell. [illegible] adding the totals for each cell, Stevens and Davis estimated a grand total of 340,000 distinguishable tones in the audible range.

Figure 2 shows Kryter's (1984) version of the graph developed by Stevens and Davis. The lower, concave curves represent [illegible] estimated mean and 90% range of "critical intensities" present [illegible] everyday [illegible] (curves labelled #4). Kryter estimates 43,093 discriminable units [illegible] this range. Curve #3 represents the audiogram of an individual with an average hearing threshold level of 15 dB for 500, 1000, and 2000 Hz. This person would have lost the capacity to perceive 16[illegible] 7,[illegible] units constituting everyday speech, and about 4[illegible] discriminable units. Curve #2 represents the audiogram of an individual with an average hearing threshold level of 25 dB at 500, 1000, and 2000 Hz. This person would have lost 31% or 15,500 of the speech units, and 13[illegible] 44,3[illegible] out of the total discriminable units. Curve #1 [illegible] a person with an average hearing threshold level of 55 dB at 500, 1000, and 2000 Hz, and a consequent loss of 96% or 41,293 of the speech units, and 44% or 150,000 out of the total number of discriminable units. Because there is a slight discrepancy between Kryter's estimate of the total number of units (3[illegible],[illegible])

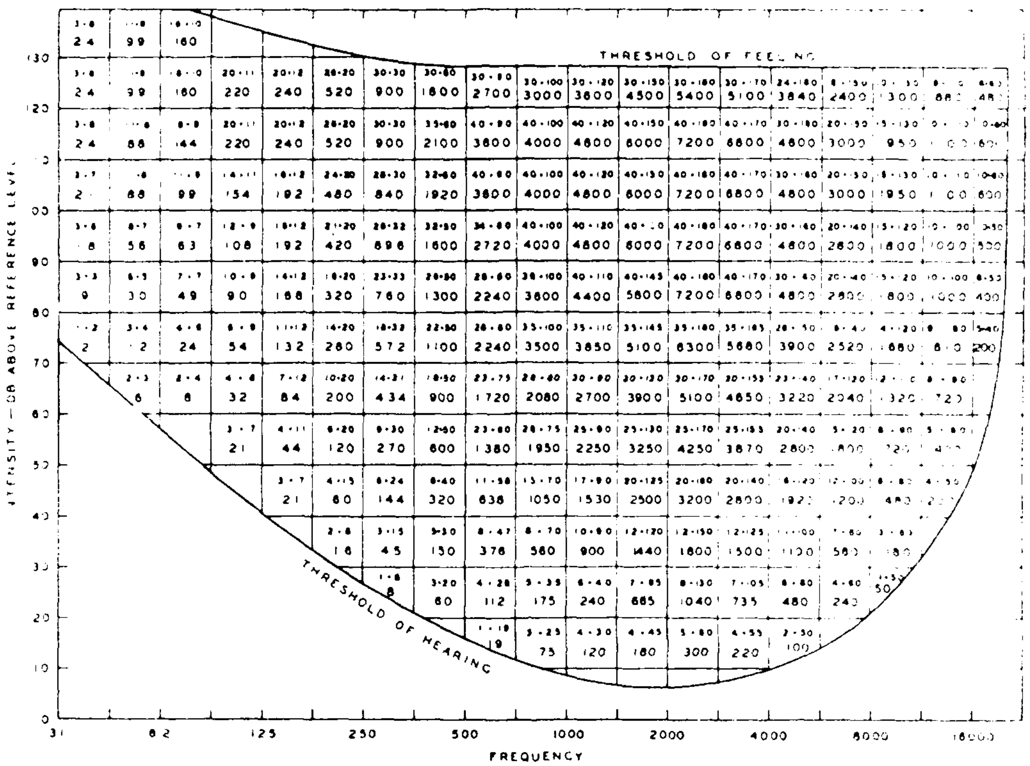

Figure 1. Number of distinguishable tones in the auditory area.

Note. From Hearing, Its Psychology and Physiology by S. S. Stevens and H. Davis, 1938 and 1983, New York: American Institute of Physics. Reprinted with permission from Hearing, Its Psychology and Physiology, copyright Acoustical Society of America, 1983.

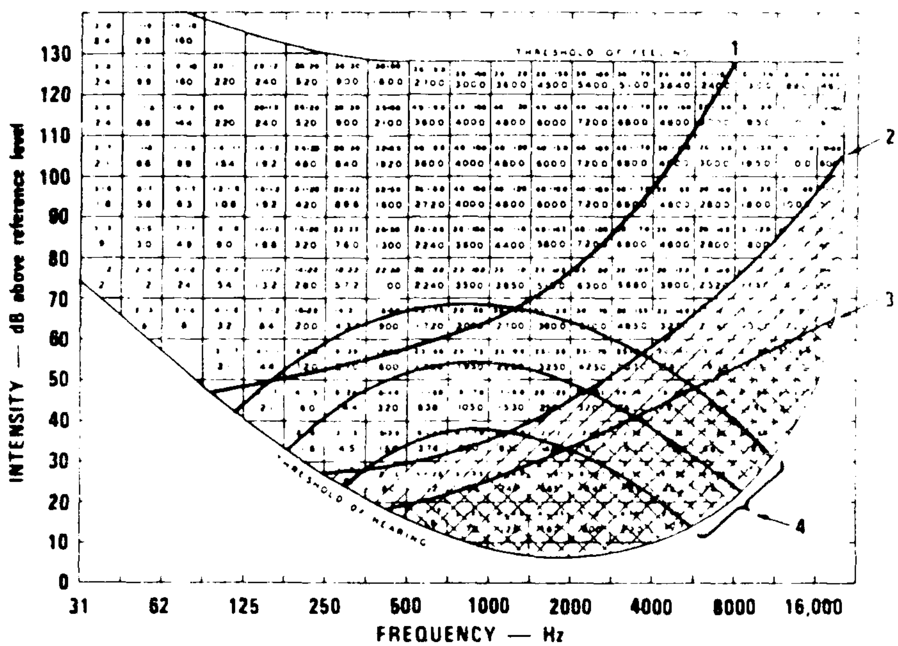

Figure 2. Number of discriminable units, as in Figure 1, with mean and 90% range of critical speech intensities, and three hypothetical audiograms superimposed.

Note. Adapted from Physiological, Psychological, and Social Effects of Noise (NASA Reference Publication 1115) by K. D. Kryter, 1984, Washington, DC: National Aeronautics and Space Administration. Reprinted by permission.

and that of Stevens and Davis (340,000), Kryter's hearing loss estimate [illegible] be slightly lower if calculated on Stevens and Davis' total. The reader should also note that these estimates are based entirely on a filter [illegible], and the situation might be somewhat different if the intensity, frequency, and temporal distortions present in many cochlear impairments were taken into account.

In another method of predicting the speech communication abilities of hearing-impaired individuals, Kryter (1970) calculates Articulation Index (AI) values corresponding to various amounts of hearing loss. Table 2, from Kryter (1970), shows AI estimates for several hearing threshold levels, based on the amount of speech expected to exceed thresholds of audibility for four levels of vocal effort. He has arrived at these estimates through a series of steps, which include subtracting 6 dB for the transition from earphones to sound field, and adjusting for the difference in threshold between pure tones and sounds having continuous spectra. According to Table 2, an individual with an average hearing level of 25 dB (ISO and ANSI) at 500, 1000, and 2000 Hz which corresponds to a level of 35 dB at 1000, 2000, and 3000 Hz will hear "everyday" speech (65 dB long-term rms) at an AI of 0.47, and will correctly hear 95% of the sentences and 73% of monosyllables presented. "Normal conversation" (55 dB long-term rms), will result in an AI of 0.26, with [illegible] sentences and 35% monosyllables recognized.

Figure 3, also from Kryter (1970) shows the estimated percentage hearing impairment and percentage of monosyllables recognized as a function of average hearing threshold level at 500, 1000, and 2000 Hz, and at 1000, 2000, and 3000 Hz. The curves represent functions calculated from the AI, and the straight lines represent the AAOO 1959 hearing handicap rule and other linear [illegible] proposed by Kryter for sentences at an everyday level, normal conversational level, and weak conversational level. Again, the reader should be aware that all of these predictions assume a quiet environment and a hearing loss [illegible] characterized by the attenuation model, without distortion.

Certain other investigations have used the AI with hearing-impaired subjects. Macrae and Brigden (1973) tested 309 hearing-impaired subjects with CID sentences, in quiet and speech-to-noise ratios of +10 and -10 dB. In a manner similar to Kryter's, they calculated an AI for each individual [illegible], and found very high correlations between AI and sentence recognition [illegible]. At the -10 dB speech-to-noise ratio, the correlation was 0.979 and at [illegible] dB speech-to-noise ratio, it was 0.989.

In a slightly different approach, Smoorenburg et al. (1981) [illegible] the AI for normal listeners, based on the speech-to-noise ratio [illegible] subjects achieved 50% sentence recognition (SRT). They then calculated [illegible] for each hearing-impaired subject, based on the speech-to-noise [illegible] corresponding to the subject's SRT and on the amount of information [illegible] not be available because of the filter effect. Whereas the average [illegible] normal subjects in A-weighted noise levels of 40, 55, and 70 dB was [illegible], the average AI for hearing-impaired subjects was 0.248. Because the [illegible] listeners could function at a slightly poorer AI than the hearing-impaired subjects (a difference in AI of 0.03), the authors conclude that reduction of audible cues does not completely explain the difference in performance between normal and hearing-impaired subjects.

Table 2

Articulation Index Estimates for Hearing Threshold
Levels in Four Levels of Vocal Effort
(From Kryter, 1970)

Avg. HL at 500, 1000 and 2000 Hz		Avg. HL at 1000, 2000 and 3000 Hz		Weak Conversational Level in Quiet (Long-Term RMS = 50 dB)			Normal Conversational Level in Quiet (Long-Term RMS = 55 dB)			Everyday Speech Level (Long-Term RMS = 65 dB)			Shouting Level (Long-Term RMS = 80 dB)		
ASA	ISO	ASA	ISO	AI	% Sent.	% 1000 PB Words	AI	% Sent.	% 1000 PB Words	AI	% Sent.	% 1000 PB Words	AI	% Sent.	% 1000 PB Words
-5	5	5	15	0.81	99	94	0.84	100	95	0.98	100	98	1.0	100	100
5	15	15	25	0.56	97	81	0.72	98	92	0.84	100	95	0.98	100	98
15	25	25	35	0.34	87	52	0.47	95	73	0.72	98	92	0.84	100	95
25	35	35	45	0.17	36	17	0.26	68	35	0.47	95	73	0.72	98	92
35	45	45	55	0.03	5	2	0.09	15	8+	0.26	68	35	0.47	95	73
45	55	55	65	0	0	0	0	0	0	0.09	15	8	0.26	68	35
55	65	65	75	0	0	0	0	0	0	0	0	0	0.03	15	8
65	75	75	85	0	0	0	0	0	0	0	0	0	0	0	

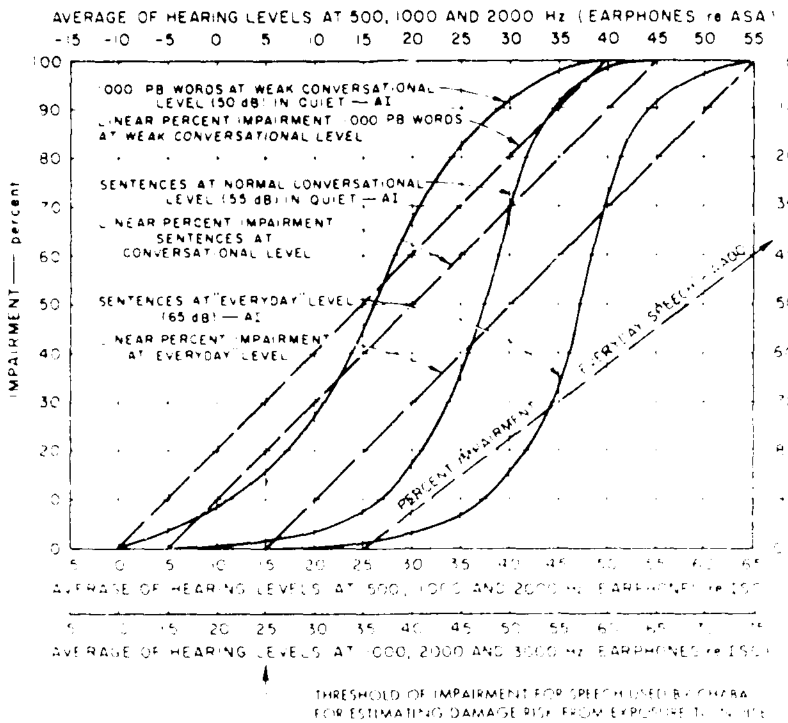

Figure 3. Estimated percentage hearing "impairment" and speech recognition as a function of average hearing level.

Note. From The Effects of Noise on Man by K. D. Kryter, 1970, New York: Academic Press. Reprinted by permission.

[illegible] speech [illegible] indexes [illegible] speech [illegible] STI, [illegible] French and Steinberg's [illegible] fluctuations in the speech [illegible]

[illegible] OF WARNING SIGNALS

Very little research has been conducted on the ability of hearing-impaired individuals to detect and recognize auditory warning signals. What little has been done has focused on the effect of hearing loss in combination [illegible]. Wilkins (1984) carried out a field study to assess [illegible] protectors and hearing loss on the perception [illegible] environment. He used [illegible] subjects with substantial [illegible] sound than others [illegible] groups responded similarly [illegible]. Wilkins attributes this to spectral differences in the signals. [illegible] many (but not all) of the subjects wore hearing protection, and [illegible] other uncontrolled variables, any conclusions from this [illegible] be made with extreme caution.

[illegible] research area is the effect of hearing impairment on [illegible] important environmental sounds, such as combat sounds. [illegible] include the sound of footfalls, barbed wire being clipped, and the [illegible] of a rifle magazine. Popular opinion holds that many of these [illegible] are predominantly high-frequency, with energy in the 2000-6000 Hz range [illegible], Aspinall and Wilson, 1986). However, Price and Hodge (1976) have shown [illegible] spectra of these types of sounds are fairly flat.

Price and Hodge (1976) developed a model for predicting the [illegible] of various noises. They analyzed 24 noise samples according to [illegible] energy in critical bands, then modeled the normal ear's method of [illegible] energy over 20-msec and 200-msec periods. Actual and predicted [illegible] showed excellent agreement. On comparing typical [illegible] exposed soldiers to the 24 noise spectra, they estimated [illegible] hearing individuals could detect these sounds at an average level [illegible] than soldiers with about 20 years of noise exposure. With the [illegible] high-frequency environmental noise (jungle with animals and [illegible]), the estimated difference between the two groups fell to 0.3 dB. A [illegible] environmental noise (recorded in rural France) produced an [illegible] difference of 7.8 dB between normal listeners and soldiers with 20 years of noise exposure. The authors explain that the reason why these differences are not greater is because listeners would be relying largely on [illegible] hearing to make most of the detections. They cautioned, however, that detection and identification are not the same, and that hearing-impaired individuals are likely to have more difficulties in analyzing sound than their normal-hearing counterparts. From the preceding discussions of suprathreshold abnormalities, it would appear that this caveat is warranted.

VI. MILITARY PERFORMANCE CRITERIA

All three military services now have hearing sensitivity criteria, which restrict personnel from certain jobs and classes of jobs. In fact, the Department of Defense now has criteria for rejection for appointment, enlistment, and induction that apply to all three services (DoD, 1986). These criteria were issued as DoD Directive 6130.3 on 31 March 1986, and were adopted by the U.S. Army on 27 July 1986. They reflect a tightening of the previous Army induction standards in that they now include the 3000-Hz frequency, and they no longer allow unlimited hearing loss in the poorer ear. It is interesting to note, however, that they are generally less stringent than the levels identified by recent researchers as the point of beginning hearing handicap (see Suter, 1978; Smoorenburg, 1982 and 1986; and Robinson et al., 1984). Table 3 specifies the acceptable hearing threshold levels for both ears:

Table 3

Department of Defense Hearing Threshold Level Induction Standards (DoD, 1986)

500-2000 Hz	Average threshold no greater than 30 dB No single frequency greater than 35 dB
3000 Hz	No threshold greater than 45 dB
4000 Hz	No threshold greater than 55 dB

A. U.S. Army

Until the DoD-wide directive, the U.S. Army has had its own induction standards, which have been somewhat more complex than the new standards (U.S. Army, 1983). Table 4 gives the Army's previous acceptable hearing threshold levels for appointment, enlistment, and induction from 1983.

Table 4

U.S. Army Hearing [illegible] Standards [illegible]
Enlistment, and Induction Prior to [illegible]
(AR 40-501, 1983)

Frequency	*Both ears*
500 Hz 1000 Hz 2000 Hz 4000 Hz	Audiometer average level of 6 readings (3 per ear) at 500, 1000 and 2000 Hz not more than 30 dB, with no individual level greater than 35 dB at these frequencies, and level not more than 55 dB each ear at 4000 Hz; or audiometer level 30 dB at 500 Hz, 25 dB at 1000 and 2000 Hz, and 35 dB at 4000 Hz in the better ear.

OR

If the average of the 3 speech frequencies is greater than 30 dB ISO-ANSI, reevaluate the better ear only in accordance with the following table of acceptability:

Frequency	*Better ear*
500 Hz	30 dB
1000 Hz	25 dB
2000 Hz	25 dB
4000 Hz	35 dB

The poorer ear may be deaf.

The Army also has criteria for aviators and air traffic controllers (U.S. Army, 1987). These are somewhat more stringent than the induction criteria. They are shown in Table 5.

Table 5

U.S. Army Hearing Threshold Level Standards for
Aviators and Air Traffic Controllers
(AR 40-501, 1987)

		Frequency (Hz)					
		500	1000	2000	3000	4000	6000
Classes 1 & 1A	Each ear	25 dB	25 dB	25 dB	35 dB	45 dB	45 dB
Class 2 (Aviators)	Better ear	25 dB	25 dB	25 dB	35 dB	65 dB	75 dB
	Poorer ear	25 dB	35 dB	35 dB	45 dB	65 dB	75 dB
Class 2 (Air Traffic Controllers)	Each ear	25 dB	25 dB	25 dB	35 dB	65 dB	75 dB
Class 3	Better ear	25 dB	25 dB	25 dB	35 dB	65 dB	75 dB
	Poorer ear	25 dB	35 dB	35 dB	45 dB	65 dB	75 dB

Soldiers may be denied appointment, enlistment and induction for numerous otological abnormalities, such as severe external or middle ear otitis, mastoiditis, or history of ear surgery. Aviators may be declared unfit for flying according to another list of otological criteria, which includes abnormalities of labyrinthine function, eustachian tube dysfunction, and deformities of the pinna which would be likely to cause problems with the use of protective headgear for extended periods (U.S. Army, 1987).

The U.S. Army has a system of profiling hearing impairments to qualify current personnel for the performance of various duties. A profile designation of 1 indicates a high level of medical fitness. A 2 profile means that a person possesses some medical condition or defect that may impose limitations on classification and assignment. A 3 profile indicates that the medical condition requires certain restrictions, and the 4 profile drastically limits performance (U.S. Army, 1983). Table 6 shows H (hearing) profiles 1 through 4, according to Army Regulation 40-501 (U.S. Army, 1987).

[illegible]

H-2 Audiometer average level of 6 readings (3 per ear) at 500, 1000, 2000 Hz of not more than 30 dB, with no individual level greater than 35 dB at these frequencies, and level not more than 55 dB at 4000 Hz; or audiometer level 30 dB at 500 Hz, 25 dB at 1000 and 2000 Hz, and 35 dB at 4000 Hz in better ear. (Poorer ear may be deaf.)

H-3 [illegible] chronic ear disease not falling below retention standards. Aided speech reception threshold measured at "comfort level", i.e., volume control of hearing aid adjusted to 50 dB HL speech noise.

H-4 Below standards contained in Chapter [illegible] July 1987). Factors to be considered [illegible] and organic disease of the ears.

According to AR 40-501 (U.S. Army, 1987), officers initially assigned to the Armor, Artillery, and Infantry branches, as well as to the Corps of Engineers, Military Intelligence, Military Police Corps and Signal Corps must qualify for the H-1 profile. However, their hearing may deteriorate and they may still be retained if they demonstrate continuing ability to perform their duties or if they are able to perform their duties with the help of a hearing aid. Other personnel may likewise be retained if they are capable of performing their duties effectively with [illegible] aid. Their assignments may, however, be limited. Personnel may be [illegible] for duty during mobilization if they achieve an SRT [illegible] while using a hearing aid.

The Army [illegible] specialties (MOS), which [illegible] H-1 [illegible] profile, sometimes with added requirements. For example, MOS such as Air Traffic Control Radar Controller ([illegible]), [illegible] Specialist ([illegible]), and Interrogator (97E) "must be a[illegible] human voice tones" (U.S. Army, 1985, p. 746). [illegible] to hear oral commands in outdoor areas [illegible]" (U.S. Army, 1986, p. 702). The majority of MOS classification [illegible] H-2 profile. In [illegible] where communication [illegible] identification is

particularly important, H-1 profiles are [illegible]
[illegible] profiles are:

Fire Support Specialist	
Cavalry Scout	[illegible]
M48, M60, and M1 Armor Crewmen	[illegible]
Multichannel Communications Equipment Operator	31M
Tactical Circuit Controller	31N
Wire Systems Operator	[illegible]
Explosive Ordnance Disposal	[illegible]
Physical Activities Specialist	[illegible]

Surprisingly, certain other occupations are given [illegible], despite the apparent need for good communication abilities. Examples are:

Air Traffic Control Tower Operator	[illegible]
Air Traffic Control Radar Controller	[illegible]
Locomotive Operator	[illegible]
Special Agent	95D

B. U.S. Air Force

The Air Force has its own set of H profiles, as shown [illegible] Air Force, 1987). The following jobs or activities are [illegible] profile:

- Air Force Academy Admission
- Flying Classes I and IA
- Initial Flying Class III
- Initial AFROTC Selection
- Initial Selection for Missile Launch Crew
- Initial Selection for Air Traffic Controller Duty
- Other Personnel Initially Entering Potentially Noise Hazardous Career Fields
- Other Personnel [illegible]

[illegible] H-2 profile is [illegible] continuing in Flying Class [illegible] the H-3 is required for [illegible] within six months [illegible] active duty personnel.

Table 7

U.S. Air Force Hearing Threshold Level Profiles
(AFR 160-43, 1987)

H-1	500 Hz	Must not exceed 25 dB, each ear
	1000 Hz	Must not exceed 25 dB, each ear
	2000 Hz	Must not exceed 25 dB, each ear
	3000 Hz 4000 Hz 6000 Hz	Sum of audiometric thresholds at these frequencies for both ears must not exceed a total of 270 dB.
H-2		Audiometric thresholds for the frequencies 500, 1000, or 2000 Hz may equal but not exceed the following:

	500 Hz	1000 Hz	2000 Hz
Better Ear	30 dB	30 dB	30 dB
Worse Ear	30 dB	50 dB	50 dB

H-3	Any hearing loss greater than H-2. The patient's remaining auditory acuity, unaided or aided, must permit the reasonable fulfillment of the purpose of the individual's employment on active duty in some occupational capacity commensurate with his or her grade.
H-4	Any hearing loss with which, despite the maximum benefit from a hearing aid, the active duty member is unable to perform the duties of his or her office, grade, or rank in such a manner as to reasonably fulfill the purpose of their employment.

U.S. Navy

The Navy does not yet have a system of H profiles, although such a system has been proposed (personal communication from John Page, U.S. Navy Environmental Health Center, Norfolk, Virginia). There are, however, criteria for the following positions and duties: qualifications for commission; appointment, enlistment, or induction; submarine duty; flight training; and Service Groups I, II, and III. These criteria are shown in Table 8 (U.S. Navy, 1980 and 1984).

Table 8

U.S. Navy Hearing Threshold Level Standards
(NAVMED 25 Nov. 1980 and 3 Aug. 1984)

Qualification for Commission (25 Nov. 1980)
Each Ear:
Av. 500, 1000, 2000 Hz must not exceed 30 dB, no single frequency greater than 35 dB
3000 Hz - 45 dB
4000 Hz - 60 dB

Appointment, Enlistment, or Induction (25 Nov. 1980)
Each Ear:
Av. 500, 1000, 2000 Hz must not exceed 30 dB, no single frequency greater than 35 dB
4000 Hz - 55 dB

OR, if the average at 500, 1000, and 2000 Hz is greater than 30 dB, the better ear must not exceed:
500 Hz - 30 dB
1000 Hz - 25 dB
2000 Hz - 25 dB
4000 Hz - 35 dB
Poorer ear may be totally deaf.

Submarine Duty (3 Aug. 1984)
Same criteria as in qualification for commission, above. Submarine [illegible] personnel must also not exceed:
500 Hz - 35 dB
1000 Hz - 30 dB
2000 Hz - 30 dB
4000 Hz - 40 dB
8000 Hz - 45 dB
If testing at 8000 Hz is impractical, 6000 Hz may be substituted, with a maximum of 40 dB, but excess loss at 6000 Hz may be disregarded if all other hearing criteria are met.

Service Groups I and II (3 Aug. 1984)
(Audiograms must be obtained on all flight physical exams.) Hearing threshold levels must not exceed:

	Better Ear	Poorer Ear
500 Hz	35 dB	35 dB
1000 Hz	30 dB	50 dB
2000 Hz	30 dB	50 dB

(continued on next page)

Table 8 (continued)

Service Group III (3 Aug. 1984)
(Audiograms must be obtained on all personnel except for personnel aboard ship.)
In general, hearing threshold levels must not exceed:

	Better Ear	Poorer Ear
500 Hz	45 dB	No
1000 Hz	40 dB	Requirements
2000 Hz	40 dB	

Individuals failing to meet these standards, but whose hearing, in the opinion of the examining physician, is commensurate with safety in flight, must be evaluated by the Naval Aviator's Speech Discrimination Test and must obtain a score of at least 70.

Standards for Flight Training Candidates (3 Aug. 1984)
Hearing threshold levels must not exceed:

	Better Ear	Poorer Ear
500 Hz	25 dB	25 dB
1000 Hz	25 dB	25 dB
2000 Hz	25 dB	25 dB
3000 Hz	45 dB	45 dB
4000 Hz	60 dB	60 dB

A series of three audiograms is necessary to disqualify a candidate.

D. Other Military Criteria

According to Frohlich (1981), all German military pilots must have hearing sensitivity no worse than 30 dB between 250 and 2000 Hz. Candidates for flight training must have hearing threshold levels of 20 dB or better between 250 and 2000 Hz and at 3000, 4000, and 6000 Hz, the combined losses in both ears must not exceed 210 dB.

Gloudemans (1981) reports the results of a survey of military hearing threshold level criteria for several nations. He gives data for Italy, Portugal, Canada, Norway, France, the Netherlands, and the U.S. These data appear to be somewhat unreliable, however, in that thresholds based on ANSI and ASA zero reference levels appear in the same table (unspecified), and the author gives criteria for the 5000 Hz frequency (attributed to the U.S. Army!).

E. Prevalence of Hearing Impairment in the U.S. Army

Walden et al. (1975) conducted a very large and thorough study of the prevalence of hearing loss within three high-risk (noisy) branches of the U.S. Army: infantry, armor, and artillery. The investigators randomly selected 1000 subjects in each of three branches, including 200 in each of five length-of-experience categories. Tests of pure-tone hearing threshold levels, SRT, and speech recognition of CNC monosyllables in quiet (at 40 dB above SRT) were [illegible]istered, and each subject was assigned the appropriate H [illegible]. The [illegible] revealed no large differences in the prevalence of [illegible] among [illegible] branches, but, significantly, they did show that [illegible] of the [illegible] in these branches have hearing losses resulting in H [illegible]. In the shortest time-in-service category (1.5-2.4 years), nearly [illegible] the personnel carried an H-1 profile. In the longest category ([illegible].5-2[illegible].4 [illegible]) however, only about 45% had an H-1 profile. Speech audiometry [illegible] results that were within normal limits, although both SRT and syllable recognition scores in quiet deteriorated slightly with increasing [illegible] service.

Walden and his colleagues also administered questionnaires to their 3000 [illegible] in which each subject was asked to state his current H profile. Of [illegible] men who knew their profiles, a substantial number of them did not [illegible] the appropriate profile. In some time-in-service categories, nearly [illegible] of the subjects had worse profiles than they reported (Walden et al.,

[illegible] questionnaires also contained items for self-reported hearing [illegible], the responses to which remained anonymous. 49.7% (1462) of the [illegible] believed they had a hearing loss. Many of these respondents [illegible] an H-1 profile, possibly indicating that this profile allows [illegible] hearing loss to be noticeable to some individuals. 63% of the 1462 [illegible] the total) felt that the hearing loss interfered with their ability to [illegible], 44.3% of the 1462 (22% of the total) reported that the hearing interfered with social functioning, and 37.4% of the 1462 (18% of the [illegible]) reported that the hearing loss interfered with job performance. [illegible], a progressively smaller number indicated difficulties with [illegible] as years of service increased. This is despite the fact that [illegible] service duration produces greater hearing loss. In contrast, the [illegible] of subjects who believed that the hearing loss interfered with [illegible] functioning tended to increase with time in service. The authors [illegible] that soldiers with considerable time in service may be less willing [illegible] that their hearing impairment can affect their abilities to communicate [illegible] perform their [illegible] adequately (Walden et al., 1975).

[illegible] of Impaired Hearing in the Military

[illegible] is no doubt that the hearing impairments characterized by the [illegible] profiles can degrade speech communication. This is even true [illegible] profile under certain conditions. To convey the extent of this [illegible] hypothetical hearing losses which typify the different H profiles [illegible] Table 9 and plotted in Figure 4 (from Richards, 1973), which show [illegible] intensities and frequencies of various speech components, at a [illegible] (conversational) level of 60 dB. One can see that even with [illegible], much of the consonant area, especially the high-frequency [illegible], and some of the third and all of the fourth vowel formant [illegible]. The H-2 profile interferes with a larger portion of the speech [illegible] which includes all of the high-frequency consonants, and all of the [illegible], most of the third and some of the second vowel formants. [illegible] typical H-3 profile will lose most consonants, most of the [illegible] vowel [illegible], and all formants above that.

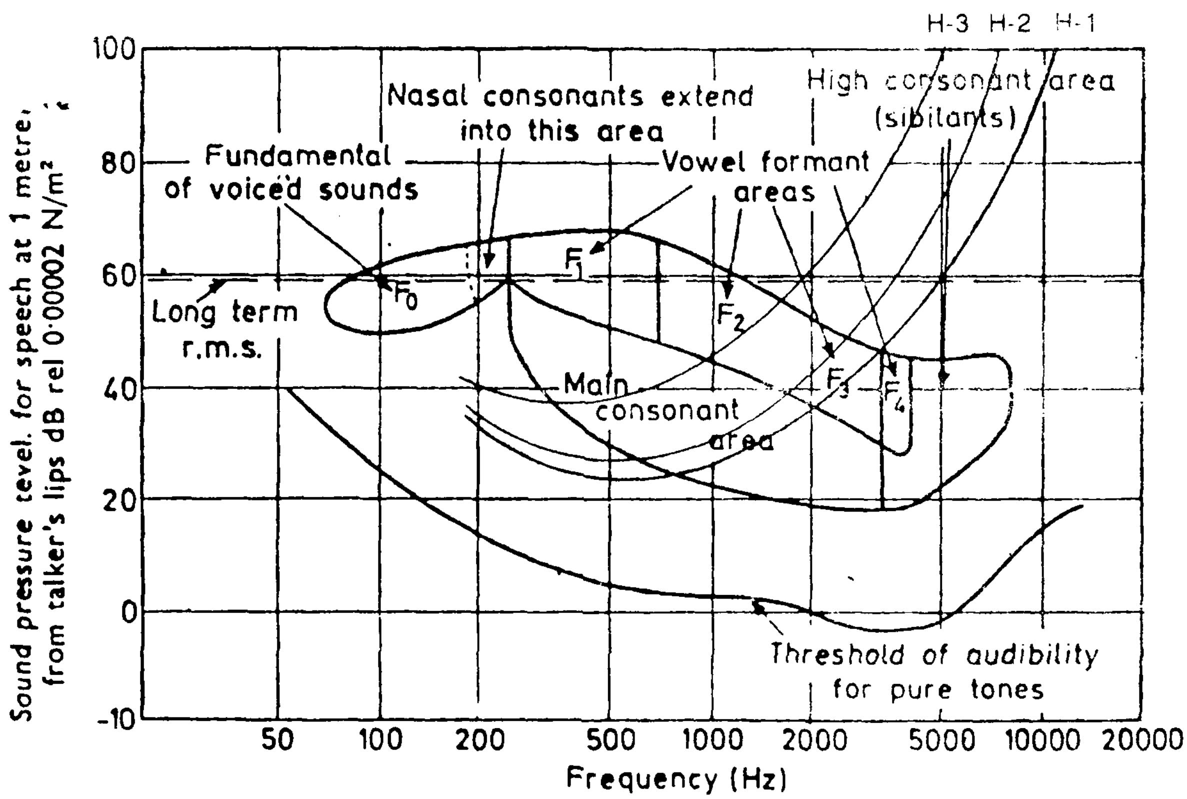

Figure 4. Relative intensities and frequencies of various speech components. Typical U.S. Army "H" profiles are superimposed.

Note. From Telecommunication by Speech: The Transmission Performance of Telephone Networks by D. L. Richards, 1973, London: Butterworths.

Table 9

Hearing Threshold Levels Typical of Army "H" Profile[illegible]

	250	500	1000	2000	3000	4000	6000 Hz
HL	5	15	20	30	40	45	60
SRT	[illegible]	26	26.5	38.5	47.5	54	68
HL	10	20	25	35	50	55	75
SRT	34.5	31	31.5	43.5	57.5	64	[illegible]
HL	15	30	40	55	70	80	[illegible]
SRT	39.5	41	46.5	63.5	77.5	89	[illegible]

[illegible] Figure 5, these typical H profiles have been plotted [illegible] developed by Stevens and Davis (1938 and 1983) (see Figure 1 [illegible]) [illegible] of discriminable units in the auditory area. [illegible] the mean and 90% of critical intensities during speech [illegible] in the lower portion of the chart. Accordingly, [illegible] typical H-1 profile would miss approximately 37% of the [illegible] in the speech range. An individual with an H-2 profile w[illegible], while the H-3 profile would cause nearly 80% of the speech [illegible] inaudible.

The reader should bear in mind that these estimates [illegible] conversational (60 dB) or "everyday" (65 dB) level of speech [illegible] that are not always typical of military situations. [illegible] considerably higher in combat conditions, but so, [illegible] levels. In addition, the estimates resulting from Figures [illegible] filtering paradigm, and do not include the additional [illegible] from the distortion component. Because the distortion [illegible] troublesome in high speech and noise levels, we [illegible] resulting degradation will more than offset the benefits [illegible] in combat-type situations.

Although most of the 3000 soldiers tested by Walden et al. [illegible] recognition scores within normal limits, the authors concl[illegible] clinical tests in quiet were not good indicators of the [illegible] resulting from high-frequency hearing loss. They observed [illegible] situations involve moderate-to-intense levels of noise. [illegible] most real-life speech will not be as highly intelligible as [illegible], nor will the listener be given the courtesy of hearing [illegible] dB above his SRT. Walden and his colleagues concluded that [illegible] soldiers can communicate fairly well under ideal conditions, [illegible] may pose great difficulties in the typical combat environ[illegible]

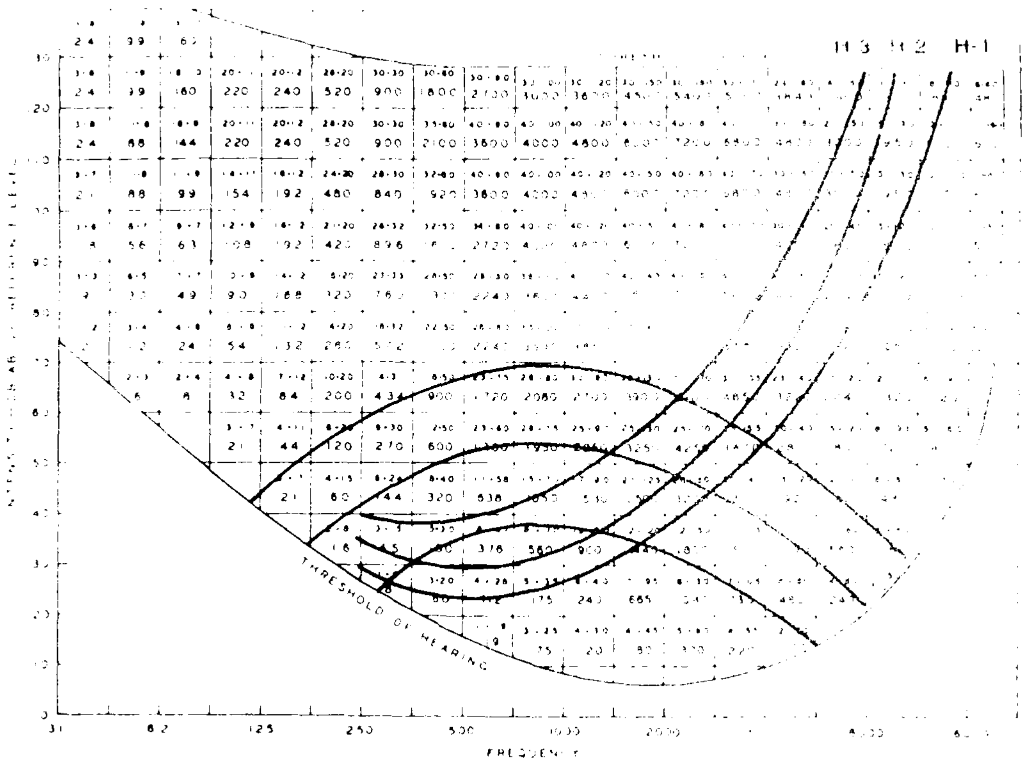

Figure 5. Typical U.S. Army "H" profiles plotted against the number of discriminable units in the speech area. (From Stevens and Davis, 1938 and 1983). Kryter's (1984) curves for critical speech intensities have been added.

Note. Adapted from Hearing: Its Psychology and Physiology by S. S. Stevens and H. Davis, 1938 and 1983, New York: American Institute of Physics.

[illegible] the statement of 18% of the 3000 soldiers [illegible] interfered with their ability to perform [illegible] recommend that the clinical evaluation of Army troops [illegible] recognition in noise. They also recommend [illegible] the A[illegible] study of the effects of hearing loss on communication [illegible] general," and that "this research should be [illegible] readiness of soldiers with noise-induced hearing loss [illegible] they noted that many soldiers do not carry the appropriate [illegible] recommend that the profile system be rigorously administered.

The study by Walden et al. (1975) indicates that many soldiers [illegible] infantry, and artillery branches need to be reassigned [illegible] a more lenient profile. According to Aspinall and Wilson [illegible] hearing conservation officers have suggested that the combat and combat [illegible] units would suffer a debilitating manpower shortage if all personnel [illegible] according to their hearing loss along with the appropriate [illegible]" (p. 11). Clearly, the extent of hearing impairment in [illegible] perhaps in the military in general, poses a significant problem. The [illegible] system appears to be inadequate for effective communication [illegible] and the system itself is poorly enforced. The situation [illegible] attention in the form of rigorous hearing conservation [illegible] study of the specific communication needs of each job [illegible] impaired personnel are assigned, and the resulting revision [illegible] schemes. The consequences of communication failures [illegible] severe, ranging from mild inconvenience to loss of [illegible] equipment and even loss of life.

SUMMARY

[illegible] Hearing Loss in Speech Recognition

There is no question that noise-induced hearing loss acts as [illegible]. There is still some debate on the extent to which distortion [illegible] auditory system further degrades the ability to hear speech, but [illegible] appears to be a matter of degree of distortion rather than [illegible] this distortion exists. There is also little doubt [illegible] with a significant degree of the distortion component [illegible] speech-to-noise ratios, perhaps up to 10 dB more [illegible] normal-hearing counterparts.

Distortions of the auditory system that interfere [illegible] can be divided into categories of frequency, intensity [illegible] processing. The frequency distortions most commonly [illegible] tuning curves and upward spread of masking, but other [illegible] distortion, have been identified. Intensity distortions [illegible], abnormal intensity discrimination, and limited dynamic [illegible] shown to have deliterious effects on speech, as have [illegible] processing, such as abnormal effects from temporal summation [illegible] backward masking, and gap detection.

Investigations have shown that hearing-impaired subjects [illegible] advantages of binaural hearing, but not as much as normal [illegible] the basis of limited data, it appears that hearing [illegible] minor difficulties localizing sounds [illegible] the horizontal [illegible] trouble identifying the source of a sound in the vertical [illegible]

Hearing Handicap

The terms "handicap", "impairment", "disability", and "material impairment" are often used interchangeably, but carry different meanings. For this report, the preferred term is "handicap", which [illegible] mean the disadvantage imposed by an impairment sufficient [illegible] one's personal efficiency in the activities of everyday living.

Most studies of speech recognition in quiet point to the importance of good hearing in the mid-frequency range. Virtually all of the studies of speech recognition in noise show the importance of high-frequency hearing. The same is true of speech that is distorted, for example, by [illegible] reverberation. Recent investigations of the "low fence" or point of beginning handicap indicate an average hearing threshold level between [illegible] the frequencies 1000, 2000, and 3000 Hz. [illegible] usually with varying amounts of background noise. The actual level of the low fence will depend mainly upon the difficulty of the specific listening task. Special consideration must be made for circumstances requiring the identification of faint or high-frequency sounds, in which case the criterion for hearing sensitivity in the high frequencies should be more stringent.

Predicting Communication as a Function of Hearing Impairment

An estimate of the effect of hearing impairment on speech communication can be made on the basis of audible discriminable units in the speech range, according to a method devised by Kryter (1984). Estimates can also be made with the use of the Articulation Index. Both of these methods model the hearing mechanism as a frequency filter, necessitating [illegible] added correction for the distortion component.

Warning Signal Identification

There has been very little research on the ability of hearing-impaired listeners to detect and recognize auditory warning signals. Research on listeners with essentially normal hearing, and the estimated responses by hearing-impaired listeners, indicates that detection differences between the two groups are not very large. These differences may turn out to be greater for actual signal recognition than they are for detection.

Military Performance Criteria

The U.S. Department of Defense now has hearing threshold level standards for appointment, enlistment, and induction that apply to all three services. The U.S. Army has had its own set of induction standards which were in use until they were superceded by the DoD directive. The Army also has standards for admission to training as aviators, air traffic controllers, and divers.

In addition, it has a profiling system of H-1 through H-4, which apply to personnel within various military occupational specialties.

The U.S. Air Force also uses H profiles, which apply to the initial selection of candidates and the tenure of certain jobs, such as aviators, air traffic controllers, and communication operators, etc. The U.S. Navy does not yet use H profiles, although a set of profiles has been proposed. The Navy does have hearing sensitivity criteria for positions and duties where good hearing is considered important.

Most of the U.S. military standards for appointment, enlistment, induction, or even for jobs requiring significant amounts of communication, are either at the upper limit, or exceed the range identified by researchers as the point of beginning hearing handicap. This becomes a risky policy in circumstances when human safety and mission success depend upon effective communication.

The German military system's criteria for flight training candidates and experienced pilots are slightly more stringent than those used by the U.S. Air Force. Hearing threshold level criteria also exist for other nations, but reliable data are not available at this time.

The prevalence of hearing handicap in the U.S. Army is very high, at least among soldiers in three high-risk branches: armor, artillery, and infantry. Many soldiers in these branches have profiles exceeding the H-1 designation, including over 65% of the soldiers in the most experienced category (17.5-22.4 years of service). Many soldiers do not carry the correct profile. Nearly one-half of the soldiers in these branches believe they have a hearing impairment, and nearly one-third of these report that the hearing impairment interferes with job performance. That these hearing impairments can impede job performance is not surprising, since many of them will exceed the range identified in recent research as the beginning of hearing handicap. The severity of the hearing loss problem in the U.S. Army, and very possibly in the military as a whole, is sufficient to be significantly disruptive of speech communication. The consequences of this disruption can be severe in terms of the destruction of costly equipment, and in extreme cases, the loss of life.

VIII. RESEARCH RECOMMENDATIONS

1. The most urgent recommendation would be to characterize the conditions in which soldiers need to communicate, and assess the abilities of hearing-impaired personnel to recognize speech in these conditions, either through modelling or through actual testing.

2. The next step would be to recommend changes of the H profiles and the assignment of profiles to MOSs in accordance with the results of recommendation #1.

3. A survey of the military standards or profiles in other nations, along with the research results or other information which formed the bases

for these standards, would be a helpful adjunct to any revision of the U.S. Army's profile system.

4. Another important project would be to continue the investigation of the ability of hearing-impaired personnel to detect and recognize warning sounds. The addition of the binaural listening mode, an assessment of signal recognition (in contrast to detection), and a population of hearing-impaired subjects would greatly strengthen the existing study.

5. It would also be useful to investigate the ability of hearing-impaired people to localize sound in the horizontal plane and especially in the vertical plane in combat-type conditions.

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