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

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This report was prepared by Gallaudet University for the U.S. Army Human Engineering Laboratory. This report has received a technical review by the Human Engineering Laboratory but it has not received an editorial review by the laboratory. This report is presented in the interest of providing information in a timely manner.

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### Title
The Effects of Hearing Loss on Speech Communication and the Perception of Other Sounds

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### Abstract
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.

(see reverse side)
Hearing in the high-frequency range is important for understanding speech in noisy conditions, or when speech has been distorted by feedback, reverberation or filtering. Recent research targets the point on the audiogram where hearing handicap or "low range" as an average hearing threshold is located between 15 and 30 dB for the audiometric frequencies 1000, 2000, and 4000 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 industrial services. In addition, the U.S. Army and the U.S. Air Force use "n" ranges between for the initial selection and tenure of certain jobs. Most "n" ranges indicate that either close to the upper limit or exceed the range for speech in researchers as the point of beginning hearing handicap. Where the prevalence of hearing handicap in the U.S. Army is more, the significant disruptions of speech communication have serious impact on task performance.
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U.S. ARMY HUMAN ENGINEERING LABORATORY
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CONTENTS

I. INTRODUCTION ................................................. 3

II. EFFECTS OF HEARING LOSS ON SPEECH RECOGNITION .......... 3
    A. Filtering vs. Distortion .................................. 3
    B. Masking .................................................... 5
    C. Distortion ................................................ 7
       1. Frequency distortion .................................... 7
       2. Intensity distortion .................................... 8
       3. Distortions in temporal processing ..................... 8
    D. Binaural Processing and Localization .................... 9

III. HEARING HANDICAP ........................................... 10
    A. Definitions ................................................ 10
    B. Audiometric Thresholds Defining Hearing Handicap ......... 11

IV. PREDICTING COMMUNICATION AS A FUNCTION OF HEARING LOSS .... 17

V. PERCEPTION OF WARNING SIGNALS ............................ 23

VI. MILITARY PERFORMANCE CRITERIA ........................... 24
    A. U.S. Army .................................................. 24
    B. U.S. Air Force ............................................ 28
    C. U.S. Navy .................................................. 29
    D. Other Military Criteria ................................... 31
    E. Prevalence of Hearing Impairment in the U.S. Army ....... 31
    F. Consequences of Impaired Hearing in the Military ....... 32

VII. SUMMARY .................................................... 36

VIII. RESEARCH RECOMMENDATIONS .............................. 38
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 (1987) 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 voiceless 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 situations physically comparable for normal-hearing subjects and those with high-frequency hearing losses. Each subject was tested at 4 speech levels (45, 75, and 85 dB) with 3 different speech-to-noise ratios (-5, -15, and -19 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
B. Masking

Fairy and Van Borsum (1981) also investigated whether attenuation in the auditory pathway for hearing-impaired listeners. As in the experiment by Humes et al. (1981), their subjects (not bilateral, cochlear impairments) had subjects showed better recruitment in masked and unmasked conditions than the impaired ears and showed no differences among listeners. 

Subjects. The error patterns of these various groups of people the most critical. To test these differences, all individuals.

The use of masking in an experiment such as the one described above, is a logical form of filtering in that it renders part of the input inaudible.

Humes et al. (1981) pointed out that masking can be used to estimate cochlear impairment than normal listeners. Normal thresholds for threshold elevations resulting from masking are produced objectively, and that in addition, noise-masked normal listeners. 

Humes et al. (1981) chose four subjects with bilateral, asymmetric, minimal median hearing impairments, each of whom was matched with three normal-hearing subjects whose noise-masked thresholds were nearly identical. 'The white noise-aided subject. Recognizing the importance of altering the background noise level, they noted that under most conditions, the hearing-aided subject's thresholds were better than that of the noise-masked normal listeners. In addition, they believed that if some deficit was there, then the noise levels would not allow recruitment had been present prior to onset. Furthermore, the effect of impaired listeners. 

Humes et al. (1981) believe that their normal-hearing listeners, and have these processing abilities, and that the speech-recognition performance, at least partially, is due to their fact that subjects "never perform below their normal-hearing counterparts" (p. 772), their data show that at least 95% of their subjects had their normal-hearing counterparts' performance.

These experiments do not support the notion that additional distortion explains, but they do suggest that the
types of experiments employing masking in the performance of normal listeners and those with hearing loss.

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

Presumably because of the distortion components, listeners appear to need more favorable speech-to-noise ratios than normal listeners. According to Plomp (1978), an individual hearing impairment needs a speech-to-noise ratio that is at least 10 dB quieter than a normal listener would require. Assuming the speech-to-noise ratios for combinations of Class A and Class D, one would expect hearing-impaired listeners to require a smaller level than 10 dB in real life. Measuring the sentences in 7 normal-hearing subjects and 12 hearing-impaired subjects with normal hearing and -1.9 dB for hearing-impaired subjects with normal hearing and -1.9 dB for hearing-impaired subjects in Class D, one would expect normal-hearing subjects needed a speech-to-noise ratio of 10 dB more favorable than the normal listeners. Although this is a significant increment, it represents a difference of -0.7 dB (Münstereif, 1982).

As the level of a noise increases, its masking effect is due to the phenomenon known as the upward spread of maskers (Menn, 1993). The popular notion that hearing loss is disproportionately affected by the upward spread of maskers. He claims that the actual effect of maskers on normal listeners when the masking stimuli are closer to the sound pressure level for all subjects (presumably an average sensation level). Martin and Pickett (1970) showed greater masker thresholds for hearing-impaired than for normal listeners (e.g., 107 dB), although the actual threshold shift was found considerable variability among subjects, and the spread of masking was not strongly related to the masker. More recently, Picard and Couture-Metz (1985) used an eight-frequency hearing aid and increases in the high frequency masking noise centered at 1000 Hz, the hearing-impaired subjects were found more sensitive to masking than normal-hearing controls. This effect occurred despite hearing the frequency of the masker.

Tagne (1983) assessed upward spread of maskers by plotting the level of masked threshold level, using only raised thresholds that exceeded the threshold level in quiet. He defined "masking" as the difference between actual and estimated thresholds, the difference of expected value that normal listeners plus the threshold levels in quiet. The results showed an effect of masking, which varied according to degree of hearing configuration. To assess the validity of his method, Sazorg and Tagne tested normal listeners with different
1. Frequency distortion

In a review entitled "The Input for a Damage Model", J. A. Steeneken describes impairment to frequency coding as a function of frequency tuning curves, a breakdown of the critical bands, and also the tuning of one frequency by another. Distant sounds in the spectrum (spread of masking) with the result that background noise is not effectively, and speech sounds mask each other. Steeneken describes harmonic distortion as a factor in the impairment of frequency coding. Normal ears respond to produce harmonics of fundamental.

While these harmonics are of low intensity at first, they increases rapidly with increasing intensity of the fundamental. Impaired cochleas tend to produce harmonics at low intensities. Therefore, these disruptive harmonics are a factor in the speech.

Recent experiments have pointed out the need for a psychophysical tuning curve. Salvi et al. (1981) describe a psychophysical curve as a set of frequency-intensity combinations. This curve relates the rate of the nerve's firing rate to exceed by a fixed amount the firing rate.
The threshold of hearing, F. A.

The threshold of hearing is the point at which a sound can just be heard. The threshold of hearing is measured in units of "decibels." The decibel scale is logarithmic, meaning that a sound that is 10 times as loud will be rated as 10 decibels higher on the scale. The smallest sound that can be heard by the average human ear is about 0 decibels, while the loudest sound that can be heard is about 120 decibels.

The threshold of hearing is affected by various factors, such as age, health, and environmental conditions. For example, older adults and individuals with hearing loss may have a higher threshold of hearing. Similarly, exposure to loud noise can permanently damage the hearing of an individual.

The threshold of hearing is an important concept in the field of audiology, as it helps to determine the appropriate level of sound for individuals with hearing loss.
duration there must be a 10-dB increase in stimulus level for a signal to be equally detectable. The ear with a cochlear impairment requires an increase of only 3.6 dB. The impaired ear integrates sounds over a shorter period of time.VER) and the normal ear integrates sounds over a longer period of time.VER) and the normal ear integrates sounds over a longer period of time.VER. A normal ear integrates sounds over a longer period of time.VER. A normal ear integrates sounds over a longer period of time.VER. A normal ear integrates sounds over a longer period of time.VER.

Parker and Yoder (1981) developed a simplified masking procedure to test temporal resolution in clinical patients. On testing subjects with normal hearing and several types of hearing impairment, they found that the normal listeners, but degraded temporal resolution ability of hearing-impaired, with more unfavorable speech-to-noise ratios produced 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. (1973) tested several measures of temporal processing as well as frequency resolution tasks on normal and hearing-impaired adults. Their hearing-impaired subjects showed poorer results than the normal listeners. In all cases, conditions of whether the two groups were compared with equal pure-tone level or equal sensation levels. Two of the temporal processing effects, increased temporal difference limen (just noticeable difference in stimulus duration) and longer gap detection thresholds (minimum detectable gap in frequency 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 poor 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 (Naebelek 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.

Naebelek and Mason (1981) tested the effect of noise and reverberation on binaural and monaural word recognition by subjects with various types of amounts of hearing loss. They found a binaural advantage of 5.9% in a environment with a reverberation time of 0.1 second and 3.7% in reverberation of 0.5 sec.

With regard to sound localization, Stephens (1976) cites Florentine and Schearf (1975) as showing that hearing-impaired subjects exhibit only minor abnormalities in perceiving sound lateralization and directionality. However, references Roffler and Butler (1968) and Butler (1970) are 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." (Letchly, Johnson, 1964)

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 concept 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 of "stress" 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 some state welfare
compensation laws use the word "impairment" with the AAOO's formulation. 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 be apparent in the subsequent discussions.

B. Audiometric Thresholds Defining Hearing Handicap

The point of beginning handicap has been the subject of much discussion and investigation over recent decades. Early experiments focused on the 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 to calculate compensation for hearing loss, even though it was not designed for that purpose. Later, the AMA adopted the Fowler-Sabine method in 1947. In 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" at 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 represents the 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-Hansen 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 I
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 average 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 Atton (1970), Suter estimated the point of beginning handicap occurs at an average hearing threshold of 19 dB at 1000, 2000, and 4000 Hz (Suter, 1979). This point translates to approximately 0 dB at 500, 1000, and 2000 Hz, and 22 dB at 1000, 2000, and 4000 Hz, relative to individuals with mild sensorineural impairments have audiometric profiles that rise toward the high frequencies. She observes, however, that the selection of a fence depends upon the definition of hearing handicap and the context 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 AAO 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Speech Material</th>
<th>Environment</th>
<th>Frequencies Most Important for Speech Recognition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harris, Haines, and Myers, 1956</td>
<td>Harvard PB Monosyllables (50% Correct)</td>
<td>Quiet</td>
<td>av. 500, 1000, 2000 Hz</td>
<td></td>
</tr>
<tr>
<td>Mullins and Bangs, 1957</td>
<td>Harvard PB Monosyllables</td>
<td>Quiet</td>
<td>2000, 3000 Hz</td>
<td></td>
</tr>
<tr>
<td>Quiggle, Glorig, Delk, and Summerfield, 1957</td>
<td>Spondees</td>
<td>Quiet</td>
<td>av. 500, 1000, 2000 Hz</td>
<td></td>
</tr>
<tr>
<td>Quist-Hanssen and Steen, 1960</td>
<td>Norwegian Monosyllables, Disyllables, Digits, and &quot;Context&quot; Speech</td>
<td>Quiet</td>
<td>av. 500, 1000, 2000 Hz</td>
<td></td>
</tr>
<tr>
<td>Kryter, Williams, and Green, 1962</td>
<td>Harvard PB Monosyllables and Sentences</td>
<td>Quiet, Noise, and Low-Pass Filtering</td>
<td>2000, 3000, 4000 Hz</td>
<td></td>
</tr>
<tr>
<td>Ross, Huntington, Newby, and Dixon, 1965</td>
<td>CID W-22 PB Monosyllables</td>
<td>Quiet and Noise</td>
<td>2000, 4000 Hz</td>
<td>Speech materials presented at 40 dB above SRT.</td>
</tr>
<tr>
<td>Source</td>
<td>Speech Material</td>
<td>Environment</td>
<td>Frequencies Most Important for Speech Recognition</td>
<td>Comments</td>
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<td>-------------------</td>
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<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Acton, 1970</td>
<td>Fry's PB Monosyllables</td>
<td>Quiet (S/N(^1 \pm 20) and Pink Noise</td>
<td>2000 Hz</td>
<td>Subjects with mild high-frequency losses (above 2kHz) performed better than normal-hearing controls.</td>
</tr>
<tr>
<td>Elkins, 1971</td>
<td>MRT</td>
<td>Quiet and Noise</td>
<td>2000, 3000, 4000 Hz in quiet, but no significant correlations in noise</td>
<td>Speech materials presented at 40 dB above SRT.</td>
</tr>
<tr>
<td>Lindeman, 1971</td>
<td>Dutch Monosyllables</td>
<td>&quot;Cocktail Party&quot; Noise</td>
<td>2000 Hz</td>
<td></td>
</tr>
<tr>
<td>Aniansson, 1973</td>
<td>Swedish PB Monosyllables</td>
<td>9 Different &quot;Everyday Milieu&quot; (Traffic Noise, Competing Speech and Mild Reverberation)</td>
<td>3000 and 4000 Hz just as important as 500 and 1000 Hz</td>
<td></td>
</tr>
<tr>
<td>Korniarz, 1973</td>
<td>Polish Monosyllables and Sentences</td>
<td>Quiet, White and Low-Frequency Noise</td>
<td>500, 1000, 2000 Hz in quiet, and 3000, 4000 Hz in noise</td>
<td>Recommended av. 1000, 2000, 4000 Hz to Polish Ministry of Health.</td>
</tr>
<tr>
<td>Suter, 1974</td>
<td>MRT and CID Sentences</td>
<td>Quiet and Speech Babble Noise (plus Mild Reverberation)</td>
<td>av. 1000, 2000, 4000 Hz in quiet; av. 1000, 3000, 4000 Hz in noise</td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Speech Material</td>
<td>Environment</td>
<td>Frequencies Most Important for Speech Recognition</td>
<td>Comments</td>
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</tr>
<tr>
<td>Smoorenburg, 1982</td>
<td>SRT for Dutch Sentences</td>
<td>Quiet and 4 Levels of Speech-Shaped Noise</td>
<td>500 Hz in quiet, 2000-3000 Hz in Noise</td>
<td>Pilot study - only 22 hearing impaired subjects.</td>
</tr>
<tr>
<td></td>
<td>2. P.A. Announcement in Railway Station Noise (plus Reverberation)</td>
<td>2. Railway Station Noise (plus 3000, 4000, 6000 Hz Reverberation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Telephone Listening</td>
<td>3. Noise at 2 dB S/N¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoorenburg, 1986</td>
<td>SRT for Dutch Sentences</td>
<td>Quiet and 4 Levels of Speech-Shaped Noise</td>
<td>250-1000 Hz in Quiet, 2000, 4000 Hz in Noise</td>
<td>200 hearing-impaired subjects.</td>
</tr>
</tbody>
</table>

Frequencies above 1000 Hz show better correlation with speech recognition even in noise levels as low as 35 dB(A).

¹S/N = speech-to-noise ratio
Smooorenburg (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 (Smooorenburg, 1986). Because hearing sensitivity at 2000 and 4000 Hz correlates so well with speech recognition in noise, Smooorenburg (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). Smooorenburg 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. Smooorenburg 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 40 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 2nd 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).
subjects had hearing impairments as well as the following SLTs at 1000, 2000, and 3000 Hz. The shape and magnitude of the resulting effects produced different results had there been no restrictions.

In the final analysis, it appears that the assessment of handicap always involved some degree of subjectivity. However, if we assume that the SLT increases at the 5% or 10 level of significance to a level of normal performance, or an estimated difference between an individual's normally or subnormally on speech recognition tasks, then the handicap involved. Fortunately, these recent experiments have shown handicap to be about 1.5 and 30 dB on the average. The only way to narrow it further would be to take the handicap in the specific conditions and the assessment of handicap is needed. One must also remember that this 1% to 2% range applies to the recognition of everyday speech. Special circumstances, such as serving 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 INTELLIGENCE

Some interesting schemes for predicting speech losses and communication losses have been developed by Krueger (1984), and one scheme he borrowed a graph from Stevens and Davis. Figure 1, from Stevens and Davis, shows an estimate of the 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 Cinder, 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 a range 17 dB above the 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. Taking the totals for each cell, Stevens and Davis estimated a total of 340,000 distinguishable units in the audible range.

Figure 2 shows Kryter's (1984) version of the graph developed by Stevens and Davis. The lower, concave curves represent patient estimates made at 90% range of "critical intensities" produced by Stevens and Davis (labeled #1). Kryter estimates 43,093 distinguishable units in this range. Curve #3 represents the audiogram of an individual with an average hearing threshold level of 15 dB at 500, 1000, and 2000 Hz. This person would have lost the capacity to perceive 15% of the speech units constituting everyday speech, and about 40%, or 15,500, of the total number of speech 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. Curve #1 represents 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. Curve #4 represents 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. Because there is a slight discrepancy between Kryter's estimate of the total number of units (17,170)
Figure 1. Number of distinguishable tones in the auditory area.

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

and that of Stevens and Davis (340,000), Kryter's hearing loss coefficients might be slightly lower if calculated on Stevens and Davis' total. The reader should also note that these estimates are based entirely on a filter model, 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 43% 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 AAO 1959 hearing handicap rule and other linear functions 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 that is characterized by the attenuation model, without distortion.

Certain other investigations have used the AI with hearing-impaired subjects. Macrae and Brigham (1973) tested 309 hearing-impaired subjects with 750 sentences, in quiet and speech-to-noise ratios of -10 and -12 dB, in a manner similar to Kryter's; they calculated an AI for each individual subject and found very high correlations between AI and sentence sentence recognition. At the -10 dB speech-to-noise ratio, the correlation was 0.979 and at the -12 dB speech-to-noise ratio, it was 0.989.

In a slightly different approach, Smoorenburg et al. (1981) measured the AI for normal listeners, based on the speech-to-noise ratio. A group of subjects achieved 50% sentence recognition (SRT). They then calculated an AI for each hearing-impaired subject, based on the speech-to-noise ratio corresponding to the subject's SRT and on the amount of information that was available because of the filter effect. Whereas the average AI for normal subjects in A-weighted noise levels of 40, 55, and 70 dB was 0.44, the average AI for hearing-impaired subjects was 0.24%. Because the normal listeners could function at a slightly poorer AI than the hearing-impaired subjects (a difference in AI of 0.03), the authors conclude that reducing 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)

<table>
<thead>
<tr>
<th>Avg. HL at 500, at 1000, Weak Conversational</th>
<th>Normal Conversational</th>
<th>Everyday Speech Level</th>
<th>Shouting Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 and 2000 and Level in Quiet</td>
<td>Level in Quiet (Long-Term RMS = 50 dB)</td>
<td>(Long-Term RMS = 55 dB)</td>
<td>(Long-Term RMS = 65 dB)</td>
</tr>
<tr>
<td>2000 Hz 3000 Hz (Long-Term RMS = 50 dB)</td>
<td>(Long-Term RMS = 55 dB)</td>
<td>(Long-Term RMS = 65 dB)</td>
<td>(Long-Term RMS = 80 dB)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ASA ISO</th>
<th>ASA ISO</th>
<th>AI Sent. PB Words</th>
<th>% 1000 AI Sent. PB Words</th>
<th>% 1000 AI Sent. PB Words</th>
<th>% 1000 AI Sent. PB Words</th>
<th>% 1000 AI Sent. PB Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5 5 5 15 0.81 93 94</td>
<td>0.84 100 95</td>
<td>0.98 100 98</td>
<td>1.0 100 100</td>
<td>1.0 100 100</td>
<td>1.0 100 100</td>
<td></td>
</tr>
<tr>
<td>3 15 15 25 0.56 87 81</td>
<td>0.72 98 92</td>
<td>0.84 100 95</td>
<td>0.98 100 98</td>
<td>0.98 100 98</td>
<td>0.98 100 98</td>
<td></td>
</tr>
<tr>
<td>15 25 25 35 0.34 77 52</td>
<td>0.47 95 73</td>
<td>0.72 98 92</td>
<td>0.84 100 95</td>
<td>0.98 100 98</td>
<td>0.98 100 98</td>
<td></td>
</tr>
<tr>
<td>25 35 25 35 0.17 36 17</td>
<td>0.26 68 35</td>
<td>0.47 95 73</td>
<td>0.72 98 92</td>
<td>0.98 100 98</td>
<td>0.98 100 98</td>
<td></td>
</tr>
<tr>
<td>35 45 45 55 0.03 5 2</td>
<td>0.09 15 8</td>
<td>0.16 68 35</td>
<td>0.47 95 73</td>
<td>0.72 98 92</td>
<td>0.98 100 98</td>
<td></td>
</tr>
<tr>
<td>45 55 55 65 0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td></td>
</tr>
<tr>
<td>55 65 75 75 0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td></td>
</tr>
<tr>
<td>65 75 75 85 0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td></td>
</tr>
</tbody>
</table>
Figure 7. Estimated percentage hearing "impairment" and speech recognizability as a function of average hearing level.

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 with other factors. Wilkins (1984) carried out a field study to review the effects of hearing protectors and hearing loss on the perception of important environmental sounds. He found that hearing-impaired listeners were able to detect but not always identify environmental sounds, and that other variables, such as visual cues, also influenced the ability to detect and identify sounds. In general, groups responded similarly to the sounds, and Wilkins attributed this to spectral differences in the signals. However, the subject's hearing protection, and the presence of other uncontrolled variables, any conclusions from this study must be made with extreme caution.

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

Price and Hodge (1976) developed a model for predicting the similarity of various noises. They analyzed 24 noise samples according to their spectra, then modeled the normal ear's method of detecting energy over 50-msec and 200-msec periods. Actual and predicted results for their model showed excellent agreement. On comparing typical soldiers to the 24 noise spectra, they estimated that normal-hearing individuals could detect these sounds at an average level. However, soldiers with about 20 years of noise exposure. With the exception of high-frequency environmental noise (jungle with animals and aircraft), the estimated difference between the two groups fell to 0.3 dB. A low-frequency environmental noise (recorded in rural France) produced an estimated 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 mid-frequency 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

<table>
<thead>
<tr>
<th>Department of Defense Hearing Threshold Level Induction Standards (DoD, 1986)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>500-2000 Hz</strong></td>
</tr>
<tr>
<td>Average threshold no greater than 30 dB</td>
</tr>
<tr>
<td>No single frequency greater than 35 dB</td>
</tr>
<tr>
<td><strong>3000 Hz</strong></td>
</tr>
<tr>
<td>No threshold greater than 45 dB</td>
</tr>
<tr>
<td><strong>4000 Hz</strong></td>
</tr>
<tr>
<td>No threshold greater than 55 dB</td>
</tr>
</tbody>
</table>

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.
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:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Better ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>30 dB</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>25 dB</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>25 dB</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>35 dB</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>6000</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Classes</th>
<th>Frequency (Hz)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>6000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 1A</td>
<td>Each ear</td>
<td>25 dB</td>
<td>25 dB</td>
<td>25 dB</td>
<td>35 dB</td>
<td>45 dB</td>
<td>45 dB</td>
</tr>
<tr>
<td>Class 2</td>
<td>Better ear</td>
<td>25 dB</td>
<td>25 dB</td>
<td>25 dB</td>
<td>35 dB</td>
<td>65 dB</td>
<td>75 dB</td>
</tr>
<tr>
<td>(Aviators)</td>
<td>Poorer ear</td>
<td>25 dB</td>
<td>35 dB</td>
<td>35 dB</td>
<td>45 dB</td>
<td>65 dB</td>
<td>75 dB</td>
</tr>
<tr>
<td>Class 2</td>
<td>Each ear</td>
<td>25 dB</td>
<td>25 dB</td>
<td>25 dB</td>
<td>35 dB</td>
<td>65 dB</td>
<td>75 dB</td>
</tr>
<tr>
<td>(Air Traffic Controllers)</td>
<td>Better ear</td>
<td>25 dB</td>
<td>25 dB</td>
<td>25 dB</td>
<td>35 dB</td>
<td>65 dB</td>
<td>75 dB</td>
</tr>
<tr>
<td></td>
<td>Poorer ear</td>
<td>25 dB</td>
<td>35 dB</td>
<td>35 dB</td>
<td>45 dB</td>
<td>65 dB</td>
<td>75 dB</td>
</tr>
</tbody>
</table>

 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 p. a. which would be likely to cause problems with the use of protective headsets or 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 5 shows H (hearing) profiles 1 through 4, according to Army Regulation 40-501 (U.S. Army, 1987).
3.2 Audiometer average level of 6 readings to per ear at 500, 1000, 2000 Hz or not more than 30 dB, with no individual level greater than 35 dB at these frequencies. Air level not more than 55 dB at 400 Hz or audiometer level 32 dB at 400 Hz. 25 dB at 1000 Hz and 15 dB at 2000 Hz, and 10 dB at 4000 Hz. In either ear, severe loss may be noted.

3-4 Chronic ear disease not falling below auditory standards. Aided speech reception threshold measured at “comfort level”, i.e., volume control of hearing aid adjusted to 60 dB NRT noise level.

3-5 Below standards reviewed in chap. 2 for P-1 approval on July 1947. Persons to be considered with psychosocial and organic disease of the ears.

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

The Army also uses the Code of Military Policing (MMC, which includes non-combatant personnel) sometimes with added requirements. For example, MMC includes Air Traffic Control, Motor Control, MP Control, Police Specials (MPS), and Interrogator (MP) "must have a hearing loss hearing wear aid" (U.S. Army, 1985, p. 725). "Hearing loss hearing aid to hear oral command in noisy areas, but not must" (U.S. Army, 1947, p. 702). The majority of these theatres, including many U.S. "H-1" profile, in the Middle East require normal or near-normal hearing.
particularly important, H-1 profiles are identified and those profiles are:

- Fire Support Specialist
- Cavalry Scout
- M48, M60, and M1 Armor Crewmen
- Multichannel Communications Equipment Operator 3M
- Tactical Circuit Controller 3M
- Wire Systems Operator 3M
- Explosive Ordnance Disposal 3M
- Physical Activities Specialist 3M

Surprisingly, certain other occupations are given a grade of 0, despite the apparent need for good communication abilities. Examples are:

- Air Traffic Control Tower Operator
- Air Traffic Control Radar Controller
- Locomotive Operator
- Special Agent

D. U.S. Air Force

The Air Force has its own set of H profiles, as shown in U.S. Air Force, 1987. The following jobs or activities are considered to be H profiles:

- Air Force Academy Admission
- Flying Classes 1 and 1A
- Initial Flying Class III
- Initial AFSC Selection
- Initial Selection for Missile Launch Crew
- Initial Selection for Air Traffic Controller Duty
- Other Permanent Initially Entering Potentially Noise-Hazardous Career Fields
- Other Permanent Selection

The H profiles require a continuing B Psychological test and the H-1 profile is not required for enlistment within the service of service.
Table 7

U.S. Air Force Hearing Threshold Level Profiles
(AFHealth 460-41, 1987)

H-1

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>Must not exceed 25 dB, each ear</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>Must not exceed 25 dB, each ear</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>Must not exceed 25 dB, each ear</td>
</tr>
<tr>
<td>3000 Hz</td>
<td>Sum of audiometric thresholds at</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>these frequencies for both ears</td>
</tr>
<tr>
<td>6000 Hz</td>
<td>must not exceed a total of 270 dB.</td>
</tr>
</tbody>
</table>

H-2

Audiometric thresholds for the frequencies 500, 1000, or 2000 Hz may equal but not exceed the following:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>30 dB</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>30 dB</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>30 dB</td>
</tr>
</tbody>
</table>

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

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 poorer 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 personnel must also not exceed:
500 Hz - 35 dB
1000 Hz - 30 dB
2000 Hz - 30 dB
4000 Hz - 40 dB
6000 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:

<table>
<thead>
<tr>
<th></th>
<th>Better Ear</th>
<th>Poorer Ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>35 dB</td>
<td>35 dB</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>30 dB</td>
<td>50 dB</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>30 dB</td>
<td>50 dB</td>
</tr>
</tbody>
</table>

(continued on next page)
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
and each subject was assigned the appropriate profile. The test revealed no large differences in the prevalence of hearing impairment. However, most significantly, they did show that men in these branches have hearing losses resulting in H-1 to H-3 profiles in the shortest time-in-service category (1.5-2.4 years), nearly 70% of the personnel carried an H-1 profile. In the longest category (17.5-21.4 years), however, only about 45% had an H-1 profile. Speech audiometry produced results that were within normal limits, although both SRT and syllable recognition scores in quiet deteriorated slightly with increasing time in service.

Walden and his colleagues also administered questionnaires to their subjects in which each subject was asked to state his current H profile. Of the men who knew their profiles, a substantial number of them did not fit the appropriate profile. In some time-in-service categories, nearly half the subjects had worse profiles than they reported (Walden et al., 1975).

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

The Causes of Impaired Hearing in the Military

It is of interest that the hearing impairments characterized by an H-2 profile can degrade speech communication. This is even more true of the fourth profile, which typifies the different H profiles, and is shown in Figure 4 (from Richards, 1973), which plots the intensities and frequencies of various speech components, at a conversational level of 60 dB. One can see that even with speech, much of the consonant area, especially the high-frequency area, and some of the third and all of the fourth vowel formant, H-2 profile interferes with a large portion of the vowel which includes all of the high-frequency consonants, and all of the initial and some of the second vowel formants. Therefore, an H-2 profile will lose most consonants, much of the formant area, and all formants above that.
Figure 4. Relative intensities and frequencies of various speech components. Typical U.S. Army "H" profiles are superimposed.

Table 9

Hearing Threshold Levels Typical of Army "H" ProfiLe

<table>
<thead>
<tr>
<th></th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
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<th>6000</th>
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<td>40</td>
<td>45</td>
<td>60</td>
<td></td>
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<tr>
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<td>26.5</td>
<td>38.5</td>
<td>47.5</td>
<td>54</td>
<td>64</td>
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<tr>
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<td>20</td>
<td>25</td>
<td>35</td>
<td>50</td>
<td>55</td>
<td>74</td>
</tr>
<tr>
<td>HLI</td>
<td>34.5</td>
<td>31</td>
<td>31.5</td>
<td>43.5</td>
<td>57.5</td>
<td>64</td>
<td>84</td>
</tr>
<tr>
<td>HLI</td>
<td>15</td>
<td>30</td>
<td>40</td>
<td>55</td>
<td>70</td>
<td>80</td>
<td>94</td>
</tr>
<tr>
<td>HLI</td>
<td>39.5</td>
<td>41</td>
<td>46.5</td>
<td>63.5</td>
<td>77.5</td>
<td>89</td>
<td>99</td>
</tr>
</tbody>
</table>

In Table 9, these typical H profiles have been plotted on a frequency of discriminable units in the auditory area. Key: X = mean, 90% critical intensities during speech, 90% lower portion of the chart. Accordingly, the H-1 profile would miss approximately 37% of the speech in the speech range. An individual with an H-2 profile would cause nearly 80% of the speech to be inaudible, while the H-3 profile would cause nearly 80% of the speech to be inaudible.

The reader should bear in mind that these estimates are intentional (60 dB) = "everyday" (65 dB) level of speech in a noise environment that are not always typical of military situations. Noise levels are considerably higher in combat conditions, but so, too, are the levels. In addition, the estimates resulting from Figure 1 will involve a filtering paradigm, and do not include the additional distortions from the distortion component. Because the distortion is relatively unobtrusive in high speech and noise levels, we can only assume distortion degradation will more than offset the benefits of better in combat-type situations.

Although most of the 3000 soldiers tested by Warden et al. had recognition scores within normal limits, the authors concluded that clinical tests in quiet were not good indicators of the type of speech resulting from high-frequency hearing loss. They observed that real-life situations involve moderate-to-intense levels of noise. Since a combatant real-life speech will not be as highly intelligible as the signal, nor will the listener be given the courtesy of hearing it correctly above his SRT. Warden and his colleagues concluded that combatants can communicate fairly well under ideal conditions, but may face great difficulties in the typical combat environment.
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.

The statement by Walden *et al.* (1975) indicates that many soldiers in the infantry and artillery branches need to be reassigned due to a more lenient profile. According to Aspinall and Wilson (1974), hearing conservation officers have suggested that the combat and bombardment units would suffer a debilitating manpower shortage if all personnel were evaluated according to their hearing loss along with the appropriate hearing conservation (p. 11). Clearly, the extent of hearing impairment in combat is still not clearly defined in the military in general, poses a significant problem. The existing system appears to be inadequate for effective communication, particularly, and the system itself is poorly enforced. The situation merits more attention in the form of rigorous hearing conservation programs. A thorough study of the specific communication needs of each branch and non-combatant personnel are assigned, and the resulting revision of existing schemes. The consequences of communication failures are extremely severe, ranging from mild inconvenience to loss of execution equipment and even loss of life.

**SUMMARY**

**1. Cause of Hearing Loss in Speech Recognition**

There is no doubt that noise-induced hearing loss acts as a handicap. There is still some debate on the extent to which distortions in the auditory system further degrades the ability to hear speech, but research appears to be a matter of degree of distortion rather than existence. This question has not been identified. There is also little doubt that the human ear, with a significant degree of the distortion components at some speech-to-noise ratios, perhaps up to 10 dB more than that of normal-hearing counterparts.

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

Investigations have shown that hearing-impaired subjects to the extent of bilateral hearing, but not as much as normal hearing.
the tasks of limited data, it appears that hearing loss may be more of a
minor difficulty in localizing sound than in the ability to identify the source
or trouble identifying the source of a sound in the environment.

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 refers to the 
handicap imposed by an impairment sufficient to interfere with a person's
ability to engage 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 the effects of
reverberation. Recent investigations of the "low bone" or point of hearing's
handicap indicate an average hearing threshold level values in the
frequencies 1000, 2000, and 3000 Hz. This is an "average" level
usually with varying amounts of background noise. The effect of each of this
situation 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 be higher.

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 a modified 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 be made to be smaller
for actual signal recognition than they are for pure tones.

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 applies 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 basis
for these standards, would be a helpful adjunct to any revision of the 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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