SPEECH DISCRIMINATION IN NOISE FOR LISTENERS WITH NORMAL HEARING AND LISTENERS WITH NOISE-INDUCED HEARING LOSS

by

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ABSTRACT

The present study investigates the effect of low-pass noise on the speech discrimination performance of 18 subjects with normal hearing and 18 subjects with noise-induced high-frequency hearing loss. W-22 word lists, low-pass filtered at 2000 Hz, were presented in sound field with a pink noise masker at three stimulus levels and three signal-to-noise ratios. Results indicated that the word discrimination performance of both groups deteriorated with increasing levels of noise and with increasing stimulus intensity levels, with the hearing-impaired group performing at a lower level throughout. While noise was shown to have a differential effect on the speech discrimination of the two groups, a satisfactory explanation of the effect, based on the study of Kiang and Moxon [Tails of tuning curves of auditory nerve fibres. Journal of the Acoustical Society of America, 1974, 55, 620-630] was not supported using the present experimental conditions.

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CHAPTER 1

1. INTRODUCTION

Patients with high-frequency noise-induced hearing loss frequently report difficulties understanding speech in a noisy environment yet experience little difficulty in a quiet listening situation. People with normal hearing, on the other hand, rarely report any such problems in quiet or noisy situations. Since patients with high-frequency losses have normal hearing through the range usually accepted as important for speech intelligibility (500 to 2000 Hz), it seems improbable that they should react differently to noise than do people with normal hearing. Nonetheless, several studies in the laboratory situation support their complaints. These studies have shown that word discrimination performance does deteriorate more rapidly in noise for subjects with high-frequency sensorineural hearing loss than for normal listeners. Few satisfactory explanations, however, have been given for this phenomenon.

One recent physiological study (Kiang and Moxon, 1974) does provide significant support for the complaints of these individuals. It proposes that neurons with a high characteristic frequency, available to normal listeners but absent in listeners with high-frequency hearing loss, may provide additional information on speech which aids discrimination in noise. The findings of this study provide a promising basis for the analysis of speech discrimination in noise.

The present study, therefore, was undertaken to determine whether noise does differentially affect the word discrimination performance of normal listeners and listeners with noise induced hearing loss, and if so, to provide a satisfactory explanation for this difference.

CHAPTER 2

2. REVIEW OF LITERATURE

2.1 THE EFFECT OF NOISE ON WORD DISCRIMINATION PERFORMANCE

Word recognition tests are commonly used by audiology clinics to assist in the differential diagnosis of various hearing impairments. Many individuals with high-frequency sensorineural hearing loss, however, show no decrease in performance on standard speech discrimination tests. The widely employed CID Auditory Test W-22 (W-22), when presented in quiet, has been shown to be of limited value in separating normal-hearing patients from those with auditory pathology (Carhart, 1965; Keith and Talis, 1972; Sher and Owens, (1974). Data published by Carhart (1965) on the word recognition scores of 170 hearing-impaired veterans tested with W-22 recordings, revealed that 60% achieved scores of 90% or better. In this case, the speech discrimination test had failed to identify either the presence, the type, or the extent of hearing loss in 60% of the patients. His findings were substantiated by Keith and Talis (1972) with clinical data from 170 of their patients with sensorineural hearing losses. Sher and Owens (1974), following subject criteria similar to that used in the present study, observed mean scores of 94.6% on the W-22 test for 35 listeners with normal hearing to 2000 Hz and high-frequency cochlear hearing losses. In the light of studies such as these, speech discrimination testing in quiet appears to be of little diagnostic value for many people.

Several studies have examined the diagnostic value of speech discrimination testing in the presence of noise. Simonton and Hedgecock (1953) used a mixture of white noise and two pure tones, 60 Hz and 112 Hz, with the Harvard Phonetically Balanced word lists (PB-50's), to study the effects of noise on normal and hearing-impaired subjects. They found no difference in the performance of listeners with normal hearing or with conductive hearing losses. Subjects with sensorineural hearing losses, however, showed increased loss of discrimination when tested in noise. Similar results were reported by Palva (1955) using a continuous white noise masker and a +10 dB signal-to-noise (S/N) ratio. Speech discrimination scores for his sensorineural-impaired listeners suffered "distinctly, and in some cases severely" (Palva, 1955, p. 240). Palva concluded that speech discrimination testing in noise might be useful in the diagnosis of perceptive (sensorineural) deafness. Ross et al. (1965), as part of a larger study, examined whether speech discrimination testing in white noise had any clinical utility. The absolute discrimination scores achieved by their hearing-impaired subjects were poorer than those of the normal-hearing subjects for both the quiet and noise conditions. However, the relative discrimination shift due to noise failed to show any significant differences between the two groups. Ross et al. (1965), suggested that the use of different kinds and sensation levels of noise could result in the desired differentiation of the groups.

Cooper and Cutts (1971) examined changes occurring in the slope of the articulation function with the introduction of noise. Northwestern University Auditory Test Number 6 (NU-6) was presented monaurally with cafeteria noise at S/N ratios of +5, +8, and +12 dB. Consistent with the previous studies, the mean performance of the sensorineural group was significantly poorer than that of the normal group. But, as found in Ross et al.'s (1965) data, the slopes of the articulation functions were not significantly different for the two groups.

In a study by Keith and Talis (1972), W-22 words were mixed with white noise in an attempt to provide a more definitive differential diagnosis of hearing impairments. Subjects with normal hearing, high-frequency cochlear losses, and flat cochlear losses were tested in quiet and at three different S/N ratios (+8, 0, -8 dB). As the S/N ratio decreased from 8 to -8 dB, the discrimination scores deteriorated and the difference in mean scores among the groups increased. The mean score of the normal-hearing group deteriorated approximately 52% from the quiet condition to -8 dB S/N ratio, the mean score of the group with high-frequency losses deteriorated approximately 57%, and the mean score of the group with flat losses deteriorated approximately 67%. These results indicated that speech discrimination testing in the presence of noise could help differentiate between patients with cochlear hearing impairments and normal listeners.

One striking finding common to all of these studies of speech discrimination performance in the presence of noise was the extreme variability among subjects, both normal and hearing-impaired. In a study of normal-hearing individuals, Rupp and Phillips (1969) found marked variability in individual performance, both in white noise and in speech-spectrum noise. One normal group tested in speech-spectrum noise at OdB S/N ratio actually demonstrated a range of 88% in individual performance. Simonton and Hedgecock (1953), Palva (1955), and Ross et al. (1965) noted wider variations in the scores of their sensorineural-impaired subjects than in their normal-hearing groups. Discrimination scores of the impaired group in Cooper and Cutts' (1971) experiment increased in variability with lower S/N ratios. At two of the S/N ratios tested, they demonstrated a range of scores twice that of the normal group. This led the authors to conclude that something more than a simple masking effect was operating to reduce the performance in noise of this impaired population. Keith and Talis (1972) found that the use of increasing levels of a white noise masker resulted in increasingly wider ranges of scores within all three subject groups. This finding made the diagnosis of a particular hearing impairment based on speech discrimination scores very difficult. Clearly, the variability introduced by the use of white noise with speech limited its diagnostic value.

In an interesting approach to this problem, Olsen et al. (1975) attempted to determine whether this variability of results, itself, could be diagnostically useful in differentiating kinds of hearing impairments. They presented NU-6 word lists in quiet and in white noise (OdB S/N ratio) to six groups of subjects including normal listeners and subjects with various types of auditory pathologies. Differences of 40% or more between scores in quiet and in noise were observed for fewer than 1% of the normal ears tested. Similar differences were found, however, for 8% of the ears with noise trauma (high-frequency loss) and 48% of the ears with Meniere's disease (flat loss). These findings concurred with those of Keith and Talis (1972). Olsen et al. (1975) concluded that a finding of a large difference in scores obtained under these conditions in quiet and in noise for either a normal listener or a listener with a high-frequency sensorineural hearing loss could be interpreted as indicating neural involvement somewhere in the auditory system. Therefore, results from speech-testing in noise could be useful in revealing abnormal auditory function ". . . but not in suggesting a particular site of involvement as being responsible for the dysfunction" (Olsen et al., 1975, p. 382).

In their concluding remarks, Keith and Talis (1972) maintained that speech-in-noise testing could only become diagnostically feasible if the variability of results could be reduced. They proposed altering the masking noise by using low-pass filtered noise as suggested by Liden (1967). Liden had stated that simultaneous presentation of word lists with a 500 Hz low-pass filtered white noise at a S/N ratio of -3 dB, made discrimination test results more sensitive diagnostically. He noted that in such a noise, the scores of patients with high-frequency sensorineural hearing losses and normal discrimination in quiet could drop to as low as 10 to 20%, while a normal-hearing individual maintained 90% intelligibility.

On the basis of Liden's suggestion, Cohen and Keith (1976) devised a study to determine whether normal and hearing-impaired subjects could be differentiated without increasing the variability of their scores. A 500 Hz, low-pass filtered white noise was mixed with taped W-22 word lists and presented monaurally to subjects with 1) normal-hearing, 2) high-frequency hearing loss, and 3) flat hearing loss. Speech discrimination performance was then measured in quiet and at -4 and -8 dB S/N ratios. Test results confirmed not only Liden's (1967) findings, but also the suggestion of Ross et al. (1965) that different types and sensation levels of noise could provide clearer differentiation of speech discrimination performance. While scores of the three groups were similar in quiet, the more negative the S/N ratio, the greater the separation of group scores. The low-pass noise provided a greater degree of separation of the groups than did the white noise employed in Keith and Talis's (1972) study. Type and level of continuous noise used as the speech masker, therefore, appears to be one of the critical factors in the differentiation of normal and hearing-impaired listeners.

Several recent studies have investigated the effects of other types of noise on speech discrimination performance. Carhart and Tillman (1970) measured discrimination for monosyllables against a background of competing sentences. Four groups comprising subjects with 1) normal hearing, 2) conductive losses, and sensorineural impairments with 3) good discrimination, and with 4) fair discrimination, were tested monaurally in a sound field. Northwestern University test 2 was presented in quiet and at four S/N ratios (+12, +6, 0, and -6 dB). Interference functions plotted from this data revealed that subjects with conductive losses performed as well as those with normal hearing when the sensation level of the signal was the same for both groups. Performances of both sensorineural groups, in contrast, were significantly disturbed by the competing sentences. Their interference functions were shifted 12 to 15 dB to the right of a reference function (plotted from previous normal data) as if the masking efficiency of the sentences had increased by 12 to 15 dB compared to that exhibited for the normal and conductive subjects. Carhart and Tillman (1970) suggested, therefore, that the presence of sensorineural hearing loss reduced the subject's ability to resist interference from the competing speech. They noted that a similar "overmasking" effect can occur when the competition is a spectrally complex steady-state noise but to a much lesser degree than that found with the competing sentences. Thus, traditionally used maskers such as white or speech spectrum noise might provide less satisfactory competition because they elicit less "overmasking".

The effects of modulated noise on the speech intelligibility of hearing impaired listeners was examined by Shapiro et al. (1972). They presented speech with continuous or modulated white noise monaurally under headphones at four

S/N ratios (-8, -12, -16, and -20 dB). The speech material was NU-6 monosyllabic words. Subjects with sensorineural losses performed poorly under all experimental noise conditions, especially in continuous noise. As in previous studies, the mean performance of this group was consistently lower than that of the normal-hearing group. Contrary to other findings, however, the slope for the normal-hearing subjects was considerably steeper with increasingly negative S/N ratios than that for the hearing-impaired subjects. The authors offered no explanation for this unusual finding. The difference in scores between their two subject groups was less than that found in Carhart and Tillman's (1970) study, a fact, they attributed to the different spectra of the interfering noises.

Finally, two studies by Findlay (1976), and Findlay and Denenberg (1977), compared the ability of normal and noise-exposed subjects to discriminate speech under difficult listening conditions. The noise-exposed group had normal thresholds to 2000 Hz with high-frequency sensorineural hearing losses. Findlay found significant differences between the groups on three speech discrimination tasks: PB-50 lists presented at 40 dB sensation level (SL), and W-22 lists presented at 30 dB SL in the presence of either speech-spectrum noise or "cocktail party" noise. The use of W-22 lists in cocktail party noise provided the greatest and most consistent differentiation between the two groups, in agreement with previous findings using competing speech as maskers.

In their continuation of this study, Findlay and Denenberg (1977) compared the performances of a group with normal hearing and two groups with high-frequency hearing loss: a younger group with predominantly noise-induced hearing loss and an older group with presbycusis and some noise exposure. Again, W-22 words were presented with competing cocktail party noise. Two test conditions were applied: one with words and noise unfiltered, the other with both words and noise low-pass filtered at 1800 Hz. This condition was to rule out any effects on speech discrimination performance resulting from differences in the high frequency sensitivity of the normals and the hypacusics. A -4 dB S/N ratio was employed. In the unfiltered condition, the discrimination performance of the normal listeners was significantly better than either hearing-impaired group. In the low-pass filtered condition, however, the younger, noise-exposed subjects achieved a significantly higher level of performance than did the normal-hearing group. Findlay and Denenberg (1977) ventured a possible explanation for this totally unexpected result: perhaps the normal listeners relied heavily on high-frequency cues to discriminate speech in noise and therefore encountered considerable difficulty when presented with only mid-frequency information. Listeners with limited high-frequency hearing, on the other hand, might have learned to make better use of their mid-frequency hearing and hence, adjusted more readily to the filtered condition.

Bilger et al. (1974, 1976) also found that sensorineural hearing loss does not always cause listeners to perform poorly in noise. Ten subjects with normal hearing and eighteen with moderate sensorineural hearing losses were tested in quiet and in noise for a consonant recognition task. This consisted of sixteen consonants paired with three different vowels in a consonant-vowel (CV) context. Ten lists of 96 syllables were then presented monaurally via headphones at 100 dB SPL with competing broad-band noise at 95 dB SPL. Upon introduction of the noise, the mean per cent recognition scores of the normal group dropped from 75% to 50%. Of the eighteen subjects with sensorineural hearing loss, however, nine demonstrated no adverse effect in noise and only four showed the drop seen in the normal group. Those with low performances in quiet tended to perform as well in noise as in quiet.

In their discussion of these findings Bilger et al. (1976) suggested that the ability to tolerate noise or to listen in noise is distributed independently of sensorineural hearing loss. It is only that people with hearing losses complain about it, whereas normal listeners do not. This remark certainly merits serious consideration. However, their observation that sensorineural hearing loss does not always result in decreased performance was based on results from subjects described simply as having "appreciable sensorineural loss" (p. 393). Neither the configuration nor the extent of their losses were detailed. They did note, however, that the subjects selected had discrimination scores not exceeding 76% on testing with W-22's, and had speech reception thresholds of 30 dB or better. Their subjects, therefore, probably represented a variety of degrees of sensorineural hearing loss including flat losses, and not solely the high-frequency configuration usually cited as demonstrating the greatest difficulties hearing speech in noise.

The study by Cohen and Keith (1976) discussed previously, concerning the effects of low-pass noise on speech discrimination testing, reported similar findings for subjects with flat hearing losses. These subjects gave consistently higher performances in the presence of noise than those with high-frequency hearing losses, achieving scores of 85.4% (at -4 dB S/N ratio) and 80.5% (at -12 dB S/N ratio) compared with the 70.5% and 55.4% scores of the latter group. Both levels of performance were lower than that of the normal-hearing group. Cohen and Keith (1976) then queried what effect the different overall sound pressure levels of speech and noise had on the discrimination scores of the groups. Since speech was presented at 40 dB SL, the words were presented at average levels of 64.4 dB SPL for the normals, 75.5 dB SPL for those with high-frequency losses, and 96.2 dB SPL for those with flat losses. To examine this question, a second experiment was devised in which five normal-hearing subjects were tested at levels equal to the levels presented to the flat-loss group in the first experiment. Word-recognition scores were obtained monaurally at -4 and -12 dB S/N ratios, with words presented at 96 dB SPL and noise at 100 and 108 dB SPL. Results showed that when speech and noise were presented at equal sound pressure levels, normal-hearing subjects had significantly poorer word-recognition scores (70.4% at -4 dB S/N ratio and 26.4% at -12 dB S/N ratio) than subjects with flat cochlear hearing losses. The similar findings in these two studies suggest that the results of Bilger at al. (1976) may have been due to the presence of persons with flat hearing losses in their subject group. However, as illustrated by Cohen and Keith's (1976) original experiment, subjects with high-frequency sensorineural hearing losses consistently showed the largest deterioration in performance in noise of the three groups. This group, unlike the group with unspecified sensorineural losses of the study of Bilger et al. (1976), did perform poorly in noise.

The results of these studies provide evidence that people with normal hearing and those with high-frequency sensorineural hearing loss do perform differently under speech discrimination tests in noise. This distinction is not a clear-cut one in view of the variability of results and the often conflicting findings documented. One fact that does emerge from these studies is that individual performance in noise cannot be predicted accurately on the basis of speech discrimination scores measured in quiet.

2.2. FACTORS CONTRIBUTING TO REDUCED SPEECH DISCRIMINATION IN NOISE

Reduced speech discrimination performance with the introduction of noise has been attributed to a number of factors. The two most obvious are the degree of sensorineural involvement of the listener and the masking effect of the noise which shifts the articulation function to the right of its position in quiet. Most theories proposed in the studies reviewed in the previous section revolve around some aspect of the interaction of these two variables.

Difficulties in speech discrimination among listeners with high-frequency sensorineural hearing losses are most commonly ascribed to reduced high-frequency sensitivity. As Bess and Townsend (1977) pointed out, the hearing loss effectively reduces or eliminates the audibility of the high-frequency consonant sounds necessary for word intelligibility. The frequencies required for the optimum understanding of speech, therefore, merit consideration.

French and Steinberg (1947) used various high- and low-pass filter conditions in a syllable discrimination task to determine the relative importance of different frequencies to discrimination. With each successive cut-off of the high-frequency portion of the spectrum, they found a progressive deterioration of syllable discrimination. Similar results were obtained upon rejection of the low frequencies. The range of frequencies either 1900 Hz and above or 1950 Hz and below each gave about a 69% correct score. In other words, the elimination of all frequencies, for example, above 1900 Hz would still leave approximately 70% of the syllables intelligible to a normal-hearing listener. Decreased discrimination under low-pass filtering conditions was also noted by Giolas and Epstein (1963). Their study demonstrated that the influence of frequency on discrimination was further modified by such variables as the familiarity and type of speech materials employed, the articulation characteristics of the speaker, and the quality of the recording.

Researchers could not agree upon the importance of frequencies above 2000 Hz in the understanding of speech. Several studies on noise-induced hearing loss attempted to relate auditory acuity at selected frequencies to speech discrimination ability. Quiggle et al. (1957), and later, Glorig et al. (1961) reported that thresholds at 500, 1000, and 2000 Hz were adequate for predicting the hearing and understanding of everyday speech. Although speech theoretically contains frequencies from 300 to 4000 Hz, its redundancy, they felt, made the contribution of the higher frequency information unnecessary. The same three frequencies were recommended for evaluation of impairment for purposes of compensation by the Committee on the Conservation of Hearing of the American Academy of Opthalmology and Otolaryngology (AAOO) (Lierle, 1959).

On the other hand, Mullins and Bangs (1957) found that speech discrimination scores correlated most highly with auditory thresholds obtained at 2000 and 3000 Hz. This led them to conclude "that these two frequencies are relatively more important for speech discrimination than are the other frequencies" (Mullins and Bangs, 1957, p. 154). In an excellent treatment of this issue, Kryter et al. (1962) suggested that test measures, such as those employed by Quiggle et al. (1957), and Glorig et al. (1961), tended to underestimate the importance of acuity at frequencies above 2000 Hz for understanding speech. Their use of "thresholds of intelligibility" rather than word intelligibility scores, spondees rather than phonetically balanced monosyllabic words

(PB's), and quiet, distortion-free test conditions did not adequately assess the ability to understand speech under actual day-to-day listening conditions. Hence Kryter et al. (1962) designed a study to determine the frequencies necessary for the understanding of speech under various conditions of noise and frequency distortion more closely resembling real everyday listening conditions. Seven groups of subjects with normal hearing and different degrees of noise-induced hearing loss took part in the experiment. Recorded phonetically balanced words and Harvard sentences were presented monaurally via headphones, both in quiet and in speech-spectrum noise at selected S/N ratios. The speech materials were low-pass filtered at 7000 Hz for some tests and at 2000 Hz for others. Test results showed that information in the speech frequencies above 2000 Hz made a significant contribution to the intelligibility of the sentences in the presence of noise even for subjects with very large losses in those frequencies. On the basis of their data, Kryter et al. (1962) found 2000, 3000, and 4000 Hz to be the most important frequencies for predicting the intelligibility of speech. In light of the AAOO recommendations and various other studies, however, they concluded that an average of the losses at 1000, 2000, and 3000 Hz for predicting the ability of hearing-impaired persons to understand everyday speech, would be a reasonably valid compromise.

Harris (1965), in his exploration of the effects of hearing loss upon the discrimination of mildly and severely distorted speech, also concluded that 1000, 2000, and 3000 Hz were the most important frequencies for understanding speech. Like Kryter et al. (1962), he argued that one rarely has the opportunity under normal listening conditions, to hear clearly articulated speech in quiet. He observed that

> . . . ordinarily . . . there is considerable masking noise, often the acoustics of the listening space are poor, the peaks of conversation occur during meal time, often the talker is smoking, chewing gum, or at least talking with slovenly vocal gesture . . . (Harris, 1965, p. 830).

In an earlier paper, Harris (1960) demonstrated how mild sources of distortion, taken individually, may reduce intelligibility only slightly, but, when combined may result in a drastic deterioration of intelligibility. In the 1965 study, he reasoned that if a patient's audiogram could be considered a type of distortion, then an audiometric defect, irrelevant to the understanding of normal speech, may exert a pronounced effect on even mildly distorted speech. Accordingly, he conducted discrimination tests on 52 subjects with sensorineural hearing loss, using sentences distorted by 1) speakers wearing nose clamps, 2) speed, 3) interruptions, and 4) reverberations (Harris, 1965). The mean score from these four conditions was averaged with the score for undistorted speech to create "50% distorted speech," a condition assumed to approximate everyday listening. As previously stated, the three frequencies found to correlate most highly with this condition were 1000, 2000, and 3000 Hz.

That frequencies above 2000 Hz do play an important role in the perceptibility of speech was given further support in a paper by Sher and Owens (1974). They discovered that individuals with normal hearing to 2000 Hz accompanied by a high-frequency loss do have difficulty identifying a substantial number of phonemes as compared to normal listeners. Consideration of these findings along with the reports of difficulties experienced in hearing distorted speech (Harris, 1965), and speech in noise (Kryter et al., 1962) indicates, in the words of Sher and Owens (1974), "that the problems these people often complain of are real" (p. 678).

Findlay (1976) and Findlay and Denenberg (1977) advanced the theory that decreased speech discrimination among subjects with noise-induced hearing loss above 2000 Hz may be partly due to undetected midfrequency auditory dysfunction. Using fixed-frequency Bekesy audiometry, Findlay found that this group consistently demonstrated separation of the continuous and pulsed-tone tracings at 2000 Hz, indicating the presence of cochlear dysfunction. No such separation was found in the normal group. Findlay and Denenberg (1977) then evaluated speech discrimination performance in noise with the signal low-pass filtered at 2000 Hz, to determine if auditory dysfunction at frequencies less than 2000 Hz was contributing, in fact, to the discrimination difficulties. The results, reviewed in the previous section, revealed that the noise-exposed listeners performed at a higher level than did the normal listeners. There was no evidence that subtle mid-frequency cochlear dysfunction was hampering the discrimination performance of this group. Findlay and Denenberg (1977) concluded that:

> . . . the complaint of noise-exposed listeners that they experience undue difficulty discriminating speech in the presence of competing noise appears to be wholly attributable to the loss of high-frequency sensitivity (p. 257).

Some researchers believe that a possible secondary factor in the decreased discrimination performance of listeners with high-frequency sensorineural hearing loss, is the occurrence of an upward spread of masking. Bess and Townsend (1977) suggest that ". . . the better hearing in the lower frequencies causes a masking effect on important high-frequency cues" (p. 232). Danaher and Pickett (1975) noted that if a low-frequency sound is presented at a high intensity level, it will produce masking that reduces the audibility of sounds in the higher frequency regions. Interest in this concept increased when research by Jerger, Tillman, and Peterson (1960), and Rittmanic (1962) suggested that listeners with sensorineural impairment exhibit a greater spread of masking than do normal listeners. Perhaps then, this could help explain the differential discrimination performance of normal and hearing-impaired listeners in noise.

A recent study by Leshowitz (1977) attempted to relate tonal masking to this same problem. He found that masked speech intelligibility thresholds for subjects with noise-induced hearing loss or presbycusis, were approximately 10 dB higher than those found for normal listeners. Pure-tone masking patterns were then measured. As much as 30 dB more upward spread of masking was revealed for the group with high-frequency hearing loss than for the normal group. In light of the strong positive relationship between the masked speech intelligibility threshold and the upward spread of masking, Leshowitz suggested that the masked threshold could be used to predict speech perception handicap in noise.

Results of a study by Martin and Pickett (1970), however, failed to support the idea of increased upward spread of masking in sensorineural listeners suggested by previous studies. Instead they found similar amounts of masking spread in both their normal-hearing subjects and in those with various degrees of hearing impairment. Within the sensorineural group they noted marked differences in masking spread, leading them to conclude:

> . . . Sensorineural subjects, as a group, cannot be described as characteristically showing either greater than normal or less than normal upward spread of masking (Martin and Pickett, 1970, p. 436).

Consideration of upward spread of masking, therefore, as a possible contributing factor to decreased discrimination in noise, should be viewed with caution.

These factors can supply at best a partial explanation of why listeners with high-frequency sensorineural hearing loss experience such difficulties understanding speech in noise.

2.3. PHYSIOLOGICAL BASIS

One important physiological study (Kiang and Moxon, 1974) does support the complaints of people with high-frequency hearing loss. In detailed studies of cats, they discovered that neurons with high characteristic frequencies (CF) also carry considerable information concerning stimuli in the speech-frequency region. Previous research (Bekesy, 1960) had suggested that the entire cochlear partition including the high-frequency basal region, may respond to low-frequency stimuli if presented at sufficiently high intensity. Support for Bekesy's suggestion may be found by examination of the tuning curve of an auditory nerve fibre. The typical tuning curve of a neuron with a high CF consists of a sharp tip in the low threshold region at the CF and a long broad tail in the high threshold region extending into the low frequencies. This neuron will be most sensitive to stimuli whose frequencies fall near its CF. However, presentation of a low-frequency stimulus at a suitably high intensity level may also activate the neuron via its low-frequency tail. Kiang and Moxon (1974) hypothesized that as these high CF neurons are broadly tuned throughout the speech frequencies, they could make a valuable contribution to the understanding of speech.

In a quiet situation, most of the information in speech is carried by neurons with CF in the speech region. This information is expressed in terms of the discharge rates associated with the phonetic elements of the speech stimulus, and in terms of the synchrony of firing of these discharges with the acoustic waveform of the stimulus. If a listener has normal hearing in the speech frequencies, he should have no difficulties hearing speech clearly in quiet. With the introduction of noise, however, the information on discharge rates carried by the speech frequency neurons, is eliminated. This leaves only the information regarding the synchronous firing of these neurons. In individuals with normal hearing, extra cues are still available in information carried by the high CF neurons. Provided the speech signal is sufficiently intense to activate these neurons, they will carry the needed information on the rate of discharge and make the speech signal more intelligible. This additional information is not available to listeners with high-frequency hearing losses. Hence, while speech intelligibility in noise remains high for normal-hearing individuals, it deteriorates for those with high-frequency losses due to the absence of this extra cue.

The results of Kiang and Moxon's (1974) study have implications for the examination of noise effects on the speech discrimination performance of normal-hearing and high-frequency impaired subjects. They suggest that as the intensity of a speech stimulus is increased beyond that level at which responses from the high CF neurons are elicited, the difference between the performance of the two groups should become more marked. This would be noted particularly if the discharge rate information of the low CF neurons was abolished through the introduction of noise. Kiang and Moxon (1974) also demonstrated that with presentation of either wide-band noise or narrow-band noise centered around the CF, the entire tuning curve of a high CF neuron is elevated in threshold. This interference with the threshold of excitation of the neuron would result, therefore, in less differentiation in the performance of the two groups. On the other hand, with presentation of a low-frequency noise, only the tip of the tuning curve is elevated, leaving the threshold of the broad tail unaffected. These findings are consistent with the results of Keith and Talis (1972), Cohen and Keith (1976), and Liden (1967) which found that the use of low-pass noise improves the diagnostic effectiveness of speech discrimination measures in separating normal listeners from those with high-frequency sensorineural hearing loss.

CHAPTER 3

3. OBJECTIVES

The masking effect of noise on the intelligibility of speech in individuals with high-frequency sensorineural hearing loss remains a controversial issue. Information gained from past studies has been incomplete, sometimes contradictory, and difficult to integrate into a clear picture of the problem. Moreover, no adequate explanation has yet evolved for the differential effect of noise on speech intelligibility if indeed such an effect exists. The findings of Kiang and Moxon (1974) provide a promising physiological framework on which to base a systematic study of the issue. Their data, while compatible with clinical observations, were obtained from cats. The present study attempts to determine whether their findings hold for human subjects as well.

The objectives of this experiment are as follows:

1) To determine whether masking noise does differentially affect the speech intelligibility of subjects with normal hearing and subjects with high-frequency sensorineural hearing losses.

2) If it does, what is the explanation?

3) To test whether Kiang and Moxon's findings can be verified with human data.

CHAPTER 4

4. METHOD

4.1. DESIGN

The study has a two by three by three factorial design. The independent variables consist of:

1) two subject groups: Normals and Patients with high-frequency, noise-induced hearing loss,

2) three stimulus levels: 60, 70, and 80 dB SPL, and

3) three S/N ratios: +5, +12, and +19 dB.

The dependent variable is the word discrimination score (WDS).

4.2. SUBJECTS

Eighteen men with normal hearing and eighteen men with high-frequency sensorineural hearing losses served as subjects. The groups were designated N and P respectively.

The N group consisted of twelve employees from the Workers' Compensation Board of British Columbia (W.C.B.), and six students from the University of British Columbia. All were in good health with no known histories of either ear pathology or prolonged noise exposure. Auditory thresholds for this group were better than 25 dB HL (ANSI 1969) at the octave frequencies from 250 to 8000 Hz in the better ear. Their ages ranged from 22 to 37 years (mean age -- 28.6 years).

The P group was composed of eighteen patients from the Hearing Branch Clinic of the W.C.B. As in the N group, subjects were healthy with no known history of middle ear pathology. All P group subjects, however, had extensive histories of prolonged noise exposure of industrial origin. Case histories and audiological evaluations conducted by W.C.B. audiologists confirmed that each patient had a high-frequency cochlear hearing loss with no evidence of retro-cochlear involvement. The original selection criteria called for auditory thresholds no greater than 25 dB HL from 250 to 2000 Hz, and no less than 60 dB HL at 4000 Hz in the better ear. Time restrictions and the shortage of suitable subjects, however, necessitated a modification of the criterion regarding 2000 Hz to allow thresholds up to 35 dB HL. A total of eight subjects were included on the basis of the modified criterion. The effect of this change on the results of the study will be considered in a later section. Patients were also to be further categorized on the basis of the severity of their hearing impairments at 4000 Hz, into mild, moderate, and severe classifications. As all but one subject (moderate) fell into the mild class (60 to 75 dB HL threshold at 4000 Hz), this further breakdown scheme was abandoned. Ages of the P group subjects ranged from 37 to 84 years (mean age -- 57.2 years).

The mean pure-tone thresholds of the two subject groups are presented in Table 1, and diagramatically in Figure 1.

4.3. STIMULI

4.3.1. Description

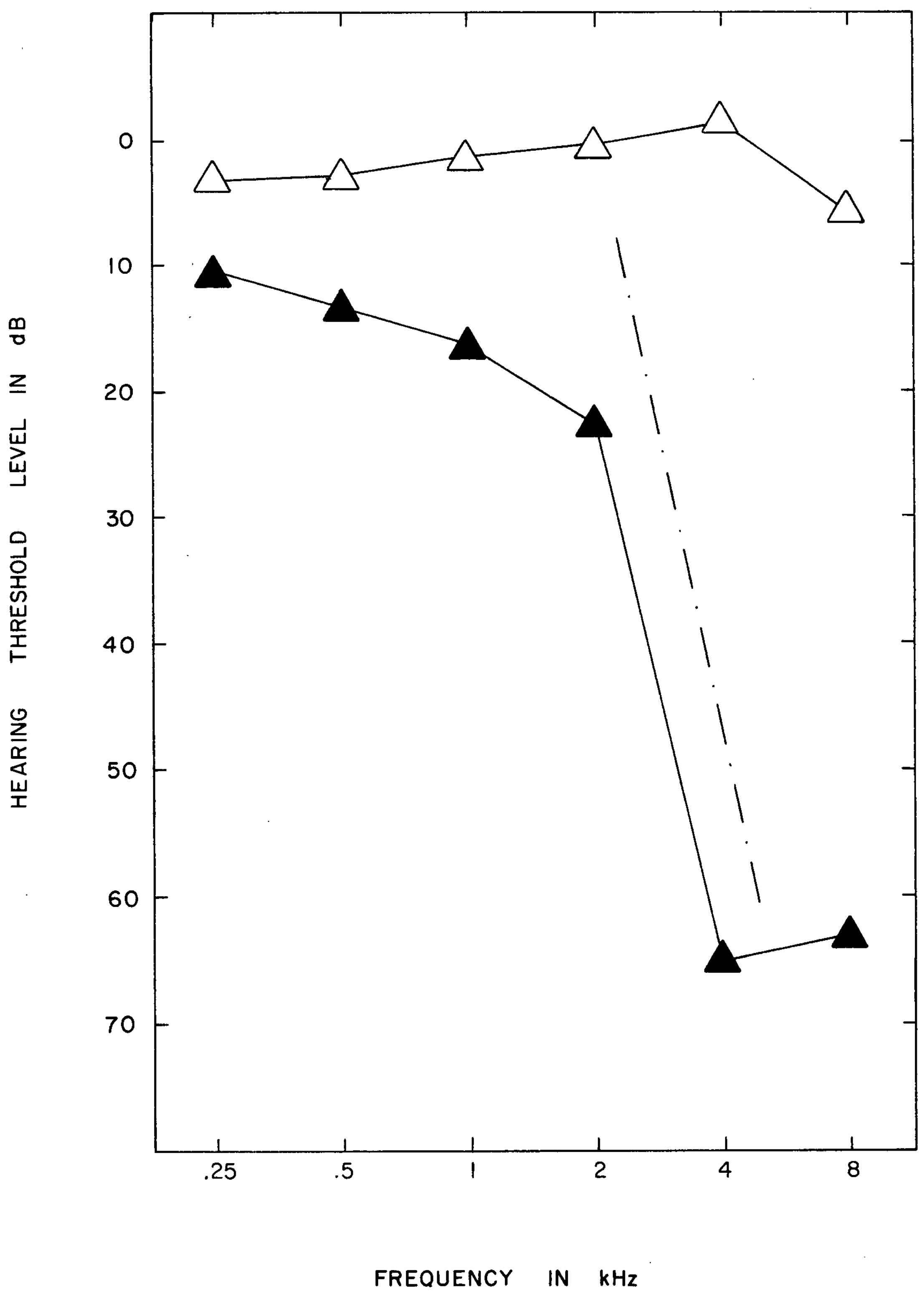
Taped recordings of CID Auditory Test W-22 were presented simultaneously with pink noise to compare the WDS's of the two groups. Subjects were assigned to one of three stimulus level groups, each consisting of six N's and six P's. For each subject, the speech stimuli then were presented at a constant intensity level while the noise level was varied to produce the required S/N ratios of +19, +12, and +5 dB. A preliminary sample of subjects had led to the establishment of this range of S/N ratios to allow a broad spread of performance.

Inasmuch as 500 Hz is important in speech and is less affected by noise exposure and presbycusis than other speech frequencies, the pure-tone threshold at 500 Hz was selected as the reference for the stimulus level. Within each of the stimulus-level conditions a certain amount of allowance was given to the subjects depending on their 500 Hz thresholds.

Table 1. Means and ranges of pure-tone thresholds of the Normal group and the Patient group at the test frequencies.

		HEARING THRESHOLD LEVELS (ANSI 1969)					
SUBJECT GROUP		250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Normals:							
	Mean	3.05	2.78	1.39	.28	-1.67	5.56
	Range	-5 - 10	-10 - 10	-10 - 10	-10 - 10	-10 - 20	-10 - 25
Patients:							
	Mean	10.27	13.33	16.11	22.5	65	62.77
	Range	0 - 20	0 - 30	5 - 30	5 - 35	50 - 85	35 - 100

Figure 1. Mean pure-tone thresholds in dB HL (ANSI 1969) of the Normal group (△) and the Patient group (▲) at the test frequencies. Also shown is the slope of the skirt of the low-pass filter used to process the speech stimuli and noise (__ . __).


HEARING THRESHOLD LEVEL IN dB
0
10
20
30
40
50
60
70
.25
.5
1
2
4
8
FREQUENCY IN kHz

Subjects with a threshold of 10 dB HL or more were given 10 dB more in stimulus level; e.g., a subject in the 60 dB group with a threshold of 15 dB at 500 Hz was actually presented a stimulus level of 70 dB SPL. Subjects with a threshold of 5 dB HL at 500 Hz were given a 5 dB allowance. Subjects with 0 dB HL or less at 500 Hz were given no allowance. While efforts were made, therefore, to accommodate individual variations in threshold, it was necessary to establish a ceiling level to avoid overlap with the succeeding stimulus level group. Any subject with a 500 Hz threshold exceeding this limit was assigned a compromise threshold level of 10 dB HL for the purposes of the experiment.

The three stimulus levels, 60, 70, and 80 dB SPL were chosen in an attempt to traverse the approximate threshold region of excitation of the high CF neurons. In this region, a marked differentiation in the performance of the N and P groups should appear. Data from Kiang and Moxon's (1974) study, obtained from cats, indicated that activation of these high CF neurons by low frequency stimuli occurred at intensity levels of 50 to 80 dB SPL. In the present study, the lowest level, 60 dB SPL, also corresponds to the region of quiet conversational speech. The highest level, 80 dB SPL, corresponds to very loud speech such as that found when conversing in a noisy environment. If the excitation of the high CF neurons does play an important role in assisting speech intelligibility in noise, it logically should occur within this stimulus intensity range.

A different 50-word list was presented at each S/N ratio. The same three lists, 2-E, 3-A, and 4-A were used for all subjects, however, the particular combination of list and S/N ratio was varied systematically from subject to subject, to avoid bias due to any possible variations in the difficulty of the tests. Fifty-word lists rather than the more commonly employed half-lists of 25-words were used on the basis of findings by Chaiklin (1968), and Keith and Talis (1972). According to Keith and Talis (1972), unpublished data reported by Chaiklin at the 1968 A.S.H.A. convention indicated that half-list scores, although reliable for normal listeners, were unreliable with hearing-impaired listeners due to the variability of their responses. Keith and Talis (1972) also found poor correlation between half-list scores for their patients with sensorineural hearing losses. Moreover, as the noise level of the masker was increased, this correlation grew even poorer. They concluded, therefore, that use of half-lists with a sensorineural population might result in a spurious score that could not be reproduced in a retest situation.

The word-lists were passed through a low-pass filter with a cut-off at 2000 Hz. This was to ensure that any real differences noted in the speech discrimination performances of the two groups were not due to their inequality in thresholds in the high frequencies. Figure 1 shows the similarity between the slopes of the filter (48 dB/octave) and the P subjects' audiograms between 2000 and 4000 Hz. Similar use of filtered speech tests to compare the performance of normal hearers and subjects with sensorineural hearing loss were reported by Sher and Owens (1974), Cohen and Keith (1976), and Findlay and Denenberg (1977).

The pink noise used as the masker in the study was also low-pass filtered at 2000 Hz. As noted earlier, Kiang and Moxon (1974) found that low-pass noise kept the excitation threshold of the tail of high CF neurons low so as to give a greater differentiation of scores between the two groups.

4.3.2. Preparation of Stimulus Tapes

One master tape was prepared with the filtered word-lists on track 1, and filtered pink noise on track 2. From this master, three cassette tapes were made, each with a different ordering of the lists, for use in the actual test situation.

Records containing lists 2-E, 3-A, and 4-A of CID Auditory Test W-22 were played on a BSR 710 turntable. From there the signal was passed through a Marantz 2215 amplifier, and then through a Rockland Programmable Dual Hi/Lo Filter with a low-pass cut-off frequency of 2000 Hz. Two filters were connected in cascade to give a filter slope, above the cut-off frequency, of 48 dB per octave. The filtered output was then taped by means of a Revox A77 tape recorder, directly onto track 1 of the master tape. The test words were recorded so that their intensity peaked at 0 dB on the VU meter.

Pink noise, generated by a random noise generator (General Radio Corporation, Model 1382), was similarly processed through the low-pass filtering system and recorded on track 2 of the master tape.

Three cassette tapes were produced from the original master. A Sony Stereo Cassette-Corder (model TC-158 SD) incorporating a Dolby B noise reduction system, was used to record the taped speech stimuli and noise onto Memorex ATC cassettes. A 30-second silent interval was inserted between each list on the cassettes.

4.4. EQUIPMENT

All experimental testing was conducted in a sound-treated test suite (Tracoustics, Model RS Z52) at the Hearing Branch of the W.C.B. in Richmond, B.C. The physical arrangement of the test room positioned the subject's head equidistant between two side speakers (Madsen FF72) placed in opposite corners of the room. Directly in front of the subject, at a distance of 1 meter, was a centre loudspeaker (Madsen FF74).

The test tape, with its separate tracks for word lists and noise, was introduced into a Madsen audiometer, Model OB70, by means of an Akai dual-channel tape recorder, Model GXC-740D. The word lists were routed through channel 1 of the audiometer and presented to the subject via the centre loudspeaker. Similarly, the noise was routed through channel 2 of the audiometer and presented via the two side speakers.

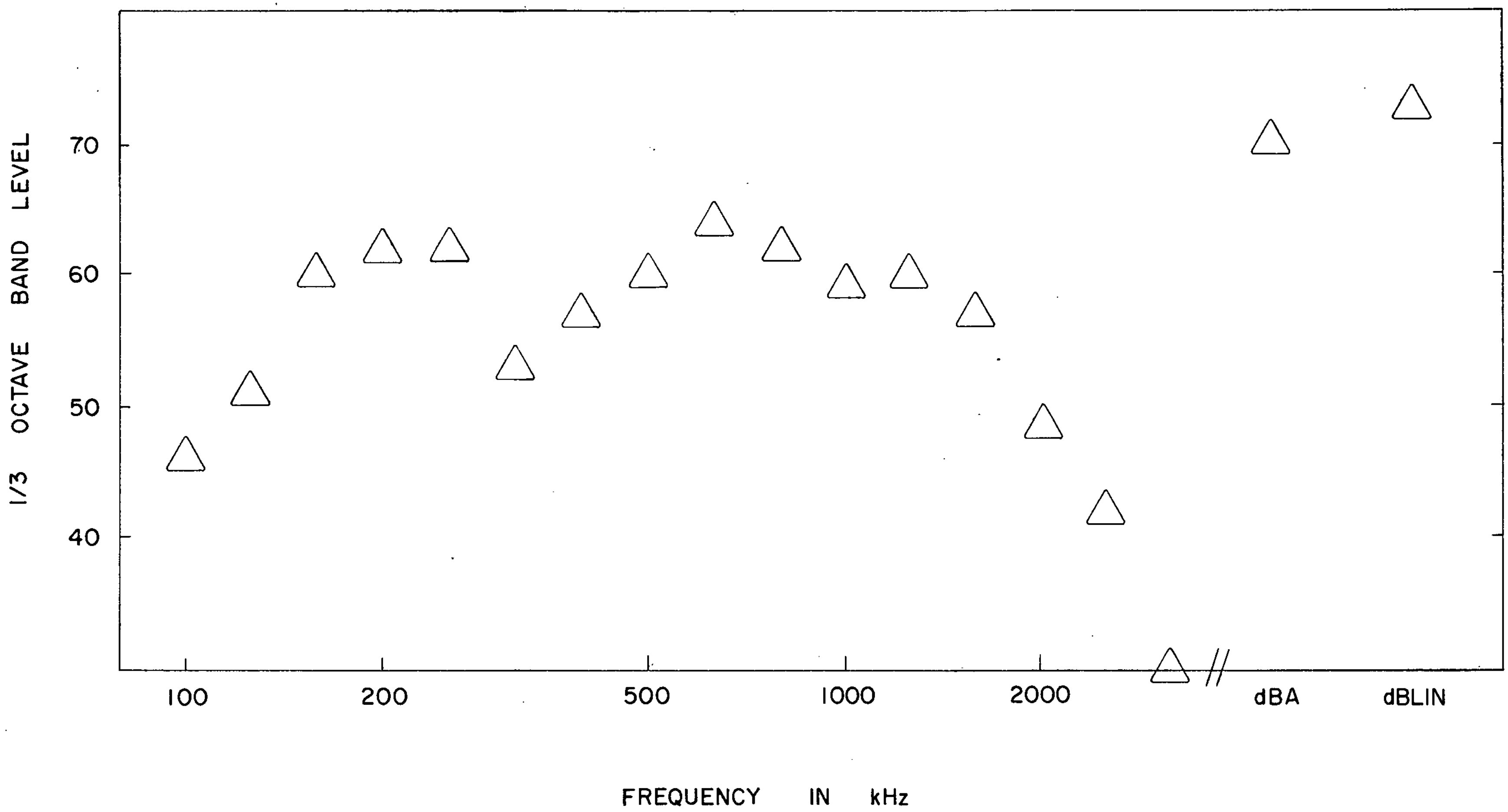
Equipment calibration was checked periodically with a Bruel and Kjaer (B and K) sound level meter, Model 2204. A half-inch microphone equipped with nose cone (B and K Model 4165) on a 1 meter tripod, was placed at the position to be occupied by the subject's head, but with the subject absent from the field. It was connected to the sound level meter, located outside the test room. Speech and noise signals were calibrated separately. The intensity level of the incoming taped signal was adjusted to peak at zero on the VU meter of the audiometer. Then the output signal, either speech or noise from their respective speakers, was picked up by the microphone and measured by the sound level meter. The audiometer settings required to produce the desired S/N ratios were then recorded.

The acoustic spectrum of the pink noise was measured by a third octave spectrometer (B and K, Model 2114), in conjunction with a graphic level recorder (B and K, Model 2307). The third octave spectrum of this noise is presented in Figure 2.

4.5. PROCEDURE

Subjects were seated on a chair maintained in a fixed position in the sound-treated chamber. Both the noise and the word lists were presented at the required intensity levels to produce S/N ratios of +19, +12, and +5 dB in that order. The subjects were familiarized with the task and instructed to repeat the word heard. They were encouraged to guess if they were not sure of the correct response. Responses were scored by the examiner in the standard manner: the entire word had to be accurately identified to be marked as correct. The administration of the entire test took approximately thirteen minutes.

Figure 2. The one-third octave band analysis of the pink noise masker measured at the ear-level of the subject in position in the test booth.


1/3 OCTAVE BAND LEVEL
70
60
50
40
100
200
500
1000
2000
dBA
dBLIN
FREQUENCY IN kHz

CHAPTER 5

5. RESULTS

The results of the experiment are summarized in Tables 2 and 3 for the N and P groups respectively. These tables report the means, ranges, and standard deviations of scores obtained by the two groups under the different experimental conditions. In addition, Figures 3 and 4 show the WDS's plotted as a function of the experimental conditions. Figure 3a shows the WDS's obtained by the N group, and Figure 3b shows the WDS's obtained by the P group, under the nine possible combinations of stimulus level and S/N ratio. Figure 4 presents another view of the same data, with the WDS's obtained by both groups at the three S/N ratios at stimulus levels of 60 dB (4a), 70 dB (4b), and 80 dB SPL (4c). In these figures, the data points represent the mean WDS's under each condition while the lines indicate the regression functions for each stimulus level.

Examination of the data for both subject groups reveals a decrease in performance with increasing noise. The highest mean scores of the N group were obtained at a stimulus level of 60 dB, with successive decreases in mean scores at the 70 and 80 dB stimulus levels. The P group, on the other hand,

Table 2. Means, ranges, and standard deviations of Word Discrimination Scores for 18 Normal subjects.

STIMULUS LEVEL	S/N RATIO	MEAN	RANGE	STANDARD DEVIATION
	+ 5	57.67	42 - 76	12.98
60 dB	+12	79.00	72 - 86	6.29
	+19	83.33	74 - 88	5.47
	+ 5	55.00	50 - 66	6.42
70 dB	+12	67.67	48 - 82	12.48
	+19	79.67	74 - 90	5.99
	+ 5	48.00	44 - 52	2.83
80 dB	+12	64.00	46 - 76	12.07
	+19	75.00	66 - 84	6.90

Table 3. Means, ranges, and standard deviations of Word Discrimination Scores for 18 Patients with high-frequency hearing loss.

STIMULUS LEVEL	S/N RATIO	MEAN	RANGE	STANDARD DEVIATION
	+ 5	41.67	34 - 46	4.27
60 dB	+12	62.67	50 - 74	9.69
	+19	76.00	64 - 90	11.38
	+ 5	45.00	28 - 64	14.85
70 dB	+12	58.67	44 - 82	13.59
	+19	81.67	76 - 90	6.12
	+ 5	37.67	30 - 50	7.42
80 dB	+12	52.67	28 - 62	12.75
	+19	67.67	58 - 76	7.94

Figure 3. Mean WDS's of the a) Normal group (open symbols), and b) Patient group (closed symbols) at 3 S/N ratios for stimulus levels of 60 dB (triangles), 70 dB (circles), and 80 dB (squares). The regression lines of WDS's versus S/N ratios for each stimulus level are represented by ____ for the 60 dB group, - - - - for the 70 dB group, and __ __ for the 80 dB group.

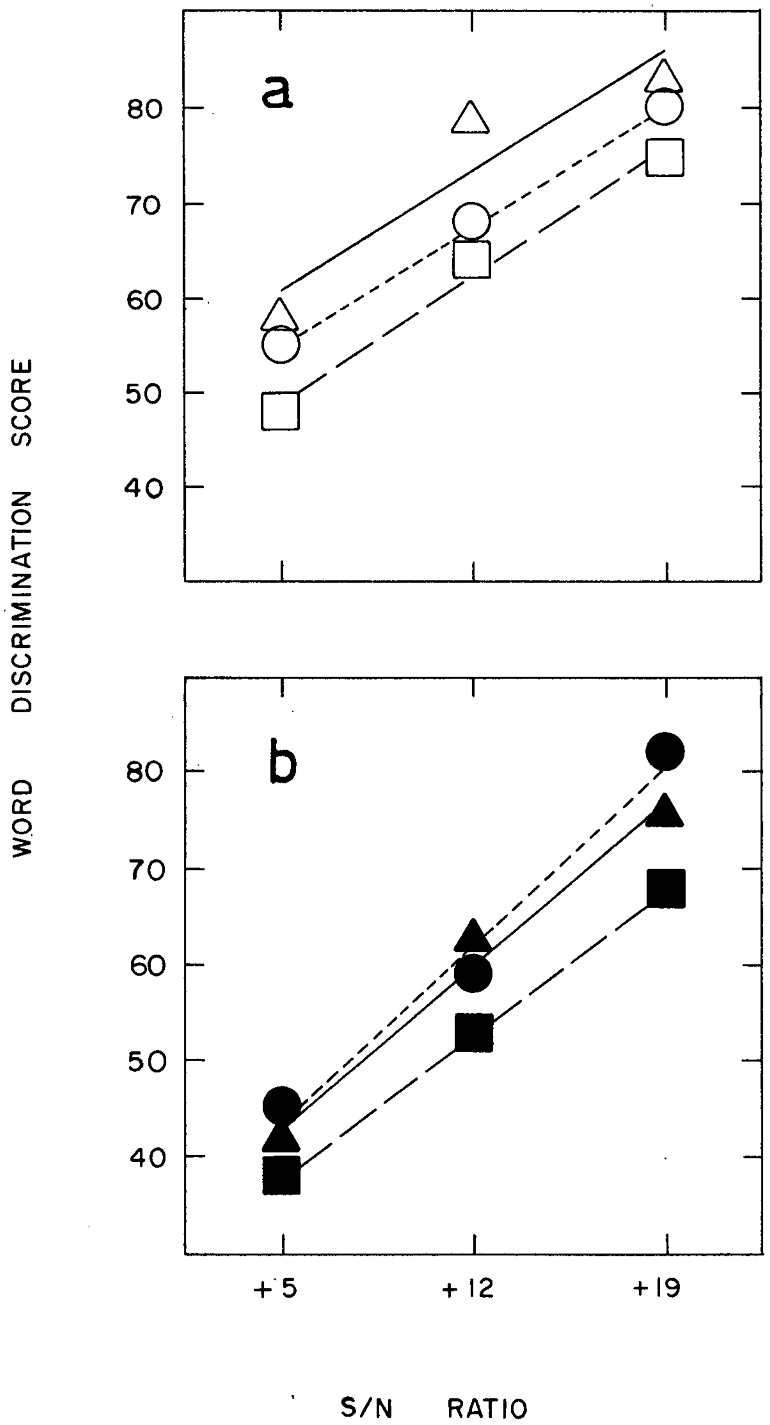
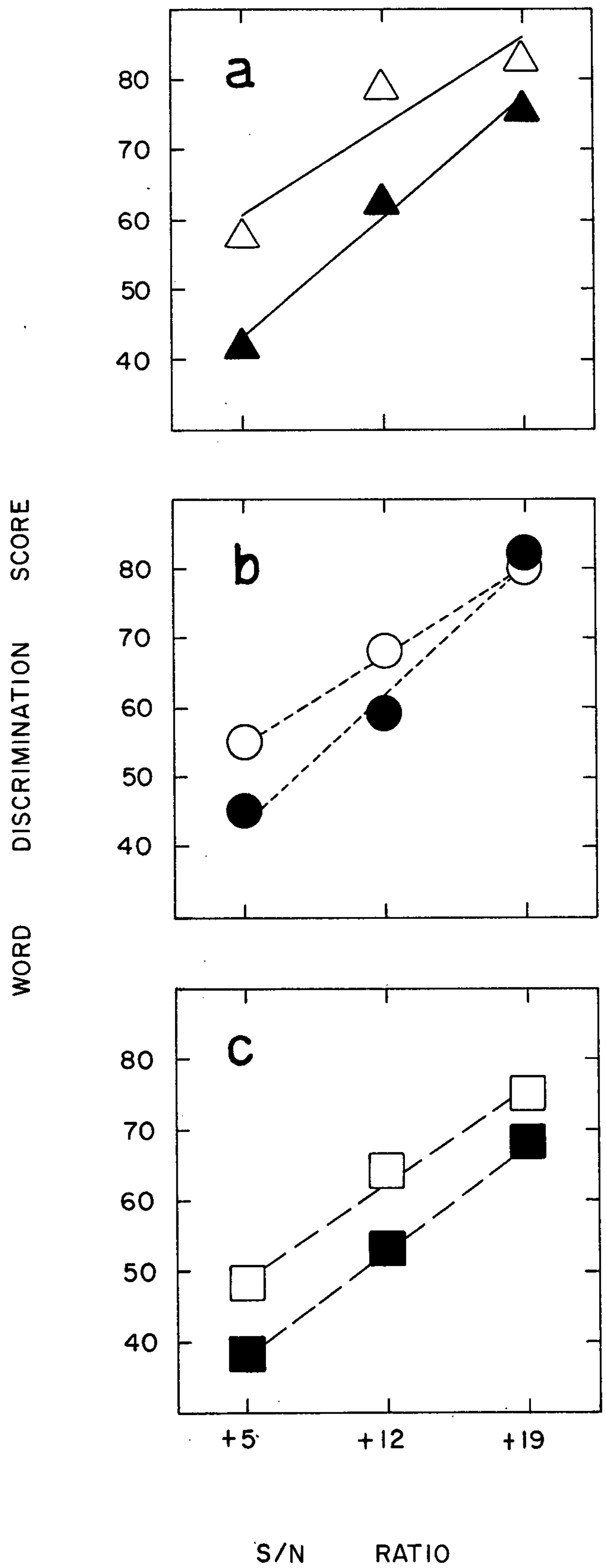

a
b
80
70
60
50
40
+5
+12
+19
WORD DISCRIMINATION SCORE
S/N RATIO

Figure 4. Mean WDS's of the Normal and Patient groups at 3 S/N ratios for stimulus levels of a) 60 dB, b) 70 dB, and c) 80 dB. Symbols and regression lines as defined in Figure 3.


a
b
c
80
70
60
50
40
WORD DISCRIMINATION SCORE
+5
+12
+19
S/N RATIO

obtained their highest mean scores at the 60 and 70 dB stimulus levels with a decrease in performance at the 80 dB stimulus level. The overall mean WDS's of the P group were consistently inferior to those of the N group with one notable exception at a stimulus level of 70 dB with a +19 dB S/N ratio. In this condition, the P group achieved a mean WDS of 81.67%, 2% higher than the 79.67% score achieved by the N group.

The slopes of the mean regression functions plotted in Figures 3 and 4 are summarized in Table 4. These slopes represent the regression of the mean WDS's achieved by the N and P groups at the three S/N ratios for stimulus levels of 60, 70, and 80 dB SPL. Again, the slopes of the P group were consistently steeper than those of the N group at all three stimulus levels.

The raw WDS's of the two groups were subjected to an analysis of variance appropriate for a three-factor experiment (subject group, S/N ratio, and stimulus level). A summary of this three-way analysis is presented in Table 5. Results indicated that significant differences existed between the discrimination performances of the N and P groups ($p < .01$). Significant differences were also noted among WDS's achieved at the three S/N ratios ($p < .01$), and at the three stimulus levels ($p < .01$). A borderline case of interaction was noted

Table 4. Slopes representing the regression functions of the mean Word Discrimination Scores achieved by Normal and Patient groups versus the 3 S/N ratios at the 3 stimulus levels.

	STIMULUS LEVELS		
SUBJECT GROUP	60 dB	70 dB	80 dB
Normals	1.79	1.79	1.93
Patients	2.43	2.64	2.14

Table 5. Summary of 3-way analysis of variance of the results of the present study.

SOURCE OF VARIANCE		SUMMARY OF ANALYSIS OF VARIANCE				
		SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	$p < .01$
A	Subjects	2,446.26	1	2,446.28	26.94	Yes
B	S/N Ratios	15,974.89	2	7,987.45	87.96	Yes
C	Stimulus Levels	1,680.89	2	840.45	9.26	Yes
AB		378.74	2	189.37	2.09	No
AC		257.18	2	128.59	1.42	No
BC		295.55	4	73.89	.81	No
ABC		69.49	4	17.37	.19	No
Within Cell		8,172.67	90	90.81		
TOTAL		29,275.67	107			

between the factors of subject group and S/N ratio. This was investigated further by a second statistical treatment of the data.

A two-way analysis of variance was performed using the slope of the regression function of the raw WDS's versus the three S/N ratios as the dependent variable. The two independent variables were the subject groups and the stimulus levels. The results of this analysis, summarized in Table 6, revealed a significant difference between the slopes of the regression functions of the two groups ($p < .05$). This suggests that the speech discrimination of the two groups was differentially affected by noise level.

Table 6. Summary of 2-way analysis of variance of the results of the present study.

SOURCE OF VARIANCE	SUMMARY OF ANALYSIS OF VARIANCE				
	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F	p .05
A Subjects	2.861	1	2.861	6.07	Yes
B Stimulus Levels	.147	2	.0735	.16	No
AB	.637	2	.3185	.68	No
Within Cell	14.139	30	.4713		
TOTAL	17.784	35			

CHAPTER 6

6. DISCUSSION AND CONCLUSIONS

The results of the experiment support the findings of previous studies that noise does differentially affect the WDS's of people with normal hearing and those with high-frequency, sensorineural hearing loss. The mean WDS's of the P group in noise consistently fell below those of the N group with the exception of a high P score at 70 dB with a S/N ratio of +19 dB. The steeper slopes of the regression functions of the P group were shown to be significantly different from those of the N group. Noise, therefore, did have a more devastating effect on the discrimination performance of the hearing-impaired group.

The differential performance of the two subject groups was not, however, as marked as that found in earlier studies, notably that of Cohen and Keith (1976). They achieved a separation of mean WDS's between their normal-hearing and high-frequency loss groups of 24.3% at -4 dB S/N ratio and 37% at -12 dB S/N ratio. The maximum separation achieved in the present case was approximately 16% at S/N ratios of both +12 and +5 dB at the 60 dB stimulus level. Aside from differences in S/N ratio, one of the reasons for this reduced separation could be the different stimuli used in the two studies. In Cohen and Keith's study, the stimuli were unfiltered CID W-22 word lists, whereas in the present study, filtered W-22 word lists were employed. The normal-hearing subjects of the former study had, therefore, all the high-frequency consonantal cues which contribute significantly to word intelligibility. As the hearing-impaired subjects lacked these cues due to their high-frequency hearing losses, the differentiation of speech discrimination performance between the groups with the introduction of noise was exaggerated. Filtering of the stimuli in the present study effectively eliminated these high-frequency cues for the normal subjects thereby reducing the difference between the mean WDS's of the two subject groups.

A similar reduction in the discrimination ability of normal listeners with filtered stimuli was reported by Sher and Owens (1974). They presented a phoneme identification task, in quiet, to two groups of listeners. One group had normal hearing to 2000 Hz with a high-frequency hearing loss, similar to the P group of the present study. The other group had normal hearing and received the speech stimuli through a low-pass filter with a cut-off frequency of 2040 Hz. Whereas the normal subjects generally scored 100% on this test in the unfiltered condition, with filtered stimuli, there was no significant difference between the mean scores (approximately 75 to 76% mean scores) of the two groups. When the filter skirt and the slope of the hearing loss were closely matched, the test behavior of the two groups was virtually the same.

Due to the filtered speech stimuli, higher S/N ratios were employed in the present study than in previous experiments. As expected, the range of +19 to +5 dB S/N ratio resulted in a broad range of scores. The combination of distortions introduced by filtering of the stimuli and the addition of noise made these S/N ratios sufficiently difficult for the purposes of the study. Lower S/N ratios might be considered for future research in this area to assess the course of the observed trends under increasingly difficult listening situations.

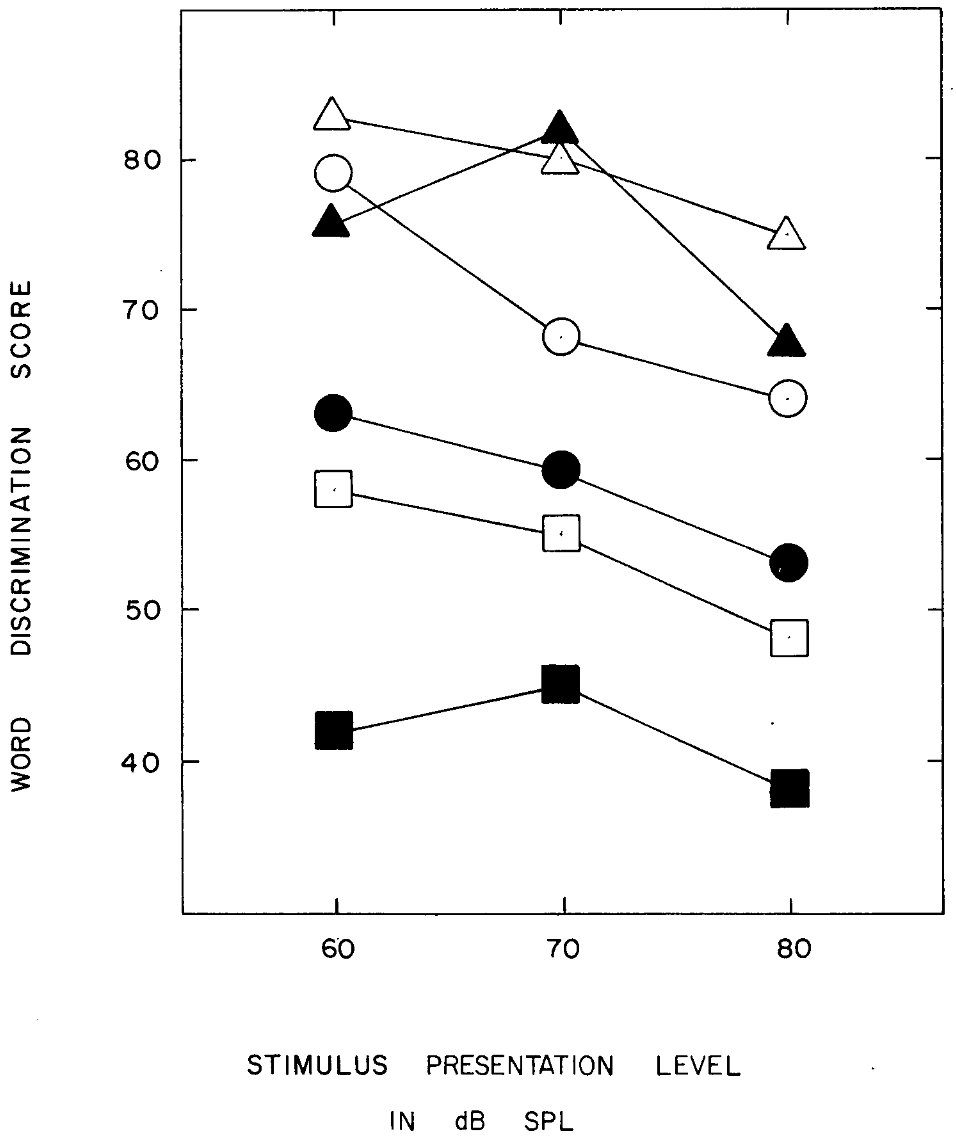
As noted earlier, an exception to the generally poorer speech discrimination performance of the P group was found at the highest S/N ratio at the 70 dB stimulus level (Figure 4b). Here no significant difference between the mean scores of the N and P groups was found.

Examination of the data presented in Figure 3a for the N group reveals decreasing speech discrimination performances with increasing stimulus levels. Examination of the data presented in Figure 3b for the P group, however, reveals little change in the performances at the 60 and 70 dB stimulus levels although a decrease in performance does occur at the 80 dB level. A likely explanation for these findings rests in the pure-tone thresholds of the two subject groups. As discussed in the "Subjects" section (4.2), the original subject criteria for both groups had called for normal hearing (thresholds no greater than 25 dB HL) up to 2000 Hz. Lack of suitable subjects, however, necessitated a modification of these criteria to allow the inclusion of several P subjects with thresholds of up to 35 dB HL at 2000 Hz. Whereas, ideally the mean pure-tone thresholds of the two groups would have been matched in this frequency range, the actual mean thresholds differed by from 7 dB at 250 Hz to 22 dB at 2000 Hz (see Table 1). Efforts were made to accommodate individual variations in auditory function up to a limit of 10 dB when assigning stimulus presentation levels. However, due to this inequality of thresholds, some P subjects were presented stimuli at the 60 dB level, which were, in actuality, 10 to 15 dB softer than those stimuli presented to their N counterparts. This partially accounts for the large differentiation of scores seen at the 60 dB level for the N and P groups (Figure 4a). The addition of a further 10 dB of stimulus intensity at the 70 dB level then probably brought the P group up to a more optimum level for word discrimination performance, already reached by the N group at the 60 dB level.

Increasing the stimulus level from 60 dB to 70 dB SPL for the P group therefore helped counteract the difference in thresholds between the two groups. However, the decrease in discrimination performance with increasing stimulus levels noted for the N group, was a trend in the opposite direction. Perhaps the opposition of these two effects in the P group therefore resulted in the similarity of performance noted at the 60 and 70 dB levels.

On the basis of Kiang and Moxon's (1974) study, the results of the present experiment were expected to demonstrate a marked difference in the discrimination performance of the two groups when the high-frequency neurons of the N group were called into play. It was anticipated that this would be revealed by a change in the slopes of the regression functions of the groups relative to each other when stimulus intensity was increased. The present study, however, failed to support this (Figure 5). There are a number of possible reasons. The first is the confoundment of results arising from the inequality of thresholds of the two groups. The application of more stringent subject criteria, ideally specifying matched group thresholds no greater than 15 dB HL through to 2000 Hz, would clarify the actual affects of stimulus and noise levels on the WDS's of the two groups.

Figure 5. Mean WDS's of the Normal group (open symbols) and Patient group (closed symbols) at the 3 stimulus levels for S/N ratios of +19 dB (triangles), +12 dB (circles), and +5 dB (squares).


80
70
60
50
40
WORD DISCRIMINATION SCORE
60
70
80
STIMULUS PRESENTATION LEVEL
IN dB SPL

A second, more fundamental reason is inherent in the experimental design. In an attempt to simulate more closely actual everyday listening conditions, the experiment was conducted in a sound field situation, using loudspeakers, rather than under headphones. This resulted in a number of unforeseen complications, the most notable of which was the aforementioned drop in the level of discrimination performance with increasing stimulus level. Ordinarily, for normal listeners under headphones in quiet, articulation curves for PB W-22 word lists reach their maximum (PB max) at approximately 50 dB SPL and remain at a constant plateau to stimulus levels of 90 dB SPL or more (Davis and Silverman, 1970, p. 212). With a filtered word list, the maximum height of the plateau might be reduced (French and Steinberg, 1947), but the PB max should still be maintained at a constant level. In the case of the present study, however, the sound field WDS did not plateau but demonstrated a "roll-over" effect, where a speech intensity of 80 dB SPL was less intelligible than speech of 70 or 60 dB SPL. (This can be seen in Figure 5 which plots the mean WDS's of the two groups as a function of stimulus level with S/N ratio as the parameter.) One possible reason for this "roll-over" of WDS's with increasing stimulus levels could be the high overall noise levels used (Pollack and Pickett, 1958). Or, it may have resulted from the use of the sound field test condition rather than the headphones. The sound-treated test suite used in the experiment was a semi-reverberant room, not an anechoic chamber. Reverberation effects could have caused the observed deterioration of scores.

Pollack and Pickett (1958) examined the deterioration of word intelligibility at high noise levels under headphones. With S/N ratio held constant, they observed a decrease in the intelligibility of monosyllabic words with increasing overall sound levels. The bend-down of the articulation curves occurred at levels of 80 dB SPL and higher and was accentuated by decreasing the S/N ratio. A stringent series of controls was carried out to ensure that the effect was not a result of equipment distortion. Pollack and Pickett (1958), therefore, concluded that the decrease in intelligibility was most likely a result of "overloading" (p. 130) of the auditory system of the listener.

Support for the possible deletrious effects arising from the sound field test condition may be found in several studies, two of which deal with the effect of hearing protection on speech intelligibility. Kryter (1946) assessed the effect of wearing earplugs on articulation scores obtained in reverberant and anechoic environments. In the reverberant room, he discovered that for normal listeners in the presence of 80 dB or more of noise, earplugs improved speech intelligibility for all speech intensities, while in less noise, they resulted in decreased intelligibility. Earplugs produced this improved articulation by effectively reducing the overall intensity level of speech and noise from high to medium levels while keeping S/N ratio constant. Similarly in the present experiment, WDS's generally improved with decreasing overall levels of speech and noise. Kryter found that for subjects not wearing earplugs, increasing the speech level with S/N ratio held constant resulted in a decrease of articulation scores, the same roll-over effect demonstrated in the present study. As the S/N ratio was decreased, the roll-over of the articulation curves was accentuated and occurred at successively lower speech intensity levels.

Tests in the anechoic chamber, on the other hand, produced maximum articulation scores for both groups which did not decrease with higher speech levels but stayed at a constant plateau. Speech at 80 dB or more above threshold was heard equally well with plugs or without.

Kryter (1946) attributed the divergence of articulation performance (approximately 10%) for the two test rooms at high speech levels, to reverberation effects which are present in the reverberant room and absent in the anechoic one. Earplugs attenuated these effects below the listener's threshold. For listeners without earplugs, however, as the speech intensity was raised, the masking effects of reverberation on intelligibility increased. This resulted in the roll-over of articulation scores noted in the reverberant room. Kryter (1946) concluded that these reverberation effects "constitute unintelligible 'noise' that interferes with speech reception" (p. 416), and that the masking effect of this reverberant speech increased with higher overall levels.

Similar findings were reported in a recent study by Martin et al. (1976) investigating the influence of earplugs and earmuffs on communication in noise. In agreement with Kryter (1946), they found that speech discrimination improved with the wearing of ear protection in high noise levels (above 85 dBA) but was degraded if protectors were worn in noise levels less than 65 dBA. Examination of their data obtained in a semi-reverberant room again reveals the roll-over of discrimination scores with high speech intensities for unoccluded ears. They, however, did not attribute this decreased speech discrimination to reverberation effects. They referred to the possible occurrence of distortion in the cochlea with increasing noise levels above 65 dB. This would appear to be akin to the auditory "overloading" of Pollack and Pickett (1958). As the wearing of ear protectors in high noise levels would reduce this distortion without affecting the S/N ratio, improved articulation could result.

In a study cited earlier, Kryter et al. (1962) presented monosyllabic word lists in noise monaurally to subjects with normal hearing and various degrees of sensorineural impairment. The speech stimuli, low-pass filtered at 7000 Hz, were presented at overall levels of either 65 dB or 95 dB SPL. For the majority of their subjects, Kryter et al., found the speech presented at 65 dB was more intelligible than that presented at 95 dB. As in the present study, intelligibility decreased with higher stimulus intensity.

A third possible reason why the anticipated change in the slopes of the regression functions of the N and P groups failed to occur with increasing stimulus intensity, lies in the particular stimulus levels used. These levels, 60, 70, and 80 dB SPL may have been so high in intensity that most of the high CF neurons were already being activated at the 60 dB stimulus level. In such a case, little change in the slopes would occur as all three levels would be representing the similar condition of high CF neuron excitation. To validate Kiang and Moxon's (1974) findings, the range of stimulus levels employed must span the threshold region of excitation of these neurons in order to demonstrate any change their excitation may bring about in word discrimination ability. Stimulus levels, therefore, lower than 60 dB SPL may be necessary to produce the anticipated results in future studies in this area.

In summary, the results of the present study support the complaints of individuals with high-frequency sensorineural hearing losses that they experience difficulties hearing speech in noise. Presentation of a filtered word discrimination task in the presence of masking noise demonstrated that noise does have a significant differential effect on the WDS's of the subject groups, N and P. A satisfactory explanation of these results based on the physiological findings of Kiang and Moxon (1974) was not accomplished, however, due to at least three possible complicating factors. These included the failure to adequately match the pure-tone thresholds of the two groups up to 2000 Hz, the use of the sound field test condition rather than headphones, and the employment of too high stimulus levels. Kiang and Moxon's (1974) study still provides a promising framework for the investigation of speech discrimination in noise. Future use of a similar filtered speech task under headphones (to eliminate reverberation effects), using carefully matched subjects and a lower range of stimulus levels, may provide a better experimental design for testing the application of Kiang and Moxon's data to humans. The more real-life situation tested in this study demonstrates that the deteriorating effect of noise on hard-of-hearing people is a complex problem that involves the interaction of many factors.

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