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PURE-TONE MASKING BY NARROW NOISE BANDS

IN NORMAL AND IMPAIRED EARS

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CHAPTER I

INTRODUCTION

Auditory masking occurs when one sound, easily heard in quiet surroundings, becomes inaudible when it occurs simultaneously with a stronger sound. Specifically, masking can be defined as the difference in decibels between the threshold sound pressure level measured in quiet and in noise.

The occurrence of masking is qualitatively evident in our everyday life whenever we encounter difficulty in hearing some sounds because of the presence of other sounds. Most of our listening occurs in a fairly complex acoustic environment. We usually listen to speech or music against a background of noise. Remarkably, most of us are able to select the specific sound or sounds which we wish to hear and to minimize the noise effects. Masking is an exception to our ability to attend to a primary auditory signal in the presence of another interfering auditory signal. When the intruding sound reaches an intensity level that results in either partial or total interference with the primary auditory signal then masking can be said to occur.

The masking phenomenon has long been a topic of interest and experimentation in the field of acoustics. As early as three centuries ago, Thomas Willis observed that persons with hearing disorders often heard speech better in noisy surroundings than persons with normal hearing. This phenomenon has since been labeled 'paracusis Willisii'. The 'paracusis Willisii' phenomenon probably results from the Lombard effect (29). That is, a person with normal hearing unconsciously speaks louder in a noisy situation in an effort to control his speaking level. Thus, the person with impaired hearing appears to hear better in noise because his impaired hearing acuity reduces the level of noise that he hears while the voice of the speaker rises above the hearing loss.

This report by Willis served to bring about an intense interest in the phenomenon of auditory masking. As a result of this interest, a great number of masking experiments have been done. The auditory system has been studied under controlled test conditions which revealed the influence of various types of masking stimuli on both pure-tone and speech thresholds. The masked signals have included those produced by musical instruments, electric bells or buzzers, pure tones, and electronically generated signals with characteristic spectra which could be described mathematically. Experimentation on the auditory masking phenomenon has included study of both the normal and the pathological ear.

The interest that has been generated in the study of auditory masking stems from practical considerations (25). Attention was focused on auditory masking for several reasons. First, behavioral scientists were interested in how the auditory mechanism actually functions. They wanted to know how the complex auditory stimuli could be analyzed into various components such as pitch and loudness. They were interested in discovering if masking bore a simple relationship to the mechanical motion of the basilar membrane or if it was a function of the degree of auditory nerve excitation. Secondly, there was a need for data on the development and refinement of communication systems. In many situations speech is accompanied by other sounds. This relationship between speech and the intensity level of the accompanying sounds is important for the development of military communications. There is a need to study the signal-to-noise ratios (the ratio of the average speech level to the average noise level). This was especially acute during the war effort. As a result, typical noise backgrounds such as those found in factories, ships, airplanes, and tanks were studied to determine their masking effects on various speech signals. Thirdly, there is a need for data relative to the differential behavior of the normal and pathological ear in the presence of various types of masking stimuli.

Early studies of the masking phenomena were somewhat crude when compared to the more recent efforts in this area. Often, the results of earlier experiments were difficult to compare because the noise spectra differed considerably from experiment to experiment. Also, there was difficulty in specifying and controlling the masking stimuli measurements. However, as new technological advances were made, it became possible to produce thermal or white noise. This noise has the advantage of a uniform electrical spectrum which can be measured and controlled in a relatively exact manner. Thermal noise is continuously and uniformly distributed at equal average energies throughout the entire frequency spectrum. This type of masking stimulus is preferred in most experimental procedures since it can be quantified and described with great accuracy. Furthermore, it has been demonstrated that the masking produced by thermal noise produces predicatable amounts of masking throughout the frequency spectrum.

Data obtained through the use of white noise have greatly enhanced our present knowledge of the auditory system. This information is of basic importance for normal ears and also for impaired ears. Essentially, one can conclude that it is extremely important to know if there are differences in the auditory behavior of the normal ear and the pathological ear. Any observed difference in the auditory behavior of the normal and impaired ear will increase our understanding of the auditory processes.

In addition to numerous studies using broad-band thermal noise, there have been various studies using narrow bands of thermal noise. The spectra of these noises have varied in width depending upon the experimenter and equipment used.

The present investigation was designed to learn more about the phenomenon of auditory masking of pure tones by narrow bands of noise in pathological ears. It was felt that a study of this nature would provide additional information about basic auditory behavior, primarily the auditory response of ears with sensori-neural impairment due to cochlear pathology. The particular task of each subject was to detect continuously variable pure-tone signals in the presence of five narrow bands of filtered thermal noise when these bands were presented at over-all sound pressure levels. One specific question asked was whether the normal ear and the ear with a sensori-neural impairment due to cochlear pathology would reveal essentially equal masked threshold sound pressure levels within the noise band. A second consideration was whether the ear with sensori-neural impairment would be shifted to greater sound pressure levels than the normal ear in the frequency regions above and below the limits of the noise bands. This second comparison may be the most effective method of demonstrating any distinguishing auditory behavioral effects between the normal and the pathological ear when stimulated by filtered thermal noise. A third question was whether the degree and configuration of the spread of masking at frequencies above and below the noise bands would be the same for the normal and impaired ear.

This study was undertaken to answer these questions. Before discussing this experiment, however, a review will be made of the earlier studies involving the audibility of pure tones in the presence of different masking signals.

CHAPTER II

HISTORICAL REVIEW OF THE PROBLEM

Introduction

Masking has been described and defined in various ways. Miller states that masking is:

> ...the shift of threshold audibility of the masked sound due to the presence of the masking sound. The difference, in decibels, between the quiet and the masked thresholds is the measure of the amount of masking produced by that particular type and intensity of interference for that particular masked sound. (28, p. 53)

French and Steinberg (10) define masking as the presence of unwanted sounds in the listener's ear reducing the ear's sensitivity to other sounds. In relation to tonal masked stimulus, they state that the reduction at any frequency due to masking is equal to the difference between the levels of a specific frequency without noise and the level at which it is just audible when noise is present. Hirsh (14) gives a definition of masking which is similar to that given by French and Steinberg (10), and Miller (28). Hirsh states that masking occurs:

> When one sound causes a second sound to become less audible by co-existing with it...(14, p. 155)

Licklider (25) describes masking in relation to the ear's analytical ability. He says that the ear can analyze complex acoustic stimuli even though there is more than one set of sound waves present at the eardrum. That is, these superimposed waves constitute only one physical wave. Nevertheless, if the ear is required to analyze a weak sound in the presence of a loud sound this analytical ability breaks down. He states that:

> Masking is thus the opposite of analysis; it represents the inability of the auditory mechanisms to separate the tonal stimulation into components and to discriminate between the presence and absence of one of them. (25, p. 1005)

Masking of Pure Tones by Pure Tones

Mayer (27) did some of the first experimental work with masking. He found that low-pitched sounds had a masking effect different from that of high-pitched sounds. In his experiments, he employed organ pipes to generate low frequencies and tuning forks for the high frequencies. He concluded that low-frequency components may completely obscure higher frequencies of rather high intensities but that higher frequencies do not obscure lower ones.

Wegel and Lane (38) conducted their study of masking in order to quantify Mayer's (27) work. However, their results only partially verified Mayer's findings. They studied the masking of one pure tone by another over a wide range of frequencies and intensities. These authors found that the masking produced by pure-tone stimuli is greatest in the frequency region adjacent to the masking tone. A slight diminuation in the amount of masking for frequencies only a few cycles apart from that of the masking tone was observed. Apparently, this decrease in the amount of masking was due to aural 'beats' caused by the fact that the masking tone and the masked tones were nearly the same frequency. In addition, they reported that rather large amounts of masking were found for frequencies above that of the masking tone while relatively little masking was produced for frequencies below that of the masking tone. Furthermore, as they increased the intensity level of the masking tone, the amount of masking for frequencies above the masking tone increased, and these threshold shifts spread to higher frequency regions.

Because of their observations of these dips in the masking curve at frequencies close to the masking tone and at the various harmonic frequencies, a harmonic analysis of the masking tone was performed. It was found that the second and third harmonics were not intense enough to cause these dips. Consequently, they concluded that the dips were caused by the non-linear characteristics of the ear's transmitting system. They were able to determine the magnitudes of these overtones by using a secondary tone and increasing the secondary tone intensity so that beats were audible. They then found the point where the beats were most audible and the intensity of this tone was considered to be equal to the overtone intensity.

Egan and Hake (6) conducted a study similar to the one of Wegel and Lane (38). They postulated that a masked signal composed of a narrow-band noise would not cause the occurrence of beats and difference tones in obtained masked thresholds which were found for tonal masking stimulus. They used a 90-cps band of white noise centered at 410 cps with masking produced by a tonal stimulus at a frequency of 400 cps. They studied the amount of threshold shift for 29 test frequencies from 100 cps to 6000 cps for both types of signals using five normal-hearing subjects. Their results for the 400-cps masking signal were approximately the same as Wegel and Lane's (38) data which revealed dips in the masking curves as the two tones approach each other and also at the harmonics. They (6) verified their own hypothesis regarding the masking produced by narrow-band white noise. They also reported that comparison of the two types of masking signals revealed that the 400-cps tone masked higher frequencies better than did the noise band.

Masking of Pure Tones by Wide-Band Thermal Noise in Normal Ears

After Wegel and Lane's (38) classic study, the trend of investigation was directed towards the study of the masking of pure tones by wide-band noise. One of the early writers, Galt (11), in 1929, measured the threshold changes for frequency-modulated pure tones with environmental sounds as the masking stimuli. Due to the fact that the acoustic spectra of these noises were not clearly defined, the masking data reported were limited in their value.

For a number of years following Galt's early work, very little data was reported regarding threshold shift of pure tones masked by noise. Nevertheless, during this interim, engineers at the Bell Telephone Laboratories were exploring masking as it affected telephonic communication. From this research effort, basic studies regarding the masking of pure tones by noise developed and, with it, the central concept of the critical band.

All of the following literature review will be concerned with the masking effects of white noise. This noise is especially convenient for experimental purposes because of its uniform spectrum. White noise consists of all frequencies at equal average energies. The intensity of white noise can be specified either as the over-all level of the broad-spectrum noise in sound pressure level (SPL) or as spectrum level (SPL per cycle), either of which has a reference value of 0.0002 microbar.

Hawkins and Stevens (13) experimented with white-noise masking of discrete frequencies in normal-hearing subjects. They found that the relationship between noise intensity and pure-tone threshold shift was linear after about 20 db of masking had occurred for any test frequency. That is, after the initial rise of the masking curve, each additional decibel of noise produced an additional amount of masking. Also, test tones in the middle frequency range revealed greater amounts of masking than tones at either end of this range. This occurs because the shift of the absolute threshold to the masked threshold is greater in the middle frequency range than at the extreme frequencies due to the greater sensitivity of the ear to tones in this mid-region.

In 1937, prior to Hawkins and Stevens' (13) classic study, Fletcher and Munson (9) experimented with masking produced at several frequencies using a white-noise stimulus. Fletcher and Munson adjusted the noise spectrum with filters so there was approximately equal masking at all frequencies from 200 cps to 10,000 cps. The data gathered from this experiment turned out to be extremely significant since parts of it led Fletcher to formulate the 'critical-band hypothesis' (8). Fletcher wanted to know the band of frequencies in this kind of noise which was essential in order to produce masking for a specific frequency.

Also, he wanted to specify the relationship between the intensity levels of the masking noise and the frequency masked.

Since it was necessary to synthesize this information into a single unifying concept, Fletcher formulated two important assumptions which define a critical band. First, masking produced for a given frequency by a wide band of thermal noise is due entirely to the energy present in the area immediately surrounding the frequency of the tone; and second, when the tone is audible in a noise background, the acoustic energy of the tone and the acoustic power of the noise is equal. This second assumption is also known as the 'equivalence of energy' assumption.

On the basis of these two assumptions, Fletcher calculated the critical-band width for different frequencies. He made these computations by: (1) obtaining the masked threshold sound pressure level in db re 0.0002 microbar for the given frequency, (2) determining the level per cycle or spectrum level of the wide-band noise, that is, the pressure level in db re 0.0002 microbar developed in a noise band one cycle wide, (3) subtracting the level per cycle value from the masked-threshold SPL for the specific frequency, (this yields the critical-band width in decibels), and (4) changing this decibel value into its equivalent power ratio, thus permitting the expression of the critical-band width in cycles per second. This expression of the critical-band width in cycles per second can be used since the energy in a white-noise band is proportional to the band width. Hawkins and Stevens (13) demonstrated this computation by using data available for 1000 cycles. They noted that the level per cycle of the masking noise for this frequency was 18 db below the masked-threshold level of the pure tone. Since 18 db equals an energy ratio of 63 to 1, the frequency band having the total energy equal to that of the 1000 cycle tone would be 63 cycles wide. The critical-band widths in cycles per second for the remaining test frequencies were found by employing the same computational procedures. The critical-band width varies from several hundred cyles at high frequencies to about 30 cycles at low frequencies.

Another central idea which is very important in the investigation of thermal-noise masking of pure tones is the concept of 'effective level' of a masking sound. The symbol (Z) is commonly used to denote the effective level, and (M) is the usual symbol for masking. By using the critical-band information, as expressed in decibels, with absolute threshold information for pure tone and spectrum level of the wide-band noise, it is possible to compute the effective level (Z) of the masking noise. Hawkins and Stevens (13) define Z as the sensation level of the critical band. This means that:

> ...Z if equal to the sensation level of a pure tone having the same energy as the critical band of frequencies that is just able to mask the tone. (13, p. 10)

Or, in other words, Z is the difference, in decibels, between the pure-tone threshold sound pressure level for a particular pure tone in quiet and the over-all sound pressure level of the critical band of noise effective in masking this tone. This concept is closely related to the equivalence of energy assumption. Hawkins and Stevens (13) demonstrated empirically the validity of this assumption.

They found that when a critical band of frequencies is presented at a just audible level, the total acoustic energy in a band is equal to that of the pure tone in the center of the band at its threshold intensity.

Fletcher and Munson (9) while at Bell Laboratories studied the relationship between masking (M) and effective level (Z). They were the first to explain this relationship. These workers discovered that M and Z were equivalent for values of Z between about 12 db and 50 db, that is, in this range M and Z were equal and linearly related. Consequently, if the value of Z for a specific frequency were known, the amount of M could be predicated for the normal ear. For Z values less than 12 db, the amount of masking observed was greater than that predicted on the basis of Z. At a Z of zero, a masking of approximately 5 db was observed. This same relationship was observed when the Z value exceeded 50 db. For example, at a Z value of 80 db, Fletcher and Munson observed approximately 84 db of masking.

Several years later, nearly all of the results reported by Fletcher and Munson (9) were confirmed by Hawkins and Stevens (13). The relationships which they reported between masking (M) and effective level (Z) for monaural masking illustrate that there is a linear relationship between the two measures once the effective level of the noise exceeds approximately 20 db. There is a gradual tapering off of the threshold curve for the ones in the presence of noise below the 20-db effective level. French and Steinberg (10) obtained similar data for values below an effective level of 50 db. However, linear slope in contrast to French and Steinberg who reported an upward swing of the M-Z relationship, indicating that the masking noise became relatively more effective at the higher levels.

French and Steinberg (10) also studied binaural listening as it relates to critical-band width. They found a 1.5-db advantage when both ears were stimulated and concluded that two ears are better than one in this type of auditory discrimination. On the other hand, Jeffress and others (17) reported that data published by Wilcott and Gales (39) suggests that the monaural and binaural values are nearly equal.

Egan and Hake (6) likewise investigated the critical-band problem. They used a 90-cps band of white noise centered at 410 cps as the masking stimulus and found the critical-band for the center frequency (410 cps) to be 14 db wide for that noise band. Other writers such as Fletcher (8) as well as Hawkins and Stevens (13) found the critical-band width for this frequency to be 17 db.

Shafers and others (31) also investigated the validity of the critical band hypothesis. Their main purpose was to test the critical-band concept in terms of the frequency spectrum of the critical band for three different frequencies. Specifically, they studied the masking of pure tones by synthetic noise bands which were narrower than the critical-band width. The synthetic noise was created by recording discrete frequencies one cycle apart. This noise was used instead of white noise so they could obtain cut-off slopes which were sharper than could be secured by filtering white noise. In addition, they used bands of white noise of approximately equal size in order to permit a comparison of the masking caused by these different noises. Their subject group was comprised of 25 normal-hearing adults. Twenty of these subjects were tested with synthetic noise and five with white noise. Band widths of 8, 16, 32, 48, and 96 cps were employed to mask pure tones of 200, 800, and 3200 cps centered in the bands. Both kinds of masking noise were presented at sensation levels of 54 db at 200 cps and of 65 db at 800 cps and 3200 cps. It was observed that masking is similar for the two types of noise used. The results generally support Fletcher's (8) data that for noise bands narrower than the critical band, a pure tone at the center of the band can be heard when its intensity equals that of the noise.

Masking of Pure Tones by Wide-Band White Noise in Pathological Ears

A substantial amount of experimentation regarding the study of masking discrete frequencies by white noise in normal-hearing subjects has been done. In addition to the number of masking studies that have been reported for normal-hearing subjects, there has been a considerable quantity of research in masking reported for pathological ears.

One of the first investigators to study the effects of noise masking on tonal signals in impaired ears was Langenbeck. As early as 1932 he reported on the diagnostic value of noise audiometry. A later article appearing in 1953 (23) summarized the majority of his research. He studied both normal and impaired ears. The impaired ear groups consisted of subjects with both conductive and sensori-neural losses. He also specified the site of lesion in the sensorineural ears. He stated that he could differentiate between various types of hearing loss on the basis of the masked-threshold curve of discrete frequencies. This tenet was based on two assumptions. First, he assumed that 'balanced noise', that is, noise with a continuous frequency spectrum, caused the same amount of stimulation at each place in the cochlea and equaled the energy of a pure tone perceived at any specific place in the cochlea. This occurred when the tone and noise were at the same sound pressure level. He stated:

> The most common form of the law of masking is that when the stimulation of the noise at that place in the cochlea where the tone is sensed is just equal to the stimulation of the tone, then the tone is just at the threshold of being masked. (23, p. 439)

Secondly, he assumed the equivalence of energies.

The type of experimental equipment Langenbeck used enabled him to measure hearing loss directly in sound pressure level with a zero reference value of 0.0001 dyne/cm^2. However, he did not specify his noise levels as mentioned above. He used the noise levels in approximately the same manner as has been reported by Hawkins and Stevens (13) regarding the effective level (Z), or the sensation level of a noise. For example, if he refers to a noise level of 60 db, he means that the intensity of the threshold tone in the presence of the noise is 60 db.

In his earlier work, Langenbeck found that both normal-hearing subjects and subjects with conductive hearing impairment gave the same shape masking curves for tones in noise. That is, both the normal-hearing subjects and conductively-impaired subjects demonstrated the same amount of masking with the conductive curves displaced by an amount equal to the hearing loss.

For subjects with a sensori-neural impairment caused by 'hair cell' lesions he found the masked thresholds were very similar to those obtained for subjects with normal hearing and conductive hearing losses. The second category of sensori-neural hearing loss included losses due to damage of the spiral ganglion cells of the eighth nerve. Results from this group revealed greater threshold shifts than from normals or conductives. Also, he discovered that the tonal signal had to be considerably more intense than the noise signal in order for the test tone to be perceived. Therefore, the equivalence-of-energy assumption, that is, the total energy of the pure tone is equal to the pure tone itself, did not apply in these cases. Langenbeck (23) reported finding this type of masking behavior in retro-cochlear losses caused by concussions, brain tumors, and diseases of the central nervous system.

When Langenbeck plotted the relationship between tone intensity and noise intensity for the retro-cochlear group, he found that the masking function for this group was non-linear. This group demonstrated an M-Z function which was observed to fall considerably above the normal curve, thus suggesting greater intensity for the total signal in the presence of noise. On the other hand the normal, conductive, and sensori-neural losses due to end-organ lesions revealed a masking function which was linear and of unit slope above 20 db. Consequently, the results from these three groups substantiated the findings of Hawkins and Stevens (13) regarding the M-Z function. But the 'hair-cell' lesion group did behave differently below the 20-db level in that the M-Z function did not become non-linear as did the other groups.

Langenbeck attempted to explain the linearity of the masking-to-noise intensity that was seen in the 'hair-cell' lesion group on the basis of 'tinnitis' which he defined as auditory stimulation created by physiological noise. He theorized that the normal inner ear hears only as much as masking by physiological noise permits. Therefore, physiological noise stimulation must have the same magnitude as an external tonal stimulus at threshold. As a consequence, when these two auditory stimuli of equal intensity act on the normal inner ear their power is additive, thus increasing the over-all level of the two intensities approximately 6 db. When listening to a threshold tone in the presence of this external and internal noise, an acuity loss of 5 db to 10 db will result. He thought that this provided an explanation of the gradual masking curve slopes for subjects with normal hearing and conductive impairments. In reference to 'hair-cell' lesions, Langenbeck stated that the facts differ considerably:

> Here the sensitivity is so reduced that tinnitus (physiological noise) does not excite the hair cells. Therefore, with an additional noise stimulation at threshold intensity, a threshold tone is still heard... This explains the continuation of the linear masking curve down to zero... (23, p. 444-445)

Subsequent to Langenbeck's initial work, a masking study was done by Weersma (37). He used masking noise, generated by a continuously sounding electric bell, and amplified thermal noise to mask pure tones. All stimuli, both pure tones and noise, were presented to the listener in a free-field test situation. The intensity levels of both the pure tones and noise were controlled by a sound-level meter. In certain parts of the experiment he passed the white noise through a low-pass filter which modified the masking signal so that it consisted of predominately low frequencies. Weersma utilized a method of measuring masked thresholds somewhat like that of Langenbeck's (23). That is, the noise was set at some arbitrary level and then the masked threshold of the test tone was measured.

When the masking curves for normal-hearing subjects tested by Weersma were compared to those of earlier writers, it was evident that the acoustic spectrum of his noise was not flat (21). Apparently, a greater part of the energy was centered in the 500-2000-cps region. When he did change the noise spectrum by low-pass filtering, the test results on the normal-hearing group revealed approximately equal masking for all frequencies above 200 cps. When these noise stimuli were used to mask pure tones in impaired ears, the amount of masking found in the mixed and conductive hearing-impaired groups was less then that observed for normal-hearing subjects. In subjects who had high-tone loss, greater than normal masking was found. Weersma did not discuss the results for noise generated by an electric bell.

In 1942, Huizing (16) proposed that thermal noise might be employed to detect recruitment in cases of bilateral hearing impairment. He advocated the establishment of masking norms for the normal and the pathological ear in order to facilitate diagnosis of hearing disorders. In his study, he used thermal noise to mask pure tones in normal, conductive and sensori-neural ears. He concluded that the pathological ear may show different masking values for the same combination of noise and pure tone, depending on the type of hearing defect. Huizing stated that if the loudness of the noise increases rapidly as a consequence of the recruitment factor, the masked threshold will be reached sooner, and the masking will increase more rapidly than for the normal ear and the conductively impaired ear.

In 1950, Webster, Lichtenstein, and Gales (35) studied the masking of pure tones by wide-band noise in both normal and impaired ears. They studied the thresholds for discrete frequencies in quiet and in white noise for 3,666 subjects at the 1948 San Diego County Fair. They were interested in finding the threshold variability in broad-band noise for various sub-groups of the total sample. Absolute pure-tone thresholds and thresholds of pure tones masked by thermal noise were obtained for all test subjects. The noise intensity was adjusted to produce an effective level of 40 db at two test frequencies (800 cps and 3520 cps) for normal ears. For the impaired ears, the effective level of the masking noise was different depending on the degree of hearing loss at both test frequencies. These workers observed that normal and sensori-neural ears revealed approximately an equal amount of masking when the effective levels of the masking noise were equivalent. An opposite finding was observed for ears with conductive and mixed-type hearing loss since they found greater than normal amounts of masking in these cases. However, it should be noted that the different types of hearing loss were determined by shape of the air conduction audiogram and that bone conduction measurements were not secured.

In 1950, Kietz (22) reported results of a rather unique method of masking pure tones by noise. Employing wide-band thermal noise of the type that Langenbeck had used, he measured the masking for a pure tone of 2000 cps using a Bekesy audiometer. The intensity level of the wide-band thermal noise was slowly increased during the fixed-frequency tracing until it reached approximately a level of 80 db re 0.0002 microbar. The subject with normal hearing demonstrated a masked threshold for this frequency that followed linearly the increasing intensity of the noise and gave a downward slope of unity. However, one subject with a sensori-neural hearing loss with loudness recruitment revealed less masking than was shown for a normal-hearing person. That is, he was able to determine threshold for the 2000-cps tone in the presence of the noise more easily than a normal-hearing person.

Zangemeister (40) also studied masking in pathological ears using the identical method applied by Kietz. He used several clinical cases with different types of hearing loss. Results of his investigation showed that the four conductively impaired ears reacted differently; one exhibited the same amount of masking as the normal ear, one showed less masking than normal, and two revealed more masking than normal. Two of the ears with 'labyrinthine hypertension' revealed masked thresholds which increased more rapidly than the noise intensity, indicating that the existence of loudness recruitment affords poorer hearing in the presence of noise than normal. These two cases with recruitment seem to conform to the principle of the hypothesis advocated previously by

Huizing (16). However, these results were exactly opposite of those reported by Kietz (22). Finally, Zangemeister (40) reported data on three more impaired-hearing cases; one case due to labyrinthine hydrops and two cases due to isolated eighth nerve degeneration. An abnormal amount of masking was observed in the former case but, in the latter two cases, a normal amount of masking was observed. These findings are the opposite of those reported by Langenbeck (23).

In 1953, Palva, Goodman, and Hirsh (31) reviewed the literature on noise audiometry and expressed the opinion that there was considerable confusion abounding in this area. It was their opinion that the recruitment factor should not result in greater masking than would be predicted on the basis of the critical band and the effective level hypothesis. These writers were not willing to accept Huizing's (16) assumption that in the pathological ear with recruitment masking increases more rapidly with noise level than in ears without recruit- out recruitment. They were convinced that the loudness of a tone and the noise in the critical band for that tone could not increase at different rates. It was their hypothesis that this was true no matter what type of ear pathology caused the hearing loss.

Consequently, they (31) designed an experiment using 18 normal-hearing subjects and 82 subjects with impaired hearing due to various types of pathology. They investigated the threshold shifts for pure tones in the presence of a band of white noise from 20 to 7000 cps. The subjects with impaired hearing were divided into four sub-groups. The subjects in one group had conductive losses with normal bone conduction curves and good speech discrimination. A second group was comprised of subjects with conductive-mixed losses who exhibited nearly identical audiometric configurations except that they all showed somewhat greater nerve involvement as detected by 'various means'. The third group was composed of subjects with greater sensori-neural loss than the second group and were placed in the mixed-nerve group. The fourth group was made up of subjects with sensori-neural impairment who had interweaving air-conduction and bone-conduction curves. This last group was split again into three sub-divisions. The first division had subjects who showed recruitment by the loudness balance method, another division had subjects who revealed no recruitment by the loudness balance method, and the third division had subjects who were not examined for recruitment.

Threshold shifts produced by a wide-band thermal noise at eight frequencies were measured. The noise was delivered at three over-all levels (70, 100, and 110 db re 0.0002 microbar). They reported that masked thresholds for frequencies from 250 to 8000 cps, including 3000 and 6000 cps, were within the same range for all groups at the 100 db level. High-frequency variation was greater than 10 db among the diagnostic categories. The variability range for the lower frequencies was approximately 5 db. As a result of this study, they concluded that the masked threshold is not a useful tool in the differential diagnosis of auditory disorders.

In 1956, Lightfoot, Gaeth, and Carhart (26) explored masking with a wide-band thermal noise on normal ears and on ears with different types and degrees of hearing loss using both speech and pure-tone stimuli

uli. They used 31 normal listeners and 59 subjects with impaired hearing. The pathological group consisted of 17 conductively impaired subjects and 42 subjects with sensori-neural hearing loss. They investigated threshold shift for both pure-tone and speech stimuli at comparable effective levels of masking noise. They assumed that the relationship between masking and the effective level concept was a general one, being applicable to different types of stimuli. Specifically, they postulated that a flat spectrum noise would result in the same amount of masking (M) in an ear which is impaired (conductive or perceptive) as it would in a normal ear provided that the intensity of the noise is adjusted so that its effective level (Z) is the same for the two ears. It was anticipated that the M-Z function would agree with the M-Z function found by such investigators as Hawkins and Stevens (13), who reported the masked thresholds of a single group of normal-hearing subjects for a number of noise levels. All of the normal ears and some of the pathological ears were tested with noise delivered at over-all levels of 60 and 80 db SPL re 0.0002 microbar. The remainder of the impaired ears were tested at noise levels of 80 and 95 db SPL.

A comparison was made between the critical-band width in decibels for the normal group and the data of French and Steinberg (10) and Hawkins and Stevens (13). Lightfoot, Gaeth, and Carhart (26) found that M-Z function agreed rather closely with the findings of previous investigators. Furthermore, the threshold shifts for sensori-neural hearing losses were greater than those found in conductive hearing losses for equal effective levels of the masking signal. As a result, these authors (26) concluded that the critical-band concept is less applicable to abnormal ears, especially those demonstrating sensori-neural impairment.

As it can be seen from this above discussion, the literature on the masking of pure tones by wide-band noise in pathological ears does not seem to reveal any consistent pattern. Some researchers reported that sensori-neural hearing losses showed greater threshold shifts than conductive losses (16, 23, 26, 30, 37). Others have found the opposite results (22, 35). A third group has found no consistent difference among any of the diagnostic categories of hearing loss and normal hearing (31, 40). Consequently, one reaches the conclusion that considerable inconsistency still abounds in this area regarding the results to be expected in white-noise masking of pure tones in impaired ears.

Because of the inconclusive research results in this area, other studies were done using narrow bands of thermal noise in an attempt to secure additional data on white-noise masking of pure tones. The investigations that have been reported on both normal and pathological ears will be presented in the following section.

Masking of Pure Tones by Narrow-Band White Noise

In 1956, Bilger and Hirsh (3) studied the masking of pure tones with bands of noise in normal-hearing subjects. Primarily, they were interested in discovering how well the masked threshold of a tone would follow the frequency characteristics of a noise band. Also, they wanted to ascertain how this behavior would change with the level of the noise band. Seven bands of noise, each corresponding to a pitch interval of 250 mels were used. The frequency locations of the bands were set up so that masking within the bands could be studied from 394 cps to 5100 cps. Over-all sound pressure levels of 40, 60, 80, and 100 db were used with each frequency band. By means of a modified-Bekesy audiometer, discrete frequency thresholds were obtained for five normal-hearing subjects at 39 frequencies between 150 cps and 6000 cps. A modified-Bekesy audiometric technique was used so that masked audiograms could be compared with the noise spectra to learn how well the ear follows the frequency characteristics of the noise bands at different intensity levels.

Bilger and Hirsh's (3) results verified the findings of Fletcher (8) and Hawkins and Stevens (13) concerning the critical-band values reported and found that these bands predicted quite pre-precisely the masking for tones whose frequencies lie within the band. These investigators, however, observed more masking than would be predicted for the frequencies above the band. A comparison of the filter characteristics and the masked thresholds revealed that the ear does not follow the filtered noise for frequencies above the band but does follow the filtered noise for frequencies which lie below the noise band for over-all sound pressure levels below 80 db. If the over-all noise level of the band was 80 or 100 db SPL re 0.0002 microbar, they noticed, in addition to the expected amount of masking in or near the center of the band, that the lower frequencies deviated from the measured slope of the noise. They labeled this threshold shift for frequencies that were located considerably below the noise band as 'remote masking'. Furthermore, this remote masking, after it appeared, did not seem to be linearly related to the function of frequency. That is, approximately 10 db of remote masking occurred at the 80-db noise level, and this remote masking was increased by more than 20 db as the noise level was raised to 100 db. The remote masking rose in an accelerated manner, as a function of the noise level, and then was observed to decelerate at the highest levels. In order to verify their observations, they checked the acoustic output of the signal passed through the filter to determine if some low-frequency noise was present at the input of the ear. These measurements revealed that such noise was not intense enough to create the masking observed for the low frequencies used.

Another experiment was executed by Bilger and Hirsh (3) to further explore remote masking with more intense noise levels for the 1000-1420-cps noise band. Over-all levels between 70 and 120 db were studied. As before, it was found that an acceleration of masking for the low frequencies occurred when the masking signal was above 80 db re 0.0002 microbar. As a consequence of this research, Bilger and Hirsh stated that:

> ...masking can occur when the effective level of the noise (entering the ear) is well below the level of the tone being masked. (3, p. 629)

They also concluded that the critical band concept was verified for frequencies which lie within or adjacent to the noise bands but not for frequencies which are remote from the bands, especially in the low-frequency range.

Spieth (33) also studied the downward spread of masking and presented results which confirm the data reported by Bilger and Hirsh (3). Spieth found the masked thresholds of five normal hearers for pure tones using a Bekesy audiometer while presenting narrow bands of noise centered at 500, 1000, 2000, and 4000 cps for three different levels in each noise band. He found that a spectrum level of 75 db re 0.0002 microbar caused from 12 db to 24 db of masking at 100 cps which was the lowest test frequency. At frequencies near the lower effective limit of the noise band he reported 25 db to 40 db of masking. Spieth explained this masking effect by saying that the ear's non-linear transduction of the noise band at these high levels generates aural difference tones which raise the thresholds for low-frequency signals. However, if the masker tone were a single frequency, as Wegel and Lane used (38), he thought that this result would not be found. He observed that, when two pure tones at frequencies and spectrum levels comparable to the noise bands were used, difference tones were produced which equaled the masked thresholds for the low frequencies when masked by bands of noise. As a result of his findings, Spieth concluded that distortion in the ear causes the low-frequency masking observed for noise bands and a 'diffuse effect' is responsible for the spread of masking to high frequencies.

Subsequently, Deatherage, Davis, and Eldredge (5) investigated the possible physiological reasons for the remote masking phenomenon that Bilger and Hirsh (3) reported. They studied this by observing the action potentials and cochlear microphonics of a guinea pig for a 500-cps tone in the presence of narrow-band noise centered at this frequency and the effect generated by another narrow noise band centered at 6950 cps. The low-frequency noise band resulted in the anticipated masking for the 500-cps test frequency. Masking did not occur for this test frequency when the high-frequency noise band was used until higher intensity levels were reached. Remote masking did occur when the noise level of the high-frequency band was 70 db as demonstrated by cochlear microphonics generated in the first and third turns of the guinea pig's cochlea. These investigators believe the evidence for remote masking consisted of the presence of a random, low-frequency cochlear microphonic appearing at the apical turn as well as the expected high-frequency cochlear microphonic at the basal turn. In conclusion, Deatherage, Davis, and Eldredge (5) state that:

> ...the ear responds non-linearly to the high-level noise and 'detects' its envelope as random low frequencies of random amplitude. (5, p. 132)

Deatherage, Bilger, and Eldredge (4) pursued this problem further. They were essentially interested in the constancy of remote masking that Bilger and Hirsh (3), as well as Deatherage, Davis, and Eldredge (5), reported. That is, it had been observed that remote masking is characterized by constant masking over frequency instead of by constant masked threshold sound pressure level over frequency. The term 'constant masking' denotes that amount of masking which is invariant with frequency, so the masked threshold is at the same sensation level. The term 'constant masked threshold' means that the masked threshold is at the same sound pressure level.

In this study, they (4) used various kinds of masking signals. Narrow, high-frequency noise bands, amplitude modulated pure tones, interrupted sinusoids, interrupted narrow-band noise, and a high-frequency tone modulated with white noise were employed. They reported results similar to those of Bilger and Hirsh (3) in that the amount of remote masking below the noise band was about 10 db. This was observed for masking stimuli comprised of narrow-band, high-frequency noise, both continuous and interrupted, and high-frequency tone amplitude modulated by white noise.

Deatherage, Bilger, and Eldredge (4) theorize that the non-linear detector which transmits its output to the sensory mechanism is not the middle ear mechanism but the inner ear. They arrive at this idea because of the reflection characteristics of the tympanic membrane and the middle ear. That is, because audio-signals for the entire frequency range are not transmitted equally by the middle ear transducer, the flat spectrum of a white noise at the ear drum is not passed as a flat spectrum to the inner ear. This means that certain segments of the noise band, depending on their frequency, are transmitted more easily that other portions. This is responsible for the masking found in frequencies in and adjacent to the noise band. But, when the noise originates in the inner ear, as it apparently does when low-frequencies are masked by an intense high-frequency noise band, the differential loss by transmission through the middle ear does not occur. Thus, constant masking invariant with frequency occurs. Deatherage and his associates state that:

> ...remote masking, is, then, clearly a function of the spectrum of the envelope of the signal as detected by the non-linear mechanism... (4, p. 541)

Subsequently, Bilger (2) studied the influence of band width on remote masking and also the relationship of over-all level and spectrum level to this phenomenon. He did a series of experiments in which he changed various parameters. First, he varied the lower cut-off frequency and held the upper cut-off frequency constant. Secondly, the over-all level of the noise band was varied. In a third experiment the lower cut-off frequency was held constant and the upper cut-off frequency was varied. In the fourth condition, he tried to find the way in which intensity must be altered as the band width of the noise is increased to produce constant remote masking. The final study was directed at a validation of the results. His results were stated as follows:

> 1. With band-width held constant, remote masking increases 2 db for each 1 db increase in the spectrum level of the noise. 2. With spectrum level held constant, remote masking increases 1 db for each 1 db increase in the band width of the masking noise. (2, p. 821)

Consequently, he concluded that spectrum level is more important than over-all level or band width in determining remote masking.

Jerger (18) studied the pure-tone masking produced by several noise bands in an ear with sensori-neural impairment and in a normal ear. The first part of the experiment was concerned with the threshold shift produced by a broad-band white noise in a subject with a unilateral high-frequency loss. He reported no difference between the normal and defective ear in the masked thresholds for frequencies within the band of noise but did observe a 20-db threshold shift for the defective ear at 8000 cps, which was above the cut-off frequency for the noise band. No shift of threshold was noted for the normal ear at 8000 cps. Additional testing with a 3200-cps to 4800-cps noise band showed that a spread of masking occurred for frequencies above the low-pass cut-off frequency for the defective ear but not for the normal ear.

Jerger (18) did a follow-up experiment in which he made threshold tracings with a Bekesy audiometer in quiet and in the presence of a 500-cps to 1000-cps octave band of white noise. Four normal-hearing listeners and seven subjects with gradually sloping sensori-neural losses were tested. He discovered the same spread-of-masking effect to frequencies above the noise band for subjects with sensori-neural hearing impairments. Also, there was evidence that thresholds were shifted for frequencies below the noise band. Normal hearers, on the other hand, did not show these effects. Jerger concluded that the most important area of masking research was in the study of frequency regions above and below a band of white-noise masking.

In 1960, Jerger, Tillman, and Peterson (21) reported the results of research which was designed to explore this abnormal spread of masking in greater detail.

The pure-tone thresholds for eleven test frequencies were obtained for 80 subjects in quiet and at two effective levels of 10 db and 30 db in each of the three octave noise bands. The nominal cut-off frequencies were 400-800 cps for the low band, 1200-2400 cps for the middle band and 3200-6400 cps for the high band. The rejection rate of the filter was reported to be approximately 70 db per octave. There were 20 subjects with normal hearing bilaterally, 10 subjects with bilateral normal hearing who had both external ear canals plugged with wax-impregnated cotton pellets, 10 subjects with bilateral otosclerosis, 10 subjects with bilateral otitis media, 10 subjects with bilateral sensori-neural loss presumably due to presbycusis, and 20 subjects with bilateral sensori-neural loss due to cochlear lesion.

The noise level was adjusted separately for each subject in order to produce a particular effective level (either 10 or 30 db). The effective level computations were based on the critical-band widths reported by Hawkins and Stevens (13).The Z was computed by subtracting the threshold sound pressure level measured in quiet for the frequency in the center of the noise band from the over-all pressure level of the critical band for that frequency. The subject's threshold sound pressure level at 500 cps was used to define the effective level of the low band (400-800 cps), the threshold at 2000 cps for the middle band (1200-2400 cps), and the threshold at 4000 cps for the high band (3200-6400 cps). In every instance, the over-all noise level was fixed so that the level per cycle of the noise plus the critical-band width in db minus the threshold sound pressure level in quiet equaled the desired effective level. At both of the intensity levels and for each of the three noise bands, masking was measured at 11 discrete frequencies from 125 cps to 8000 cps using a modified psychophysical method of adjustment.

They found that for frequencies within the noise band the results were equivalent for all groups studied at either effective level. However, the sensori-neural subjects were obviously different from the other subjects in the amount of masking produced if the spread effects were measured both above and below the limits of the noise band.

In the narrow band (400-800 cps), the mean amount of masking produced at effective levels (Z) of 10 db and 30 db in each of the six experimental groups was approximately the same. At a Z of 30 db, however, the mean masking values revealed an abnormal amount of spread of the frequencies both above and below the noise band for the two groups with sensori-neural hearing loss.

For the middle bank (1200-2400 cps), the mean amount of masking produced at a Z of 10 db revealed that the six groups were essentially identical at all test frequencies. At a Z of 30 db, there was again evidence of a spread of masking to higher and lower frequencies for both the presbycusic and sensori-neural groups. For frequencies within the band there was no significant difference in the amount of Z observed among the six groups.

The mean masked threshold produced by the high band (3200-6400 cps) at a Z of 10 db once again showed no significant differences among the six groups at any test frequency. At a Z of 30 db, however, the sensori-neural group exhibited considerably more masking than the other five groups at 8000 cps, and a slight but uniform tendency towards more masking than the other five groups at all frequencies below the noise band. However, unlike the results observed with the low and middle bands, the presbycusic group failed to display any abnormality in the high band.

Jerger and Bucy (19) recently reported on the masking of pure tones by thermal noise on a patient following surgical removal of a meningioma in the right cerebellopontine angle. They presented broad-band noise at an equal over-all level of 80 db re 0.0002 microbar. The masked threshold sound pressure levels for the normal left ear and the impaired right ear were virtually identical. Furthermore, in the presence of octave-bands of thermal noise adjusted to equal effective levels, the spread of masking for frequencies above and below the bands was slightly <u>less</u> on the impaired side than had been previously demonstrated (<u>21</u>) in ears with cochlear losses of essentially equal magnitude.

The findings of the above-mentioned studies (<u>19</u>, <u>21</u>) failed to support the argument that the impaired ear and the normal ear can be identified in any way by the amount of masking revealed in the presence of broad-band thermal noise at an equivalent effective level. This observation is in accord with the findings of Palva, Goodman, and Hirsh (<u>31</u>).

Summary

Two fundamental conclusions can be drawn from the masking literature which has been reviewed in this chapter. First, it is obvious that the critical-band concept, as Fletcher advanced it, is true for white-noise masking in normal ears. Second, the experimental literature concerning white-noise masking on impaired ears fails to substantiate any claim of being able to differentiate the auditory behavior of the normal and impaired ear on the basis of broad-band masking of pure tones at equivalent effective levels.

The above-mentioned study (19) indicates that when a specific narrow band of thermal noise is adjusted to equivalent effective levels for the normal ear and the ear with a sensori-neural impairment due to cochlear damage, the pathological ear will be excessively masked in the frequency ranges both above and below the narrow noise band. Conversely, the ear with a sensori-neural impairment due to retro-cochlear damage does not display excessive spread of masking (21).

CHAPTER III

SUBJECTS, APPARATUS AND PROCEDURE

Introduction

This experiment was designed to explore the masking of pure tones by narrow bands of noise in normal, plugged-normal, and impaired ears when the bands of noise were adjusted to equal overall sound pressure levels, Threshold shift and spread of masking were measured at 11 different frequencies for the three groups of subjects.

The apparatus utilized in this study consisted basically of an audio-oscillator, noise generator, variable filters, amplifier, and mixing network. The audio-oscillator was used to generate sinusoids through the mixing network. The white-noise signal from the noise generator was passed through the variable filters, fed to the amplifier, and then to the mixing network. The noise signal and continuously variable pure-tone signal were then mixed and transduced by the test earphone.

The masking produced by narrow bands of white noise on discrete frequencies was studied in three groups of subjects: (a) a group with normal hearing bilaterally, (b) a group of normal hearers with the test ear plugged, and (c) a group with bilateral hearing loss, presumably due to cochlear pathology.

The experimental data were collected by first obtaining air-conduction and bone-conduction pure-tone thresholds for each subject. Subsequent to this step, the subject was given a sweep frequency threshold test on a Bekesy audiometer for a practice trial. Thereafter, six randomized experimental conditions were run employing the sweep frequency threshold test. These conditions included a record of threshold plots in the presence of five narrow bands of noise at equal over-all sound pressure levels.

A detailed description of the subjects, experimental apparatus, and procedures is presented in the subsequent sections.

Subjects

Three experimental groups were used in this study. One group was comprised of normal-hearing subjects. The second group consisted of normal-hearing subjects with artificial conductive hearing losses induced by plugging the test ear. A third group contained subjects with hearing losses due to cochlear pathology. The mean age, sex, test ear and number of subjects on whom medical diagnosis was available are presented in Table 1.

TABLE 1

MEAN AGE, SEX DISTRIBUTION, TEST EAR, AND NUMBER OF SUBJECTS ON WHOM DIAGNOSIS WAS AVAILABLE FOR THREE GROUPS OF SUBJECTS

Group		Mean Age	Sex M	Sex F	Test Ear R	Test Ear L	Number of Subjects On Whom Diagnosis was Available
Normal	10	20.9		10	5	5	
Plugged-Normal	10	20.4		10	5	5	
Sensori-Neural	20	42.3	5	15	13	7	11

Normal Group

All of the normal-hearing subjects, with the exception of one, were college age, young adults from the University of Oklahoma School of Nursing There were 10 females in this group. The age range of this group was from 18 to 26 years with a mean age of 20.9 years. Prior to being selected for the experimental group, each subject was required to respond successfully to an audiometric screening test. A bilateral audiometric screening test of each subject was given at a hearing level of 10 db re USPHS norm at octave frequencies from 125 cps through 8000 cps in addition to 750, 1500, 3000, and 6000 cps. Only one ear of each subject was used in the collection of data. Also, each of these subjects gave a negative history of ear disease and exposure to noise trauma. None of the subjects were considered a sophisticated listener.

Plugged-Normal Group

All of the ten subjects in the plugged-normal group were selected from the sophomore class at the University of Oklahoma School of Nursing. The entire group was female. This group had an age range of 20 to 22 years with a mean age of 20.4 years. The same screening criteria and procedures used for the normal group was applied to this group. Only one ear of each subject was tested in the plugged-normal group.

One ear of each subject was plugged before experimental tests were begun. The earplug was made from a commercially available ear-mold mix (Plastex Laboratories). The mean hearing level in db re USPHS for the plugged ears is given in Figure 1 for 11 test frequencies. These mean hearing levels were obtained by subtracting the hearing level values for the plugged condition from the hearing level values in the unplugged ears. The threshold pattern is presented in Figure 1.

In order to insure the stability of the occlusion caused by the insertion of ear plugs, periodic threshold checks were made at two test frequencies, 500 cps and 2000 cps, throughout the experimental test session. If the threshold values varied by more than 6 db, the data were discarded, a new ear plug was made, and the subject retested.

Sensori-Neural Group

The 20 subjects with pure sensori-neural hearing losses were

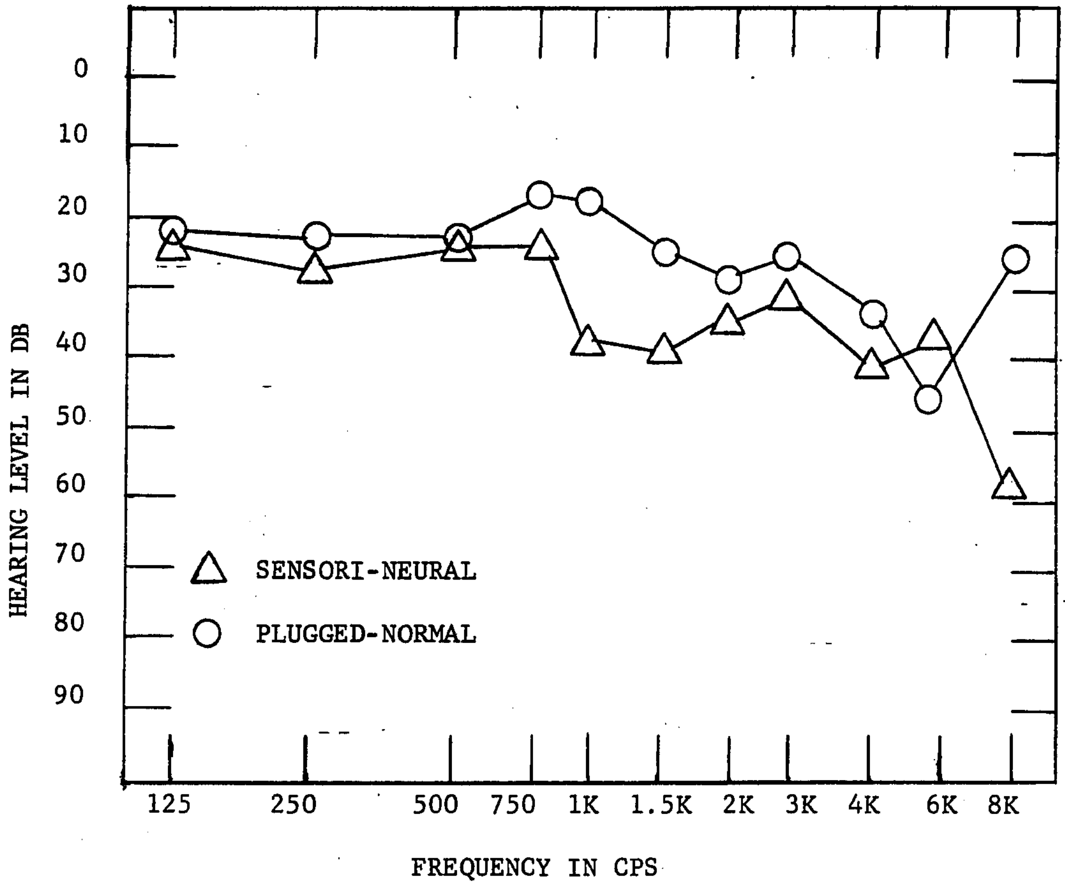

Fig. 1. Mean hearing levels in decibels re USPHS norms at seven test frequencies for the sensori-neural group and plugged-normal group by air conduction.

selected from various sources. Hundreds of audiometric records were examined in order to find individuals who had the specified audiometric configuration and met the stringent requirements of the experimental design. The sensori-neural subjects were selected from the case history files of the University of Oklahoma Speech and Hearing Center, from the files of a private otologist in Oklahoma City[1], and from the files of the Beltone Hearing Aid Service in Oklahoma City.

The experimental design of this study stipulated that a subject with sensori-neural loss should be one who demonstrated interweaving air-conduction and bone-conduction threshold configurations between 250 and 4000 cps and who scored at least 70% on the Short Increment Sensitivity Index at 4000 cps in the test ear.

Audiometric Configuration. Each of the 20 sensori-neural subjects who were used in this study was required to have an audiometric contour which did not show threshold differences greater than 25 db between adjacent octaves from 250 to 4000 cps. This was done in order for each noise band to show a relatively uniform effect across the frequency range. Also, the greatest amount of difference between the maximum and minimum hearing levels in the frequency range between 250 and 4000 cps could not exceed 50 db. In addition, a subject must exhibit at least a 15-db hearing loss at frequencies 250 through 4000 cps. Figure 1 shows the mean hearing levels at the 11 test frequencies for sensori-neural subjects.

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The term sensori-neural heaving loss could conceivably include any site of lesion from the inner ear through the auditory pathways up to the temporal cortex. Therefore, a subject choice based on this classification alone could easily result in a rather heterogeneous sample when such factors as etiology, site of lesion, age of onset, and type of auditory responses are considered. In order to control these variables and obtain as much homogeneity as possible, the label sensori-neural loss was qualified to denote only those subjects whose hearing impairments were attributable to some type of cochlear pathology. This was achieved by administering the Short Increment Sensitivity Index (SISI) developed by Jerger, Shedd, and Harford (20). No subject was included in this experimental sample who did not attain at least a score of 70% in the test ear when the SISI was administered at 4000 cps. Scores of this magnitude and larger have been reported by Jerger and his associates only for cases revealing cochlear pathology.

Age, Test Ear, and Sex Distribution. The minimum age for subjects in the sensori-neural group was restricted to 17 years. No subject older than 75 years of age was tested. Furthermore, no subject was accepted who was more than 50 years of age at the time of onset of his hearing loss. These criteria were stipulated in an attempt to minimize presbycusis as a major causative factor in any of the subjects tested. The age range of the subjects finally selected was 17 to 75 years with a mean age of 42.3 years.

The choice of which ear to test was dependent on the experimental criteria mentioned above. Nevertheless, if both ears met the qualifying criteria, the ear with better hearing was chosen. The right ear was the test ear for 13 subjects and the left ear for 7 subjects. Sex distribution was not controlled in this study. Five subjects were male and 15 were female.

Discussion. In both normal-hearing groups, the audiometric screening methods were applied before any individual was accepted for testing. For the sensori-neural group, the selection criteria presented above were applied to audiometric records previously on file before any person was called as a potential subject. Also, after the subject reported to the clinic for the experimental test, he was given a threshold audiometric test by air conduction and bone conduction. Eleven frequencies were tested by air conduction and the octave frequencies 250 to 4000 cps were tested by bone conduction. After this test, the SISI was administered at 4000 cps in both ears.

The purpose for using 10 subjects in each of the two normal-hearing categories and 20 subjects in the sensori-neural group was based on this premise. That is, normal-hearing subjects tend to exhibit a much greater degree of homogenous response to various kinds of auditory tests. Conversely, this degree of homogeneity of auditory behavior is not usually seen in impaired ears even when they are of the same etiological classification. Therefore, it was thought that a larger number of subjects would be required in order to achieve greater stability of measures of central tendency and variability.

All subjects who participated in this research project donated approximately two and one-half hours of time for each test session.

Apparatus

All tests, both screening and experimental, were conducted in a specially constructed sound-isolated room at the Speech and Hearing Center, University of Oklahoma Medical Center.

Screening Apparatus

A commercially available pure-tone audiometer (Beltone, Model 10 AW) feeding either of two earphones (Telephonic, Type 39-10Z) or a low impedance hearing-aid type, bone-conduction oscillator (Beltone, Model B-70) was used in the screening tests administered to both normal-hearing subjects and in obtaining the threshold audiograms by air conduction and bone conduction for subjects with sensori-neural hearing losses. The earphones were mounted in MX-41/AR cushions and held in a standard headband. The bone-conduction oscillator was held in a standard oscillator headband.

The acoustic output of the air-conduction system of this audiometer was calibrated by means of an Audiometer Calibration Unit (Allison, Model 300).

The bone-conduction system of the audiometer was calibrated in the following way. Air-conduction and bone-conduction thresholds at octave intervals from 250 to 4000 cps were measured for five normal hearing subjects in a sound-treated test room. An attenuator providing a fixed loss of 20 db was inserted in both the air-conduction and bone-conduction circuits prior to obtaining threshold measurements. This procedure permitted thresholds to be recorded at levels below that indicated on the -10 db setting on the hearing loss dial. The mean air-conduction and bone-conduction thresholds for these five normal-hearing subjects were then computed at the five test frequencies. The amount by which the mean bone-conduction threshold deviated from the mean air-conduction threshold at a specific frequency represented the correction factor that it was necessary to apply to that frequency in order to obtain a proper calibration. Correction factors were limited to 5-db increments and no correction was applied unless the deviation between the mean air-conduction and bone-conduction thresholds exceeded 2.5 db.

SISI Apparatus

The Short Increment Sensitivity Index (20) requires the monaural presentation of a steady-state, pure-tone signal to a subject at a supra-threshold level of 20 db. An amplitude increment of 1 db is added to the continuous tone once every five seconds. The subject is instructed to give a response each time he is sure that he has detected the increment. Twenty of these increments are presented. The number of correct responses is converted into a percentage of the total of 20 increments and this percentage becomes the score attained by the subject at the frequency under test.

Figure 2 shows a simplified block diagram of the apparatus used in administering the SISI test to the sensori-neural subjects.

The output of a pure tone audiometer (Beltone, 15A) was fed into a fixed attenuator, passed into a variable attenuator and then to an earphone (Telephonics, Type 39-10Z) mounted in a rubber earphone cushion (MX 41/AR).

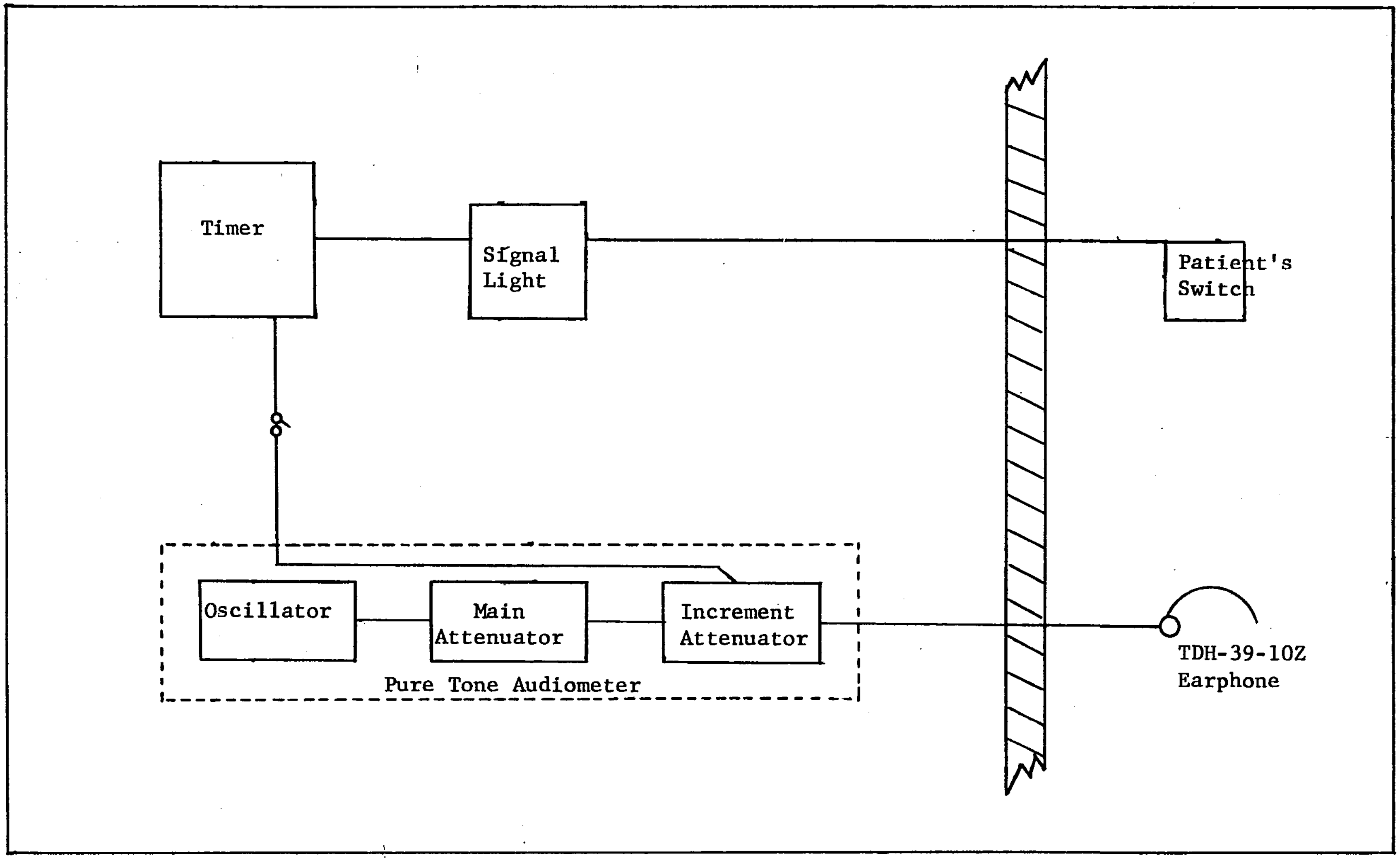

Fig. 2. Simplified block diagram of SISI apparatus.

When the switch activating the mechanical timer was open, the signal transduced by the earphone consisted of a continuous tone from the pure-tone oscillator. However, when the switch was closed, 1-db increments were superimposed on the continous tone approximately once every five seconds. A timer (Industrial Timer Corporation) triggered the increment attenuator so that it transferred a signal for a total of 200 msec. at 4.8-second intervals. The increment attenuator was pre-set to control the amplitude of increment.

Experimental Test Apparatus. Figure 3 shows a simplified block diagram of the experimental apparatus that was used in measuring the pure-tone thresholds in quiet and in each of the five noise conditions. The apparatus consisted of two channels. The pure-tone signals were produced by the upper channel and the various masking signals by the lower channel.

The pulsating, pure-tone signals at test frequencies 100 cps through 8000 cps were produced by a Bekesy audiometer (Grason Stadler, Model E800). The output of this audiometer was passed through a mixing network and then fed to an earphone (Telephonics, 39-10Z).

The stability of the oscillator frequency was maintained by periodic monitoring of the oscillator with a counter-timer (Berkeley, Model 7350).

The source of the noise for the lower channel of the test apparatus was a thermal noise generator (Grason-Stadler, Model E 5539A). The output of the noise generator was monitored by a vacuum-tube voltmeter (Hewlett-Packard, Model 400 DR). The output of the

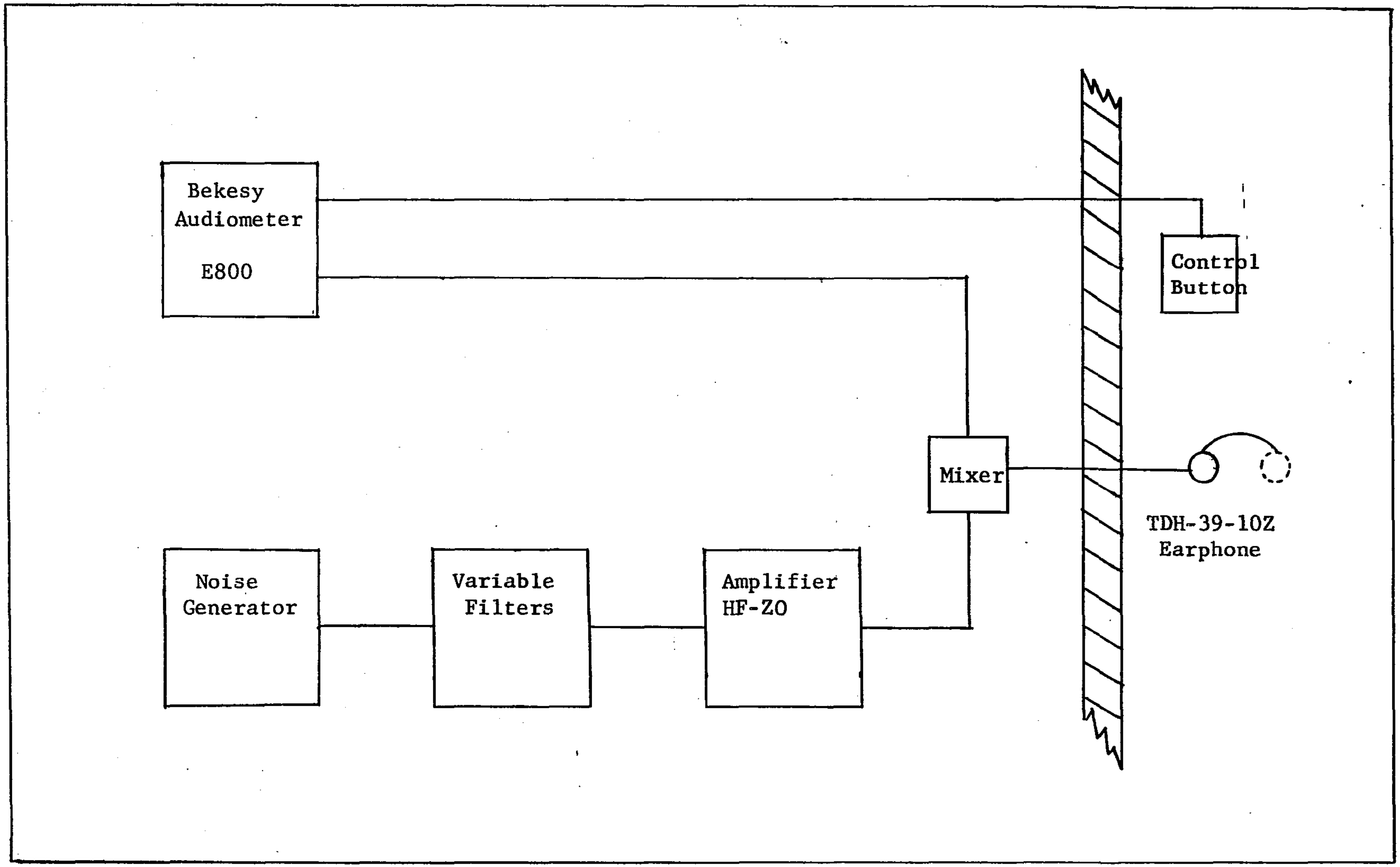

Fig. 3. Simplified block diagram of the experimental apparatus for measuring pure tone thresholds in quiet and under various noise conditions.

noise generator was fed through two variable electronic filters (Spencer-Kennedy, Model 302), and then passed to an amplifier (Eico, Model HF-20). This amplified signal was then fed into a mixing network which combined the pure tone and noise signals and then passed them to an earphone (Telephonics, 39-10Z) mounted in a rubber cushion (MX-41/AR). A companion earphone (Telephonics, 39-10Z) mounted in a rubber cushion (MX-41/AR) was placed on the ear contralateral to the test ear. A white-noise masking signal was fed to this earphone at an over-all sound pressure level of 85 db re 0.0002 microbar. The acoustic output of the filter system was periodically checked with an Audiometer Calibration Unit (Allison, Model 300). Using this apparatus, the over-all level of the pass bands could be expressed in sound pressure level re 0.0002 microbar as developed in a 6cc coupler. The over-all sound pressure levels developed by the five pass bands used in this study were measured daily throughout the entire experiment.

The sound pressure level developed at the earphone at each of the 11 test frequencies was measured at daily intervals during the entire course of the experiment. The maximum variation in output over the nine-week test period was 3.0 db and the week-to-week variation revealed no systematic trend over time. Figure 4 shows the maximum acoustic output developed by the earphone at various test frequencies and at the time of initial calibration as well as the maximum variations which occurred during the course of the testing. The maximum variation in over-all acoustic output generated by the various noise bands during the experimental testing was 4.65 db. Week-to-week variation in the acoustic output of the noise channel revealed no systematic trend over time.

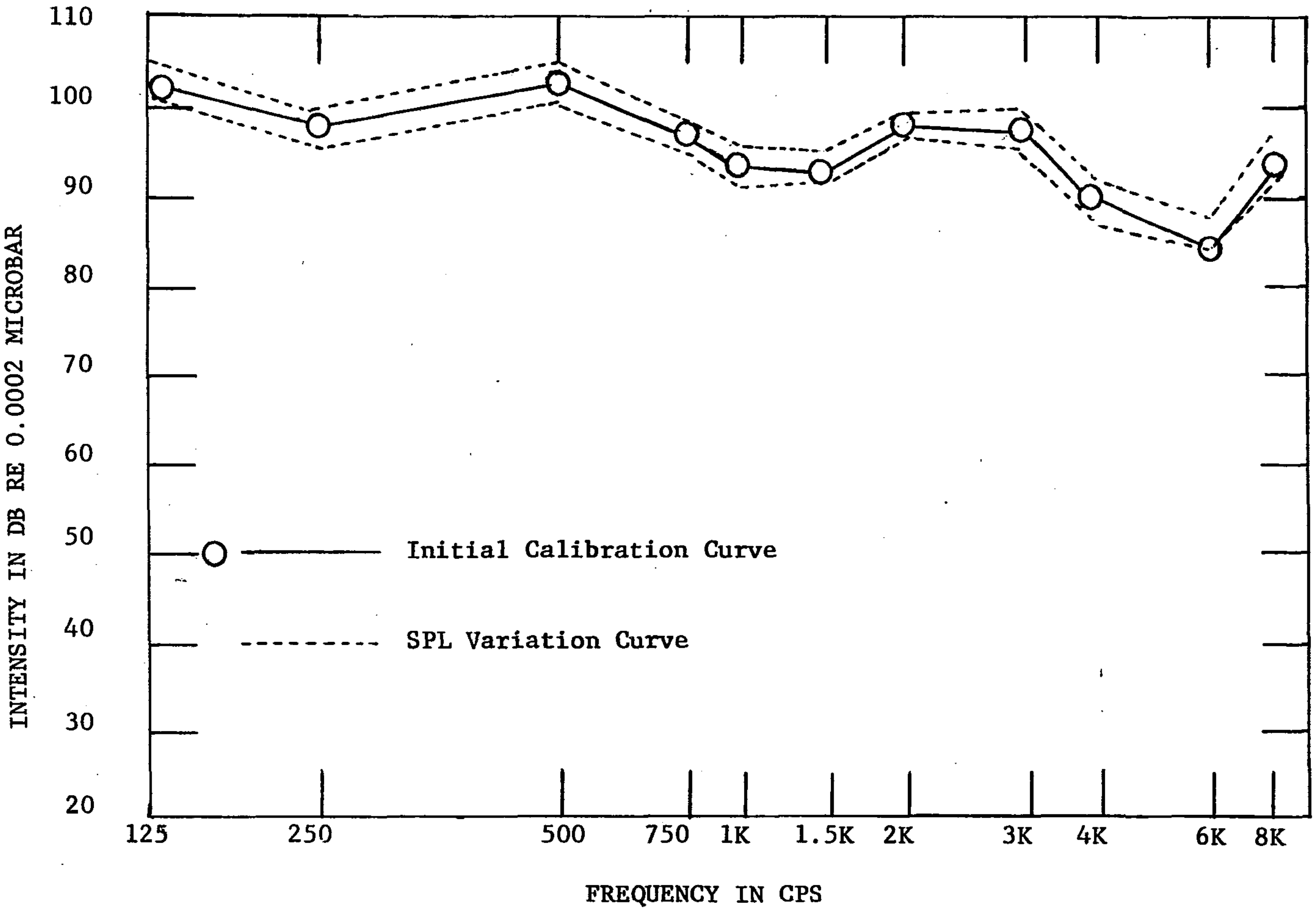

Fig. 4. Initial acoustic output developed for earphone at various test frequencies with positive and negative variation observed over the entire test period.

Table 2 demonstrates the maximum over-all acoustic output developed by the earphone for the various noise bands and the maximum positive and negative variations from that output which occurred during the entire experimental period.

TABLE 2

MAXIMUM OVER-ALL ACOUSTIC OUTPUT OF NOISE BANDS IN DB RE 0.0002 MICROBAR ON DATE OF CALIBRATION, MAXIMUM POSITIVE AND NEGATIVE VARIATIONS FROM THESE LEVELS OVER TESTING PERIOD, AND TOTAL RANGE OF VARIATION IN DB

	Band Passed in cps				
	250	500	1000	2000	4000
Maximum Output	100.0	100.0	100.0	100.0	100.0
Maximum Positive Variation	2.76	1.62	1.84	1.10	1.22
Maximum Negative Variation	1.99	1.48	.98	.88	.55
Total Range of Variation	4.65	3.10	2.82	1.98	1.77

Two variable electronic filters (Spencer-Kennedy Laboratories, Model 302) were used to band pass the noise signal. These filters were placed in series with two sections used as high-pass and two sections used as low-pass filters. In order to produce a specific narrow band of noise centered at one of the five test frequencies (250, 500, 1000, 2000, 4000 cps) all four sections of the filter network were set to the same cut-off frequency, namely, that of the test tone. Each section of these filters rejects at the rate of 18 db per octave beyond the cut-off frequency, thus producing the narrow bands of noise with cut-off slopes of 36 db per octave above and below the frequency of the test tone. Figure 5 shows the frequency response characteristics of the filter network for the noise bands centered at 250, 500, 1000, 2000, and 4000 cps.

The filter frequency response characteristics for the five narrow bands of noise were plotted by means of an audio-oscillator (Hewlett-Packard, Model 400 DR and Ballantine, Model 300). The first voltmeter was used to monitor the output voltage of the oscillator which was held constant throughout the frequency range and fed through the filter network. The second voltmeter was bridged across the output of the filter network and used to read the voltage of any given frequency relative to the input voltage. Readings were made over the frequency range covered by the band to points considerably above and below the nominal cut-off points.

All parts of the experimental apparatus described above except the earphone and mixer were located in the control room. The subject was seated in the test room adjacent to the control room. Communication between the experimenter and subject was affected by an appropriate talkback system.

Procedures

This study was designed to measure the masked threshold sound pressure levels produced by five different narrow bands of filtered thermal noise presented at an over-all sound pressure level of 100 db re 0.0002 microbar in normal ears, ears with a conductive loss created

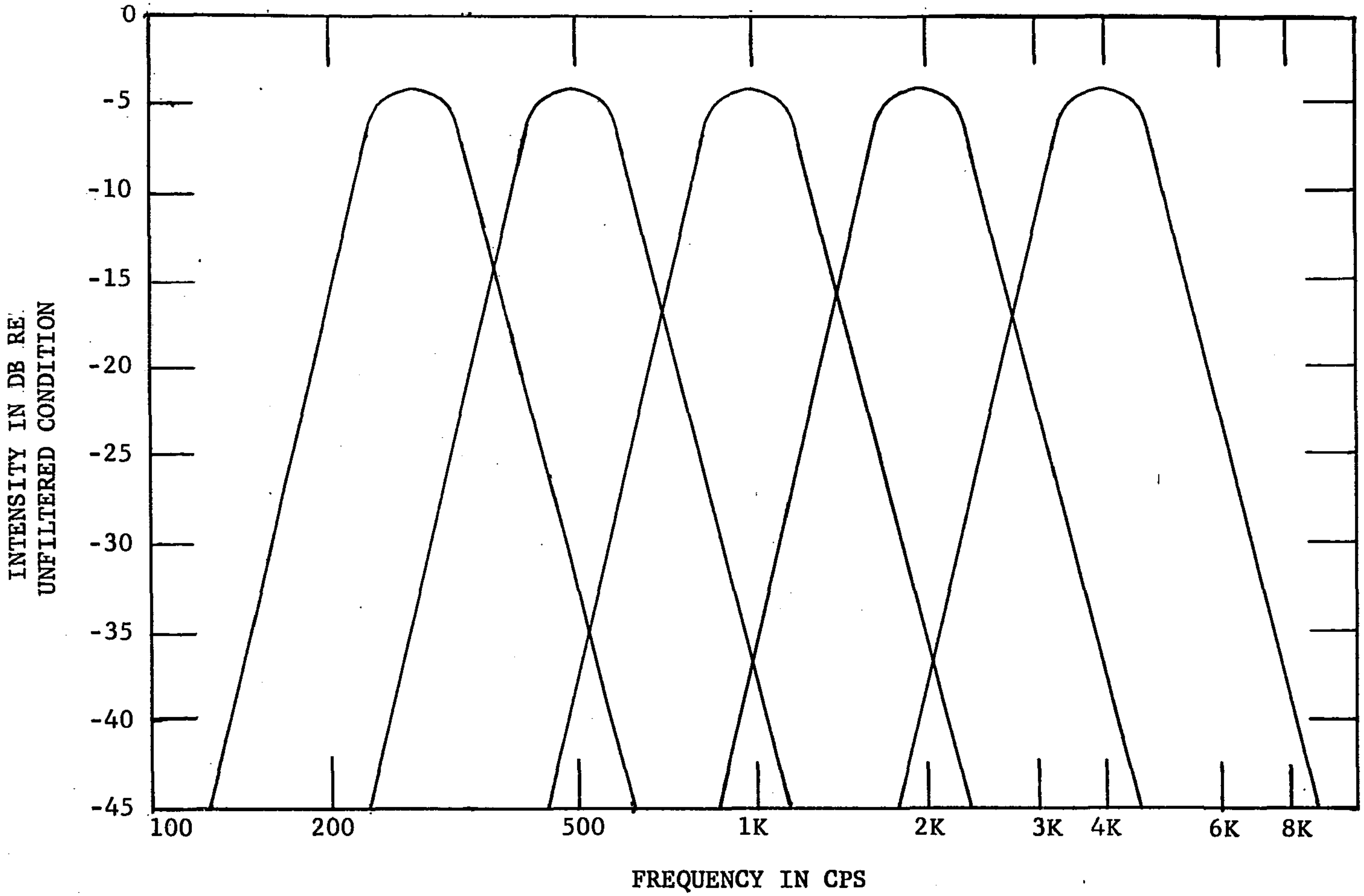

Fig. 5. Frequency response characteristics of the filter system for five narrow bands of filtered thermal noise. Nominal center frequencies were: band one, 250 cps; band two, 500 cps; band three, 1000 cps; band four, 2000 cps, band five, 4000 cps.

by plugging the test ear with earmold material, and ears with a sensori-neural loss presumably due to cochlear pathology. The masked threshold sound pressure levels were measured at 11 test frequencies, some of which fell at the center of each narrow band of noise and the others which fell above and below the specific noise band. It was felt that this experimental design would furnish the best method of obtaining data on the following questions. First, do the normal ear and the ear with cochlear hearing impairment show essentially equal masked threshold sound pressure levels at frequencies within the narrow noise band? Secondly, does the ear with cochlear impairment reveal greater masked threshold sound pressure levels above and below the noise band than those yielded by the normal ear in these same frequency regions? Thirdly, is the pattern of the masked threshold curves at frequencies above and below the various noise bands the same for the normal ear as the impaired ear?

The initial test procedures used with each of the experimental groups were discussed in the section pertaining to subject criteria. Essentially, the bilateral hearing sensitivity of the normal-hearing subjects was screened at a hearing level of +10 db re USPHS norm. This test was administered at octave intervals from 125 to 8000 cps and included 750, 1500, 3000, and 6000 cps as well. The subjects in the sensori-neural group also received bilateral threshold acuity tests. Threshold values were obtained over the same frequencies by air conduction and by bone conduction at octave intervals for the frequency range 250 cps to 4000 cps. Also, the SISI was administered at 4000 cps in both ears to each subject with a sensori-neural hearing loss.

Although the initial screening and qualifying tests differed for the normal-hearing groups and the sensori-neural group, the experimental test procedure employed to measure masking was the same for both the normal and pathological ears tested in this study.

Seven pulsed-tone Bekesy, threshold tracings were plotted from 100 through 8000 cps for each normal and pathological subject. Two of these Bekesy tracings were made in quiet and five were plotted in the presence of five different narrow bands of noise delivered at an over-all sound pressure level of 100 db re 0.0002 microbar. The pure-tone stimulus presented to the subject was fed to an internally-timed electronic switch so that a pulsed-tone with a clickless onset, pulsing 2.5 times per second was produced. After suitable amplification and control attenuation, this signal was fed to a modified portion of a sound-level recorder in such a manner that its level was controlled by a motor-driven attenuator. The direction of the attenuator was controlled manually by the listener. Level was also recorded indirectly as a function of frequency; a mechanical link between the oscillator and the recorder furnished the needed synchronization.

Each of the 40 subjects was instructed to depress his attenuator-control button as soon as he heard the pulsating tone and to release the button when he could no longer perceive the tone. One audiogram was made in quiet at the beginning of each experimental session. This constituted the 'practice' trial for each subject for the purpose of familiarizing him with the test procedure. The results of this initial test were not used in the analysis of the experimental data.

The following instructions were read to each subject prior to the initial unmasked Bekesy threshold tracing in the quiet condition:

> In this test you will hear a pulsating tone which gradually increases in loudness. As soon as you hear this pulsating tone, you are to depress this switch (demonstrate) and keep it down until you no longer can hear the pulsating tone. Then, when you are sure you no longer can hear the pulsating tone, release the switch immediately and wait until the tone reappears. Once again, as soon as you become aware of the pulsating tone depress the switch until the tone fades out and is no longer detectable. Then, when you are sure you can no longer hear it, release the switch and wait until the tone reappears. Continue to listen carefully and respond in this way throughout the entire test. Are there any questions?

After completion of the initial unmasked Bekesy threshold tracing in quiet, the following additional instructions were given to each subject:

> Now you are going to take this same test again but you will also hear another sound. This will sound like rushing air or a loud hissing noise. Although this noise will be present throughout the entire test, you are to ignore it as much as possible and continue to respond only to the pulsating tone in exactly the same way as you did in your first (practice) test. Remember, do not push down on the switch until you hear the pulsating tone. Are there any questions?

Following the above-mentioned procedures, five masked audiograms and one audiogram in quiet were obtained. The five, octave-band, thermal-noise signals were delineated by adjusting the high-pass and low-pass sections of the filters to the same frequency setting. This was done in order to obtain the narrowest possible noise bands. Figure 5 show the frequency response characteristics used to modify the wide-band, flat-spectrum, thermal-noise signal to produce these narrow noise bands. The intensity of each of these noise bands was adjusted to produce an equal over-all sound pressure level of 100 db re 0.0002 microbar for each of the 40 ears tested. Monaural thresholds were taken on the better ear of each listener.

A visually interpolated midline was drawn through the envelope of each Bekesy audiogram. The point at which this midline intersected a frequency was considered to be the threshold for that frequency. The masked threshold sound pressure levels produced under each of these five noise conditions for each of the 40 ears in this experiment were measured at 11 test frequencies (125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 cps). These thresholds were then converted to sound pressure level (db re 0.0002 microbar in an ASA Type-1 coupler).

The six Bekesy threshold plottings (not including the initial practice plot in quiet were considered to comprise six test conditions: the quiet condition and five noise conditions. These six conditions were presented to each of the 40 subjects in random order. In addition, the order of the beginning frequency was counterbalanced. That is, half of the subjects in each experimental group were started at 100 cps and the frequency went from low to high. The other half of the subjects in each experimental group were started at 8000 cps and the frequency went from high to low. Also, in order to control the possible auditory fatigue caused by presenting bands of noise at the over-all sound pressure level of 100 db re 0.0002 microbar, a five minute interim was interjected between each test condition.

No subject was permitted to remove the earphone during the entire test session because of the possibility of a change in occlusion effects. Furthermore, when each of the masked audiograms was traced, a wide-band thermal masking noise at a sound pressure level of 85 db re 0.0002 microbar was fed into the ear contralateral to the test ear. This was done in order to avoid any possibility of the non-test ear responding to the pure-tone signal heard in the opposite ear when the test tone was delivered at such high intensity levels.

Following the above-mentioned procedures, it was possible to compute the amount of masking produced at any given test frequency under any noise condition by subtracting the threshold sound pressure level in quiet from that in a specific noise condition.

Each of the 40 subjects in this study was tested in a single experimental session. The approximate length of each session depended on the subject's facility in learning the task. The average test session required approximately two hours for the normal hearers and about two and one-half hours for the sensori-neural group.

Summary

The purpose of this study was to measure the masking of pure tones by five narrow bands of thermal noise. The experimental procedures were administered to three groups of subjects. The first group was composed of 10 normal-hearing subjects. The second group included 10 normal-hearing subjects in whom pseudo-conductive hearing losses were created by occluding the test ear with special earmold fabricating material. The third group contained 20 subjects who had sensori-neural hearing losses presumably due to cochlear pathology. The subjects in this latter group were selected especially so that the degree of their hearing impairment approximated, as nearly as possible, those of the plugged-normal subjects. Also, the selection criteria required for the sensori-neural group assured that the configuration of their audiometric records would be relatively flat as were the audiometric contours of the plugged-normal group. In summary, then, the audiometric criteria for the sensori-neural group was such that the plugged-normal group could serve as a control for the sensori-neural group.

The narrow-band, thermal-noise, masking stimuli used were generated by band-pass filtering a wide-band thermal-noise signal. The five noise bands were identified by the following nominal cut-off frequencies: 250, 500, 1000, 2000 and 4000 cps.

The intensity of the five bands of thermal-noise was adjusted to an over-all sound pressure level of 100 db re 0.0002 microbar. The amount of masking produced by these five bands at this intensity level was measured for each of 40 subjects at 11 test frequencies from 125 to 8000 cps. As a result, six threshold Bekesy tracings over this frequency range were made for each subject: one in quiet and one in each of the five noise conditions.

The design of this study permitted comparison of the three groups, not only in terms of the amount of masking below and above the specific noise bands, but also in relation to the characteristic pattern of masking outside of the five noise spectra. The results of the experimental methodology described above are reported in the following chapter.

CHAPTER IV

RESULTS

Introduction

Three groups of subjects were studied in this investigation of auditory masking. These three groups were composed of subjects whose hearing sensitivity was normal, artificially impaired (due to plugging the test ear with plastic material), and impaired hearing (presumably due to cochlear pathology). Five narrow bands of thermal noise were used as masking signals. The masking generated by these five narrow bands of thermal noise was presented at an over-all sound pressure level of 100 db re 0.0002 microbar. The masked threshold sound pressure levels were measured in each group at 11 test frequencies from 125 through 8000 cps. The results of these auditory measurements will be discussed separately for each of these narrow bands of thermal noise centered at the following cut-off frequencies: 250 cps, 500 cps, 1000 cps, 2000 cps, 4000 cps.

250-cps Noise Band

The high-pass and low-pass sections of both filters were adjusted to the cut-off frequency of 250 cps. The mean over-all sound pressure level of the masking produced by this narrow noise band for the three groups was plotted as a function of frequency in Figure 6. Inspection of this figure revealed that the masked threshold values

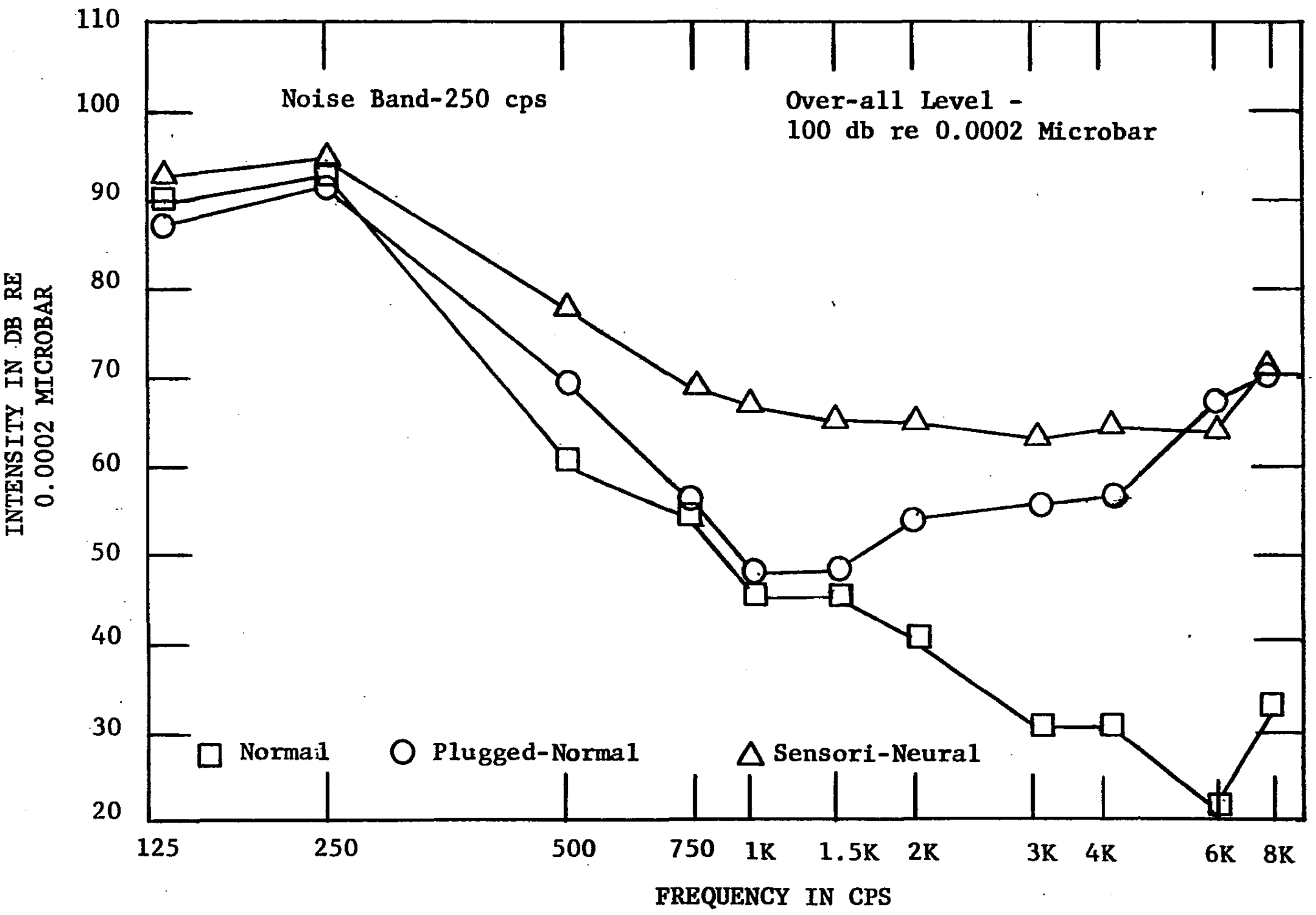

Fig. 6. Mean masked thresholds produced by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

were essentially the same at the center cut-off frequency for all three groups. Above the cut-off frequency of 250 cps a definite difference in the amount of masking among the three groups was apparent. That is, while the plugged-normal and normal-hearing groups continued to exhibit lower masked threshold values as the frequency increases, the masked threshold of the sensori-neural group remained at a considerably higher level. This difference in the masked threshold values became evident at 500 cps. At this frequency, the mean masked threshold of the sensori-neural group was shifted 7 db more than the plugged-normal group and 15 db more than the normal group. This excessive spread of masking became more marked as the frequency of the test tone increased and continued out to 4000 cps. Beyond 4000 cps, the plugged-normal and sensori-neural groups no longer revealed significant differences in their masked threshold levels.

At frequencies below the cut-off frequency of 250 cps, there was only the slightest hint of an excessive downward spread of masking for the sensori-neural group. However, since no measurements were taken below 125 cps, no further data are available to substantiate this observation and thus no definitive statement regarding excessive masking can be made for frequencies lying below the narrow noise band centered at 250 cps.

An indication of the variability in the auditory masking performance of these three groups is shown in Figure 7. This figure presents the standard deviations for each of the three groups plotted as a function of frequency. At this intensity level, the standard deviations of the mean masked threshold shifts did not exceed 5 db

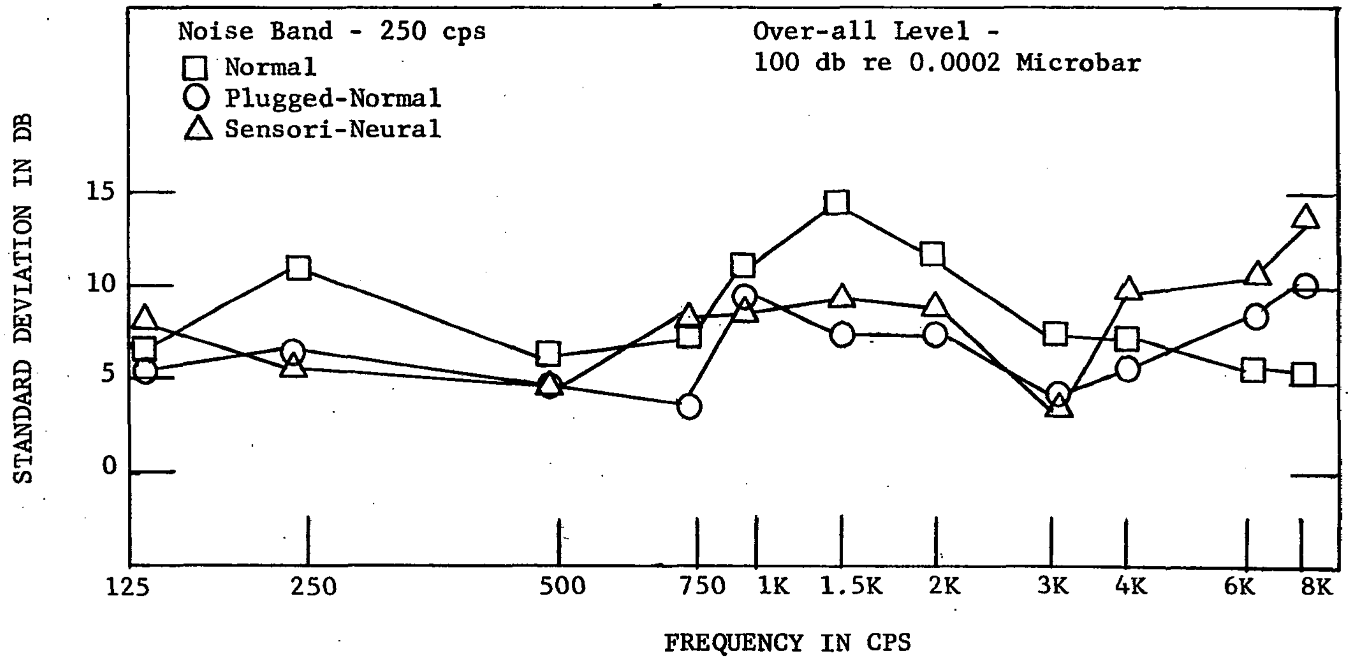

Fig.7. Standard deviations of masking by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

at the cut-off frequency of 250 cps for the two impaired-hearing groups. The normal group revealed a standard deviation of 12 db at the cut-off frequency. The two impaired-hearing groups exhibited essentially interweaving curves out to 4000 cps after which an increase appeared in the amount of variability among the sensori-neural and plugged-normal subjects. Conversely, there was a lessening of variability after 4000 cps for the normal-hearing group.

In general, then, it can be stated that the variability increased considerably in the higher frequencies among subjects with auditory impairment while becoming increasingly stabilized for the normal ear. In the frequency range below the cut-off frequency no essential difference in variability was noted.

The above-mentioned data for the narrow band of noise centered at 250 cps and displayed in Figures 6 and 7 are presented in Table 3 in numerical form.

500-cps Noise Band

The high-pass and low-pass sections of the two variable filters were set to the cut-off frequency of 500 cps. The mean over-all sound pressure level of the masking produced by this narrow noise band for the three groups was plotted as a function of frequency in Figure 8. This figure disclosed that there was essentially no difference in the masked threshold curves among the three groups at the frequency in the center of the noise band. At frequencies above 500 cps there was a definite difference in the amount of threshold shift revealed by all groups. At 750 cps and above, two salient features were

TABLE 3

MEAN MASKED THRESHOLDS AND STANDARD DEVIATION IN DB FOR THREE GROUPS PRODUCED BY THE 250-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

	Frequency in cps										
	125	250	500	750	1k	1.5k	2k	3k	4k	6k	8k
	Normal Group										
M	90	92	61	53	45	38	37	26	26	23	33
SD	6.31	11.52	5.99	6.45	10.29	12.34	9.99	7.09	6.23	6.75	4.98
	Plugged-Normal Group										
M	88	92	69	55	48	48	54	52	53	69	80
SD	4.49	6.08	4.38	3.39	9.65	6.15	6.89	3.77	5.64	9.44	10.07
	Sensori-Neural Group										
M	93	94	76	69	66	65	64	60	63	64	81
SD	7.84	5.51	4.29	7.47	8.75	7.50	7.31	4.69	0.07	11.49	14.30

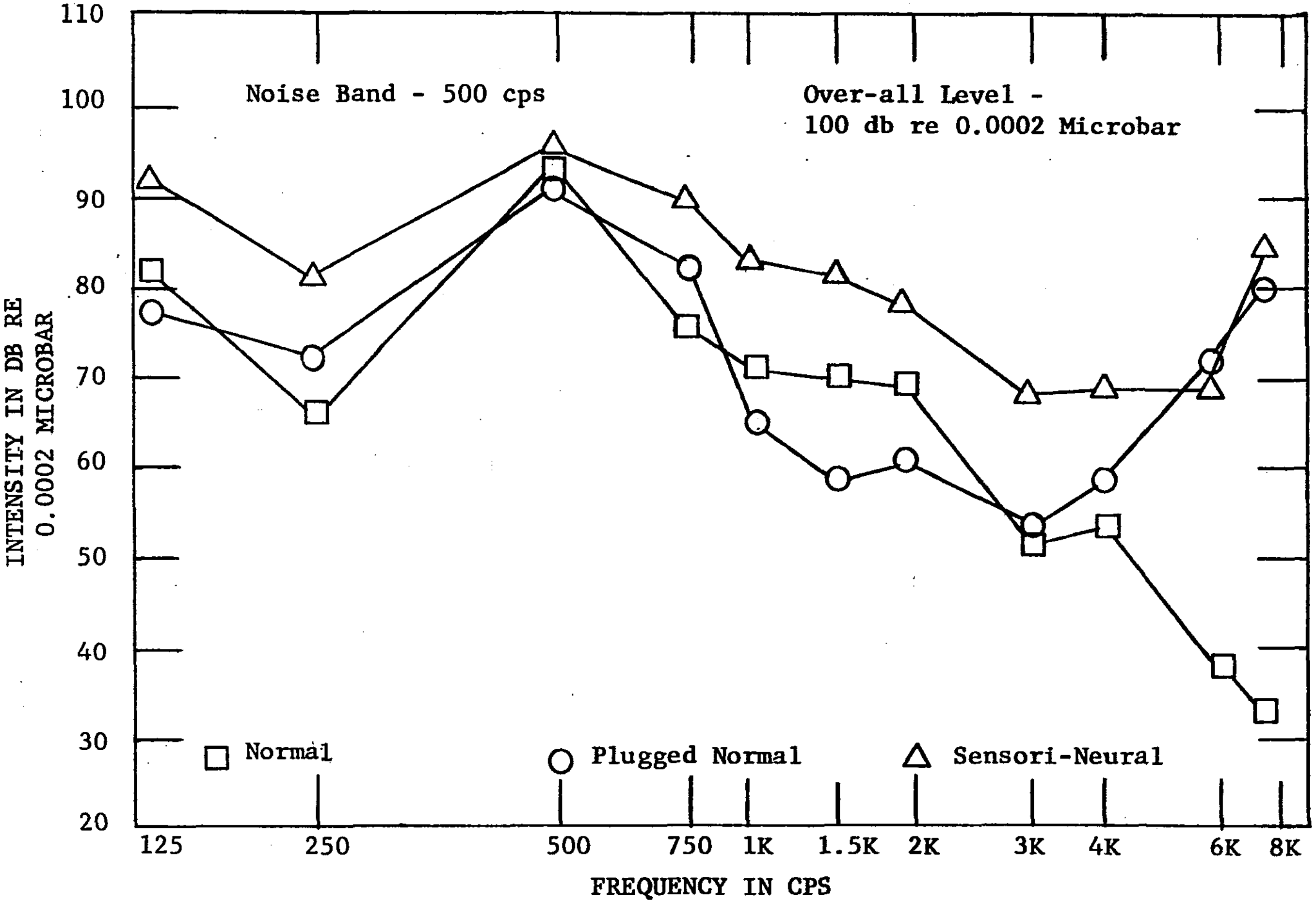

Fig.8. Mean masked thresholds produced by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

evident. First, the sensori-neural group continued to display masked threshold sound pressure levels approximately 10 to 20 db higher than the plugged-normal and normal groups. This excessive spread of masking seen in the sensori-neural ear was evident out to 4000 cps. At 6000 and 8000 cps, the plugged-normal and sensori-neural groups no longer display this excessive spread of masking. Secondly, the plugged-normal group evidenced considerably less masking at 1000, 1500, and 2000 cps than did the normal group.

The differences among the three groups in the downward spread of masking became quite distinct below this narrow noise band. At 250 cps there was an 8-db difference between the sensori-neural and plugged-normal groups and a 15-db difference between the sensori-neural and normal groups at this frequency. Although all three groups demonstrated greater masked thresholds at 125 cps than they exhibited at 250 cps, the relative differences in masking among the groups remained similar to those seen at 250 cps. However, the excessive spread of masking for the sensori-neural group was very apparent since this group continued to exhibit a masked threshold approximately 10 to 14 db higher than did the other two groups. Bilger and Hirsh (3) reported a non-linear increase in the masked threshold shifts for frequencies below their lowest noise band (394-670 cps) as well as a 'constant masking' which clearly diverged from the characteristics of their variable-filter network. The results observed for the 500-cps noise band in the present study compare quite closely to those findings reported by Bilger and Hirsh (3) for their noise band (394-670 cps). First, a non-linear increase in the masked-threshold shifts for frequencies below the noise band was apparent. Second, 'constant masking' was produced for frequencies below the noise-band limits. Finally, an excessive spread of masking was demonstrated by the sensori-neural group for frequencies both above and below the cut-off frequency.

Figure 9 displays the variability in the amount of masking revealed by these three groups in the presence of a narrow noise band centered at 500 cps. The standard deviations of the masked thresholds for the sensori-neural and plugged-normal groups did not exceed 5 db at the cut-off frequency whereas the normal group showed a 9-db variation. However, below 500 cps, the sensori-neural group demonstrated greater variability than the normal and plugged-normal groups which revealed essentially the same degree of deviation. At frequencies above 500 cps, the normal group continued to display more variability out to 4000 cps above which the two impaired-hearing groups showed more variability than the normal group. Basically, it can be seen that the sensori-neural group manifested the greatest variability below 500 cps whereas the normals revealed the most deviation in the frequency range from 750 to 3000 cps above which the two impaired-ear groups presented greater instability.

Figures 8 and 9 and Table 4 contain the data for the narrow band noise centered at 500 cps.

1000-cps Noise Band

In order to secure the narrowest possible noise band centered at 1000 cps both the high-pass and low-pass sections of the two

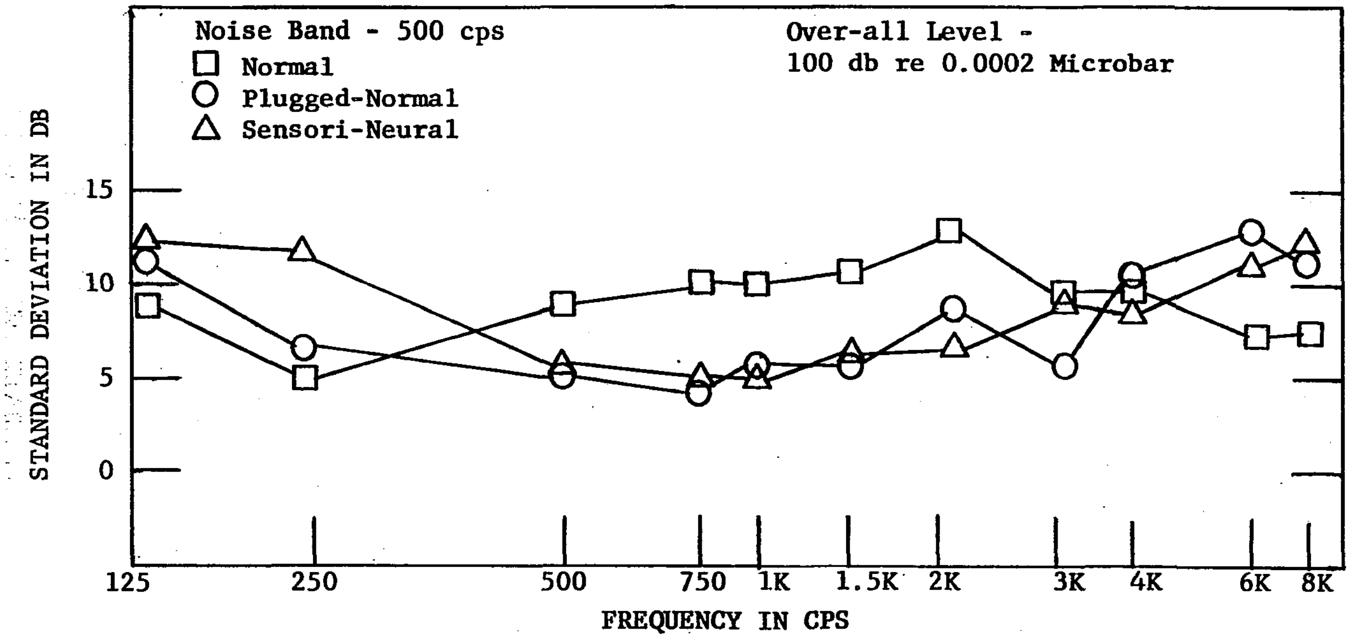

Fig.9. Standard deviations of masking by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

TABLE 4

MEAN MASKED THRESHOLDS AND STANDARD DEVIATION IN DB FOR THREE GROUPS PRODUCED BY THE 500-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

	Frequency in cps										
	125	250	500	750	1k	1.5k	2k	3k	4k	6k	8k
						Normal Group					
M	82	66	92	75	69	68	67	51	53	37	43
SD	9.20	5.02	8.07	9.01	8.71	9.52	12.43	9.82	9.54	7.28	7.12
						Plugged-Normal Group					
M	78	73	90	80	63	56	58	53	56	71	80
SD	10.80	6.05	4.84	4.08	5.30	5.58	6.26	6.08	10.55	13.54	11.01
						Sensori-Neural Group					
M	92	81	94	87	81	78	76	68	69	68	84
SD	12.99	11.64	5.25	15.05	4.93	6.21	4.76	9.12	8.78	12.11	13.99

variable filters were adjusted to 1000 cps. This band of noise was passed to the earphones at an over-all sound pressure level of 100 db re 0.0002 microbar.

Figure 10 shows the mean masked threshold curves for the three groups plotted as a function of frequency. An examination of Figure 10 reveals that the masked threshold values for the three groups were essentially the same for the cut-off frequency within the narrow band. But, at frequencies above 1000 cps, the sensori-neural group displayed a consistently greater degree of masking than did the other two groups. At 3000 and 4000 cps, the differences between the masked thresholds of the normal and sensori-neural groups were approximately 20 db. Furthermore, at 8000 cps, the sensori-neural group showed a 'bounce' effect which shifted the masked threshold to within 5 db of the masked threshold value at the cut-off frequency of 1000 cps. This same bounce pattern was revealed by the plugged-normal group to a lesser degree but was not apparent for the normal group.

The difference in the auditory masking behavior of the sensori-neural group, when compared to the other two groups, was also apparent at frequencies below the center of the noise band. The normal and plugged-normal groups followed the filter characteristics out to 500 cps and then displayed 'constant masking' at 250 and 125 cps with a sharp non-linear increase in masked threshold levels for these two frequencies. The sensori-neural group also revealed 'constant masking' at 250 and 125 cps but with less of a steep non-linear increase in masked threshold levels since the

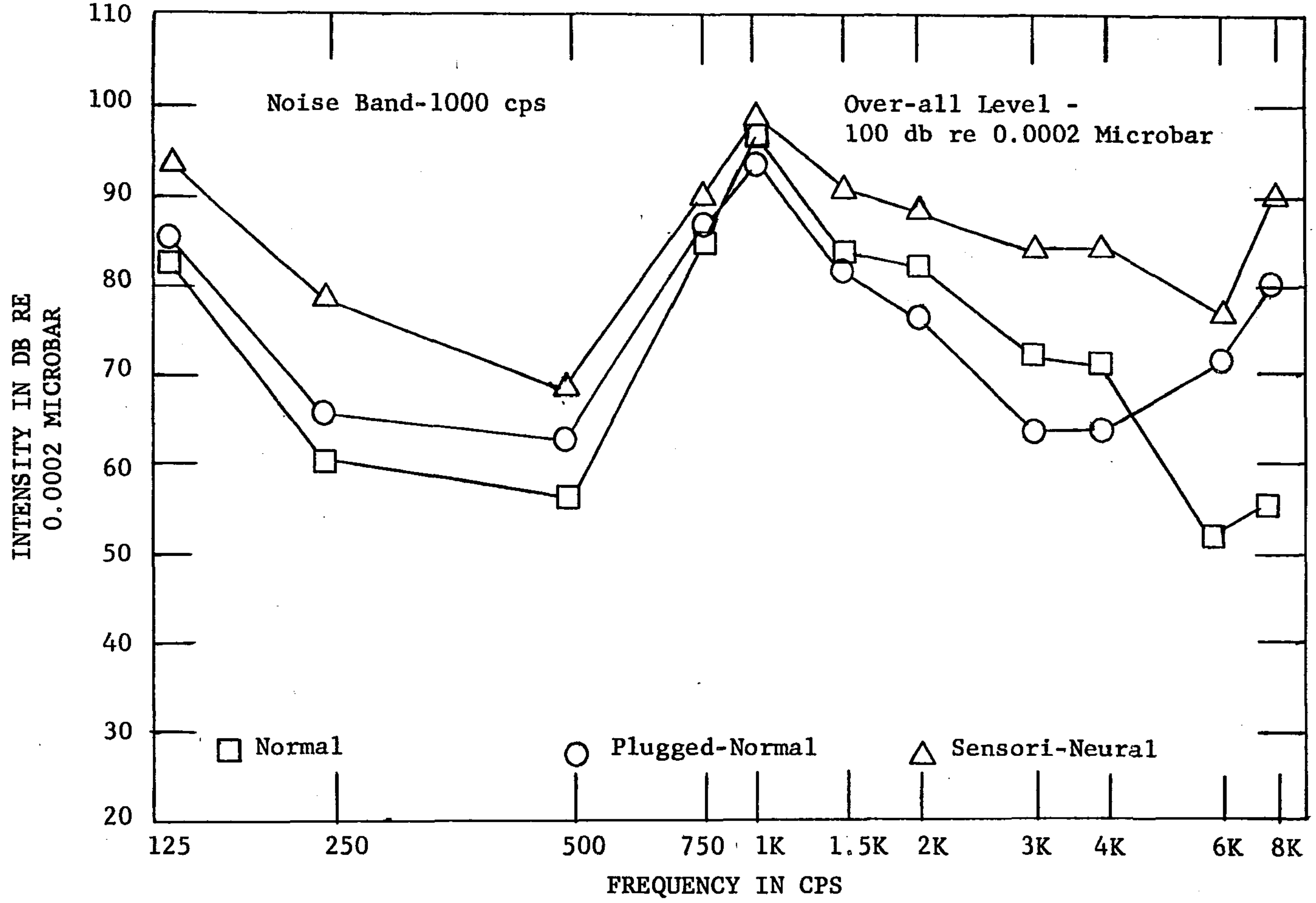

Fig. 10. Mean masked thresholds produced by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

excessive spread of masking had maintained decidedly higher masked threshold values for the entire frequency range below the 1000-cps cut-off frequency.

The variability of the masked thresholds as a function of frequency for the three groups is shown in Figure 11. At the cut-off frequency of 1000 cps the three groups revealed standard deviations of approximately 6 to 8 db and at 750 cps only 3 to 5 db. However, for frequencies below 750 cps the sensori-neural group displayed substantially more variability than did the other two groups. In the frequency range above 1000 cps all three groups demonstrated fairly close and interweaving variability curves without any really apparent difference.

The data for the narrow band centered at 1000 cps is included in Figures 10 and 11 as well as Table 5.

2000-cps Noise Band

The high-pass and low-pass sections of both filters were set to the cut-off frequency of 2000 cps in order to secure the narrowest possible noise band centered at this frequency. This band of noise was presented at an over-all sound pressure level of 100 db re 0.0002 microbar.

The mean masked thresholds for the three groups are presented in Figure 12. This figure shows that the mean masked thresholds for these three groups were approximately equivalent for the frequency located at the center of the narrow noise band. However, in the frequency range above 2000 cps, more masking was demonstrated

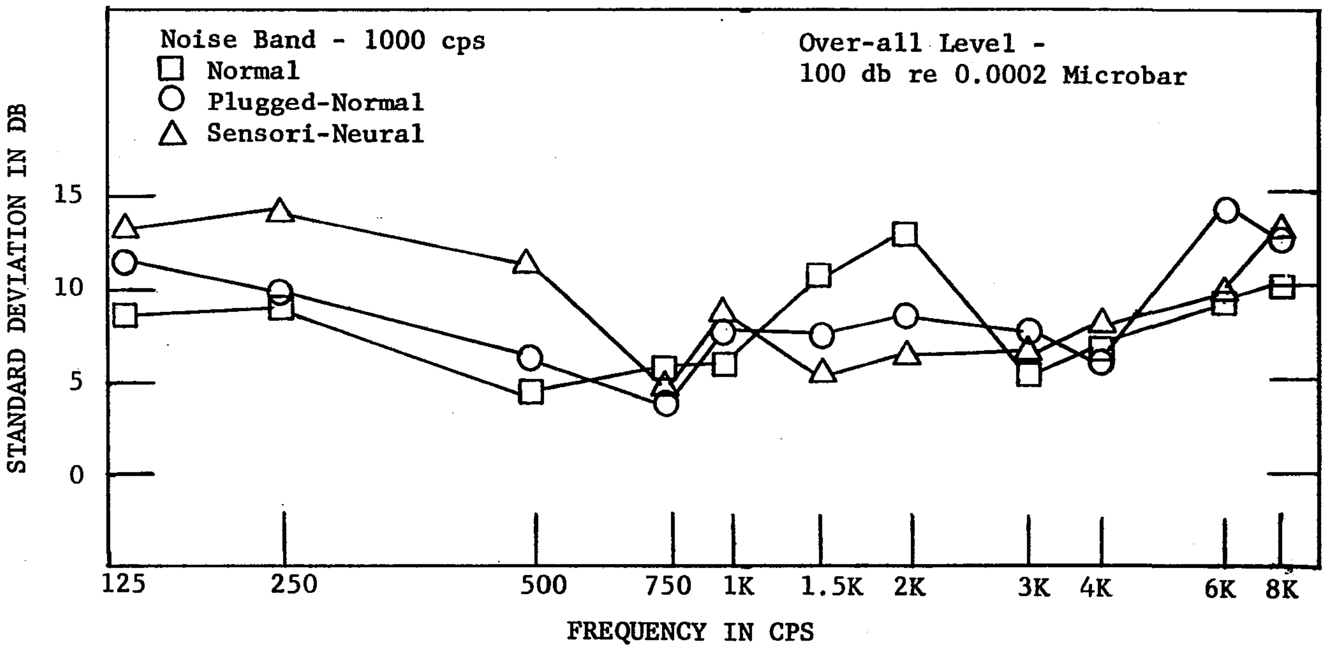

Fig. 11. Standard deviations of masking by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

TABLE 5

MEAN MASKED THRESHOLDS AND STANDARD DEVIATION IN DB FOR THREE GROUPS PRODUCED BY THE 1000-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

	Frequency in cps										
	125	250	500	750	1k	1.5k	2k	3k	4k	6k	8k
					Normal Group						
M	82	60	55	82	92	80	78	66	68	51	54
SD	6.98	8.35	4.61	4.88	6.50	9.46	11.63	5.32	6.65	9.49	9.80
					Plugged-Normal Group						
M	85	64	61	83	89	79	74	59	59	71	80
SD	10.90	8.53	5.23	3.26	7.40	5.94	7.64	7.33	5.50	13.60	12.70
					Sensori-Neural Group						
M	93	78	68	88	95	89	84	78	78	75	90
SD	13.09	14.81	10.83	4.68	8.50	14.76	6.29	6.39	8.06	9.69	13.10

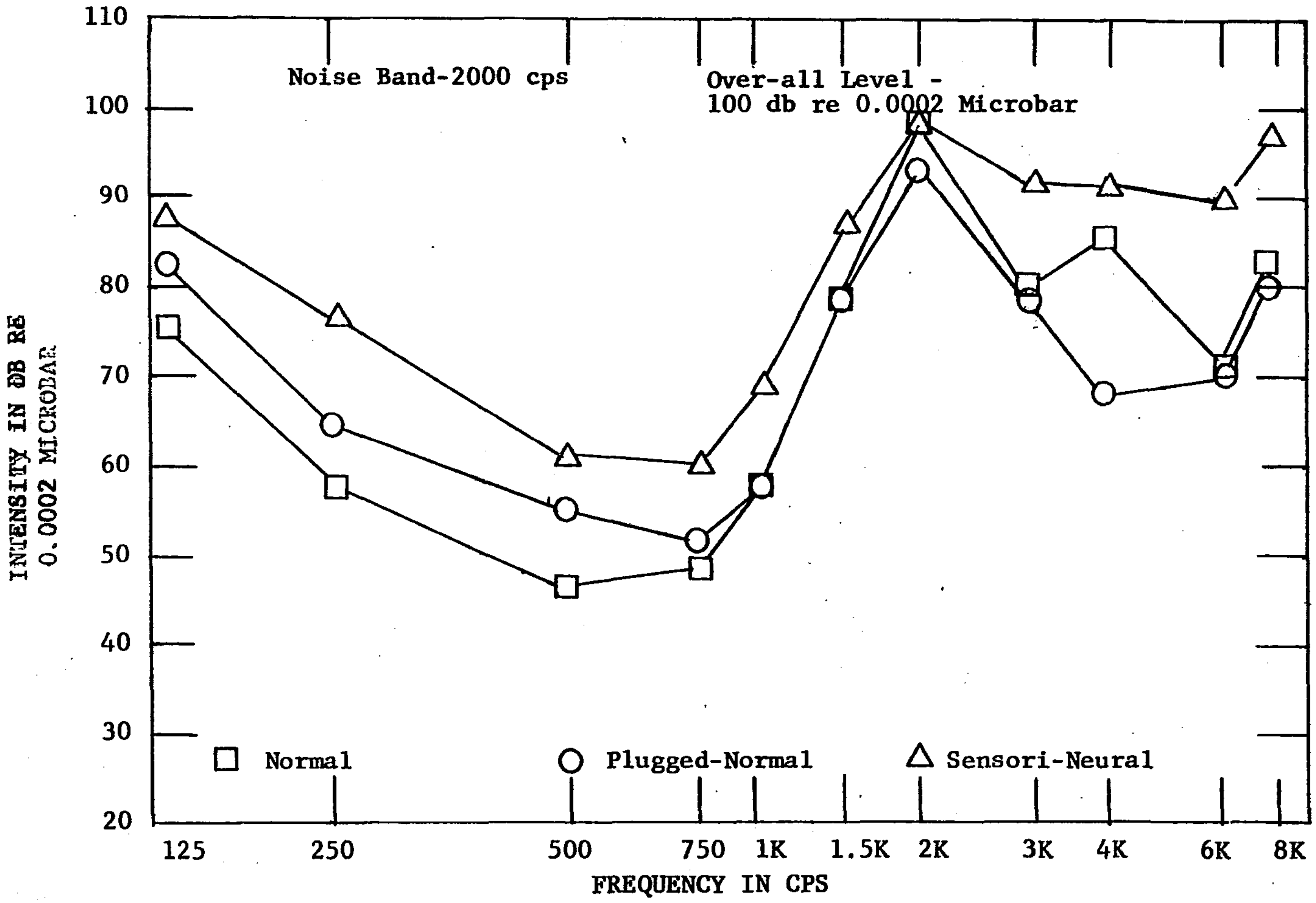

Fig. 12. Mean masked thresholds produced by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

by the sensori-neural group than by either of the other groups. This excessive spread of masking remained relatively constant out to 8000 cps. At 8000 cps the mean masked threshold curve showed a 'bounce' effect which surpassed the mean masked threshold value at the cut-off frequency of 2000 cps. The plugged-normal and normal groups exhibited the same masked threshold value at 3000 cps but the plugged-normal masked threshold curve continued to descend well below the other two curves at 4000 cps and quickly accelerated to nearly equal intensity levels with the normal curve at 6000 and 8000 cps. Palva, Goodman, and Hirsh (31) observed a similar reaction in their study. They used a wide-band thermal-noise signal to mask pure tones and consistently found that the masked threshold sound pressure levels for their conductive and mixed groups fell below those of the normal and other impaired groups in the 3000 through 8000 cps frequency range. In the present study, at 8000 cps the normal and plugged-normal groups both demonstrated a 'bounce' or increase in masked threshold sound pressure level although not nearly to the degree revealed by the sensori-neural group.

At frequencies below the cut-off frequency of 2000 cps, a definite difference in the auditory masking behavior of the three groups was apparent. The sensori-neural masked threshold curve revealed a greater spread of masking than either of the other two groups. In the frequency region below the narrow-band noise a tendency towards equal masking over frequency was evident for all three groups. Two octaves below the cut-off frequency, the masked threshold curves for all three groups no longer follow the characteristics of the filter curve but exhibited a sharp acceleration to relatively high masked threshold values. This observation is in agreement with Bilger and Hirsh (3) who studied how closely the masked threshold values. This observation is in agreement with Bilger and Hirsh (3) who studied how closely the masked threshold of a tone would follow the frequency characteristic of each narrow band of noise. They reported that the ear does not follow the filtered noise for frequencies which lie above the noise band. In addition, this same observation was reported for frequencies below the noise bands for over-all sound pressure levels of 80 db and higher. This threshold shift for frequencies below the noise band was labeled 'remote masking' by these writers.

The masking curves in Figure 13 show the intersubject variations of the masked thresholds at each frequency for the 2000 cps noise band. At 2000 cps the three groups displayed only 4 db to 5 db of variation. As the frequency range increased, the standard deviation values for the three groups tended to remain fairly close out to 4000 cps. Thereafter, the plugged-normal and sensori-neural groups showed an unsystematic trend toward greater variability. For frequencies below the cut-off frequency of 2000 cps, the sensori-neural group revealed the greatest variability out to 250 cps. At 250 cps, the plugged-normal group had the least variability while the normal group demonstrated a greater degree of inter-subject variability. The normal group also demonstrated the greatest variability at 500 cps. However, at 125 cps the three groups were essentially equal in intersubject variability.

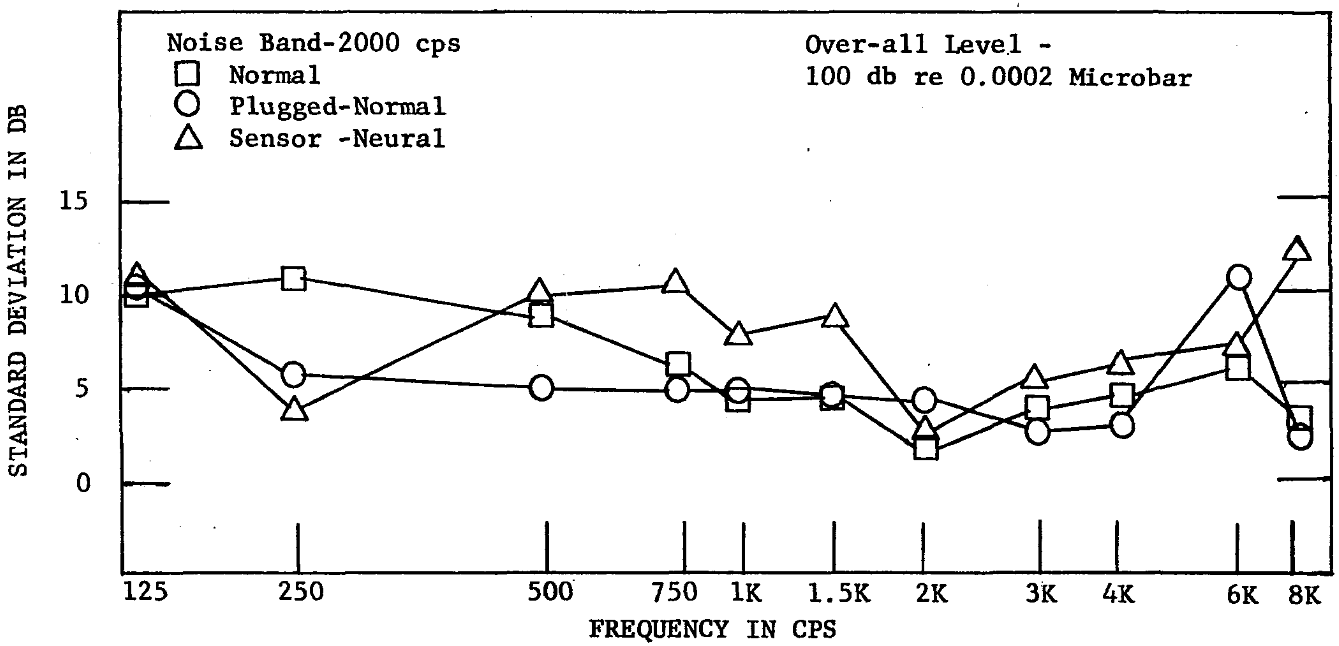

Fig. 13. Standard deviations of masking by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

TABLE 6

MEAN MASKED THRESHOLDS AND STANDARD DEVIATION IN DB FOR THREE GROUPS PRODUCED BY THE 2000-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

	Frequency in cps										
	125	250	500	750	1k	1.5k	2k	3k	4k	6k	8k
	Normal Group										
M	75	57	43	46	55	83	95	80	85	73	82
SD	10.12	10.94	8.58	5.08	3.56	3.32	2.65	4.34	4.70	6.55	8.56
	Plugged-Normal Group										
M	82	63	53	50	55	76	91	79	67	72	80
SD	10.28	5.60	4.75	3.83	3.75	3.65	5.41	3.15	3.98	11.55	7.05
	Sensori-Neural Group										
M	86	75	59	58	67	84	95	90	89	88	98
SD	10.62	3.20	9.94	10.15	6.89	7.57	3.48	5.48	6.88	7.88	12.55

The data for the 2000-cps noise band are presented in Figures 12 and 13 and also in Table 6.

4000 cps-Noise Band

All four sections of the filter network were set to the identical cut-off frequency, namely 4000 cps. This was done in order to obtain the narrowest possible noise band centered at 4000 cps. This narrow band of thermal noise was passed to the earphones at an over-all sound pressure level of 100 db re 0.0002 microbar.

The mean masked threshold curves for the three groups were plotted as a function of frequency and are shown in Figure 14. The mean masked threshold levels at the nominal cut-off frequency were approxmately the same for all three groups. As the frequency increased the sensori-neural group was again shifted to the greatest masked threshold level at 6000 and 8000 cps. Also, the normal group was shifted to a higher sound pressure level than the plugged-normal group. However, all three groups displayed the same general pattern of masked threshold. That is, all three groups showed a mild to moderate dip at 6000 cps and then a sharp rise. At 8000 cps both the sensori-neural and normal groups revealed greater masked threshold than they had at the cut-off frequency of 4000 cps. However, the sensori-neural group still continued to exhibit a greater masked threshold sound pressure level than either of the other two groups.

For frequencies located below the noise band cut-off frequency of 4000 cps the group differences in masked threshold levels were again evident. The sensori-neural group revealed an excessive spread of masking at all frequencies out to 500 cps and then continued to show slightly more masking than the other two groups. The normal and plugged-normal groups revealed a masked threshold plot which followed more closely the filter characteristics out to 100 cps. Then, beyond 750 cps, these two groups also demonstrated a definite increase in masked threshold levels of the constant masking over frequency. This observation is in accord with the Bilger and Hirsh (3) study regarding the non-linear spread of remote masking when narrow bands of noise were presented at sound pressure levels greater than 80 db.

The data relative to the 4000-cps narrow noise band are presented in Figures 14 and 15 and in Table 7.

Summary

In this study, pure tone masked thresholds produced by five narrow bands of noise were measured for three groups of subjects. These three groups consisted of normal-hearing subjects, subjects with normal-hearing whose test ears were plugged to induce conductive hearing losses, and subjects with sensori-neural hearing loss presumably due to cochlear pathology. The narrow bands of noise were adjusted to generate equal over-all sound pressure levels of 100 db re 0.0002 microbar. The masked thresholds produced by each of these narrow noise bands were measured at 11 test frequencies from 125 to 8000 cps. The following statements summarize the results of this study:

1. In any specific narrow bandof thermal noise at an over-all

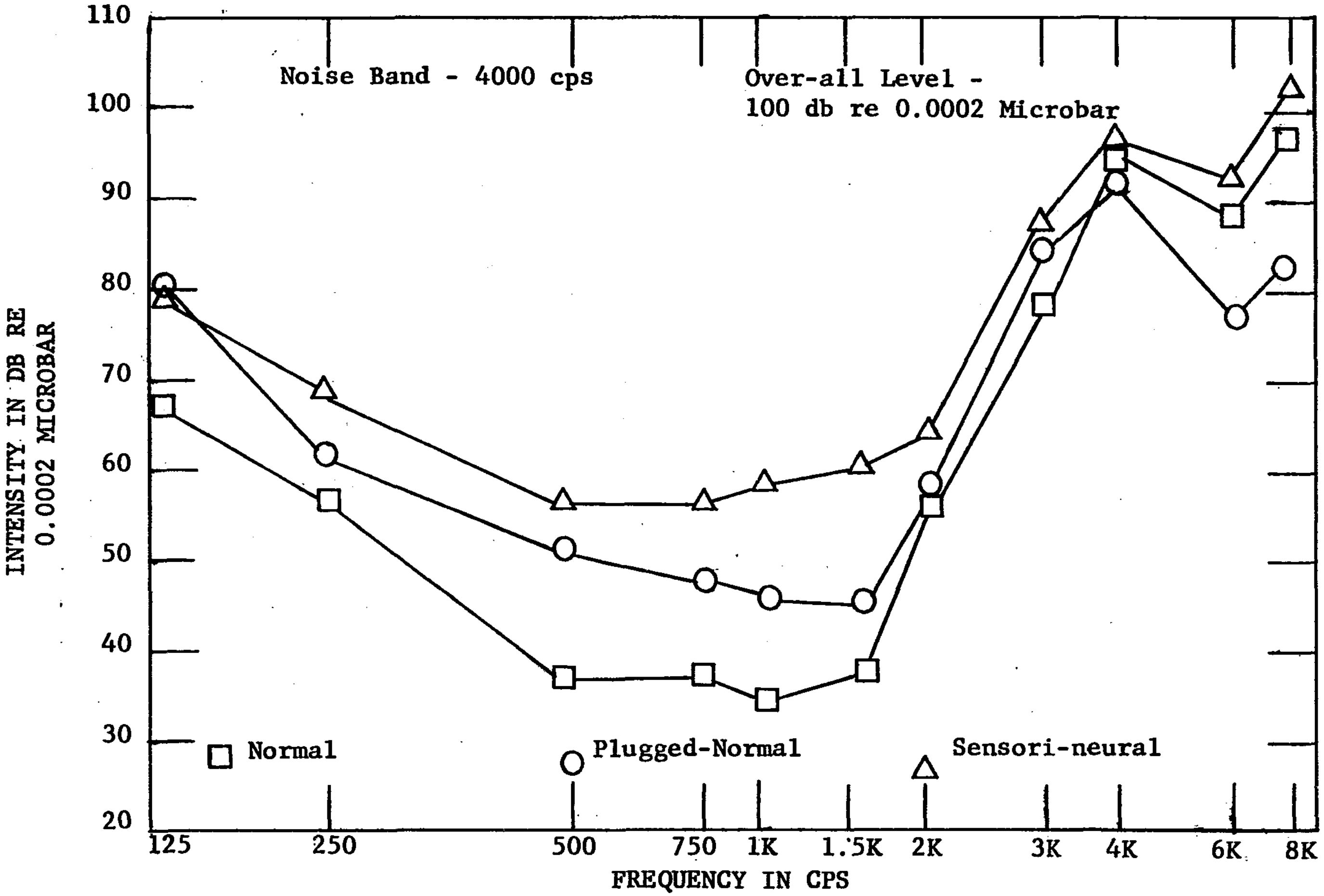

Fig. 14. Mean masked thresholds produced by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

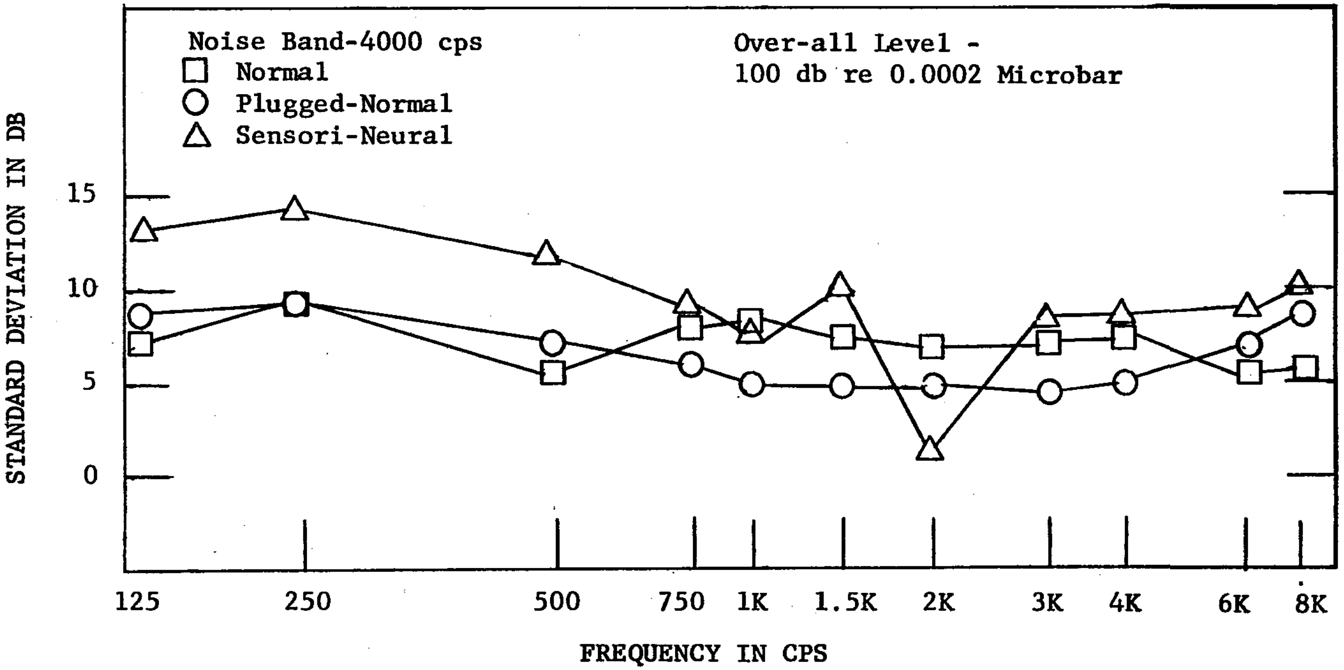

Fig. 15. Standard deviations of masking by narrow-band thermal noise at equal over-all sound pressure levels for three groups.

TABLE 7

MEAN MASKED THRESHOLDS AND STANDARD DEVIATION IN DB FOR THREE GROUPS PRODUCED BY THE 4000-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

	Frequency in cps										
	125	250	500	750	1k	1.5k	2k	3k	4k	6k	8k
					Normal Group						
M	66	53	34	36	33	41	55	76	93	88	97
SD	7.18	8.35	5.23	7.76	6.45	6.58	5.93	6.51	7.41	5.49	6.39
					Plugged-Normal Group						
M	80	61	51	46	44	48	59	85	92	79	84
SD	8.65	8.08	6.66	5.40	4.37	4.45	3.66	3.77	3.92	7.00	8.96
					Sensori-Neural Group						
M	79	68	54	54	57	61	66	89	97	92	103
SD	11.63	13.30	11.37	9.05	6.05	8.87	0.96	7.98	8.33	9.88	10.12

sound pressure level of 100 db re 0.0002 microbar, the masked threshold levels at the cut-off frequency were essentially equal for the three experimental groups.

2. An excessive spread of masking at frequencies above and below the cut-off frequency was observed for the sensori-neural group. This was apparent for every narrow noise band masking signal.

3. The sensori-neural group demonstrated the most excessive spread of masking in the frequency range above the noise band. The excessive spread of masking below any specific noise band was us usually characterized by equal masking across frequencies.

4. The sensori-neural group exhibited the greatest inter-subject variability at frequencies both above and below the narrow noise bands centered at 1000, 2000, and 4000 cps. For the narrow noise bands centered at 250 and 500 cps, the normal group displayed the greatest intersubject variability for the low-frequency and middle frequency range and lesser amounts in the higher frequencies.

5. The intersubject variability for the masked threshold sound pressure levels of all three groups tended to be highest in the 250-cps noise band.

6. All three groups revealed a definite dip and subsequent rise of their masked threshold curves in the presence of the narrow band of noise centered at 4000 cps. That is, there was a decrease in the masked threshold level at 6000 cps and then a sharp increase. This non-linear response was evident for all three groups but was marked for the sensori-neural and normal groups.

CHAPTER V

Discussion

The purposes of this chapter are: (1) to compare the experimental results of this study with previous investigations and (2) to try to explain the excessive spread of masking demonstrated by sensori-neural ears in this study.

A review of the literature regarding the masking of pure tones by wide-band thermal noise still presents considerable conflicting evidence. A substantial portion of the research on this subject suggests that the hearing impaired ear, depending on the etiological category, is masked more than the normal ear. Others claim the impaired ear displays less masking that the normal ear. Still other investigators contend that under equal masking conditions, the impaired ear is masked to approximately the same amount regardless of etiological category.

Webster, Lichenstein, and Gales (35) found that the normal ear and the ear with nerve deafness revealed essentially equal masking at equivalent effective noise levels. However, they reported that conductively impaired ears and ears with mixed losses displayed more masking than the normal and sensori-neural ear. Kietz (22) reported that one of his subjects with a sensori-neural loss with recruitment demonstrated less than the normal amount of masking.

Zangemeister (40) observed that when the masking behavior of the pathological ear is compared to the normal ear it may show more, less,or equal amounts of masking depending on the site of lesion. Lightfoot, Carhart, and Gaeth (26) found that threshold shifts for sensori-neural hearing losses were greater than those found in conductive losses for equivalent effective levels of masking. However, at some frequencies the sensori-neural group yielded less than normal masking.

Langenbeck (23) used wide-band thermal noise signals adjusted to produce equal masking over frequency. He studied subjects with normal hearing, subjects with conductive losses and subjects with sensori-neural losses. The sensori-neural losses included ears with losses due to cochlear impairment and ears with losses due to eighth nerve damage. He reported equivalent amounts of masking for all ears except those with eighth nerve lesions. The retro-cochlear ear revealed more masking than the others.

Palva, Goodman, and Hirsh (31) also studied the masking behavior of the normal and pathological ear. The pathological group included impairments due to both conductive and sensori-neural lesions. The sensori-neural group was divided into subjects with cochlear pathology and retro-cochlear pathology. They were unable to differentiate the normal ear from the impaired ear in regard to the masking behavior.

Other workers (20) employed narrow-band thermal noise signals to mask pure tones. They studied subjects with normal hearing, subjects with conductive losses, and subjects with sensori-neural hearing impairments due to presbycusis and cochlear pathology. They reported that for frequencies within the narrow band of noise the masking results were essentially the same for all subjects. However, they did note an excessive 'spread of masking' both above and below the limits of the noise bands.

In 1956, Bilger and Hirsh (3) studied the masking of pure tones with narrow bands of noise using normal-hearing subjects. They observed the expected amount of masking within and near the center of the noise band. In addition, they reported a threshold shift for frequencies located considerably below the noise band. This was termed 'remote masking'. Furthermore, after this remote masking appeared, it did not seem to be linearly related to the function of frequency. At all frequencies below the noise band, approximately 10 db of masking was noted at the 80-db noise level and this remote masking increased by more than 20-db as the noise level was raised to 100 db. This remote masking rose in an accelerated manner as a function of noise level.

Spieth (33) also studied the downward spread of masking in normal hearing subjects. He reported findings which concurred with those of Bilger and Hirsh (3).

Rationale for the Spread of Masking

Upward Spread of Masking

In order to develop an explanation of the spread of masking it is necessary to review the findings of other experiments.

Wegel and Lane (38) noted greater threshold shifts for frequencies above the masking tone than for frequencies below the masking tone. This observation was reported for all frequencies above the masker tone regardless of the frequency location of the masking tone. It was their contention that this phenomenon could be explained on the basis of the distortion generated by the transmission mechanism of the middle ear. Furthermore, they postulated that subjective harmonics were produced by the subject's ear which caused the threshold shifts observed for frequencies above the masking tone. A harmonic analysis of their masking signal revealed that energy was not present at higher frequencies and therefore could not have caused this masking. In order to obtain more definitive information on the probability of subjective harmonics, they employed an exploring tone slightly more than one octave above the fundamental frequency of the masking tone. In this way, they were able to determine the intensity of these subjective tones by observing the level at which beats were most audible. These intensity levels demonstrated close agreement with the amount of masking that had been noted previously for these higher frequencies.

In the light of these findings, Wegel and Lane (38) stated the premise that masking occurs when one tone produces action on the basilar which exceeds the stimulation generated by another tone. That is, the masked tone is not audible because the basilar membrane is reacting to the stimulation of the more intense masking tone. Further evidence for this idea came from their observation that as the frequency difference between the masked tone and the masking tone increased, the amount of masking became less. This occurred because the place of maximum stimulation on the basilar membrane was steadily becoming farther and farther removed from that of the masking tone.

More recent experiments have been reported which describe the spread of masking. Bilger and Hirsh (3) used narrow bands of thermal noise to mask pure tones in normal-hearing subjects. Their results revealed that the masking produced by narrow bands of noise also produces a spread of masking to frequencies above those present in the noise band.

Lawrence and Yantis (24) reported a study which lent considerable support to the idea of the ear's nonlinear distortion characteristics. They used an exploring tone technique similar to the one reported by Wegel and Lane (38). In general, when the input signal to the ear exceeded the ability of the ear to follow the signal in a linear manner and transduce it without introducing harmonics, harmonic distortion was created. In other words, aural overload occurred when the linear range of response to intensity changes was exceeded. These authors contended that this phenomenon originated in the hair cells of the organ of Corti as shown by animal experimentation which utilized the recordings of electrical potentials from the cochlear region. In view of the above-mentioned research, it seems logical to infer that the threshold shifts at frequencies above that of the masking signal were produced from the energy generated within the inner ear itself. This energy created within the ear itself is manifested as 'aural harmonics'. The slope of the masked audiogram showed the intensity of these harmonics to be linearly related to the intensity of the masking signal up to a specific level of intensity. Beyond this critical intensity level, the intensity of the aural harmonics seemed to accelerate more rapidly than that of the masking stimulus. Bilger and Hirsh (3) reported that this critical intensity level was located between 80 and 100 db re 0.0002 microbar.

Deatherage, Davis, and Eldredge (5) reported physiological evidence for this type of masking. The cochlear microphonic (CM) for a low frequency is first noticed in the apical turn of the cochlea as are action potentials (AP). Then, as the intensity of this signal is increased the CM becomes evident at places in the cochlea closer to the basal end. When the ear is stimulated by a high-frequency tone, the CM and AP appear only at the basal end and not at the apical end. These investigators obtained this inforation by implanting an electrode in the cochlea of a guinea pig. Consequently, on the basis of their study it would seem that the spread of masking to frequencies above the masking tone is definitely related to the spread of action within the cochlea to elements more important for response to higher frequencies as the masking signal intensity level is increased.

Although there is ample evidence that the upward spread of masking results from the ear's generation of aural harmonics, it is still necessary to explain the observation of an excessive upward spread of masking demonstrated by the subjects with sensori-neural hearing losses in this present study.

A test called the Threshold Aural Overload Test was developed by Lawrence and Yantis (24). This test purported to measure harmonic distortion by determining the intensity relationship between two tones when audible beats were first detected. This intensity of the 'fundamental frequency' was the threshold of aural overload. Their data was reported in terms of sensation level above an absolute threshold for the 'fundamental frequency' and resulted in a designation of the range of linear response. For normal ears and conductively impaired ears, the range was observed to be from 51 db to 57 db. Whereas the range for ears with cochlear pathology was relatively restricted and revealed values of 18 db to 24 db. Although there was a great deal of variability within all groups, the over-all results disclosed a greatly restricted range of linear response for the ears with cochlear pathology. Thus, abnormal non-linear response was evident for the sensori-neural group.

In the present study, the excessive upward spread of masking pattern demonstrated by the sensori-neural group can be related to the ear's abnormal linear distortion. The sensori-neural ear with cochlear pathology undoubtedly has some degree of damage or deterioration of the cochlear structures as well as possible neural degeneration in the higher auditory pathways. Thus, the sensori-neural group in this study was composed of subjects exhibiting cochlear damage reported previously (24). Therefore, if this assumption can be made for the sensori-neural group in the present study, then the greater spread of masking to test frequencies above the five narrow bands of filtered thermal noise can be attributed to the phenomenon of abnormal nonlinear distortion in the cochlea. This means that the relationship of the range of linearity to the intensity increase for the sensori-neural group is evidently restricted. Consequently, it seems logical to assume that aural harmonics were generated in the ear with cochlear pathology when the stimulus was at a much lower sensation level than was necessary to produce nonlinear distortion in the normal ear and the conductively impaired ear. This excessive upward spread of masking was not demonstrated by the normal and plugged-normal groups in the present study. If the over-all intensity level of the five noise bands had been a significant variable, an identical upward spread of masking would have been seen for the normal and plugged-normal group.

Therefore, it seems reasonable to assume that upward spread of masking observed in the sensori-neural group with cochlear pathology in the present study can be attributed to an abnormal nonlinear distortion in the cochlea.

Downward Spread of Masking

The spread of masking to frequencies below narrow bands of noise has been mentioned by several authors (2, 3, 4, 5, 21, 33). The first to describe this phenomenon were Bilger and Hirsh (3). They labeled this 'remote masking' and described it as equal masking over frequency. They noted this auditory phenomenon at overall sound pressure levels of 80 db re 0.0002 microbar and above.

Subsequent to Bilger and Hirsh's (3) study on 'remote masking'.

Deatherage, Davis, and Eldredge (5) did a follow-up study in an attempt to explain this type of auditory behavior. They stated that the nonlinear action of the inner ear causes this behavior. In order to study this more thoroughly, they used guinea pigs and placed intracochlear electrodes at the first and third turns of the cochlea. It was reported that a low-frequency tone pip is masked by both a high-frequency noise band and a high-frequency tone amplitude modulated by a low frequency. Observations were made of random electrical potentials at the apical turn of the guinea pig cochlea in response to intense acoustic stimulation by a high-frequency band of noise, which caused a threshold shift for the los-frequency tone pip. As a result of these findings, they hypothesized two possible explanations which could be operative to cause the masking behavior observed. First, it could have a relationship to the electrical potentials actually produced in the initial turn of the cochlea. Or secondly, it could be related to the electrical potentials produced in the third turn transmitted to the first turn by the action of the entire cochlear partition. However, comparison of the action potential recorded from just the first turn with cochlear microphonics recorded from both the first and third turns revealed that the cochlear microphonic from the third turn was advanced in time by approximately one millisecond.

Therefore, Deatherage and others (5) concluded that:

> ...a mechanical disturbance corresponding to the envelope of CM, is produced in the cochlear partition and is distributed along the partition exactly as if the stimulus had been the envelope of CM. The latency of the

> large AP waves, moreover, is of the proper order of magnitude; they lag behind the waves of the envelope by about the same interval that the AP waves follow the individual waves of a CM, response to a 500 cps signal...The aural mechanism is responding to the envelope of the stimulus with an immediate electrical output in the first turn which we take to be the sign of an underlying mechanical response. The mechanical response is propagated toward the apex as a 'traveling wave of displacement,' and is evident in our records as CM_3. (5, p. 134-135)

These findings suggested that there was an unsymmetrical mechanical action in the cochlea which was revealed by the spread of masking to the frequencies below the specific narrow band of noise.

In a study of remote masking, Deatherage, Bilger, and Eldredge (4) investigated this phenomenon of constant masking using pure tones and selected bands of noise. They employed a modified-Bekesy audiometer to measure remote masking from 200 to 5000 cps. Five normal-hearing subjects were given six noise signals at intensity levels of 100 db re 0.0002 microbar. Specifically, these stimuli were: (1) a 4000-cps tone; (2) a 4000-cps tone 50% amplitude modulated by a 500-cps sinusoid; (3) a 4000-cps tone interrupted at 500 times per second (50% duty cycle); (4) a 4000-cps to 6000-cps noise band; (5) a 4000-cps to 6000-cps noise band interrupted 500 times per second (50% duty cycle); (6) a 4000-cps tone 50% amplitude modulated by a wide-band thermal noise. All of the first five signals were filtered after they had been changed so there was no energy at 500 cps. The sixth signal was passed through a band-pass filter network in which the high-pass and low-pass sections had been set to 4000 cps.

The results of the above-mentioned study revealed that no remote masking was generated by the 4000-cps tone whose wave-form envelope did not vary in amplitude. This finding sustained the hypothesis that remote masking is produced by a detection of the fluctuating envelope of a masking sound. No remote masking was produced by either the modulated 4000-cps tone or the interrupted 4000-cps tone except at 500 cps. Although no acoustic energy was delivered to the inner ear at 500 cps, energy was produced at that frequency in the inner ear by detection of the masking-signal envelopes which were modulated in amplitude at 500 cps. Conversely, the narrow-band noise, the 4000-cps tone modulated by the wide-band noise, and the 4000-cps to 6000-cps noise band, which was interrupted at the rate of 500 times per second, produced equal masking over frequency, that is, remote masking. The envelopes of the masking signals were varied in a random manner thus producing random noise in the inner ear which resulted in equal masking over frequency. In the 4000-cps to 6000-cps noise band which was interrupted 500 times per second, the amplitude of the masking signal envelope varied randomly except at 500 cps when it varied in a regular manner. This resulted in equal masking over frequency except at 500 cps where a greater degree of masking was produced than at any of the other remote frequencies.

The results of the above-mentioned study (4) support the contention that when relatively intense narrow bands of noise are used to mask pure tones in normal-hearing subjects, the downward spread of masking results from a detection of envelope of the masking signal by the nonlinear action of the inner ear.

The three groups of subjects in the present study displayed a downward spread of masking characterized by equal masking over frequency. However, the downward spread of masking revealed by the sensori-neural group was excessive when compared with that shown by the normal and plugged-normal groups. It should be remembered that the greater amount of the downward spread of masking occurred even though the three groups were masked at the same over-all sound pressure level. If the over-all intensity level of the five noise bands had been an important factor, the three groups would have been shifted to approximately the same masked threshold sound pressure levels. Therefore, in an effort to explain the greater magnitude of remote masking observed in the sensori-neural group, it is this writer's speculation that the ear with cochlear pathology detects the masking-signal envelope at a lower sound pressure level than the normal and plugged-normal ears. In addition, this initial differential detection of the spectrum envelope continues as the intensity of the signal is increased.

Summary

The results of the present investigation agree quite closely with other studies (3, 4, 33) regarding the nature and amount of masking observed in normal-hearing subjects. Furthermore, an excessive spread of masking to frequencies above and below the narrow-band thermal noise was noted in the group with cochlear pathology. This observation of an excessive spread of masking is in general agreement with the findings of Jerger, Tillman, and

Peterson (21) regarding ears with cochlear pathology. However, the spread of masking results in the present study are even more striking for two reasons. First, the bands of noise were narrower than any previously used with pathological ears. Second, all three groups were masked at the same over-all sound pressure level and not the same effective levels as previously reported (21).

CHAPTER VI

SUMMARY

An impressive amount of literature is available regarding the reactions of the normal and impaired ear in the presence of noise. The greater part of this literature is concerned with the use of different types of noise signals and their effects on the pure-tone threshold. The research findings on the masking of pure tones by wide-band thermal noise in normal ears reveal close agreement. The earlier studies which furnished the basis for the formulation of the critical-band hypothesis and the concept of effective level masking have been verified by several investigators.

In relation to the impaired ear, however, there is not good agreement regarding the effects of thermal-noise masking. There is one major school of thought which advocates the use of noise audiometry as a reliable clinical technique in the differential diagnosis of hearing disorders. Conversely, another group of writers contend that the masking of pure-tone signals by wide-band thermal noise at equivalent relative levels of noise does not differ from that observed in normal ears.

However, in 1957, another attack was made on this controversial problem. This research effort produced data which demonstrated that the normal ear and sensori-neural ear were equally masked within a narrow-band thermal-noise signal. But of more significance was the fact that the sensori-neural ear revealed excessive amounts of masking in the range of frequencies both above and below the narrow band of noise. This unique auditory behavior was termed as an excessive 'spread of masking'. The present study was designed to obtain additional data on this phenomenon.

Experimental Design

The purpose of this study was to investigate the hypotheses that narrow bands of thermal noise adjusted to the same overall sound pressure level would: (1) produce equal masked threshold shifts in the normal and impaired ear at frequencies located at the center of any particular noise band, (2) cause an excessive 'spread of masking' to frequencies above and below any specific noise band in the ear with sensori-neural impairment, and (3) would cause a 'spread of masking' pattern which would be characterized by the presence of dips and peaks at frequencies above the noise bands.

These hypotheses were tested by obtaining three groups of subjects. The first group was comprised of 10 normal-hearing subjects. The second group consisted of 10 normal-hearing subjects whose test ears were plugged with a plastic earmold material in order to create a conductive hearing loss. The third group was composed of subjects with sensori-neural hearing impairments presumably due to cochlear pathology. The audiometric configuration was a relatively flat one for both of the impaired hearing groups. This arrangement was employed so the plugged-normal group could act as a control for the sensori-neural group.

Five narrow bands of thermal noise were used as masking signals in this study. The cut-off frequencies for these various bands were; (1) 250 cps, (2) 500 cps, (3) 1000 cps, (4) 2000 cps, and (5) 4000 cps. Each of these narrow bands of noise were presented at an over-all sound pressure level of 100 db re 0.0002 microbar for each of the 40 ears tested. The masked thresholds in each of the five noise conditions for each of the 40 ears were measured at 11 test frequencies from 125 cps through 8000 cps. The psychophysical method of limits was used to obtain the thresholds both in quiet and in noise.

The above-mentioned experimental procedure allowed the three groups to be compared with reference to the masked threshold values within the noise band, to the 'spread of masking' to frequencies above and below the five noise bands, and to the pattern of the masking revealed by all groups.

Results

The experimental data obtained for the five narrow bands of thermal noise at an over-all sound pressure level of 100 db re 0.0002 microbar showed that all three groups were shifted to approximately equal masked threshold levels within any specific narrow band of thermal noise.

An excessive spread of masking was observed at frequencies above and below the cut-off frequencies of the narrow bands of thermal noise for the sensori-neural group. This was evident for each noise band masking signal. The excessive spread of masking below any specific noise band was characterized by equal masking over frequency.

In general, the sensori-neural group demonstrated greater inter-subject variability in the presence of noise bands centered at 1000, 2000, and 4000 cps. For the noise bands centered at 250 and 500 cps, the normal group exhibited slightly greater inter-subject variability in the low and middle frequency ranges.

The standard deviations of the masked threshold values for all three groups tended to be highest in the 250-cps noise band.

Conclusions

The following experimental results were revealed when the sensori-neural ear with cochlear pathology is compared to the normal ear in the presence of narrow-band thermal noise at an over-all sound pressure level:

1. The normal ear and the ear with sensori-neural loss were shifted to approximately the same masked threshold SPL's at frequencies within the narrow noise band when the noise is presented at the same over-all sound pressure level.
2. The sensori-neural ear revealed an excessive 'spread of masking' to frequencies both above and below the noise band.
3. In the presence of narrow-band noise centered at 4000 cps,

all three groups demonstrated spread of masking patterns which were essentially the same in contour in the frequency region above this noise band. This similarity of the upward spread of masking configuration among the three groups was not observed in the presence of noise bands centered at 250, 500 1000, and 2000 cps.

Earlier writers have reported that there is an upward spread of masking in normal ears for both pure-tone and narrow-band noise signals. They speculate that this auditory behavior is due primarily to the nonlinear distortion in the inner ear caused by relatively intense acoustic stimulation. Subsequent research indicated that the ear with cochlear pathology revealed this kind of nonlinear distortion but at a much lower sensation level than the normal or conductively impaired ear. Apparently, this is the most plausible reason for the occurrence of the excessive 'spread of masking' demonstrated by the sensori-neural group in this study.

The downward spread of masking has also been reported by several investigators who used narrow-band thermal noise signals to mask pure tones in normal ears. There is considerable physiological evidence available to substantiate the idea that this remote masking of frequencies below the noise band is caused from noise generated in the inner ear. That is, a nonlinear mechanical action results in the detection of the masking signal envelope which varies in amplitude. Therefore, it seems reasonable to assume that the excessive spread of masking to the frequencies below the noise band, as seen in the sensori-neural group tested in this study, can be attributed to the fact that the detection process begins at a lower intensity level in the impaired ear due to cochlear pathology.

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Appendix A

Subject Identification

TABLE 8

IDENTIFYING INFORMATION FOR SUBJECTS IN THREE TEST GROUPS

Group	Subject Number	Age	Sex	Test Ear	SISI Score in Percent at 4 cps
	1	26	F	RE	
	2	20	F	RE	
	3	23	F	RE	
	4	23	F	LE	
Normal	5	20	F	RE	
	6	20	F	LE	
	7	20	F	LE	
	8	20	F	LE	
	9	20	F	LE	
	10	20	F	LE	
	1	20	F	RE	
	2	20	F	RE	
	3	20	F	RE	
	4	20	F	RE	
Plugged-Normal	5	20	F	LE	
	6	22	F	RE	
	7	22	F	LE	
	8	20	F	LE	
	9	20	F	RE	
	10	20	F	LE	
	1	44	F	RE	100
	2	35	F	RE	70
	3	19	F	LE	85
	4	65	F	RE	95
Sensori-Neural	5	42	M	RE	75
	6	17	M	LE	100
	7	40	F	LE	90
	8	66	F	RE	100
	9	54	F	LE	70
	10	34	M	RE	100
	11	65	F	RE	100
	12	54	F	RE	100
	13	22	M	RE	80
	14	45	F	RE	95
	15	40	F	LE	100
	16	62	F	RE	100
	17	23	F	RE	75
	18	65	F	RE	100
	19	26	F	LE	100
	20	38	F	LE	90

Appendix B

Individual Subject Data

TABLE 9

INDIVIDUAL SUBJECT DATA. MASKED THRESHOLD SOUND PRESSURE LEVELS IN DECIBELS FOR THREE GROUPS PRODUCED BY THE 250-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

Subject Number	125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
					Normal						
1	97	88	67	66	54	57	53	36	30	32	43
2	96	85	60	49	32	20	24	18	21	15	24
3	94	87	61	57	51	35	36	17	23	19	26
4	93	89	54	49	40	27	31	29	12	10	34
5	92	88	50	47	32	23	22	30	32	32	44
6	95	91	73	62	63	52	49	36	41	34	34
7	89	93	61	57	49	48	48	26	28	18	30
8	90	94	60	50	46	43	40	29	26	25	30
9	89	93	63	46	38	33	31	18	24	19	30
10	94	88	59	50	42	28	36	18	23	23	39
					Plugged-Normal						
1	93	102	69	54	41	39	43	38	42	50	72
2	89	93	77	57	49	48	49	49	55	70	28
3	89	88	69	49	41	48	60	48	52	64	80
4	87	81	65	53	42	45	50	58	59	77	81
5	90	90	64	52	45	48	52	46	50	66	80
6	83	101	75	62	58	56	58	57	57	65	66
7	91	91	73	57	53	53	59	58	60	83	91
8	78	95	65	55	49	58	67	66	60	76	87
9	92	86	71	53	48	47	47	47	48	80	98
10	91	91	65	57	49	41	50	49	50	62	64
					Sensori-Neural						
1	94	85	73	64	54	59	58	45	60	53	84
2	109	99	82	78	77	74	66	62	59	68	84
3	86	97	76	75	72	76	77	77	76	61	57
4	82	97	73	69	72	65	70	52	50	62	81
5	77	98	84	78	78	75	73	64	55	42	70
6	93	83	74	58	51	47	47	53	72	87	93
7	100	94	75	74	71	68	63	67	57	53	51
8	97	93	73	66	62	57	60	56	61	53	82
9	104	100	81	74	71	69	69	63	68	62	88
10	90	97	78	73	64	54	58	55	59	68	85

Frequency in cps

TABLE 9-Continued

Subject Number	125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
	Frequency in cps										
11	88	82	67	52	46	54	57	45	52	61	85
12	85	97	75	67	71	68	63	69	75	66	88
13	96	102	82	80	77	73	71	86	87	87	91
14	106	99	80	70	70	69	73	69	64	77	90
15	91	95	75	67	63	62	62	54	53	47	62
16	95	92	71	64	63	67	56	43	52	63	89
17	100	93	76	63	67	63	53	44	53	56	54
18	96	88	72	55	54	59	63	66	77	71	97
19	88	97	79	69	70	67	67	64	69	72	94
20	88	94	81	74	70	66	64	60	61	66	102

TABLE 10

INDIVIDUAL SUBJECT DATA. MASKED THRESHOLD SOUND PRESSURE LEVELS IN DECIBELS FOR THREE GROUPS PRODUCED BY THE 500-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.002 MICROBAR.

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
					Normal						
1	94	78	90	80	74	84	83	68	60	38	54
2	82	66	89	67	66	70	70	53	50	30	42
3	95	73	96	89	80	81	83	58	70	50	48
4	91	62	88	77	74	75	79	60	55	33	41
5	79	67	85	64	54	56	40	38	40	31	37
6	82	65	88	81	71	69	64	56	61	46	52
7	74	66	84	70	64	54	56	46	47	44	43
8	75	61	91	74	71	62	65	57	62	36	39
9	79	63	94	87	77	70	63	39	49	30	33
10	64	63	92	61	59	61	66	39	39	28	35
					Plugged-Normal						
1	87	68	98	85	65	57	55	43	42	37	56
2	73	65	92	81	62	51	48	48	57	69	78
3	98	74	90	83	61	53	66	52	54	70	88
4	89	78	91	77	54	50	54	56	51	78	77
5	92	77	83	86	67	62	60	52	51	72	85
6	78	68	95	83	72	62	63	54	58	69	83
7	92	71	96	79	68	63	66	60	63	79	78
8	67	66	99	75	56	60	63	65	83	90	80
9	98	73	86	74	67	54	51	47	48	83	101
10	101	86	94	76	61	46	52	51	52	64	71
					Sensori-Neural						
1	94	75	93	89	74	74	78	55	70	53	89
2	94	79	81	72	70	66	60	55	51	53	67
3	84	77	100	90	82	83	80	78	69	69	60
4	77	64	85	86	79	84	78	58	61	60	79
5	67	69	92	85	79	73	75	66	62	45	75
6	101	80	97	90	82	73	73	79	82	84	92
7	84	71	92	84	85	82	75	78	72	65	64
8	112	103	95	85	75	79	78	70	69	75	81
9	116	102	96	89	80	77	75	69	73	58	79
10	80	83	96	86	85	76	74	64	69	86	91

TABLE 10-Continued

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
11	73	64	83	79	80	68	71	49	47	62	87
12	83	69	94	88	84	75	72	72	79	76	94
13	109	93	100	96	90	89	82	87	83	88	85
14	103	103	98	92	86	82	83	75	75	73	100
15	87	73	97	88	84	80	78	67	67	54	61
16	94	86	93	87	81	78	74	66	68	68	93
17	109	98	99	92	87	84	76	65	64	58	69
18	97	70	93	86	73	73	76	70	76	83	100
19	92	85	99	91	83	83	79	76	74	75	101
20	89	74	92	90	84	77	80	65	74	75	109

TABLE 11

INDIVIDUAL SUBJECT DATA. MASKED THRESHOLD SOUND PRESSURE LEVELS IN DECIBELS FOR THREE GROUPS PRODUCED BY THE 1000-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR.

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
					Normal						
1	91	67	54	88	95	89	88	66	65	44	60
2	88	63	54	79	89	77	81	70	75	45	52
3	96	81	67	83	101	90	85	71	80	68	74
4	79	57	48	77	88	77	81	71	73	50	31
5	82	57	56	76	86	68	61	58	60	43	58
6	78	51	55	88	87	94	95	73	75	56	59
7	74	55	58	79	79	64	58	62	61	61	54
8	82	55	53	76	88	74	66	66	72	59	59
9	75	53	56	87	101	88	76	56	61	36	34
10	76	55	53	87	91	80	86	65	62	46	48
					Plugged-Normal						
1	92	69	59	81	92	91	91	69	57	41	55
2	69	58	64	84	90	74	66	51	55	69	83
3	89	61	61	84	86	83	82	43	51	67	82
4	93	74	69	85	96	74	66	63	62	83	78
5	70	53	50	74	69	74	71	66	66	61	72
6	80	57	59	86	96	79	75	61	60	69	79
7	90	60	54	82	94	84	76	63	63	83	89
8	70	62	62	85	88	72	68	61	67	88	89
9	92	67	61	84	91	82	76	61	58	85	104
10	101	83	66	82	89	73	57	54	50	64	67
					Sensori-Neural						
1	89	65	53	84	89	84	88	65	80	63	89
2	107	99	86	94	98	94	86	81	79	76	88
3	89	74	62	87	97	89	87	83	81	77	70
4	81	54	53	89	93	90	84	70	69	68	94
5	66	57	60	89	93	92	84	74	68	54	72
6	103	75	58	81	94	91	92	83	94	81	96
7	88	66	72	89	95	90	84	84	79	76	79
8	112	108	80	87	93	87	86	83	85	84	104
9	112	98	85	87	93	80	71	78	82	60	92
10	69	67	70	89	96	84	82	69	69	89	94

TABLE 11-Continued

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
11	89	71	57	84	91	86	73	69	54	76	82
12	82	63	61	88	97	84	78	82	89	75	99
13	101	96	83	98	99	97	91	88	86	90	91
14	103	94	78	87	97	98	94	88	85	86	110
15	95	75	64	92	95	89	87	82	73	68	73
16	93	84	71	83	92	87	83	78	77	79	92
17	107	91	71	95	99	94	89	76	70	65	64
18	91	70	57	79	92	87	72	74	80	68	100
19	90	78	84	93	93	90	83	83	79	77	94
20	90	72	64	84	97	92	90	75	75	79	116

TABLE 12

INDIVIDUAL SUBJECT DATA. MASKED THRESHOLD SOUND PRESSURE LEVELS IN DECIBELS FOR THREE GROUPS PRODUCED BY THE 2000-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR.

Subject	Frequency in cps									
Number	125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
					Normal						
1	89	69	48	52	53	79	96	84	87	83	99
2	91	69	61	48	52	81	92	80	86	73	83
3	84	69	45	50	59	84	95	83	81	72	84
4	67	46	42	42	49	79	100	74	85	62	74
5	74	66	42	44	56	82	98	86	92	85	94
6	67	46	33	37	52	81	92	81	81	70	79
7	63	46	36	45	58	87	98	80	82	77	84
8	69	47	32	40	53	84	93	78	84	67	79
9	82	68	51	54	59	87	96	82	90	73	74
10	68	47	36	45	59	89	94	75	76	71	70
					Plugged-Normal						
1	93	75	55	53	55	79	96	82	72	50	67
2	64	51	56	55	56	84	92	78	67	70	79
3	82	60	48	45	49	59	97	81	70	70	82
4	93	74	60	58	57	79	88	76	63	83	82
5	84	71	47	46	49	52	77	74	65	62	80
6	73	50	45	49	58	84	95	82	66	69	76
7	87	58	56	49	53	77	89	79	67	83	86
8	67	57	51	49	62	82	91	74	65	79	80
9	88	65	56	48	56	82	92	83	73	91	95
10	93	73	57	51	56	83	90	80	59	63	74
					Sensori-Neural						
1	89	70	53	49	54	84	98	80	95	88	109
2	105	88	72	79	75	87	94	87	86	85	99
3	77	66	49	48	64	89	96	96	82	84	82
4	76	56	42	41	60	92	95	86	83	75	94
5	60	55	49	61	74	87	96	90	86	75	71
6	92	76	52	51	60	84	97	93	103	94	112
7	88	73	68	75	73	83	88	92	94	85	82
8	96	89	65	55	67	83	91	85	88	103	108
9	105	94	75	70	68	79	93	87	90	75	94
10	76	70	60	52	65	85	95	88	86	90	100

TABLE 12-Continued

Subject Number	125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
	Frequency in cps										
11	85	82	54	50	56	80	92	85	76	92	191
12	72	59	53	53	74	90	97	92	103	84	101
13	90	78	70	67	79	90	99	105	97	100	102
14	95	85	63	62	68	89	105	97	96	93	102
15	83	74	52	49	64	77	97	93	84	82	81
16	95	83	66	65	64	85	91	86	86	95	99
17	89	78	54	58	74	89	95	87	82	83	72
18	88	68	49	48	59	54	93	85	92	92	107
19	80	78	79	72	70	87	93	95	91	98	129
20	87	69	53	57	61	80	96	91	92	85	104

TABLE 13

INDIVIDUAL SUBJECT DATA. MASKED THRESHOLD SOUND PRESSURE LEVELS IN DECIBELS FOR THREE GROUPS PRODUCED BY THE 4000-CPS NARROW NOISE BAND AT AN OVER-ALL SOUND PRESSURE LEVEL OF 100 DB RE 0.0002 MICROBAR

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
					Normal						
1	79	69	43	52	42	51	61	84	97	95	111
2	69	55	33	29	27	26	41	53	75	90	91
3	73	55	31	35	36	42	57	82	94	81	94
4	64	43	34	38	34	44	51	76	95	79	90
5	60	55	39	37	31	40	58	78	95	86	91
6	60	46	25	25	24	39	56	76	95	83	96
7	57	45	35	41	39	47	60	81	97	90	97
9	59	45	30	27	25	37	50	68	83	94	104
9	75	65	42	43	43	46	61	82	101	88	92
10	65	50	30	32	31	37	57	82	97	95	100
					Plugged-Normal						
1	85	62	47	40	37	44	60	82	97	84	92
2	68	53	48	48	44	49	58	84	95	73	84
3	71	58	48	35	42	43	58	82	95	76	92
4	88	73	61	49	42	47	60	85	88	83	86
5	79	68	46	41	39	47	50	89	85	70	82
6	72	47	40	46	54	55	60	90	93	74	72
7	88	62	51	46	47	57	62	82	94	86	87
8	69	53	52	47	44	51	66	85	93	79	76
9	88	63	61	50	44	47	58	78	87	92	97
10	91	72	59	55	45	44	58	90	94	70	69
					Sensori-Neural						
1	74	65	43	44	44	49	58	85	100	78	109
2	98	76	66	68	67	69	69	85	99	97	108
3	61	55	42	50	59	72	79	95	98	93	94
4	62	45	40	46	54	63	70	85	96	86	97
5	61	50	49	59	70	71	73	98	102	99	107
6	83	62	49	49	48	47	60	93	101	83	99
7	69	56	69	73	70	66	67	91	95	92	93
8	89	84	62	49	57	49	57	83	93	103	104
9	101	87	73	67	62	65	70	83	93	76	93
10	72	74	52	42	42	40	59	94	98	89	107

TABLE 13-Continued

Subject Number	125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
	Frequency in cps										
11	72	79	61	51	47	58	64	91	94	116	120
12	74	54	42	47	72	71	71	88	101	87	99
13	70	52	43	50	55	56	74	104	101	100	96
14	91	89	69	57	61	70	75	92	105	90	109
15	74	56	43	47	50	57	65	92	102	86	94
16	87	77	59	58	60	61	56	72	90	82	102
17	94	81	55	59	60	62	66	99	98	99	89
18	81	63	44	40	44	57	62	79	94	80	107
19	80	78	76	66	67	69	70	90	100	101	119
20	83	78	51	54	56	58	64	73	97	100	123

TABLE 14

INDIVIDUAL SUBJECT DATA. THRESHOLD SOUND PRESSURE LEVELS IN DECIBELS FOR THREE GROUPS MEASURED IN QUIET

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
				Normal							
1	62	46	32	30	17	18	21	15	21	20	42
2	47	36	15	4	5	8	10	3	10	4	23
3	55	40	26	21	19	21	18	12	20	10	24
4	62	44	20	14	11	16	20	8	15	11	28
5	49	43	26	19	14	19	18	12	12	19	38
6	62	38	18	15	14	15	19	12	21	13	32
7	46	33	18	19	19	14	16	13	18	23	21
8	49	42	25	16	17	14	16	10	21	23	37
9	49	35	23	17	15	14	16	12	21	18	26
10	54	32	16	14	12	12	16	6	14	14	23
				Plugged-Normal							
1	86	55	38	30	23	29	40	34	40	58	67
2	60	49	48	35	34	40	42	44	55	68	79
3	75	55	43	36	43	48	60	50	52	72	85
4	77	67	48	44	34	38	51	55	51	75	82
5	75	67	42	36	30	47	48	39	48	64	77
6	61	43	36	31	36	45	50	54	57	61	71
7	81	57	49	38	39	47	56	57	58	76	80
8	60	52	49	42	41	48	55	54	74	83	77
9	76	59	51	39	39	41	45	42	46	78	93
10	80	72	51	44	35	31	40	42	45	55	57
				Sensori-Neural							
1	59	55	33	29	29	39	43	35	50	43	79
2	96	71	62	65	65	64	58	52	55	64	81
3	61	43	38	46	44	71	69	73	65	54	40
4	65	49	36	44	48	56	57	40	50	58	79
5	63	46	46	56	67	64	60	50	41	43	71
6	83	67	45	47	47	46	46	60	71	73	80
7	68	53	65	67	64	62	56	62	55	48	59
8	87	82	58	52	53	49	48	53	65	66	83
9	98	87	72	67	64	63	66	62	71	56	83
10	62	61	50	40	40	29	41	54	57	68	82

TABLE 14-Continued

Subject Number	Frequency in cps 125	250	500	750	1K	1.5K	2K	3K	4K	6K	8K
11	72	53	34	37	43	47	45	42	42	55	85
12	68	48	39	48	69	62	59	63	70	74	86
13	70	57	43	56	57	59	59	69	74	78	79
14	80	82	56	56	49	63	66	62	63	75	86
15	70	57	40	39	46	52	50	49	51	46	61
16	85	73	57	52	53	49	38	38	48	53	97
17	91	86	61	51	56	56	52	43	50	56	56
18	74	58	40	37	40	57	61	62	68	74	94
19	73	75	69	61	62	62	57	57	63	72	89
20	74	60	46	51	52	54	50	47	53	73	119