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Masking patterns of high frequency pure tones

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AN ABSTRACT OF THE THESIS OF Judith Eide Widen for the Master of Science in Speech with major emphasis in Audiology and Speech Pathology presented on March 8, 1974.

Title: Masking Patterns of High Frequency Pure Tones.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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Previous investigations of masking have established that the action of the masking tone spreads upward in frequency, creating significantly more masking (threshold shift) above the masker frequency than below. It was the purpose of this study to investigate the masking pattern produced by high frequency pure tones, heretofore uninvestigated.

Masking patterns were obtained for nine normal-hearing young adults utilizing the method of adjustment.

The masking produced by an 11000 Hz pure tone of 40 dB sensation level was measured at three frequencies above and three frequencies below the masker frequency. Analysis of the data revealed a downward spread of masking. Pure tone stimuli below the 11000 Hz masker showed significantly more threshold shift than those above the masker frequency. On the basis of the data collected in this investigation, it must be concluded that the upward-spread-of-masking phenomenon is not applicable at certain high frequencies.

A method for obtaining high frequency thresholds is discussed and the results compared to recent normative studies pertaining to the extra high frequencies.

MASKING PATTERNS OF HIGH FREQUENCY PURE TONES

by

JUDITH EIDE WIDEN

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requirements for the degree of

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TO THE OFFICE OF GRADUATE STUDIES:

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CHAPTER I

INTRODUCTION

Masking is the ability of one sound to make another difficult or impossible to hear. Licklider (1951) pointed out that masking is the opposite of analysis. It represents the inability of the auditory system to separate the tonal stimulation into components and to discriminate between the presence or absence of one of them. Traditionally, masking has been operationally defined as "the amount by which the threshold of audibility of a sound is raised in the presence of another (masking) sound. The unit customarily used is the decibel" (ANSI Standard Acoustical Terminology, S1.1-1960, Sonn, 1969). The definition assumes the method of measurement will be a comparison of two thresholds, that of the masked tone with the masking agent present and without the masking agent present. Because of this emphasis on threshold, not everyone has been willing to accept the definition.

There are those who insist on some reference to "partial" masking or the reduction in loudness of a stimulus when other signals are introduced (Scharf, 1964). In accordance with signal detection theory, some definitions avoid the word "threshold" and stress the impairment of

detectability of one sound, the signal, in the presence of another sound (Studebaker, 1973).

The signal energy necessary for detection is dependent upon many factors: shape and duration of tone, psycho-physical method, placement of earphone, instructions to the listener, etc. Even when these are held as constant as possible, there will be considerable fluctuation of "threshold." This inherent variability of response is consistent with the notion that the task of signal detection is always that of discriminating signal-plus-noise from noise alone. In a sense, then, measurement of absolute threshold is just a special case of masking: when listening for a weak tone, the subject must distinguish the tonal signal from the physiological background noise (Ward, 1963).

Whatever the definition, masking experiments are fundamentally the same. The change in threshold (usually pure tone threshold) is noted when a second auditory stimulus is presented simultaneously. These threshold changes can be attributed to several different sources. When the masker and the maskee are in the same ear and in the same frequency region, we speak of ipsilateral direct masking. A masker can produce changes in threshold in the contralateral ear because the two ears are not entirely insulated from each other acoustically. This is called transcranial masking. If the threshold of the contralateral ear is raised even when the intensity of the masker is too low to

lateralize to that ear, we are dealing with central masking. This is believed to occur because the two ears are not insulated neurologically (Ward, 1963). Remote masking causes threshold shifts for sounds in a different frequency region from that of the masker. It can be either an ipsilateral or a contralateral phenomenon. When dealing with the temporal effects of masking, forward masking refers to the threshold shift which occurs when the masker is presented prior to presentation of the test signal. It is sometimes called residual masking or poststimulatory threshold shift. Backward (also precedent or retroactive) masking describes the condition in which the masker appears after the masked sound (Sonn, 1969). The most common use of the word "masking" and the one with which this study deals is ipsilateral direct masking.

CHAPTER II

HISTORY OF THE PROBLEM

MASKING OF PURE TONES BY PURE TONES

For half a century now, the masking effects of one tone upon the response to another tone have been of continuing interest in physiological and psychological acoustics. Interest stems in part from the belief that such data are informative about both the nature of the activity on the basilar membrane and of neural response to simple waveforms.

As long ago as 1894, while experimenting with organ pipes and tuning forks, A. M. Mayer concluded that low frequency tones may completely "obliterate" higher frequencies of considerable intensity, but higher frequencies do not "obliterate" lower ones (Jeffress, 1970). In 1924, in a paper that has now become a classic, Wegel and Lane published the first quantitative results showing the masking of pure tones by pure tones.

A major finding of their study was that if the masking tone is fairly intense, then the amount of masking produced as a function of frequency of the masker is quite asymmetrical. In particular, a low frequency tone, such as a 500 Hz

tone at a 60 dB sensation level, may produce 20 dB of masking at 2000 Hz; but a higher frequency one, such as 2000 Hz at 60 dB sensation level, will produce no appreciable masking at 500 Hz. In other words, given comparable high-intensity maskers, low tones mask high tones more than the reverse. Additionally, sinusoids near the signal frequency, whether above or below it, are more effectively masked than frequencies farther removed. Figure 1 demonstrates both of these notions.

Figure 1. The amount of masking depends upon the frequency and intensity of the tones. The curves show the extent to which various tones must be elevated above their normal threshold when listened to in the presence of a masking tone of 1200 Hz. The masking tone was presented at each of 3 sensation levels, as shown by the numbers on the curves. (After Wegel and Lane, 1924.)

Wegel and Lane (1924) found that when the maskee is above the masked threshold, the sensation cannot be described simply as a pair of tones; it is complicated by the presence

of beats, harmonics and combination tones. Their curves are characterized by notches occurring at frequencies near the signal. These notches result from beats between the masker and the signal--fluctuations in intensity level that render the signal more conspicuous and easier to detect. Notches at 2400 and 3600 Hz were explained by the beating of the signal with the harmonics of the 1200 Hz masker, generated in the ear as a consequence of its nonlinearity at the high intensity levels. In addition, Wegel and Lane (1924) used their data to infer the frequency-dependent patterns of excitation along the basilar membrane.

Subsequent studies of the masking of pure tones by pure tones are in agreement with the basic findings of Wegel and Lane (1924):

- 1) When the masking tone is weak (20 dB sensation level or less), the masking pattern produced is symmetrical around the masker frequency.
- 2) As the intensity of the masker is increased, however, the masking pattern becomes asymmetrical, with more masking above than below the frequency of the masker (Studebaker, 1973).

In an attempt to assess the relative importance of aural harmonics and cochlear spread as the mechanisms of extended masking, Ehmer (1959a) provided extensive data on pure tone masking patterns. Wegel and Lane (1924) had noted earlier that the second peak (first peak above the

frequency region of the masker in Figure 1) fell one octave above the pure tone masker frequency, thus attributing its production to aural harmonics. Ehmer, however, observed that at lower intensity levels the peak was about one-half octave above the masker frequency, migrating upward in frequency as the sensation level of the masker was increased. Only at 100 dB sensation levels did the peak fall at or near the masker harmonic. He concluded that the masking pattern of a pure tone results primarily from the activity pattern in the cochlea. At low intensities the cochlear activity is confined to a local region and the masking pattern is narrow. As the masking intensity increases, the cochlear activity spreads only toward the basal region, while retaining a maximum amplitude at the location of the original response; thus, the masking pattern extends asymmetrically to high frequencies (Ehmer, 1959a).

Small (1959) utilized a different paradigm to substantiate previous findings on pure tone masking. Rather than getting threshold shifts of the signal, he measured the intensity level of the masker just necessary to mask the signal. Generally, the masking patterns he obtained were similar to previous ones, except, like Ehmer, he found that the irregularities in the curve above the masker frequency did not fall at the one-octave interval. He too ruled out aural harmonics as the cause of extended masking.

MASKING OF PURE TONES BY NOISE

Hypothesizing that the activity pattern is the primary determinant of the extent (in frequency) and amount (in intensity) of masking, Ehmer (1959b) conducted a second study comparing masking by tones and by noise bands. Supposedly a narrow band noise with the same over-all level as a pure tone masker and centered at the same pure tone masker frequency should produce the same extended masking. If the noise band is broad enough to include a few critical bandwidths,¹ its energy should be sufficiently spread out to minimize the production of harmonics due to overload. His results corroborated this. The narrow band noise produced slightly more masking near the center frequency of the masker band, probably because the noise did not interact with the test tone as did the pure tone masker. Despite the absence of any possible harmonic distortion, the noise-masking curves were very nearly identical to the tone-masking curves in their extension to the high frequencies.

Other studies by Egan and Hake (1950) and Carter and Kryter (1962) likewise compared the masking patterns of narrow bands of noise to pure tone patterns. Both found

¹As the width of a band of noise is increased, holding the spectrum level constant, there is a point at which masking ceases to grow. Additional frequency ranges do not contribute to masking although they raise the over-all level. The frequency limits at which this occurs is defined as the critical band (Hirsch, 1952).

that the use of noise eliminated the problems of interaction of two pure tones as beats and difference tones, thus reducing the irregularities in the curves of pure tone maskers while maintaining similar extended masking. Both concluded, as did Ehmer (1959b), that it was the cochlear activity of the tone, not harmonic distortion, which caused the upward spread of masking.

REMOTE MASKING

Not to be confused as a downward spread of masking (Spieth, 1957), is the phenomenon of remote masking, which was first observed and named by Bilger and Hirsch in 1956. Unlike direct masking, remote masking occurs in a different frequency region from the masker. Studies by Deatherage, et al. (1957a and b) and Spieth (1957) suggest that remote masking is associated with aural harmonic distortion due to high-level noise.

PHYSIOLOGICAL EVIDENCE OF MASKING

Masking has been shown to be a neural and not a sensory phenomenon. It is not found in the cochlear potentials but makes its appearance in the nerve action that follows (Wever, 1949). Attempts to explain and quantify the physiological processes involved in masking are difficult because of the problems in demonstrating an action potential that is sensitive to tonal frequency and also is representative of a

population of auditory elements that can be measured. For this reason, research on the physiological correlates of masking are few.

In 1935 Derbyshire and Davis demonstrated that the action potentials recorded from the round window were amenable to masking, whereas the microphonic portion of the response to a click appeared to be unaffected by a "hissing" sound (Finck, 1966). In 1945, Lowy, using a watch tick as a stimulus, showed that the response recorded from the auditory nerve of the cat could be masked by different tones (Finck, 1966). Teas, et al. (1962) concluded that noise eliminates part of the action potential. It "acts primarily by eliminating portions of the normal response at times appropriate to the frequency characteristics and level of the noise" (Studebaker, 1973).

Katsuki, et al. (1958) furnished evidence of the nature of masking: a pure tone produces a spike in a single auditory nerve fiber at a characteristic rate, but when a low tone also is presented and raised in intensity, the rate becomes changed to the characteristic of the low masking tone. Neither Katsuki, et al. (1958) or Tasaki (1954) observed inhibition or reduction of response, and subsequently concluded that the mechanism involved in this masking seems only to be the overriding of the stimulus effects of the signal by the masking tone.

Coats (1967) recorded action potentials in cats and

supported the concept of overlap as the factor which determines amount of masking. He defined overlap as the number of "responding units" (nerve fibers, sensory hair cells or both) which the masking and the masked stimulus have in common.

Recording action potentials from the auditory nerve of the hamster, Finck (1966) followed the paradigm used by Small (1959) in his psychoacoustic study. Finck defined masking in terms of the pure tone masker level required to obliterate the gross 8th nerve response to the pure tone test signal. Results were remarkably similar to those of Small, even to the location of irregularities in the masking curve. The similarities of these two studies--one physiological, the other psychophysical--suggest that the mechanisms involved in the masking of the neural response and the detectability of a signal in simple pure tone masking are comparable. Finck attributed masking to direct effects that result from the overlap of signals in the cochlea--a kind of preempting of neural activity by a secondary tone.

MASKING AT HIGH FREQUENCIES

Research interest has dwelled upon the upward spread of masking; however, careful attention to the data presented shows that not all masking spreads upward. The work by Ehmer in 1959 is the most complete in terms of investigating

the masking patterns produced by a number of frequencies at varying intensity levels. He obtained masking patterns for pure tones spaced by octaves from 250 Hz through 8000 Hz at five sensation levels (20-100 dB). Masking curves were symmetrical at 20 dB sensation levels for all frequencies of the masking tone except 250 Hz, which showed the upward spread even at this low level. He reported that all other frequency curves clearly departed from symmetry above 40 dB SL, with masking increasing rapidly in both amount and extent at higher frequencies while failing to spread to the lower frequencies.

In reviewing all of Ehmer's masking curves, it was noted that the extension of masking to the higher frequencies is more marked for lower frequencies of the masking tone than for higher frequencies. Of additional interest, at 100 dB sensation levels of the 4000 and 8000 Hz maskers, a downward spread of masking is evident. In an effort to explain this unusual phenomenon, Ehmer stated:

. . . a subharmonic cannot be invoked to explain the downward spread of masking from 4000 cps or 8000 cps at 100 dB SL since no subharmonic was heard, there were no beats heard near the subharmonic frequency, and there was no peak at this frequency. At present it cannot be said that this downward spread of masking is a result of spread of the masking-tone activity towards the apex of the cochlea since such has not been observed. It is not remote masking, since this results from detection of the envelope of the stimulus in the cochlea. . . . [It] seems to involve interference or inhibition of some sort (Ehmer, 1959a).

The evidence that the upward spread of masking is less pronounced as frequency is increased (Ehmer, 1959a;

Studebaker, 1973; Wever, 1949), and the evidence of a downward spread of masking in Ehmer's masking curves suggests that the very high frequencies may produce symmetrical or downward masking patterns. Unfortunately, Ehmer did not plot masking curves at sensation levels lower than 100 dB for the 8000 Hz tone. In fact, there is no research reported in the literature which has investigated masking patterns at frequencies above 8000 Hz.

If the trend toward upward spread of masking continues at the high frequencies, then we would expect to find greater threshold shifts above the masker frequency than below it. If, however, masking ceases to spread upward, as Ehmer's data seems to imply, then we might expect the thresholds of frequencies below that of the masker to be shifted by the same amount or perhaps even more than the tones above the masker frequency. In other words, at high frequencies the downward spread of masking may be as great or greater than the upward spread. Such information could contribute to our knowledge of cochlear mechanics and might also be useful to those investigating the use of high frequencies for diagnostic and rehabilitative purposes.

PURPOSE

The purpose of this study is to investigate the spread of masking produced by pure tones above 8000 Hz. More specifically stated, the question is: At frequencies above

8000 Hz, do pure tone stimuli below the masker frequency show significantly more threshold shift than those above the frequency of the masker?

CHAPTER III

METHOD

SUBJECTS

Subjects for this study were necessarily young, normal hearing listeners. It was unlikely that older or pathological ears could hear the high frequency test tones, and it was important that their masking patterns be typical of normal cochlear function. Thus, criteria for participation were two: 1) the subject must be under 30 years of age and 2) must demonstrate hearing threshold levels of 10 dB American National Standards Institute (ANSI) or better from 250 to 8000 Hz as determined by standard audiometric procedure. Since norms have not been established for the high frequencies, "normal" hearing could be documented only through 8000 Hz. Nine of the first 13 subjects tested met the criteria. Six were female, three were male. Ages ranged from 23 to 27 years with a mean of 25 years. All had had some exposure to hearing testing or hearing research, but none had had previous experience with the parameters of this study.

INSTRUMENTATION

Testing was conducted in an Industrial Acoustics

Company (IAC) double wall sound-treated environment at the Kresge Hearing Research Laboratory in association with the University of Oregon Medical School Department of Otolaryngology which is located in the Portland Center for Hearing and Speech.

Pure tone stimuli used for threshold determination were generated by a General Radio 1309 oscillator, and passed through an internally timed electronic switch (Grason Stadler 1287) thus maintaining a pulsed signal of 200 msec duration with a 50% duty cycle (200 msec on, 200 msec off). Rise and decay time was 25 msec in accordance with standard Bekesy and automatic audiometry. This pulsed signal was fed through a Hewlett Packard 350D Attenuator Set, a Grason Stadler Recording Attenuator (E3262A), a Marantz Model 240 power amplifier followed by a tail-end attenuator, and delivered to the transducer, a University T-201 Sphericon "tweeter."

For masking, a constant tone produced by another General Radio 1309 oscillator and controlled by a second Hewlett Packard attenuator was mixed with the pulsed signal by means of a Grason Stadler mixer (Attenuator-Mixer 1292). A block diagram of the test equipment is shown in Figure 2.

Impedance matching transformers were used preceding and following the recording attenuator. The two oscillators were maintained at a constant output voltage as ascertained by a Honeywell Digitest Model 333 Voltmeter. Nominal

Figure 2. Block diagram of testing apparatus.

frequency was controlled at ± 1 Hz as monitored by a Monsanto Model 100A Counter-Timer.

A specially designed speculum, connected to the speaker via tubing, was used to deliver the directional high frequency tones into the ear canal. A rubber tip provided a snug seal. To maintain proper and constant alignment in the canal, the speculum was held in place by a speculum holder mounted to a ring and attached with velcrou straps around the head.² This apparatus is shown in Figure 3.

Figure 3. Photograph of the head gear. The tubing leading from the speculum was connected to the speaker during testing. The probe-tube microphone is in place.

²Appreciation is extended to Mr. Herman Bender, Medicon Corporation, for construction of the head gear.

Measurement of the pure tone signals was accomplished by means of a calibrated probe-tube microphone positioned in the speculum. For calibration of the system, following each test session, the signal was routed to a Bruel and Kjaer microphone power supply, then via cathode follower to a General Radio 1900 Wave Analyzer.

PROCEDURE

The nine subjects used a self-administered Bekesy tracking technique (fixed-frequency mode) to trace their pure tone thresholds in quiet and in the presence of an 11000 Hz steady tone masker. Test frequencies were 9000, 10000, 10500, 11500, 12000 and 13000 Hz. Masking was then determined by the amount of threshold shift expressed in dB from quiet to masked condition and masking curves were plotted as a function of frequency. Testing procedures, a description of which follows, were identical for each subject.

The speculum-holding apparatus was secured comfortably but tightly around the test-ear and the speculum positioned in the canal until the subject reported a snug fit. Screw adjustments fixed that position for the entire test session allowing no movement of the speculum, but some head movement. A probe tube was positioned in the speculum to insure that conditions during sound measurement would be identical to those of threshold testing.

The subject traced his own threshold by alternately depressing and releasing a hand-held switch, which, when connected to the recording attenuator, provided a graphical representation of his responses. Using the Bekesy method, the datum from a single trial actually comprised a series of judgments based on the psychophysical method of adjustment. Consistent with other masking studies, the signal tone was pulsed for all listening conditions. Figure 4 is a graphical representation of that signal.

Figure 4. Schematic diagram of the signal pulses.

The pulsed tone was first presented at a suprathreshold level. The subject was instructed to depress the switch as long as he heard the tone pulses, to release the switch when the signal was no longer audible, and to depress the switch again when the tones reappeared. Each subject thus bracketed his threshold until the positive and negative excursions on the graph reflected approximately equal amplitudes (± 2 dB). This bracketing process required a minimum of 9 excursions for each threshold. Data from two of the original 13 subjects was rejected because excursions were not stable. Figure 5 shows an acceptable threshold trace.

Figure 5. Schematic representation of masked and unmasked thresholds. The signal was attenuated at a rate of 2 dB per second.

The steady tone masker was then introduced. The subject was instructed to allow the pulsed signal tone to again become audible, then press the signal switch until he could no longer hear the tones. Thresholds were again bracketed. Criteria for masked thresholds was the same as unmasked. Finally, the masker was removed and absolute threshold levels were again recorded.

The test schedule for each subject is given in Table I. Each subject was given two practice sessions, one of threshold determination in quiet and one masked practice. Threshold for 11k Hz, from which the intensity level of the masker was determined, was then established. At each test frequency threshold was obtained in quiet, then again in the presence of an 11000 Hz masking tone which was continuously present at a sensation level of 40 dB. The final threshold

TABLE I
TESTING SCHEDULE

Practice threshold in quiet
Practice masked threshold
Threshold for 11k Hz in quiet
9k Hz in quiet
9k Hz in presence of 11k Hz at 40 dB SL
9k Hz in quiet
10k Hz in quiet
10k Hz masked
10k Hz in quiet
10.5k Hz as above
11.5k Hz
12k
13k
11k Hz in quiet

measurements were a repeat of the initial condition. In psychophysical terms, this is an A-B-A design which offers the advantages of minimizing or eliminating progressive and accumulative effects such as fatigue, practice, learning, adaptation, etc.

The choice of frequency of masking and test tones was arbitrary. A 40 dB SL masking level was chosen because it should be great enough to produce the asymmetrical masking pattern if such exists and yet low enough to avoid the possibility of introducing aural harmonics and combination tones (Carter and Kryter, 1962; Ehmer, 1959a).

The order of threshold testing always started with the lowest frequency (9000 Hz) and proceeded systematically to the highest (13000 Hz). This same procedure was followed

by previous masking studies.

The masking tone (11k Hz) was established at 40 dB above the threshold for each subject. That threshold was rechecked at the end of the "masked" trials. If these two threshold determinations did not agree within 2 dB, the data were discarded. Such an occurrence happened only once.

In order to determine an actual sound pressure value for threshold, the sound pressure present at the end of the speculum was measured. Figure 6 is a schematic diagram of the sound-measuring apparatus in the ear canal. Approximate distance from the microphone to the tympanic membrane is 25 mm, varying, of course, with individual differences in

Figure 6. Schematic diagram of sound-measuring apparatus in the ear canal.

length and diameter of the external canal. Equipment is not sensitive enough to measure sound at the levels where the subjects reported threshold. However, the probe tube microphone had been calibrated at $\frac{1}{2}$ μ bar, 1 μ bar, 10 μ bar, and 100 μ bar producing a linear function. Therefore threshold values were obtained with confidence through extrapolation.

Sound pressure measurements were conducted at the frequencies noted in Table I. The steady tone was introduced into the canal and its intensity was increased until the voltage equaling 1 μ bar was registered in the wave analyzer. The amount of attenuation necessary to produce 1 μ bar was noted. The attenuation value at threshold was then subtracted from that value to determine the threshold value in dB re: 1 μ bar. For example, the microphone calibration value for 1 μ bar at 11k Hz was 64 μ volt. For Subject #9, 1 μ bar (or 64 μ volt) was generated in the ear canal with 12 dB of attenuation. Threshold for #9 had been obtained with 78 dB of attenuation, e.g. 12 dB - 78 dB = -66 dB. Thus threshold was -66 dB re: 1 μ bar. To convert dB re: 1 μ bar to the more conventional sound pressure level terminology (re .0002 dyne/cm²), 74 dB is added to -66 dB to obtain 8 dB.

Approximately three minutes were spent testing each frequency. The total time spent, from speculum-positioning through sound measurement procedures, varied from 45 to 60 minutes.

Threshold was designated as the median value of a minimum of 9 excursions and calculated by averaging positive and negative peaks. The amount of masking was measured in the usual way, as the difference in sound pressure, expressed in dB, for masked and unmasked thresholds. This may also be referred to as the amount of threshold shift from quiet to masked condition. The amount of masking for the example in Figure 5 would be 11 dB.

CHAPTER IV

RESULTS

PRESENTATION OF RESULTS

The masking pattern shown in Figure 7 represents the mean amount of masking for all nine subjects at each of the test frequencies with variation among listeners noted by the range and standard deviations. The figure clearly shows a downward spread of masking, with greater threshold shift below the masker frequency (11000 Hz) than above.

This average masking pattern preserves the characteristic features of the individual records. Without exception, every subject showed a similar pattern: greater masking below rather than above the masker frequency. Histograms in Figure 8 show this pattern for each subject. In every instance the greatest threshold shift is shown at 10.5k Hz. In most cases the masking at 10k Hz also exceeded the amount of shift at 11.5k Hz. No one subject was found to have consistently more (or less) masking at all test frequencies when compared with other subjects.

Using the Wilcoxon paired sign-rank test (Steel and Torrie, 1960; Wilcoxon, 1949), significant differences were found between amounts of masking at 10.5k Hz and 11.5k Hz at the 0.01 level of confidence. Comparisons of masking

Figure 7. Average masking pattern for 11000 Hz at a 40 dB sensation level for nine listeners.

Figure 8. Bar graphs representing threshold shift at each frequency above and below the 11000 Hz masker for individual subjects.

at 10k and 12k Hz and at 9k and 13k Hz similarly yielded significant differences at the 0.01 level. Table II delineates these differences.

TABLE II
A COMPARISON OF MEAN THRESHOLD SHIFT
(MASKING) BY FREQUENCY

Frequency	Mean Threshold Shift (dB)	Analysis of Difference
10.5k Hz	24	p > 0.01
11.5k Hz	15	
Difference	9	
10k Hz	17	p > 0.01
12k Hz	5	
Difference	12	
9k Hz	8	p > 0.01
13k Hz	3	
Difference	5	

The significance of the differences between thresholds in quiet and masked thresholds was also examined statistically by means of the Wilcoxon test. These results revealed significant differences beyond the 0.01 level of confidence at every test frequency. Further testing at 8k Hz and 14k Hz, had time and equipment allowed, might have provided information as to the extent of the spread above and below the masker.

For all nine subjects, the thresholds in quiet before and immediately after the masked thresholds differed by no

more than 2 dB, suggesting that practice effect and/or fatigue were negligible.

With respect to variability of threshold shift among subjects, it can be seen from Figure 7 that the variability tended to be greater at the frequencies where the greatest amount of masking was produced. Thus standard deviations at 10k and 10.5k Hz were 4.96 and 4.44, whereas at 12k and 13k Hz, where very little masking was evident, standard deviations were as small as 2.40 and 2.38. Egan and Hake (1950) found that variability was greatest at the point of maximum masking, which in their case was for frequencies above the masker. Similarly, the greatest variability in the present data was below the masker frequency in the region of maximum spread.

Duplicate sets of data were collected for three of the subjects during second test sessions. Comparisons of amount of masking at each test frequency were made between the two sets of data (Figure 9). Masking patterns were remarkably similar for the two sessions for all three subjects. Test-retest reliability was .97 as calculated by Spearman's Rank Correlation Coefficient (Mendenhall, 1971).

Of secondary interest to the present study are the absolute threshold levels obtained for the high frequencies under test. Because of problems with calibration, coupling, and/or standardization, conventional audiometry has been confined to a frequency limit of 8000 Hz. Recent interest

Figure 9. Comparison of the masking patterns obtained on two separate test sessions for three subjects.

in high frequency sensitivity has stimulated a number of investigations aimed at providing normative data (Harris and Myers, 1971; Harris and Ward, 1967; Lipscomb and Cutts, 1971; Northern, et al., 1971; Rice, et al., 1969; and Zislis and Fletcher, 1966). Other researchers have investigated changes in high frequency thresholds due to noise, disease or drugs that would not be detected with conventional audiometric procedure (Cunningham, 1972; Fletcher, et al., 1967; Jacobson, et al., 1969; Rosen, et al., 1964a and b, 1965).

The mean high frequency thresholds obtained for the nine listeners in the present investigation are plotted in Figure 10. Thresholds for Subject 2 were consistently the poorest at every frequency. At 12k Hz, her threshold was 15 dB greater than any other subject, no doubt contributing to the increased variability at that frequency. There was no evidence, however, that the masking curves for Subject 2 differed from the other subjects either in amount or extent of masking. No one subject yielded thresholds which were consistently best.

The absolute threshold levels obtained for the subjects who were tested twice were compared. Thresholds for each subject differed by no more than 5 dB from first to second testing. Spearman Rank Correlation Coefficient showed good agreement ($r_s = .86$) between the two test runs.

Table III and Figure 11 compare the high frequency threshold data of this investigation with the normative

Figure 10. Unmasked hearing threshold levels, showing mean, range, and standard deviation for the nine subjects.

TABLE III
AVERAGE HEARING THRESHOLD LEVELS IN dB
(RE 0.0002 DYNE/CM²) FOR EIGHT
DIFFERENT HIGH FREQUENCY
AUDIOMETRIC THRESHOLD
STUDIES

Frequency	Sivian and White	Dadson and King	Rudnose	Zislis and Fletcher	Harris and Ward	Northern et al.	Northern et al.	Widen
kHz	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
8	20	17	16	14	20	21	5	
9			18	16		23	4	11
10	29	24	21	18	4	26	4	10
11			18	18		25	9	13
12	35	29	14	18	13	20	15	14
13			15	19		28	15	13
14	46	37	17	22	6	27	15	
15	50	41	17	22		32	17	
16			18	38	19	36	24	
18			27	64	24	60	51	

- (1) 1933 - Weighted data based on a sample of both young and older subjects.
- (2) 1952 - Smoothed curve based on two studies; one for 198 ears through 15k Hz, the other for 512 subjects (1024 ears), both 18-25 years.
- (3) 1961 - 12th grade, 12 subjects through 14k Hz, 3 subjects 15-18 Hz.
- (4) 1966 - 6th-12th grade females, 60 ears.
- (5) 1967 - 10-12 year old children.
- (6) 1971 - 20-29 years, 117 subjects randomly chosen.
- (7) 1971 - Recommended high frequency threshold values for "0" dB hearing level.
- (8) 1974 - 23-27 years, 9 normal-hearing subjects.

Figure 11. Summary of the average hearing threshold levels for eight different high frequency audiometric threshold studies.

studies of others. Population, equipment and methods varied among studies precluding any strict comparison. It may be observed that data from the present investigation most closely coincide with that of Northern, et al. (1971, 7).

DISCUSSION OF RESULTS

It is a generally accepted premise that masking spreads upward along the frequency scale and that masking will be greater above the masker frequency than below. This is based upon only a few studies, none of which dealt with frequencies above 8000 Hz. The results of the present study indicate that the upward-spread-of-masking phenomenon is not applicable at the higher frequencies. Indeed, a downward shift seems to be the case. Figures 7 and 8 show that an 11000 Hz pure tone of 40 dB sensation level produces significantly more threshold shift at frequencies below it than above it.

In an effort to rule out possible variables which may have contributed to a downward pattern, one subject was retested on a reversed testing schedule. Threshold testing was begun at 13k Hz, proceeding systematically to 9k Hz. The masking produced during this reverse run remained within 1 dB of the subject's original results at 10k, 10.5k, 11.5k, and 12k Hz. At 9k and 13k, threshold shifts were 3 dB greater for the second run. It was concluded that order of presentation of frequency could not account

for a shift in either direction.

Masking patterns were obtained for another subject (#3) at low frequencies, using a 1200 Hz masker. The resulting masking pattern is shown in Figure 12. Consistent with earlier studies, the greater threshold shift is found above the masker frequency. In terms of extent of masking, however, the masking seems to extend farther into the lower frequencies. Several variables could possibly have contributed error at these low frequencies, such as speaker inefficiency below 5000 Hz. Although the masking pattern for the 1200 Hz tone was not identical to those of previous studies, it did differ significantly from those obtained at the high frequencies in this study. Thus, it was assumed that factors within the testing equipment itself were not responsible for the downward pattern at high frequencies.

The possibility that the two tones, masker and maskee, might interact before reaching the ear was tested in the preliminary calibration of equipment before data collection was begun. Using the wave analyzer to measure changes in signal intensity, it was found that an 11k Hz tone 40 dB more intense than the test signals did not effect changes in the intensity of pure tones 9k Hz through 13k Hz, nor did the various test frequencies affect the intensity of the 11k Hz masker.

Due to limitations in producing the high frequency

Figure 12. Masking pattern of a 1200 Hz pure tone of 40 dB sensation level for one listener.

stimuli, the present study necessarily differed in some aspects from earlier masking studies. A conventional Bekesy audiometer which sweeps continuously from low to high frequency was used in several of the other studies. This allowed observations of peaks and valleys in the masking curve. As a masker, narrow bands of noise might have been preferable to the pure tone, however, equipment was not available to produce narrow band noise at these high frequencies. The directional nature of the high frequency stimuli required the use of unconventional head gear. Greater air space thus existed between the transducer and the eardrum than is usual, e.g., when the transducer is mounted within an earphone cushion. Since sound was measured within the canal, this greater air space should not be an influencing factor.

A study such as Ehmer's (1959a) which employed several masker frequencies at varying sensation levels would provide a complete picture of high frequency masking patterns.

The results of this study show a definite downward shift of masking with respect to amount of masking. With respect to extent of masking, the results suggest that the pattern extends farther into the lower frequency region than the high. Masked thresholds at two additional frequencies, 8k and 14k Hz, could probably have confirmed this trend.

There is no evidence to suggest that the mechanisms

responsible for high frequency masking patterns are different from the lower frequency patterns. At levels up to 60 dB SL the cochlear activity pattern of the masking tone is thought to determine its masking pattern (Carter and Kryter, 1962; Ehmer, 1959a and b; Studebaker, 1973). For lower frequencies, the cochlear activity spreads toward the base as masking intensity increases, producing an upward spread of masking. For the very high frequency tones, of interest to our study, the area of maximum displacement on the basilar membrane will be at the very basal end of the cochlea. With increased cochlear activity the only direction available for spread would be downward in frequency or in a more apical direction in the cochlea.

A further test of this hypothesis and an interesting follow-up to the present study might involve an investigation of the physiology of high frequency masking. The effect of a high frequency masker on nerve action potentials in animals, such as the guinea pig, might be measured and the masking patterns compared to those of this study. Systematic destruction of portions of the Organ of Corti above and below the area of the basilar membrane responsible for the masker frequency would allow observation of masking pattern changes. If the downward spread of masking is due to cochlear activity toward the apex, then destruction of hair cells and nerve endings below (in an apical direction)

that portion of the basilar membrane should reduce or eliminate the downward spread. Destruction at the very basal end should have little effect.

CHAPTER V

SUMMARY AND IMPLICATIONS

SUMMARY

Previous investigations of masking have established that the action of the masking tone spreads upward in frequency, creating significantly more masking (threshold shift) above the masker frequency than below. It was the purpose of this study to investigate the masking pattern produced by high frequency pure tones, heretofore uninvestigated.

Masking patterns were obtained for nine normal-hearing young adults utilizing the method of adjustment. The masking produced by an 11000 Hz pure tone of 40 dB sensation level was measured at three frequencies above and three frequencies below the masker frequency. Analysis of the data revealed a downward spread of masking. Pure tone stimuli below the 11000 Hz masker showed significantly more threshold shift than those above the masker frequency.

On the basis of the data collected in this investigation, it must be concluded that the upward-spread-of-masking phenomenon is not entirely applicable at high frequencies. It is proposed that, as the activity pattern of

the masking tone reaches the high frequency region at the basal end of the cochlea, the spread of masking is reversed in the direction of available space--toward the apex. The findings point to a need for further investigation for the purpose of explanation and possible clinical application of this new information.

IMPLICATIONS FOR FURTHER RESEARCH

The present study has opened many possibilities for further investigation.

Extensions of the present study, using maskers of other frequencies and varying sensation levels, could answer questions such as these: At what frequencies does the upward spread of masking no longer apply? At what frequencies is the downward spread first noticeable? Does the downward spread of high frequency masking continue at high intensity levels? Does the downward spread become more pronounced at higher intensities and higher frequencies?

An N_1 study of masking, as was mentioned in the discussion section of this paper, might provide physiological support for the findings presented here and possible explanations for the downward spread at high frequencies.

Researchers have investigated the possibility of using masking patterns in differential diagnosis (Harbert and Young, 1965; Jerger, et al., 1960; Pickett and Martin,

1970; and Rittmanic, 1962). Perhaps differences in high frequency masking patterns can assist in identifying site of lesion.

Generally there is no relief for the person plagued with high frequency tinnitus. What are the possibilities of masking the tinnitus with another high frequency tone which is not as noticeably audible?

The present study may have clinical utility for high frequency audiometry. If contralateral masking is found to be necessary, data of this type could be used to determine effective masking levels.

The data of this study point to the need for investigating the possibility that high frequency, high intensity level noise may produce a deleterious effect on hearing in the audible frequency range.

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