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TEMPORAL RELATIONS IN PURE-TONE MASKING

CHAPTER I

INTRODUCTION

The phenomenon of masking occurs when one sound reduces the detectability of another sound. The sound producing the masking effect is the masker and the sound being affected is the maskee.

The process of auditory masking was described during the time of Aristotle. Auditory sensation was thought to depend on the "aer internus" or internal air.

> If it is set into motion, ear noises will result. Such noises can, however, be covered by louder noises coming from the outside (3).

This is apparently the first recording of the phenomenon of auditory masking.

Masking is defined, therefore, as a reduction in the ability of the auditory system to perceive the maskee in the presence of the masker. By measuring the threshold for the maskee in quiet and comparing that value with the threshold obtained for the maskee in the presence of a masker, masking efficiency is assessed. For the purposes of this paper, masking efficiency is the number of decibels the maskee threshold has been raised by the presence of the masker.

Until the late 1950's, masking efficiency was generally considered to be invariant throughout the duration of the masking stimulus even though the loudness of the masker was found to decrease over time. Prior to 1957, the only study which could be interpreted as being a challenge to the concept of the invariance of masking was conducted by Wever and Truman (56) in 1928. They used pure tones as both the "figural" signal (maskee) and "background" signal (masker). Their experiment revealed a decrease (improvement) in threshold for the "figural" tone during the first two minutes of continuous background stimulation. The results could be interpreted as a reduction in masking efficiency during the presentation of the "background" tone.

In June, 1957, Samoilova presented a paper at the Acoustic Conference in Moscow. An English translation of his work was published in 1959 (41). The major emphasis of his report was on preceding (backward) masking and residual (forward) masking and a comparison of the magnitude and duration of each. One of his graphs, however, shows a curve which was obtained in a simultaneous masking situation. This curve indicates that pure-tone masking efficiency changes over time when a maskee of brief duration is utilized.

The results of several investigators (19, 29, 39, 61, 62, 64) have either shown or have been interpreted as showing no changes for masking efficiency over time. On the other hand, some experimenters (23, 41, 42, 53, 56, 58) have reported findings which indicate that masking does change during the course of the masker. Zwicker (65) reports that masking change occurs only when there is a great difference between the spectra of the masker and maskee and that no temporal masking change is observed when the masker and maskee have similar frequency spectra. Samoilova (41) and Zwislocki, et al. (68, 69) have presented evidence contrary to Zwicker's hypothesis. Samoilova observed an ipsilateral masking change while using only pure-tone signals for the masker and the maskee. A change in contralateral masking efficiency over time has been reported by Zwislocki and his co-workers who also employed pure-tone signals. The conflicting results and conclusions among the above masking studies indicate the need for an investigation of ipsilateral and contralateral masking efficiency over time when pure tones are employed as both the masker and the maskee.

The primary goal of the present study is to investigate temporal changes in the masking of a pure-tone signal and to determine how the changes relate to spread of the masking pattern. A secondary aim is to compare masking efficiency and masking patterns for ipsilateral and contralateral maskers.

The next chapter encompasses a review of the pertinent literature on auditory masking with detailed emphasis on the articles concerned with temporal changes in masking efficiency. Subsequent chapters contain a description of the design and procedures used to conduct this investigation, the results of the study and a discussion of the findings relative to previous reports.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Auditory masking occurs when one sound (the masker) interferes with or reduces the detectability of another sound (the maskee). Masking may be observed when the masker and maskee are presented to the same ear, or when they are independently presented to the opposite ears of a listener. The former case is commonly known as peripheral masking and the latter, as central masker.

Although the terms peripheral and central are used in this review, the more general terms ipsilateral and contralateral will be used in describing the masking conditions in the present study. Peripheral masking requires that the two sounds stimulate the same cochlea and implies that the masking takes place in the peripheral mechanism. On the other hand, central masking occurs when the masker stimulates one cochlea and the maskee stimulates the opposite cochlea and implies that the masking occurs at the brain stem level or above. Thus, central masking occurs by itself only when the sounds are isolated from one another by being below the level of interaural attenuation.

A variety of sounds including wide-band noise, narrow-band noise and pure tones has been employed in various combinations to explore the phenomenon of masking. In the present study, only pure tones are used as the masker and maskees, and masking patterns of both ipsilateral and contralateral maskers will be evaluated.

Peripheral masking studies have been conducted by several investigators to explore the excitation pattern of a stimulus in the auditory system. Their findings reveal that peripheral masking is highly frequency specific to the spectrum of the masker and the frequencies adjacent to the masker (4, 6, 20, 21, 22, 24, 25, 30, 38, 39, 45, 46, 55). The thresholds of the test signals most affected by the masker increase linearly with increases in the masker level, except at low masker levels (6, 24, 25, 55, 67). As the masker level is increased, the masking pattern spreads more to the frequencies above the masker than to frequencies which are below the masker (4, 6, 20, 21, 22, 24, 25, 30, 46, 55). Under certain conditions, subjective tones can be perceived when pure tones are used as masker and maskee (20, 22, 24, 46, 55).

Central masking is measured by delivering the masker and the maskee so as to stimulate the opposite ears of a listener. Investigators have shown that the magnitude of central masking is quite small (7, 8, 9, 10, 11, 17, 18, 23, 31, 32, 33, 45, 54, 55, 67, 68, 69) and may increase only slightly with increases in the level of the masker (17, 18, 45, 55, 68, 69). It appears to be frequency specific to the region surrounding the masker (7, 8, 9, 18, 33, 45, 68, 69). Central masking has been attributed to the neurological interconnection of the two ears in the auditory system (7, 9, 10, 11, 32, 33, 55, 67, 68, 69) and may represent a complex neurophysiologic interaction process (68).

Since the major purpose of the present study is to investigate changes in pure-tone masking efficiency over time, the remainder of this chapter will include a review of those studies which deal with temporal relations in simultaneous masking.

Temporal Relations in Masking

Peripheral Masking

Four years after Wegel and Lane's (55) detailed tone-on-tone masking investigation, Wever and Truman (56) presented data which demonstrated that the threshold for one tone in the presence of another tone decreases over a period of several minutes. This decrease in threshold may be considered to result from a decrease in the efficiency of the masker during the test procedure.

Wever and Truman assumed that Wegel and Lane had used interrupted maskers and maskees in their experiment. They suggested that the results represented only the pulsed maskee-pulsed masker condition and hypothesized that threshold would change when both the masker and maskee are presented continuously.

In order to investigate this possibility, they used a sustained 1000-Hz signal for the "background" tone (masker) and a 2250-Hz signal for the "figural" tone (maskee). One threshold was obtained for the 2250-Hz tone every 15 seconds by the classical method of limits. Descending and ascending threshold crossings were alternated and a total of 20 thresholds were measured over a period of five minutes of continuous stimulation. The two subjects used in the study had received practice at the task prior to the collection of data in the experimental sessions.

A graphic representation displayed the results in intensity DLs over time for each of the 20 thresholds. When each of the 10 pair of ascending-descending thresholds is averaged, it appears that the magnitude of masking reduction over the five-minute period is from 4 to 8 dB (using 1 DL $\approx$ 1 dB) with the majority of masking change occurring within the first two minutes of stimulation.

Wever and Truman then compared these measurements with others obtained in essentially the same manner except that the "ground" tone was sustained for four minutes prior to beginning the threshold determinations. They made this comparison to test two possibilities which they thought could account for the change in threshold over time. First, they hypothesized that a psychological process might be involved whereby the "figural" tone was initially novel and gained an attentional advantage over the sustained and monotonous "ground" tone. The second hypothesis was that an independent factor, such as sensory fatigue, accounted for the masking reduction.

This second investigation revealed a slight decrease in threshold (2 to 3 dB) during the five-minute measurement period. The reduction was much less than that observed in the first experiment leading them to conclude that both attention and auditory fatigue may be involved in the change in threshold observed during constant stimulation.

Although the above study is interpreted in this review as illustrating masking change as a function of masker duration, the first experiment specifically designed for such a purpose was reported by Harris (29) in 1947. He performed a masking experiment preliminary to measuring pitch discrimination in noise. Masked thresholds were obtained for a 1000-Hz tone at the beginning of and at five-minute intervals during a 20-minute exposure to a 45-dB SL white noise. The results on 10 subjects showed no change in the masking effect of noise for the 20-minute period.

Egan (19) confirmed the results of Harris in a more detailed study in which the masked threshold for a 1000-Hz tone was measured in the presence of 90-dB SPL of white noise. Egan knew that the ear demonstrated measurable perstimulatory fatigue with the 90-dB signal and sought to relate the amount of fatigue to the amount of masking change. Masking and fatigue were repeatedly measured over a period of seven minutes, and although the ear fatigued 17 dB, masking was found to be invariant. In a limited follow-up experiment, Egan presented a 1000-Hz tone as the masker and measured the threshold for a 1100-Hz signal. Less than 1 dB of masking change was observed during seven minutes of masking stimulation. On the basis of these studies, Egan concluded that masking was independent of the loudness decrease which occurs during constant stimulation.

In 1956, Thwing (53) used a masking technique to determine the amount an ear would adapt during a sustained 1000-Hz, 70-dB SPL tone. The tone was presented for six minutes and white noise was introduced intermittently and adjusted to the level necessary to just mask the tone. With this method, Thwing demonstrated that the noise could be reduced by 6 dB during the six minutes of constant stimulation. He interpreted his results as a measure of adaptation for the pure tone over the test period. The experiment has also been interpreted by

Elliott (23) as demonstrating a 6-dB reduction in the masking efficiency for a 1000-Hz pure tone over a period of six minutes.

Samoilova, (41) in 1959, studied backward and forward masking and, in addition, made a brief reference to a simultaneous-masking condition. During the presentation of a 1000-Hz masking tone of 300-msec duration, a 1380-Hz maskee was introduced. The maskee duration was 20 msec and its rise and decay times were set to preclude the production of switching transients. The maskee was delivered at various intervals during the course of the masker. His graph (Fig. 8, p. 15) shows that masking efficiency decreases 10 dB in the first 120 msec of the masker and remains stable thereafter.

In 1962, Scholl (42) reported tnat the ear is highly frequency specific, but that this pattern of selectivity is not instantaneous and requires time to develop. He stated that at the instant of onset of a sound, the pattern of excitation in the ear is broad and unsharpened. As the sound continues to stimulate the ear over a period of time, the excitation pattern becomes narrowed and the selectivity of the ear is enhanced. Scholl obtained quantitative information to support his hypothesis with the following masking experiment.

Two noise bands separated by a frequency gap and positioned on either side of 2000 Hz were used as the masker. The gap was measured between the upper cut-off frequency of the lower frequency noise band and the lower cut-off frequency of the upper frequency band. The effect of varying the width of the gap from 0 Hz to 1800 Hz was investigated. The masker had a duration of 500 msec and was presented at an overall level of 60 dB. The maskee was a 3-msec, 2000-Hz tonepip with 1-msec rise and decay times. Thresholds for the maskee were measured for various frequency gaps in the masker under four temporal delay conditions; masker onset to maskee onset intervals of 3 msec, 10 msec, 50 msec and 300 msec. Curves were plotted for each of the four temporal delay positions on a graph which was measured in level of the maskee (in dB) by width of masker frequency gap (Δf).

Results of this experiment indicated that the pattern of excitation for the masker was considerably wider (by 300 Hz) near the masker onset than after a period of 300 msec of stimulation.

Scholl performed another experiment in which the frequency gap between the masker noise bands remained constant (at 750 Hz). Threshold was monitored for a 2000-Hz tone centered between the noise bands and delivered at various delays with respect to the onset of the masker. An illustration of the results shows a masking reduction of 19 dB during the first 300 msec of masker duration.

Experiments were also conducted by Scholl to determine if this sharpening in the auditory system was frequency specific. In one phase, he positioned two masker bands on either side of a 6000-Hz tone to produce a frequency gap (between bands) of 2100 Hz. Thresholds for the 6000-Hz maskee (3-msec duration) were measured at several temporal positions. The same paradigm was used for noise bands placed on either side of a 500-Hz tone of 15-msec duration.

The results again showed a decrease in masking at both frequencies. Approximately 18 dB of reduction in masking efficiency was measured for the noise masker around 6000 Hz. A decrease of 11 dB of masking was observed for the masker positioned on either side of

500 Hz. Scholl attributed the 7-dB difference in the amount of masking change primarily to the difference in the maskee durations, and not to the frequency difference. Since the 6000-Hz maskee was 3 msec in duration, this allowed the masking pattern to be sampled at more discrete intervals than was possible for the 15-msec, 500-Hz maskee.

Scholl concluded that the narrowing of the excitation pattern indicated by his experimental findings may result from physiological processes (inhibition). Since time is required for inhibition to occur, this time is reflected as a change in masking efficiency.

Osman and Raab (37) attempted to perform a temporal masking experiment in audition analagous to a visual experiment conducted by Crawford (12). They utilized a wide-band noise as the masker and measured thresholds for 0.1-msec clicks as a function of the temporal relation between the noise and the click. The thresholds were obtained at intervals varying from 50 msec before the masker onset to 10 msec after the termination of the masker. The noise bursts were presented at levels of 60-, 75-, 85- and 95-dB SPL and had durations of 10, 100 and 500 msec.

Results from two subjects are reported to reveal "more or less flat-topped" curves for the various conditions. Although the authors state that "...no marked elevation of probe threshold is encountered near onset or termination..." they do indicate that minimal on- and off-effects are reflected in two of their curves.

Wright (64), in 1964, reported on backward and simultaneous masking and on how backward masking relates to temporal summation. Thresholds for 1000-Hz tones of various durations were measured in the presence of narrow-band noise bursts of 40, 60 or 80 dB which were centered at 1000 Hz. The intervals between the onsets of the masker and the maskees were varied. In some conditions the tone onset preceded the noise onset and only a portion of the noise and tone overlapped in time. In other conditions, true simultaneous masking occurred with the tone onset either coincident with or delayed from the masker onset. In all conditions the 1000-Hz tone was terminated prior to the termination of the noise. In a second experiment the threshold for a 10-msec, 1000-Hz tone was measured with the intervals between the onset of the tone and onset of the noise being the same as those used in the first experiment. The second experiment, however, did not include a simultaneous masking condition.

In the simultaneous masking conditions of the first experiment, a threshold shift is noted as the onset-to-onset interval is increased. This, however, is attributed to reducing the duration of the maskee (temporal integration) and not to a change in masking efficiency over time. Such a temporal change in masking is unlikely in this case since the duration of the maskee near masker onset was from 300 to 500 msec. A maskee of this duration would extend beyond the point (considered to be 200 to 300 msec) where masking efficiency ceases to change significantly (<u>23</u>, <u>65</u>, <u>66</u>, <u>69</u>).

In a subsequent investigation in 1964, Wright (<u>62</u>) extended the experiment to frequencies outside the narrow-band noise centered at 1000 Hz. Thresholds for test-tone frequencies of 800, 1000, 1200 and 1750 Hz were measured to evaluate the spread of the backward masking effect of the noise.

Although no simultaneous masking data were presented, Wright reached conclusions from the backward masking experiment which were interpreted with respect to simultaneous masking. He states that the pattern for backward masking (with narrow-band noise) appears first at the central portion of the masker band and then spreads to adjacent frequencies. He then infers from his backward masking data to a simultaneous masking situation and states that the simultaneous masking pattern appears to be "...established either before or at the instant that a masking sound is presented." This conclusion that he has reached from a backward masking experiment, implies that simultaneous masking is invariant over time.

Some questions must be raised concerning the conclusions reached by Wright and how they apply to simultaneous masking. His findings do reveal that backward masking is observed earlier in time and with greater magnitude for test frequencies near that of the masker. However, because of the rather lengthy maskee durations employed in the simultaneous masking condition of his first experiment, and the failure to investigate simultaneous masking in the second experiment, Wright's conclusions regarding the simultaneous masking pattern seem unjustified. Statements made relative to the pattern obtained in simultaneous masking should be based only on direct measurements of simultaneous masking.

In 1965, Zwicker (66), reported on several investigations which he undertook to evaluate the effect of masking over time. In each case, the masker was a white noise and the maskees were either a 1000-Hz or 5000-Hz tone, a white noise or a filtered noise. He varied several parameters of the signals and of the masker to obtain a measure of "overshoot" (this term, appears to have been borrowed from visual masking and refers to the increase in masking observed at the onset of a masker compared to steady-state masking).

Results from Zwicker's work revealed an overshoot of 2 to 3 dB when a white noise pulse (2-msec over-all duration) was used as a maskee and was delayed in time relative to the onset of the masker.

With 2-msec maskees composed of filtered noise and varying in bandwidth from 1 to 20 critical bands centered at 4800 Hz, the overshoot progressively decreased (approximately 8 dB) with increases in the bandwidth of the maskees. For a 5000-Hz pure-tone signal of 2-msec duration, the overshoot was 12 to 13 dB. Zwicker concluded that very little overshoot was observed when masker and maskee have the same or similar broad frequency spectra, but that it increased (to as much as 13 dB) when the maskee was a tone and masker was a broad-band noise.

In 1965, Zwicker (65) reported another study concerning overshoot in the auditory system. After reviewing the investigations of this topic (19, 37, 42, 61, 66), he attempted to explain why overshoot does not occur consistently in investigations of temporal masking relations. Since overshoot occurred when the frequency spectra of the masker and maskee were different (19, 42, 66), and did not occur (at least not significantly) when the spectra were the same or similar (37, 61, 66), he suggested that overshoot was related to differences of the masking signal spectra.

Zwicker then demonstrated that by decreasing the bandwidth of a masker surrounding a 5000-Hz test signal, the magnitude of the overshoot decreased. He replicated the experiment by Scholl (42) and confirmed that an overshoot occurred when the threshold of a test signal was measured within a frequency gap in noise.

Both Zwicker and Scholl demonstrated overshoot under several experimental conditions. Zwicker, indicated that the auditory system exhibits "normal overshoot" only under certain signal conditions. He repeatedly disagreed with Scholl's hypothesis, that the pattern of excitation requires time to sharpen and may result from neurological inhibition, and in one portion of his article concluded that excitation in the hearing mechanism is produced almost immediately and does not change as a function of on-time of the masker.

It is paradoxical that in another section of Zwicker's article, the following statement is found:

> However, the experimental results are consistent with the idea that the selectivity of the ear may be achieved through an increase of the basilar-membrane selectivity originating in lateral inhibition provided that lateral inhibition involves only a simple configuration at the very early stations near the receptors and requires very little time to occur.

Zwicker reported, however, that the above possibility was doubtful. He finally attempted to attribute overshoot to a strong mechanical filtering process. The process is composed of the displacement of the basilar membrane and of the stimulated hair-cell pattern arrangement. However, he failed to explain how such a process functions during the period of overshoot.

Elliott (23) in 1965, presented her detailed work in simultaneous masking. Wide- and narrow-band noises were used as maskers of pure-tone signals. In one experiment, she measured thresholds for a 5- or 10-msec, 1000-Hz tone in the presence of a wide-band noise. All rise and decay times for the maskers and signals were reported to be 1.8 msec. Maskees were delivered at various delays relative to the onset of the masker. Elevated masking was observed near the onset and termination of the masker when masker durations ranged from 100 to 1000 msec. Overshoot was as much as 10 to 15 dB at the onset; however, at the offset, the overshoot appeared to be somewhat less. When masker durations were less than 100 msec, onset overshoot remained the same, however, no overshoot was found at offset.

Elliott also replicated the study of Osman and Raab (37), and reported that her findings were consistent with theirs. She hypothesized that overshoot is due to general neural "on-effects" and would likely occur at other frequencies. She then studied the effect of varying the frequency of the test stimulus within and around a narrow-band masking noise. Various maskee frequencies were used with masker bands which were centered at 250, 1270 and 2550 Hz. Overshoot was generally less for frequencies within the band then for those which were just outside of it.

An attempt was also made by Elliott to determine if overshoot was frequency related when a wide-band masker was administered. Pure-tone maskees ranged in frequency from 200 to 6000 Hz. Results showed that more overshoot occurred at higher frequencies than at lower frequencies. Two of the three subjects failed to demonstrate overshoot below 1000 Hz while the third subject exhibited slight overshoot down to 200 Hz.

Elliott suggested that Scholl's hypothesis, that the pattern of excitation narrows over time, may be operationally synonymous with Zwicker's "normal overshoot." Since both Scholl and Zwicker obtained masking overshoot the only reason for their disagreement appears to be the cause of the overshoot. Elliott's findings also appeared to concur with Scholl's hypothesis.

Criticism should be raised at this point relative to the use of brief signals with extremely fast rise and decay times. Scholl (42), Zwicker (65, 66) and Elliott (23) have employed rise and decay times for their signals which were extremely fast for the transducers used. Zwicker (66) illustrated his maskee envelope with 1-msec rise-decay times as it appeared on an oscilloscope prior to transduction. He apparently did not examine the acoustic output from the transducer and was possibly unaware of the potential transient energy accompanying such a signal. Elliott utilized 1.8-msec rise and decay times which were also too brief at some frequencies for the earphones used. Wright (60, 63) has reported on the effects of similar energy pulses sent to transducers and has subsequently used 10-msec rise and decay times for the signals in his studies (62, 64).

Dirks and Norris (18) in 1966, conducted a masking experiment which used both monotic and dichotic conditions. In the monotic portion of the experiment thresholds for frequencies at 250, 1000 and 4000 Hz were measured in the presence of a wide-band noise. The effects of three temporal relations of the masker and the maskee were investigated on normal-hearing subjects. One condition required the masker and maskee to be simultaneously pulsed (P-P) while for another condition the masker and maskee were presented continuously to the listener (C-C). A third condition in which the maskee was pulsed and the masker was continuous (P-C) was also studied.

The results of their study illustrated that in the P-P condition masking was more effective than in either the C-C or P-C conditions. Masking magnitudes in the C-C and P-C conditions were generally comparable to one another. The effectiveness of the P-P condition was found to increase with respect to the other conditions when higher masker frequencies were utilized.

Wilbanks (58) in 1967, reported an experiment on temporal relations in masking. He used as a maskee a 250-Hz tone of 50-msec duration with rise and decay times of 10 msec. The masker was a filtered wide-band noise which extended down in frequency from 3000 Hz. Intervals between the masker onset and maskee onset ranged from 0 to 150 msec at intervals of 25 msec. His data illustrated a reduction in masking over time of approximately 1½ dB. The rather lengthy signal used by Wilbanks may account for the masking change being so small.

Studies have been conducted using numerous types of auditory signals to determine if temporal relationships between the masker and maskee affect the magnitude of peripheral masking. Some investigators (18, 23, 41, 42, 53, 56, 58,) have observed these changes in masking, whereas others (19, 29, 37, 62, 64), have failed to obtain temporal masking effects in their experiments. Zwicker (65) has attempted to reconcile these differences by suggesting that the frequency spectra of the masker and maskee may determine the presence or absence of temporal masking changes. As yet, a definite answer is not apparent regarding whether masker and maskees with similar spectra manifest temporal masking changes.

Central Masking

In 1961, Sherrick and Mangabeira-Albernaz (45) conducted an investigation to determine if the auditory system demonstrated contralateral masking as Sherrick (44) had found with cutaneous stimulation in a vibrotactile experiment.

The first phase of their study was to measure threshold for pure tones at octave intervals from 250 to 4000 Hz during the presence of either a pulsed white noise or a continuous white noise. The maskers and maskees were presented either in monotic or dichotic conditions. The maskee was pulsed at a rate of one per second and had a 50-per cent duty cycle. When the noise was pulsed, it was presented simultaneously with the maskee. The pulsed masker condition was demonstrated to be more effective for both the monotic and dichotic conditions.

The second and third phases of the investigation revealed that both monotic and dichotic masking were frequency specific. They employed a 40-dB SPL narrow-band noise centered at 4000 Hz as a masker. Thresholds for 1000- and 4000-Hz pure-tone maskees were measured in the presence of both steady and pulsed ipsilateral and contralateral masking. Masking was not observed for the 1000-Hz tone under any masking condition. For the 4000-Hz tone under the monotic masking condition, the pulsed masker produced 4.3 dB more masking than the steady masker. Under the contralateral masking condition (central masking), 1.93 dB of masking was measured in the presence of the continuous masker and 4.71 dB of masking resulted from the pulsed masker.

They also used a 1000-Hz pure tone as a masker and monitored thresholds under the same conditions for pure-tone maskees ranging from 500 to 1100 Hz. The results revealed that under the steady dichotic masking condition, negligible central masking was obtained at all frequencies. For the pulsed masker condition, central masking increased to as much as 12 to 13 dB as the maskee frequency approached that of the masker.

A final experiment performed by Sherrick and Mangabeira-Albernaz was to establish the relationship between the masker level and the amount of masking observed. Narrow-band and wide-band masking noises were presented at 50- to 90-dB SPL in 10-dB intervals. There were only slight increases noted in contralateral masking with increases in the masker level until the masker energy reached a level where it directly affected the maskee ear by way of cross conduction.

Dirks and Malmquist (17) reported on the masking efficiency of a contralateral masker. They used either pulsed or continuous pure-tone maskees of 250, 1000 and 4000 Hz. Thresholds were measured in the presence of a contralateral narrow-band noise masker centered at 4000 Hz which was delivered at either 50-, 70- or 90-dB SPL. The masker was delivered via an insert receiver and was either pulsed with the maskee or presented continuously. They found that the greatest central masking was obtained either when the masker and maskee were pulsed simultaneously (P-P) or when they were both presented continuously (C-C). In addition, they confirmed the report by Sherrick and Mangabeira-Albernaz that less masking occurs when the maskee is pulsed and the masker is continuous (P-C).

Central masking was found to increase with the level of the masker. A threshold shift of 4.08 dB was recorded for a 4000-Hz tone in the presence of the 50-dB SPL pulsed masker. When the masker was presented at 70- and 90-dB SPL, the central masking increased to 6.08 and 8.33 dB.

Elliott's experiment (23), discussed previously, dealt primarily with monotic masking. Dichotic masking, however, was also investigated and masking effectiveness was determined under several temporal delay conditions. The masker was a narrow-band noise centered at either 250, 1270 or 2500 Hz. It was presented at a level of 70-dB SPL for a duration of 500 msec. The 10-msec pure-tone maskees were located at several frequencies both within and outside the frequencies of the masker bands. Temporal delays between the masker onset and maskee onset of 5 msec and 300 msec were investigated. Elliott found that overshoot (considered as the difference in threshold between the 5-msec delay and 300-msec delay) occurred at all three frequency regions.

Approximately 4 dB of overshoot was measured for all frequencies from 200 to 1000 Hz for the noise band centered at 250 Hz. For the two higher frequency maskers, very little overshoot (1 to 2 dB) was observed for frequencies within the spectra of the masking bands while for frequencies just outside the bands, as much as 5 dB of overshoot was demonstrated.

As mentioned in the preceding section of this chapter, Dirks and Norris (17) investigated temporal relations in central as well as peripheral masking. The effects of three temporal conditions (P-P, P-C and C-C) were explored. Masking patterns were obtained for pure-tone masker frequencies of 1000 and 4000 Hz. Pure-tone maskees from 800 to 1200 Hz were used to define the pattern for the 1000-Hz masker. The pattern for the 4000-Hz masker was determined with maskees ranging from 2400 to 5600 Hz.

Temporal effects were observed for both masker frequencies. The C-C condition produced the most central masking (from 4 to 16 dB), and the P-C condition yielded the least masking (from 1 to 4 dB). The P-P condition resulted in intermediate values.

In 1967, Zwislocki, Damianopoulos, Buining and Glantz (69) reported on central masking as a function of various signal parameters. Their experiment was the first to specify and measure masking change at discrete points during the decay period from masker onset to the steady-state masking condition. These measurements were made with pure tones used as both the masker and maskee signals. The masker was a 1000-Hz tone delivered to the listener at 60-dB SL through an Audivox 9-C receiver connected to a soft semi-insert tip. This arrangement was used to functionally increase interaural attenuation. The masker was 250 msec in duration and was presented once every second. The maskee varied in frequency from 250 to 3000 Hz and consisted of tone bursts with an approximate Gaussian envelope and a duration of 10 msec measured between the half-power points. The onset of the maskee was delayed with respect to the masker onset by from 0 to 170 msec.

Central masking was measured by the Bekesy tracking method. For a 1000-Hz test tone, masking decreased from 10 to 3 dB within the first 160 msec of the masker. The masking decayed rapidly within the first 50 msec and tended to stabilize for durations beyond 160 msec.

The authors suggested that this rapid change in masking effectiveness is a reflection of the fast neural adaptation which has been observed in the auditory system.

In addition to the rapid change in masking efficiency, a slow decay of masking was noted over a period of minutes similar to what Wever and Truman (56) had observed for peripheral masking. Because of this slow reduction in central masking, Zwislocki, et al. accepted only the threshold measures obtained during the first minute of each test run. They found that the slow decay was present only for maskees near the frequency of the masker and did not occur when the test signal was several hundred cycles away. This gradual change in masking was not observed when the masker was a wide-band noise but appeared to be limited to pure-tone or narrow-band maskers.

Zwislocki, Buining and Glantz (68) in a second investigation reported on the frequency distribution of central masking. Two parameters were studied: masker intensity and time delay between the onset of the masker and the onset of the maskee. Pure-tone signals with envelope characteristics similar to those used in the previous study were again employed for the masker and maskee. However, in order to minimize the slow adaption of central masking which was previously observed, the 1000-Hz maskee was fixed at a constant level and the masker was varied in frequency and intensity to define the masking pattern.

Although irregularities were observed in the masking patterns which were obtained, the point of maximum masking was found to be either at the masker frequency or displaced toward the frequencies below the masker. It was suggested that the irregularities in the masking patterns reflected interactions between excitatory and inhibitory neural processes. Central masking was also found to decrease rapidly within the first 150 msec after masker onset. The amount of masking decay or overshoot was reported to be related to the magnitude of the initial threshold shift and not directly to the test frequency. As the time delay between the masker and maskee increased, the masking curves became less peaked. The authors suggested that their results reveal the presence of complex nonlinear processes which make up the auditory system.

Temporal effects in central masking experiments have been consistently observed (17, 18, 23, 45, 68, 69). Early studies focused on differences between various combinations of pulsed and continuous signals. A more refined technique allowed Elliott (23) to show that central masking is greater near masker onset (region of overshoot) than after 300 msec of stimulation. Zwislocki and his co-workers (68, 69) have conducted detailed qualitative and quantitative studies of the decay of central masking following masker onset. They suggest that a rather large and rapid decay of masking occurs within the first 160 msec after masker onset. Following the rapid decay but only under certain signal conditions, a slow decay of little magnitude may be evident over a period of several minutes.

Summary

Temporal changes in auditory masking were alluded to in 1928, however, only recently has interest been repeatedly focused on this topic to determine if such changes really exist. Experimenters have provided both negative and positive evidence in a variety of studies. Zwicker (65) considers overshoot to be a normal process and suggests it may result from a mechanical filtering mechanism. He has attempted to explain the conflicting reports of the occurrance of overshoot by stating that the masking change occurs only when there is a great difference in frequency spectra between the masker and the maskee, and that no temporal change is observed when the masker and maskee have similar frequency spectra. The majority of the findings of other studies justify this hypothesis.

However, Zwicker (66) himself using broad-band noise for both masker and maskee (similar spectra) has shown overshoot, but discounted it due to its small magnitude. In addition, Samoilova using only pure-tone signals (with similar spectra) has also shown overshoot. Therefore, Zwicker's hypothesis does not appear to be consistent with the results of all studies.

Although Zwicker does not discuss the binaural situation, temporal relations in central masking (68, 69) reveal that overshoot does occur for pure-tone stimuli.

The present study is designed to investigate temporal changes in the masking of a pure-tone stimulus and to determine how these changes relate to spread of the masking pattern. A secondary aim is to compare masking efficiency and the masking patterns of ipsilateral and contralateral maskers.

The next chapter contains a description of the design and procedures used to conduct this investigation.

CHAPTER III

INSTRUMENTATION AND PROCEDURE

Introduction

This study was designed to investigate the contralateral and ipsilateral masking patterns of a pure tone under three conditions of delay time between the onsets of the masker and test signal. The masker was always a 1000-Hz pure tone presented at 50-dB sound pressure level (SPL). Several frequencies (500, 800, 900, 950, 1000, 1050, 1100, 1200, 1500 Hz) of test signals were used as maskees to sample the effects of masking spread for the 1000-Hz masker. Thresholds for the maskees were determined by a method of limits. The method of obtaining threshold is described in detail in the Procedure section of this chapter.

The three delay times utilized were as follows: (1.) a 3-msec delay time between the onset of the masker and the onset of the maskee which served as the "initial" position, (2.) a 497-msec delay time between masker onset and maskee onset which was the "medial" position; and, (3.) a 982-msec delay time between the masker onset and maskee onset which was the "final" position. The termination of the maskee in the "final" position preceded the offset of the masker by 3 msec.

Only pure tones were used for the masker and maskees, and the envelope and duration of both signals were shaped so as to avoid the production of transients. As mentioned in the previous chapter, transients due to rapid rise and decay times of signals may have contaminated the results of some of the previous studies.

Subjects

The experimental group consisted of four normal-hearing male subjects between the ages of 29 and 36 years, (mean age 31 years). The subjects were selected from the student body of the Department of Communication Disorders, University of Oklahoma Medical Center, Oklahoma City, Oklahoma. Normal hearing was defined as thresholds not greater than 20 dB (International Standard Organization 1964) at frequencies from 250 through 3000 Hz. This range extends from one octave below to one octave above the frequencies used in the experiment. Actually, the ears of all subjects were audiometrically normal from 250 to 8000 Hz except subject #3 whose left ear manifested a mild sensorineural hearing impairment at 4000 Hz. The participants also reported a negative history of ear pathologies. Each subject had several hours of practice and had demonstrated an ability to perform the required task before participating in the investigation.

All subjects received both ipsilateral and contralateral masking conditions, all three temporal delay conditions, and in addition, thresholds were obtained under all conditions for both the right and left ears. The order of presentation of the above conditions was counterbalanced among the four subjects. The counterbalancing scheme is presented in Table 1. The nine maskee frequencies were presented in a different random order to each subject.

TABLE 1

ORDER OF PRESENTATIONS FOR EACH SUBJECT FOR EACH SESSION

Hz	Session #1				Session #2				Session #3				Session #4			
	S#1	S#2	S#3	S#4	S#1	S#2	S#3	S#4	S#1	S#2	S#3	S#4	S#1	S#2	S#3	S#4
	RI	LI	RC	LC	RC	LC	RI	LI	LI	RI	LC	RC	LC	RC	LI	RI
1	t	i	m	f	m	t	f	i	f	t	m	i	m	f	t	i
2	i	m	f	t	i	m	t	f	t	m	i	f	f	t	i	m
3	m	f	t	i	f	i	m	t	m	i	f	t	t	i	m	f
4	f	t	i	m	t	f	i	m	i	f	t	m	i	m	f	t
5	t	i	m	f	m	t	i	f	i	t	f	m	f	i	t	m
6	m	f	i	t	f	m	t	i	t	f	m	i	i	t	m	f
7	f	i	t	m	i	f	m	t	f	m	i	t	t	m	f	i
8	i	t	m	f	t	i	f	m	m	i	t	f	m	f	i	t
9	t	m	f	i	m	t	i	f	i	f	m	t	f	m	i	t

Note: The nine maskee frequencies (Hz) were randomized for each subject in each session.

S = subject
R = right ear
L = left ear
I = ipsilateral masker
C = contralateral masker

t = threshold in unmasked condition
i = threshold in "initial" masked condition
m = threshold in "medial" masked condition
f = threshold in "final" masked condition

Apparatus

Acoustic Environment

All screening, practice and experimental tests were conducted in a sound room (Industrial Acoustics Company, model 400) located at the Veterans Administration Hospital, Oklahoma City, Oklahoma. Visual communications were maintained through a window located in the side of the IAC chamber. The test room contained a standard headset with matched earphones, a chair for the subject and a response switch for conveying the subject's judgement to the experimenter. All other equipment was located outside and adjacent to the test room.

Ambient noise levels within the test room were measured (at the approximate locus of the subject's head) by a sound-level meter (General Radio, Type 1551-C) combined with an octave-band noise analyzer (General Radio, Type 1558-AP). Readings were obtained for octave bands whose center frequencies were at octave intervals from 125 Hz to 8000 Hz. The average spectrum levels and levels per critical band (49) for the bands centered at the standard audiometric testing frequencies were calculated. The determination of the effective masking level of this noise was obtained by subtracting the attentuation characteristics of MX-41/AR earphone cushions (43, p. 165) from the critical band levels. These effective levels were found to be considerably below the ISO 1964 standard threshold levels of normal listeners. The results of the above procedures are reported in Table 2.

TABLE 2

NOISE CHARACTERISTICS UNDER EXPERIMENTAL CONDITIONS

Frequency	125	250	500	1000	2000	4000	8000
<u>Noise levels in sound chamber</u>							
Octave band level	39.0	28.0	14.0	12.0	13.0	16.0	17.0
Level per critical band	37.5	22.5	6.0	3.5	2.5	6.5	7.0
Average attenuation of earphones	10.0	8.0	8.0	16.0	29.0	35.0	31.0
Average noise level at subject's ears	27.5	14.5	-2.0	-12.5	-26.5	-28.5	-24.0

All levels are expressed in dB re: .0002 dyne/cm^2

Screening Apparatus

The screening apparatus consisted of a commercially available Bekesy audiometer (Grason-Stadler, model E800) feeding one of a pair of earphones (Telephonic TDH-39 10Z) set in MX-41/AR cushions and mounted on a standard headband. The standard switch used in Bekesy audiometry was controlled by the subject to produce a tracing of his audiometric threshold. Instructions to the subject were those advocated by Stream and McConnell (52). The Bekesy audiometer was calibrated with an artifical ear (Allison Labs, model 300).

Practice and Experimental Test Equipment

Two pure-tone audio oscillators (Hewlett-Packard, model 200 ABR) were employed as sources for the masker and maskee. One oscillator (01) was set at 1000 Hz and used to generate the masker. In two of the experimental conditions the output from 01 was divided into two channels by a splitting network (SP). This allowed the 1000 Hz signal to be used as both the masker and maskee. For the production of the masker, 01's output was connected to an electronic switch, (E1) (Grason-Stadler, model 829C) which was appropriately triggered and set to give the desired masker envelope and duration. The masker was then directed through one channel of a speech audiometer (Grason-Stadler, model 162) to an earphone.

The second audio oscillator (02) was used for all maskee frequencies except 1000 Hz, (500, 800, 900, 950, 1050, 1100, 1200 and 1500 Hz). Its output was coupled to electronic switch (E2)

(Grason-Stadler, model 829E) which in turn was coupled to electronic switch (E3) (Grason-Stadler, model 829C). Switches E2 and E3 were arranged in series to provide the brief tonal pulse used as the maskee. The signal was passed through a properly loaded 1-dB step attenuator which had a range of 100 dB (Hewlett-Packard, model 350C). It was then directed to the remaining channel of the speech audiometer which enabled the experimenter either to mix the masker and maskee and present them through one earphone (for the ipsilateral masking condition), or to route the masker and maskee to separate earphones (for the contralateral masking condition). The earphones were a matched pair of Telephonic TDH-39 10Z set in MX-41/AR cushions and mounted on a standard headband. The earphones were wired so that a common signal would be out of phase at the two earphones. When a 1000-Hz maskee frequency was required, the output of 01 was split with the maskee portion directed through the same path described for the signals from 02. A schematic diagram of the experimental apparatus is shown in Figure 1. The timing apparatus is presented in greater detail in Figure 2.

The phase relationships between the frequency of the masker and the frequencies of the maskees were not controlled and were considered to be random except for the 1000-Hz masker-1000-Hz maskee condition. Since, under this condition, the same oscillator (01) provided the 1000-Hz signal for both the masker and maskee, the signals were in phase for the ipsilateral masking condition. In the contralateral masking condition the 1000-Hz signals were functionally out of phase with one another since the earphones were wired in that way. By delivering these signals at opposite phases to the two ears,

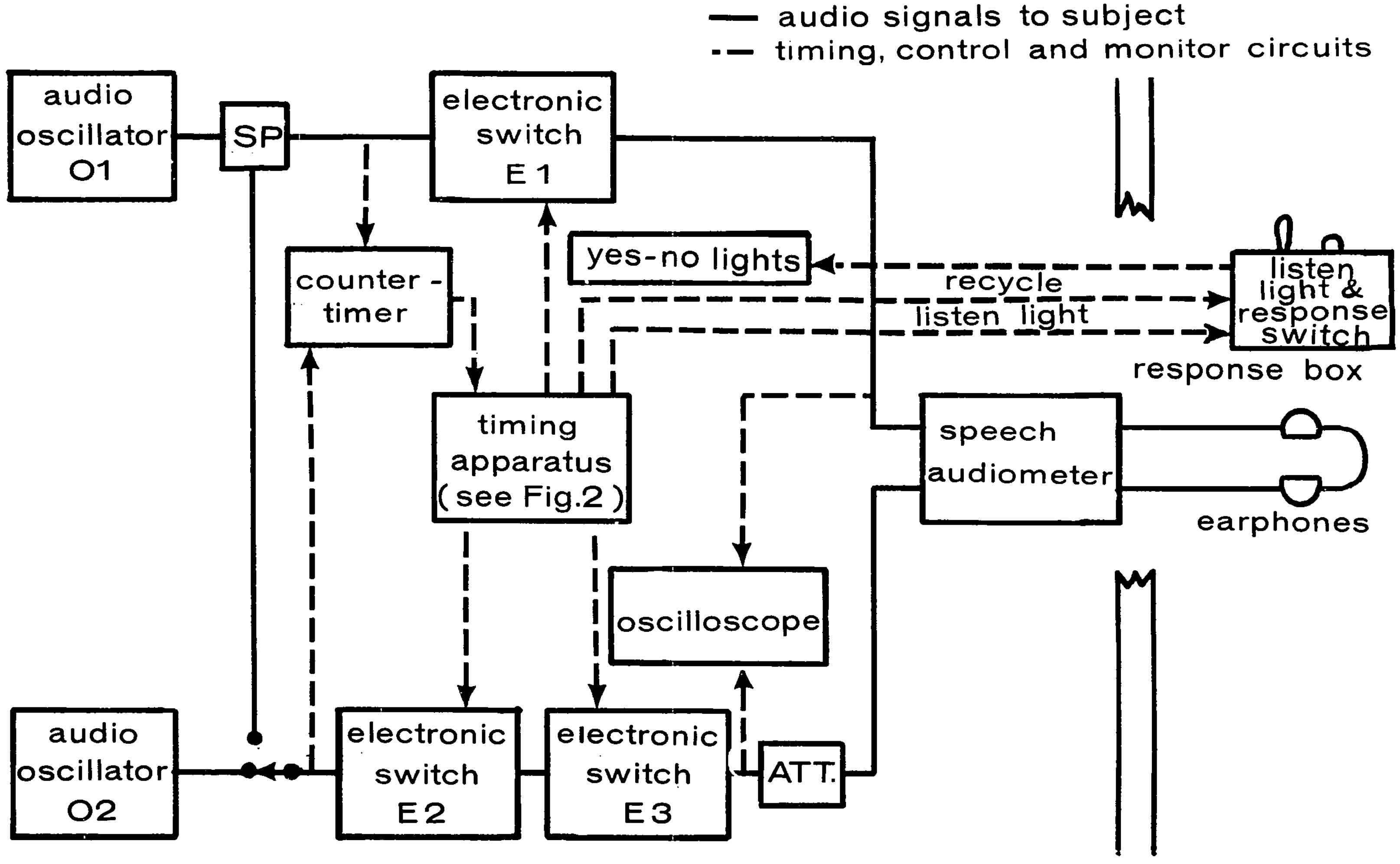

Figure 1. Schematic diagram of experimental apparatus.

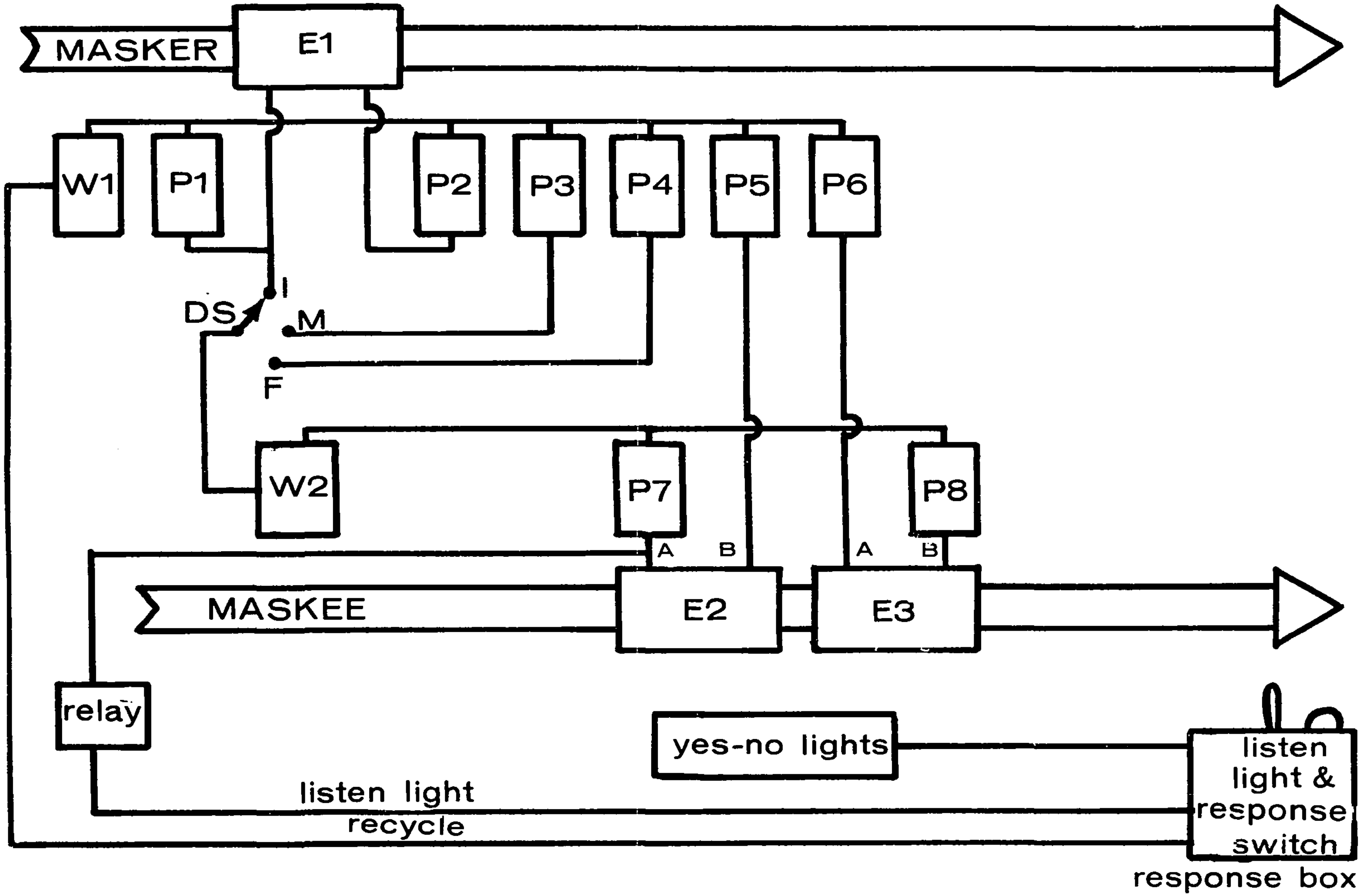

Figure 2. Block diagram of timing apparatus.

mid-plane locatization cues were minimized.

The timing network used to trigger the electronic switches consisted of two waveform generators (Tektronix, type 162) and eight pulse generators (Tektronix, type 161). Two power supplies (Tektronix, type 160A) were required for the Tektronix equipment. The "delay" switch (DS) which coupled waveform generator #2, (W2), to either pulse generator #1, (P1); #3, (P3); or #4, (P4) was used to allow the experimenter the choice of the "initial", "medial" or "final" delay condition for the maskee.

The subject was able to throw his response switch in one of two directions. The YES position indicated that he had heard the signal and the NO meant that he had not heard the signal. The throwing of the switch controlled the YES-NO lights situated in front of the experimenter and thus conveyed to him the subject's response after each signal presentation. The switch also initiated a recycling of the timing apparatus regardless of the position to which it was thrown.

Located on the response box, which contained the subject-response switch, was a "listen" light. This light flashed during the presentation of the maskee and informed the subject of when the signal might occur during the course of the masker. The listen light also facilitated the determination of the unmasked threshold for the maskee when it was presented alone.

The masking tone (masker) was maintained at its maximum amplitude for 1000 msec and had rise-decay times of 10 msec as shown in Figure 3. The shaping of the masking signal and the rise-decay times were provided by switch E1.

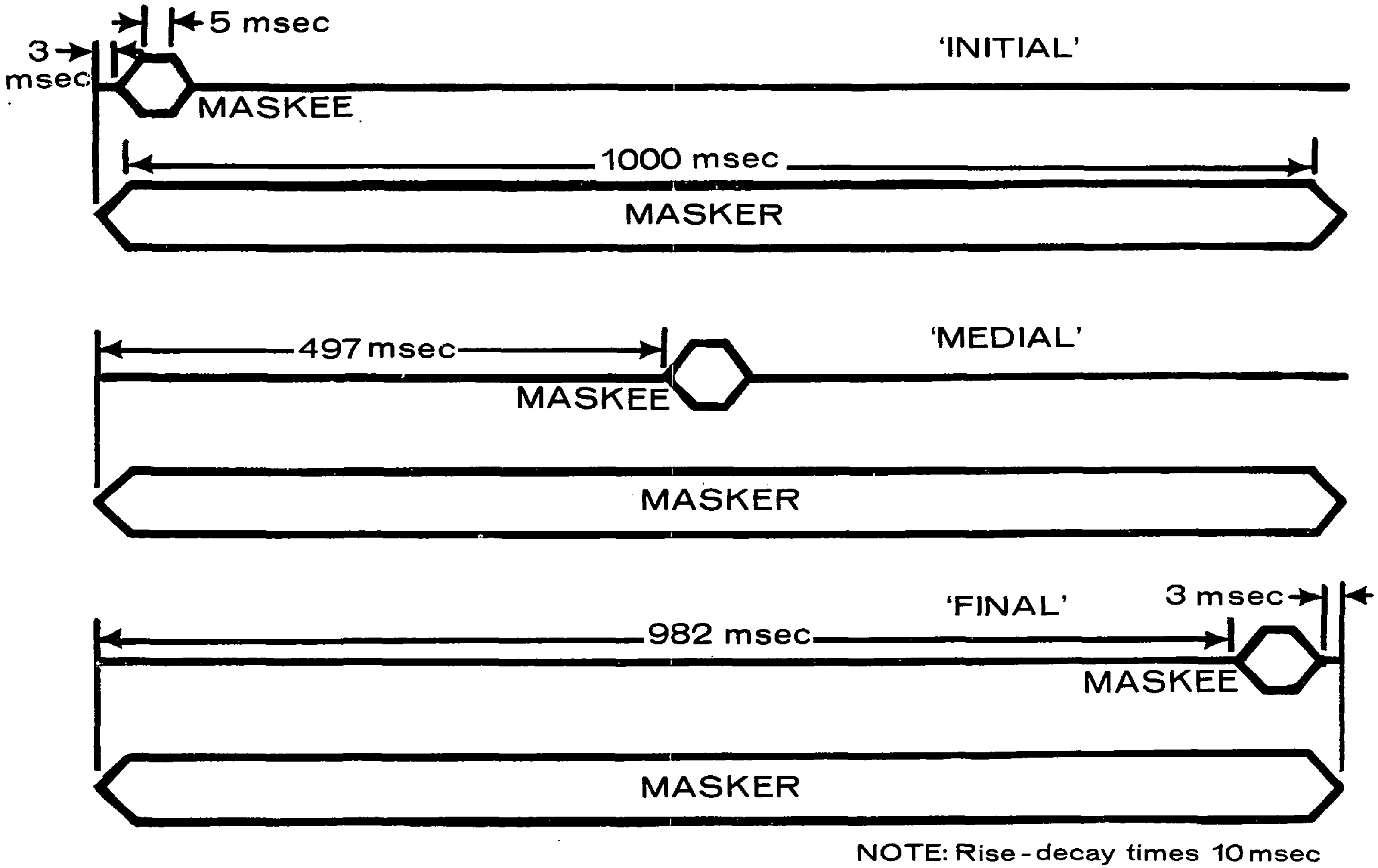

Figure 3. Timing and relationships in the three temporal conditions.

The test signal (maskee), also shown in Figure 3, had rise-decay times of 10 msec and a duration at maximum amplitude of 5 msec. The shaping of the envelope and duration of the maskee were achieved by coupling switches E2 and E3 in series. These switches provided the rise and decay portions of the maskee respectively. The delay of 3 msec between masker onset and maskee onset employed in the "initial" position, and the 3 msec difference between the maskee offset and the masker offset employed in the "final" position were provided to insure that no part of the maskee preceded or extended beyond the presentation of the masker.

The utilization of such a brief maskee, 5 msec with 10-msec rise and decay times served two purposes. First, the brevity of the maskee permitted sampling of the masking pattern of the 1000-Hz masker at intervals very close to the masker onset and offset. Second, by reducing the duration of the maskee, beats and difference tones were greatly reduced and possibly eliminated. Jeffress, et al., (34) have reported that a signal duration of 25 msec or less precludes the production of beats.

Calibration and visual monitoring of the temporal relations between the masker and the test signal were performed before and after each experimental session. The duration of the masker was established by adjusting pulse generators P1 and P2 to produce an interval of 1010 msec as measured by a counter-timer (Transistor Specialties, Inc., model 361). The maskee waveform with maximum amplitude of 5 msec was calibrated in the same manner by adjusting an appropriate interval between P7 and P8. The maskee was observed on an oscilloscope

(Tektronix, type 561-A) to insure that the waveform and duration were as specified. The counter-timer was used to calibrate the 3-msec, 497-msec and 982-msec delays between the onset of the masker and the onset of the maskees. To accomplish these three measurements, the delay switch was set at each of its three positions. The 3-msec delay used for the "initial" maskee position was measured from P1 to P7 and was adjusted to the desired value by varying the delay of P7. In the "medial" maskee position, timing was again measured between P1 and P7; however, the adjustment for the 497-msec delay was accomplished by varying the delay of P3. For the "final" position, the delay of P4 was adjusted to obtain the 982-msec timing between P1 and P7. Visual monitoring was accomplished prior to, during, and following each session by the use of the oscilliscope. This was done to insure that the temporal patterns being presented to the subject were the same as those illustrated in Figure 3.

The calibration of sound intensities for the masker and maskee was performed prior to each experimental session and immediately following each session. The 1000-Hz masker was passed through an earphone to an artifical ear (Allison, model 300). The intensity was adjusted to obtain a 100-dB SPL reading. The masker level was then reduced 50 dB by an attenuator on the speech audiometer. This provided the desired masker intensity of 50-dB SPL.

The intensity of 50-dB SPL for the masker was chosen for three reasons. First, it is a level that in many of the previous peripheral masking studies, had provided a symmetrical masking pattern. Second, according to Fletcher (24) and Ehmer (22) it is low enough to eliminate or greatly minimize the production of subjective tones when only pure-tone signals are used. Third, since a part of this experiment is concerned with contralateral or central masking, the masker level chosen is below the interaural attenuation of the head for a 1000-Hz signal and therefore, reduces the possibility of the masker directly stimulating the test ear in the contralateral masking condition.

The intensity of the maskee was measured on the same artificial ear. By setting the second oscillator, 02, to 1000 Hz and positioning the Hewlett-Packard attenuator to deliver no attenuation, the gain was adjusted to provide a reading of 80-dB SPL through the earphone. The system was then considered to be calibrated.

The same earphone was used to deliver the maskees for the ipsilateral and contralateral masking conditions. Since the output from this earphone was not linear across the maskee frequencies, calibration corrections were required. These correction values were determined prior to the experiment in the following way: Oscillator 02 was set at 1000 Hz and its output was passed through the maskee channel which was adjusted to produce an SPL of 80 dB at the earphone. As 02 was adjusted to each of the eight test frequencies it would provide during the experiment, SPL values for these frequencies were measured by the artificial ear and recorded. Any deviation from the desired 80-dB SPL reading was also recorded for each frequency. These values were used as corrections for the data collected in the experimental sessions. Appropriate corrections were also obtained when 01's output was split and utilized in the 1000-Hz masker-1000-Hz maskee condition.

The frequency of the 1000-Hz masker was calibrated before and after each experimental session with the use of a counter-timer. The counter-timer was also used in adjusting and calibrating the maskee frequency prior to each experimental threshold run. Frequency count deviated no more than ± 1 Hz from the specified frequency throughout the experiment.

Procedure

General

The experiment consisted of two practice sessions and four experimental test sessions for each of the four subjects. The formats for the practice and experimental sessions were very similar. Each session, whether practice or experimental, lasted approximately three hours and was divided into three test periods separated from one another by five to ten minute rest periods. Only the data obtained in the experimental sessions were used in the statistical analysis.

Eaoh session began after the subject was seated comfortably in a reclining chair within the test booth. A copy of the following instructions was read to him prior to the start of the test period:

> The experiment in which you are about to participate, is designed to determine how the threshold of one sound is affected by the presence of another sound.
>
> There are two types of thresholds which will be obtained during this experiment. One type is an unmasked threshold when only the test signal will be presented. The other is a masked threshold in which a 1000-Hz pure-tone masker of one second duration will be employed. Masked thresholds will be determined for the test signal when it is presented at either the

beginning, the middle or the end of the 1000-Hz masker. The masker may be in either the same ear as the test signal or in the ear opposite the test signal.

The test signal which you are to listen for is synchronized with the "listen" light located on the box in front of you. You are required to watch this light in order to know when to listen for a signal. This is especially important during the unmasked threshold determination.

During the presentation of a masked condition you will periodically hear the 1000-Hz pure-tone masker which will last for one second. You must listen for the test signal either at the <u>beginning</u>, <u>middle</u>, or <u>end</u> of the 1000-Hz tone. Before the beginning of each condition, you will hear a sample of that condition with the test signal presented at a level high enough to be clearly audible so you will know which condition is to be run. Following this initial presentation, your task will be to determine if a sound is present or absent when the "listen" light flashes. You are to respond after <u>each</u> presentation. The response switch in front of you must be thrown in the "YES" direction if you hear the test signal and in the "NO" direction if you do not. After each presentation you may respond whenever you choose, but remember, your first impression is usually correct. You are urged <u>not</u> to guess, and if there is any doubt as to whether the test signal is present, throw the switch to the "NO" position. After you have responded, approximately three seconds will elapse before you hear another presentation.

Do you have any questions?

Occasionally, the experimenter would elaborate on the instructions when asked to do so.

During a pilot study in which subjects were not restricted from guessing, occasional false-positive responses occurred. These were noted predominantly for the "initial" condition. Therefore, to reduce false-positive responses in this experiment, the subjects were instructed not to guess and to respond NO when in doubt. This greatly minimized positive responses by the subject and their acceptance by the experimenter when the test signal was actually below threshold.

The response of the subject following each presentation was conveyed to the experimenter by way of YES–NO lights. When the subject threw the response switch to the YES position, the YES light positioned on the equipment rack in front of the experimenter illuminated briefly. The NO light illuminated when the subject made a NO response. With this information the experimenter was able to make the proper attenuator adjustment for each subsequent presentation.

The classical psychophysical method of limits was employed to determine both the masked and the unmasked thresholds. Following the presentation of an initial supra-threshold signal used to alert and acquaint the listener with the condition being tested, several ascending and descending threshold crossings were made. The threshold determinations were made in one-decibel steps, and each threshold crossing was terminated as soon as the subject altered his response from "detection of the signal" to "no detection" or vice versa depending on whether threshold was crossed from below or above. The experimenter recorded the level of the first "detection" of each ascent and the level of the first "no detection" of each descent. Threshold was considered to be the average of these recorded levels.

Practice Sessions

The general procedures described above were followed during the practice sessions. The two practice sessions required for each subject were designed to achieve the following goals: (1.) to acquaint the subject with the general requirements of the investigation; (2.) to improve subject performance in making threshold decisions; (3.) to give the subject practice with the "initial", "medial" and "final" maskee delay positions using ipsilateral and contralateral maskers; and, (4.) to obtain approximate thresholds for each subject at each maskee frequency both without the masker and under each masking and delay condition.

In each practice session thresholds were obtained for only one ear. These were for each of the nine test frequencies under the silent and each of the three delay conditions and under the ipsilateral and contralateral masking conditions. In each of the three periods of each session, testing was completed for three frequencies. Only two ascending and two descending threshold crossings were employed for each condition. The four values obtained from these crossings were averaged to obtain threshold. No attempt was made to counterbalance conditions or randomize the order of test frequencies in the practice sessions.

Experimental Sessions

Upon the completion of practice, each subject was considered to be proficient at the required task. He was then scheduled to participate in the four experimental sessions. Each experimental session consisted of thirty-six threshold determinations utilizing the classical method of limits. These thresholds were for each of the nine frequencies under the unmasked and under each of the three delay conditions. In two of the sessions, right ear thresholds were measured under ipsilateral (RI) and contralateral (RC) masking conditions, while in the remaining two sessions, left ear thresholds (LI and LC) were measured under the same conditions. As in the practice sessions, three frequencies were tested in each period of each experimental session. Four ascending and four descending threshold crossings were made for each condition instead of two for each condition as in the practice. The first threshold obtained for each crossing was not recorded nor was it included in the evaluation. The test-signal intensity levels from which the ascents and descents were made ranged in a random fashion from 5 to 9 dB on either side of the threshold determined for the same condition in the practice sessions. Whether threshold was initially approached from an ascending or a descending level was also determined by a randomization schedule as was the order of frequency presentation for each subject. The counterbalancing of the delay, ear and masking condition is displayed in Table 1, page 28.

An example of the use of Table 1 is as follows: Subject #1 receives the RI (maskee to the right ear with ipsilateral or right ear masking) condition in the first session. According to the random order of test frequencies, 1000 Hz is the first frequency to be tested. The order of delay conditions (including the unmasked threshold) for the first frequency is _t_ (unmasked), _i_ ("initial"), _m_ ("medial"), and _f_ ("final"). This order is the same for the first frequency of the first session of each subject. The test order at subsequent frequencies for this and the other sessions is as indicated in Table 1.

Upon completion of the experimental sessions for all subjects, the experimenter converted the raw data into thresholds for each frequency in the unmasked and in each of the masked conditions. The six values recorded for each condition from the threshold crossings were averaged to obtain threshold. The difference in decibels for each frequency was determined between each masked threshold and the unmasked threshold obtained in the same session. These differences were then corrected for transducer nonlinearity and then coded by algebraically adding 10 to all values. The resultant figures were utilized for statistical analysis. These values for each subject are found in Appendices B through E.

A factorial arrangement of treatments was chosen for the analysis. These factors were; frequencies (9), temporal conditions (3 - "initial", "medial" and "final"), masking conditions (2 - ipsilateral and contralateral) and ears (2). The subjects were considered as a random factor.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of the present study was to investigate possible changes in masking efficiency over time for a simple auditory stimulus. These changes were explored relative to the masking pattern of a 1000-Hz pure tone for both ipsilateral and contralateral masking.

Masking patterns were sampled in each ear of four normal-hearing subjects. The 1000-Hz masker had a duration of 1000 msec and a sound pressure level of 50 dB. Thresholds for nine maskee frequencies, ranging from 500 to 1500 Hz, were measured under an unmasked condition and at three temporal positions under the masked conditions. During a masking condition, the maskee was delivered either near the beginning ("initial"), at the middle ("medial") or near the end ("final") of the masker. The maskees had a duration, at maximum amplitude, of 5 msec; and rise and decay times for both the masker and maskees were 10 msec. The classical method of limits was employed in obtaining all thresholds.

Data were obtained for a factorial arrangement of treatments with subjects considered as a random factor. Repeated measures were made on the following four factors: ears, masking conditions, frequencies and temporal delays. Statistical comparisons were made among the treatments by an analysis of variance (AOV) similar to that described for a mixed model by Winer (59, chapter 7). When appropriate, the Duncan's New Multiple Range Test (DNMRT) was used to make comparisons among means within each factor (48). Results of the AOV and DNMRT's are presented in Appendix A.

Results

The amount of masking at each frequency in each ear was determined by subtracting the threshold obtained in quiet from the threshold obtained under each masking and delay condition. The resultant thresholds were corrected for transducer nonlinearities and appropriately coded for analysis.

A large difference between ipsilateral and contralateral masking was expected in this experiment. Wegel and Lane (55) in 1924, reported that central masking was very small in magnitude when compared to the extensive pattern obtained for peripheral masking. The findings in the present study, illustrated in Figure 4, confirm that ipsilateral masking is of much greater magnitude than contralateral masking. The AOV (Table 7, Appendix A) revealed that this difference was significant at the 0.05 level. The data presented in all appendices have been coded by adding 10 to each value.

Masking values measured at each frequency and for both masking conditions are located in Table 3. Obvious differences are apparent between the ipsilateral and contralateral masking conditions for all frequencies tested except 500 and 1500 Hz. The DNMRT for treatment means was used to compare the thresholds for the ipsilateral and contralateral masking conditions at each of the test frequencies. Statistical differences ($P < 0.05$) were observed at all frequencies except 500 and 1500 Hz.

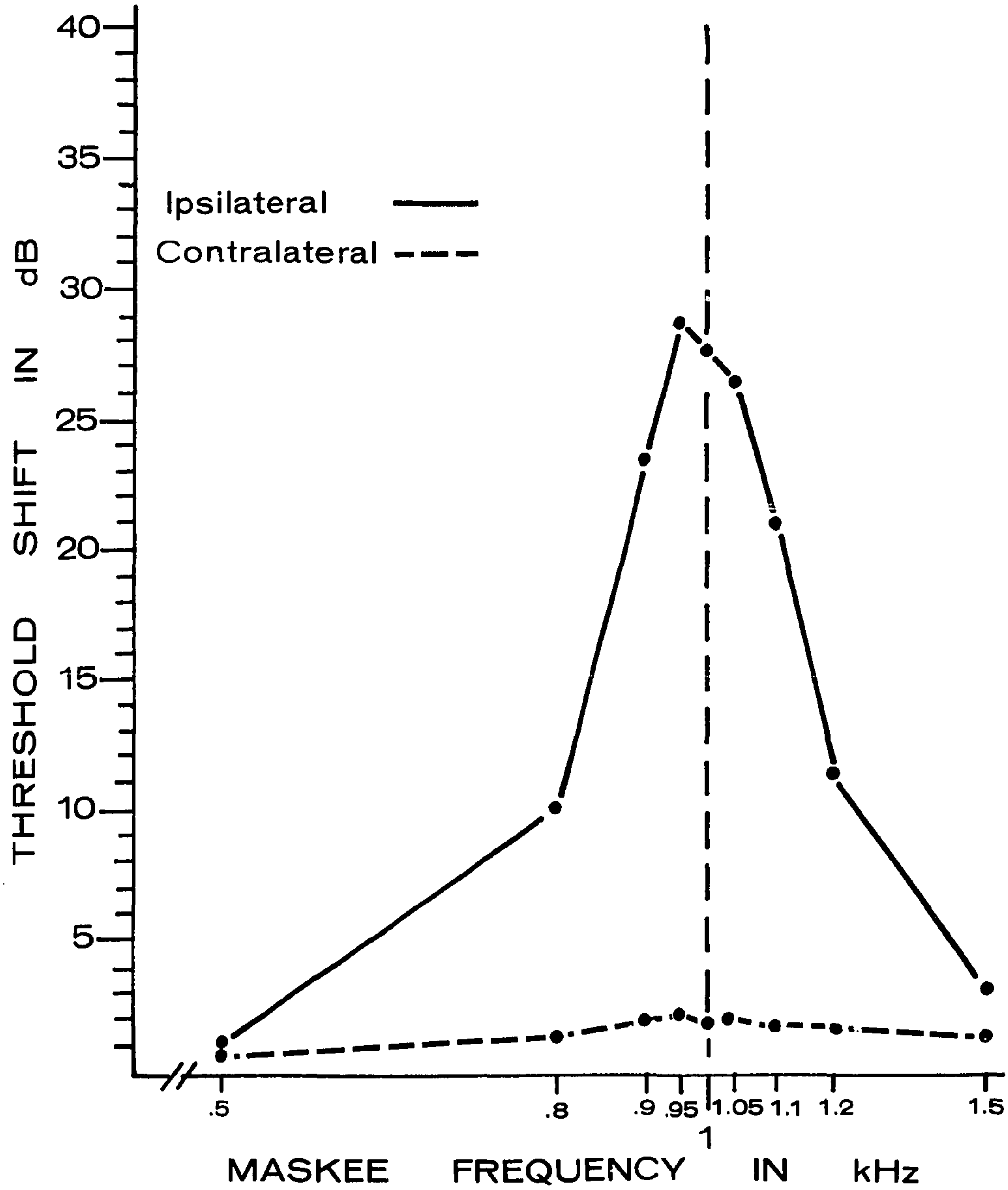

Figure 4. Ipsilateral and Contralateral masking patterns averaged across all other conditions.

TABLE 3

IPSILATERAL AND CONTRALATERAL MASKING (in dB) FOR THE NINE MASKEE FREQUENCIES AND AVERAGED ACROSS SUBJECTS, EARS AND TEMPORAL DELAYS

Masking Condition	Maskee Frequencies (Hz) 500	800	900	950	1000	1050	1100	1200	1500
Ipsilateral	1.04	10.01	23.38	28.67	27.66	25.42	20.82	11.26	3.09
Contralateral	0.89	1.29	1.96	2.08	1.86	2.18	1.70	1.90	1.37

This is probably due to the fact that little masking was produced at these extreme frequencies which are at or beyond the edges of the masking pattern.

The direct comparison between ipsilateral and contralateral masking conditions reveals marked differences. It is also generally accepted that ipsilateral and contralateral masking reflect patterns of excitation at different regions in the auditory system. For these reasons, and for simplicity in presentation, ipsilateral and contralateral masking data will be reported and discussed separately in the remainder of this chapter.

Ipsilateral Masking

Ipsilateral masking occurs when the masker and the maskee are delivered to the same ear. In the present study, ipsilateral masking was measured at each level of the other three factors (ears, frequencies and temporal delays) for all four subjects.

Effect of Ear. It was not the primary purpose of the present investigation to explore the effects of laterality on masking; however, the design of the experiment did allow the data to be collected in such a manner that this effect could be analyzed. Since only recently have investigators (5, 35) found that certain verbal and nonverbal auditory tasks result in minute differences between the ears of normal subjects, it would be interesting to know if ipsilateral auditory masking exhibits laterality.

The masking patterns for both right and left ears are presented in Figure 5. The ipsilateral masking patterns for both ears essentially coincide with one another. Only at 1100 Hz was a substantial

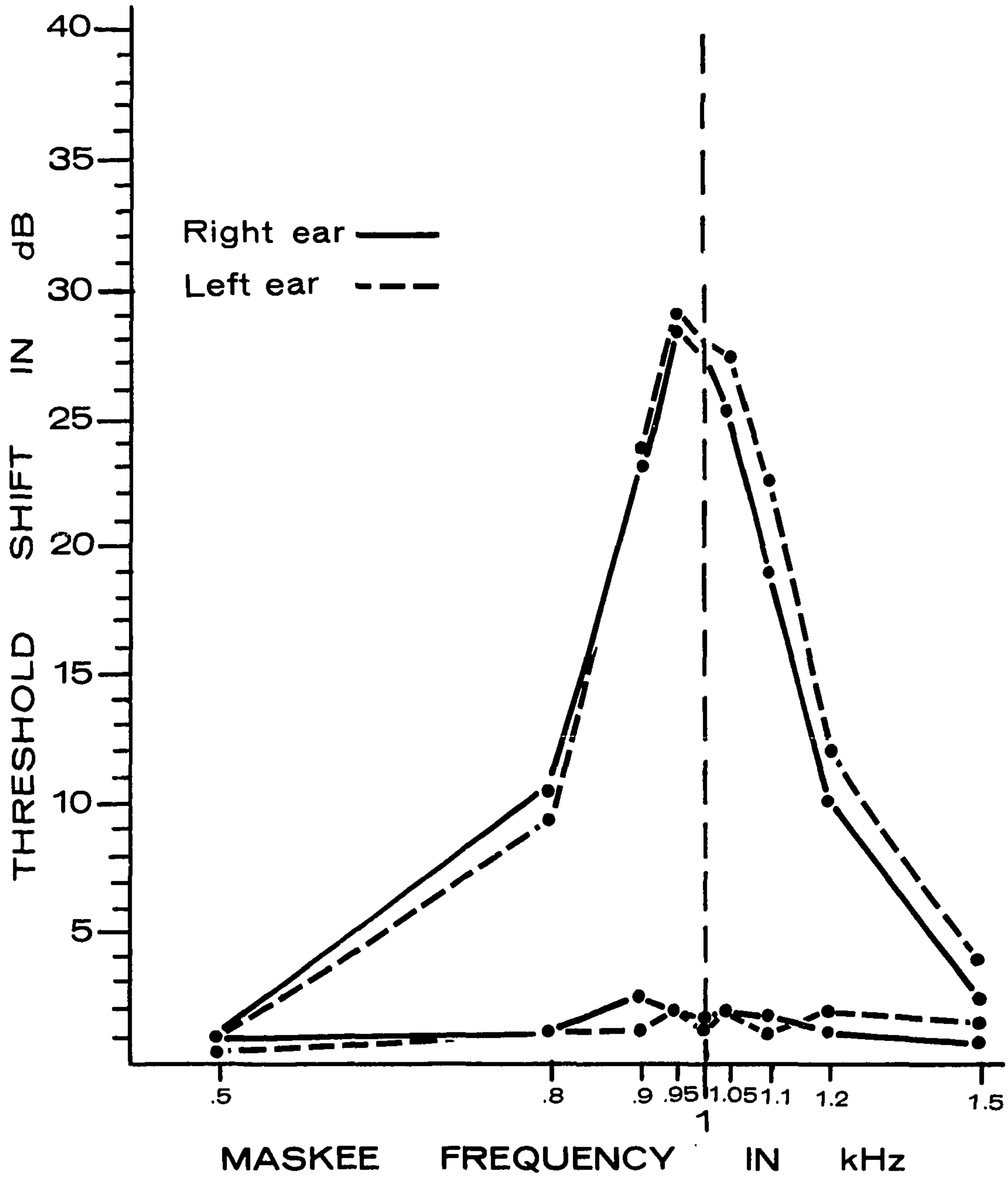

Figure 5. Ipsilateral (upper curves) and Contralateral (lower curves) masking patterns for Right and Left ears.

difference (3.55 dB) observed. All other differences were less than 2.09 dB.

The AOV (Appendix A, Table 7) revealed that there was no significant difference ($P>0.05$) for ears or for the ear-by-masking condition interaction. The interactions of ear-by-temporal delay and ear-by-frequency were also nonsignificant ($P>0.05$). A DNMRT comparing left and right ear ipsilateral masking means at each of the test frequencies revealed a statistically significance difference ($P<0.05$) only at 1100 Hz where the left ear manifested more masking than the right ear. It is likely that the statistically significant finding at this isolated frequency was due to chance.

Effect of Frequency. The ipsilateral masking pattern measured in this experiment is in good agreement with the findings of previous investigators (21, 55). The masking effects are presented in Figure 4 and in Table 3. Masking was observed to increase sharply as the test frequency approached that of the masker. The masking pattern extended as far down as 500 Hz where 1.04 dB of masking was obtained. Upward spread was apparently somewhat greater as 3.09 dB of masking was produced at 1500 Hz. Of the nine test frequencies, 950 Hz exhibited the most ipsilateral masking (28.67 dB), while at 1000 Hz only 27.66 dB was measured. The greater masking effect at 950 Hz compared to 1000 Hz is attributable to one subject (S #2). All other subjects showed greater masking, overall, at 1000 Hz than at 950 Hz, but because of a much larger difference in the opposite direction for S #2, the overall mean was greatest at 950 Hz.

For frequencies adjacent to the masker it appeared that greater masking occurred just below the masker than above the masker. However, with frequencies farther away from the masker, there appeared to be a greater effect in the higher frequencies than in the lower frequencies.

The AOV (Table 7 in Appendix A) revealed that the overall effect for frequency produced an F ratio of 65.55 $[P(F > 3.83) < 0.005]$. The frequency-by-masking condition interaction was also significant ($P < 0.005$) with an F ratio of 67.79. The DNMRT comparing frequencies was performed on the ipsilateral masking means (Appendix A, Table 8). Significant differences ($P < 0.05$) were found between all frequency pairs except 950 and 1000 Hz.

The use of underlining was employed to denote nonsignificance of DNMRT mean comparisons (48). The absence of underlining between or among means is indicative of a significant difference ($P < 0.05$).

The AOV also revealed that the frequency-by-temporal delay interaction was statistically significant ($P < 0.05$, $F = 2.36$) while all other frequency interactions were not significant. Although the frequency-by-masking condition-by-temporal delay interaction was not statistically significant, the DNMRT was employed to compare ipsilateral masking means among frequencies under each temporal delay condition.

Results of this statistical analysis are found in Appendix A, Table 9. For the "initial" position, differences were not significant between 950 and 1000 Hz, between 1000 and 1050 Hz or between 800 and 1200 Hz. All other test frequency comparisons were significant ($P < 0.05$).

The results for the "medial" position revealed no significant differences between 950 and 1000 Hz, between 800 and 1200 Hz or between 500 and 1500 Hz. All remaining differences were statistically significant ($P < 0.05$).

The "final" position results revealed no significant differences between 950 and 1000, between 1000 and 1050 Hz or between 800 and 1200 Hz. All other mean comparisons revealed significant differences.

A graphic illustration of the frequency-by-masking condition-by-temporal delay interaction is presented in Figure 6. This figure shows the ipsilateral masking patterns for the three temporal delay positions. The "initial" and "final" masking curves generally show more masking than is illustrated for the "medial" curve. The "initial" position also yields consistently higher thresholds than the "final" position. This comparison will be discussed in greater detail in a subsequent section of this chapter.

The comparison between the overall ipsilateral masking data obtained in this experiment and results reported by other investigators is tenuous because the conditions employed in this study differ from those used by others. In several instances ipsilateral masking patterns have been obtained for masker frequencies other than 1000 Hz. Even when the frequency of 1000 Hz was used, the masker level was generally not comparable to the intensity utilized in this study. Ehmer (21) has reported, however, on the masking efficiency of a 1000-Hz masker delivered at 40-dB SL. This is essentially the same as the 50-dB SPL masker than was employed in the present experiment. The results from the present study are in good agreement with Ehmer's findings.

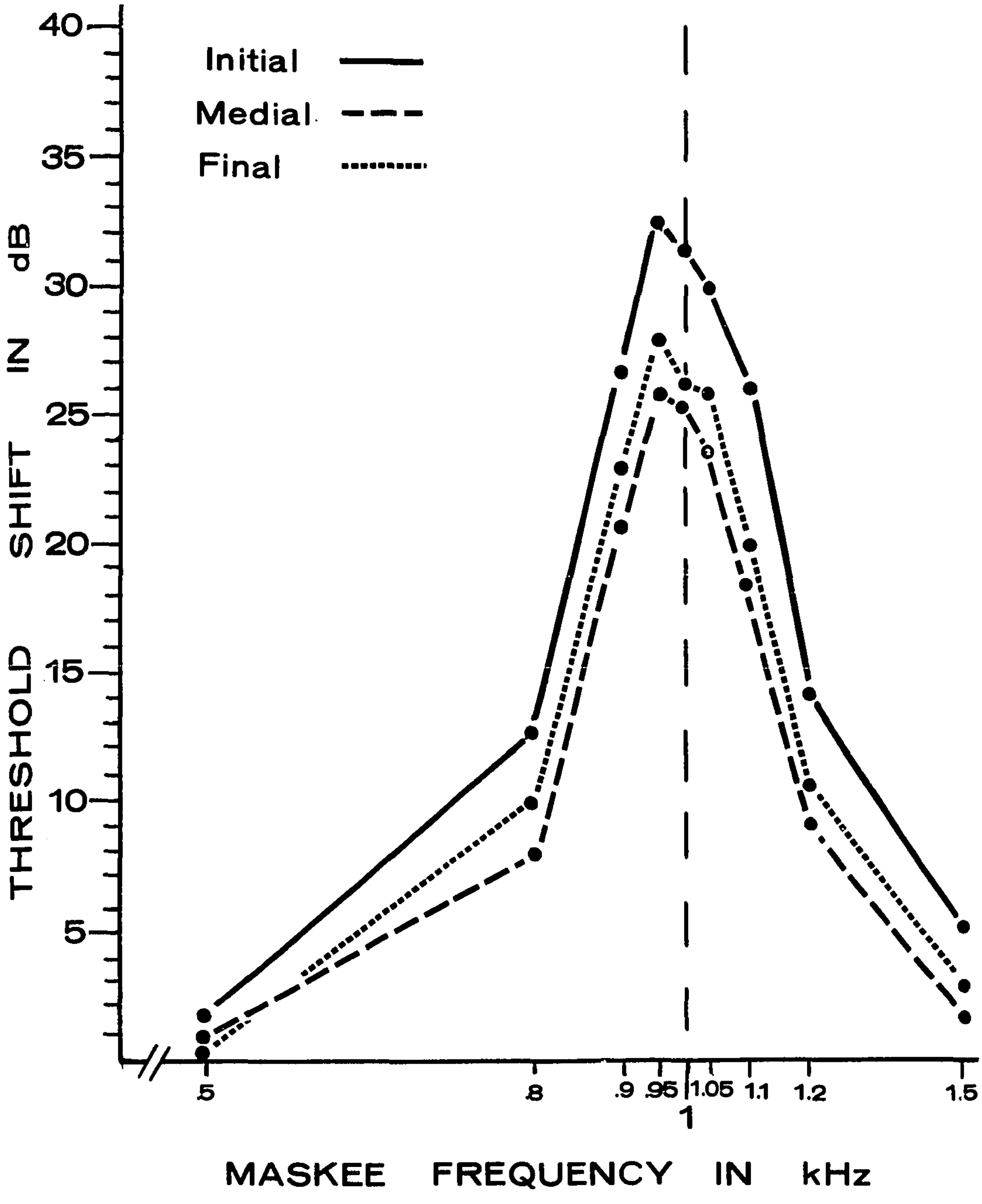

Figure 6. Ipsilateral masking patterns for Initial, Medial and Final positions.

Carter and Kryter (6) measured the masking of a 1000-Hz tone at a sensation level of 68 dB. Maskees ranged between 100 and 10,000 Hz. A direct comparison of their findings to the results of the present investigation is restricted because of the difference in masker levels. The masking pattern which they obtained extended from 500 to 6000 Hz. Unlike the masking pattern in the present study, their findings showed an extensive upward spread of masking. This is probably a result of the higher masker level which they employed.

Although Wegel and Lane (55) did not measure masking for a 1000-Hz masker, they did examine the patterns for tones of 800 and 1200 Hz. The shape and magnitude of masking for both of their maskers, when presented at a comparable level, were similar to that observed in the current study for the 1000-Hz masker.

Small (46) presented masking data for maskees ranging from 400 to 6400 Hz which were delivered at constant 15-and 30-dB sensation levels, and recorded the level of various maskers needed to just mask the maskee. No direct comparison can be made between the present findings and Small's results, however, the distributions of masking are quite similar.

In general, ipsilateral masking for a pure-tone signal was found to be similar to that reported by other investigators showing an extensive masking effect for frequencies near the masker. The findings also show that the masking pattern approaches but does not reach symmetry around the masker frequency. For frequencies nearer to the masker, more masking effect was observed below the masker than above the masker. For frequencies farther removed from the masker, more masking was found above than below the masker.

Effect of Temporal Delay. Some investigators (23, 41, 45, 53, 56, 58) have reported that masking efficiency changes during the course of the masker while others (19, 29, 39, 61, 62, 64) have found that no change occurs. The primary goal of the present study was to determine if masking efficiency changes over time for a pure-tone masker. Three temporal delays of the maskees with respect to the onset of the masker were compared. The "initial" position placed the maskee near the beginning of the masker. The "medial" position required the maskee to be midway between the onset and offset of the masker. In the "final" position, the maskee was placed near the offset of the masker. These temporal delays are illustrated in Figure 3, page 36.

Overall threshold results obtained for each temporal position for the ipsilateral masking condition revealed mean masking values of 19.80 dB for the "initial" position, 14.79 dB for the "medial" position and 16.06 dB for the "final" position. Results for each delay position at each frequency are reported in Table 4. An illustration of the effect of temporal delay at each frequency is presented in Figure 7. Curves for each frequency are plotted in dB of masking by milliseconds of temporal delay. The curves consistently show more masking at the "initial" position than at either of the other positions. Except at 500 Hz, all curves show greater masking at the "final" than at the "medial" delay position.

The term overshoot applies to an increase in masking efficiency when compared to steady-state masking. Several investigators consider steady-state masking to occur after the masker duration has reached 200 to 300 msec (23, 65, 66, 69). Therefore, the "medial" position

TABLE 4

IPSILATERAL MASKING (in dB) FOR THE NINE MASKEE FREQUENCIES
AT THE THREE TEMPORAL POSITIONS AND AVERAGED
ACROSS SUBJECTS AND EARS

Temporal Delay	Maskee Frequencies (Hz)								
	500	800	900	950	1000	1050	1100	1200	1500
Initial	1.71	12.40	26.54	32.46	31.49	30.15	24.21	14.17	5.04
Medial	0.90	7.96	20.63	25.81	25.36	23.46	18.34	9.04	1.64
Final	0.52	9.67	22.96	27.75	26.13	25.75	19.91	10.58	2.58
Mean	1.04	10.01	23.38	28.67	27.66	26.45	20.82	11.26	3.09

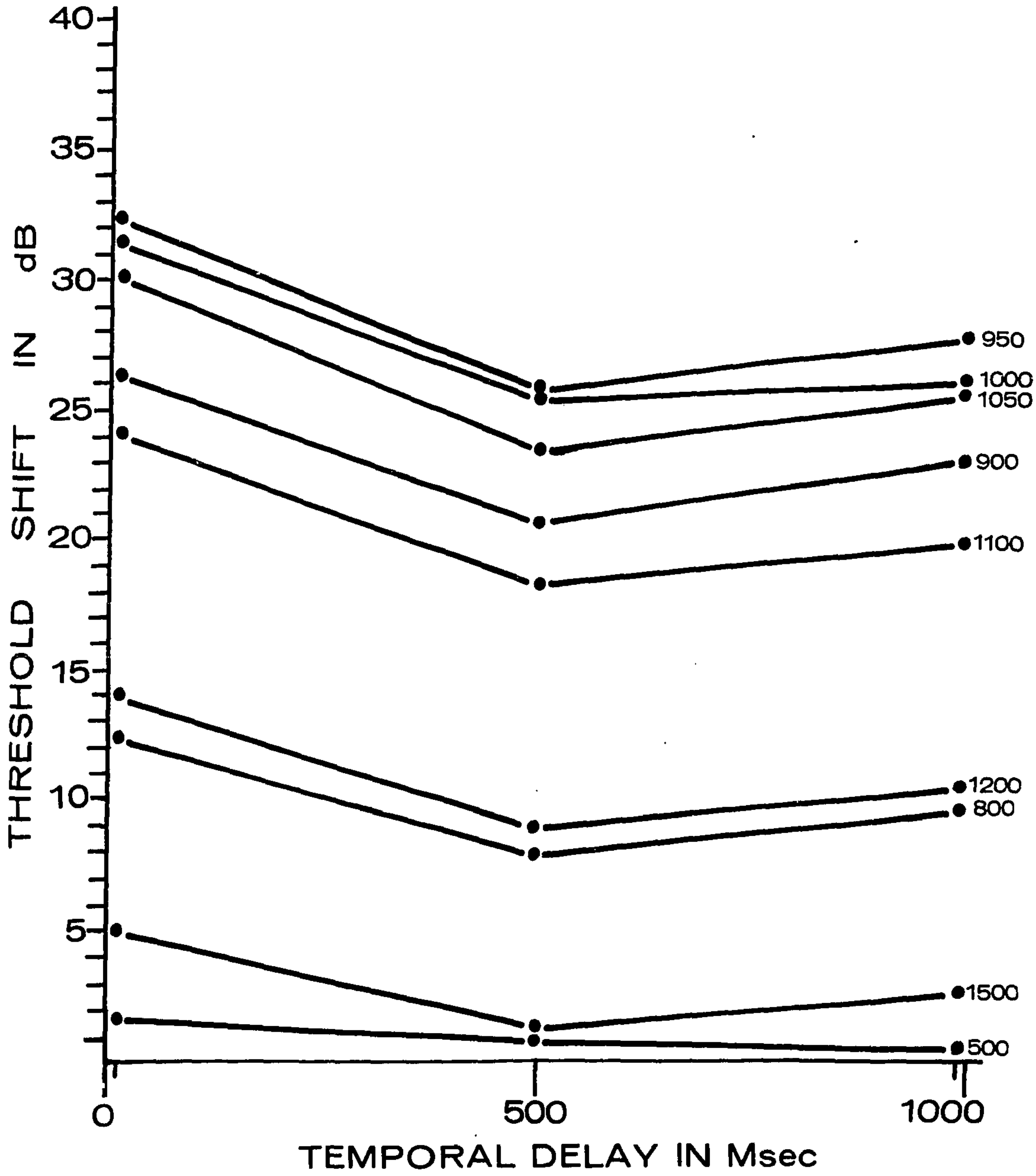

Figure 7. Ipsilateral masking as a function of time between masker and maskee for each frequency.

(500-msec delay) threshold obtained in the present study could be interpreted as being representative of steady-state masking. By subtracting the "medial" position results from the "initial" and "final" position results, the magnitude (in dB) of overshoot was determined near onset and offset of the masker. This procedure was carried out for each test frequency for both ipsilateral and contralateral masking conditions, and the results are presented in Table 5.

Overshoot near the onset of the masker was consistently larger than that observed at the offset of the masker. Near both the onset and offset, a somewhat symmetrical pattern of overshoot surrounding the frequency of the masker was observed. Onset overshoot, however, appeared to be better related to the amount of "initial" threshold shift than to the frequency difference between the masker and maskee.

For offset overshoot, it was difficult to determine whether frequency difference between the masker and maskee or the amount of threshold shift was best related to the magnitude of overshoot.

The relationship between onset overshoot and "initial" threshold shift appeared to hold at all test frequencies except 1000 Hz. Overshoot near both the onset and offset of the masker was greater at 950 and 1050 Hz than at 1000 Hz. However, for the majority of subjects, the greatest masking effect was observed at 1000 Hz. A single explanation may account for this observation. When the 1000-Hz tone was used as both the masker and maskee, the two signals in the ipsilateral masking condition were always in phase with respect to each other. The phase relationship was random for all other test frequencies. The threshold measured for the 1000-Hz maskee is based only on the phase relation

TABLE 5

OVERSHOOT (in dB) OBTAINED AT THE INITIAL AND FINAL DELAY POSITIONS FOR THE IPSILATERAL AND THE CONTRALATERAL MASKING CONDITIONS

Masking Condition	Region of Overshoot	Maskee Frequencies (Hz) 500	800	900	950	1000	1050	1100	1200	1500
Ipsilateral	Initial	0.81	4.44	5.91	6.65	6.13	6.69	5.87	5.13	3.40
	Final	-0.38	1.71	2.33	1.94	0.77	2.29	1.57	1.54	0.94
Contralateral	Initial	1.25	2.25	2.70	3.59	3.21	2.66	3.13	2.56	1.57
	Final	0.42	0.88	1.29	0.97	0.32	-0.44	0.46	0.19	-0.14

which produces summation between the two signals. This threshold could be considerably lower, therefore, than the threshold determined for these maskees which were at random phase with the masker, and with which both summation and cancellation could have occurred.

Statistical analysis for the overall temporal delay effect can be found in Table 7 of Appendix A which contains the results of the AOV. The F ratio of 10.87 revealed that the temporal delays produced a significant effect on threshold ($P < 0.05$). The temporal delay-by-masking condition interaction yielded an F ratio of 6.04 and was also significant ($P < 0.05$). A DNMRT was performed to compare the overall ipsilateral masking condition means at each of the three delay positions. Statistically significant ($P < 0.05$) differences were obtained for all possible comparisons of the "initial", "medial" and "final" positions. The only other temporal delay interaction which resulted in a significant F ratio ($P < 0.05$) was the temporal delay-by-frequency interaction ($F = 2.37$).

Although the temporal delay-by-masking condition-by-frequency interaction was not significant, a DNMRT was employed at each frequency to compare the ipsilateral masking means for the three temporal delays. Results of this statistical test are presented in Table 10 of Appendix A. It was noted that only at 500 Hz did nonsignificance occur among the mean values at all three temporal positions. The three positions differed ($P < 0.05$) from one another at 900, 950 and 1050 Hz. At 800, 1000, 1100, 1200 and 1500 Hz differences were observed between the "initial" position and both the "medial" and "final" positions; however, the "medial" and "final" positions themselves did not yield significantly different results.

Individual Subject Data. Appendices B through E contain tabulations and illustrations of individual subject data. Tables 13, 14, 15 and 16 contain coded data for the four subjects for each ear, masking condition, frequency and temporal delay. Figures 10, 12, 14 and 16 represent the overall ipsilateral and contralateral masking patterns for each subject. Figures 11, 13, 15 and 17 illustrate ipsilateral and contralateral masking for each of the three temporal delays.

The consistency of the ipsilateral masking patterns (Figures 10, 12, 14 and 16) is generally good among the four subjects, although differences among subjects are evident at certain frequencies. The pattern for subject #1 showed less overall masking than the patterns for the other three subjects. Subject #2 manifested more ipsilateral masking than the other subjects. Subject #2 also showed more masking at 950 Hz than at 1000 Hz whereas for the other subjects, the reverse was true.

The effect of the three temporal delay positions can be seen on the masking patterns for each subject in Figures 11, 13, 15 and 17. Subject #2 showed consistently more onset overshoot than the other three subjects. All of the subjects generally showed the most masking at the "initial" position, while the least masking occurred when the maskee was in the "medial" position.

Contralateral Masking

Contralateral masking occurs when the masker is presented to one ear and the maskee is delivered to the other ear. In the present experiment, contralateral masking was measured at each level of the other three factors (ears, frequencies and temporal delays) for all four subjects.

Effect of Ear. Contralateral masking patterns for each ear are illustrated in Figure 5, page 51. Overlap of the right and left ear patterns is observed, and as reported previously, statistical comparison of overall ear effects revealed (AOV, Table 7 of Appendix A) that the difference between ears was nonsignificant ($P > 0.05$). The DNMRT produced no significant differences ($P > 0.05$) when right ear and left ear means were compared at each test frequency under the contralateral masking condition.

Effect of Frequency. Contralateral masking as a function of frequency is presented in Table 3, page 49 and illustrated in Figure 4, page 48. The masking pattern is relatively flat between the test frequencies of 500 and 1500 Hz. There was only a slight indication that masking increases at test frequencies surrounding the masker. The magnitude of contralateral masking ranged from a minimum of 0.89 dB at 500 Hz to a maximum of 2.18 dB at 1050 Hz.

Although the overall effect for frequency was significant ($P < 0.005$) with an F ratio of 65.55, and the frequency-by-masking condition interaction revealed an F ratio of 67.79 and was also statistically significant ($P < 0.005$), the DNMRT comparing frequencies (Appendix A, Table 8) showed a significant difference ($P < 0.05$) only between 1050 and 500 Hz. All other mean frequency comparisons were not significant.

The AOV also revealed that the frequency-by-temporal delay interaction was statistically significant ($P < 0.05$), while all other frequency interactions were not significant. Although the frequency-by-masking condition-by-temporal delay interaction was not significant, the DNMRT was employed to compare contralateral masking means among frequencies for each temporal delay.

Appendix A, Table 11, contains the results of this DNMRT. Analysis for the "initial" position revealed that frequencies 950, 1000, 1050 and 1100 Hz each differed significantly from 500 Hz ($P < 0.05$); however, all other frequency comparisons were not significant. The "medial" and "final" delay results for the contralateral masking condition showed no differences among any of the nine test frequencies ($P > 0.05$).

A graphic illustration of the frequency-by-masking condition-by-temporal delay interaction is presented in Figure 8. This figure shows that the "initial" delay position manifests the greatest masking at all frequencies. The "medial" and "final" curves show essentially no difference at 1000 Hz and above; however, below 1000 Hz, the curve for the "final" position shows more masking than the curve for the "medial" position.

Contralateral pure-tone masking has been reported by several other investigators (8, 18, 31, 33, 68, 69) to be consistently greater than that observed in the present experiment. However, the results of Wegel and Lane, (55), appear comparable to the present findings.

Wegel and Lane's (55) masking experiment shows very little contralateral masking for a 1200-Hz masker at frequencies from 350 to 4000 Hz. Extrapolating from their masking curves, contralateral masking is less than 2 to 3 dB even for frequencies close to the masker. No masking effect was obtained at test frequencies farther removed from the masker.

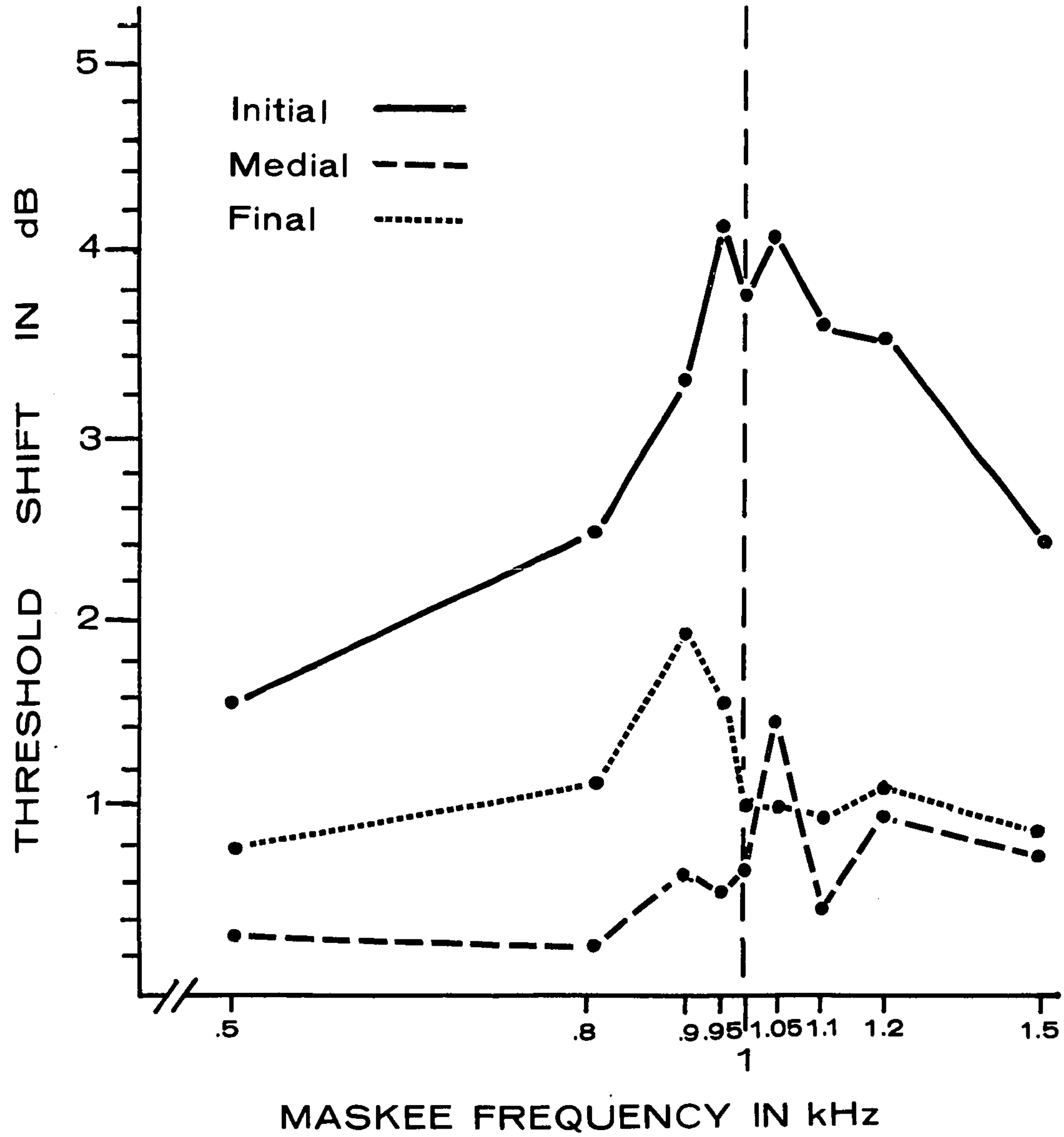

Figure 8. Contralateral masking patterns for Initial, Medial and Final positions.

Dirks and Norris (18) were primarily concerned with the measurement of pure-tone contralateral masking for various temporal relations between the masker and maskee. Maskee frequencies extended from 800 to 1200 Hz while the masker was 1000 Hz. Their P-C condition was similar to the "medial" position of the present study with regard to temporal relations. The "medial" position data revealed less masking (0.25 to 1.44 dB) than Dirks and Norris found (1 to 4 dB). The Dirks and Norris P-C data, however, is in good agreement with the data obtained for the "initial" position in the present investigation.

Zwislocki and his co-workers (68, 69) measured contralateral masking during the steady-state masking condition and compared it with masking during the transient or overshoot period. The steady-state masking produced by a 1000-Hz masker at 40-dB SL ranged from approximately 0.5 dB to 3 dB at test frequencies between 700 and 1500 Hz (69). This was greater than the current findings for the "medial" position but essentially the same as the present "initial" and "final" position results. Contralateral masking during the transient period was considerably greater for the average of the three subjects of Zwislocki, et al. (68) (ranging from 1.5 dB at 300 Hz to 8 dB at 1000 Hz) than for the four subjects of the present study (ranging from 1.58 dB at 500 Hz to 4.15 at 950 Hz). One of their subjects exhibited as much as 12 dB of masking at a frequency adjacent to the masker during the transient period. All conditions showed the greatest masking at frequencies closely surrounding the frequency of the masker.

Hughes (31) reported a very large central masking effect when a 1100 Hz tone was utilized as both the masker and the maskee. Masker levels of 5, 10 and 15 dB above threshold were employed. Masking magnitudes at these levels were 4.1, 7.3 and 9.5 dB respectively. Hughes obtained greater masking for his 5-dB SL masker than was observed at any frequency with the 50-dB SPL masker used in the present investigation.

Ingham (33) measured the central masking pattern of a 1000-Hz masker at 30-dB SL with maskees ranging from 200 to 4000 Hz. Frequencies near the masker showed 12 to 13 dB of masking whereas frequencies farther away showed negative masking (-1 to -3 dB). In a subsequent experiment, he again sampled the masking pattern of a 1000-Hz masker with test frequencies ranging from 600 to 1400 Hz. The masking pattern was found to be restricted to frequencies above 760 Hz with only 1 dB of masking observed at 1240 and 1400 Hz. Maximum masking (9 dB) occurred below the frequency of the masker at 920 Hz while only 5.5 dB of masking occurred at a comparable higher frequency (1080 Hz). Ingham's results were generally of greater magnitude than those obtained in the present study.

Several of the above studies have reported considerably more contralateral masking than the present investigation. Two factors may account for this discrepancy.

First, the subjects used in the present experiment had performed in numerous other psychophysical experiments using auditory stimuli and were considered to be sophisticated listeners for this type of task. In addition, they underwent six hours of practice to train them to perform at an optimum level. The compound effects of subject sophistication and training could account for the small magnitude of masking obtained in the present study.

Second, the method of threshold determination may account for reported difference. In the present investigation the classical method of limits was employed. Several other investigators (32, 33, 55) have used a modified method of limits in which only ascending threshold measures were considered. By using only the ascending technique the amount of masking may have been overestimated. Whether or not the above factors have influenced the amount of contralateral masking must await further investigation.

Effect of Temporal Delay. The effects of temporal relations on contralateral masking have been demonstrated by several investigators (17, 18, 23, 45, 68, 69). Changes in masking efficiency over time were studied in the present experiment. Pure-tone maskees were presented at three temporal delays relative to a 1000-Hz, 1000-msec contralateral masker. Under the three temporal delay conditions the maskees were presented near the onset of the masker ("initial" position), at the midpoint of the masker ("medial" position) and near the offset of the masker ("final" position). The temporal delay positions are illustrated in Figure 3, page 36.

An overall mean of threshold results obtained for each temporal position revealed contralateral masking values of 3.24 dB for the "initial" position, 0.76 dB for the "medial" position and 1.20 dB for the "final" position. Results for each delay position at each frequency are presented in Table 6. An illustration of the effect of temporal delay at each frequency is presented in Figure 9. This figure is divided into three graphs (A, B and C) for simplicity of presentation.

TABLE 6

CONTRALATERAL MASKING (in dB) FOR THE NINE MASKEE FREQUENCIES
AT THE THREE TEMPORAL POSITIONS AND AVERAGED
ACROSS SUBJECTS AND EARS

Temporal Delay	Maskee Frequencies (Hz)								
	500	800	900	950	1000	1050	1100	1200	1500
Initial	1.58	2.50	3.33	4.15	3.89	4.10	3.63	3.54	2.46
Medial	0.33	0.25	0.63	0.56	0.68	1.44	0.50	0.98	0.89
Final	0.75	1.13	1.92	1.53	1.00	1.00	0.96	1.17	0.75
Mean	0.89	1.29	1.96	2.08	1.86	2.18	1.70	1.90	1.37

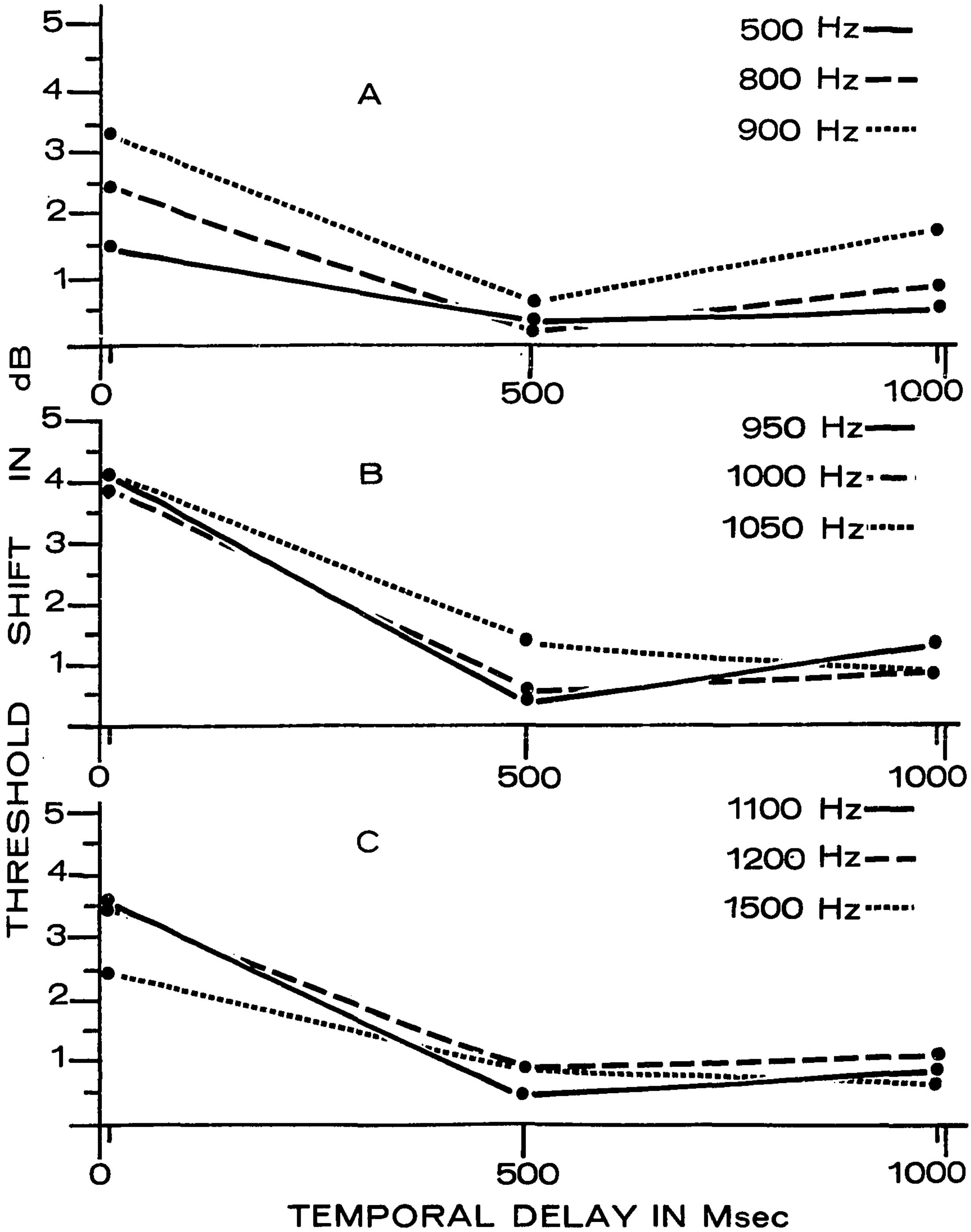

Figure 9 A,B, and C. Contralateral masking as a function of time between masker and maskee for each frequency.

Masking curves for each frequency are plotted in dB along the ordinate with the abscissa defined in milliseconds of delay.

The curves of Figure 9 show generally more masking at the "initial" position than at either of the other delay positions. Although statistically significant differences were not obtained at any frequency between the "medial" and "final" positions, a slight masking increase at the "final" position is evident at all frequencies except 1050 and 1500 Hz.

Overshoot was measured as the difference between the "initial" and "medial" and the "final" and "medial" positions for the contralateral masking conditions. The magnitude of overshoot at each frequency is presented in Table 5, page 61.

Onset overshoot for a contralateral masker was found at each of the nine test frequencies. Although there appeared to be a small amount of offset overshoot at some frequencies, the "final" position thresholds were not consistently greater than the thresholds at the "medial" position.

Zwislocki, _et al_. (_68_) have reported that overshoot at the onset of a contralateral masker was related to the initial shift in threshold. This was supported in the findings of the present investigation as onset overshoot was generally greater at frequencies which showed the greater amount of masking at the "initial" position.

Comparison of the magnitude of overshoot between the ipsilateral and contralateral masking conditions is presented in Table 5. It shows that the ipsilateral "initial" overshoot is approximately twice the amount of contralateral "initial" overshoot.

Although the ipsilateral "final" overshoot is greater than the contralateral "final" overshoot the ratio does not appear to be constant.

The results of the AOV (Appendix A, Table 7) reveal that the overall effect of temporal delay was significant ($P < 0.05$) with an F ratio of 10.87. Statistical significance ($P < 0.05$) was also obtained for the temporal delay-by-masking condition interaction with an F ratio of 6.04. The DNMRT comparing overall contralateral masking means at each of the three delays, revealed significant differences ($P < 0.05$) only between the "initial" position and the other two delay positions. The "medial" and "final" positions did not yield significantly different magnitudes of masking. The only other temporal delay interaction which was significant ($P < 0.05$) was obtained for the temporal delay-by-frequency interaction with an F value of 2.36.

Although the temporal delay-by-masking condition-by-frequency interaction was not significant, a DNMRT was used to compare the contralateral masking means for the three temporal delays at each test frequency. Results of this statistical test are presented in Table 12 of Appendix A.

At no frequency was a significant difference found between the "medial" and "final" position means ($P > 0.05$). The "initial" position differed from the "medial" position at all frequencies except 500 and 1500 Hz. The "initial" position and the "final" position yielded significantly different results at only 950, 1000, 1050, 1100 and 1200 Hz ($P < 0.05$).

Individual Subject Data. Appendices B through E contain tabulations (Tables 13, 14, 15 and 16) of individual subject data and graphic illustrations of the individual masking patterns. Overall ipsilateral and contralateral masking patterns for each subject are presented in Figures 10, 12, 14 and 16. Ipsilateral and contralateral masking curves for each of the three temporal delays are presented for each subject in Figures 11, 13, 15 and 17.

The overall consistency for the contralateral masking patterns (Figures 10, 12, 14 and 16) was only fair among the four subjects. Only for Subject #1 did maximum masking occur at the frequency of the masker. For the other three subjects, maximum masking occurred at some other frequency within 200 Hz of the masker.

The effect of the temporal delay positions as illustrated for each subject in Figures 11, 13, 15 and 17, shows that maximum onset overshoot for Subject #1 occurred near the frequency of the masker, whereas for Subject #2 and #4 substantial onset overshoot occurred at nearly every test frequency. In contrast to the other three subjects, Subject #3 showed generally more overshoot near the offset of the masker than near its onset. Very little onset overshoot occurred at any test frequency for this subject.

In Figures 10, 11 (for Subject #1) and 14 (for Subject #3) a "W-shaped" pattern of contralateral masking is observed. This pattern has also been obtained by Klinke, Boerger and Gruber (36) who measured the activity in neurons of the cochlear nucleus of a cat during contralateral stimulation. They attributed this pattern to the effects of neural inhibition and suggest that this may result from the functioning of the crossed efferent fibers which emanate from the olivocochlear bundle.

Discussion

The findings of the present investigation indicate that both ipsilateral and contralateral pure-tone masking change over time. The remainder of this chapter will be devoted to a discussion of overshoot (the increased masking which occurs during the transient onset and offset periods of a masker) in ipsilateral and contralateral masking, and also to a review of neurophysiological findings which demonstrate transient onset and offset activity in the auditory system.

Ipsilateral Masking

Overshoot was obtained near the onset and offset of an ipsilateral pure-tone masker. This supports the findings of Samoilova (41) who described onset overshoot for an ipsilateral pure-tone masker, and Elliott (23) who reported both onset and offset overshoot for an ipsilateral narrow-band noise masker. The present findings, therefore, are in conflict with Zwicker's (65) hypothesis that no overshoot is to be expected when the masker and maskee have similar frequency spectra.

The only experiment in which ipsilateral pure-tone masking over time was measured in a manner similar to that used in this study was conducted by Samoilova (41). He reported a greater change in masking at 1380 Hz for a 1000-Hz masker (12 dB) than was obtained between the "initial" and "medial" positions for any frequency (a maximum of 6.69 dB at 1050 Hz) in the present investigation. This discrepancy may be accounted for by the difference in masker levels employed in the two studies. In the present investigation a 50-dB SPL masker was used, whereas Samoilova presented his masker at 90-dB SL.

Ipsilateral masking overshoot (Table 5) occurs at all nine test frequencies in both the "initial" and "final" positions. The overshoot near the onset of the masker was considerably greater than overshoot near the offset. It appears that the magnitude of the onset overshoot is better related to the amount of threshold shift measured in the "initial" position than to the frequency difference between the masker and maskee. This finding was not reported by Elliott (23) who used narrow noise bands as maskers. She stated that the greatest overshoot appeared near the cut-off frequencies of the noise bands and not within the band itself. On the other hand, it was not possible to determine whether the magnitude of offset overshoot was best related to either the amount of theshold shift or to the difference in frequency between maskee and masker.

Several investigators have discussed the physiological bases underlying the phenomenon of temporal masking changes. Scholl (42) has suggested that masking overshoot is a result of the reduction in the pattern of excitation over time. This in turn, has been attributed to a neural inhibitory mechanism. Zwicker (65) suggested that "normal overshoot" is due to a mechanical filtering process, but he does not rule out the possibility of lateral inhibition. Elliott (23) reported that her findings support the hypothesis of Scholl, that the excitation pattern is widest at masker onset and requires a brief time for "organizing" or "sharpening" to a more narrow band. She has demonstrated that overshoot for a narrow-band noise is greatest at the interface of excitation and nonexcitation. Elliott does not speculate however, on the physiological structures which may be involved in onset overshoot, although her findings could be explained by lateral inhibition, a process which has been described by Bekesy (2).

It is suggested by the author that the auditory system may function in a slightly different manner for a pure-tone signal than for sounds composed of numerous frequencies (noise bands). For a pure tone the pattern of excitation in the auditory system is relatively specific. This specificity results from the inherent characteristics of the basilar membrane, the pattern of hair cell arrangement, and the interconnections of the nerve fibers in the organ of Corti. Because of this relatively specific pattern produced by a pure-tone stimulus, the need for further "tuning" or restriction of the pattern is reduced. For a noise band signal, however, the auditory system is stimulated over a larger area. Therefore, the pattern of excitation may be reduced or simplified without losing pertinent information. This results in a narrowing of the excitation pattern of a noise band during the initial few millseconds of stimulation. Scholl (42), Zwicker (65) and Elliott (23) have demonstrated this reduction in the excitation pattern of a noise band in their psychophysical experiments.

Offset overshoot for a pure-tone masker has not been reported by previous investigators. Elliott (23) has suggested that the offset overshoot which she found for a narrow-band masking noise is attributed to "backward masking" produced by the neural offset at the termination of the masker. In the present investigation, backward masking is a tenable explanation for pure-tone offset overshoot.

Contralateral Masking

Overshoot for the contralateral masking condition occurred consistently only near the onset of the pure-tone masker. An indication of overshoot at masker termination was observed at some frequencies although statistically significant differences were not obtained at any frequency between the "medial" and "final" delay positions. The magnitude of contralateral overshoot at each frequency is presented in Table 5, page 61.

The occurrence of contralateral pure-tone masking change over time near the onset of the masker supports the findings of Zwislocki and his co-workers (68, 69). However, overshoot in the present study was considerably less than they reported for their individual subject data. Averaging the maximum amount of overshoot reported for their three subjects resulted in a mean value of 8 dB for frequencies at or near the 1000-Hz masker. Onset overshoot in the present investigation was at its maximum (3.59 dB) at 950 Hz when averaged across the four subjects. This difference in the magnitude of onset overshoot may be attributed to several factors.

First, as reported previously in this chapter, the four subjects used in this study were sophisticated at performing auditory judgements in psychophysical experiments. These subjects were also throughly practiced at the masking task. Optimum performance resulting in low contralateral masking thesholds as well as reduced overshoot could be attributed, therefore, to the combination of sophistication and training of the subjects.

Second, contralateral masking may exhibit a slow adaptation (68, 69) over a period of several minutes. This is observed as a reduction in the amount of contralateral pure-tone masking at frequencies adjacent to the masker during the testing procedure. Thus, the masking pattern may become flattened during a prolonged threshold measurement process. In the present study, each threshold required numerous presentations of the masker and maskee in the classical method of limits. It is possible that slow adaptation may have occurred, or may have been in the process of occurring throughout the measurement period. This could have accounted for the reduced overshoot and the smaller degree of central masking obtained in the present study when compared to the findings of Zwislocki, et al. (68).

Third, the maskee envelope must be restricted to a brief duration in order to sample the masking pattern as early as possible during the course of the masker (42, 66). Zwislocki and his co-workers (68, 69) utilized a maskee which was approximately 4 msec shorter than the one employed in the present study. Furthermore, they did not employ any delay between masker and maskee onsets in their initial position whereas in the present study, a 3 msec delay was used. Since the transient overshoot decreases very rapidly after the onset of the masker, Zwislocki, et al. were able to sample masking nearer the masker onset than was possible in the present investigation. By sampling the pattern precisely at onset with as brief a maskee as possible, it is anticipated that more overshoot would occur.

The cause of contralateral masking overshoot has not been ascertained. Zwislocki, Buining and Glantz (68) have demonstrated a masking pattern with several maxima and minima surrounding the frequency of the masker. They have interpreted this as being indicative of excitatory-inhibitory interactions in the auditory nervous system. In the present investigation, similar maxima and minima occurred in the masking pattern. If central excitatory and inhibitory interactions are related to overshoot, the findings of the present study demonstrate that the effect is twice as great for ipsilateral as for contralateral masking.

Contralateral offset overshoot, although not consistently present in this experiment, may exist at least at frequencies below the masker. Its occurrence could be a result of backward masking as suggested by Elliott (23) for the ipsilateral masking condition.

Review of Physiological Studies

The measurement of an overshoot in psychophysical studies prompts a review of physiological experiments for possible analagous results. Galambos (26) has reported that neural onset responses of short latency have been recorded (1) at all levels in the auditory pathway. At the medial geniculate body the onset response appears essentially the same for a click as it does for the onset of a tone (27).

The actual function of a neural onset is unknown. However, its occurrence at the initiation of a stimulus has lead Galambos (26) to suggest:

> ...that the arousal of a relatively non-specific neural response may be the first consequence of tonal stimulation, and that the distinctive neural events required to diffentiate tones from any other type of sound emerge only after a time interval to be measured in tens of milliseconds has elapsed.

Starr and Livingston (47) have demonstrated in anesthetized cats an increased neural onset activity which occurs at the cochlear nucleus, superior olive, inferior colliculus and medial geniculate body. Offset responses for the same group of animals illustrated activity at all of the same anatomical locations except the inferior colliculus. For a conscious group of cats, onset responses were observed only at the medial geniculate body whereas a significant offset response was found at the cochlear nucleus, superior olive, inferior colliculus, medial geniculate body and the auditory cortex.

Neural on- and off-effects have been recorded in the cochlear microphonics of a cat (15, 50). Stevens and Davis (50) report that this electrical activity is complicated and that it occurs immediately after both onset and offset of a sound. The activity very closely resembles that which results from a single isolated click, however, it can occur even when no physical transients are associated with the signal production.

Stevens and Davis (50) also report for a given signal intensity, that the off-effect is usually less prominent than the on-effect. However, both are similar in that they both consist of similar waves and decline at approximately the same rate. This on-effect is interpreted as being a "wide-spectrum stimulus which is quickly damped out leaving only the cochlear microphonic.

The measurement of an "on-transient" and "after-potential" have also been recorded as a part of the summating potential (51, 57). These transient effects were found to be related to the rise and decay times of the signal. They were most evident for abrupt rise and decay times and were almost completely absent when the rise-time was 50 msec. Stopp (51) reports that this after-potential is similar to that observed in neurons, and she suggests that it may represent an after-potential of the afferent transmitter mechanism.

The measurement of decreasing activity in the eighth nerve has been termed "equilibrated" adaptation by some (15) or rate-adaptation and amplitude-adaptation by others (28). Galambos and Davis (28, page 42) illustrate this adaptation in a single auditory nerve fiber. Although this fiber required approximately one minute to achieve steady-state functioning, the greatest reduction in activity occurred within the first 100 msec of stimulation.

Neural onset responses to auditory stimulation have been recorded by many investigators at the cortical level. Offset responses have been recorded at the cortical level by only a few (13, 14, 16, 40). Davis and Zerlin (13) report that the on- and off-effects appear only for signals longer than 500 msec and that the on and off patterns are very similar to each other. They state that the off response grows in amplitude with increasing duration of the signal, while the on response grows in regard to increasing intervals of quiet.

From a brief review of the auditory neurophysiological literature, onset and offset activity have been recorded consistently at all levels in the auditory nervous system. Little is known about the exact orgin of this activity or about how the activity affects the normal hearing process. Although the neurophysiological and psychophysical data appear to be somewhat similar, a direct relationship between the two has not been demonstrated.

Summary

Change in masking efficiency over time has been demonstrated for both ipsilateral and contralateral pure-tone maskers. This change or overshoot occurs at masker onset for both masking conditions and at masker offset for only the ipsilateral masker. The experiments of several investigators lead them to suggest that masking overshoot may result from either mechanical changes or neurological inhibitory processes in the auditory system. Electrophysiological studies have demonstrated that on and off responses occur at various levels in the auditory system in response to both the presentation and the termination of a stimulus. Whether or not this neurological activity is related to the psychophysical measurement of overshoot awaits further investigation.

CHAPTER V

SUMMARY

Introduction

The literature on masking contains conflicting reports on whether the magnitude of masking changes over time. When such a change is measured, it appears to be due to a masking increase or "overshoot" near the onset and sometimes near the termination of a masker. Recent studies have shown that overshoot does occur with certain masking and test signals.

Zwicker (65) has suggested that for maskers and maskees with similar frequency spectra, no masking overshoot will be obtained. For maskers and maskees with different frequency spectra, significant overshoot will be observed. His hypothesis appears to reconcile the differences between the findings of many masking experiments. However, Samoilova (14) and Zwislocki, *et al.* (68, 69) who investigated masking by using signals with similar frequency spectra (pure tones) have reported significant overshoot.

The present study, using only pure-tone signals, was designed to resolve the above conflict. The primary goal of the experiment was to investigate temporal changes in the masking of a pure-tone signal and how the changes relate to spread of the masking pattern. A secondary aim was to compare masking efficiency and the masking pattern for ipsilateral and contralateral maskers.

The masker used in this study was always a 1000-Hz tone of 1000-msec duration delivered at 50-dB SPL. It was presented either ipsilateral or contralateral to the test signal. The nine test frequencies (500, 800, 900, 950, 1000, 1050, 1100, 1200 and 1500 Hz) each had a duration of 5 msec at maximum amplitude, and they were presented at each of three delays with respect to the masker onset. The 3-msec delay was termed the "initial" delay position and sampled the masking pattern near the onset of the masker. In the "medial" delay position the maskee was presented 497 msec after the masker onset and measured the masking pattern at the middle of the masker which is essentially the same as steady-state masking. The "final" delay position required the maskee to terminate 3 msec prior to the masker offset. Rise and decay times were set for all signals at 10 msec to preclude the production of transient energy from the earphones. An illustration of the three temporal delays is found in Figure 3, page 36.

Results

Ipsilateral Masking

The pure-tone ipsilateral masking pattern obtained in the present investigation was in good agreement with the results that have been presented by other investigators using only pure-tone signals. The pattern showed more masking at frequencies near the masker than at frequencies farther removed from the masker. The pattern was essentially symmetrical; however, for frequencies near the masker, more masking occurred just below the masker (900 and 950 Hz) than above the masker (1050 and 1100 Hz). For frequencies farther removed from the masker, more masking occurred above the masker (1200 and 1500 Hz) than below the masker (500 and 800 Hz).

The masking pattern for the left ear was compared to the pattern for the right ear. No significant difference was found at any frequency except at 1100 Hz were the left ear demonstrated more masking than the right ear. It is likely that the significant finding at this isolated frequency is due to chance.

Differences in the amount of masking measured at the three temporal positions were also compared. The "initial" position showed consistently more masking than the "medial" or "final" positions. The "final" position showed more masking than the "medial" position. Differences in dB between the "initial" and "medial" and between the "final" and "medial" delay positions were computed to determine the amount of overshoot near the onset and offset of the masker.

Overshoot near the onset of the masker was greater than overshoot near the offset. Onset overshoot appeared to relate better to the "initial" threshold shift than to the difference in frequency between the masker and maskee. It was not possible to determine which factor correlated better with offset overshoot.

Contralateral Masking

The magnitude of contralateral pure-tone masking was found to be small (ranging from 0.89 dB to 2.18 dB) and the pattern was relatively flat. There was only a slight indication that masking increased for frequencies near the frequency of the masker. The magnitude of contralateral masking measured in the present study, was generally less than that reported by previous investigators.

The effect of ears upon the masking pattern was also evaluated. No significant differences due to ears were obtained at any of the nine test frequencies.

Masking was compared among the three temporal delay positions for the contralateral masker. More masking was observed at the "initial" position than at either of the other two delay positions. Although the data appeared to show a slight increase in masking at some frequencies for the "final" position when compared to the "medial" position, no significant differences were obtained when these comparisons were made. Therefore, when overshoot was computed from the results, the only substantial amount of overshoot appeared near the onset of the masker. This onset overshoot appeared to increase as the maskee approached the frequency of the masker, but it was more closely related to the magnitude of the "initial" threshold shift.

Conclusions

This experiment has shown that masking does change over time for a pure-tone ipsilateral or contralateral masker. Significant onset overshoot occurred for both the ipsilateral and contralateral masking conditions, while only for the ipsilateral masker was significant offset overshoot obtained.

Changes in ipsilateral masking over time for a pure tone support the findings of Samoilova (41), while similar changes in contralateral pure-tone masking support the results of Zwislocki, *et al.* (*68*, *69*). The findings of the present study, however, are in conflict with Zwicker's (*65*) hypothesis. Zwicker has suggested that when masker and maskee have similar frequency spectra, significant overshoot will not be obtained. In the present investigation, only signals with similar frequency spectra (pure tones) have been employed for the masker and maskee, and overshoot was measured. Zwicker's hypothesis, therefore, does not appear to hold for pure-tone signals.

Neural inhibitory processes and a mechanical filtering mechanism have been suggested as possible causes for onset overshoot. Backward masking has been suggested as a cause of offset overshoot. Electrophysiological studies have demonstrated the presence of onset and offset activity within the auditory system. This neurological activity may be related to the psychophysical measurement of overshoot.

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Appendix A

Results of Statistical Analyses

TABLE 7

SUMMARY OF THE ANALYSIS OF VARIANCE

Source	df	Sum of Squares	Mean Square	F
Between Subjects	3	640.17	213.39	
Within Subjects				
Ears (A)	1	40.15	40.15	N.S.
Subject (E) x Ears	3	450.30	150.10	
Masking Condition (B)	1	24,940.00	24,940.00	126.33[a]
Subject x Masking Condition	3	592.22	197.40	
Temporal Delay (C)	2	1,092.72	546.36	10.86[b]
Subject x Temporal Delay	6	301.63	50.27	
Frequency (D)	8	11,822.97	1,477.87	65.54[a]
Subject x Frequency	24	541.12	22.54	
Ears x Masking Condition	1	26.90	26.90	N.S.
Subject x A x B	3	128.18	42.72	
Ears x Temporal Delay	2	0.96	0.48	N.S.
Subject x A x C	6	23.37	3.89	
Ears x Frequency	8	89.47	11.18	N.S.
Subject x A x D	24	270.37	11.26	
Masking Condition x Temporal Delay	2	116.68	58.34	6.04[b]
Subject x B x C	6	57.94	9.65	
Masking Condition x Frequency	8	10,406.76	1,300.84	67.78[a]
Subject x B x D	24	460.56	19.19	
Temporal Delay x Frequency	16	129.80	8.11	2.36[b]
Subject x C x D	48	164.43	3.42	
A x B x C	2	9.84	4.92	N.S.
E x A x B x C	6	38.77	6.46	

TABLE 7 Continued

A x B x D	8	56.25	7.03	N.S.
E x A x B x D	24	237.25	9.88	
A x C x D	16	21.98	1.37	N.S.
E x A x C x D	48	82.25	1.71	
B x C x D	16	31.42	1.96	N.S.
E x B x C x D	48	150.75	3.14	
A x B x C x D	16	18.51	1.15	N.S.
E x A x B x C x D	48	124.82	2.60	

[a] Significant at the .005 level of confidence
[b] Significant at the .05 level of confidence

TABLE 8

RESULTS OF THE DNMRT IN THE COMPARISON OF THE NINE MASKEE FREQUENCIES FOR BOTH THE IPSILATERAL AND CONTRALATERAL MASKING CONDITIONS

Masking Condition	Ranked Frequency (Hz) means (coded) for the masking conditions								
Ipsilateral	(950) 38.67	(1000) 37.66	(1050) 36.45	(900) 33.38	(1100) 30.82	(1200) 21.26	(800) 20.01	(1500) 13.09	(500) 11.04
Contralateral	(1050) 12.18	(950) 12.09	(900) 11.96	(1200) 11.89	(1000) 11.86	(1100) 11.70	(1500) 11.37	(800) 11.29	(500) 10.89

TABLE 9

RESULTS OF THE DNMRT IN THE COMPARISON FOR THE NINE FREQUENCIES
FOR THE INITIAL, MEDIAL AND FINAL TEMPORAL DELAYS
FOR THE IPSILATERAL MASKING CONDITION

Temporal Delay	Ranked frequency (Hz) means (coded) for each temporal delay								
	(950)	(1000)	(1050)	(900)	(1100)	(1200)	(800)	(1500)	(500)
Initial	42.46	41.49	40.15	36.54	34.21	24.17	22.40	15.04	11.71
	(950)	(1000)	(1050)	(900)	(1100)	(1200)	(800)	(1500)	(500)
Medial	35.81	35.36	33.46	30.63	28.34	19.04	17.96	11.64	10.90
	(950)	(1000)	(1050)	(900)	(1100)	(1200)	(800)	(1500)	(500)
Final	37.75	36.13	35.75	32.96	29.91	20.58	19.67	12.58	10.52

TABLE 10

RESULTS OF THE DNMRT IN THE COMPARISON OF THE THREE TEMPORAL DELAYS FOR EACH OF THE NINE TEST FREQUENCIES FOR THE IPSILATERAL MASKING CONDITION

Test Frequency (Hz)	Ranked Temporal Delay Means (Coded) for Each Frequency		
500	(initial) 11.71	(medial) 10.90	(final) 10.52
800	(initial) 22.40	(final) 19.67	(medial) 17.96
900	(initial) 36.54	(final) 32.96	(medial) 30.63
950	(initial) 42.46	(final) 37.75	(medial) 35.81
1000	(initial) 41.49	(final) 36.13	(medial) 35.36
1050	(initial) 40.15	(final) 35.75	(medial) 33.46
1100	(initial) 34.21	(final) 29.91	(medial) 28.34
1200	(initial) 24.17	(final) 20.58	(medial) 19.04
1500	(initial) 15.04	(final) 12.58	(medial) 11.64

TABLE 11

RESULTS OF THE DNMRT IN THE COMPARISON FOR THE NINE FREQUENCIES
FOR THE INITIAL, MEDIAL AND FINAL TEMPORAL DELAYS
FOR THE CONTRALATERAL MASKING CONDITION

Temporal Delay	Ranked frequency (Hz) means (coded) for each temporal delay								
	(950)	(1050)	(1000)	(1100)	(1200)	(900)	(800)	(1500)	(500)
Initial	14.15	14.10	13.89	13.63	13.54	13.33	12.50	12.46	11.58
	(1100)	(1050)	(1200)	(1500)	(1000)	(900)	(950)	(500)	(800)
Medial	11.50	11.44	10.98	10.89	10.68	10.63	10.56	10.33	10.25
	(900)	(950)	(1200)	(800)	(1000)	(1050)	(1100)	(500)	(1500)
Final	11.92	11.53	11.17	11.13	11.00	11.00	11.96	10.75	10.75

TABLE 12

RESULTS OF THE DNMRT IN THE COMPARISON OF THE THREE TEMPORAL DELAYS FOR EACH OF THE NINE TEST FREQUENCIES FOR THE CONTRALATERAL MASKING CONDITION

Test Frequency (Hz)	Ranked Temporal Delay Means (Coded) for Each Frequency		
500	(initial) 11.58	(final) 10.75	(medial) 10.33
800	(initial) 12.50	(final) 11.13	(medial) 10.25
900	(initial) 13.33	(final) 11.92	(medial) 10.63
950	(initial) 14.15	(final) 11.56	(medial) 10.56
1000	(initial) 13.89	(final) 11.00	(medial) 10.68
1050	(initial) 14.10	(medial) 11.44	(final) 11.00
1100	(initial) 13.63	(final) 10.96	(medial) 10.50
1200	(initial) 13.54	(final) 11.17	(medial) 10.98
1500	(initial) 12.46	(medial) 10.89	(final) 10.75

Appendix B

Subject #1 Results

TABLE 13

SUBJECT # 1 DATA (CODED) FOR EACH EAR, MASKING CONDITION, FREQUENCY AND TEMPORAL DELAY

Masking Condition	Ear	Temporal Delay	500	800	900	950	1000	1050	1100	1200	1500
			Maskee Frequencies (Hz)								
Ipsilateral	R	initial	12.66	16.50	29.84	35.17	39.80	30.17	20.00	9.66	10.00
		medial	12.00	12.50	24.34	29.17	28.30	25.17	16.00	10.16	9.50
		final	10.66	16.50	26.34	29.50	32.63	28.34	17.17	10.16	11.00
	L	initial	10.66	21.67	33.34	42.66	42.47	38.33	37.83	20.16	11.50
		medial	10.50	16.50	28.34	36.50	36.14	34.00	30.16	17.33	9.66
		final	10.16	16.67	29.50	39.16	36.47	34.50	33.66	18.83	10.50
Contralateral	R	initial	10.50	12.33	8.84	13.17	11.50	9.33	9.83	10.00	10.17
		medial	10.80	12.50	9.34	9.00	11.17	11.50	10.66	9.50	12.67
		final	9.17	10.83	13.17	10.83	10.17	9.00	12.16	11.67	9.67
	L	initial	10.83	12.50	12.00	16.50	17.30	17.66	11.16	15.16	14.33
		medial	11.17	11.50	9.83	10.67	11.96	12.00	9.16	10.16	10.83
		final	10.67	11.66	11.83	11.17	12.63	11.33	10.16	10.66	11.67

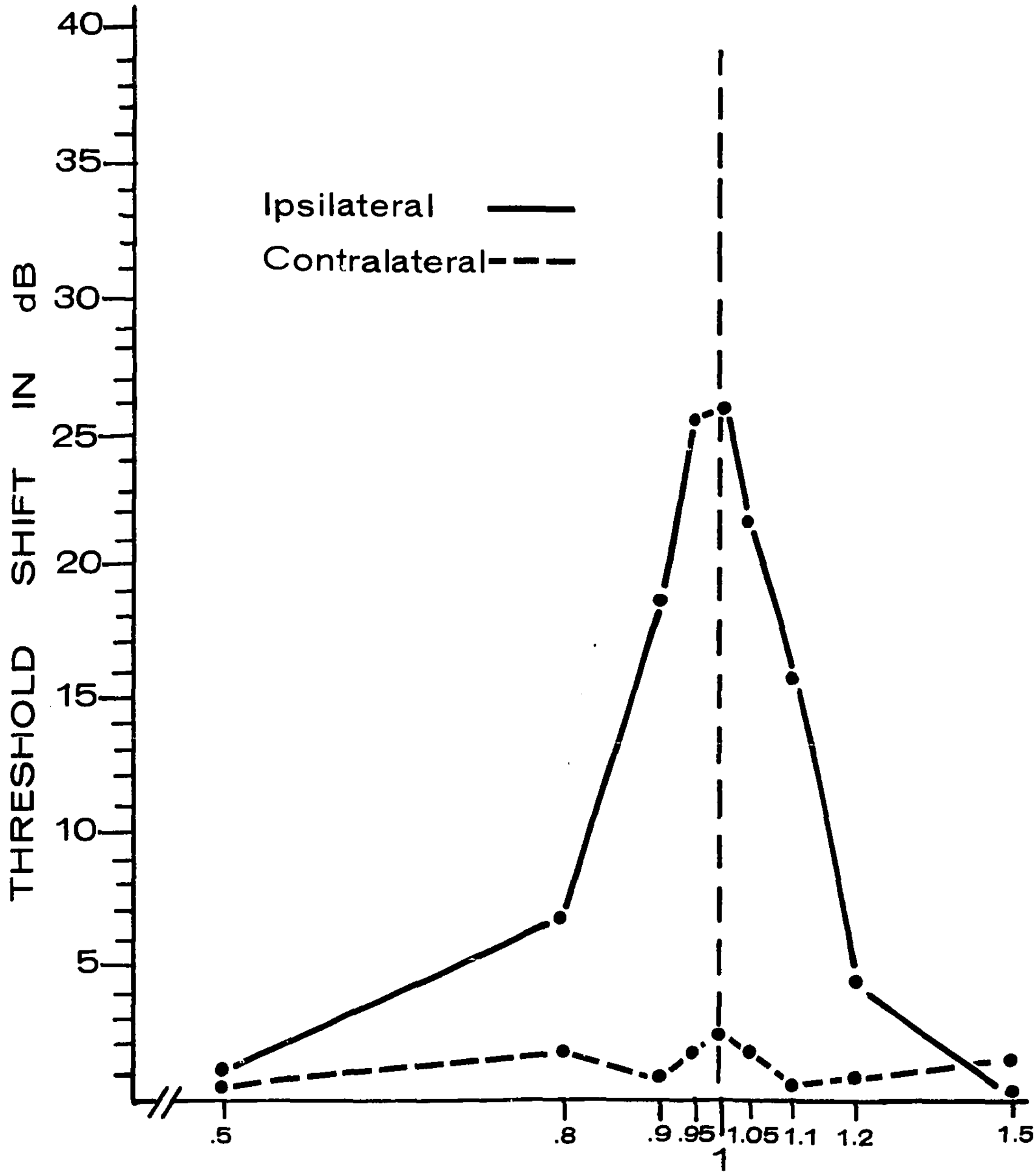

Figure 10. Ipsilateral and Contralateral masking patterns for Subject #1.

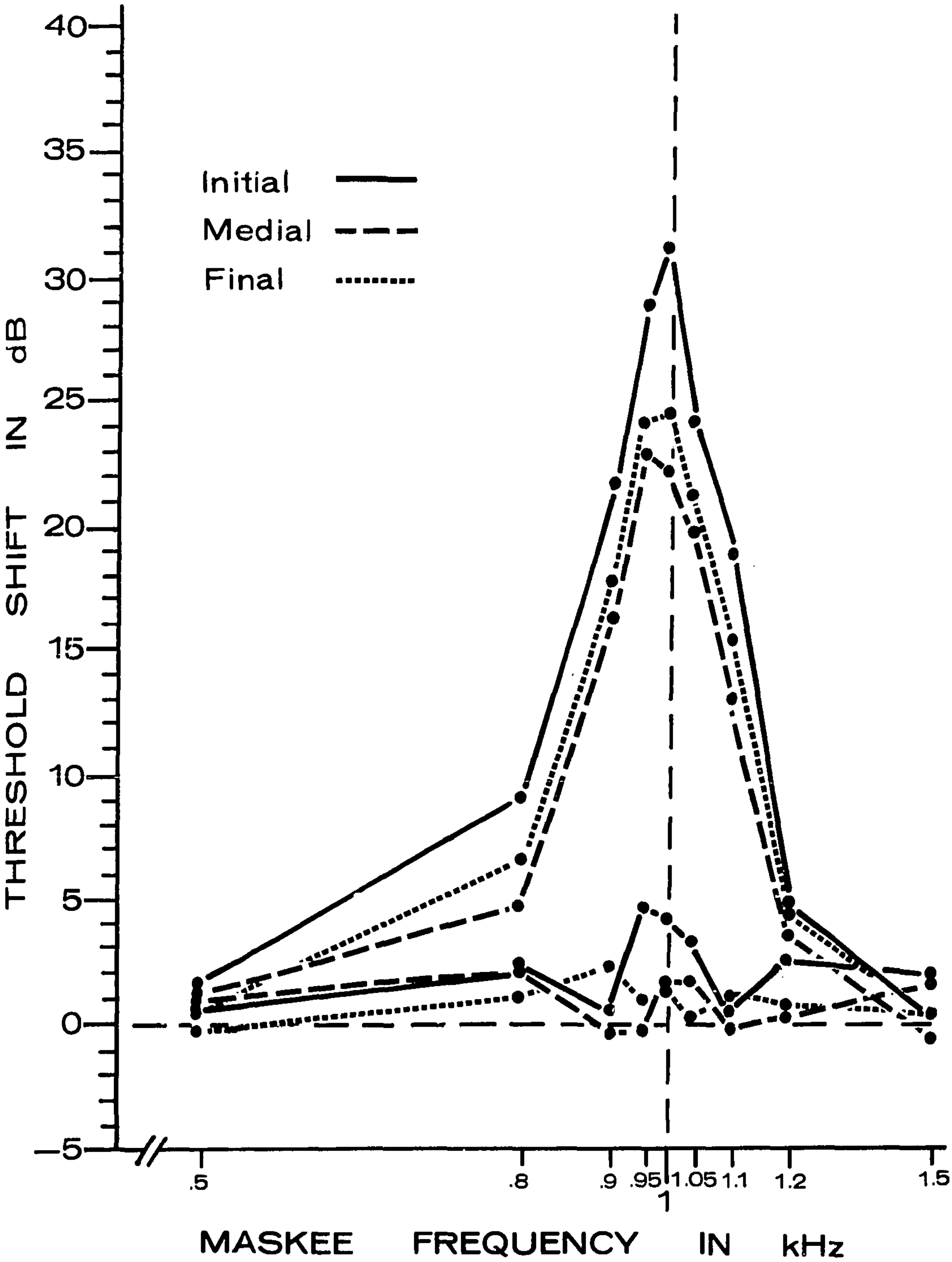

Figure 11. Ipsilateral (upper curves) and Contralateral (lower curves) masking patterns for Initial, Medial and Final positions for Subject #1.

Appendix C

Subject #2 Results

TABLE 14

SUBJECT # 2 DATA (CODED) FOR EACH EAR, MASKING CONDITION, FREQUENCY AND TEMPORAL DELAY

Masking Condition	Ear	Temporal Delay	500	800	900	950	1000	1050	1100	1200	1500
			Maskee Frequencies (Hz)								
Ipsilateral	R	initial	10.00	23.34	40.00	50.17	43.13	41.84	42.00	38.33	20.50
		medial	9.83	19.37	31.00	39.00	35.30	35.17	30.16	27.17	12.67
		final	10.33	19.50	34.17	39.50	30.63	35.84	31.50	28.17	13.67
	L	initial	11.50	30.16	41.67	48.50	42.63	44.33	41.33	40.50	21.84
		medial	11.50	16.16	33.17	38.33	37.96	34.84	30.83	28.16	15.50
		final	10.16	20.16	39.00	39.66	36.80	35.34	31.50	28.33	18.67
Contralateral	R	initial	13.66	9.83	16.50	14.67	14.50	16.33	14.00	16.50	11.50
		medial	10.16	8.67	9.83	9.17	10.00	10.00	9.50	10.83	10.67
		final	10.33	9.50	11.50	10.84	7.83	9.16	10.16	9.50	9.50
	L	initial	10.17	13.67	14.50	16.16	16.00	14.33	14.87	17.50	13.16
		medial	9.17	9.67	12.84	11.16	10.83	9.83	9.70	11.00	9.66
		final	9.17	12.34	12.34	10.66	11.50	12.16	10.87	12.50	11.50

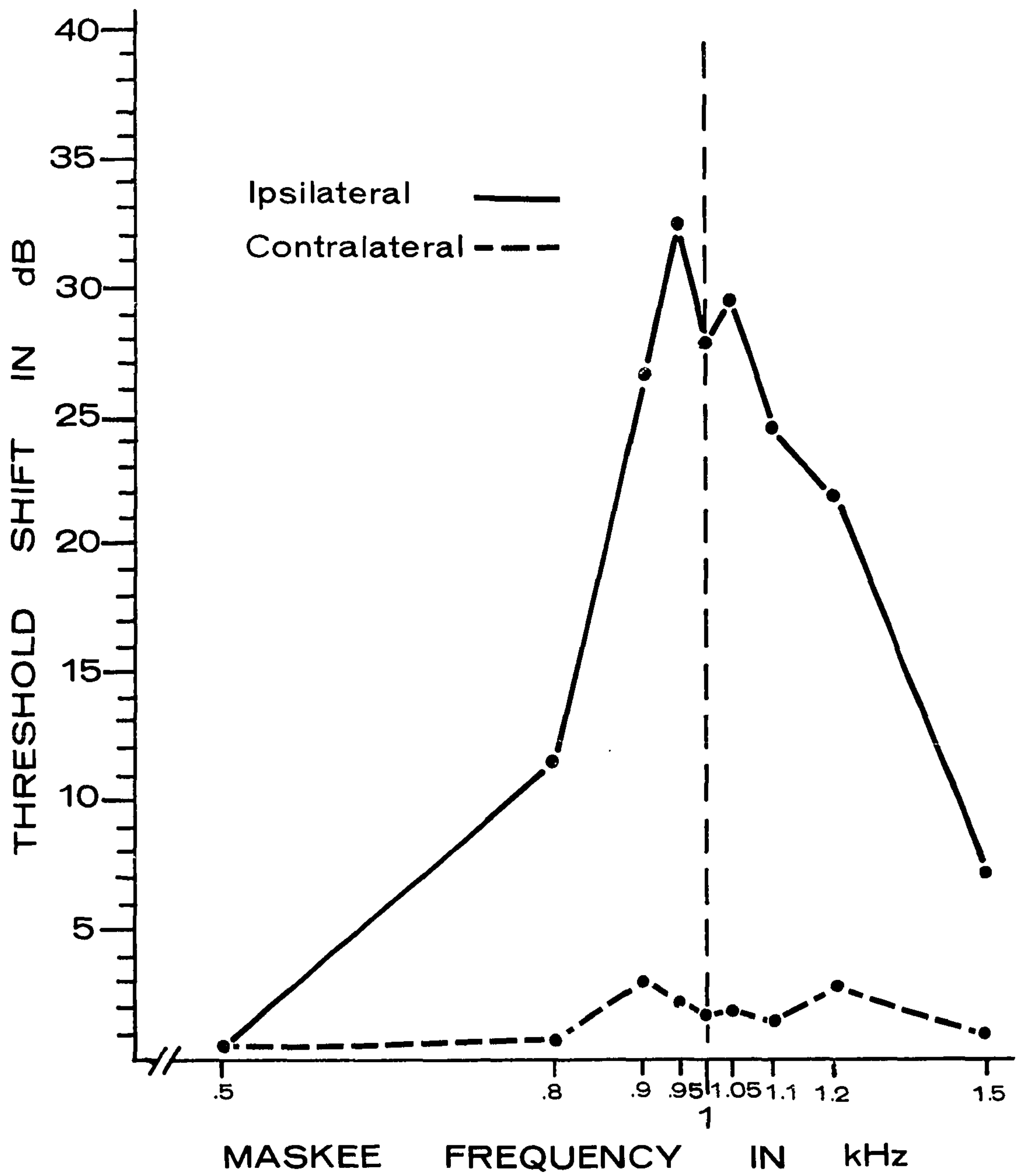

Figure 12. Ipsilateral and Contralateral masking patterns for Subject #2.

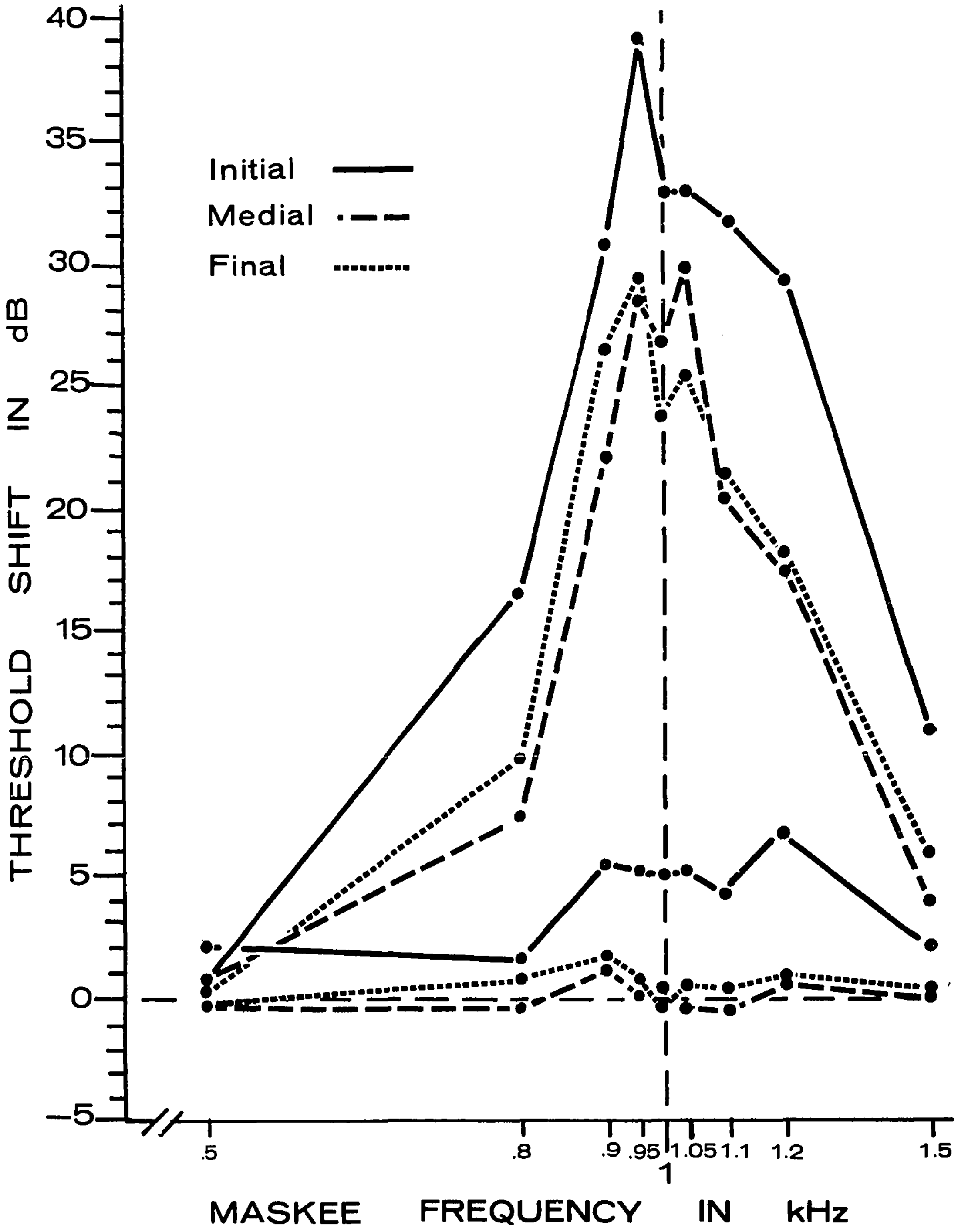

Figure 13. Ipsilateral (upper curves) and Contralateral (lower curves) masking patterns for Initial, Medial and Final positions for Subject #2.

Appendix D

Subject #3 Results

TABLE 15

SUBJECT # 3 DATA (CODED) FOR EACH EAR, MASKING CONDITION, FREQUENCY AND TEMPORAL DELAY

Masking Condition	Ear	Temporal Delay	Maskee Frequencies (Hz)								
			500	800	900	950	1000	1050	1100	1200	1500
Ipsilateral	R	initial	10.50	24.67	37.50	44.50	41.64	43.00	35.70	22.50	10.50
		medial	10.50	22.00	33.50	39.50	38.97	36.67	29.70	19.50	10.66
		final	10.50	24.34	37.67	39.67	40.14	41.00	33.00	22.50	11.50
	L	initial	10.33	19.16	35.33	39.66	40.63	44.17	31.67	16.50	11.33
		medial	10.67	16.00	29.00	36.50	34.80	37.00	29.67	12.50	10.83
		final	10.50	19.16	32.66	36.16	40.13	38.00	30.34	16.00	11.00
Contralateral	R	initial	11.17	10.67	13.83	11.33	9.67	13.50	14.66	11.16	11.66
		medial	10.50	10.00	13.50	10.17	11.17	13.00	10.16	11.00	10.16
		final	12.50	11.50	14.67	13.50	14.50	12.83	10.83	10.83	10.33
	L	initial	11.00	10.00	10.50	9.84	10.16	7.66	12.00	12.50	12.83
		medial	11.33	10.00	9.67	10.84	10.83	10.16	11.83	13.16	11.83
		final	12.67	11.00	10.50	11.17	13.50	10.16	12.33	13.66	10.83

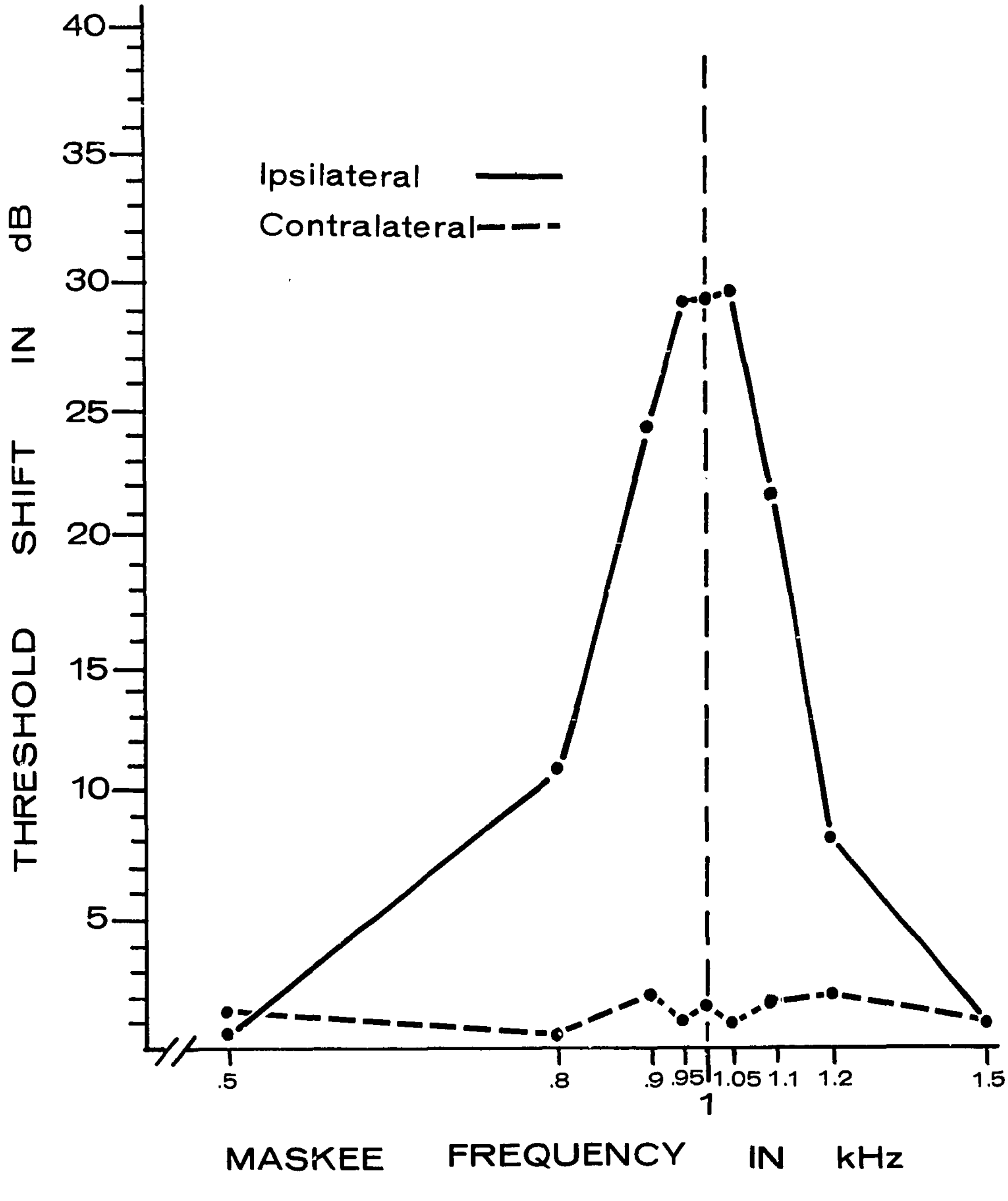

Figure 14. Ipsilateral and Contralateral masking patterns for Subject #3.

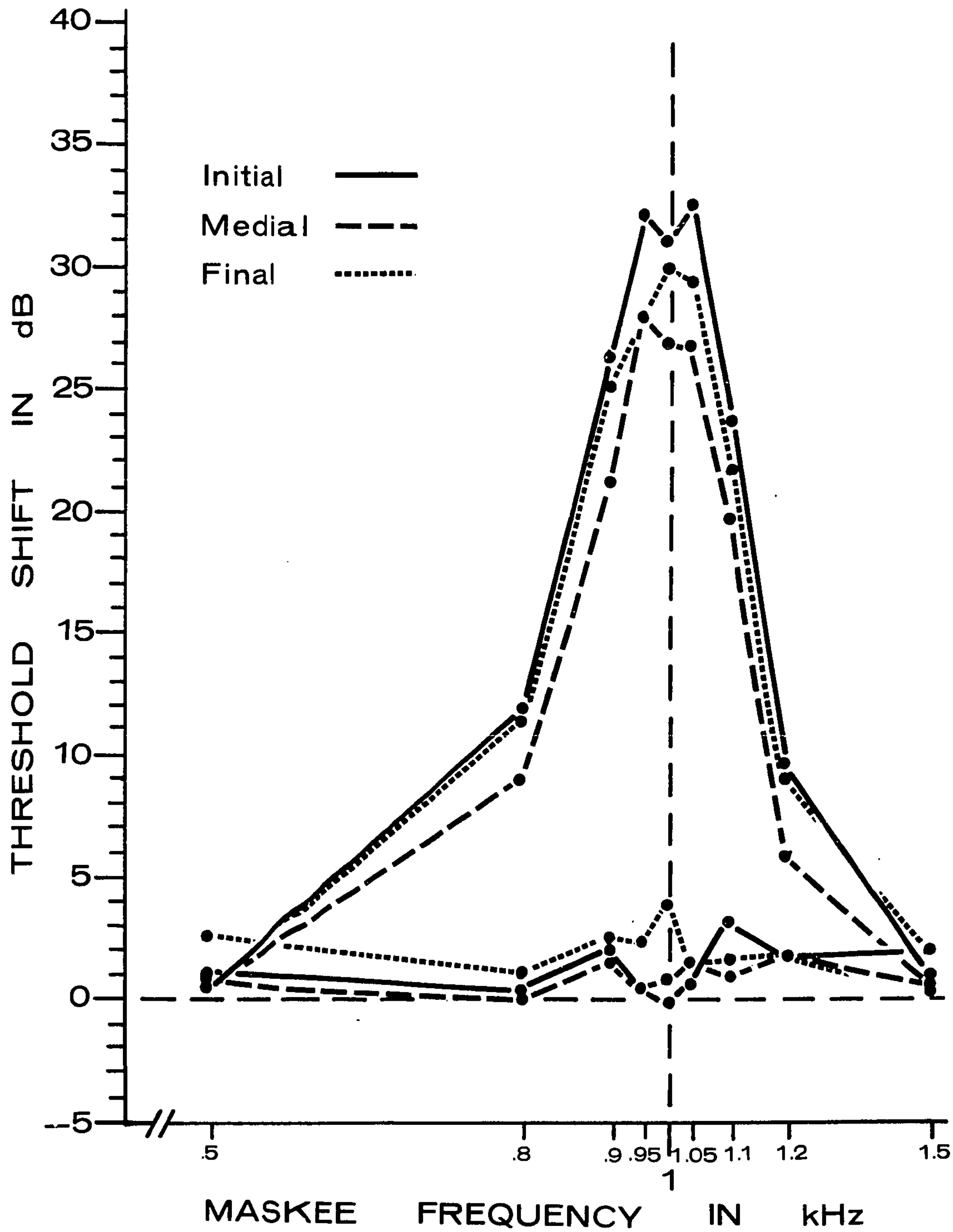

Figure 15. Ipsilateral (upper curves) and Contralateral (lower curves) masking patterns for Initial, Medial and Final positions for Subject #3.

Appendix E

Subject #4 Results

TABLE 16

SUBJECT # 4 DATA (CODED) FOR EACH EAR, MASKING CONDITION, FREQUENCY AND TEMPORAL DELAY

Masking Condition	Ear	Temporal Delay	Maskee Frequencies (Hz) 500	800	900	950	1000	1050	1100	1200	1500
Ipsilateral	R	initial	13.50	24.00	37.50	40.17	40.30	37.67	32.50	20.50	13.00
		medial	11.17	22.83	33.50	34.00	37.80	33.34	30.33	15.67	11.33
		final	10.84	21.66	32.67	40.83	39.80	36.67	30.43	18.67	10.66
	L	initial	14.50	19.67	37.16	38.83	41.30	41.66	32.66	25.17	21.66
		medial	11.00	18.34	32.16	33.50	33.63	31.50	29.83	21.83	13.00
		final	11.00	19.34	31.66	37.50	32.47	36.33	31.66	22.00	13.66
Contralateral	R	initial	13.16	17.84	18.33	18.50	19.17	18.16	18.50	13.33	12.33
		medial	10.16	9.50	10.50	12.00	10.83	12.50	12.34	10.17	11.50
		final	11.83	11.84	12.00	12.50	8.83	11.00	10.34	10.00	12.33
	L	initial	12.16	13.17	12.16	13.00	12.83	15.83	14.00	12.17	13.66
		medial	9.33	10.17	9.50	11.50	8.66	12.50	10.66	12.00	10.83
		final	9.66	10.34	9.33	11.83	9.03	12.33	10.83	10.50	10.16

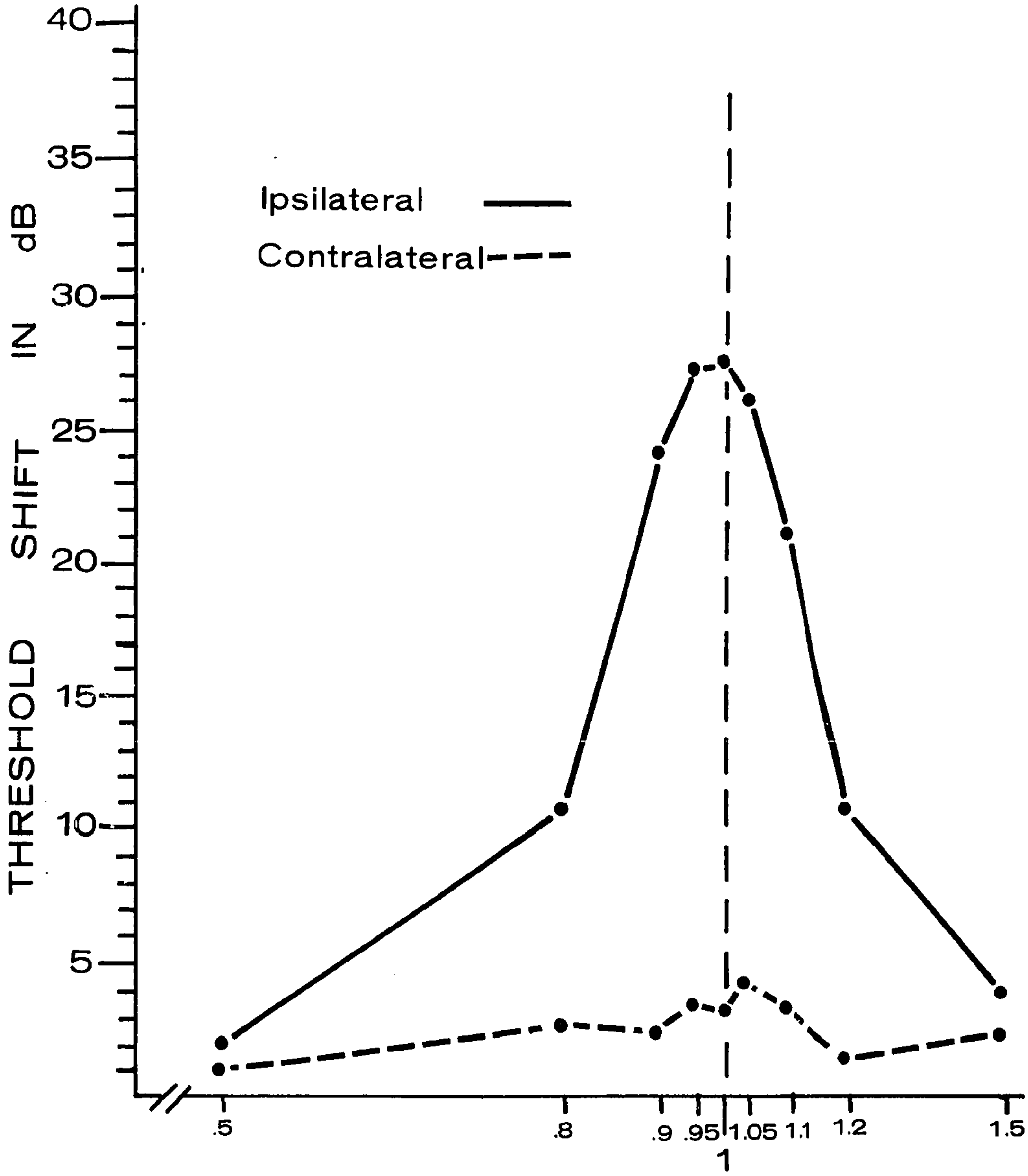

Figure 16. Ipsilateral and Contralateral masking patterns for Subject #4.

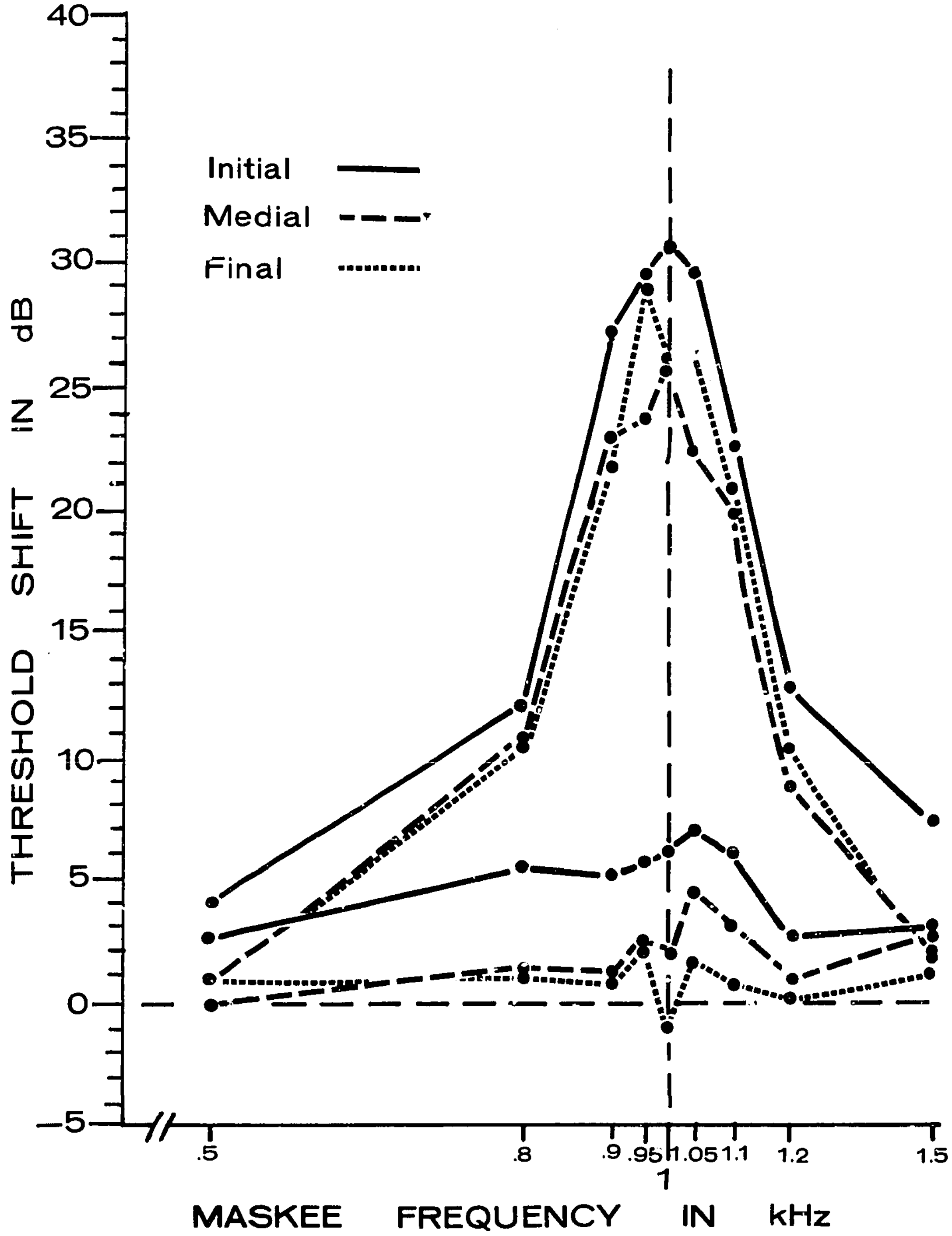

Figure 17. Ipsilateral (upper curves) and Contralateral (lower curves) masking patterns for Initial, Medial and Final positions for Subject #4.