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CHAPTER I

INTRODUCTION

Auditory masking is ". . . (1) the process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound . . . (2) the amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound" (Sonn, 1969).

The signal that causes a shift in the threshold of audibility for a second signal is called the masker. The signal for which a shift in the threshold of audibility occurs in the presence of a masker is called the maskee. If the masker and maskee are presented to the same ear, the signal condition is called ipsilateral masking. If the masker is presented to one ear and the maskee is presented to the opposite ear, the signal condition is called contralateral masking. The above conditions refer to the ear, or ears, to which the signals are directed and do not necessarily reflect the physiological processes involved.

Threshold shifts obtained in ipsilateral masking experiments represent peripheral masking that results from a conflict of stimuli in the cochlea. Threshold shifts obtained in contralateral masking experiments are not as simple to interpret physiologically as are those obtained in ipsilateral masking experiments. If the intensity of a contralateral masker is less than that required to cross to the opposite cochlea through or around the head (i.e., exceed interaural attenuation), the threshold shifts represent central masking that results from a neural interaction in the central auditory system. If the intensity of a contralateral masker is greater than that required to exceed interaural attenuation, threshold shifts may represent, at least in part, some peripheral masking effects due to direct stimulation of the test ear by the masker. The term central masking will be used in this dissertation only when it is reasonably certain that the masker did not exceed interaural attenuation.

Masking overshoot is the enhancement of masking efficiency for brief maskees located near the onset of the masker compared to the masking that occurs after the onset of the masker. Overshoot may occur under either ipsilateral or contralateral masking conditions.

Wegel and Lane (1924) investigated both ipsilateral and contralateral pure-tone masking over a wide range of intensities and frequencies. They concluded that ". . . there are two kinds of masking, central and peripheral, the former being generally small and resulting from the conflict of sensations in the brain and the latter originating from overlapping of stimuli in the end organ." Since 1924, many investigators have reported ipsilateral and/or contralateral masking experiments, but some problems remain to be studied. Further investigation of low-frequency pure-tone contralateral masking should provide useful information concerning differences between central and peripheral masking processes.

This experiment was designed to study and quantify several characteristics of low-frequency pure-tone contralateral masking. Certain specific masking effects were explored including the temporal effects of masking (overshoot, and pulsed versus steady-state masking), frequency spread of masking, and growth of masking. Selected ipsilateral masking conditions were included for comparison to the contralateral masking results of this experiment and to the ipsilateral masking results of other investigators.

A series of 200 Hertz (Hz) pure-tone maskers were presented at 10, 30, 50, and 70 decibels (dB) sensation level (SL) and both continuous (steady-state) and pulsed masking conditions were studied. The pulsed maskers were 500 msec in duration with a period of 3.5 seconds. The maskees were 30 msec tone bursts presented every 3.5 seconds during steady-state masking. The maskee was located near the masker onset or in the middle of the masker (pulsed-initial and pulsed-medial masking, respectively) during the pulsed masking conditions. Steady-state and pulsed-initial contralateral masking were investigated at maskee frequencies of 170, 230, 500, 750, 1500, and 1400 Hz. Pulsed-medial contralateral masking and all ipsilateral masking conditions were investigated at maskee frequencies of 230 and 4000 Hz only.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Since Wegel and Lane's experiment (1924), investigators have studied the effects of pure- and complex-tone maskers, narrow- and broad-band noise maskers, speech maskers, and click maskers. At least as many different types of maskee signals have been investigated. Temporal relations in masking have been researched in considerable detail including simultaneous masking, forward masking (masker preceeds maskee), and backward masking (maskee preceeds masker), as well as combinations thereof.

The results of most masking experiments may be partitioned into three categories: the effects of masker-maskee temporal relations; the effects of masker intensity (growth of masking); and the effects of masker-maskee frequency relations (frequency spread of masking).

Temporal Relations in Simultaneous Masking

Maskers may be presented continuously (steady-state masking) or periodically pulsed (pulsed masking). Similarly, maskees may be presented in steady-state or pulsed conditions. Most commonly, either the masker and maskee are simultaneously pulsed and of equal duration, or the masker is steady-state and the maskee is pulsed. Overshoot occurs whenever brief maskees are more effectively masked when they are located near the onset of pulsed maskers than when they are located after the masker onset.

Temporal Relations in Ipsilateral Masking

Dirks and Norris (1966) investigated ipsilateral masking under three different masker-maskee temporal patterns. The maskers and maskees were presented continuously, or pulsed simultaneously with 500 msec durations, or the maskers were steady-state and the maskees were pulsed with a duration of 500 msec. A broad-band noise masker was presented at either 60 dB SPL or 15 dB effective masking level for each maskee frequency of 250, 1000, and 4000 Hz. Approximately equal masking resulted for the two steady-state masker conditions at each of the masker intensities with either pulsed or steady-state maskees. Greater masking (2-5 dB) was noted when the maskers and maskees were simultaneously pulsed and of equal duration than for either of the remaining temporal conditions.

Steady-state versus simultaneously pulsed masking experiments with pulsed maskees yield several common features. First, from 2 to 12 dB greater masking results from simultaneously pulsed masking than from steady-state masking of comparable intensity (Sherrick and Mangabeira-Albernaz, 1961; Campbell, 1966; Green, 1966, 1969; Campbell and Lasky, 1967; Johnson, 1968). Second, the difference between steady-state and simultaneously pulsed masking is approximately the same over a wide range of masker intensities (Campbell, 1966, 1969; Dirks and Norris, 1966; Campbell and Lasky, 1967). Third, if simultaneously pulsed maskers and maskees are less than about 150 msec duration, these relations may not exist (Campbell and Lasky, 1967; Tucker, Williams, and Jeffress, 1968; Campbell, 1969).

Conflicting evidence exists concerning the frequency effects of steady-state versus simultaneously pulsed masking differences. Sherrick and Mangabeira-Albernaz (1961) and Dirks and Norris (1966) report that the difference between steady-state and simultaneously pulsed broad-band noise masking is less for low-frequency than for high-frequency maskees. This finding may be due, in part, to the fact that a constant-level broad-band noise produces greater masking for high-frequency maskees than for low-frequency maskees. However, Dirks and Norris (1966) and Johnson (1968) found that steady-state versus simultaneously pulsed masking differences were greater for high-frequency maskees than for low-frequency maskees when the noise maskers were adjusted to equal effective masking levels at the individual maskee frequencies. Campbell (1966) used pure-tone maskers and maskees of equal frequency and found that the difference between steady-state and simultaneously pulsed masking remain approximately the same at comparable sensation levels from 250 to 4000 Hz.

Temporal Relations in Central Masking

Dirks and Malmquist (1965) and Dirks and Norris (1966) investigated central masking with several masker-maskee temporal patterns. Broad-band noise maskers, narrow-band noise maskers, and pure-tone maskers were used with pure-tone maskees. Unlike ipsilateral masking experiments in which masking is approximately the same for either steady-state maskers and maskees or for steady-state maskers and pulsed maskees, these experiments yield from 1 to 7 dB greater masking for steady-state maskers and maskees than for steady-state maskers and pulsed maskees. Some instances were noted in which steady-state masking of steady-state maskees was approximately the same as simultaneously pulsed masking of pulsed maskees. Several investigators report that simultaneously pulsed maskers (broad-band noise, narrow-band noise or pure tones) result in from 2 to 7 dB greater central masking than do steady-state maskers with pulsed pure-tone maskees (Sherrick and Mangabeira-Albernaz, 1961; Dirks and Malmquist, 1965; Dirks and Norris, 1966; Johnson, 1968). These differences remain about the same over a wide range of masker intensities.

Differences between steady-state and simultaneously pulsed central masking for pulsed maskees decrease with decreasing maskee frequency when the masker is a constant-level broad-band noise (Sherrick and Mangabeira-Albernaz, 1961; Dirks and Norris, 1966). These differences are not as great, however, when the noise maskers are adjusted to equal effective masking levels at the individual maskee frequencies (Dirks and Norris, 1966; Johnson, 1968).

Overshoot

Overshoot may occur under certain experimental conditions where the maskers are generally greater than 250 msec in duration and the maskees are generally less than 50 msec in duration. The temporal location of the maskee is shifted in relation to the onset of the masker and overshoot occurs if the maskees require greater intensity to be detected when they are located near the onset of the maskers than when delayed from the onset.

<u>Overshoot in Ipsilateral Masking</u>. Ipsilateral masking over-

shoot occurs when any of a variety of signals are employed as maskers and maskees, including pure tones. Samoilova (1959) found that masking is about 10 dB more effective when brief 1380 Hz maskees are located near the onset of 90 dB SL, 1000 Hz pulsed maskers than when they are delayed from the masker onset by 120 msec. The maskee threshold remained relatively stable for delays from the masker onset of 120 to 260 msec. Similar findings have been reported by Deatherage and Evans (1969), Green (1969), and Lankford (1969).

Overshoot also occurs and ranges from about 10 to 15 dB when broad-band noise maskers are used with pure-tone maskees (Elliott, 1965; Zwicker, 1965a; Zwicker, 1965b; Wilbanks, 1967; Elliott, 1969). Overshoot does not occur for broad-band noise maskers and click maskees (Osman and Raab, 1963; Elliott, 1965; Wilson and Carhart, 1971) or when both maskers and maskees are broad-band noises (Zwicker, 1965a).

Narrow-band noise maskers yield conflicting results in overshoot experiments. von Scholl (1962) studied the masking of brief pure tones located in a frequency gap between two narrow-band noise maskers and reported that overshoot ranged from 11 to 18 dB. Elliott (1965) used narrow-band noise maskers centered at 250, 1270, and 2550 Hz to investigate overshoot for brief pure-tone maskees. Less than about 7 dB overshoot occurred when the maskees were contained within the frequency limits of the noise bands. The 1270 and 2550 Hz noise bands yielded greater overshoot for maskees located outside the frequency limits of the noise bands than for maskees contained within the frequency limits of the noise bands. Zwicker and Wright (1963) conducted an experiment similar to Elliott's and concluded that ". . . there is no systematic change in the threshold for (brief) tones both within and outside the noise band as a function of the time interval between noise and tone onset." In a more recent study, Zwicker (1965b) studied overshoot for pure-tone maskees with noise maskers that ranged from about 1 to 24 critical bands in width. Little or no overshoot occurred with the narrowest noise-band maskers but overshoot increased as the width of the noise-band maskers was increased, ultimately resulting in about 12 dB overshoot for the widest noise band.

The magnitude of overshoot is dependent upon the maskee duration. Zwicker (1965b) found that overshoot decreases from about 8 to 2 dB as the maskee duration is increased from 2 to 100 msec with all other signal conditions held constant. Further evidence of this effect may be inferred from a study performed by Wilbanks (1967) who investigated overshoot with broad-band noise maskers and 50 msec pure-tone maskees. He found consistantly less overshoot than reported by other researchers who used similar masker characteristics with maskee durations less than 25 msec.

Finally, overshoot may be more pronounced for high-frequency maskees than for low-frequency maskees with noise-band maskers. Elliott (1965) used 70 dB SPL broad-band noise maskers with pure-tone maskees from 200 to 6000 Hz and found that overshoot is greater for the high-frequency maskees than for the low-frequency maskees. Zwicker (1965a) used a 25 dB (spectrum level) broad-band noise masker and found that overshoot is greater for 5000 Hz maskees than for 1000 Hz maskees. These findings may be due simply to the influence of greater effective masking for high frequencies than for low frequencies with constant level broad-band noise maskers. On the other hand, they may represent a frequency effect independent of the effective masking concept.

Overshoot in Central Masking. Elliott (1965) reported the existence of central masking overshoot for narrow-band noise maskers and brief pure-tone maskees. Less than 5 dB overshoot occurred when the maskee frequency was either within or outside the frequency limits of the noise bands. Central masking overshoot, ranging from about 3 to 10 dB, has also been demonstrated for pure-tone maskers and maskees (Zwislocki, Damianopoulos, Buining, and Glantz, 1967; Zwislocki, Buining, and Glantz, 1968; Deatherage and Evans, 1969; Lankford, 1969).

Zwislocki, Buining, and Glantz (1968) studied central masking overshoot with 1000 Hz pure-tone maskees and pure-tone maskers from 300 to 2000 Hz. The magnitude of overshoot was directly related to the amount of masking that occurred for the maskees located near the masker onset. That is, if the threshold shift for maskees located near the masker onset is large, overshoot is also large. As expected, overshoot was greater when the masker approached the maskee frequency than when the two were distant from one another.

Time-Course of Overshoot. The above investigators report that masking of a brief pure tone reaches an asymptotic level after a delay from masker onset of from 100 to 300 msec for both ipsilateral and contralateral masking. Maximum masking occurs near the onset of the masker and decreases with further delays from the masker onset until a relatively stable threshold level is achieved.

Zwicker (1965b) suggests that the threshold of brief maskees located 300 msec after the onset of broad-band noise maskers ". . .

should be quite close to the value for continuous masking noise, which may be referred to as the steady-state condition." He verified this hypothesis by means of mathematical calculations and experimental procedures. Elliott (1969) used ipsilateral steady-state and pulsed-noise maskers with brief pure-tone maskees to investigate overshoot. The pulsed maskers were 1500 msec in duration with interstimulus intervals from 25 to 500 msec. Maskee thresholds were measured under steady-state masking and at various delays from the onset of the pulsed maskers. Steady-state masking yielded approximately the same threshold shifts as did pulsed masking when the maskee was located 250 msec after the masker onset for the 25 and 50 msec interstimulus intervals. When the interstimulus interval was increased to 500 msec, however, the thresholds for the maskee located 250 msec after the masker onset were from $2\frac{1}{2}$ to 5 dB greater than those yielded by steady-state masking presented at comparable levels. Lankford and Stokinger (1969) and Stokinger and Lankford (1969) reported that the threshold for pure-tone maskees located 500 msec after the onset of one second pulsed pure-tone maskers was less than that yielded by steady-state masking at comparable intensity levels. Therefore, Zwicker's hypothesis remains in doubt because of conflicting experimental findings.

Frequency Spread of Simultaneous Masking

Under certain conditions, a signal may cause masking at frequencies other than that of the masker. This phenomenon is called "spread of masking" and is most commonly determined by measuring unmasked and masked thresholds at many different frequencies. Thus, a graphic display of the frequency spread of masking is generated. A spread of masking function is dependent on the intensity and frequency characteristics of the masker as well as the temporal relation between the masker and maskee.

Frequency Spread of Ipsilateral Masking

Wegel and Lane (1924) studied the frequency spread of ipsilateral masking with pure-tone maskers from 250 to 3500 Hz at sensation levels from zero to above 80 dB. The maskees were pure tones from 150 to 5000 Hz and both maskers and maskees are assumed to have been presented in a steady-state condition. Wegel and Lane concluded that:

> A tone of a frequency much below the masking tone is not perceptibly masked for the lower range of intensities and hardly more than perceptibly so when the tones are very loud. A tone of much higher frequency than the masking tone is not perceptibly masked for the lower range of intensities, but rather definite high intensity masking occurs perceptibly and quickly becomes very great as the masking tone is increased. In general, masking is greater when the tones lie together.

Wegel and Lane's masking results have been substantiated by several other investigators (Ehmer, 1959; Small, 1959; Carter and Kryter, 1962). They found that increasing masker intensity results in increased masking, greater masking occurs when the maskee frequency is near that of the masker, and pure-tone frequency spread of masking functions are relatively symmetrical at low masker intensities, becoming less symmetrical with increased masker intensity.

The configuration of an ipsilateral spread of masking function is frequency dependent. Low-frequency maskers (below about 500 Hz) result in wider frequency spread of masking than do higher-frequency maskers at comparable sensation levels (Wegel and Lane, 1924; Ehmer, 1959; Carter and Kryter, 1962). Fletcher (1938) noted that ". . . the 200 cycle tone covers a much greater per cent of the total nerve endings than the 4000 cycle tone." Pestalozza (1954) concluded that, "In general, the lower the pitch of the masking tones, the greater is the masking effect." Small (1959), however, did not report such a trend. He studied this phenomenon by maintaining the maskee frequency and intensity at constant values while varying the masker frequency and intensity to achieve masking functions. Due to the different technique used in Small's experiment, it is difficult to compare his data to those of other studies.

Several investigators have studied very low-frequency ipsilateral spread of masking effects (Bekesy, 1960, p. 265; Finck, 1961; Jerger, Alford, and Coats, 1966). The masker frequencies ranged from 10 to 50 Hz and their intensities were less than 50 dB SL. Normal auditory threshold between these frequency limits range from about 75 to 90 dB SPL (Corso, 1958). Therefore, although rather low masker sensation levels were used in these studies, relatively high sound-pressure levels were generated. Each of the above investigators found that these maskers resulted in extremely broad spread of masking functions, and it was not uncommon to observe masking at 4000 Hz. The spread of masking functions obtained in these studies are much wider than even those resulting from 200 to 500 Hz maskers.

Frequency Spread of Central Masking

Wegel and Lane (1924) studied contralateral masking with 1200 Hz pure-tone maskers at sensation levels from zero to above 100 dB. Both maskers and maskees are presumed to have been presented in a steady state. The authors concluded that "if the masking tone is introduced into the opposite ear, no appreciable masking occurs until the intensity is sufficient to reach the listening ear through the bones of the head." However, they also stated that "central masking is probably always present to a certain extent . . . ." Hughes (1940) studied pure-tone central masking and concluded that "the monaural threshold is unaffected by contralateral audible stimuli for intensities of the latter up to 15 dB above their threshold. This holds for notes differing considerably in pitch, but there is a rise in threshold when the notes are in unison." Hughes reported about 9.5 dB central masking when both maskers and maskees were 1000 Hz when the masker was presented at 15 dB SL.

Ingham (1959) studied the frequency spread of central masking with 200, 400, 840, and 1000 Hz pure-tone maskers presented at 30 dB SL. Both the maskers and the maskees were presented in a steady state. The 400, 840, and 1000 Hz maskers yielded spread of masking functions that were symmetrical about the masker frequency and relatively narrow in width. The 200 Hz masker, however, yielded a very broad masking curve with approximately 6 dB masking occurring at 230 Hz and about 3.5 dB masking occurring at 3900 Hz. Other investigators who used mid- and high-frequency maskers have also shown that the frequency spread of central masking is symmetrical about the masker frequency, possesses a narrow frequency range, and yields maximum masking at maskee frequencies near that of the masker (Wegel and Lane, 1924; Dirks and Norris, 1966; Zwislocki, et al., 1967; Zwislocki, Buining, and Glantz, 1968; Lankford, 1969).

Growth of Simultaneous Masking

Growth of masking is the increase in threshold shifts resulting from increases in the masker intensity. Only studies in which more than two masker intensity levels were used are reviewed in this section since it is necessary to investigate a wide range of masker intensities to describe growth of masking characteristics.

Growth of Ipsilateral Masking

Growth of masking for pure-tone maskees with broad-band noise maskers is linear with a slope of one for effective masking levels from 10 dB to above 80 dB (Hawkins and Stevens, 1950; Dirks and Norris, 1966). This indicates that for every unit of masker intensity increase the maskee intensity must be raised one unit in order to maintain detection. The growth of ipsilateral masking is similar in slope for either steady-state or simultaneously pulsed broad-band noise maskers with pulsed pure-tone maskees (Dirks and Norris, 1966). Zwicker (1965a) also noted a linear growth of masking function with a slope of one for brief pure-tone maskees located at delays of either 2 or 200 msec from the onset of pulsed broad-band noise maskers.

Growth of masking for pure-tone maskees contained within the frequency limits of narrow-band noise maskers is also linear with a slope of one when both maskers and maskees are steady state (Carter and Kryter, 1962), when the maskers are steady state and the maskees are pulsed (Egan and Hake, 1950; Campbell, 1969), and when the maskers and maskees are simultaneously pulsed (Campbell, 1969).

Growth of masking functions for pure-tone maskers and maskees are more complex than are those for noise maskers and pure-tone maskees.

If the maskee frequency is near but not equal to that of the masker, growth of masking is relatively linear with a slope of approximately one from masker sensation levels of from 10 dB to about 70 or 80 dB when both maskers and maskees are steady-state (Wegel and Lane, 1924; Carter and Kryter, 1962) and when the maskers are steady state and the maskees are pulsed (Egan and Hake, 1950; Ehmer, 1959). At masker sensation levels higher than 70 or 80 dB, a decrease in the slope of the growth of masking function is observed.

Detection of a maskee in the presence of a masker of the same frequency may be considered either a masking task or an intensity difference-limen task. Harris (1963) investigated this topic at some length and the interested reader is referred to his monograph for further information. Growth of masking for pure-tone maskers and maskees of the same frequency is relatively linear with a slope slightly less than one for steady-state maskers and pulsed maskees (Campbell, 1966; Campbell and Lasky, 1967). A growth of masking slope less than one indicates that for every unit increase in masker intensity the maskee intensity must be elevated by less than one unit to maintain detectibility. These investigators also noted that simultaneously pulsed maskers and maskees of equal frequency yield a relatively linear growth of masking function with a slope even less than that found for steady-state maskers and pulsed maskees.

If the maskee frequency is significantly higher than that of the masker, relatively little masking results for low-intensity maskers while high level maskers may result in maskee threshold shifts greater than the increments of masking employed. If the maskee frequency is significantly lower than that of the masker, little or no masking is observed even at relatively high masker intensities, except in the case of remote masking that occurs under certain unique conditions.

Growth of Central Masking

Sherrick and Mangabeira-Albernaz (1961) investigated growth of central masking with steady-state and simultaneously pulsed broad-band noise maskers of from 50 to 90 dB SPL and 1000 Hz pulsed pure-tone maskees. A relatively linear growth of masking function was noted for simultaneously pulsed masking with an approximate 8 dB threshold shift resulting over the 40 dB range of masker intensities. Steady-state masking yielded a linear growth of masking function with a slope slightly less than that observed for simultaneously pulsed masking. Dirks and Norris (1966) reported similar findings for broad-band noise maskers and pure-tone maskees when both were steady state, when both were simultaneously pulsed, and when the maskers were steady state and the maskees were pulsed. The growth of masking slopes varied slightly with changes in masker-maskee temporal relations.

Growth of central masking is relatively linear for narrow-band noise maskers and pure-tone maskees (Dirks and Malmquist, 1965). Masker-maskee temporal variations affect the slope of the growth of masking function as is the case for broad-band noise maskers.

Zwislocki, et al. (1967) studied several aspects of the growth of central masking with pure-tone maskers and maskees. The growth of central masking for pulsed 1000 Hz pure-tone maskers and brief 1000 Hz maskees located near the masker onset was linear from 20 to 60 dB SL. Approximately 10 dB masking resulted over the 40 dB range of masker intensities, comparing favorably with the central masking obtained by Sherrick and Mangabeira-Albernaz (1961). The growth of central masking for steady-state 1000 Hz maskers and brief 1000 Hz maskees differed considerably from that described above. Maskee thresholds were observed to increase slightly with increases in steady-state masking from 10 to 40 dB SL remaining stable thereafter or decreasing with additional masker intensity increases up to 80 dB SL. No greater than 3 dB central masking was found under any of the steady-state masker conditions regardless of intensity.

Factors Affecting Masking Experiments

The literature reviewed in this section is primarily concerned with theoretical and methodological factors related to masking experiments. These areas are presented in support of the use of certain techniques and procedures in the design and execution of this experiment.

Interaural Attenuation

Presentation of a signal to one ear at successively increasing intensities will ultimately result in stimulation of the opposite ear due to the signal crossing through or around the head. Interaural attenuation for normal-hearing subjects is the decibel difference between the intensity of a signal presented to one ear that is just barely sufficient to stimulate the opposite ear and the threshold for that signal when presented directly to the opposite ear. Peripheral stimulation of the test ear will occur in contralateral masking experiments if interaural attenuation is exceeded by the masker intensity.

A survey of interaural attenuation studies reveals that minimum interaural attenuation values of about 40 dB are obtained at 250 Hz with average values being somewhat higher (Sparrevohn, 1948; Tschiassny, 1952; Zwislocki, 1953; Palva, 1954; Miller, 1959; Liden, Nilsson, and Anderson, 1959; Gyllencrentz and Liden, 1966; Chaiklin, 1967). Therefore, it may be assumed that minimum interaural attenuation at 200 Hz is approximately 40 dB for any subject. Contralateral maskers less than 40 dB SL, therefore, are presumed to have no direct masking effect on the test ear.

Masking over Time

Ipsilateral Masking over Time. Egan (1955) investigated ipsilateral masking over time with a steady-state 1000 Hz, 90 dB SPL masker and 1100 Hz pulsed maskees. Continuous masking was maintained for seven minutes and the subject (N=1) adjusted the maskee intensity during 15 second periods to yield threshold at the onset of the masker and each minute thereafter. No change in ipsilateral masking was observed throughout the seven-minute exposure duration. Thwing (1956) found little or no change in pure-tone ipsilateral masking over a six-minute period of time when experienced subjects were utilized. Noffsinger (1968) used three-minute steady-state pure-tone maskers (500 and 3000 Hz) at 40, 65, and 90 dB SPL to study masking over time. Pulsed-maskee thresholds at 200 and 2000 Hz, respectively, did not change significantly during the three-minute masker stimulation.

These experiments suggest that ipsilateral steady-state masking does not shift over time, at least for the masker durations and intensities investigated.

Central Masking over Time. The only available data concerning central masking changes over time are reported by Zwislocki, et al. (1967). The maskers were 250 msec pure tones of either 600 or 950 Hz presented once every second. The maskees were brief 1000 Hz pure tones located near the masker onset. When the masker frequency was distant from that of the maskee, no change in central masking was observed over 10 minutes of stimulation. When the masker frequency was close to that of the maskee, however, masked thresholds improved by approximately 4 dB (i.e., less effective masking) during the first four minutes of masker stimulation remaining stable thereafter until termination of the 10 minute exposure. The authors termed this shift in central masking over time "slow decay of central masking".

Ipsilateral and contralateral masking over time was investigated in a pilot study performed with two subjects prior to this experiment. The steady-state maskers were 200 Hz in frequency and were presented at 90 dB SPL. The maskees were 230 Hz pure-tones of 30 msec duration from beginning of onset to termination of offset and were presented once every four seconds. A forced-choice transformed up-and-down tracking procedure (Levitt, 1971) was used during at least 13 minutes of masker stimulation. No systematic change in ipsilateral or contralateral masking was noted for either of the subjects over the stimulation period. In addition, no systematic changes in ipsilateral or contralateral masking over time were noted in the main experiment regardless of the masker-maskee temporal relations or the masker intensities utilized.

Determination of Auditory Thresholds

Well-practiced listeners are often used in psychoacoustic experiments in an effort to reduce intra-subject variability and, to some extent, inter-subject variability. Zwicker (1965a) noted that "It . . . was found that untrained people measure more 'overshoot' in relation to the results of the same people having some experience." Because of the difficulties experienced in other experiments with unsophisticated subjects, all subjects in this experiment were practiced in the threshold determination tasks under a representative set of experimental conditions until acceptable performance was obtained.

Many of the experimenters who have investigated masking phenomena used the Bekesy tracking method to facilitate rapid data acquisition thereby allowing the study of the greatest number of experimental parameters in a reasonable period of time. Smedely (1969) investigated contralateral masking with three different psychophysical methods including Bekesy tracking, a modified ascending method of limits, and a two-interval forced-choice tracking method. The Bekesy tracking method consistently yielded greater central masking than did the two other methods and Smedely concluded that ". . . the greater shifts observed with the (Bekesy tracking method) were presumed to result from non-auditory influence associated with performance variables of the listeners . . ."

Smedely's findings suggest that the Bekesy tracking method results in an inflated estimate of central masking. Therefore, a transformed up-and-down psychophysical method, recently described by Levitt (1971), was chosen as the psychophysical procedure by which auditory thresholds would be determined in this experiment. There are several advantages to this method. First, since discreet observation intervals including listen and respond lights are used in this method, it was assumed that the subjects' attention to the task would be less inclined to wander than during a Bekesy tracking task. Second, auditory thresholds obtained with this procedure (i.e., the mean value of attenuator reversal points) are representative of an approximate 70 per cent correct signal detection probability instead of the 50 per cent probability yielded by a simple up-and-down method. This is important when it is noted that the a priori probability of correct response in a one-interval forced-choice paradigm is 50 per cent. Third, this method allows the experimenter to alter the intensity steps according to need; that is, each threshold run was initiated with the use of 3 dB intensity steps. After one or two attenuator reversals, the intensity steps were reduced to 2 dB and finally to 1 dB. This procedure resulted in a more rapid convergence to the threshold value than would be the case with one decibel steps.

A simple forced-choice up-and-down psychophysical method requires that signal attenuation be increased after every "yes" response and decreased after every "no" response. A "yes" response indicates that the subject detected the signal during the observation interval. The transformed up-and-down method used in this experiment requires that signal attenuation be increased only after the subject detects the signal in two consecutive observation intervals. If the subject does not detect the first signal after an attenuation change, attenuation is decreased and a new series of signal presentations is started. If the subject detects the first signal after an attenuation change but does not detect the second signal, attenuation is decreased and a new series of signal presentations is started. The subject's responses to a series of observation intervals result in attenuation changes which are composed of ascending and descending runs of discrete intensity increments. The 70 per cent correct signal detection level is calculated as the mean of a predetermined number of ascending and descending reversal points of the attenuator. This value is defined in this experiment as the auditory threshold for a stimulus.

Definition of Research Questions

This review of the literature has prompted a delineation of several questions on which the design of this experiment is based. These areas encompass parameters of importance to any masking study including temporal relations in contralateral masking, frequency spread of contralateral masking, and growth of contralateral masking. The primary purpose of this experiment is to study several specific aspects of low-frequency contralateral masking that are expected to yield information of pertinence to further knowledge of central masking phenomena.

Temporal Relations in Masking. Experiments in which steady-state versus simultaneously pulsed masking was studied suggest that these masking differences decrease as the masker and/or maskee frequency is decreased. On the basis of this indirect evidence, it is hypothesized that the magnitude of overshoot decreases with decreasing masker and/or maskee frequency. Overshoot studies utilizing low-frequency maskers have not been reported but there is limited evidence showing that overshoot with noise maskers decreases with decreasing maskee frequency. This experiment is designed to investigate contralateral and ipsilateral masking overshoot with a low-frequency pure-tone masker.

Conflicting experimental findings are noted when steady-state masking is compared to pulsed masking with brief pure-tone maskees located from 200 to 500 msec after the pulsed masker onset. This experiment is also designed to investigate pulsed-medial versus steady-state low-frequency ipsilateral and contralateral masking at several masker intensities.

Frequency Spread of Contralateral Masking. Ipsilateral masking experiments commonly yield broader frequency spread of masking functions for low-frequency maskers than for higher-frequency maskers. Only one investigator (Ingham, 1959) has reported an investigation of this aspect of central masking. Ingham found that a 30 dB SL low-frequency contralateral masker resulted in a significantly broader frequency spread of masking than did maskers of higher frequency. The effects of masker-maskee temporal relations on low-frequency spread of masking has not been reported. This experiment is designed to investigate the spread of low-frequency contralateral pulsed and steady-state masking in an effort to determine the conditions under which a broad spread of masking function results.

Growth of Contralateral Masking. Most ipsilateral and contralateral masking experiments show that growth of masking is linear regardless of the masker-maskee temporal relations used. Zwislocki, et al. (1967), however, noted that the growth of steady-state contralateral masking of brief pulsed maskees is not linear and reaches a plateau at rather low masker intensities. In fact, a negative growth of masking function was observed for masker intensities above 40 dB SL. This study is designed to investigate the growth of low-frequency ipsilateral and contralateral steady-state and pulsed masking.

CHAPTER III

INSTRUMENTATION AND PROCEDURES

Introduction

This experiment was designed to investigate several aspects of low-frequency contralateral masking. This was accomplished by evaluating the influence of masker intensity at six maskee frequencies for three masker-maskee temporal patterns. A 200 Hz pure-tone masker was used throughout the experiment. The masker was presented at intensities of 10, 30, 50, and 70 dB sensation level in both steady-state (continuous) and pulsed conditions. Ipsilateral steady-state and pulsed masking was also investigated for the purpose of comparison with the contralateral masking results of this experiment and with the ipsilateral masking results of other investigators.

All maskees were brief pure tones. The contralateral maskee frequencies were 170, 230, 500, 750, 1500, and 4000 Hz and the ipsilateral maskee frequencies were 230 and 4000 Hz. Maskees were situated at the onset or in the middle of the pulsed maskers.

The four subjects in this experiment were given extensive practice with representative experimental conditions prior to beginning the experimental sessions. A transformed up-and-down psychophysical method was used for the determination of unmasked and masked auditory thresholds.

Subjects

Four normal-hearing graduate students (two male, two female) voluntarily served as subjects for this experiment. All subjects were drawn from the student body of the Department of Communication Disorders, University of Oklahoma Health Sciences Center. Each subject was compensated at the rate of two dollars ($2.00) per hour. The mean subject age was 28 years, 1 month with a range from 25 years, 7 months to 30 years, 11 months.

All of the subjects evidenced pure-tone air-conduction thresholds less than 20 dB (ANSI, 1969) in each ear at standard test frequencies from 125 to 4000 Hz. In addition, all subjects evidenced pure-tone air conduction thresholds at 200 Hz that were no more than 4 dB greater for one ear than for the other ear. The female subjects were not in menstruation during either the practice or the experimental sessions. All subjects successfully completed an extensive practice regimen prior to being entered into the experiment. It was required that each subject exhibit stable and reliable performance over a range of tasks that were representative of those required in the experiment.

Signal Conditions

All subjects received the entire set of experimental conditions. The order of presentation of the experimental conditions was either counterbalanced among subjects, randomly selected, or ordered, as explained in the Procedures section of this Chapter. A summary of the experimental conditions is presented in Table 1.

TABLE 1

EXPERIMENTAL CONDITIONS

	Maskee Frequency (Hz)					
	170	230	500	750	1500	4000
Masker	C	C,I	C	C	C	C,I
Temporal Pattern	PI	PI	PI	PI	PI	PI
		PM				PM
	SS	SS	SS	SS	SS	SS
Masker Intensity (dB SL)	NM	NM	NM	NM	NM	NM
	10	NM	10	10	10	NM
	30	NM	30	30	30	NM
	50	10	50	50	50	10
	70	30	70	70	70	30
		50				50
		70				70

LEGEND

C = Contralateral masker

I = Ipsilateral masker

PI = Pulsed-initial masking

PM = Pulsed-medial masking

SS = Steady-state masking

NM = No masking (threshold in quiet)

Maskers

The maskers were 200 Hz pure tones presented at sensation levels of 10, 30, 50, and 70 dB. Both steady-state and pulsed maskers were used in this experiment. All maskers had rise-decay times of 10 msec as measured between the 10 and 90 per cent points of maximum amplitude. The pulsed maskers were 500 msec in duration exclusive of rise-decay segments. The interval between successive pulsed maskers was approximately $3\frac{1}{2}$ seconds. The maskers were low-pass filtered in order to reduce harmonic distortion. The filter had a cut-off frequency of 200 Hz and a filter slope of 48 dB per octave.

Maskees

The maskees were brief pure tones at 170, 230, 500, 750, 1500, and 4000 Hz. All maskees had 10 msec rise-decay times as measured between the 10 to 90 per cent points of maximum amplitude. The maximum amplitude duration of the maskees was only one or two msec exclusive of rise-decay segments. Oscilloscopic calibration yielded a signal that was 30 msec in duration from the beginning of onset to the termination of offset. A pure-tone signal with these temporal characteristics is not expected to generate transient distortion at the earphone. No such distortion was detected by the subjects or by several other sophisticated listeners and the maskees retained a definite tonal quality at all frequencies.

Maskees were presented at 3.5 second intervals during steady-state masking, as illustrated in Figure 1A. Maskees were presented either near the pulsed masker onset or in the middle of the pulsed maskers, as illustrated in Figures 1B and 1C, respectively. Pulsed-

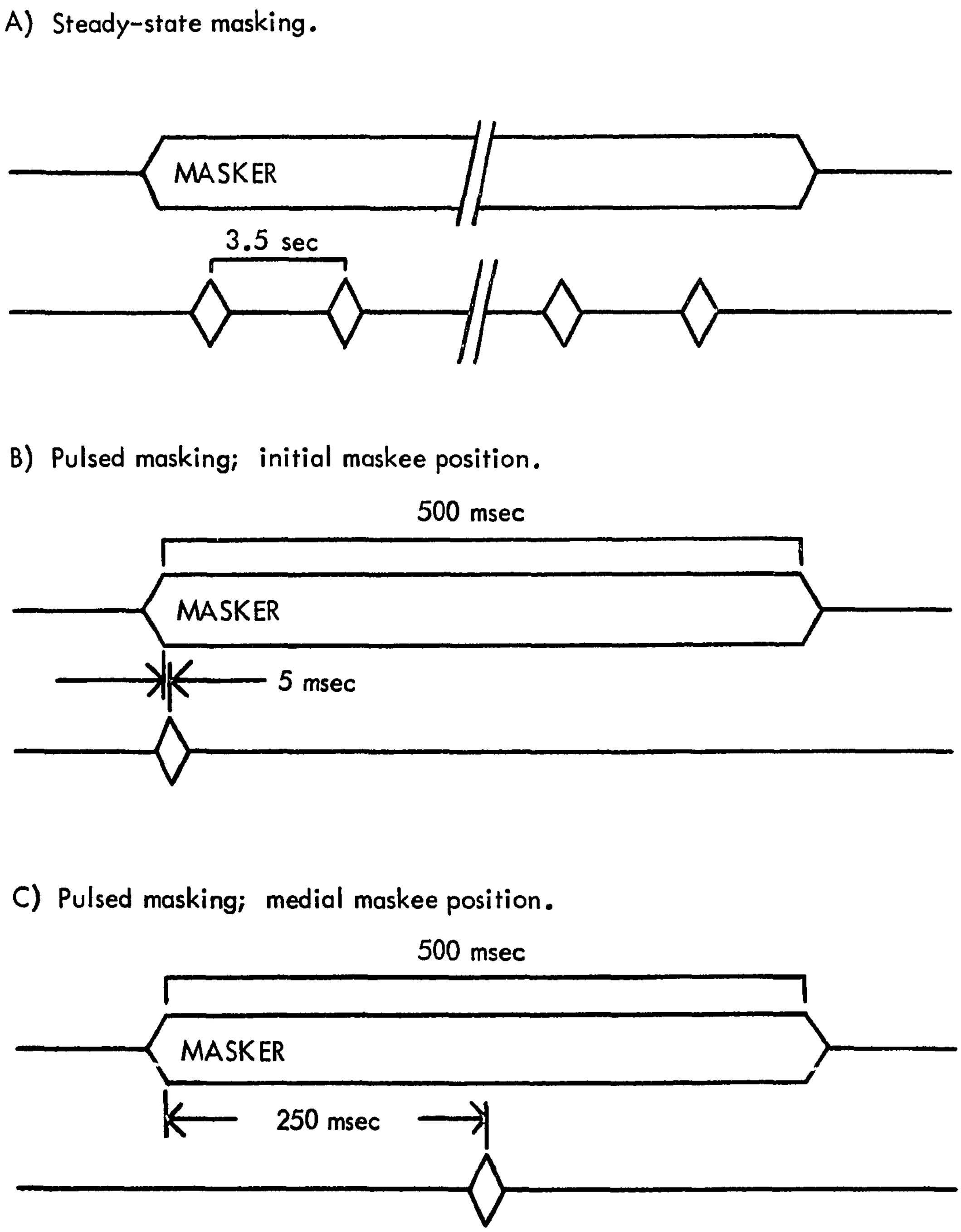

Figure 1.--Schematic illustration of the experimental masker-maskee temporal relations.

initial masking was defined in such a way that the point of maskee maximum amplitude was delayed 5 msec from the onset of masker full amplitude. Pulsed-medial masking was defined in such a way that the point of maskee maximum amplitude was located equidistant from the onset and offset of the masker (delayed from the masker full-amplitude onset by 250 msec).

In order to assess normal subject variability for a series of unmasked threshold determinations, three unmasked thresholds were determined, ipsilaterally and contralaterally (see Table 1), prior to introduction of the masker at maskee frequencies of 230 and 4000 Hz. This information was used to define the threshold shift beyond which masking is considered to be statistically significant.

Contralateral Masking. All of the maskee frequencies were used to assess the effects of 200 Hz contralateral maskers at four intensities with several masker-maskee temporal relations. The maskee frequencies of 170 and 230 Hz were low-pass filtered to reduce harmonic distortion (cut-off frequencies of 170 and 230 Hz, respectively, with a filter slope of 36 dB per octave). This was particularly important for the low-frequency maskees since their harmonics occur at frequencies where the human ear is more sensitive than it is at the fundamental frequency. The range of maskee frequencies in this experiment was chosen on the basis of a pilot study that showed it to be sufficient to sample the spread of contralateral masking under these masker conditions.

All maskee frequencies were investigated under steady-state and pulsed-initial contralateral masking conditions. Maskee frequencies of 230 and 4000 Hz were also investigated under the pulsed-medial masking condition. The initial maskee position was chosen to measure the frequency spread of contralateral masking based on the expectation that masking would be greatest for this temporal condition as opposed to the other temporal conditions. The medial maskee position was investigated at 230 and 4000 Hz in order to measure overshoot and compare pulsed-medial versus steady-state masking at maskee frequencies where greater (230 Hz) and lesser (4000 Hz) magnitudes of masking were expected.

Ipsilateral Masking. Ipsilateral masking was investigated at 230 and 4000 Hz. The 230 Hz maskees were low-pass filtered at 36 dB per octave. Ipsilateral masking was included to provide comparison data to the contralateral masking results of this experiment and to the findings of other investigators. These maskee frequencies were chosen to represent near-maximum and near-minimum ipsilateral masking effects of a 200 Hz masker.

Both ipsilateral maskee frequencies were investigated under steady-state, pulsed-initial, and pulsed-medial masking conditions, allowing the study of overshoot and pulsed versus steady-state masking.

Apparatus

Acoustic Environment

This experiment was conducted at the facilities of the Audiology and Speech Pathology Service, Veterans Administration Hospital, Oklahoma City, Oklahoma. All tests were conducted in a sound-deadened room (Industrial Acoustics Co., Model 400). The ambient noise level in this room was measured at the approximate location of the subjects' head with a sound level meter (General Radio Co., Type 1551-C) and octave band noise analyzer (General Radio Co., Type 1558-AP). The octave band ambient noise levels were found to be well below those that would cause masking at zero hearing level (ANSI, 1969) from 125 to 4000 Hz under TDH-39 earphones in MX-41/AR cushions as held by a standard headband.

The test room contained the experimental headphones and subject response switch. All other apparatus was located outside of the test room. Verbal communication between the experimenter and the subjects was not allowed during experimental sessions. Between sessions, however, the test room door was opened to permit the subjects to ask questions or comment about the previous session.

Instrumentation

The instrumentation described in this section was identical for practice and experimental sessions. Figures 2, 3, 4, and 5 show simplified schematic illustrations of the apparatus.

The masker was generated by an audio oscillator (Hewlett-Packard, Model 200 ABR) and led directly to an electronic switch (ES3; Grason-Stadler, Model 829 C) as illustrated in Figure 2. The ES3 was triggered on and off by the timing network. The masker was led from the output of ES3 to the input of a filter system with a cut-off frequency of 200 Hz and filter skirts sloped at 48 dB per octave (Krohn-Hite, Model 3202 R). The output lugs of ES3 were paralleled with a 600 ohm resistive load as recommended by the manufacturer. The signal was routed from the output of the filter to the input of a line amplifier (Altec, Model 436 C; compression circuit not active) and from the 600 ohm output of the amplifier to a 600 ohm attenuator network (Hewlett-Packard, Model 350 D). The masker was then led from the output of the attenuator through an impedance matching transformer (United Transformer

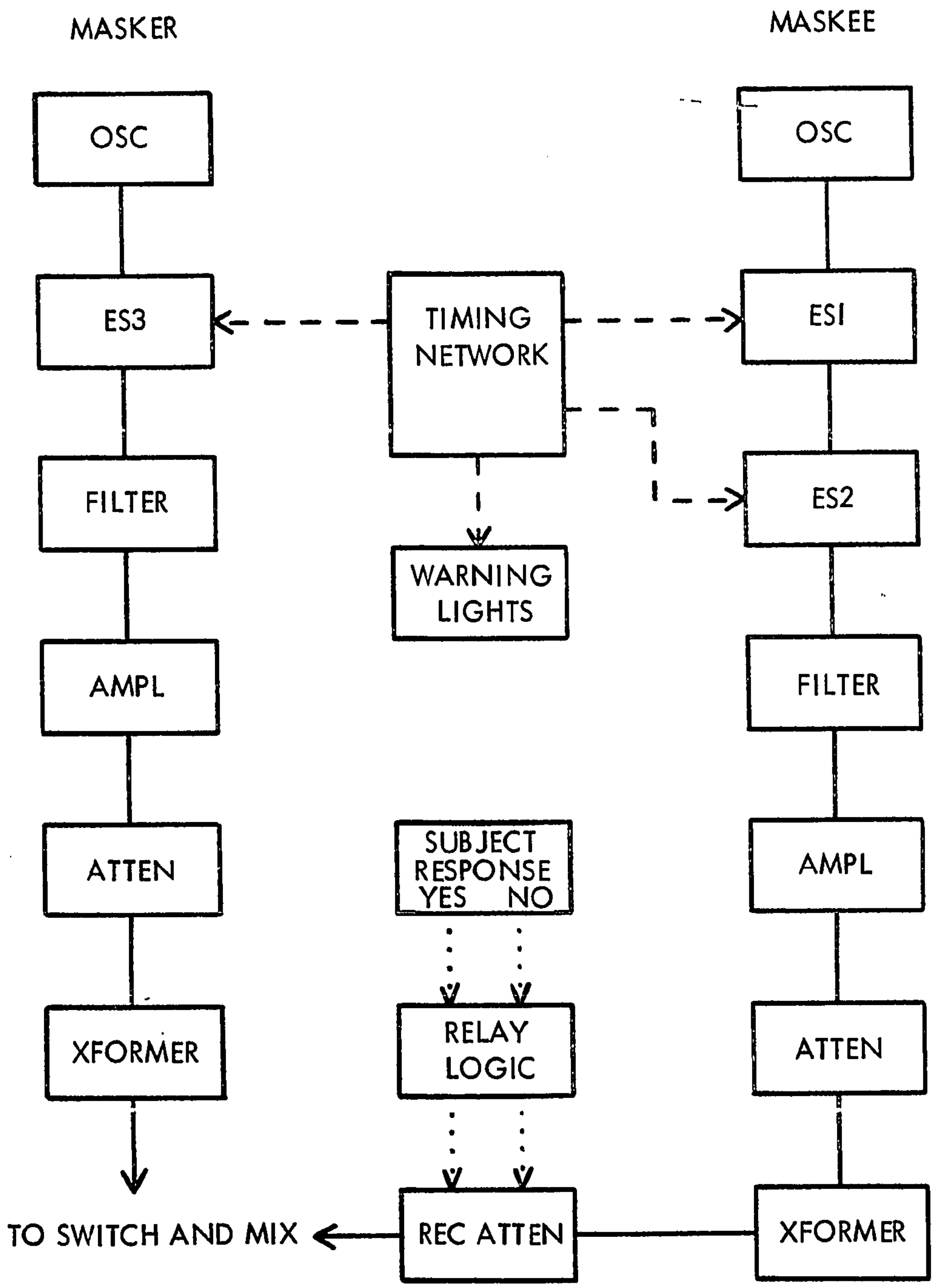

Figure 2.--Schematic illustration of the experimental apparatus.

Corp., Model LS 32) to a 10 ohm custom-built switching-mixing network (See Figure 3). The masker was led from the switching-mixing network to either the left or right earphone for contralateral or ipsilateral masking, respectively. The earphones used in this experiment were a new matched pair of Telephonic TDH 39 transducers contained in MX-41/AR cushions and held by a standard earphone headband.

The maskees were generated by an audio oscillator (Hewlett-Packard, Model 200 ABR) and led directly to two electronic switches connected in series (ES1 and ES2; Grason-Stadler, Models 829 C and 829 S, respectively) as illustrated in Figure 2. ES1 and ES2 were triggered on and off by the timing system. According to manufacturer's instructions, the maximum-amplitude duration of a signal being switched by a single electronic switch must be at least six times the duration of the rise time in order to maintain optimum switching and amplitude characteristics. In this experiment, the duration of the maskees at maximum amplitude was only one or two msec and the rise time was 10 msec. Therefore, this rule would be violated if only one electronic switch was used to switch the maskee on and off. To avoid this problem, two electronic switches (ES1 and ES2) were connected in series. The ES1 permitted the signal to pass for a duration sufficient to allow optimum performance. The signal entered ES2 that had been activated previously, and ES2 terminated the signal at a time appropriate to provide the required maskee duration. The output of ES2 was led to the input of a low-pass filter system (Spencer-Kennedy Laboratories, Inc., Model 302) and the output lugs of the switch were paralleled with a 600 ohm resistive load. The low-pass filter system was used only at maskee frequencies of 170 and 230 Hz. The cut-off frequency was set at one or the other of these frequencies and the filter skirts had a slope of 36 dB per octave. The filter was adjusted to the "out" position at all other maskee frequencies to eliminate filtering. The output of the filter was routed to the input of a line amplifier (Altec, Model 436 C, compression circuit not active) and from the 600 ohm output of the amplifier to the input of a 600 ohm attenuator network (Hewlett-Packard, Model 350 D). The signal was directed from the output of the attenuator through an impedance matching transformer (United Transformer Corp., Model LS 32) to the 10 ohm input of a recording attenuator (Grason-Stadler, Model E 3262 A) that was operated in the stepped mode. The maskees were then led from the 10 ohm output of the recording attenuator to the input of a 10 ohm switching-mixing network (See Figure 3). The maskees were directed to the right earphone through the switching-mixing network.

The custom-built switching-mixing network consisted of a double-throw triple-pole switch and a 10 ohm resistive mixing network as illustrated in Figure 3. The maskers were led from a transformer to the switch where they were subsequently routed to either the left earphone (contralateral masking) or to one input of the mixer (ipsilateral masking). The maskees from the recording attenuator were directed to the remaining input port of the mixer. When the switch was thrown to the contralateral masking position, the open port of the mixer (masker input) was automatically paralleled with a 10 ohm resistive load so that impedances at the other ports would not change. When the switch was thrown to the ipsilateral masking position, the 10 ohm resistive load was disengaged from the masker input port of the mixer

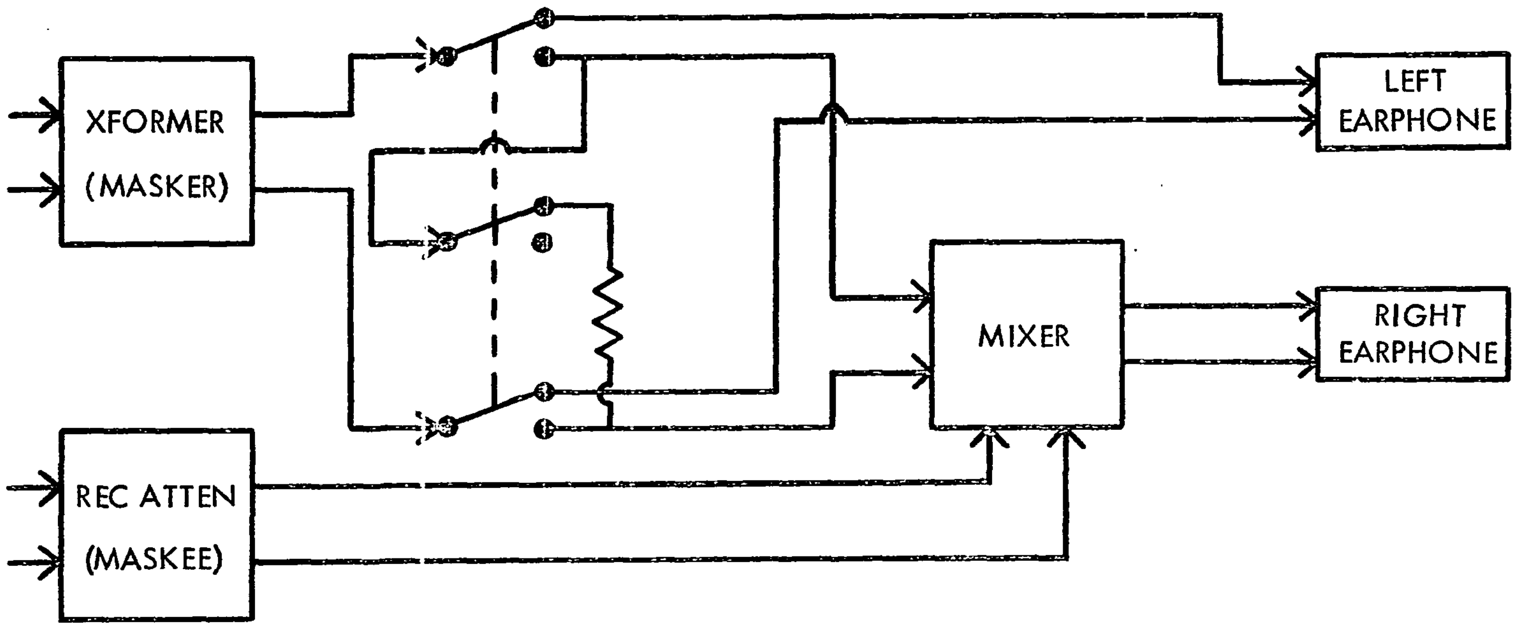

Figure 3.--Schematic illustration of the switching-mixing network.

and the maskers were led through that port to be mixed with the maskees and subsequently directed to the right earphone.

The timing network is illustrated in Figure 4. The network consisted of two waveform generators (Tektronix, Type 162) and nine pulse generators (Tektronix, Type 161), all of which were powered by two power supplies (Tektronix, Type 160 A). The first waveform generator (W1) regulated the interstimulus interval of the pulsed maskers and the maskees. W1 was set to the recurrent mode of operation at the beginning of each session, thereby generating successive 3.5-second sawtooth waveforms until turned off at the end of each session. All other pulse and waveform generators in the system were directly or indirectly triggered from W1 and each fired once during a single waveform.

During each waveform from W1, a one-second observation interval occurred that included the presentation of a maskee or both a maskee and a masker when a pulsed masker condition was scheduled. The beginning of each observation interval occurred 500 msec after the initiation of the waveform from W1. At that time, pulse generator P_L generated a pulse that tripped a relay (not illustrated) causing momentary completion of a 6 V a/c circuit and resulting in the flashing of a yellow "listen" light. One second after the beginning of the observation interval, P_R generated a pulse that tripped another relay (not illustrated) causing momentary completion of a 6 V a/c circuit and resulting in the flashing of a green "respond" light. The "listen" and "respond" lights defined each observation interval that occurred once every 3.5 seconds.

Pulse generators P2 and P3 regulated the on-off cycle of the pulsed maskers. Once second after the initiation of the waveform from

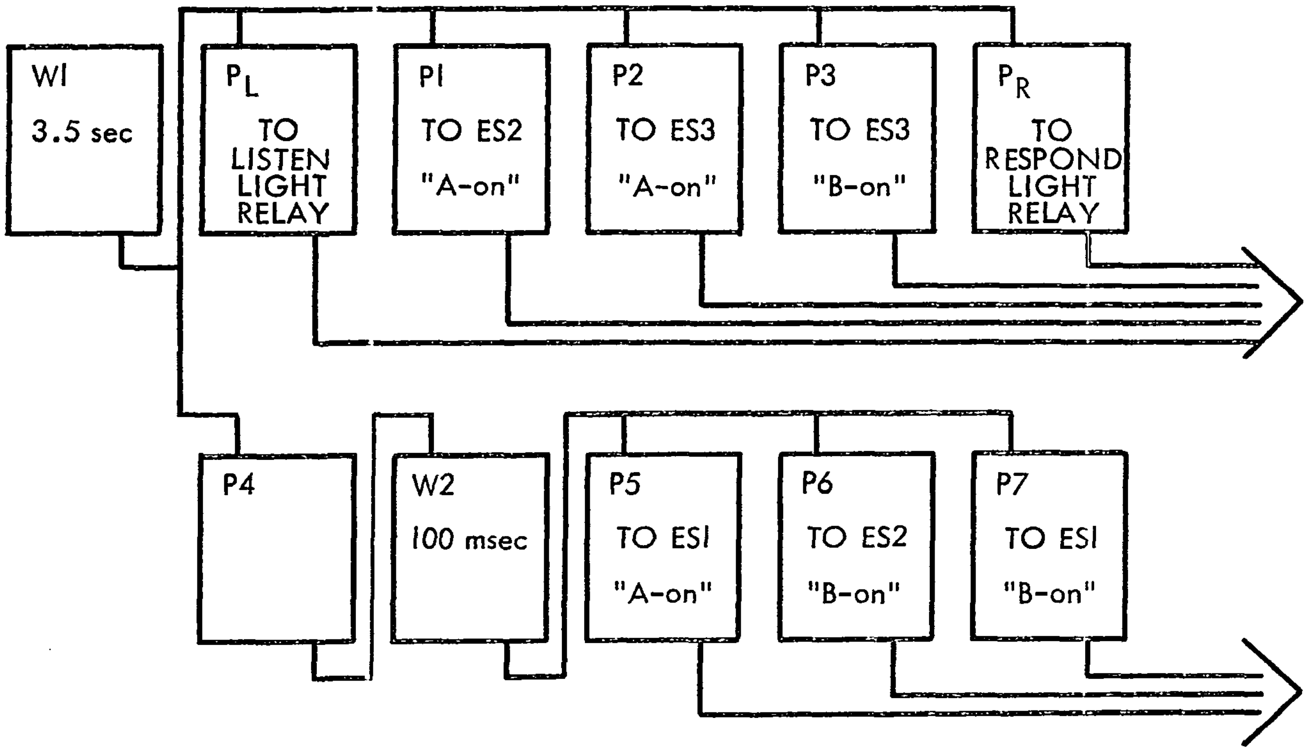

Figure 4.--Schematic illustration of the timing network.

W1, a pulse from P2 triggered "A-on" of ES3, thereby initiating the onset of the masker. After an additional interval of 510 msec, a pulse from P3 triggered "B-on" of ES3, thereby terminating the masker after a full-amplitude duration of 500 msec. Initiation of the green "respond" light followed termination of the masker by a duration no greater than 100 msec. During steady-state masking, ES3 was set to "A-on" instead of "external triggering" allowing the masker to pass continuously through the switch.

The maskees were shaped by the combined action of two electronic switches connected in series. ES1 turned the maskee on and ES2 turned it off. The pulse generators responsible for initiating the maskee (P5) and for terminating the maskee (P6) were triggered from waveform generator W2 that was set to the "triggered" operating mode. W2 generated a 100 msec sawtooth waveform and was triggered by a pulse from P4. A pulse from P5 triggered "A-on" of ES1 20 msec after the onset of the waveform from W2. The pulse delay of P6 was adjusted in relation to that of P5 so that a pulse from P6 triggered "B-on" of ES2 to yield a maximum amplitude maskee duration of only one or two msec. This adjustment was carried out by the use of a calibrated oscilloscope (Tektronix, Model 561 A) connected to the output lugs of ES2. This adjustment yielded maskees that were 30 msec in duration from the beginning of onset to the end of offset. After the maskees were properly shaped and their duration fixed, adjustment of P4 resulted in changing the location of the maskees within the period of W1 without disturbing the onset-offset relation (P5 and P6). In this manner, the maskee position was easily changed from pulsed-initial to pulsed-medial or vice-versa. The maskees occurred in the middle of the observation intervals during steady-state masking. A pulse from P1 triggered "A-on" of ES2 about 500 msec after the beginning of W1 in preparation for the ensuing pulse from P6 that triggered "B-on" of the same switch to terminate the maskees. A pulse from P7 triggered "B-on" of ES1 about 90 msec after the beginning of W2 in preparation for the next cycle of events in which a pulse from P5 would trigger "A-on" of the same switch to initiate the maskee.

The subject response and relay logic circuit is illustrated in Figure 5. The transformed up-and-down psychophysical method used for determination of maskee thresholds in this experiment (Levitt, 1971) requires that maskee attenuation be increased if the subject responds "yes" twice in succession (indicating that the maskee was detected during both of two successive observation intervals) and that maskee attenuation be decreased if the subject responds either "yes-no" in two successive observation intervals or "no" to the first observation interval. The relay logic system was designed to automatically increase or decrease the maskee intensity through the recording attenuator in 1 dB steps upon completion of any of the above response sequences. After the recording attenuator was changed, the relay logic system automatically reset.

The subjects held a metal box that contained a spring-loaded double-throw switch. When the switch was thrown one way a "yes" (maskee detected) response was indicated and when thrown the other way a "no" (maskee not detected) response was indicated. A "yes" response caused momentary completion of a 6 V a/c circuit that tripped a relay (R1)

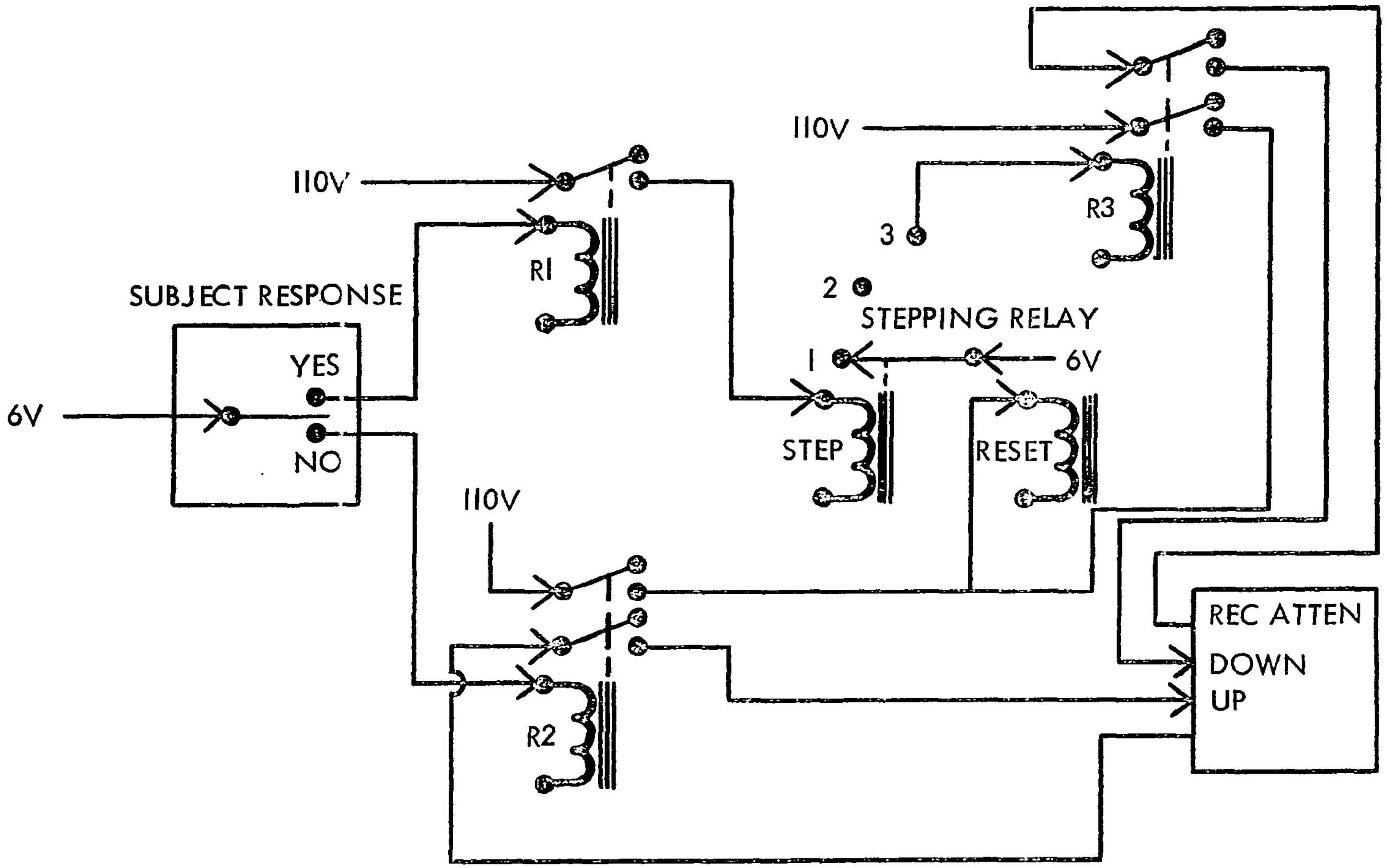

Figure 5.--Schematic illustration of the subject response and relay logic system.

allowing brief completion of a 110 V a/c circuit that advanced the stepping relay (SR) one position. A second "yes" response caused the stepping relay to advance one step further. Upon reaching the second step, relay R3 was tripped momentarily causing brief completion of a circuit from the recording attenuator that resulted in a 1 dB increase in maskee attenuation and brief completion of a 110 V a/c circuit that reset the SR in preparation for the next series of signal presentations. A "no" response resulted in momentary completion of a 6 V a/c circuit that tripped relay R2 causing brief completion of a 110 V a/c circuit that reset the SR and completion of a circuit from the recording attenuator that resulted in a 1 dB decrease in maskee attenuation. In the event a "yes" response was followed by a "no" response, the SR was first advanced one step (the first step of the SR is holding logic only) and upon receiving the "no" response, the SR was reset and the recording attenuator subsequently decreased maskee attenuation by 1 dB. This procedure resulted in a series of attenuation reversals that were recorded on the chart paper of the recording attenuator. These recordings were used to calculate unmasked and masked auditory thresholds.

The experimenter was in control of an auxilliary switch (not illustrated) that allowed momentary completion of the appropriate recording attenuator circuit to cause attenuation changes independent of subject responses and the relay logic device. This switch was used at the beginning of each threshold run to approach threshold more rapidly than would have been possible by use of subject responses and the relay logic device only.

Calibration Procedures and Evaluation of Instrumentation

Complete evaluation of the experimental apparatus was conducted before and after the experiment. Routine evaluation and calibration of the apparatus were performed regularly during the course of the experiment.

Attenuator linearity was evaluated from the earphones by the use of a condenser microphone (Western Electric, Model 640 AA), a 6 cc artificial ear (Grason-Stadler, Type 9A), a pre-amplifier and microphone complement (Western Electro-Acoustic Laboratory, Type E and Type 100 D/E, respectively), and an acoustic wave analyzer (Hewlett-Packard, Model 302 A). A 200 Hz signal was used for evaluation of the masker attenuator and a 1000 Hz signal was used for evaluation of the maskee attenuators. The masker attenuator was found to be sufficiently linear throughout the range used in this experiment. Ten decibel attenuation changes resulted in measured sound pressure level changes of ± 0.2 dB from the indicated value and 2 dB attenuation changes resulted in measured sound pressure level changes of ± 0.2 dB from the indicated value. The maskee attenuator exhibited the same linearity characteristics as did the masker attenuator. The recording attenuator, however, was not as linear as were the other attenuators. Ten decibel attenuation changes of the recording attenuator over the range used in this experiment resulted in measured sound pressure level changes of ± 0.8 dB from the indicated value and 2 dB changes in attenuation resulted in measured sound pressure level changes of ± 0.6 dB from the indicated value. Most of the deviations, however, were on the order of 0.4 dB or less. The attenuators were considered to be sufficiently isolated from one another since the output level from any one of the attenuators did not vary with changes of the other attenuators.

Harmonic distortion components of the masker and maskee frequencies were evaluated by the use of the same apparatus described in the above paragraph. A steady-state 100 dB, 200 Hz signal (masker) was generated at the earphone. Table 2 shows the measured relative harmonic distortion contents of the masker (ipsilaterally and contralaterally).

TABLE 2

RELATIVE HARMONIC DISTORTION OF THE MASKING SIGNAL AT 100 dB SPL

	Relative Harmonic Distortion (dB)	
Frequency (Hz)	Right Earphone	Left Earphone
200 (fundamental)	0	0
400 (first harmonic)	- 41	- 40
600 (second harmonic)	- 46	- 44
800 (third harmonic)	- 68	- 64
1000 (fourth harmonic)	- 63	- 68
1200 and higher	$<$ - 65	$<$ - 65

A sub-experiment in which the effects of harmonic distortion on contralateral masking was performed after the practice sessions were finished but prior to the gathering of experimental data. Pulsed-initial contralateral masking was studied with a 400 Hz masker presented at 50 dB SPL, a 600 Hz masker presented at 45 dB SPL, and a 1000 Hz masker presented at 40 dB SPL. These masker characteristics approximate the first, second, and fourth harmonic components of a 100 dB SPL, 200 Hz steady-state masker. Maskee frequencies of 500 and 750 Hz were investigated with the 400 and 600 Hz maskers and 1500 Hz was investigated with the 1000 Hz masker. The threshold procedure was the same as that used in the main experiment. The greatest mean masking yielded under the above conditions was 1.8 dB for the four subjects. Therefore, it may be concluded that the masker harmonic distortion components for pulsed-initial masking at 100 dB SPL do not yield mean contralateral threshold shifts greater than 2.0 dB for the subjects of this experiment at the above maskee frequencies. A 100 dB SPL, 200 Hz masker intensity corresponds roughly to a 70 dB masker sensation level.

Harmonic distortion components of the maskee frequencies were measured with steady-state signals presented at 80 dB SPL through the right earphone. Maskee frequencies of 170 and 230 Hz were low-pass filtered at 36 dB per octave with cut-off frequencies of 170 and 230 Hz, respectively. The first harmonics of these signals were more than 40 dB down from the fundamental and higher harmonics were more than 60 dB down from the fundamental. Maskee frequencies of 500, 750, 1500, and 4000 Hz were unfiltered and their first harmonics were all more than 40 dB down from the fundamental and higher harmonics were always at a lower level than that of the first harmonic.

The vertical (time) and horizontal (voltage) bases of the oscilloscope were calibrated weekly throughout the experiment and were found to remain stable during that time. Vertical calibration was obtained by the use of the internal voltage source of the oscilloscope. Horizontal calibration was obtained by the use of a frequency-time standard generated by a counter-timer (Transistor Specialties, Inc., Model 361).

All of the electronic switches were balanced weekly and possessed characteristics within manufacturer's specifications. A weekly check of the rise-decay times of the electronic switches was performed by the use of the calibrated oscilloscope. Rise and decay times were measured from the 10 to 90 per cent points of maximum envelope amplitude. The rise time of ES1 ranged from 9.5 to 10 msec over the experimental period. The decay time of ES2 ranged from 10 to 11 msec over the experimental period. The rise time of ES3 ranged from 9.5 to 11.5 msec over the experimental period. The decay time of ES3 was not measured.

At the beginning of each experimental day, the gain controls of the audio oscillators and electronic switches were adjusted to yield a one volt output from the electronic switches as measured by a vacuum-tube voltmeter (Ballantine Laboratories, Inc., Model 300). In addition, the masker steady-state level was adjusted at the amplifier to yield 100 dB SPL at the right earphone when the masker attenuator was set to 20 dB. This adjustment never required more than a 0.5 dB change from day to day. The maskee level was adjusted at the amplifier to yield a 100 dB SPL output at the right earphone for a steady-state 170 Hz signal (unfiltered) when the maskee attenuator and recording attenuator were set to 10 dB. The levels of the remaining maskee frequencies were then recorded without further adjustment. Day-to-day variation between maskee levels did not exceed one decibel at any of the maskee frequencies. The timing network was calibrated at the beginning of each experimental day by the use of the counter-timer.

Prior to the beginning of each experimental session, masker and maskee frequencies were calibrated by use of the counter-timer. As experimental requirements changed from session to session, the timing network was adjusted as required by experimental design at the beginning of each session.

Electrical representation of the acoustic signals was monitored on an oscilloscope from the output lugs of ES2 (maskee) and ES3 (masker). The timing characteristics of pulsed-initial masking were adjusted at the beginning of each appropriate session by use of the oscilloscope. The timing characteristics of steady-state and pulsed-medial masking were adjusted at the beginning of each appropriate session by use of the counter-timer. These adjustments were continuously monitored throughout the sessions.

Experimental Procedures

All subjects completed a series of unmasked and masked auditory threshold trials designed to give them practice with a representative sample of experimental listening conditions. Following successful completion of the practice sessions, subjects were entered into the experimental phase of this research. The maskees were presented to the subjects' right ear during all practice and experimental sessions. The maskers were presented to the subjects' right ear for ipsilateral masking and to the subjects' left ear for contralateral masking.

Practice Sessions

The subjects experienced both unmasked and masked threshold conditions in the practice sessions under the same temporal conditions used in the experiment. The masker was a 50 dB SPL, 200 Hz pure tone and the maskees were 500 Hz pure tones. Pulsed-initial, pulsed-medial, and steady-state ipsilateral and contralateral masking conditions were included in the practice sessions. A 500 Hz signal was chosen as the maskee frequency because effective masking is expected to occur, but the pitch of a 500 Hz maskee is sufficiently different from that of a 200 Hz masker to allow easy discrimination of one from the other.

The order of testing in the practice sessions was designed so that the easiest listening tasks occurred before the more difficult listening tasks as shown in APPENDIX A. Masker and maskee thresholds in the practice sessions were obtained in the same manner employed for the experimental sessions.

Instructions to the subjects were very informal and general during the practice sessions. Prior to each threshold session, subjects were informed of the specific masker and maskee conditions, the purpose of the "listen" and "respond" lights, and the use of the subject response switch. Subjects were encouraged to guess at the proper response whenever detection of the maskee was in doubt.

If any of the subjects showed highly variable performance during the practice sessions, or if the subjects exhibited erratic and confused behavior, the trial was repeated later until acceptable performance was achieved. Although specific subject performance criteria were not formally established, it was generally expected that threshold tracking would not drift significantly over time and that the range between peaks and valleys of threshold tracking would not exceed 5 dB.

Even after practice, these performance criteria had to be relaxed for ipsilateral pulsed masking conditions due to the extreme difficulty of maskee detection. Each subject was required to repeat at least one practice trial. The subjects met the response criteria relatively easily, however, and extensive practice on any of the individual tasks was not required. After completion of the practice sessions, the subjects were considered to be experienced and reliable listeners in this type of task.

Experimental Sessions

Experimental sessions were initiated after completion of the practice trials. Each subject experienced 20 separate experimental sessions, ranging from about 20 to 45 minutes in duration. Each session consisted of a series of unmasked and masked threshold determinations for a single experimental condition. Table 1 of this chapter lists a summary of all experimental conditions.

Experimental sessions were ordered for each subject (See APPENDIX B) in the following manner. Half of the subjects received the ipsilateral conditions prior to the contralateral conditions and the other half received the reverse order. Of the two subjects who received ipsilateral masking before contralateral masking, one received the steady-state before the pulsed conditions for ipsilateral masking and the opposite for contralateral masking while the other subject received the reverse order. The same counter-balancing of steady-state versus pulsed masking was assigned to those subjects who received contralateral masking before ipsilateral masking. Each session was concerned with only one maskee frequency and the order of maskee frequencies was determined for each masker condition from a random numbers table without replication. For those maskee frequencies where both initial and medial temporal patterns were investigated, half of the subjects received pulsed-initial masking before pulsed-medial masking and the other half received the reverse order. Finally, masker intensity was ordered in the same manner for all subjects and all sessions with unmasked thresholds always preceding masked thresholds and masked thresholds tested in order of increasing masker intensity (i.e., 10, 30, 50, and 70 dB SL). Increasing masker intensity was chosen to minimize the effects of temporary threshold shift due to intense masker stimulation. In fact, no greater than a 4 dB change in absolute masker thresholds occurred between sessions for any subject when sessions were performed with less than a two hour inter-session interval. The direction of these changes was not consistent.

Rest periods of at least 15 minutes were allowed between experimental sessions. No more than three consecutive experimental sessions were conducted without a rest period of at least two hours prior to the fourth session.

At the beginning of each experimental session, a pulsed masker threshold was determined by the experimenter and all masker sensation levels in that session were referred to this threshold value. Subjects were instructed to listen for the masker during each observation interval and to throw the response switch to the "yes" position if it was detected. No response was required if the masker was not detected. Guessing was encouraged if detection of the masker was in doubt. A "yes" response caused an audible relay click that informed the experimenter when the subject detected the presence of the masker. Masker thresholds were determined by the modified ascending threshold technique (Carhart and Jerger, 1959) with 2 dB attenuation steps. Manual adjustment of the masker attenuator was performed by the experimenter according to whether or not the masker was detected during the preceding observation interval.

Maskee thresholds were determined by the use of a transformed up-and-down psychophysical method (Levitt, 1971) in which the subjects were required to decide whether or not the maskee was present during each observation interval. If the maskee was audible, subjects responded "yes" with the response switch and if the maskee was inaudible, they responded "no" with the response switch.

After the masker threshold was determined at the beginning of each session, subjects were instructed not to remove the headphones and were read the following instructions:

> During this session, you will hear a very brief pure-tone signal in your right ear, either alone or in the presence of a . . . (one of the below, according to design)
>
> (a) . . . pulsed masker in your left ear. The maskee will be located near the onset of the masker.
>
> (b) . . . pulsed masker in your left ear. The maskee will be located near the middle of the masker.
>
> (c) . . . continuous masker in your left ear.
>
> (d) . . . pulsed masker in your right ear. The maskee will be located near the onset of the masker.
>
> (e) . . . pulsed masker in your right ear. The maskee will be located near the middle of the masker.
>
> (f) . . . continuous masker in your right ear.
>
> Your task is to listen for the maskee during the period immediately following each yellow "listen" light and to respond when

> the green "respond" light flashes. Respond either "yes" or "no" with your switch depending upon whether or not you detected the maskee. In the event you are not sure you heard the maskee, you are to respond according to what you think you heard; do not be afraid to guess. Please do not remove the earphones during this session. There will be a short pause between threshold determinations; just wait until the "listen" light indicates the beginning of a new run. I will open the door and inform you when the session is finished.

Complete instructions were read to each subject during the first few sessions of the experiment. Thereafter, it was sufficient to inform the subjects only of the signal condition that would occur during the session since they were familiar with the experimental task.

The determination of unmasked thresholds preceded the determination of masked thresholds in all sessions. During unmasked threshold runs, the masker attenuator was adjusted to yield an intensity at least 10 dB below the subject's threshold. The maskee attenuator was adjusted at the beginning of each session so that the approximate unmasked threshold was located in an appropriate range of the recording attenuator chart paper (i.e., 50-70 dB attenuation). This maskee attenuator setting was not changed throughout the session.

The intensity of the maskees was adjusted at the recording attenuator to a level that would be easily audible prior to each threshold run (the experimenter possessed an override switch that controlled the recording attenuator). The first descending run was performed in 3 dB steps. After the first "no" response, an ascending run was commenced in 3 dB steps. The second and third descending runs and the second ascending run were performed in 2 dB steps. This procedure was followed in order to approach maskee threshold more rapidly than would have been possible with the 1 dB steps initiated by the subject responses and relay logic circuit. All subsequent attenuation changes following the approach to threshold were made in 1 dB steps. At least fourteen attenuation reversals were obtained prior to terminating the session. The first twelve reversals were used to calculate threshold for that experimental condition. Occasionally, it was necessary to extend or repeat the threshold approach procedure because of inconsistant subject responses.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

A review of masking literature reveals that low-frequency contralateral pure-tone masking has not been investigated as thoroughly as have other masking phenomena. The primary purpose of this experiment, therefore, was to define and quantify several effects of a low-frequency contralateral pure-tone masker. Several specific aspects of low-frequency contralateral masking encompassing the parameters of major importance to any masking study were investigated. These parameters included temporal relations between maskers and maskees, frequency spread of masking, and growth of masking. The results of this experiment allow further definition of the basic nature of central masking.

This investigation of the temporal aspects of low-frequency contralateral masking included the study of overshoot and pulsed versus steady-state masking. Experimental evidence suggests that overshoot becomes less in magnitude as the masker and/or maskee frequencies are decreased. One purpose of this experiment was to confirm the existence and ascertain the magnitude of overshoot for a low-frequency contralateral masker. Zwicker (1965b) hypothesized that pulsed-medial ipsilateral masking should approximate that resulting from a steady-state ipsilateral masker of comparable intensity. Conflicting experimental evidence in this area is noted, however. Another purpose of this experiment was to compare the magnitude of pulsed-medial and steady-state contralateral and ipsilateral masking under comparable masker intensities.

The extent and nature of the spread of low-frequency contralateral masking does not appear to have been adequately established. Although Ingham (1959) showed that the effects of a 200 Hz contralateral masker extend as high as 3900 Hz, it is not clear how the spread of low-frequency contralateral masking is affected by masker intensity or masker-maskee temporal relations. An additional purpose of this experiment was to investigate the spread of low-frequency contralateral masking at various masker intensities with different masker-maskee temporal relations.

Finally, this experiment was designed to investigate the growth of low-frequency contralateral masking with several masker-maskee temporal patterns. Zwislocki, et al. (1967) reported that steady-state contralateral pure-tone masking results in minimal threshold shifts even at high masker intensities. It does not appear that this experiment has been replicated. A further purpose of this experiment was to investigate the magnitude of steady-state contralateral low-frequency masking at several masker intensities.

The effects of low-frequency contralateral masking were investigated with 200 Hz pure-tone maskers at sensation levels of 10, 30, 50, and 70 dB. The maskers were presented in a steady-state condition and in a pulsed condition with a duration of 500 msec and a period of $3\frac{1}{2}$ seconds. All maskers and maskees were initiated and terminated with 10 msec rise-decay times. Maskees were brief 30 msec pure tones when measured from the beginning of onset to the termination of offset. This procedure yielded a maximum amplitude duration of only one or two msec. The spread of contralateral masking was investigated with pure-tone maskees of 170, 230, 500, 750, 1500, and 4000 Hz under pulsed-initial and steady-state masking conditions. Maskee frequencies of 230 and 4000 Hz were also investigated under pulsed-medial masking.

Several ipsilateral masking conditions were included in this study for comparison to the contralateral masking results, as well as to the ipsilateral masking results of other investigators. Ipsilateral maskee frequencies of 230 and 4000 Hz were investigated at masker intensities of 10, 30, 50, and 70 dB SL under pulsed-initial, pulsed-medial, and steady-state temporal conditions. This design permitted the study of growth of ipsilateral masking, ipsilateral overshoot, and pulsed versus steady-state ipsilateral masking.

Four normal-hearing subjects participated in this experiment. A transformed up-and-down psychophysical procedure was used for the determination of unmasked and masked auditory thresholds. All subjects completed a practice program prior to being entered into the experimental portion of this research.

Results

Absolute Masker and Maskee Thresholds

It was not a specific goal of this experiment to report absolute masker and maskee thresholds. These data are presented to show the normal hearing characteristics of the subjects and to illustrate the intra- and inter-subject reliability of the measures.

Pulsed masker thresholds were obtained at the beginning of each experimental session regardless of whether steady-state or pulsed masking was scheduled. Absolute masker thresholds were calculated by subtracting the attenuator value at each subject's threshold from the calibrated value at zero attenuation. Sixteen contralateral (left ear) and six ipsilateral (right ear) masker thresholds were obtained for each subject during the experiment. Table 3 presents the subjects' masker

TABLE 3

INDIVIDUAL THRESHOLDS (IN dB SPL) FOR MASKERS PRESENTED TO THE SUBJECTS' RIGHT AND LEFT EARS

	Right Ear (Ipsilateral Masking)		Left Ear (Contralateral Masking)	
	Mean	SD	Mean	SD
Subject #1	38.0	2.8	34.8	1.5
Subject #2	33.3	1.6	32.6	1.0
Subject #3	36.7	1.6	34.2	2.0
Subject #4	29.0	1.1	30.6	1.7

thresholds in sound-pressure level for ipsilateral and contralateral masking conditions.

A normative threshold value for 200 Hz is not available in the current standard data (ANSI, 1969). Linear interpolation between the normative threshold values for 125 and 250 Hz yields an estimate of 33.3 dB SPL for normal auditory threshold at 200 Hz via TDH-39 transducers. Table 3 shows that the individual masker thresholds for both right and left ears are very close to that expected from normal-hearing subjects. In fact, the highest single masker threshold obtained for any subject during the experiment was 42 dB SPL, less than 10 dB greater than the interpolated normal threshold level. None of the subjects demonstrated an interaural threshold difference at 200 Hz greater than four decibels.

Calculation of absolute maskee thresholds required more factors to be considered than was the case for masker thresholds. First, the maskee duration was so brief as to necessitate the use of a correction factor to account for normal temporal integration between the maskee duration and the normal critical duration. Temporal integration has been studied by several investigators (Garner, 1947; Miskolczy-Fodor, 1959; Goldstein and Kramer, 1960; Dallos and Johnson, 1966; Olsen and Carhart, 1966). According to the equivalent duration formula of Dallos and Johnson (1966), the maskees employed in this experiment have a duration of just less than 10 msec. A signal of this duration is expected to yield a threshold approximately 13 dB greater than a signal with a duration of 200 msec or more. Second, the maskee frequencies of 170 and 230 Hz were filtered, whereas the other maskee frequencies were not. Each of the two filters in the low-pass filter set was adjusted by frequency so that the maskees were three decibels less than the original unfiltered intensity level. This yielded a six decibel reduction of the filtered maskee intensity compared to the unfiltered condition since the filters were connected in series.

Absolute unmasked thresholds in sound pressure level were calculated by subtracting the recording attenuator value at each subject's threshold from the calibrated sound pressure level when the recording attenuator was set to zero attenuation. The resulting value was then decreased by 13 dB to account for normal temporal integration and, if appropriate, decreased by an additional six decibels to account for the filter loss. Unmasked and masked maskee threshold values in sound pressure level for all ipsilateral and contralateral experimental conditions are presented in APPENDIX C.

All absolute unmasked thresholds were relatively close to one another among subjects and sessions. Therefore, only the mean unmasked maskee thresholds are presented in Table 4. Normal auditory thresholds

TABLE 4

MEAN MASKEE THRESHOLDS (IN dB SPL)

	Maskee Frequency (in Hz)					
	170	230	500	750	1500	4000
Mean	42.0	33.2	14.2	10.9	12.5	11.4
SD	5.6	4.6	3.8	4.3	2.8	10.4
Normal Auditory Threshold (ANSI, 1969)	38.0*	28.6*	11.5	9.2*	6.5	9.5

*Linearly interpolated from threshold standards adjacent to the maskee frequency.

(ANSI, 1969) at the maskee frequencies are presented for comparison purposes. The normal threshold values at 170, 230, and 750 Hz were linearly interpolated from the standard threshold data on both sides of the appropriate maskee frequency for TDH-39 earphones.

Table 4 shows that the mean unmasked maskee thresholds obtained for all subjects across all experimental sessions are slightly greater than those designated as zero hearing level by ANSI (1969). None of the mean unmasked thresholds exceed the normative values by more than 10 dB. The standard deviation of unmasked maskee thresholds at 4000 Hz is greater than those obtained at other maskee frequencies due to the fact that one subject showed elevated unmasked thresholds and another showed considerably more sensitive unmasked thresholds at that frequency than did the remaining subjects. From the above data, it is assumed that the maskees did not contain harmonics or other signal artifacts that would result in more sensitive thresholds (especially for low-frequency maskees) than would be expected from normal auditory threshold standards.

Normal Unmasked Threshold Variability

Serial repetition of any psychophysical measurement will yield slightly different scores based upon a subject's normal variability of responses. One of the primary shortcomings of many psychophysical studies is that a small number of subjects are utilized and normal variability of subject performance on the required task is not presented. If large differences among experimental conditions are found, this point may be of little significance. However, if small differences among experimental conditions are found, this point is of greater significance. In addition, it is generally recognized that the utilization of inferential parametric statistics with small sample sizes ($n < 10$) results in testing procedures that possess low power, leading to increased probabilities of committing type II (Beta) errors.

This experiment was designed so that a procedure would be available by which a threshold shift could be considered either significant (due to the presence of the masker) or non-significant (possibly attributable to the normal variability of subject responses). The following statistical treatment of the experimental data was recommended by the statistical consultant.

Prior to the introduction of the masker, a series of three consecutive unmasked thresholds were obtained for each subject during the experimental sessions in which maskee frequencies of 230 and 4000 Hz were presented. These frequencies were chosen to sample unmasked threshold variability at or near both limits of the frequency range used in this experiment. Each subject experienced twelve such sessions yielding 36 unmasked replicate threshold determinations. These measures resulted in a pooled within subject variance of replicate unmasked threshold determinations equal to 0.50604 with 96 degrees of freedom. Based on this variance of replicate unmasked threshold determinations, 90 per cent confidence intervals were established with 60 degrees of freedom (The Student's "t" distribution does not stipulate values between 60 and 120 degrees of freedom). These confidence limits may be interpreted in such a way that any threshold shift less than 1.68 dB from an unmasked threshold may be attributed to normal variability of unmasked threshold measurements in 90 per cent of the trials performed. Therefore, a maskee threshold shift greater than 1.68 dB may be considered to have resulted from the introduction of the masker and is called a significant threshold shift or "masking". All graphs in this chapter include a horizontal dashed line at 1.68 dB that defines the point above which a threshold shift is considered to be statistically significant.

All threshold shifts at maskee frequencies of 170, 500, 750, and 1500 Hz were calculated by subtracting the masked thresholds from the unmasked threshold obtained in each session. All threshold shifts at maskee frequencies of 230 and 4000 Hz were calculated by subtracting the masked thresholds from the average of the three unmasked thresholds obtained in each session because the average of three unmasked thresholds yields a better estimate of the true unmasked threshold than does a single unmasked threshold.

Ipsilateral Masking

Ipsilateral masking was investigated with 200 Hz pure-tone maskers presented at 10, 30, 50, and 70 dB SL. Steady-state, pulsed-initial, and pulsed-medial masking were measured at maskee frequencies of 230 and 4000 Hz. All unmasked and masked ipsilateral maskee thresholds in sound pressure level are presented in APPENDIX C. Table 5

TABLE 5

MEAN THRESHOLD SHIFTS (IN dB) FOR IPSILATERAL MASKING

Maskee Frequency (in Hz)	Masker Condition	Maskee Position	Masker Intensity (in dB SL) 10	30	50	70
230	Pulsed	Initial	3.1	20.2	42.1	>58.9
230	Pulsed	Medial	-0.6*	8.6	23.8	42.4
230	Steady-State	-	1.2*	8.7	22.6	39.8
4000	Pulsed	Initial	0.3*	1.7	7.8	19.9
4000	Pulsed	Medial	0.0*	-0.2*	2.1	9.7
4000	Steady-State	-	-0.1*	-0.1*	1.3*	8.8

*Threshold shift not statistically significant.

shows the mean ipsilateral masking obtained under the experimental conditions of this study. These data are graphically displayed in Figures 6 and 7.

Table 5 shows that the average masking obtained at 230 Hz for the 70 dB SL pulsed-initial condition was greater than 58.9 dB. This figure is based on the average results of three subjects. The fourth subject showed greater than 59.2 dB masking for this condition but, because his masked threshold exceeded the sound pressure output of the experimental apparatus, the calculation of an average based on all subjects was impossible. The threshold shifts marked with an asterisk in Table 5 are not statistically significant and may not represent masking.

Temporal Relations in Ipsilateral Masking. The investigation of temporal relations in ipsilateral masking included the study of overshoot and the comparison of steady-state to both pulsed-initial and pulsed-medial masking.

Overshoot in Ipsilateral Masking. Overshoot is calculated by subtracting pulsed-medial masking from pulsed-initial masking at comparable masker intensities. Table 6 shows the mean overshoot obtained for the ipsilateral masking conditions of this experiment. These data may be observed in Figures 6 and 7 by the comparison of mean pulsed-initial and mean pulsed-medial masking at any of the masker intensities.

The data marked with an asterisk in Table 6 were calculated when either the pulsed-initial or the pulsed-medial threshold shift, or both, were not statistically significant. Table 6 shows that mean overshoot at 230 Hz for the 70 dB SL masker is greater than 15.7 dB. This value is based on the results of three subjects. The fourth subject showed

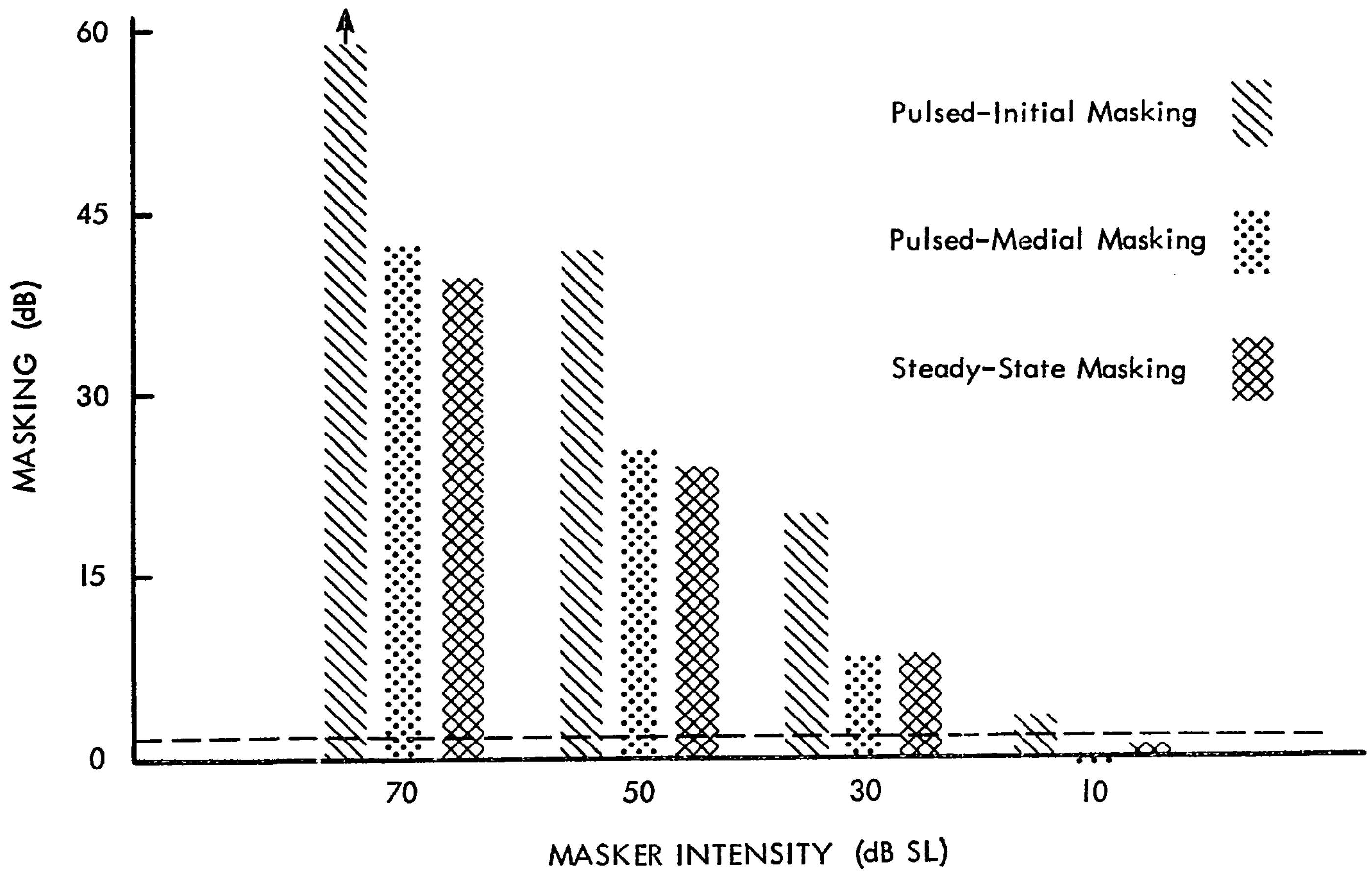

Figure 6.--Mean threshold shifts (in dB) at 230 Hz for pulsed-initial, pulsed-medial, and steady-state ipsilateral masking.

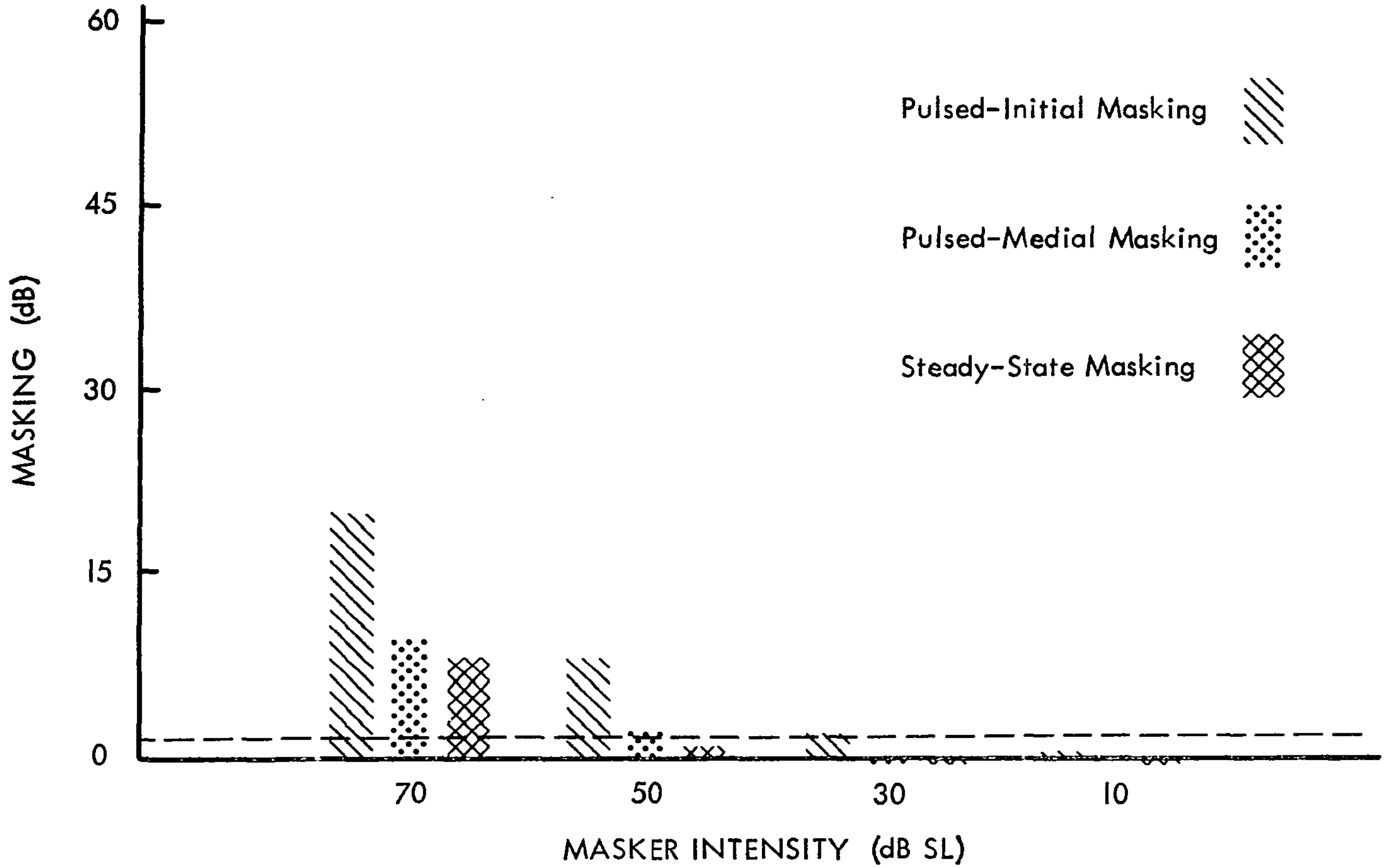

Figure 7.--Mean threshold shifts (in dB) at 4000 Hz for pulsed-initial, pulsed-medial, and steady-state ipsilateral masking.

TABLE 6

MEAN OVERSHOOT (IN dB) FOR IPSILATERAL MASKING

Masker Intensity (in dB SL)	Maskee Frequency (in Hz) 230	4000
10	3.7*	0.3*
30	11.6	1.9*
50	18.3	5.7
70	> 15.7	10.2

*see text

greater overshoot than the average of the remaining subjects but his threshold for the pulsed-initial condition exceeded the sound pressure output of the experimental apparatus, thereby rendering calculation of average overshoot for all subjects impossible.

Table 6 and Figures 6 and 7 show that overshoot exists for low-frequency ipsilateral masking at maskee frequencies near and far removed from that of the masker. Whenever significant threshold shifts occurred, mean pulsed-initial masking was greater than mean pulsed-medial masking. The individual subject data showed considerable variability in the magnitudes of masking, but all of them evidenced overshoot whenever significant masking occurred at 230 Hz and all but one subject showed overshoot whenever significant masking occurred at 4000 Hz.

Mean overshoot generally increases as the masker intensity is increased. Table 6 shows that mean overshoot at 50 dB SL for the 230 Hz maskees is less than the mean overshoot at 70 dB SL. It will be remembered that overshoot at 70 dB SL is based on an average of only three subjects while the other levels are comprised of an average of all subjects. When mean overshoot is calculated on the basis of only those three subjects who yielded measurable results, the 10 dB SL masker resulted in 2.2 dB overshoot, the 30 dB SL masker resulted in 10.0 dB overshoot, the 50 dB SL masker resulted in 15.8 dB overshoot, and the 70 dB SL masker resulted in 15.7 dB overshoot. The mean growth of overshoot at 230 Hz increases from the 10 to the 50 dB masker sensation levels but remains essentially the same at the 50 to the 70 dB masker sensation levels. This suggests the existence of either a maximum magnitude of overshoot or a non-linear growth of overshoot. It was not possible to ascertain which, if either, of these possibilities is true in this study.

Mean overshoot at 4000 Hz was considerably less than mean overshoot at 230 Hz. Only the 50 and 70 dB masker sensation levels resulted in significant pulsed-initial and pulsed-medial threshold shifts. Overshoot at 4000 Hz increases in magnitude with increased masker intensity but the rate of the growth of overshoot cannot be ascertained because of the insignificant masking obtained for pulsed-initial and/or pulsed-medial conditions at the 10 and 30 dB masker sensation levels.

Comparison of the mean ipsilateral overshoot results of this study to those of other investigators can be made only on a limited basis because others have not reported on the use of maskers at or near 200 Hz. In general, these data show greater mean overshoot for a 200 Hz masker than would be predicted from other studies. Samoilova (1959) found about 10 dB overshoot for 1380 Hz maskees under the influence of 90 dB SL, 1000 Hz maskers. This is less overshoot than was obtained at

230 Hz in the current experiment for either the 50 or 70 dB masker sensation levels and about equal to that obtained for the 30 dB SL maskers. Samoilova used a maskee with full amplitude duration of 20 msec and a "smooth" rise-fall time (she did not specify the rise-fall duration). In this study, maskees of considerably shorter peak duration were used. The discrepancy of results between this experiment and Samoilova's experiment may be explained, in part, by the fact that overshoot is greater for very brief maskees than for longer-duration maskees (Zwicker, 1965a; Zwicker, 1965b).

Lankford (1969) found that mean overshoot for maskees near in frequency to a 1000 Hz, 50 dB SPL masker did not exceed 6.7 dB. A 50 dB SPL, 1000 Hz masker intensity corresponds to 43 dB sensation level if normal threshold at 1000 Hz is assumed (ANSI, 1969). The current experiment yielded greater mean overshoot (11.6 dB) at 230 Hz for a 30 dB SL masker than Lankford found for any of his experimental conditions. The maskees were of similar temporal characteristics and precise threshold determination procedures were used in both studies. The primary differences between the two studies were the masker and maskee frequencies.

Overshoot has been shown to exist for ipsilateral low-frequency pure-tone masking for maskees near and distant from the masker frequency. Thus, the hypothesis that overshoot is minimal or absent for low-frequency stimulation is incorrect. This hypothesis was based on studies in which narrow- or broad-band noise maskers were used to investigate overshoot (Elliott, 1965; Zwicker, 1965a) and studies in which steady-state versus simultaneously pulsed masking was investigated

(Dirks and Norris, 1966; Johnson, 1968). Comparison of the overshoot results of this experiment to those of other investigators suggest that ipsilateral pure-tone overshoot increases with decreasing masker frequency under comparable masker sensation levels for maskees near in frequency to that of the masker. Furthermore, the current data suggest that growth of overshoot may reach a maximum below the 70 dB masker sensation level for 200 Hz maskers with maskees near in frequency to that of the masker.

Pulsed Versus Steady-State Ipsilateral Masking. Steady-state versus both pulsed-initial and pulsed-medial masking was investigated at 230 and 4000 Hz with 200 Hz ipsilateral maskers at 10, 30, 50, and 70 dB SL. The data presented in Table 7 show the mean pulsed versus

TABLE 7

MEAN DIFFERENCES (IN dB) BETWEEN PULSED AND STEADY-STATE IPSILATERAL MASKING

Masker Intensity (in dB SL)	Pulsed-Initial Minus Steady-State Masking		Pulsed-Medial Minus Steady-State Masking	
	230 Hz	4000 Hz	230 Hz	4000 Hz
10	1.9*	0.4*	-1.8*	0.1*
30	11.5	1.8*	-0.1	-0.1*
50	19.5	6.5*	1.2	0.8*
70	> 17.5	11.1	2.6	0.9

*see text

steady-state ipsilateral masking obtained in this study. These data were graphically illustrated in Figures 6 and 7.

The data in Table 7 marked with an asterisk were calculated whenever either of the threshold shifts were not statistically significant. The mean pulsed-initial minus mean steady-state masking difference at 230 Hz under 70 dB SL masking is based on the data of only three subjects. The fourth subject evidenced pulsed-initial masking at 70 dB SL that was greater than the sound level output of the experimental apparatus. Therefore, an average difference for all subjects could not be calculated. The pulsed-initial minus steady-state masking difference yielded by the fourth subject at 70 dB SL was greater than the average of the remaining subjects.

All pulsed-initial ipsilateral masking conditions in this experiment yielded greater mean threshold shifts than did steady-state ipsilateral masking conditions at comparable masker intensities. While individual masking magnitudes varied considerably, only one subject showed greater steady-state than pulsed-initial masking (at 4000 Hz under the 50 and 70 dB masker sensation levels). Pulsed-initial minus steady-state ipsilateral masking differences are intensity dependent, with increasing differences occurring at 230 Hz from the 10 to the 50 dB masker sensation levels. These differences were not found to increase between the 50 and the 70 dB masker sensation levels, however.

Differences between mean pulsed-medial and mean steady-state ipsilateral masking obtained in this experiment are also presented in Table 7. These comparisons may be graphically observed in Figures 6 and 7. Mean pulsed-medial masking was greater than mean steady-state masking at 230 Hz for the 50 and 70 dB SL maskers. All other pulsed-medial versus steady-state ipsilateral masking differences are not considered to be significant. Analysis of the individual subject data shows that the 70 dB SL maskers yielded greater pulsed-medial than steady-state ipsilateral masking for all subjects at 230 Hz and all but one subject at 4000 Hz. The 50 dB SL masker yielded greater pulsed-medial than steady-state masking for all but one subject at 230 Hz and for two of the four subjects at 4000 Hz. The 10 and 30 dB SL maskers yielded greater pulsed-medial than steady-state masking for some subjects but not for other subjects. Many of the subjects failed to show significant masking for the 10 dB SL conditions at either frequency and for the 30 dB SL conditions at 4000 Hz.

The pulsed-medial versus steady-state ipsilateral masking results of this study support those of Elliott (1969) in which pulsed-medial masking yielded about 2.5 dB greater threshold shifts than did steady-state masking when the noise maskers were presented at 71 dB SPL and the brief pure-tone maskees were located 250 msec after the masker onset. Zwicker (1965a) hypothesized that masking of brief signals located 300 msec after the onset of a pulsed masker should be equal to that resulting from steady-state masking of comparable intensity. Close observation of his data reveals that, although the two conditions yielded similar results, the pulsed noise maskers presented at 71 dB SPL generally resulted in several decibels greater masking of the brief pure-tone maskees than did the steady-state maskers.

Lankford and Stokinger (1969) compared pulsed-medial and steady-state ipsilateral masking with 50 dB SPL, 1000 Hz maskers. The pulsed maskers were one second in duration and the maskees were presented 500 msec after the pulsed masker onset. The maskee frequencies were all within 200 Hz of the masker frequency and the maskee duration was comparable to that used in the current study. They found that mean steady-state masking yielded approximately 16 per cent poorer maskee detection than did mean pulsed masking when the maskees were within about 100 Hz from the masker frequency. Because a signal detection paradigm was used in Lankford and Stokinger's study, it is not known what decibel difference in the maskers would have yielded equivalent detectability of the maskees. In the current study, mean maskee detection was better with steady-state than with pulsed-medial ipsilateral masking at 70 dB SL. Several differences between this study and Lankford and Stokinger's study may explain the apparently conflicting results. Lankford and Stokinger used a masker duration of one second while a masker duration of 500 msec was used in this study. The maskees in Lankford and Stokinger's study were located 500 msec after the onset of the pulsed maskers while maskees were located 250 msec after the pulsed masker onset in the current study. Lankford and Stokinger used a 1000 Hz masker, and a 200 Hz masker was used in this study. A more likely cause for the apparent differences between the studies, however, is the difference in masker levels employed since it appears from the data of this investigation that pulsed versus steady-state masking differences are greater for high-intensity maskers than for low-intensity maskers.

Frequency Spread of Ipsilateral Masking. Ipsilateral maskee frequencies of 230 and 4000 Hz were investigated with pulsed-initial, pulsed-medial, and steady-state masking at 10, 30, 50, and 70 dB SL. Since a wide range of maskee frequencies was not used, it was not possible to obtain ipsilateral spread of masking information in this experiment.

Inspection of Table 5 and Figure 7 allow several generalizations to be drawn concerning the spread of low-frequency ipsilateral masking under various masker-maskee temporal relations. First, none of the 10 dB SL masking conditions resulted in significant mean threshold shifts at 4000 Hz. Second, the 30 dB SL pulsed-medial and steady-state maskers did not result in significant mean threshold shifts at 4000 Hz while the 30 dB SL pulsed-initial maskers resulted in a mean threshold shift which just barely exceeded significance. Third, only pulsed maskers of 50 dB SL and above resulted in significant mean threshold shifts at 4000 Hz and the mean pulsed-medial threshold shift with the 50 dB maskers barely exceeded significance. Finally, only the 70 dB SL maskers resulted in significant mean threshold shifts at 4000 Hz for all temporal relations studied. In all instances where significant mean threshold shifts occurred at 4000 Hz, pulsed-initial masking was greater than pulsed-medial masking and pulsed-medial masking was greater than steady-state masking. This suggests that ipsilateral frequency spread of masking characteristics depend on the masker-maskee temporal relations used.

Comparison of the ipsilateral masking data of this experiment to those of other experiments is somewhat tenuous because of the differences in masker-maskee temporal relations and masker intensities used. Dirks and Norris (1966) found that ipsilateral masking is essentially equivalent for steady-state maskers with either steady-state or pulsed maskees. If maskers and maskees are simultaneously pulsed, however, greater ipsilateral masking is found than with either of the other two temporal patterns. Wegel and Lane (1924) and Carter and Kryter (1962) studied pure-tone ipsilateral masking with steady-state maskers and maskees. The pulsed-medial and steady-state masking obtained in this experiment at 230 Hz is approximately 10 dB less at all maskers intensities than observed by the above investigators. The mean pulsed-initial masking obtained in this experiment compares well with data reported by Carter and Kryter and Wegel and Lane.

Growth of Ipsilateral Masking. The growth of ipsilateral masking in this study can best be observed at 230 Hz as illustrated in Figure 8. The mean masking results obtained at 4000 Hz, illustrated in Figure 9, are too limited to allow the evaluation of growth of masking characteristics. The growth of masking patterns for individual subjects closely parallel the mean data shown in Figures 8 and 9, although individual differences in the magnitudes of masking are evident.

Growth of ipsilateral pure-tone masking at maskee frequencies near that of the masker is linear with a slope of approximately one, regardless of the masker-maskee temporal relations (Wegel and Lane, 1924; Egan and Hake, 1950; Ehmer, 1959; Carter and Kryter, 1962). The data of the current experiment generally support these findings. Mean growth of pulsed-initial ipsilateral masking was found to be linear with a slope of approximately one between masker sensation levels of 10 and 70 dB. Mean growth of pulsed-medial masking at 230 Hz showed a slope of approximately one between masker sensation levels of 50 and 70 dB, and a slope less than one at masker sensation levels below 50 dB. Similarly, mean growth of steady-state masking evidenced a slope of approximately one (though slightly less than pulsed-medial masking) between

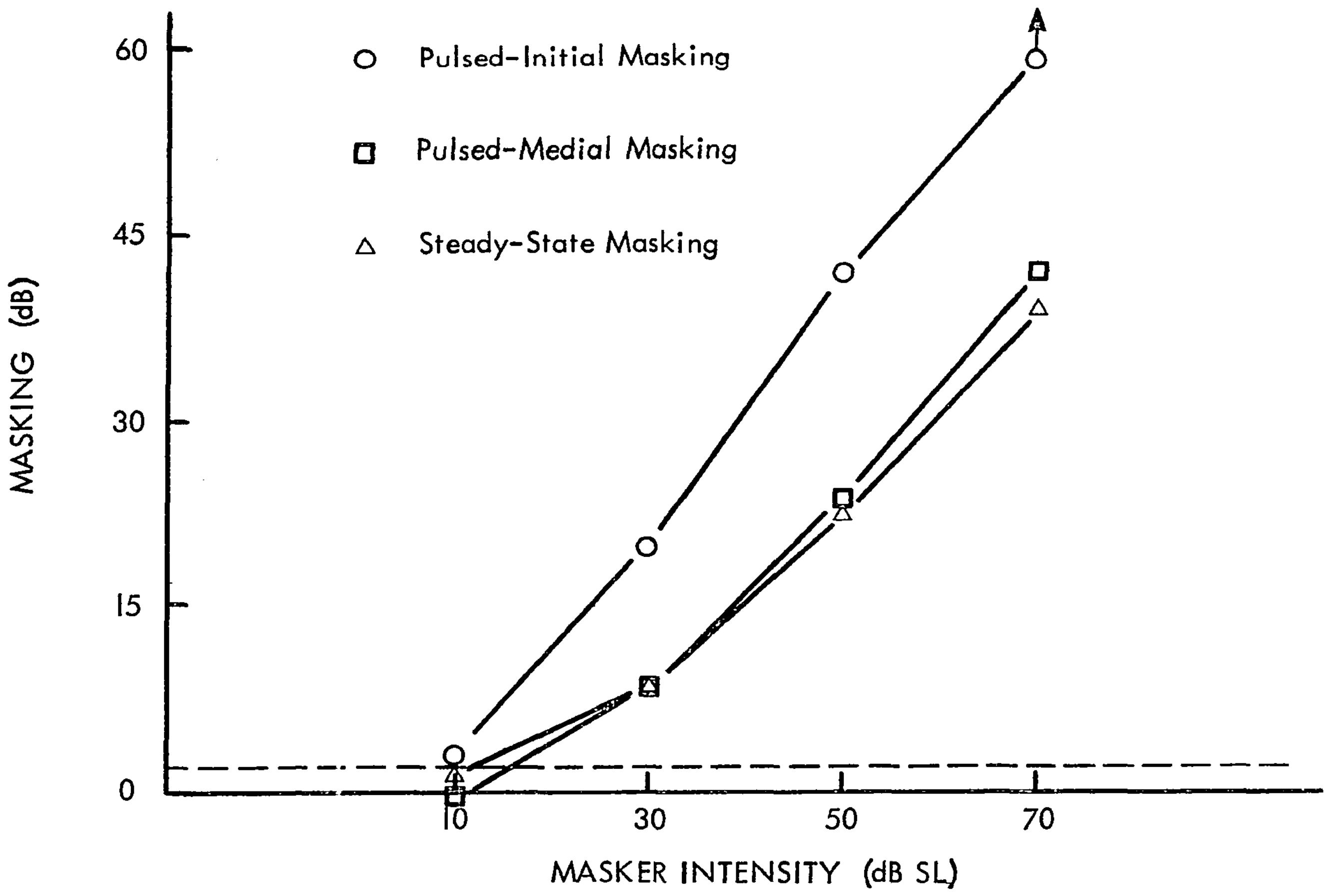

Figure 8.--Mean growth of ipsilateral masking (in dB) at 230 Hz for pulsed-initial, pulsed-medial, and steady-state maskers.

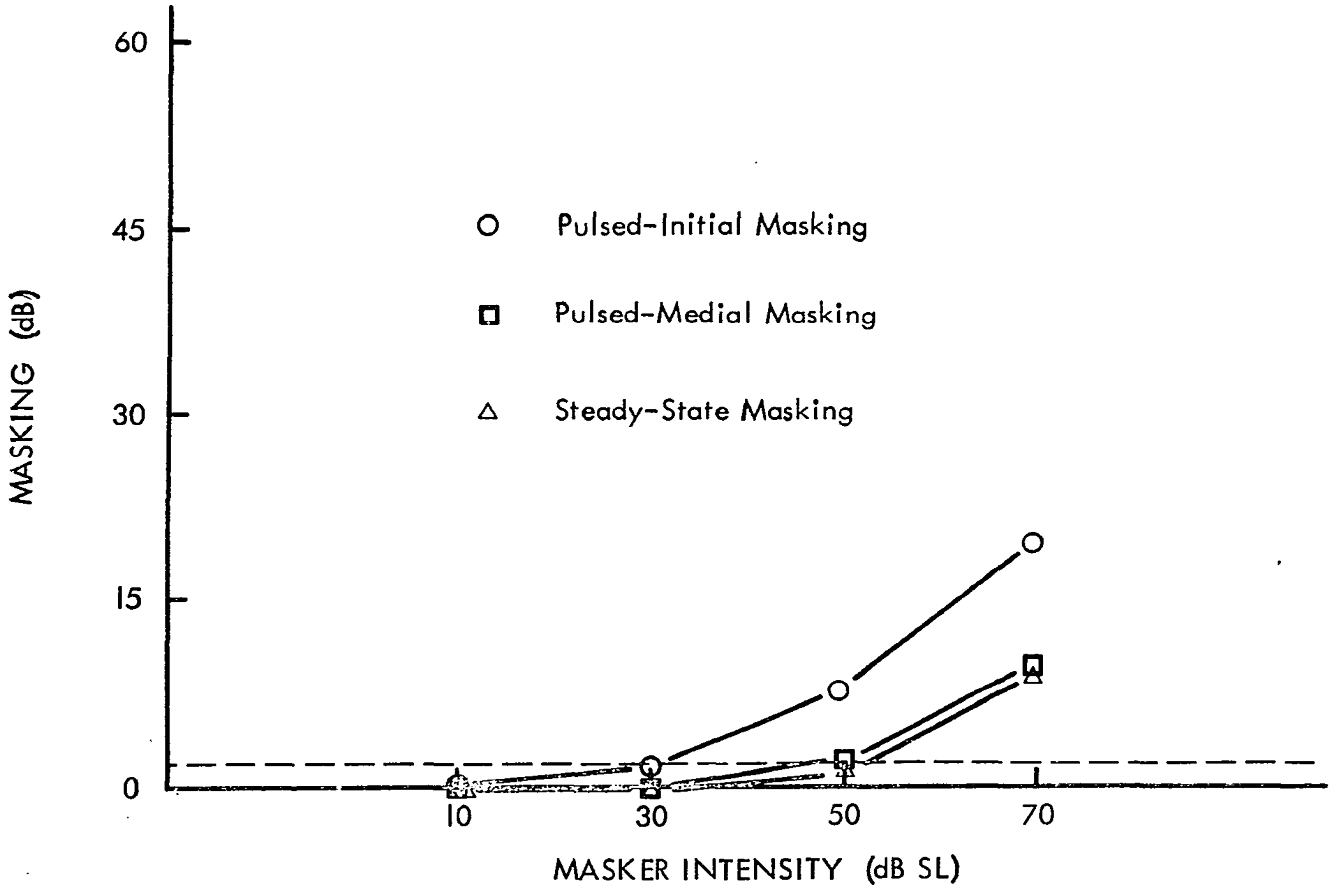

Figure 9.--Mean growth of ipsilateral masking (in dB) at 4000 Hz for pulsed-initial, pulsed-medial, and steady-state maskers.

50 and 70 dB SL and a slope of less than one at masker sensation levels below 50 dB. Therefore, the growth of pulsed-medial and steady-state ipsilateral pure-tone masking is not precisely linear and does not reach a slope of one until high masker intensities are achieved.

Figure 8 shows that the mean growth of masking functions for pulsed-medial and steady-state conditions at 230 Hz are not identical. The two functions intersect at a masker sensation level interpolated to be approximately 40 dB. Mean steady-state masking is greater than mean pulsed-medial masking at 10 and 30 dB SL and mean pulsed-medial masking is greater than mean steady-state masking at 50 and 70 dB SL. This finding may contribute to an explanation of the differences in efficiency for pulsed-medial and steady-state masking noted in the literature (Zwicker, 1965a; Lankford and Stokinger, 1969; Elliott, 1969).

The growth of masking data of this experiment also support the previously expressed hypothesis that overshoot increases in magnitude up to a masker intensity of about 50 dB SL and remains relatively stable in magnitude at higher masker intensities (see Overshoot in Ipsilateral Masking in this chapter) and that pulsed-initial minus steady-state ipsilateral masking differences increase in magnitude up to a masker intensity of about 50 dB SL and remain relatively stable at higher masker intensities (see Pulsed Versus Steady-State Ipsilateral Masking in this chapter). Figure 8 shows that the mean growth of pulsed-initial masking diverges from the mean growth of pulsed-medial and steady-state masking from 10 to 50 dB SL. Between the 50 and 70 dB masker sensation levels, however, all three functions are essentially parallel.

Contralateral Masking

Several aspects of contralateral masking were investigated with 200 Hz maskers at sensation levels of 10, 30, 50, and 70 dB. The temporal conditions included pulsed-initial, pulsed-medial, and steady-state masking. Pulsed-initial and steady-state masking were studied at maskee frequencies of 170, 230, 500, 750, 1500, and 4000 Hz. Pulsed-medial masking was investigated at 230 and 4000 Hz only. Table 8

TABLE 8

MEAN THRESHOLD SHIFTS (IN dB) FOR CONTRALATERAL MASKING

Maskee Frequency (in Hz)	Masker Condition	Maskee Position	Masker Level (in dB SL) 10	30	50	70
170	Pulsed	Initial	-0.1*	3.2	7.1	14.1
170	SS	-	0.8*	1.1*	0.5*	2.9
230	Pulsed	Initial	2.0	4.6	10.1	14.6
230	Pulsed	Medial	1.6*	1.6*	2.6	7.2
230	SS	-	1.2*	1.4*	1.4*	6.6
500	Pulsed	Initial	0.7*	4.0	7.5	11.0
500	SS	-	0.1*	0.7*	1.4*	3.0
750	Pulsed	Initial	-0.5*	2.2	6.0	7.9
750	SS	-	0.2*	0.1*	1.4*	3.1
1500	Pulsed	Initial	0.0*	0.8*	4.0	8.2
1500	SS	-	-0.2*	-0.9*	-0.6*	-0.6*
4000	Pulsed	Initial	0.1*	1.6*	3.3	5.0
4000	Pulsed	Medial	1.0*	0.5*	1.2*	2.2
4000	SS	-	0.3*	0.9*	0.8*	0.1*

*Threshold shift not statistically significant.

contains the mean threshold shifts obtained in this experiment for all contralateral masking conditions. These data are graphically displayed in Figures 10 and 11. All unmasked and masked contralateral thresholds reported in sound pressure level are presented in APPENDIX C.

Temporal Relations in Contralateral Masking. The investigation of temporal relations in contralateral masking include the study of overshoot and pulsed versus steady-state masking.

Overshoot in Contralateral Masking. Contralateral masking overshoot was investigated at maskee frequencies of 230 and 4000 Hz. Overshoot is calculated by subtracting pulsed-medial masking from pulsed-initial masking. Table 9 shows the mean overshoot obtained in

TABLE 9

MEAN OVERSHOOT (IN dB) FOR CONTRALATERAL MASKING

Masker Level (in dB SL)	Maskee Frequency (in Hz) 230	4000
10	0.4*	-0.9*
30	3.0*	1.1*
50	7.5	2.1*
70	7.4	2.8

*See text

this study for all contralateral conditions. This data may be graphically observed by the comparison of mean pulsed-initial and mean pulsed-medial masking in Figures 10 and 11.

The data marked with an asterisk in Table 9 were calculated

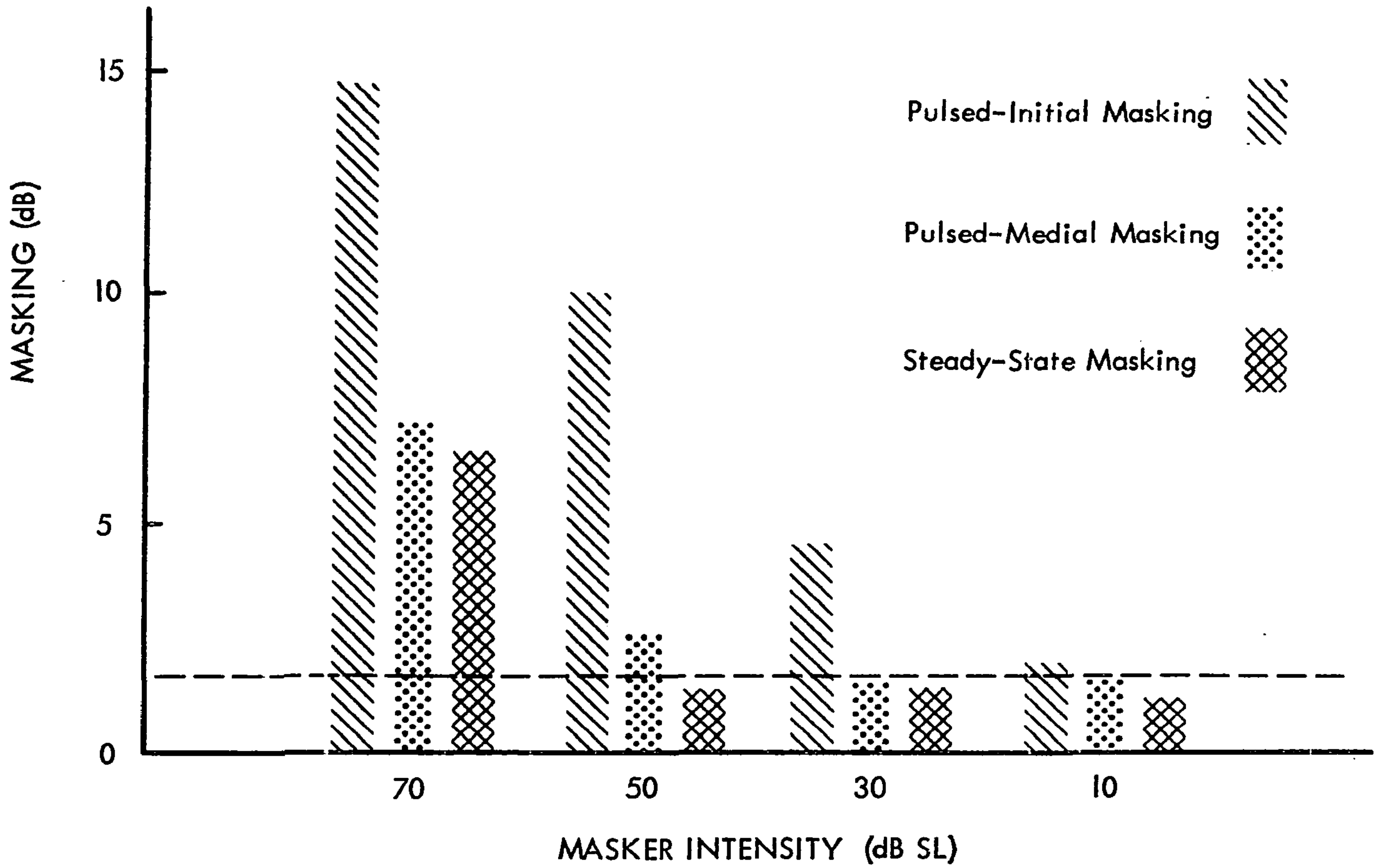

Figure 10.--Mean threshold shifts (in dB) at 230 Hz for pulsed-initial, pulsed-medial, and steady-state contralateral masking.

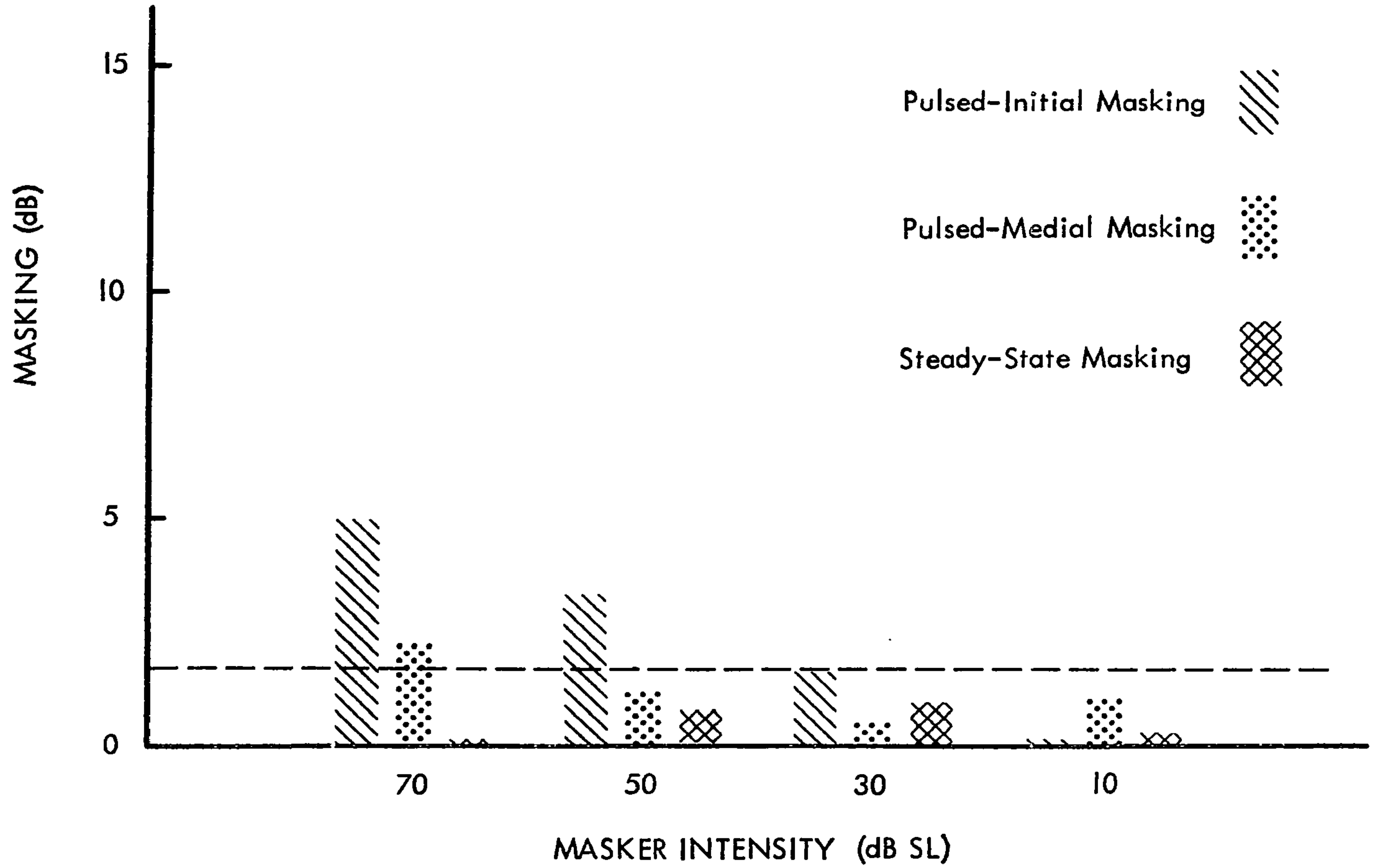

Figure 11.--Mean threshold shifts (in dB) at 4000 Hz for pulsed-initial, pulsed-medial, and steady-state contralateral masking.

when either the mean pulsed-initial or the mean pulsed-medial threshold shifts, or both, were not statistically significant. Most of the individual subject data support the trends noted in Table 9 and Figures 10 and 11. Only a few exceptions to these trends were noted and they occurred at the low masker sensation levels.

This experiment shows that overshoot exists for a low-frequency contralateral masker at maskee frequencies near and far removed from that of the masker. Whenever significant contralateral masking occurred, mean pulsed-initial masking was greater than mean pulsed-medial masking. Several instances occurred where pulsed-initial masking resulted in significant threshold shifts but pulsed-medial masking did not (230 Hz at 10 and 30 dB SL and 4000 Hz at 50 dB SL). The expectation that overshoot would be minimal for low-frequency contralateral masking was based on findings of investigators who studied the efficiency of steady-state and simultaneously pulsed noise maskers with pulsed pure-tone maskees (Dirks and Norris, 1966; Johnson, 1968). The maskers were adjusted to equal effective masking levels at the individual maskee frequencies and differences between pulsed and steady-state masking decreased as the maskee frequency was decreased.

Zwislocki, Buining, and Glantz (1968) reported that central masking overshoot for 60 dB SL pure-tone maskers located near in frequency to 1000 Hz maskees range from about 6 to 16 dB. Two of their three subjects showed from about 6 to 8 dB overshoot. Mean overshoot in the current experiment at 230 Hz for the 50 and 70 dB masker sensation levels was approximately 7.5 dB, nearly the same as that noted for two of the subjects employed by Zwislocki, Buining, and Glantz.

Lankford (1969), however, noted substantially less central masking overshoot with a 1000 Hz, 50 dB SPL masker than did Zwislocki, Buining, and Glantz. Lankford found no greater than 3.6 dB mean overshoot for any of the maskees investigated. These results represent less than half the overshoot noted in this experiment for the 50 dB masker sensation level. If normal threshold at 1000 Hz (ANSI, 1969) is assumed for Lankford's subjects, the 50 dB SPL masker represents a sensation level of 43 dB. Similar maskee duration and temporal patterns were utilized in this study and in Lankford's study and both investigators used relatively precise psychophysical methods for the determination of unmasked and masked auditory thresholds. Therefore, it is difficult to explain the difference in overshoot magnitude between the two studies, except to note that 200 Hz maskers were used in the present study while Lankford employed 1000 Hz maskers. These findings suggest that contralateral overshoot may be greater for low-frequency masker-maskee combinations than for mid- and high-frequency masker-maskee combinations.

Comparison of the results of this experiment to those of Deatherage and Evans (1969) are rendered difficult because the latter used a signal detection paradigm to assess the temporal effects of contralateral masking with 1000 Hz maskers and maskees. Deatherage and Evans found that contralateral masking was generally greatest at the masker onset becoming less effective when the maskees were located after the masker onset.

Pulsed Versus Steady-State Contralateral Masking. Pulsed-initial versus steady-state contralateral masking at 10, 30, 50, and 70 dB SL was studied with maskee frequencies of 170, 230, 500, 750, 1500, 4000 Hz. Pulsed-medial versus steady-state contralateral masking was studied at 230 and 4000 Hz only.

The mean pulsed-initial minus mean steady-state contralateral masking differences obtained in this experiment are shown in Table 10.

TABLE 10

MEAN DIFFERENCES (IN dB) BETWEEN PULSED-INITIAL AND STEADY-STATE CONTRALATERAL MASKING

Masker Level (in dB SL)	Maskee Frequency (in Hz) 170	230	500	750	1500	4000
10	-0.9*	0.8**	0.6*	-0.7*	0.2*	-0.2*
30	2.1**	3.2**	3.3**	2.1**	1.7*	0.7*
50	6.6**	8.7**	6.1**	4.6**	4.6**	2.5**
70	11.2	8.0	8.0	4.8	8.8**	4.9**

*See text
**See text

The data marked with one asterisk (*) in Table 10 were calculated when both mean pulsed-initial and mean steady-state threshold shifts were not statistically significant. The data marked with two asterisks (**) in Table 10 were calculated when the mean pulsed-initial threshold shift achieved significance but the mean steady-state threshold shift did not. Mean contralateral pulsed-initial masking was always greater than mean steady-state masking whenever the pulsed-initial threshold shifts were significant. It must be emphasized that mean contralateral steady-state masking threshold shifts did not achieve significance except at 170, 230, 500, and 750 Hz for the 70 dB masker sensation level. Most of the individual data show the same general trends observed in Table 10. Steady-state masking yielded greater threshold shifts than did pulsed-initial masking for several subjects, but these usually resulted when either or both of the threshold shifts failed to reach significance.

Mean pulsed-medial minus mean steady-state contralateral masking differences obtained in this experiment are shown in Table 11.

TABLE 11

MEAN DIFFERENCES (IN dB) BETWEEN PULSED-MEDIAL AND STEADY-STATE CONTRALATERAL MASKING

Maskee Frequency (in Hz)	Masker Level (in dB SL)			
	10	30	50	70
230	0.4*	0.2*	1.2**	0.6
4000	0.7*	-0.4*	0.4**	2.1**

*See text
**See text

The data marked with one asterisk (*) in Table 11 were calculated when both mean pulsed-medial and mean steady-state threshold shifts did not reach statistical significance. The data marked with two asterisks (**) were calculated when the mean pulsed-medial threshold shift was significant but the mean steady-state threshold shift was not. The individual subject data generally support the trends shown in Table 11. Some conflicting results were noted but these were few and generally occurred at the lowest masker intensities.

Stokinger and Lankford (1969) investigated pulsed-medial versus steady-state contralateral masking with 50 dB SPL, 1000 Hz maskers. The pulsed maskers were one second in duration and the maskees were brief pure tones from 800 to 1200 Hz located 500 msec after the masker onset. A signal detection paradigm was used to assess the efficiency of the two masking conditions. Mean maskee detectability was better for pulsed-medial masking than for steady-state masking indicating that greater masking occurred for the steady-state condition than for the pulsed-medial condition. The greatest difference in signal detection between the two conditions, however, was only about 12 per cent, a figure which does not translate readily into decibels. A 12 per cent difference in maskee detection is probably equivalent to no more than one decibel difference in masker intensity or is essentially the same as equal detection. In this experiment where significant mean threshold shifts occurred for both pulsed-medial and steady-state contralateral masking, a difference of less than one decibel in the opposite direction was noted. Even though the present study and Stokinger and Lankford's study yielded opposite findings, neither demonstrated a difference in efficiency between pulsed-medial and steady-state contralateral masking that is considered significant.

Frequency Spread of Contralateral Masking. The frequency spread of low-frequency contralateral masking was studied with 200 Hz pure-tone pulsed and steady-state maskers presented at 10, 30, 50, and 70 dB SL. Pulsed-initial and steady-state masking was investigated at maskee frequencies of 170, 230, 500, 750, 1500, and 4000 Hz.

Figure 12 graphically displays the mean frequency spread of

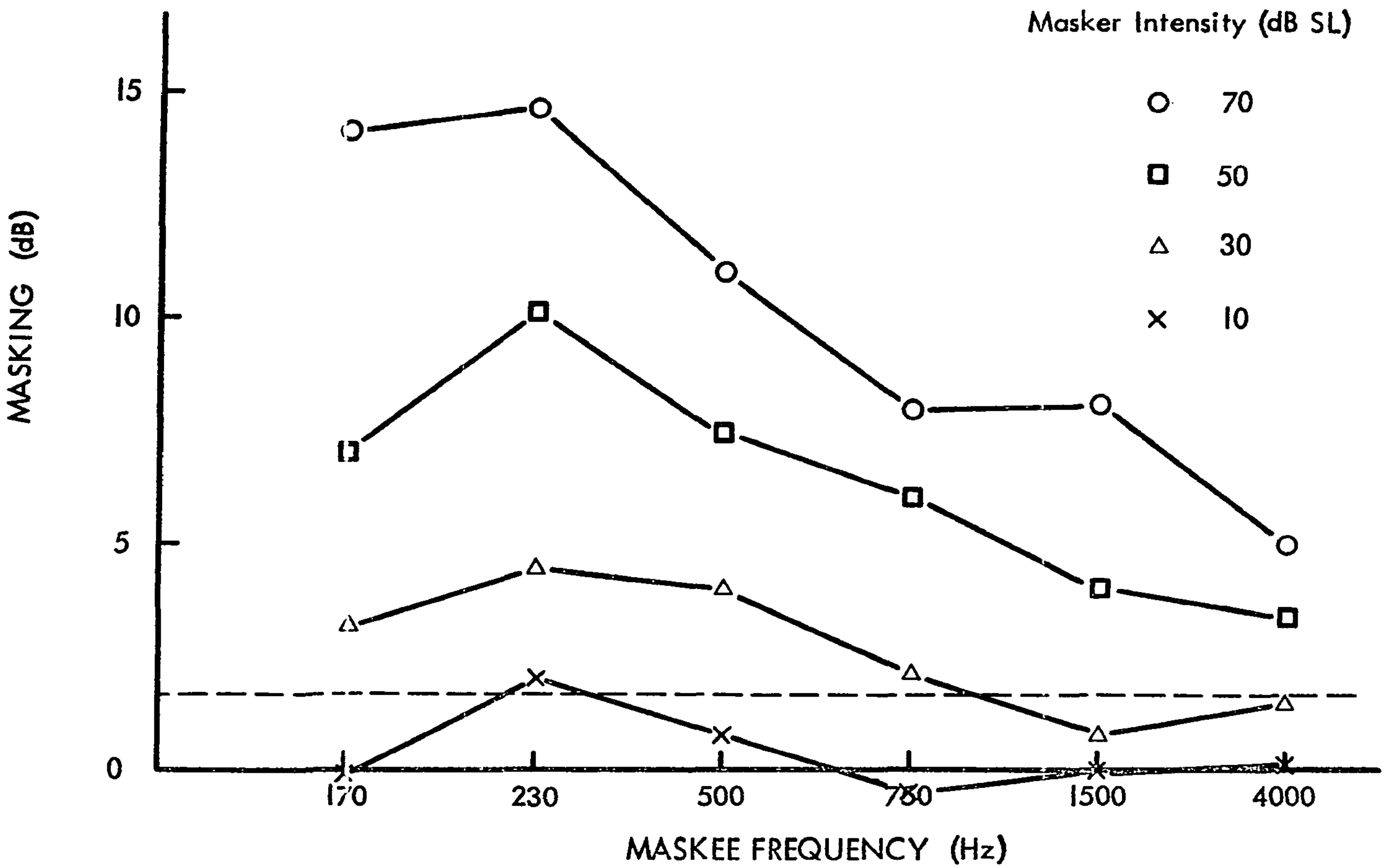

Figure 12.--Mean frequency spread of pulsed-initial contralateral masking at 10, 30, 50, and 70 dB masker sensation levels.

contralateral pulsed-initial masking obtained in this experiment. Pulsed-initial masking at 10 dB SL resulted in significant mean threshold shifts only near the frequency of the masker. As the masker intensity was increased, the frequency spread of contralateral masking also increased, but even the most intense masker resulted in an approximate mean threshold shift of only 5 dB at 4000 Hz. The spread of masking functions for the four masker intensities maintained similar configurations. At each level of masking, maximum threshold shifts were observed near the masker frequency and as the maskee frequencies became more distant from the masker frequency, the threshold shifts became less in magnitude.

Figure 13 graphically displays the mean spread of low-frequency contralateral steady-state masking obtained in this experiment. Several important differences are noted in contrast to the spread of contralateral pulsed-initial masking illustrated in Figure 12. The only significant threshold shifts under contralateral steady-state masking occurred at 170, 230, 500, and 750 Hz at the 70 dB masker sensation level. The 50 dB SL steady-state maskers resulted in mean threshold shifts that border on significance at 230, 500, and 750 Hz. The 10 and 30 dB steady-state masker sensation levels resulted in non-significant mean threshold shifts at all maskee frequencies. It is possible that the significant threshold shifts observed at 70 dB SL are the result of transcranial or cross-masking of the test ear. This point is discussed further in the Growth of Contralateral Masking section of this chapter.

Figure 13 also reveals that consistant negative mean threshold shifts occurred under steady-state masking at 1500 Hz for all masker

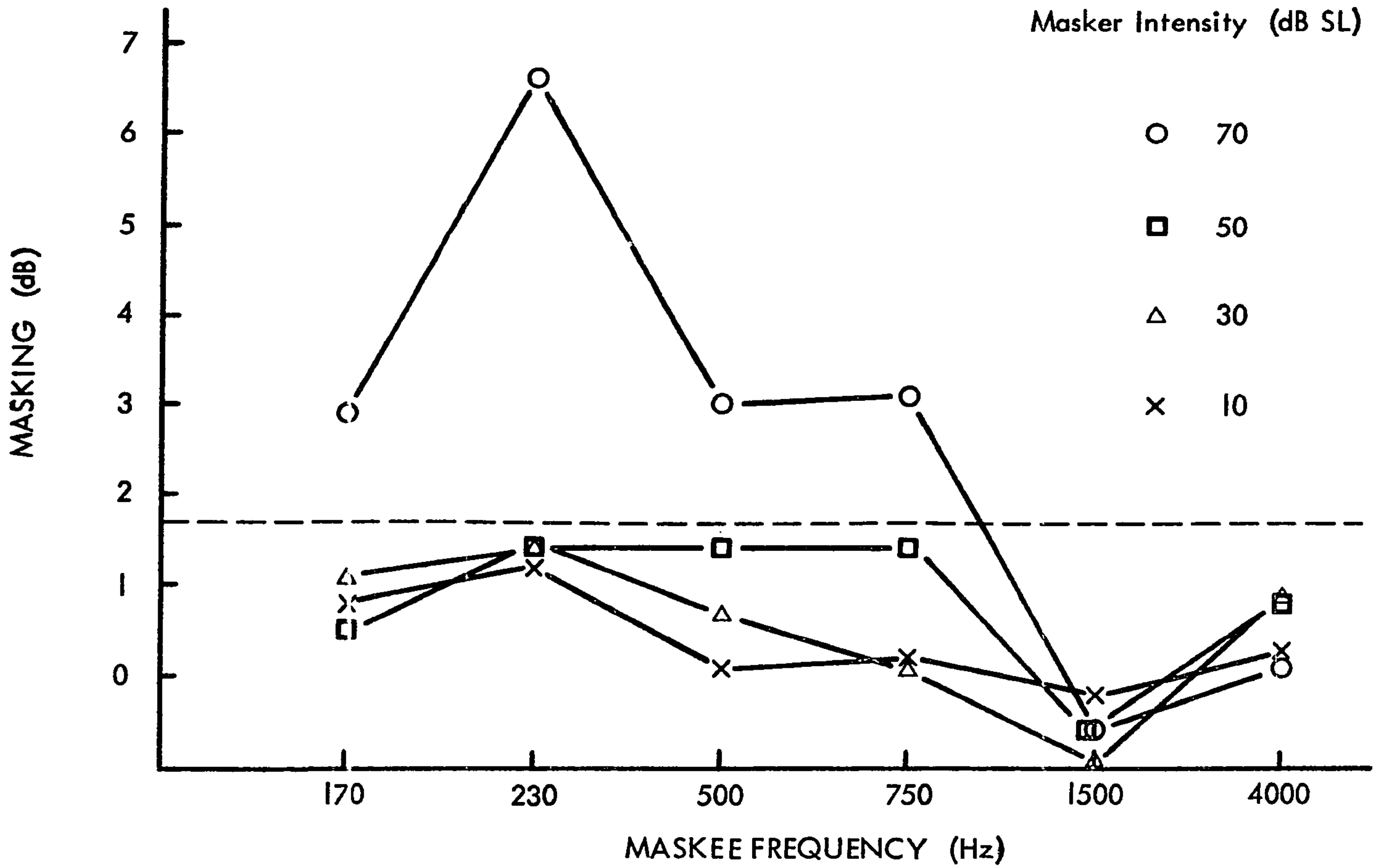

Figure 13.--Mean frequency spread of steady-state contralateral masking at 10, 30, 50, and 70 dB masker sensation levels.

intensities. None of the negative threshold shifts, however, reached a statistically significant value (-1.68 dB). Finally, the steady-state spread of masking function at 70 dB SL possesses a more limited frequency range than was observed for the spread of pulsed-initial contralateral masking.

Several comparisons can be made between these data and those of other investigators. Figure 12 shows that the mean spread of contralateral pulsed-initial masking is relatively broad for the 50 and the 70 dB masker sensation levels. In fact, significant masking occurred at 4000 Hz under both of these conditions. Other investigators have found that higher-frequency contralateral pure-tone maskers result in very narrow spread of masking functions up to masker intensities of about 60 dB SL, usually limited to less than two octaves on either side of the masker (Wegel and Lane, 1924; Ingham, 1959; Dirks and Norris, 1966; Zwislocki, Buining, and Glantz, 1968; Lankford, 1969). Therefore, it appears that the spread of contralateral masking is dependent on the frequency of the masker as well as its intensity.

Ingham (1959) observed that 30 dB SL low-frequency (200 Hz) contralateral pure-tone maskers resulted in broader spread of masking functions than did higher frequency maskers. This experiment supports Ingham's findings since the low-frequency contralateral maskers also resulted in a very broad spread of masking function. However, the magnitudes of masking and the spread of masking obtained in this experiment are considerably less than those found by Ingham at 30 dB SL (Ingham used only one masker intensity). None of the temporal patterns in the present experiment resulted in significant mean threshold shifts at 4000

Hz for the 30 dB masker sensation level. Significant mean contralateral threshold shifts at 4000 Hz occurred only for pulsed-initial masking at 50 and 70 dB SL and for pulsed-medial masking at 70 dB SL.

Several differences are noted between the procedures used by Ingham and those of this experiment that may explain the difference in results noted between the two studies. First, the masker-maskee temporal relations differed in the two studies. The pulsed-initial temporal pattern used in this study, however, was chosen because it yields maximum masking when compared to other masker-maskee temporal relations. Second, even though Ingham required his subjects to complete brief practice sessions, it is expected that they were not as sophisticated in the task of threshold judgments as were the subjects of this experiment. Finally, Ingham did not conduct his experiment in a sound-controlled environment as was the case in this experiment. Ingham consistantly obtained up to about 3 dB greater mean masking at 170, 230, and 550 Hz for the 30 dB SL, 200 Hz contralateral masker when compared to the results of this study. This suggests that the differences between the studies may be attributable to methodological and procedural variations.

Other investigators have noted that the frequency spread of contralateral masking near 1000 Hz contains multi-modal maxima and minima near the masker frequency that do not seem to be related to signal harmonics or other artifacts (Zwislocki, et al., 1967; Zwislocki, Buining, and Glantz, 1968; Lankford, 1969). None of these investigators, however, reported consistant negative contralateral masking threshold shifts (sensitization) similar to those observed in this experiment at 1500 Hz under steady-state masking. This phenomenon was not the result of one or two deviant subject responses. All but one subject showed a negative threshold shift at 1500 Hz for 70 dB SL steady-state masking. All subjects showed negative shifts for 30 and 50 dB SL steady-state masking and only one subject showed a positive threshold shift for 10 dB SL steady-state masking. Since the 1500 Hz maskee frequency is far removed from the 200 Hz masker and since the two were stimulating opposite ears, it is unlikely that this phenomenon is the result of signal artifacts. The significance of these negative threshold shifts is questionable, however, and a reasonable explanation for their occurrance has not been formulated.

Growth of Contralateral Masking. The growth of pulsed-initial and steady-state contralateral masking was investigated at 10, 30, 50, and 70 dB masker sensation levels for all maskee frequencies. The growth of pulsed-medial contralateral masking was investigated at 230 and 4000 Hz only.

Growth of masking functions are important in contralateral masking experiments for the purpose of assessing the probable role of transcranial or cross-masking at high masker intensities. If the contralateral masker intensity exceeds interaural attenuation at that frequency, the threshold shifts may be considered to represent, at least in part, peripheral masking effects due to direct masker stimulation of the test ear. Such a phenomenon was noted by Wegel and Lane (1924) and was employed more recently to ascertain interaural attenuation for pure tones (Zwislocki, 1953).

Figures 14, 15, and 16 graphically display the mean growth of contralateral masking obtained in this experiment for pulsed-initial,

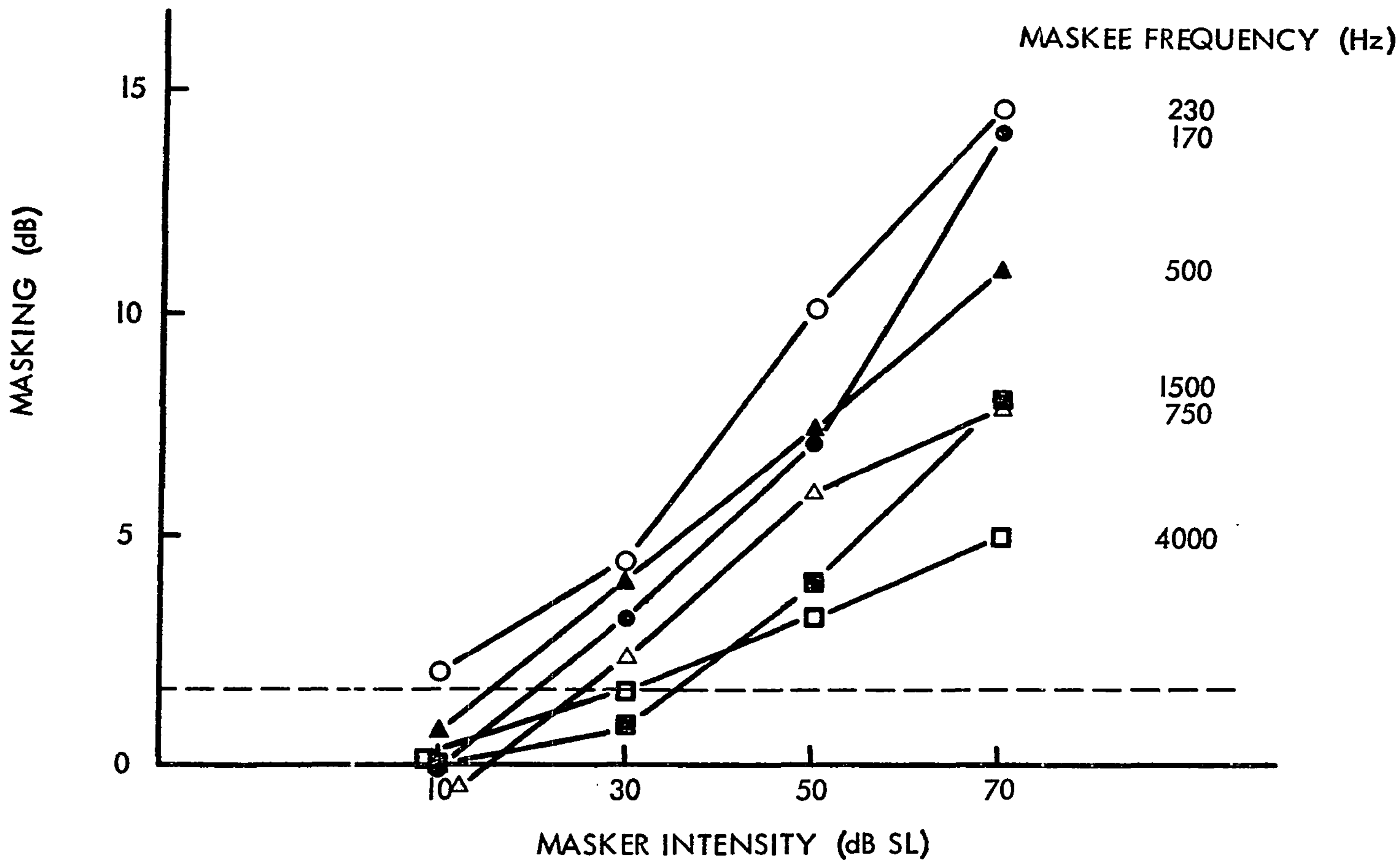

Figure 14.--Mean growth of pulsed-initial contralateral masking (in dB) at all maskee frequencies.

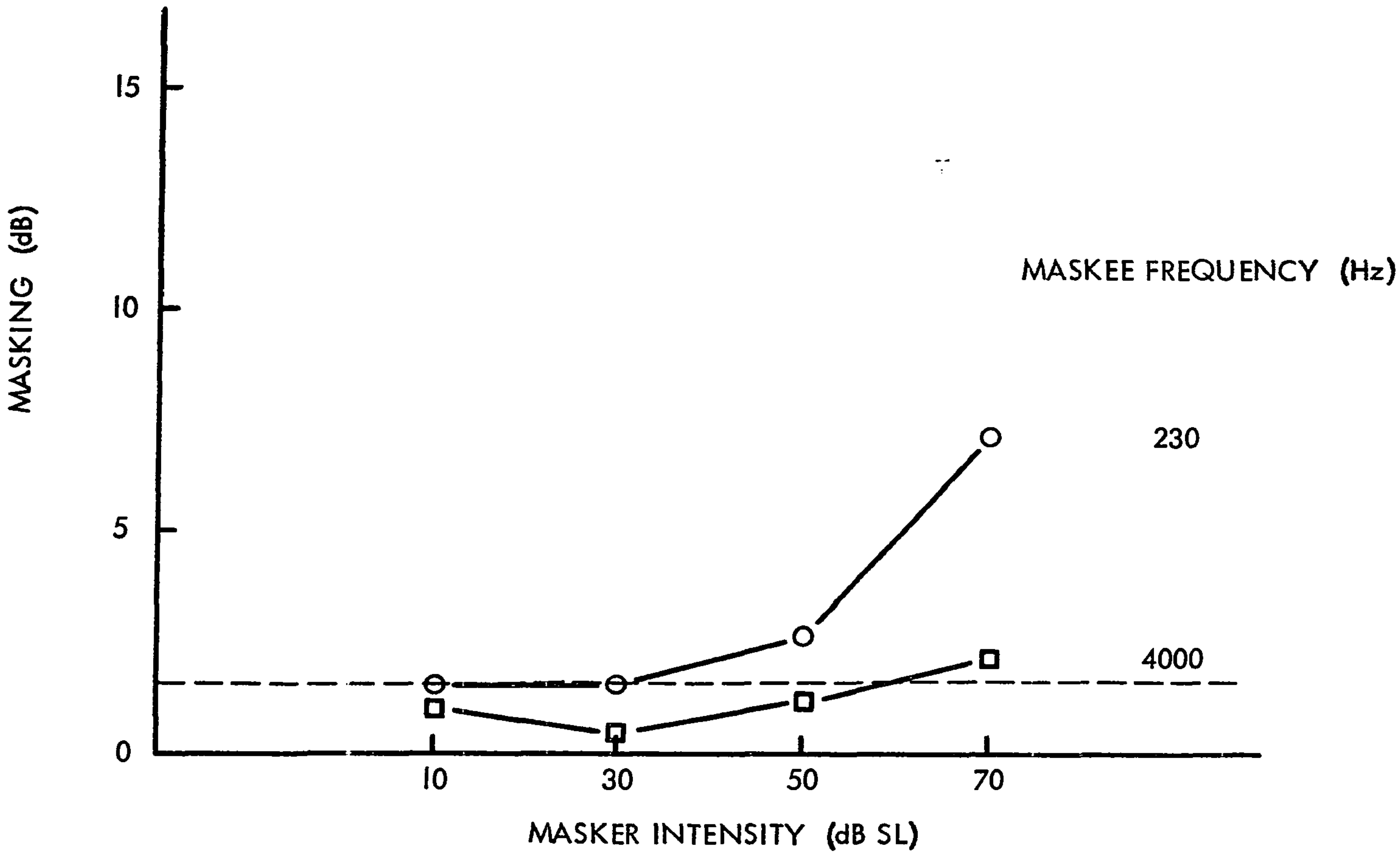

Figure 15.--Mean growth of pulsed-medial contralateral masking (in dB) at 230 and 4000 Hz.

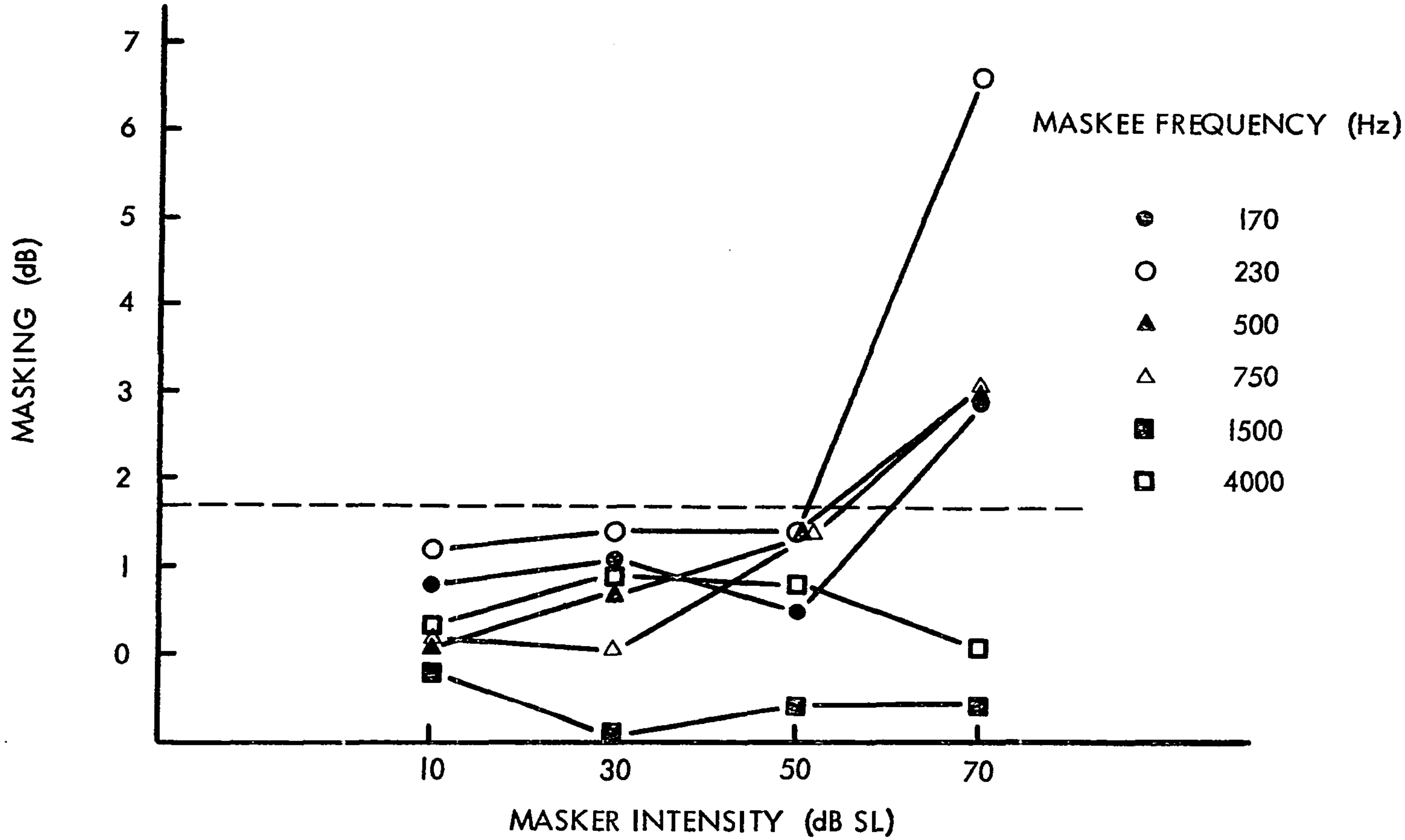

Figure 16.--Mean growth of steady-state contralateral masking (in dB) at all maskee frequencies.

pulsed-medial, and steady-state masking conditions, respectively. Figure 16 possesses a different ordinate scale than those of Figures 14 and 15. Individual subject data generally followed the trends illustrated in these figures, although differences in magnitudes of masking were common.

Figure 14 reveals that the characteristic increase in growth of contralateral masking due to transcranial masking at high masker intensities is not present for the pulsed-initial condition. It was expected that such an increase would occur between the 50 and the 70 dB masker sensation levels since interaural attenuation at 200 Hz is approximately 45 to 50 dB. There is little question that the 70 dB SL masker exceeded interaural attenuation at 200 Hz but whether or not this high-intensity masker caused peripheral masking in addition to central masking is open to question. If a simple combination of central and peripheral masking occurred, a significant increase in the growth of contralateral masking function would be expected. This pattern was not observed for mean pulsed-initial contralateral masking. If interaural attenuation at 200 Hz is assumed to be about 50 dB (see Chapter II), the 70 dB SL masker would appear to be equivalent to a 50 dB SL contralateral masker plus a 20 dB SL ipsilateral masker due to transcranial masking. The simple addition of mean central masking at 230 Hz for a 50 dB SL masker (about 10 dB) and mean peripheral masking at 230 Hz for a 20 dB SL masker (about 12 dB, interpolated from Figure 8) results in expected masking of about 22 dB. Only 14.6 dB mean contralateral masking was noted at 230 Hz for the 70 dB SL pulsed-initial maskers. This finding suggests that the mean pulsed-initial masking at 70 dB SL is not a simple additive function of central and peripheral masking. In fact, the present mean masking for 230 Hz under the 70 dB SL pulsed-initial condition is less than 5 dB greater than that expected from either a 50 dB SL contralateral masker or a 20 dB SL ipsilateral masker.

Figure 15 graphically displays the mean growth of contralateral pulsed-medial masking obtained in this experiment at 230 and 4000 Hz. Significant mean pulsed-medial contralateral threshold shifts occurred for the 50 and 70 dB masker sensation levels at 230 Hz and for the 70 dB masker sensation level at 4000 Hz only. It is impossible to analyze the growth of contralateral pulsed-medial masking due to the lack of significant threshold shifts. The increase in the mean growth of masking at 230 Hz between masker sensation levels of 50 and 70 dB may be due to transcranial masking effects but interaural attenuation at 200 Hz was not assessed for the subjects of this experiment.

Figure 16 graphically displays the mean growth of contralateral steady-state masking obtained in this experiment. The ordinate scale of Figure 16 is different from those of Figures 14 and 15. The 10, 30, and 50 dB SL contralateral steady-state maskers did not result in significant mean threshold shifts at any of the maskee frequencies. The 70 dB masker sensation level yielded significant mean threshold shifts at 170, 230, 500, and 750 Hz only. It is hypothesized that the significant threshold shifts observed for the 70 dB masker sensation level are due to the effects of transcranial masking because this masker level exceeds interaural attenuation at 200 Hz.

Zwislocki, <u>et al</u>. (1967) also found that contralateral steady-state masking is of minimal magnitude even at high masker levels. Less than 3 dB contralateral masking was observed for 1000 Hz steady-state maskers at intensities of from 10 to 80 dB SL (a special insert transducer was utilized to maximize interaural attenuation). Steady-state contralateral masking increased slightly up to masker sensation levels of from 10 to 40 dB remaining relatively constant or decreasing with further increases in masker intensity. When the growth of a masking function showed less masking at higher intensities than at lower intensities, Zwislocki called the phenomenon "decay of central masking". The authors concluded that "The decay of central masking (with steady-state maskers and pulsed maskees) at high sensation levels was found a sufficient number of times to be considered a real phenomenon." The current findings support those of Zwislocki, et al., since no significant mean contralateral steady-state threshold shifts were noted at any maskee frequency at or below the 50 dB SL masker intensity. Implications of the present findings and those of Zwislocki, et al. are treated further in the Discussion section of this chapter.

Discussion

The results of this experiment provide information relevant to several aspects of masking. This discussion is primarily concerned with contralateral rather than ipsilateral masking phenomena. Contralateral versus central masking, the nature of central masking, and neurological correlates of overshoot are discussed in this section.

Contralateral Versus Central Masking

Contralateral masking occurs when the maskers are presented to one ear and the maskees are presented to the opposite ear. If the masker intensity does not exceed interaural attenuation, threshold shifts in the opposite ear represent central masking since the masker and maskees are acoustically insulated from one another. If the masker intensity exceeds interaural attenuation, threshold shifts in the opposite ear may also represent transcranial masking that includes peripheral masking due to direct stimulation of the test ear by the masker. Determination of interaural attenuation is, therefore, necessary in contralateral masking experiments to separate the effects of central and peripheral masking.

Interaural attenuation values for pure tones have been determined by many investigators using various techniques. Several studies have been reported (see Chapter II) in which subjects with total unilateral hearing loss were used for the determination of interaural attenuation values. It is assumed that interaural attenuation is the decibel difference between the pure-tone threshold in the better ear for signals presented to that ear and the pure-tone threshold in the better ear for signals presented to the poorer ear. Other investigators (Wegel and Lane, 1924; Zwislocki, 1953) used a masking technique to determine the magnitude of interaural attenuation. Maskee thresholds are obtained at several levels of contralateral masking and interaural attenuation is assumed to be exceeded when the growth of masking function rises sharply. This change in the function is due to direct stimulation of the test ear by the masker. Lane (1925), Zwislocki (1953), and Bekesy (1960, p. 175) used the method of best beats to determine the magnitude of interaural attenuation for pure-tone signals. Zwislocki (1953) also used the method of compensation, in addition to those procedures mentioned above, to investigate interaural attenuation.

Interaural attenuation is dependent on the signal frequency and the type of transducer used in the measurement. A review of the literature yields considerable agreement among investigators and techniques with interaural attenuation at 200 and 250 Hz ranging from about 40 to 55 dB. The mean growth of contralateral masking function at 230 Hz in this experiment generates an approximation of the magnitude of interaural attenuation via the masking method. The mean growth of steady-state contralateral pure-tone masking (Figure 16) rapidly increases between masker intensities of 50 and 70 dB SL. The mean growth of pulsed-medial contralateral masking (Figure 15) increases between masker intensities of 50 and 70 dB SL, though not as rapidly as the growth of steady-state masking. The mean growth of contralateral pulsed-initial pure-tone masking (Figure 14), however, is approximately linear and does not increase significantly between masker intensities of 50 and 70 dB SL. The only difference among the three masking conditions is the temporal relation between the maskers and maskees. These results demonstrate that the growth of contralateral masking is dependent upon masker-maskee temporal relations, as well as frequency and transducer factors. It is unknown whether these temporal effects influence the central or peripheral components of contralateral masking or both.

Further investigation of contralateral masking may yield additional evidence of the effect of masker-maskee temporal relations on interaural attenuation. It is suggested that such an investigation include low, middle, and high frequency pure-tone maskers presented in various temporal relations with the test signals. The experiment should employ intensities that encompass the normal range of interaural attenuation with the size of the steps selected to provide the most accurate results.

Most of the contralateral masking results discussed in Chapter II of this dissertation were referred to as "central masking", either because the investigators used masker intensities that did not exceed interaural attenuation or because they used special transducers to maximize interaural attenuation. The results of this investigation have been classified, thus far, under the general term "contralateral masking". It is reasonable to assume that the mean threshold shifts resulting from pulsed-initial, pulsed-medial, and steady-state maskers presented at or below 50 dB SL are due to "central masking". The mean pulsed-medial and mean steady-state contralateral masking data obtained at 70 dB SL probably reflect transcranial masking effects. The results from the 70 dB SL pulsed-initial contralateral masking condition present a classification problem with respect to the underlying masking phenomena that cannot be resolved without further experimentation.

The Nature of Central Masking

The mean pulsed-initial contralateral masking results of this experiment support Ingham's (1959) findings and suggests that central masking is directly dependent on cochlear mediation of the masker. This suggestion is based on the observation that low-frequency peripheral maskers result in broader spread of masking functions than are reported for mid- or high-frequency maskers of comparable sensation level. Certain low-frequency pure-tone contralateral maskers also result in broader spread of central masking than do mid- or high-frequency maskers. The peripheral mechanism or cochlea is, therefore, implicated as the locus of the primary mediator of central masking characteristics. There can be little argument, however, that the actual central masking phenomenon results ultimately when neural interaction or interference occurs between the stimuli in the central auditory system.

The auditory masking pattern of a pure tone is generally described by its intensity and frequency characteristics. Thus, increases in masker intensity result in increases in masking and greater masking occurs at maskee frequencies near that of the masker than at frequencies removed from that of the masker. The masking pattern for a pulsed-initial contralateral masker may be described by the above characteristics. First, significant threshold shifts resulted from the introduction of the masker. Second, increases in masking resulted from increased masker intensity. Third, masking was greater for maskees near in frequency to that of the masker than for maskees more distant from the masker. The steady-state masking patterns (i.e., under masker sensation levels of 10, 30, and 50 dB), however, do not conform to the above description. These contralateral masking conditions did not result in significant threshold shifts at any maskee frequency investigated. In addition, increases in masker intensity did not necessarily result in increases in masking. Finally, only a limited frequency specificity of the threshold shifts was observed. Other investigators have also reported only minimal threshold shifts and limited frequency specificity for pulsed-medial and/or steady-state central masking conditions (Zwislocki, 1967; Zwislocki, Buining, and Glantz, 1968; Lankford, 1969). These results suggest that classical central masking either does not exist or is markedly reduced under pulsed-medial or steady-state pure-tone masking conditions.

On the basis of these experimental findings, it is appropriate to reclassify central masking according to the masking patterns produced by the masker. Classical central masking that results in significant, frequency-specific, and intensity-dependent threshold shifts is produced by maskers of a transient nature (see Chapter II). These include broad- and narrow-band noise, clicks, and perhaps the onset and offset of pure tones. Evidence from this experiment suggest that steady-state pure tones, including the medial position of pulsed pure tones, do not produce classical central masking patterns.

Although this and other investigations have yielded only minimal or non-significant threshold shifts for steady-state central masking, positive threshold shifts do occur regularly under these conditions. However, these shifts do not fit the classical pattern that results from central or peripheral pure-tone masking. It is possible that the locus for such threshold shifts may be in the reticular formation of the brain stem and/or the nuclei of the thalamus. Galambos (1954), Whitfield (1967, p. 10) and others suggest that the afferent auditory system projects collaterals to and through the reticular formation. Many of these projections still remain unclear from an anatomical and physiological viewpoint. The thalamus is a neural center through which the majority of sensory information passes to the cortex (Truax and Carpenter, p. 475).

Gescheider and Niblette (1967), Gescheider, et al. (1969) and Gescheider (1970) investigated cross-modality masking between acoustic signals presented to the ear and tactile signals presented to the fingertips. Both signals were brief clicks. When the acoustic and tactile signals were presented simultaneously, either was capable of masking the other depending upon which was chosen as the masker. The intermodality masking obtained under these conditions was minimal. The 70 dB SL acoustic masker resulted in approximately a 3.2 dB shift in the tactile threshold from the unmasked condition. The authors concluded that:

> The suppression of neural responses in one modality by stimulation in another is determined, at least in part, by the activity of the reticular formation of the brain stem, a region where neural impulses from all sensory modalities converge . . . . The findings of the present experiment may (partially) be accounted for in terms of the action of the reticular formation.

Neurological Correlates of Overshoot

Masking overshoot has been demonstrated in this experiment as well as by many other investigators (see Chapter II). Numerous neurophysiological studies have shown a similar phenomenon at many levels of the auditory system.

Neural "on-effects" may represent the mechanism responsible for overshoot. The onset of a stimulus results in a greater rate of neural firing and/or higher spike voltages in some units than are measured during steady-state stimulation. The on-effect has been noted for pure-tone stimuli in individual neural units of the auditory nerve of monkeys (Katsuki, Suga, and Kanno, 1962; Nomoto, Suga, and Katsuki, 1964), in the cochlear nuclei of cats (Galambos and Davis, 1943) and gerbils (Smith and Zwislocki, 1971), in the inferior colliculi of cats (Katsuki, et al., 1958; Erulkar, 1959; Rose, et al., 1963; Hind, et al., 1963), in the medial geniculate body of cats (Galambos, 1952; Katsuki, Watanabe, and Maruyama, 1959) and in the auditory cortex of cats (Katsuki, Watanabe, and Maruyama, 1959) and monkeys (Katsuki, Suga, and Kanno, 1962).

It is reasonable to assume that detection of a brief pure-tone stimulus (maskee) may be reduced during the greater neural activity period of the on-effect than during steady-state neural firing under either ipsilateral or contralateral masking. Special reference to the work of Smith and Zwislocki (1971) is made for those who wish to pursue this topic at greater length.

CHAPTER V

SUMMARY

Introduction

Since Wegel and Lane's (1924) investigation of pure-tone ipsilateral and contralateral masking, little effort has been directed toward quantifying the effects of masker-maskee temporal relations on contralateral masking. In addition, little research is available that delineates the characteristics of low-frequency contralateral masking. The primary purpose of the present investigation was to describe and quantify the effects of a low-frequency contralateral masker with respect to masker-maskee temporal relations, frequency spread of masking, and growth of masking. Several ipsilateral masking conditions were also studied for the purpose of comparison to the contralateral masking results of this study and to the ipsilateral masking results of other studies.

A review of masking literature reveals that masker-maskee temporal relations have not been thoroughly investigated for low-frequency ipsilateral or contralateral pure-tone masking. Indirect experimental evidence suggests that overshoot may be minimal or absent under these conditions. One purpose of this experiment was to establish the existence and magnitude of this phenomenon. A further purpose of this experiment was to compare the effects of steady-state masking to pulsed masking with the maskees located midway between the masker onset and offset (pulsed-medial masking). Some experimenters have found that the two conditions yield approximately equal masking while others have not.

The spread of low-frequency ipsilateral pure-tone masking is commonly found to be wider in frequency range than that resulting from mid- or high-frequency ipsilateral pure-tone masking. Ingham (1959) reported a similar central masking phenomenon. However, the effects of masker-maskee temporal relations on the spread of low-frequency contralateral masking remain unclear. This experiment was designed to study the frequency spread of a low-frequency contralateral masker under two different masker-maskee temporal patterns at several masker intensities.

The growth of ipsilateral masking is linear with a slope of one for many different temporal relations. The growth of contralateral masking is also generally considered to be linear but the slope is much less than one. Zwislocki, et al. (1967), however, noted that the growth of steady-state contralateral pure-tone masking was not linear. Maximum masking occurred at masker sensation levels from 10 to 40 dB and further increases in masker intensity resulted in either no additional increases in masking or in decreases in masking. The growth of ipsilateral and contralateral pure-tone masking for low-frequency maskers was investigated in this experiment under both steady-state and pulsed masking conditions.

Quantification of these different aspects of low-frequency pure-tone contralateral masking was expected to result in further clarification and definition of contralateral and central masking processes.

Method

Low-frequency pure-tone masking was investigated with 200 Hz maskers presented at 10, 30, 50, and 70 dB sensation levels. The maskers were presented continuously (steady-state masking) or in a pulsed state with a duration of 500 msec and a period of 3½ seconds. All maskers and maskees had 10 msec rise-decay times. The maskees were brief tone bursts with a duration of 30 msec when measured from the beginning of onset to the termination of offset. Maskees were presented once every 3½ seconds during steady-state masking. Under the pulsed-masking conditions, the maskees were located near the onset (pulsed-initial masking) or in the middle (pulsed-medial masking) of the maskers. Steady-state, pulsed-initial, and pulsed-medial ipsilatersl masking was investigated at maskee frequencies of 230 and 4000 Hz. Steady-state and pulsed-initial contralateral masking was investigated at 170, 230, 500, 750, 1500, and 4000 Hz, and pulsed-medial contralateral masking was studied at 230 and 4000 Hz. The maskees were always presented to the subjects' right ear. Four normal-hearing subjects participated in this experiment and a transformed up-and-down psychophysical method was used for the determination of unmasked and masked auditory thresholds.

Results

Ipsilateral Masking

The investigation of temporal relations in low-frequency ipsilateral masking showed that mean pulsed-initial masking was always greater than either mean pulsed-medial or mean steady-state masking whenever significant threshold shifts occurred. Mean overshoot (pulsed-initial minus pulsed-medial masking) was found to exist for low-frequency ipsilateral masking and was greater in magnitude than noted by other investigators who used higher masker frequencies. The mean magnitude of ipsilateral masking overshoot increased from the 10 dB to the 50 dB masker sensation levels but did not increase further at the 70 dB masker level. Pulsed-medial masking yielded greater mean threshold shifts than did steady-state masking at the two highest masker intensities but these conditions yielded approximately equivalent masking at the two lowest masker intensities.

Investigation of the frequency spread of ipsilateral masking was not possible in this experiment because only two maskee frequencies were employed. However, mean ipsilateral low-frequency masking extended at least to 4000 Hz and its magnitude was dependent upon the masker-maskee temporal pattern and the intensity level of the masker.

The mean growth of ipsilateral pulsed-initial pure-tone masking was linear with a slope of one from the 10 dB to the 70 dB masker sensation levels. The mean growth of steady-state and pulsed-medial ipsilateral pure-tone masking increased in slope as the masker sensation level increased, finally achieving a slope of approximately one between the 50 dB and the 70 dB masker levels.

Contralateral Masking

The investigation of temporal relations in low-frequency contralateral masking showed that mean pulsed-initial masking was always greater than either mean pulsed-medial or mean steady-state masking whenever significant threshold shifts occurred. Overshoot was found to exist for low-frequency contralateral masking and was greater in magnitude than noted by other investigators who used higher masker frequencies. The mean magnitudes of contralateral masking overshoot increased from the 10 to the 50 dB masker sensation levels but did not increase further at the 70 dB masker level. Pulsed-medial contralateral masking yielded slightly greater mean threshold shifts than did steady-state masking at the highest masker intensity but essentially equivalent results were noted for the two conditions at the 10, 30, and 50 dB masker sensation levels.

The mean spread of pulsed-initial contralateral masking was found to be broad in frequency range with significant masking observed at 4000 Hz under the 50 and 70 dB masker sensation levels. The mean spread of steady-state contralateral masking at 70 dB SL was more limited in frequency range. No significant masking occurred under the 10, 30, or 50 dB contralateral steady-state masking conditions.

The mean growth of pulsed-initial low-frequency contralateral masking was linear from the 10 dB to the 70 dB masker levels with a slope representing an approximate two decibel increase of central masking for each 10 dB increase in masker intensity. The mean growth of low-frequency contralateral masking under the steady-state and pulsed-medial conditions was negligible up to a masker sensation level of 50 dB. Between masker sensation levels of 50 and 70 dB the slope approximated that observed under the pulsed-initial conditions.

Conclusions

The results of this experiment, in conjunction with results of other experiment, allow the formulation of several conclusions. These conclusions relate to the nature of interaural attenuation and the nature of the central masking process.

It is hypothesized that temporal relation differences between maskers and maskees may alter the effects of transcranial masking. This hypothesis is based on the finding that the growth functions for pulsed-medial and steady-state contralateral masking showed a sharp increase at the highest level which may have been due to peripheral stimulation of the test ear, whereas pulsed-initial contralateral masking resulted in a linear growth function from masker intensities of 10 to 70 dB SL.

Based on the finding that low-frequency contralateral masking yields broader frequency spread of central masking than is usually observed for higher-frequency maskers, it is concluded that the characteristics of central masking are dependent upon peripheral mediation of the masker, probably at the cochlear level, even though the actual central masking process occurs in the central auditory system.

Significant central masking occurred for the pulsed-initial conditions but not for the pulsed-medial or the steady-state conditions (excluding the 70 dB masker sensation level that is assumed to have yielded cross masking). The pulsed-medial and steady-state contralateral masking conditions at 10, 30, and 50 dB SL did not yield masking patterns similar to those usually found in pure-tone ipsilateral and contralateral masking experiments. On the basis of these results, it is hypothesized that significant central masking occurs only with maskers of a transient nature such as noise maskers or the onset and offset of pure-tone maskers.

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APPENDIX A

Order of Signal Presentation for All Subjects
During Practice Sessions

ORDER OF SIGNAL PRESENTATION FOR ALL SUBJECTS
DURING PRACTICE SESSIONS

(Masker = 200 Hz, Maskee = 500 Hz)

Trial Number	Experimental Condition	Masker Intensity
1	C, Unmasked	
2	C, PM	50 dB SPL
3	C, PI	50 dB SPL
4	C, Unmasked	
5	C, SS	50 dB SPL
6	I, Unmasked	
7	I, PM	50 dB SPL
8	I, PI	50 dB SPL
9	I, Unmasked	
10	I, SS	50 dB SPL

LEGEND

C = Contralateral masker

I = Ipsilateral masker

PI = Pulsed-initial masking

PM = Pulsed-medial masking

SS = Steady-state masking

APPENDIX B

Order of Experimental Conditions

ORDER OF EXPERIMENTAL CONDITIONS

Session	Masker	Temporal Pattern	Masker Frequency (Hz)	Intensity
Subject #1				
1.	I	SS	4000	b
2.	I	SS	230	b
3.	I	PI	230	b
4.	I	PM	230	b
5.	I	PI	4000	b
6.	I	PM	4000	b
7.	C	PI	750	a
8.	C	PI	230	b
9.	C	PM	230	b
10.	C	PI	170	a
11.	C	PI	1500	a
12.	C	PI	500	a
13.	C	PI	4000	b
14.	C	PM	4000	b
15.	C	SS	500	a
16.	C	SS	230	b
17.	C	SS	750	a
18.	C	SS	170	a
19.	C	SS	4000	b
20.	C	SS	1500	a
Subject #2				
1.	I	PM	4000	b
2.	I	PI	4000	b
3.	I	PM	230	b
4.	I	PI	230	b
5.	I	SS	4000	b
6.	I	SS	230	b
7.	C	SS	1500	a
8.	C	SS	230	b
9.	C	SS	170	a
10.	C	SS	4000	b
11.	C	SS	500	a
12.	C	SS	750	a
13.	C	PM	230	b
14.	C	PI	230	b
15.	C	PI	1500	a
16.	C	PI	170	a
17.	C	PI	750	a
18.	C	PI	500	a
19.	C	PM	4000	b
20.	C	PI	4000	b

Session	Masker	Temporal Pattern	Masker Frequency (Hz)	Masker Intensity
Subject #3				
1.	C	SS	500	a
2.	C	SS	4000	b
3.	C	SS	170	a
4.	C	SS	1500	a
5.	C	SS	230	b
6.	C	SS	750	a
7.	C	PI	750	a
8.	C	PI	4000	b
9.	C	PM	4000	b
10.	C	PI	170	a
11.	C	PI	500	a
12.	C	PI	230	b
13.	C	PM	230	b
14.	C	PI	1500	a
15.	I	PI	4000	b
16.	I	PM	4000	b
17.	I	PI	230	b
18.	I	PM	230	b
19.	I	SS	4000	b
20.	I	SS	230	b
Subject #4				
1.	C	PM	4000	b
2.	C	PI	4000	b
3.	C	PI	500	a
4.	C	PI	1500	a
5.	C	PI	170	a
6.	C	PI	750	a
7.	C	PM	230	b
8.	C	PI	230	b
9.	C	SS	500	a
10.	C	SS	4000	b
11.	C	SS	1500	a
12.	C	SS	170	a
13.	C	SS	230	b
14.	C	SS	750	a
15.	I	SS	230	b
16.	I	SS	4000	b
17.	I	PM	230	b
18.	I	PI	230	b
19.	I	PM	4000	b
20.	I	PI	4000	b

LEGEND

C = Contralateral masker
I = Ipsilateral masker
PI = Pulsed-initial masking
PM = Pulsed-medial masking

SS = Steady-state masking
a = NM, 10, 30, 50, and 70 dB SL
b = NM, NM, NM, 10, 30, 50, and 70 dB SL
NM = Unmasked threshold

APPENDIX C

Individual Maskee Thresholds (in dB SPL) for All Experimental Conditions

INDIVIDUAL MASKEE THRESHOLDS (in dB SPL) FOR ALL EXPERIMENTAL CONDITIONS

A) Ipsilateral Pulsed-Initial Masking

Frequency (in Hz)	Subject	Masker Intensity (in dB SL) NM_1	NM_2	NM_3	10	30	50	70
230	1	38.0	38.5	40.5	44.8	59.5	86.3	98.2
	2	34.3	34.7	36.9	38.9	61.8	83.7	95.7
	3	33.8	34.8	35.0	38.8	58.9	74.7	95.2
	4	32.3	32.1	31.9	30.8	41.6	64.6	87.7
4000	1	14.1	14.9	14.7	13.8	14.1	15.4	23.8
	2	7.4	7.9	9.2	9.6	11.1	27.4	46.7
	3	25.5	25.7	25.7	25.4	25.8	28.0	36.0
	4	1.0	1.8	1.8	2.2	5.8	10.1	23.1

B) Ipsilateral Pulsed-Medial Masking

Frequency (in Hz)	Subject	Masker Intensity (in dB SL) NM_1	NM_2	NM_3	10	30	50	70
230	1	41.4	41.6	41.0	39.1	45.5	62.7	81.4
	2	36.4	35.2	35.3	35.3	45.1	61.1	79.8
	3	37.2	36.8	38.6	37.5	49.6	61.3	80.9
	4	31.2	31.9	32.8	32.4	40.8	56.4	73.9
4000	1	11.1	13.1	13.0	11.1	11.9	12.6	16.0
	2	8.3	8.8	9.1	9.1	8.4	10.8	21.1
	3	20.8	21.9	23.3	23.0	22.8	25.0	28.0
	4	-0.1	0.1	0.6	0.2	-0.4	3.2	17.1

C) Ipsilateral Steady-State Masking

Frequency (in Hz)	Subject	Masker Intensity (in dB SL) NM_1	NM_2	NM_3	10	30	50	70
230	1	41.4	42.1	41.6	41.4	44.0	58.5	76.4
	2	36.4	37.2	36.2	38.9	49.2	60.7	77.4
	3	35.4	34.3	34.9	37.8	46.5	62.5	77.8
	4	30.4	31.3	30.1	30.6	38.6	52.6	71.2
4000	1	8.5	8.8	7.9	7.2	6.7	11.0	25.6
	2	8.2	8.2	8.6	8.8	9.8	10.3	16.1
	3	27.0	27.4	27.2	26.9	26.1	26.6	26.9
	4	-0.8	-0.7	-1.0	-0.5	0.0	0.4	9.9

D) Contralateral Pulsed-Initial Masking

Frequency (in Hz)	Subject	Masker Intensity (in dB SL) NM_1	NM_2	NM_3	10	30	50	70
170	1	35.5			37.7	39.6	42.1	39.1
	2	39.2			38.2	43.4	44.6	63.4
	3	53.5			51.7	52.6	57.8	60.7
	4	40.2			40.6	45.4	52.1	61.5
230	1	27.8	28.0	28.0	33.8	31.4	41.0	40.6
	2	26.6	26.2	27.2	26.4	33.9	37.3	43.4
	3	35.3	35.4	36.6	38.4	39.9	44.6	47.8
	4	24.0	23.4	23.7	23.6	27.2	31.8	40.5
500	1	14.3			13.6	16.6	21.0	23.8
	2	15.7			15.6	17.3	18.2	23.1
	3	15.5			15.2	20.3	21.7	25.1
	4	9.3			13.2	16.6	24.0	27.0
750	1	15.6			15.5	17.0	21.3	22.7
	2	11.3			10.6	16.0	15.9	17.0
	3	13.9			11.7	13.1	20.1	21.9
	4	4.2			5.2	7.7	11.8	14.8
1500	1	9.1			8.7	10.0	11.9	13.3
	2	15.7			14.2	15.7	19.2	28.8
	3	9.5			10.5	10.8	16.5	18.9
	4	13.6			14.3	14.4	16.4	19.6
4000	1	5.9	8.4	6.4	6.2	7.4	8.6	9.0
	2	7.2	7.0	8.0	7.3	8.3	11.1	13.1
	3	26.2	26.4	26.8	27.8	27.8	29.9	33.4
	4	1.8	0.6	1.7	1.1	5.0	5.6	6.6

E) Contralateral Pulsed-Medial Masking

Frequency (in Hz)	Subject	Masker Intensity (in dB SL) NM_1	NM_2	NM_3	10	30	50	70
230	1	32.6	33.6	33.7	33.3	33.8	32.2	37.6
	2	28.4	28.4	28.4	29.2	30.0	33.8	38.6
	3	36.4	35.1	34.4	36.3	35.6	36.1	39.9
	4	23.9	24.7	26.4	29.6	28.8	30.4	34.8
4000	1	9.8	9.8	9.5	8.3	9.4	9.2	10.6
	2	10.2	9.3	10.7	11.5	9.9	11.2	11.4
	3	32.8	32.8	33.6	34.0	32.5	34.1	35.3
	4	-1.6	-2.2	-1.0	1.6	1.5	1.3	2.7

F) Contralateral Steady-State Masking

Frequency (in Hz)	Sub- ject	Masker Intensity (in dB SL)						
		NM_1	NM_2	NM_3	10	30	50	70
170	1	42.7			43.7	42.6	42.0	44.2
	2	40.4			42.1	40.0	42.3	44.0
	3	46.4			46.0	48.6	45.3	45.6
	4	38.4			39.3	40.9	40.2	45.7
230	1	33.7	34.2	34.7	34.4	34.8	35.9	40.7
	2	31.5	32.8	32.6	33.9	33.5	34.3	41.4
	3	31.7	32.0	32.6	33.2	33.6	32.6	36.6
	4	29.5	30.1	31.8	32.4	32.8	32.0	36.8
500	1	19.3			19.0	18.8	19.9	21.0
	2	13.0			12.4	13.3	14.5	15.5
	3	18.0			18.2	18.8	19.3	20.6
	4	8.4			9.5	10.4	10.5	13.6
750	1	16.5			16.5	16.5	17.0	19.3
	2	8.6			8.7	8.4	12.9	16.1
	3	10.5			10.9	11.0	11.4	12.5
	4	6.9			7.0	7.0	6.8	7.1
1500	1	15.1			14.2	12.8	13.8	14.0
	2	15.5			15.0	14.8	15.2	16.1
	3	11.2			11.2	10.6	10.6	10.8
	4	10.6			11.4	10.5	10.4	8.9
4000	1	13.1	12.6	14.8	14.4	18.0	17.7	13.4
	2	4.2	5.0	5.4	5.4	5.4	6.0	5.4
	3	28.0	28.8	29.1	27.0	27.0	26.2	26.1
	4	-4.1	-3.3	-3.2	-2.3	-3.2	-3.0	-1.2

LEGEND: NM = No masking (unmasked threshold)