Central masking: Some steady-state and transient effects[1]

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The contralateral threshold shift was investigated as a function of various parameters of the masking and masked stimuli. Because of a measured high acoustic attenuation between the ears, the threshold shift is interpreted as central masking. Both steady-state and pulsed maskers were used and their effect on the contralateral threshold was determined as a function of the masker intensity, the frequency difference between the masking and masked tones, the time delay from the masker onset, and the duration of an intermittent masker.

Central masking occurs when the masking sound is applied to one ear and the test sound to the other in such a way that a direct acoustic interference between the two sounds is practically eliminated. High attenuation between the ears can be obtained particularly well with insert- or semi-insert earphones.

Central masking was probably first noted in 1924 by Wegel and Lane who found it to be very small. That verdict seems to have discouraged further investigation for almost 20 years. Central masking became primarily a small nuisance in audiometric testing when one ear had to be excluded by means of a masking noise.

In 1940, Hughes found a central masking of 4 to 10 dB produced with pure tones. Zwislocki mentioned similar threshold shifts in 1953. Then, Ingham published two studies on the subject in 1957 and 1959. He was able to produce contralateral threshold shifts of more than 10 dB when the masking and masked tones were closely spaced on the frequency scale. Chocholle (1960) essentially confirmed Ingham's results. Finally, Sherrick and Albernaz (1961) found, among other things, that central masking was substantial when the masking and masked stimuli were either both continuous or pulsed simultaneously, and very small when the first was continuous and the second pulsed. Their finding was recently confirmed by Dirks and Malmquist (1965).

The present investigations have been undertaken because central masking is relatively unexplored and also because it appears to hold promise for an experimental analysis of the auditory system. When direct acoustic interference between the masking and masked stimuli is eliminated, it appears reasonable to regard central masking as a neural interaction between the ears. Several similarities between contralateral threshold shifts and neurophysiological results obtained at low levels of the auditory system have already been noted.

This first article describes experiments of an exploratory nature which have served as a guide for further research. It contains four parts.

The first is a short description of a pilot study performed by the senior author in 1951; the second concerns a later replication and extension of this early study; the third describes a preliminary investigation of temporal effects, and the fourth lists some general conclusions.

STEADY STATE MASKING

Pilot Study

The masker was a continuous 1000 cps tone of variable intensity. The test tone, of variable frequency, was pulsed at a rate of one in 2 sec. with an on-off time fraction of one. The masking earphone consisted of an acoustically shielded electrodynamic driver connected to the ear by means of a plastic tube and a perforated sealing plug, the latter secured in the bony meatus (Békésy, 1948). A standard PDR-10 phone mounted in a doughnut socket delivered the

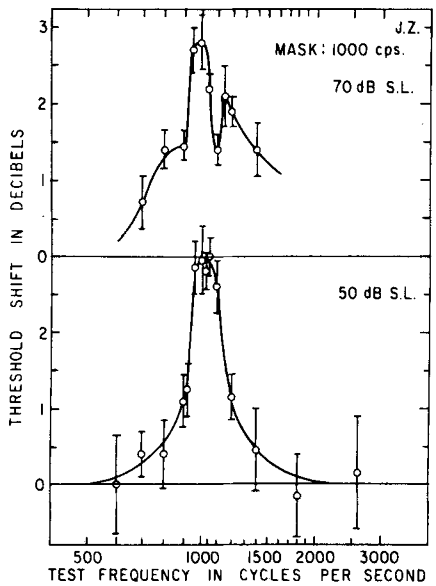

Fig. 1. Contralateral threshold shifts for a 1000 cps steady-state masker and a pulsed test tone of variable frequency. Lower curve corresponds to a masker sensation level of 50 dB, upper curve to that of 70 dB. Circles indicate means of 14 adjustments, vertical bars the standard error. Results are for one observer.

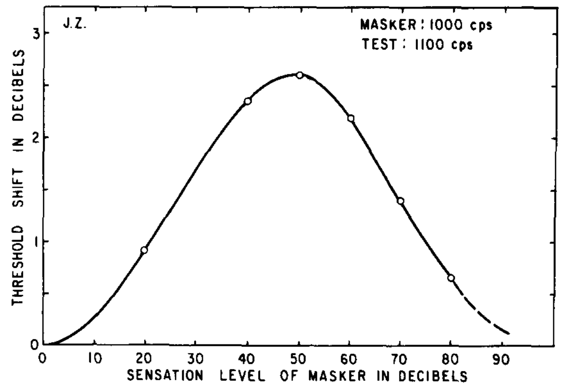

Fig. 2. Contralateral threshold shift for a 1000 cps steady-state masker of variable sensation level and a pulsed test tone of 1100 cps frequency. Circles indicate mean experimental values; the curve is a normal probability curve on log-log coordinates. Results are for one observer.

test tone. The interaural attenuation of the masker amounted to more than 90 dB. Since the investigation was intended as a pilot study involving only one observer, the psychophysical method of adjustment was deemed sufficient.

The results are shown in the first two figures. In Fig. 1, the contralateral threshold shift is plotted as a function of test frequency for two sensation levels of the masker. The vertical bars indicate the standard error of the measurements (14 adjustments per datum point). The maximum threshold shift is about 3 dB for both sensation levels. Its location coincides approximately with the masking frequency. At a 50 dB sensation level of the masker, only frequencies in the immediate neighborhood of the masking frequency are substantially affected. At 70 dB, the frequency spread of the threshold shift is somewhat broader and a relative minimum appears at 1100 cps. Both masking curves are consistent with a highly frequency-selective system.

The relative minimum at 1100 cps seemed to point toward a possible mechanism of the frequency selectivity and, for this reason, underwent further investigation. The threshold shift at the frequency of the relative minimum (1100 cps) is shown in Fig. 2 as a function of the masker sensation level. The threshold shift does not increase monotonically, as in ipsilateral masking, but decays toward zero after having passed through a maximum. The curve approximating the experimental points is a normal probability curve on log-log coordinates. Although the significance of this functional relation is not clear, a reasonable hypothesis is suggested below.

Replication Study

The contralateral threshold shift was again investigated as a function of frequency difference between the masking and masked tones and as a function of the masker sensation level. The frequency of the masker was 1000 cps. The earphones were two Audivox 9-C receivers secured in the ear canals by means of highly damped 2 cc couplers and soft semi-insert tips. The system provides an interaural sound attenuation of more than 75 dB at 1000 cps. The psychophysical method of tracking by means of a Békésy type attenuator was used to determine thresholds. The sound intensity was made to increase or decrease at a slow rate of 1 dB per sec. The masking tone was continuous, the test tone was pulsed at a rate of 2 per sec. with equal on and off intervals. Two of the five listeners were run four to five times at each frequency and sensation level. The remaining three listeners were used at a smaller number of parameter values. Each run consisted of 20 up and down reversals of the attenuator. The means of the mid-point values between the intensity minima and maxima were accepted as threshold estimates.

Some typical results are shown in Figs. 3, 4, and 5. Figure 3 shows individual data obtained in four to five runs for a test frequency of 1000 cps. The open circles indicate medians of the runs. Figure 4 shows individual threshold shifts as a function of test frequency for four sensation levels of the masker. The points indicate medians of four runs. Note the consistent occurrence of maxima and minima at all sensation levels, especially of the minimum at 1200 cps for E. B. and at 850 cps for J. G. Finally, the contralateral threshold shift as a function of masker sensation level is shown in Fig. 5 for three listeners and four frequencies. The points indicate medians of four to five runs; the smooth curves have been

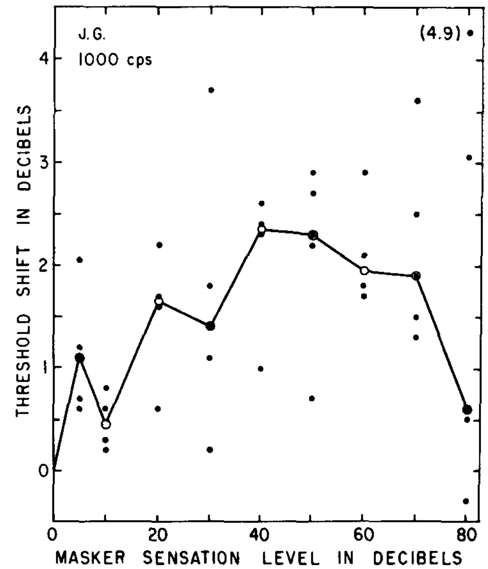

Fig. 3. Contralateral threshold shift for a 1000 cps steady-state masker of variable sensation level and a pulsed test tone of the same frequency. Closed circles indicate medians of single runs, open circles the median of medians. Results are for one observer.

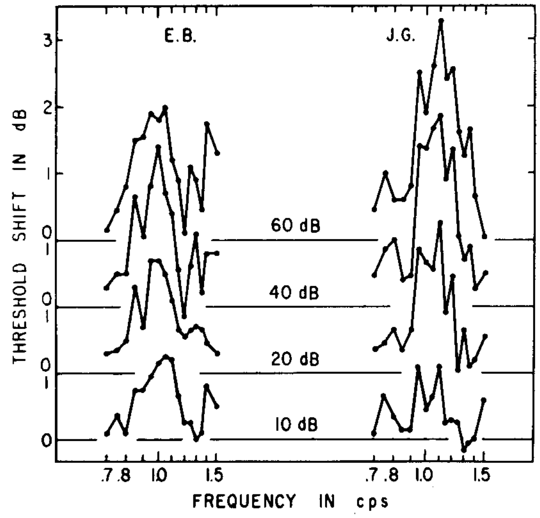

Fig. 4. Contralateral threshold shifts for a 1000 cps steady-state masker at 4 sensation levels and a pulsed test tone of variable frequency. Points indicate medians of 4 runs by each of the two observers.

drawn by eye to show the main trends. Note that the curves either reach an asymptote or fall at high sensation levels.

Both the relative minima in the frequency characteristics and the maximum that occurs at medium sensation levels of the masker for certain frequencies of the test tone are in agreement with the results of the early pilot study. However, it seems that more than one relative minimum may be present in an individual frequency characteristic. The location of the relative minima varies from listener to listener, and there seems to be no simple correlation between the location of the minima and the occurrence of a falling threshold shift at high masker sensation levels.

The decay of masking at high sensation levels was found a sufficient number of times to be considered a real phenomenon. It can perhaps be explained by an interaction of excitatory and inhibitory effects in the neural activity produced by the masker. If the excitation as a function of the stimulus intensity could be approximated by a function proportional to the normal probability integral on log-log coordinates and the inhibition by a similar function but, in general, of different magnitude and displaced along the intensity scale, the interaction between the two functions would produce a family of curves containing the curves of Figs. 2, 3, and 5.

It may be of interest to mention that a substantial number of neurons in the auditory nerve and in the cochlear nucleus produce a decreasing steady-state firing rate as the sound pressure level increases from medium to high values (Kiang, 1965; Goldberg & Greenwood, 1966). Of course, the psychophysical response should not be compared directly to the response of a single neuron but presumably to that of an aggregate of neurons whose individual characteristics may vary over a substantial range.

SOME TRANSIENT EFFECTS

Substantially greater masking effects may be obtained when the masker is pulsed simultaneously with the test stimulus. The temporal effects involved were investigated in the following manner.

The masker was presented in the form of a 250 msec. burst repeated at a rate of 1 per sec. The test stimulus consisted of bursts with an approximately Gaussian envelope and a duration of 10 msec. as measured at half power points. The onset of test bursts could be delayed with respect to the onset of masking bursts by various time intervals. The contralateral threshold shift was determined by means of Békésy's tracking method as a function of time delay, sensation level of the masker, and frequency difference between the masking and masked tones.

Some of the results are shown in the following four figures. In Fig. 6 are plotted individual threshold shifts as a function of test frequency for a masker of 1000 cps and 60 dB sensation level, and an onset time delay of 20 msec. The maximum shift is now about 15 dB. The frequency distribution shows a narrow peak of about 170 cps. Its width is equal to the critical band at 1000 cps, as determined by Zwicker, Flottorp, and Stevens (1957). On each side of the peak, the threshold shift appears to go either through a slight relative minimum or a plateau that extends for several hundred cycles. Such a frequency characteristic cannot be easily explained without invoking lateral inhibition processes acting upon the neural excitation produced by the masker. Note that a substantial

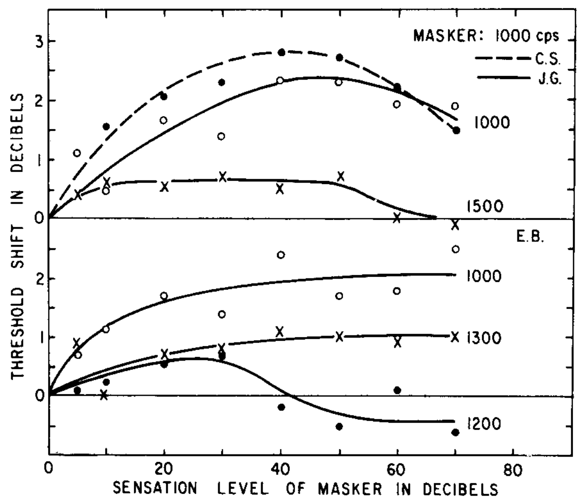

Fig. 5. Contralateral threshold shifts for a 1000 cps steady-state masker of variable sensation level and a pulsed test tone at several frequencies. Points indicate medians of 4 runs; curves are fitted by eye to indicate trends.

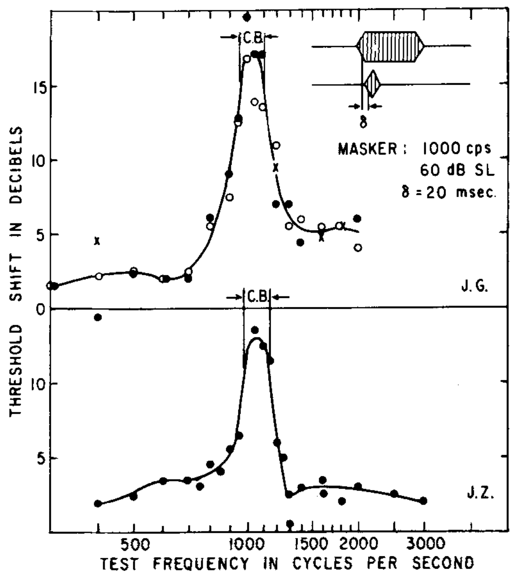

Fig. 6. Central masking obtained by means of 250 msec. masking bursts of a 1000 cps tone and 10 msec. bursts of a test tone of variable frequency. The onset of test bursts was delayed relative to that of masking bursts by 20 msec.; the masker was at 60 dB SL. Points indicate medians of individual runs for two subjects. Curves were fitted by eye. The width of a critical band (C. B.) is indicated.

masking effect was achieved although the masking and masked stimuli were not turned on or off simultaneously.

An even more pronounced difference between the masking effect near the onset of the masker and that produced by a steady-state masker is shown in Fig. 7. When the test tone is presented at the onset of the masking burst the threshold shift increases monotonically with the masker intensity and does not appear to approach an asymptote. The resulting curve has a shape similar to that of the monaural masking curve, but its slope is much flatter. Since the monaural masking curve approximates a slope of one, a smaller slope indicates a nonlinear relation. Hence, the binaural interaction is either nonlinear itself, or it is preceded by a nonlinear transformation. Since the N_1 neural response at the round window exhibits a similar nonlinearity (Teas, Eldredge, & Davis, 1962), the latter eventuality appears to be true.

It may be of interest to note that the slope of the contralateral threshold shift measured at the masker onset parallels the slope of the monaural loudness function (Hellman & Zwislocki, 1963). This is not true, however, when the threshold shift is measured by means of a pulsed test tone in the presence of a continuous masker.

The contralateral threshold shift as a function of onset time delay is shown in Fig. 8 for two listeners. Two other listeners produced similar results. A rapid decay is evident. Within 160 msec., the threshold shift decreases from about 11 dB to about 3 or 4 dB. This behavior may be the principal cause of the difference between steady-state and pulsed maskers. It probably reflects a fast neural adaptation. A similarly rapid decay of neural activity in the auditory system was demonstrated by Galambos and Davis (1943) in single neurons of the second order.

Figure 9 shows still another time effect, an effect that complicated our experiments. When one ear is exposed to the intermittent masking stimulus the initial threshold shift in the contralateral ear may gradually decrease until, in a matter of minutes, it reaches an asymptote. The closed circles indicate the effect obtained on one subject when the masker frequency was at 950 cps and the test frequency at 1000 cps. When the frequency difference was increased, the effect disappeared, as is evident from the location of the open circles obtained with a masker of 600 cps. Crosses in Fig. 9 show that the effect does not seem to be present either when the masker consists of a wide-band noise. The effect appears to be limited to pure tones, or to narrow-band stimuli, closely spaced on the frequency scale.

The slow decay of the masking effect shown in Fig. 8 rendered the measurement of the threshold shift as a function of test frequency, time delay, and masker intensity difficult. Either very short runs had to be used or the threshold computation had to be limited to the first minute of a longer run. The decay probably contributes to the lowering of the steady-state masking below the level produced by the fast decay.

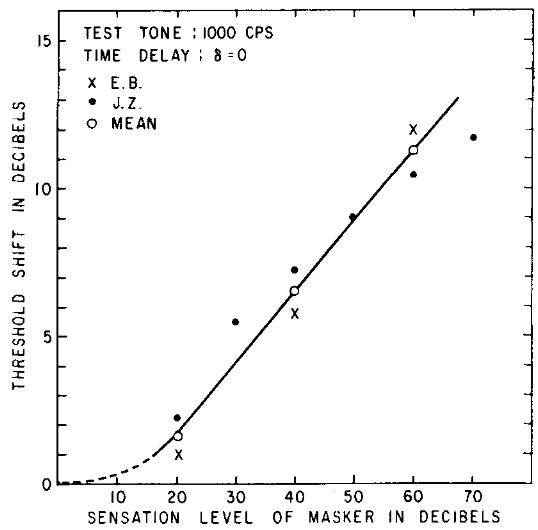

Fig. 7. Central masking at the onset of masking bursts as a function of masker sensation level. Masker and test frequency at 1000 cps. Closed circles and crosses indicate individual data, open circles their means.

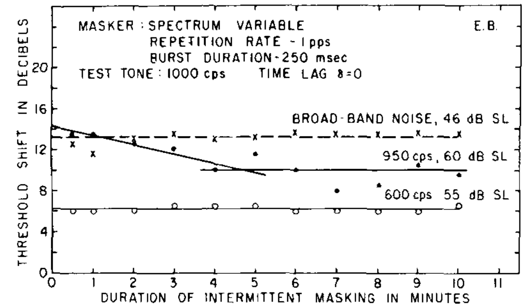

Fig. 9. Central masking at the onset of masking bursts as a function of the duration of the experimental period. Test stimulus: 1000 cps tone in 10 msec. bursts. Masker: 250 msec. bursts of a 950 cps tone at 60 dB SL, of a 600 cps tone at 55 dB SL, or of a broad-band noise at 46 dB SL.

The slow decay of central masking closely parallels the slow decay of neural activity in the 8th nerve. The latter was already observed in the 1930's by Derbyshire and Davis (1935). It exhibits the same time constant as the perstimulatory loudness decay (Egan, 1955).

CONCLUSIONS

The following conclusions appear justified—at least for the frequency range near 1000 cps.

1. Central masking is highly frequency selective. The threshold shift is maximum at or near the frequency of the masker and decays rapidly at lower and higher frequencies. The frequency distribution of the threshold shift does not show the asymmetry of monaural masking, but is nearly symmetrical with respect to the frequency of the masker. The frequency distribution produced by a steady-state masker may contain several local minima. The frequency distribution produced at the onset of a masking burst is more regular and there is a tendency for a shallow minimum to occur at each side of the absolute maximum.

2. Central masking is maximum at the onset of the masker and decays within 160 msec. from a threshold shift of about 10 dB to about 3 dB for a masker of 60 dB sensation level. This decay may be a major factor in reducing the effect of a steady-state masker relative to that produced by a pulsed masker when the test tone is turned on and off simultaneously.

3. When masking bursts of 250 msec. duration are repeated for several minutes and short test bursts are presented at the onset of each masking burst, the initial threshold shift may decay by a few decibels over a period of approximately 4 min. and then reach an asymptote. This slow decay was found for a small frequency difference between the masking and masked tones. No such decay occurred for a frequency difference of several hundred cycles, or when the masker consisted of broad-band noise.

4. The threshold shift measured at the onset of masking bursts increases monotonically with the masker intensity level. The slope of the resulting curve on log-log coordinates is considerably smaller than that of a corresponding monaural curve and indicates a nonlinear relation between the threshold and the masker intensity. The threshold shift produced by a steady-state masking tone may or may not be monotonically related to the masker intensity level. The resulting curves tend to be negatively accelerated and either approach an asymptote or decay after having passed through a maximum.

5. Central masking correlates with other psychophysical characteristics. The threshold shift as a function of the frequency difference between the masking and masked tones forms a peak whose width is compatible with the critical band that has resulted from the research of Zwicker and other investigators. The central masking measured at the masker onset increases with the masker intensity approximately at the same rate as the loudness function. The slow temporal decay of central masking has the same time constant of about 3 min. as the perstimulatory loudness decay.

6. The characteristics of central masking are correlated with neural potentials recorded in the peripheral and low central portions of the auditory system. The threshold shift as a function of masker intensity grows at approximately the same rate as the N_1 potential of the auditory nerve. The initial fast decay of the threshold shift as a function of the time delay from the masker onset approximately parallels the fast decay of the 8th nerve activity and of the single neuron activity in the cochlear nucleus. The later slow decay appears to be consistent with the slow decay of the 8th nerve activity.

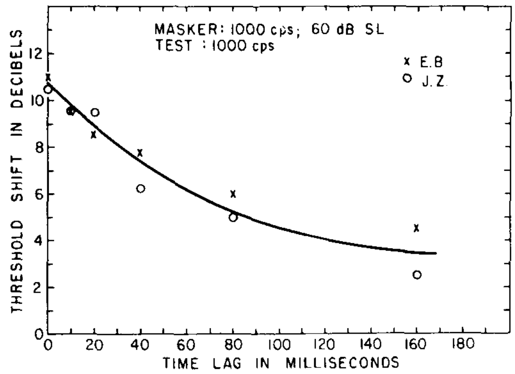

Fig. 8. Central masking as a function of time delay from the onset of masking bursts. Masker and test frequency at 1000 cps, masker sensation level at 60 dB. Circles and crosses indicate individual data; the curve is fitted by eye.

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Note

1. This research was supported by a grant from the National Institute of Neurological Diseases and Blindness (NIH grant no. NB 03950-04).

(Accepted for publication November 21, 1966.)