sponse effects are obtained with drugs other than the stimulants; for example, antidepressants (*18*) and anticonvulsants (*19*) improved attending behavior as the dose was lowered. Although we found a significant decrement in learning in children given 1 mg of methylphenidate per kilogram, a standard medical textbook (*20*) recommends 2 mg/kg as the optimum dose and many writers argue for larger doses (*21*). Our data indicate that dosage should be routinely considered, if not directly manipulated, in pediatric psychopharmacological studies.

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13. On the basis of data collected on 291 normal children and 64 children diagnosed as hyperactive in Champaign-Urbana, Ill. (*7*), a score of 15 out of a possible 30 on the Conners' Abbreviated Rating Scale is two standard deviations above the mean (0.43) for the normal children. Thus, a score of 15 has been set as a minimum cutoff score for accepting children in the project.
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Masking of Electrical by Acoustic Stimuli: Behavioral Evidence for Tonotopic Organization

Abstract. *When pure-tone acoustic masking stimuli of various frequencies were presented simultaneously with electrical stimuli applied to cochlear nucleus, only those maskers within a limited frequency range interfered with the detection of the electrical stimuli. The form of the masking functions obtained suggests that the electrical stimulus directly activated only a small population of neurons which were functioning in a tonotopic fashion.*

Single-unit data from both anesthetized and decerebrate preparations indicate that the neurons of the cochlear nucleus are systematically arranged according to the acoustic frequencies to which they are most sensitive (*1, 2*). The purpose of the present research was to determine whether the tonotopic organization of the neurons in the cochlear nucleus could also be demonstrated in the unanesthetized, intact animal.

An electrical stimulus delivered within the superior olivary complex can be masked by a simultaneous presentation of an acoustic stimulus (*3*). In our work reported here, we used the masking paradigm to investigate the neural organization of the cochlear nucleus. The approach was based on the assumption that the masking of an electrical stimulus by an acoustic stimulus would be maximal when the two stimuli activated the same target population of auditory neurons. In a nucleus in which the individual neurons were tonotopically organized, the cluster of neurons activated by a near-threshold electrical stimulus would have a limited range of best frequencies, so that acoustic masking should be maximal when the frequency of the acoustic masker falls within that same limited frequency range (*4*). Our experiments indicate that electrical stimuli presented to the cochlear nucleus are, in fact, masked by a limited range of acoustic frequencies, and suggest that tonotopic organization prevails in the cochlear nucleus during alert, waking behavior.

The subjects of our experiments were three adult cats, with stainless steel (75 μm diameter, 0.5 mm exposed tip) electrodes permanently implanted in the cochlear nucleus. A self-paced operant detection task (*5*) was used to measure the sensitivity of the animals to electrical stimuli applied to the electrodes. Briefly, in the self-paced task, the animal initiated a detection trial by placing a paw in a slot operandum, after which the electrical stimulus was presented, with a variable delay of 1 to 9 seconds. A correct detection, or a paw withdrawal within 1.5 seconds of stimulus onset, was rewarded with blended fish; a false alarm, or a paw withdrawal before stimulus onset, was punished by a 12-second time out. A miss, or failure to withdraw the paw within 1.5 seconds, was neither rewarded nor punished.

To determine detection thresholds (the current level at which there were 50 percent correct detections) for animals working in the self-paced task, we used a titration procedure in which stimulus intensity was adjusted, upward after each miss or downward after each correct detection, in steps of 1 db (*6*). These procedures yielded threshold estimates which decreased only slightly during our experiments (*7*). In the present experiments, mean 50 percent detection thresholds ranged from 13 to 20 μa (22 to 26 db with reference to 1 μa) for the three animals. The stimuli used were constant current cathodal pulses of 0.3 msec duration, presented at 5 hertz for a maximum of four pulses per trial.

In the first experiment, we examined the effect of broad-band noise bursts on the detection threshold for electrical stimuli. The noise bursts (20 hertz to 20 khz; 3-msec rise or fall time; 20-msec duration; loudspeaker source 0.6 m from the cat's head; 75 db sound pressure level with reference to 0.0002 dyne/cm^2 for the continuous noise measured in the vicinity of the cat's head) were presented at 5 hertz throughout each threshold session. The electrical stimulation pulses were delivered either 12.6 msec after noise pulse onset (masked condition), in the middle of the interval between noise bursts (staggered condition), or against a background of silence (control condition). For each animal, four thresholds were obtained for each condition. The experiment demonstrated masking of the electrical stimuli by the acoustic stimuli for all three animals. Compared to mean thresholds in silence, average masked electrical thresholds were elevated by 11, 7, and 5 db in cats 188, 216, and 220, respectively. Thresholds in the staggered condition were not higher than thresholds in silence for any animal, indicating that the elevation of detection threshold in the masked condition was not a behavioral artifact resulting from the presence of the masking noise.

The frequency specificity of the masking effects was measured in the second and third experiments. In the second experiment, the procedure was the same as that used with white noise masking, except that pure tone maskers (3-msec rise or fall; 20-msec duration: 75-db sound pressure level with reference to 0.0002 dyne/cm^2 for the continuous tone) were substituted for the noise, and the staggered condition was omitted. After each animal had completed two thresholds at each of seven masker frequencies (0.25, 0.5, 1, 2, 4, 8, and 16 khz), it was clear that the elevation of detection threshold depended on the frequency of the concurrent acoustic masker. Each animal showed the maximum increase in detection threshold (range, 3 to 9 db) at one of the masking frequencies and showed progressively less (to 0 db) threshold elevation at higher or lower masker frequencies.

The third experiment provided a more detailed description of the frequency-specific masking phenomenon. In order to minimize the volume of tissue directly excited by the electrical stimulus, the stimulus intensity was reduced to approximately 1 db above the threshold level obtained in the control condition (*8*). Pure tone maskers (3-msec rise or fall; 20-msec duration; 50-db sound pressure level with reference to 0.0002 dyne/cm^2 for a continuous tone) were then repeated throughout the session at 5 hertz and were synchronized with the electrical stimulus pulses as in the prior experiments. In this experiment, however, the masker frequency was changed between individual detection trials, according to a counterbalanced design, and the intensity of the electrical stimulus was held constant.

Figure 1 shows the results obtained with the constant stimulus method. Masking effects were dependent upon masker frequency for each animal, and, except for a suggestive minor second peak in the data from cat 220, the shapes of the psychophysical functions relating masking effect to masker frequency were similar for all three animals. Since the electrical stimuli presumably excited a population of cells, the finding of frequency-specific masking implies that populations of neighboring cochlear nucleus cells were sensitive to a narrow range of best frequencies. In short, the masking results suggest that the cochlear nucleus functions in the behaving animal in a manner compatible with the concept of tonotopic organization.

Figure 1 also shows that the electrode tips were located in the anteroventral division of cochlear nucleus (AVCN) (*9*); our results may be compared with the prior description of the tonotopic structure of AVCN. First, anatomic (*10*) and single-unit data (*1*) indicate that projections from the cochlea to AVCN are arranged so that acoustic signals of high, middle, and low frequencies activate dorsal, middle, and ventral portions of AVCN, respectively. In our experiments, stimulation of the ventral AVCN (cat 188) was best masked by a relatively low frequency tone (2.8 khz), whereas stimulation of the middle regions of AVCN (cats 216 and 220) was best masked by midrange tones (5.6 and 11.3 khz).

As a second point, single-unit data have indicated that frequency-response curves of individual cochlear nucleus neurons are typically asymmetric, with response thresholds rising more rapidly for frequencies above the neuronal best frequency than for frequencies below the neuronal best frequency (*11*). Our data show a similar asymmetry, with the magnitude of the masking effects diminishing more rapidly for frequencies above the optimal masking frequency than for frequencies below the optimal frequency.

Finally, available data (*1, 12*) indicate that neuronal best frequencies change at a maximum rate of approximately 1.5 octaves per millimeter of tissue, within AVCN. Our finding that masking effects were reduced as little as 0.5 octave (or 0.33 mm) from the optimal masker frequency suggests that the electrical stimuli probably directly excited cells only in the immediate vicinity of the 0.5-mm electrode tip. This finding of a very restricted spread of the effective stimulating current in the vicinity of a monopolar macroelectrode appears compatible with estimates of current spread in the vicinity of a microstimulating electrode (*13*).

We conclude that the concept of tonotopic organization, as defined by neurophysiological and anatomic data, also represents a functional concept applicable in the conscious animal to neural

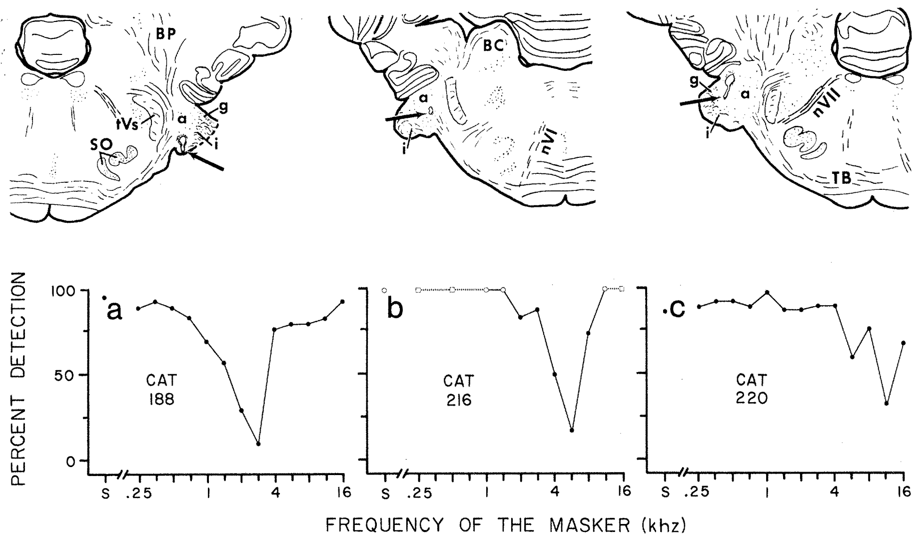

Fig. 1. The electrode tip location is shown by the arrow tip in the upper panel, and performance on the constant stimulus task in the lower panel, for each of the three animals. The masker frequency is shown on a logarithmic scale in the lower figures; the points between numbers are octave and half-octave points. After one practice session, each animal was run through 30 blocks of detection trials with each masker frequency and the silence condition (s) was presented once per block. Cat 216 was run through an abbreviated version in which only those frequencies yielding masking were repeated through 30 blocks. For cat 216, the open circles show performance levels for 6 (1 and 1.4 khz), 10 (s), and 16 (11.3 khz) trials, and the open squares are estimates of performance, based on the fact that the indicated masker frequencies caused essentially no elevation of detection threshold in the first experiment on frequency-specific masking. Abbreviations: *BC*, brachium conjunctivum; *BP*, brachium pontis; *SO*, superior olive; *TB*, trapezoid body; *tVs*, spinal tract of Vth nerve; *nVI*, VIth nerve; *nVII*, VIIth nerve; *a*, anteroventral regions of the cochlear nucleus; *g*, granule cell; *i*, interstitial.

aggregates in AVCN. Whether the concept might also prove applicable to aggregates of neurons elsewhere in the auditory system remains undecided. We suggest that the technique of masking a central electrical stimulus with a peripheral sensory stimulus is a precise and useful tool for the study of sensory neural organization in the behaving animal.

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8. Stimulation intensities were 15.8, 14.1, and 22.4 μa for cats 188, 216, and 220, respectively. In silence, those stimuli were detected by the animals on 85 to 100 percent of the trials.
9. Electrode tip locations were confirmed by examination of serial sections (50 μm) stained alternately for Nissl substance (thionin) or myelin (Weil). In agreement with others [N. Y. S. Kiang, D. A. Godfrey, B. E. Norris, S. E. Moxon, *J. Comp. Neurol.* **162**, 221 (1975); K. K. Osen, *ibid.* **136**, 453 (1969); J. R. Brawer, D. K. Morest, G. C. Kane, *ibid.* **155**, 251 (1974)], we have taken as an anteroventral subdivision of the nucleus the region lying rostral, dorsal, and slightly medial to the interstitial zone of entrance and bifurcation of the acoustic nerve. The electrode tip of cat 188 was found at the ventral border of AVCN, adjacent to the interstitial zone, the electrodes of cats 216 and 220 were more dorsally situated within AVCN.
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Receptive Fields of Auditory Neurons in the Owl

Abstract. *The influence of sound location on the responses of auditory neurons in the forebrain of the owl (*Tyto alba*) was studied directly by using a remotely controlled, movable sound source under free-field, anechoic conditions. Some auditory neurons demonstrated well-defined receptive fields that were (i) restricted both in elevation and in azimuth and (ii) relatively independent of the intensity and the nature of the sound stimulus. The majority of the fields were located frontally and contralateral to the recording site.*

The ability to localize sound sources in space is vital to the survival of many animals and represents one of the most important functions performed by the auditory system. Most neurophysiological studies on sound localization have dealt with the responses of auditory neurons to interaural time, phase, and intensity differences, by using a closed system in which sound reaches the eardrums through hollow ear-bars (*1*). Although this method permits the accurate control of dichotic stimulus parameters, it cannot directly reveal the attributes that auditory neurons might exhibit in response to sound sources in real space (*2*).

We have studied directly the influence of sound location on the responses of telencephalic auditory neurons in the barn owl (*Tyto alba*), a species known for its sound localization abilities (*3–5*). Using a movable sound stimulus under free-field anechoic conditions, we have found auditory units with well-defined receptive fields (*6*) that were restricted both in elevation and in azimuth and that were relatively independent of the intensity and the nature of the sound stimulus.

Five owls were used in these experiments (*7*). Anesthesia was induced with an intramuscular injection of Ketamine (4 mg per kilogram of body weight) and was maintained at a light level by repeated injections as necessary. The experiments were carried out in an anechoic chamber (3 by 3 by 5 m) (*8*). Sound stimuli, including clicks, tone bursts, frequency modulation, and band-filtered noise, were delivered from a 5-cm speaker (*9*) that moved in azimuth along a semicircular track 2 cm wide and 2 m in diameter. The track could be rotated to provide changes in speaker elevation. Azimuth and elevation were controlled independently by two stepping motors located outside the chamber. Thus the speaker could be moved to any point on a sphere of radius 1 m centered at the owl's head, except for a 20° sector blocked by a supporting post for the owl. The owl was positioned within the sphere by using retinal landmarks, so that the intersection of the owl's visual and median planes corresponded to 0° elevation, 0° azimuth of the speaker (Fig. 1) (*10*).

Auditory units were recorded with glass-insulated tungsten electrodes from the primary auditory projection area in the owl's telencephalon, field L. The statements made in this report are based on the response properties of 213 units out of 314; the 101 units excluded from this report responded only to complex stimuli such as finger snapping, sandpaper grating, or whistling. Although these units displayed definite and often quite small receptive fields, they could not be driven by our electronic sounds and therefore could not be accurately mapped.

The procedure for mapping auditory receptive fields was as follows. After a single unit had been isolated, its approximate receptive field was determined by the experimenter's entering the chamber and making sounds at various positions. The experimenter would then leave the chamber and position the movable speaker at the appropriate location. The best sound for driving the unit and the unit's threshold for that sound were determined. While using the best sound at 10 db above threshold, we moved the speaker in elevation and azimuth to locations where the unit failed to respond.