TECHNICAL NOTES AND RESEARCH BRIEFS

Rudolph H. Nichols
93 West End Avenue, Summit, New Jersey 07901

Editor's Note: Original contributions to the Technical Notes and Research Briefs section are always welcome. Manuscripts should be double-spaced, and ordinarily not longer than about 1500 words. There are no publication charges, and consequently, no free reprints; however, reprints may be purchased at the usual prices.

Development of the place principle [43.66.Ba]

Edwin W. Rubel, Brenda M. Ryals, and William Lippe

Laboratory of Developmental Neuro-Otology, Box 430, University of Virginia School of Medicine, Charlottesville, Virginia 22908

The brilliant contribution of von Békésy, showing that there is an orderly sequence of frequency selectivity along the length of the basilar membrane (the place principle), is the foundation of modern hearing sciences. While species differ radically in the frequency range to which they are responsive, it has generally been assumed that the frequency organization of an individual is relatively constant throughout its life span. A paradox between the development of the inner ear and the ontogeny of frequency sensitivity led us to question this assumption and examine the representation of frequency along the basilar membrane during hearing development. Two experiments showing that there is a systematic shift in the frequency code along the basilar membrane during hearing development were published in *Science* [**219**, 512–516 (4 February 1983)]. In both experiments embryonic and hatchling chickens were used. Their hearing development parallels what has been found in a large variety of birds and mammals.

In the first experiment, high-intensity sound was used to produce localized damage to the basilar papilla (cochlea) of chicks at three different ages (embryonic day 20, postnatal day 10, and postnatal day 30). At each age, separate groups of animals were exposed to broadband white noise or a pure tone at 500, 1500, or 3000 Hz for 12 h at 125 dB (SPL). Following 10-day survival, hair cell damage was determined from serial sections of the cochlea. There was a systematic developmental shift in the position of damage produced by each of the acoustic stimuli. Broadband white noise produced damage only in the basal one-half of the cochlea in the embryonic animals while after hatching it produced damage throughout the length of the cochlea. Exposure with each of the pure tones produced a discrete area of hair cell loss. However, with each frequency the region of damage shifted apically as a function of age of the animal at the time of sound exposed. That is, the site of maximum stimulation by intense tones appears to change systematically during this period; in young animals a given frequency will maximally activate regions located further toward the base of the cochlea than in the mature animal of the same species. This result was consistent across all groups showing hair cell loss due to overstimulation.

In the second study, we examined the tonotopic organization of second and third order neurons in the brain stem auditory nuclei of embryonic and hatchling chickens. Microelectrode mapping procedures were used to define the relationship between characteristic frequency of neurons and their anatomical positions within the brain stem auditory nuclei. Neurons at any position within these nuclei were maximally sensitive to much lower frequencies in embryos than in hatchlings. The characteristic frequencies of neurons in 17-day-old embryos were 1 to 1½ octaves below what is found in hatchlings at the same anatomical positions. These results again suggest that the frequency organization of the cochlea is shifting during development such that regions responsive to high frequencies in the adult are maximally sensitive to much lower frequencies in the neonatal animals. As the basal region becomes responsive to high frequencies progressively apical regions become tuned to the lower frequencies.

These results are of interest for several reasons. First, they provide a mechanism to explain heretofore conflicting results regarding development of the auditory system in a variety of birds and mammals. Second, they suggest that the place code is not fixed, but changes during the development of hearing. One wonders if it also changes at other times in the life span, for example, during periods of stress or during aging. Finally and more speculatively, these results suggest that low frequency stimuli which are pervasively available in all environments optimally stimulate each region of the cochlea and, thereby, each region of the central auditory projection areas during progressive stages of development.

This research was supported by funds from the NINCDS, the Deafness Research Foundation, and the Lions of Virginia Hearing Foundation.

Variable-position acoustic levitation [43.20.Ka, 43.35.Ty]

A method of acoustic levitation supports objects at positions other than the acoustic nodes. Acoustic force is varied so that it balances gravitational (or other) force, thereby maintaining an object at any position within an equilibrium range. When the acoustic frequency is the fundamental resonance of the acoustic chamber, the equilibrium range is one-fourth of the chamber length (see Fig. 1).

The levitation method, which was developed by M. B. Barmatz, J. D. Stoneburner, N. Jacobi, and T. G. Wang of Caltech for NASA's Jet Propulsion Laboratory, is applicable to containerless processing. In a levitation furnace, for example, it could be used to manipulate specimens without contacting them, perhaps moving them through a temperature gradient.

The acoustic levitation depends upon the sample height z and chamber vertical length L, according to a function that is proportional to $\sin(2\pi Nz/L)$, where $N =$ the order of the harmonic of the fundamental chamber frequency. In the fundamental mode ($N = 1$), the maximum upward acoustic force occurs at $z = L/4$ (Fig. 1). Above this height, the lifting force decreases with increasing height, (as with an object supported by a spring). When this maximum force is greater than or equal to the opposing force (gravity), a sample will levitate at or above the $L/4$ position. Thus, $L/4$ is the minimum height at which an object can be supported in equilibrium. Above $L/2$, the force of gravity acts on the specimen in the same direction as the acoustic force, and further levitation is resisted.

A specimen is placed in an acoustic chamber excited at its fundamental mode. The acoustic amplitude (and thus the acoustic force) is increased until it is just sufficient to hold the specimen at a height of $L/4$. The acoustic amplitude is increased further until the sample rises to the desired position, anywhere between $L/4$ and $L/2$. Given the densities of the sample and gas medium, the equilibrium position between these two points can be determined from the acoustic pressure. There are additional regions of equilibrium if the chamber is excited by harmonics of the fundamental frequency.