High-Frequency Sensitivity in Infants

Abstract. *Auditory thresholds were determined for infants and adults to half-octave bands of noise centered at 10,000 and 19,000 hertz. Adults were significantly more sensitive than infants at 10,000 hertz, but at 19,000 hertz, adults and infants had comparable thresholds.*

In 1876, Sir Francis Galton reported his invention of a brass whistle for the purpose of testing the audibility of "shrill notes" (*1*). Although Galton noted that "young people hear shriller sounds than older people," he did not specify what he meant by young or old. In any case, it is clear that Galton did not try his whistle on infants or young children.

To our knowledge there have been no subsequent studies of age-related changes in high-frequency sensitivity in infancy and early childhood largely because of technical difficulties in determining auditory thresholds in this population (*2*). We have recently developed a signal-detection technique, however, which can be used to determine auditory thresholds for infants as young as 6 months of age (*3*). This technique is a refinement of the visual reinforcement audiometry procedures developed by Moore *et al.* (*4*). A mother is seated in the corner of a double-walled, sound-attenuating chamber with the infant on her lap facing away from her. On either side of the infant at angles of 45° are loudspeakers for presenting auditory signals. Directly on top of each speaker is a smoked glass enclosure containing a mechanical toy that can be illuminated and activated for a 4-second period. An experimenter, who is seated in the booth facing the mother and infant, waits until the child looks directly at her before pressing a button to begin a trial. A sound is then presented on one of the two speakers (selected at random) and remains on until the infant makes a head turn of 45° or more toward either side. (A head turn is typically elicited quickly on the first trial.) The experimenter then presses one of two buttons to indicate the direction of the head turn. If the head turn is in the direction of the speaker producing the signal, the signal is turned off and the toy above that speaker is illuminated and activated for 4 seconds. If the turn is in the opposite direction, a silent intertrial interval of 4 seconds occurs. During the entire session, the mother and experimenter wear earphones over which a masking noise is presented to prevent them from detecting the location of the sound.

We used two test signals—a half-octave band of noise centered at 10,000 Hz

and another centered at 19,000 Hz. The half-octave bands were produced by filtering the output of a white-noise generator (General Radio) with a universal band-pass filter (General Radio). Signals had a rise and decay time of 25 msec (and a 30-dB falloff per octave on either side of the half-octave) and were presented over tweeters (ESS-Heil HT 400). Other circuit details and calibration procedures were identical to those reported earlier (*3*).

Wherever possible, infants were tested in two sessions with the order of test stimuli counterbalanced and with a 10-minute break between sessions. To ensure that an infant could perform the task, he or she had to meet a training criterion consisting first of four successive correct responses at 72-dB sound-pressure level (SPL). The intensity was then reduced 10 dB and the same criterion employed. Four different test levels were then presented five times each in a randomized order, constrained as in our earlier study (*3*). The test levels were 7, 17, 27, and 37 dB (SPL) for 10,000 Hz and 17, 27, 37, and 47 dB (SPL) for 19,000 Hz. At the beginning of the second ses-

sion, the training criterion was again introduced with the exception that only two correct responses at each level were required. Test conditions for adults were comparable except that reinforcement was limited to illumination of an empty toy chamber.

In our search for developmental changes, five different age groups were tested: 6, 12, 18, and 24 months of age, as well as young adults (mean age, 26 years). Of the 40 infants tested at 6 months of age, 8 failed to reach the training criterion but very few infants outside of this age group failed in this respect. Only four infants across all age groups were eliminated because of fussing, and three other infants because of equipment problems. The vast majority of infants at all age levels completed both sessions, as did all adults.

For subjects who completed both experimental sessions, a Mann-Whitney U test was performed to check for order effects (*3*). Since there were no effects due to the order in which the subjects encountered the two stimuli, results were collapsed over order for the remaining analyses. If subjects completing only a single session are included, the number of infants at each frequency and age group ranged from 23 to 31.

As the intensity level increased, the percentage of correct responses increased systematically (Fig. 1). The infant groups never quite reached 100 per-
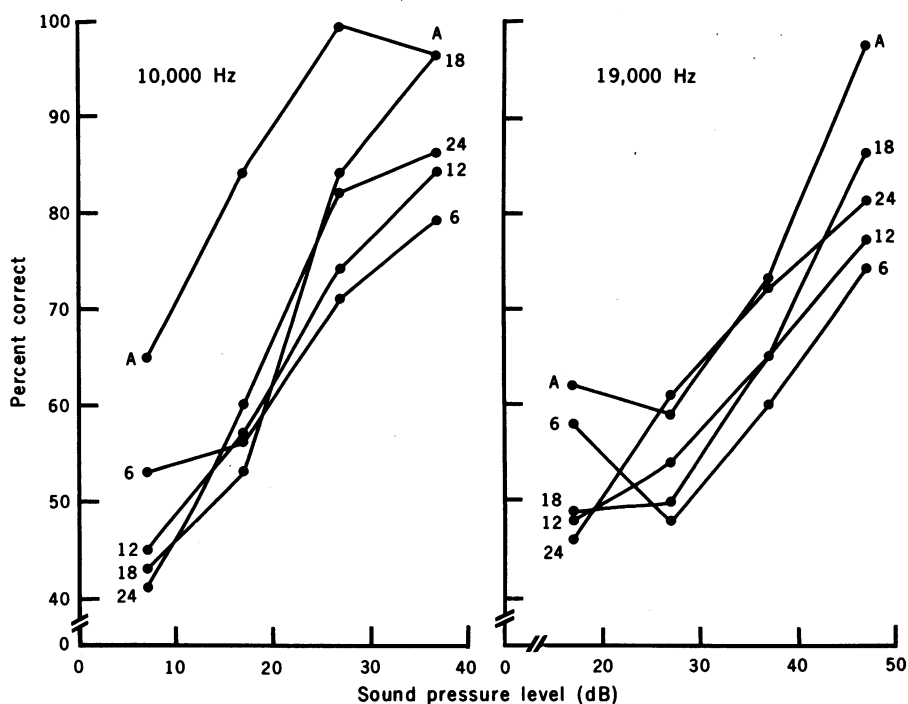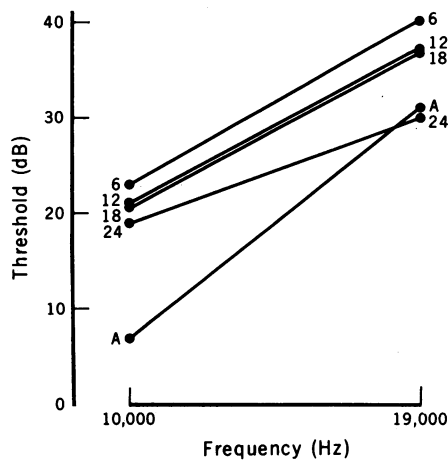

Fig. 1. Percentage of correct head turns as a function of decibel level of half-octave band noises with center frequencies of 10,000 and 19,000 Hz for infants 6, 12, 18, and 24 months of age and for adults.

Fig. 2. Thresholds for half-octave band noises with center frequencies of 10,000 and 19,000 Hz for infants 6, 12, 18, and 24 months of age and for adults.

cent correct responses, even at higher intensities. This result is probably attributable to momentary lapses of attention. For the 10,000-Hz noise, the psychometric functions for the four infant groups are similar, but the adults were substantially more sensitive than the infants (5). In contrast, the psychometric functions for the children and adults exhibit more overlap at 19,000 Hz (6).

At 10,000 Hz, the thresholds for the four infant groups are similar and 12 to 16 dB higher than that for the adult group (Fig. 2). (Threshold was defined as the intensity at which the signal was detected 65 percent of the time.) At 19,000 Hz, however, this adult-infant difference is attenuated substantially. These results confirm a trend that we reported in our earlier study (3) on octave band noises, namely, a decrease in the disparity between infant and adult thresholds as the center frequency of the noise band increased. In that study, the disparity was 20 to 30 dB at the lower frequencies (200 to 400 Hz) and 10 dB at 10,000 Hz. In the present study the disparity disappears at about 19,000 Hz for the older infants (7).

It is difficult to determine the locus of these developmental changes in frequency sensitivity; in addition to possible maturational changes in the nervous system during the first few years of life, there are changes in the size of the infant's head and, in particular, in the size and shape of the external and middle ear structures (8). Age-related changes in these dimensional characteristics and changes in the impedance matching properties of the middle ear no doubt affect frequency sensitivity, but the precise nature of these effects is unknown (8).

The implications of such high-frequency sensitivity in infants are considerable. Presbycusis, the gradual loss of hearing with advancing age, is usually more pronounced in the high-frequency region (9). The onset of such high-frequency hearing loss may actually begin in infancy since there is morphological evidence of loss of hair cells in the extreme basal portion of the cochlea in infants ranging in age from 2 or 3 hours to several months (10). Furthermore, hair-cell loss with corresponding nerve degeneration slowly ascends from the basal end of the cochlea, involving an increasingly larger portion of the basal turn, over the first two decades of life (10). Since the basal

end of the cochlea mediates high-frequency hearing, we would expect hearing losses associated with aging to manifest themselves first in the very high-frequency region, possibly at an early age. Furthermore, if the basal end of the cochlea is fragile and consequently susceptible to damage, losses in sensitivity due to environmental exposure, illness, or other trauma might first appear at the higher frequencies. In particular, since exposure to noisy environments affects the degree of high-frequency hearing loss in adults (11), the effects of noisy environments on young children might first manifest themselves in this high-frequency region. The course of auditory development from 6 months to 6 years of age should be mapped to answer questions such as these.

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References and Notes

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5. An analysis of variance for 10,000 Hz showed a significant effect for stimulus level ($P < .0001$), age group ($P < .0001$), and interaction ($P < .025$). Post hoc comparisons among age groups according to Sheffe's method indicated that adults were significantly better than each infant group ($P < .0001$ for 6, 12, and 24 months and $P < .001$ for 18 months) but that there were no significant differences among infant groups. The interaction between stimulus level and age group reflects the fact that adults quickly reached the ceiling of 100 percent correct responding, whereas the infant groups continued to improve as stimulus intensity increased.
6. The analysis of variance for 19,000 Hz showed a significant effect for stimulus level ($P < .0001$) and age group ($P < .001$), but no significant interaction effect. Post hoc comparisons among age groups according to Scheffe's method indicated that adults were significantly better than the 6- ($P < .01$) and 12- ($P < .025$) month-old infants, but there were no significant differences in any of the other comparisons.
7. The same general pattern appears if a 75 percent rather than a 65 percent threshold criterion is chosen. With a 75 percent criterion, thresholds at 10,000 Hz for the four infant groups are still similar and 12 to 20 dB higher than those of adults. At 19,000 Hz, the adult-infant difference is attenuated an average of 8.75 dB for the 75 percent criterion as opposed to 8.9 dB for the 65 percent criterion. Furthermore, the thresholds for the adult and 24-month-old infants are within 2 dB of each other. Hence, our conclusions do not depend specifically on our choice of the 65 percent threshold criterion. Since our research has indicated that 6- and 12-month-old infants tend to reach asymptote at a lower level than older infants (3), threshold criteria in excess of 75 percent are likely to be affected by the rate of inattention.
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Shark Skin and Locomotion

Wainwright *et al.* (1) report on stretching a piece of shark skin lengthwise while holding it stretched laterally with constant stress. (According to their description of their procedure it was not constant lateral stress that they applied, but constant lateral tension—that is, they kept the lateral tensioning force constant instead of making it proportional to the length of the specimen as the latter was stretched. The practical effect of the difference between the two procedures is small.) They say that the area under the longitudinal force-extension curve "is a measure of the energy required for and

recovered from skin deformation," and note that this energy is higher when the lateral stress is higher. Because the hydrostatic pressure inside the shark is elevated wherever the body is curved, the elevation increasing with swimming speed, the circumferential stress in the skin will rise also and, with it, the apparent longitudinal stiffness of the skin. It might appear that shark skin is a spring of controllable stiffness that stores energy wherever the body is curved, in an amount that increases with swimming speed.

But because the experiment did not