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A Comparison of Pure Tone Auditory Thresholds in Human Infants and Adults*

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Abstract

Pure tone auditory thresholds for frequencies from .250 to 8.0 kHz were obtained from 277-to-11-month-old human infants and nine adults using a go—no-go operant head-turning technique combined with an adaptive staircase (tracking) discrimination procedure. New methods were devised for maintaining infants under stimulus control during threshold testing through the use of randomly interleaved “probe” and “catch” trials. Reliable threshold data were obtained from every infant studied, and identical threshold criteria were applied to infants and adults alike. Although infant thresholds were 17–27 dB higher than those of adults, infant inter-subject variability was no greater than that of adults. Adult audiograms were nearly flat between frequencies of .500 and 8.0 kHz with sensitivity ranging between 7 and 14 dB SPL. Infant audiograms were flat between frequencies of .500 and 4.0 kHz, with sensitivity ranging between 30 and 36 dB SPL. The most sensitive frequency for infants was 8.0 kHz (25 dB SPL).

Keywords

audition; hearing; sensory development

Behavioral studies of auditory function in human infants have been characterized by two prominent trends: (a) a focus on high level auditory processing (e.g., speech perception) without recourse to potential underlying constraints on the processing of elementary acoustic information (e.g., absolute threshold, frequency, and intensity discrimination, etc.), and (b) the marked absence of sophisticated psychophysical methods to reliably assess auditory functions for comparisons with adult performances. In the present report we describe a methodology that has been developed to allow for direct comparisons in auditory sensitivity between infants and adults and that permits the application of identical threshold criteria to both groups. The emphasis in this report is on a comparison of pure-tone thresholds as a function of frequency.

Although there are estimates of infant pure-tone thresholds available from the clinical literature using head-turning techniques (Haug, Baccaro, & Guilford, 1967; Liden & Kankkunen, 1969; Suzuki & Ogiba, 1961), there are a number of difficulties in interpreting the results of these studies. For example, in these reports experimenters were not blind to the test situation, and the authors readily acknowledge that the success of the particular technique was largely dependent upon the audiologist's skill in evaluating the responsiveness of infants. Moreover, control or catch trials were not used. These studies also

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lack a detailed treatment of the data; for example, individual psychometric functions were never displayed to illustrate reliable infant responding as an orderly function of stimulus level, and precise comparisons with adults were never made. Most importantly, however, it is difficult to understand how these early studies differentiated between sensory threshold measurements and attentional variables that may have affected the infants during testing, since objective criteria for accepting or rejecting data were not clearly defined. Despite these criticisms, these studies have reported infant thresholds to be approximately 30 dB above those of adults.

A new, more objective method for making direct comparisons of infant and adult auditory sensitivity has been recently developed by Trehub, Schneider, and Endman (1980). These authors employed a “go-right—go-left” version of the operant head-turning technique to obtain absolute thresholds for octave band noises. Subjects were reinforced by a blind experimenter for making appropriate head-turns to the right or left in response to stimuli randomly presented from either a right or left speaker. Such a forced-choice procedure allowed the auditory stimuli to remain on indefinitely, and eliminated the need for catch trials. Stimuli were presented according to the method of constant stimuli, and fairly complete psychometric functions were obtained from infants and adults alike. In the Trehub et al. study, however, identical threshold criteria were not applied to infants and adults. Since many infant functions never reached 100% correct detection for suprathreshold stimuli (attributed to “lapses of attention”), the authors considered a lower value on the functions (65%) to represent infant thresholds, while the more conventional value of 75% was retained for adults. Using these analyses, infant thresholds were reported to be 20–30 dB higher than adults for frequencies below 4.0 kHz, but at higher frequencies (10.0 kHz) infant sensitivity approached that of adults.

If valid sensory comparisons are to be made between infants and adults, techniques must be developed that maintain infants under an optimal degree of stimulus control during threshold testing so that identical threshold criteria can be applied to all subjects. The present experiment represents an attempt to overcome these general difficulties in infant testing by presenting a new version of the operant head-turning technique, based on the earlier work of Aslin, Pisoni, Hennessy, and Perey (1981). Major modifications were made to assess the degree of infant stimulus control during threshold testing through the use of randomly interleaved “probe” and “catch” trials. Using this procedure, infants and adults were compared directly in absolute auditory sensitivity to pure-tone stimuli, and identical threshold criteria were applied to both groups. The purpose was to provide a data base for infant researchers who might wish to compensate for different sensation (hearing) levels between infant and adult subjects in pure-tone psychophysical experiments, as well as to clarify and extend the recent work of Trehub et al. (1980) to include pure tone stimuli.

METHODS

Subjects

Subjects were 27 infants aged 7.2–11 months (11 male, 16 female). Three were naive, and the other 24 had had from 3 to 5 sessions of previous testing experience in speech discrimination experiments. Seven infants had successfully completed speech testing and 17 had not. In assigning infants to the present experiment, no attempts were made to differentiate between those who had successfully completed the speech experiments and those who had not. All infants appeared in good health on test days. Parents of infants were paid \$3 per visit to the laboratory. Adult subjects were 8 females and 1 male in their early twenties. None reported any hearing difficulties at the time of testing.

Stimuli

Stimuli were sine wave tones of .250, .500, 1.0, 2.0, 4.0, and 8.0 kHz, with rise-fall times of 20 msec, that were generated digitally on a PDP 11/34 computer. Tones from .250–4.0 kHz were synthesized at a rate of 10.0 kHz, and were low-pass filtered at 4.8 kHz during presentation. The 8.0 kHz tone was synthesized at a rate of 20 kHz and presented through a 10.0 kHz low-pass filter. Two sets of tones were constructed, differing in duration. One set consisted of 1.0 sec tones from .250–4.0 kHz. The other set consisted of .5 sec tones from .500–8.0 kHz.

Apparatus

Digitized waveforms were stored in computer memory where they were accessible for on-line read out via a 12-bit D-to-A converter. The signals were then filtered, passed through a programmable digital attenuator, a manual attenuator, audio amplifier, and loudspeaker (Radio Shack, No. 40-1980A), located inside the test booth.

Sessions were conducted inside a single-walled (2m × 2m) sound attenuation chamber (IAC No. 402). In one corner was a chair for the parent and infant. Directly in front of this was a chair for the booth assistant and a table with toys. Underneath the table was a cassette tape recorder with two sets of headphones that provided masking music to the parent and assistant during test sessions. Directly above the table a closed-circuit TV camera focused on the infant. To the left of the infant were the speaker and two visual reinforcers. The reinforcers were arranged vertically one on top of the other, and were enclosed in smoked plexiglass boxes so that they could not be seen until the lights within each of them were illuminated. One toy was a bear that beat on a drum, and the other was a monkey that clapped its hands. Outside the booth were the TV monitor and the response box, which contained buttons that were operated by the experimenter and were sensed by the computer as input events to the threshold program. The computer controlled all the experimental contingencies and recorded all the data.

Calibration

Calibration of the sound pressure level (SPL) of the stimuli was accomplished with a General Radio meter (No. 1551 -A, C scale), equipped with a circular rochelle salt crystal microphone (No. 9898). The meter was placed on the parent seat so that the microphone was pointed horizontally towards the speaker at the approximate position of the infant's head. While reading the meter the experimenter sat in the assistant's seat. Six measurements were made approximately 2" apart in the general vicinity of the infant's head position, one measurement at right and left, front and back, and above and below center head position. These measurements, summarized in Table 1 for each of the test frequencies, were also verified daily with a portable Triplet Sound Level Meter (No. 370).

The level of the ambient noise within the booth was 40 dB SPL (C scale). Measurements with a wave analyser (General Radio, No. 1900-A, 50 Hz band) and graphic level recorder (General Radio, No. 1521 -B) revealed that the level varied as a function of frequency, with a smooth drop-off of about 10 dB between .250 and 8.0 kHz. The level per cycle at 1.0 kHz was -12 dB SPL.

Procedure

Each infant sat on the parent's lap while the assistant played with toys to attract the infant's gaze straight ahead. Adult subjects sat alone in the booth in the parent seat so that their head position approximated that of the infants. The experimenter viewed the subject through the monitor and operated the response box, which had three function buttons. Button 1 was pressed by the experimenter to present trials to the subject. Button 2 was pressed whenever

the subject made a head-turn. Button 3 was an abort button and was pressed only under unusual circumstances, for example to terminate a session if an infant began to cry.

The computer program that controlled the experimental contingencies consisted of a sequence of four states:

1. *Intertrial interval*: This state was normally of variable duration (10–15 sec). Button 1 was inoperative and the experimenter could not initiate trials. Button 2 was operative and the experimenter recorded each false alarm, which reset the intertrial interval to a maximum duration of 15 sec.
2. *Observation interval*: This state, which followed the intertrial interval and was of indeterminate length, was cued to the experimenter by a flashing light on the response box. Button 1 was operative and, if the subject was calm and looking straight ahead, the experimenter pressed Button 1 and the program presented a trial (see 3 below). During the observation interval Button 2 was operative and each false alarm prior to trial presentation returned the subject to the intertrial interval, which was reset to a maximum duration of 15 sec.
3. *Trial*: This state lasted for 3 sec and consisted of a 1.0-sec (or .5-sec) tone followed by 2.0-sec (or 2.5-sec) of additional response time. Button 2 was operative and if a head-turn was recorded, the program delivered reinforcement (see 4 below). If no head-turn occurred, the program returned to the intertrial interval for another trial sequence.
4. *Reinforcement*: The visual reinforcer inside the booth was illuminated and activated for 3 sec, after which the program returned to the intertrial interval for another trial sequence.

These four basic states were used in the construction of two separate subroutines, which were distinguished on the basis of the types of trials that were presented.

Shaping Routine—The purpose of the shaping routine was to train a naive infant subject to turn his/her head to the tone stimulus, or, in the case of a trained subject, to ensure that previous training had not been forgotten at the beginning of an experimental session. All experiments began with the shaping routine, which presented two types of trials: (a) Probe trials—which presented suprathreshold tones, initially set to be 10 dB below the values presented in Table 1; and (b) Shaping trials—which were similar to probe trials except that the reinforcement was programmed to activate automatically at the termination of the 1.0 sec tone.

The shaping routine always began with the presentation of a probe trial. If the initial probe was not responded to, as was usually the case with a naive subject, then the following trial sequence presented a shaping trial, in which the reinforcement occurred automatically. Normally, all subjects responded with a head-turn on a shaping trial. If the subject did not, shaping trials were repeated until a head-turn response occurred. When this happened, the following trial sequence then presented a probe trial. The program recycled in this manner until two consecutive probe tones were responded to, at which point the subject entered the testing routine (see below). A state diagram of the shaping routine is shown in Figure 1 (top panel).

Testing routine—When the subject had responded to two successive probe trials in the shaping routine, he/she entered the testing routine, in which three types of trials were presented: (a) test trials; (b) catch trials; and (c) probe trials. For every sequence of eight trials, there were always four test trials, two probe trials, and two catch trials. Their exact

order of occurrence was randomly permuted after every sequence of eight, so that the experimenter was always blind as to what type of trial was being presented at any time.

Test trials presented tones according to an adaptive staircase (tracking) procedure. The first test tone was always presented at the same intensity level as the initial probe tones. Each test tone responded to caused the next scheduled test tone to be decremented by 10 dB. Each missed test tone caused the next one to be incremented by 10 dB. This one-up, one-down algorithm specified that an obtained threshold would converge on the 50% detection point of the psychometric function (Levitt, 1971).

Catch trials were of equal duration (3.0 sec) as test trials, and the programmable attenuator was set to its maximum level (−127 dB) such that no tone was audible. If a false alarm occurred, the subject was returned to the intertrial interval, which was set to a maximum duration of 15 sec. If the subject did not respond to the catch trial, the immediately following intertrial interval was set to a minimum value of 1.0 sec. This allowed another trial to be initiated almost immediately and thus ensured that long periods of time without audible signals never occurred during testing.

Probe trials consisted of suprathreshold stimuli and were similar to probe trials presented during shaping. However, during testing the intensity level of a probe was determined by the subject's prior response to test tones: A probe was always set at 20 dB above the intensity of the last test tone that was correctly detected. For example, if the subject had responded to a test tone of −40 dB, and then missed one at −50 dB, the next scheduled probe tone would be presented at a level of −20 dB. However, probe intensity levels never exceeded the initial intensity level used in shaping. A state diagram of the testing routine is shown in Figure 1 (bottom panel).

If the subject missed a probe trial during testing, further testing was discontinued and the subject returned to the shaping routine. Normal shaping contingencies were in effect except for the following changes: The reinforcement was changed from bear to monkey or vice versa, and the probe tones were maintained at a level of 20 dB above the last test tone responded to. Furthermore, if the subject then missed two consecutive probes after re-entering shaping, the session automatically terminated. However, if two consecutive probes were responded to after re-entering shaping, the subject re-entered testing and continued where he/she left off. If a second probe was missed during testing, the session automatically terminated. In both of these cases, missed probes were taken as an objective indication that the infant was no longer operating under a reliable degree of stimulus control.

The experiment also terminated automatically after six response reversals were obtained in the test trials. A threshold was calculated by averaging the six reversal points (Levitt, 1971), and was considered valid if no more than one catch trial had been responded to, and no more than one probe trial had been missed during testing. Typically, four to six probe and catch trials occurred in a session.

Infants and adults were tested in weekly sessions. Frequencies were randomly varied from session to session. No subject was tested more than once for any given frequency-duration stimulus condition. Adults were tested for 5–10 sessions, and infants were tested for 4–12 sessions. After four sessions of testing, infants were not tested further if two consecutive sessions occurred with terminations because of missed probe trials. Infants began a session with an alternate reinforcer each week. Of the 27 infant subjects, 16 were tested on 1.0 sec tones only. Eleven were tested with 1.0 sec tones and then transferred to .5 sec tones. Of the adults, 7 were tested with 1.0 sec tones, and three of these were then retested with .5 sec tones. Two adults were tested only with .5 sec tones.

RESULTS

Twenty-six out of 27 infants were successfully shaped and entered into testing in their first experimental session. One infant required two shaping sessions. The mean number of shaping trials before testing was initiated was 5.56, $SD = 4.25$, Range = 2–21. At least one session of usable threshold data was obtained from each infant tested. One female infant produced 10 consecutive sessions of usable data. Altogether, the 27 infants were tested for a total of 154 sessions. Of these, 91 were successful in yielding usable data; that is, the infant missed no more than one probe trial and responded to no more than one catch trial during testing. Forty-five of the 154 sessions did not yield usable data because more than one probe was missed (resulting in automatic termination), and 14 of the 154 sessions contained more than one catch trial response. Four sessions were aborted prematurely by the experimenter when the infant started to cry. Of the 91 usable sessions, 38 were “perfect” sessions, with 100% probe responses and 0% catch trial responses. Thirty-one were sessions with one catch trial response, and 12 sessions contained a single missed probe. Ten sessions contained both a missed probe and a catch trial response. Adult subjects never missed probe stimuli, and only one adult responded to a single catch trial during one test session.

Individual Data

An example of a male infant’s performance during the shaping and testing routines is shown in Figure 2. The subject began the session in the shaping routine, responded to two consecutive probe tones at trials 6 and 7, and entered the testing routine at trial 8. During testing, catch and probe trials were randomly interleaved with test trials, and threshold was tracked until six response reversals were obtained. One catch trial was responded to at trial 20, but no probe trials were missed. His reversal points were (in attenuation values): 60, 50, 70, 60, 70, and 60 dB. A threshold was calculated by averaging the six reversals for a mean of -61.6 dB, or 12.7 dB SPL.

Examples of individual audiograms are shown in Figure 3, for one sensitive adult (KD), one insensitive adult (SK), one sensitive infant (LH), one moderately sensitive infant (BH), and one insensitive infant (EG). Also plotted for comparison purposes is the classic function of Sivian and White (1933) for binaural minimum audible field data, as replotted in Green (1976, p. 38). The sensitive adult overlapped the function of Sivian and White, but the insensitive adult approached the function of the sensitive infant. For both adults, no differences in sensitivity appeared with 1.0 and .5 sec tones. The infant LH was consistently 3–5 dB more sensitive with 1.0 sec than with .5 sec tones.

Average Data

Mean thresholds and standard deviations for 1.0-sec tones from .250 to 4.0 kHz are shown in Table 2A, for both adults and infants. For infants, the mean probabilities of responding to probe trials and catch trials are also shown. For each frequency, infants responded to probe stimuli with a probability of greater than .90, whereas for catch trials, the probability was .10 or less. An additional analysis of the infant threshold data was performed using only “perfect” sessions (100% probe responses and 0% catch trial responses). These thresholds differed by no more than 5 dB from the analyses derived from all sessions. Average infant and adult audiograms for 1.0-sec tones are displayed graphically in Figure 4 (top panel). Both audiograms were flat from .500 to 4.0 kHz, with thresholds at .250 kHz slightly elevated. The infant audiogram was 21 to 27 dB higher than the adult.

Mean thresholds and standard deviations for .5-sec tones from .500 to 8.0 kHz are shown in Table 2B. Thresholds for both infants and adults were similar to those for 1.0-sec tones. Infant thresholds were 17–25 dB higher than those of adults. Average audiograms for .5 sec

tones are graphed in Figure 4 (bottom panel). Adult audiograms were flat from .500 to 8.0 kHz, while infants showed a slight increase in sensitivity at 8.0 kHz, relative to the other frequencies. At 8.0 kHz the standard deviations of the infant and adult populations overlapped slightly. Overall, for both .5 and 1.0 sec tones, standard deviations for infant thresholds were no larger than those for adults.

DISCUSSION

Methodology

Overall, infants in the present experiment appeared to be operating under a high degree of stimulus control during threshold tracking, such that responses were made to over 90% of the probe trials and less than 10% of the catch trials. Such results compare favorably with stability criteria required from subjects in animal psychophysical experiments (e.g., Stebbins, 1970). High false alarm rates, resulting in unusable data, occurred primarily in the initial sessions of testing. It is conceivable that “punishing” false alarms by returning the infant to the intertrial interval, and thus delaying further trial presentation, may have had some effect in extinguishing this behavior.

After the initial sessions, as false alarms declined, it then became increasingly important to prevent the head-turn response from extinguishing. Loss of stimulus control occurs frequently with animals on tracking procedures (Harrison & Turnock, 1975; Stebbins, 1970). The strategy of randomly interleaving suprathreshold probe stimuli with test stimuli served two purposes; first, these probe stimuli provided both infants and adults with salient discriminations during difficult periods of tracking stimuli near threshold. However, since probe stimuli were never set higher than 20 dB above the test stimuli, these discriminations were not so salient as to distract subjects from making the more difficult ones.

A second function of the probe stimuli was to catch moments of infant inattentiveness, after which an attempt was made to recapture the infant by returning to the shaping routine. For example, if the infant was not permanently satiated, but had simply experienced a transitory lapse of attention (e.g., had gotten too involved with the antics of the booth assistant), then upon returning to shaping, the infant would view the alternate reinforcer. The booth assistant would view this as well, and would proceed to reduce her activity. Infants were successfully revived in this way in 22 sessions. On the other hand, if the infant was becoming permanently satiated with both reinforcers, then “reshaping” was to no avail and the infant continued to disregard both probes and shaping stimuli.

One observation from the present experiment indicated that infant inattentiveness to the stimuli was actually less of a problem than false alarms. For example, an examination of sessions where infants made only one “mistake” reveals that there were more with a catch trial response (31 sessions) than with a missed probe (12 sessions). This suggests that, at least before the point in time when the infant became permanently satiated with the reinforcer (and had to be dropped from the experiment), temporary lapses of attention occurring on a moment-to-moment basis during testing did not appear to be a major problem in this experiment.

A striking result of the present experiment was that the attrition rate for infants was essentially 0%, since at least one session of usable data was obtained from each infant tested. It should be noted that most infants had already had previous exposure to the testing situation in speech discrimination experiments; however, it might be expected that this experience would have contributed more to boredom and fatigue on the part of the infants than to an enhancement of performance.

One final important aspect of the present methodology was that it provided objective criteria for terminating an experimental session. Infant studies in the literature readily report that sessions were terminated when infants began to “fuss” or not attend to the assistant (e.g., Eilers, Gavin, & Wilson, 1979; Trehub et al., 1980). In the present study, only four experimenter-induced terminations took place and all were initiated when infants began to cry. All other sessions were automatically terminated by the computer program according to the objective criteria out-lined earlier in the procedure section. Allowing the experimenter to terminate a session based on subjective criteria could easily lead to experimenter bias. Such issues are currently causing considerable controversy with regard to a number of recent findings in infant speech perception (see Aslin & Pisoni, 1980). The use of more objective methodologies such as that presented here should help to clarify such controversies.

Auditory Sensitivity

The adult audiograms of the present study appeared quite flat in the range from .500–8.0 kHz. The Sivian and White data show an increase in sensitivity at 2.0 and 4.0 kHz. There are a number of possible reasons for this mismatch. First, Sivian and White conducted their studies in an anechoic chamber that provided minimal acoustic reflections. Inside our IAC testing booth, our calibrations may have been influenced by the occurrence of acoustic reflections that could create standing waves and sound shadows, particularly at the higher frequencies. In addition, the head-turning technique, for which the subject’s head cannot be rigidly fixed, may be too gross to pick up all the subtle aspects of the audibility curve. Also, our adult subjects were not repeatedly tested as they should be to obtain their most sensitive thresholds at each frequency. Because repeated testing was difficult with most infants, we attempted to maintain both groups under testing conditions that were as closely comparable as possible.

The most important result of our study is that, for a sample of infants and adults tested under conditions as similar as possible, infant pure tone thresholds are 17–27 dB above those of adults, at least over the frequency range used for speech. In this sense, our results appear similar to those of Trehub et al. (1980), who reported a 20–30 dB difference between infants and adults for detections of octave band noises. However, in comparing the results of the two studies, it is important to note that Trehub et al. used a more liberal threshold criterion for infants (only 65% correct) compared to adults (75% correct) in their forced-choice procedure. (“Chance” responding in a forced-choice procedure is 50% correct.) Since many infant psychometric functions never reached 100% correct detection (attributed to “lapses of attention”), these authors reasoned that threshold criterion for infants should be lowered when compared to adult performance. In viewing the data of Trehub et al., it appears that use of the adult 75% threshold criterion for infants would have resulted in elevating their thresholds by approximately 5–10 dB. This, in turn, would have resulted in threshold *differences* between infants and adults on the order of 25–35 dB, or even 30–40 dB, instead of the reported 20–30 dB. In the present study, identical threshold criteria were applied to infants and adults alike, because reliable infant responding to probe and catch trials indicated that loss of stimulus control during threshold testing was not a major problem. Furthermore, if our infant threshold measurements had been confounded by the occurrence of significant “attentional lapses”, it might be expected that infants would have exhibited larger standard deviations compared to adult subjects, but this was not the case. Trehub et al. did not report comparisons of variability between their infant and adult subjects.

Assuming that the infants in the present study were operating under adequate stimulus control, one hypothesis to account for the diminished sensitivity of infants relative to adults is that there are real sensory threshold differences between these populations. Electrophysiological work with infants indicates that, at all levels of the auditory system from the periphery to the cortex, infant thresholds may range from 10 to 30 dB above those

of adults (Hecox, 1975). Another possibility is that threshold differences are related to differing selective attentional mechanisms elicited by the experimental situation. Whereas adults were presumably attending selectively to the auditory stimuli in a situation akin to a vigilance task, the infants were being entertained visually during threshold testing. Thus, infants were faced with a forced division of attention between the simultaneous visual and auditory stimulation. Although there is evidence that human adults can perform simultaneous auditory and visual discriminations with no interfering effects (e.g., Shiffrin & Grantham, 1974), it is not known whether this would also be the case for infants. It is conceivable that a division of attention, while not affecting responsiveness to suprathreshold stimuli, could have caused an elevation of the infants' sensory thresholds.

There were no reliable differences in auditory sensitivity between infants who had successfully completed the previous speech discrimination experiments in our laboratory and those who had not. Although the infant shown in Figure 2 had successfully completed speech testing, another infant (not shown) who had also completed this testing went on to exhibit the highest auditory thresholds obtained from any infant in the present study (54 and 55 dB SPL at .250 and .500 kHz, respectively). None of the infants shown in Figure 3 had completed the speech experiments, including LH, the most sensitive infant. In general, it appeared that many infants who failed to complete speech testing were subsequently able to complete at least one or two sessions of pure tone threshold testing.

No indications of increased low frequency sensitivity as a function of age were found for infants in the present study, as Trehub et al. (1980) reported for their subjects. It is possible that the age range covered by our subjects was too small for such a trend to emerge. Trehub et al. found the greatest difference in sensitivity between the ages of 6 and 12 months. We did not test many infants less than 8 months or greater than 10 months of age. However, the present study provides support for another finding of Trehub et al. that relates to the convergence of infant and adult sensitivity as frequency increases. Whereas adult audiograms were flat from .500 to 8.0 kHz, many infants showed increases in sensitivity at 8.0 kHz (see Figure 3).

Finally, although few researchers would attempt to build a theory of speech perception solely from "lower" level auditory capabilities, it is clear that such abilities place basic constraints on the infant's ability to process the complex acoustic information contained in speech signals. For example, current accounts of human speech perception have emphasized psychophysical explanations according to which the distinction between, for example, /b/ and /d/ relates to intensity differences between high and low frequency components of the speech spectrum at the time of release of the consonant (e.g., Stevens & Blumstein, 1978). Further research comparing human infants and adults in their capacities for frequency, intensity, and temporal discrimination should help to determine whether such accounts could be applied to infant hearing and speech processing.

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Figure 1.

State diagrams of the shaping and testing routines. ITI = intertrial interval; OBS = observation interval; RF = reinforcement; PRB = probe trial; TEST = test trial; CATCH = catch trial.

Figure 2.

Trial-by-trial record of an experimental session from one infant showing performance in the shaping routine and threshold tracking during the testing routine. Test trials are linked by a solid line. Numbers (1–6) with test trials indicate occurrence of response reversals.

Figure 3.
Individual audiograms obtained from three infants and two adults.

Figure 4.
Average audiograms for infants and adults for 1.0 sec and .5 sec tones.

TABLE 1

Calibrations in dB SPL of the Test Area

	Frequency (kHz)					
	.250	.500	1.0	2.0	4.0	8.0
$\bar{X}$	79.0	70.1	69.3	72.3	74.3	69.8
SD	2.37	2.71	3.08	2.66	2.25	2.40

Table 2A
Mean Thresholds and Standard Deviations for Infant and Adult Subjects for 1.0 sec Tones

	Frequency (kHz)				
	.250	.500	1.0	2.0	4.0
<i>Infants</i>					
N	13	13	11	14	16
$\bar{X}$	37.7	30.3	31.2	36.1	34.3
SD	8.53	11.8	10.2	9.01	12.3
Probe	1.00	.96	.94	.92	.92
Catch	.04	.07	.06	.09	.10
<i>Perfect Sessions</i>					
N	9	5	5	5	4
$\bar{X}$	40.1	29.2	33.6	31.8	31.7
SD	8.91	12.4	13.6	4.92	15.2
<i>Adults</i>					
N	7	7	7	7	7
$\bar{X}$	15.5	8.50	8.00	12.4	7.29
SD	9.61	5.80	7.42	8.73	5.53
Diff	22.2	21.8	23.2	23.7	27.0

Table 2B
Mean Thresholds and Standard Deviations for Infants and Adults for .5 sec Tones

	Frequency (kHz)					
	.500	1.0	2.0	4.0	8.0	
<i>Infants</i>						
N	5	7	2	5	5	
$\bar{X}$	33.6	35.0	36.5	31.2	25.0	
SD	4.98	7.51	10.6	7.79	9.97	
Probe	1.00	.95	1.00	.93	.94	
Catch	.06	.09	.20	.07	.09	
<i>Adults</i>						
N	5	5	5	5	5	
$\bar{X}$	11.0	9.20	14.2	7.60	7.2	
SD	5.48	10.4	9.23	9.04	8.07	
Diff	22.6	25.8	22.3	23.6	17.8	