Infant psychometric functions for detection: Mechanisms of immature sensitivity[a)]

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Psychometric functions are described for individual 6- to 9-month-old infants and for individual adults for auditory detection of repeated, long- and short-duration tone bursts in quiet and for single, long-duration tone bursts in quiet and in noise. In general, infant psychometric functions have reduced upper asymptotes, shallower slopes, and poorer thresholds than adult psychometric functions. Infant–adult differences in slope and threshold are greater for short-duration tones than for other stimuli. Infant upper asymptotes are around 0.85 correct for all stimuli. One explanation for these findings is that infants are inattentive a certain proportion of time during the detection task. This model cannot account for the very shallow short-duration stimulus slope, nor can it account for infant–adult threshold differences for any stimulus. Other models of immature attention, or listening strategies, may be able to account for the slope and upper asymptote as well as the threshold of infant psychometric functions. Some combination of inattentiveness and primary neural immaturity may also account for the data. Although immaturities exist, some aspects of the detection process appear to be quantitatively similar in infants and adults. © *1995 Acoustical Society of America.*

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INTRODUCTION

Infants' sound detection thresholds are worse than those of adults. This has been found for long-duration signals presented in quiet (Berg and Smith, 1983; Nozza and Wilson, 1984; Olsho *et al.*, 1988; Schneider *et al.*, 1980; Sinnott *et al.*, 1983; Trehub *et al.*, 1980) and in background noise (Bull *et al.*, 1981; Nozza and Wilson, 1984; Schneider *et al.*, 1989), and for short-duration signals presented in quiet (Thorpe and Schneider, 1987; Werner and Marean, 1991). While the finding that infant thresholds are higher than those of adults is well established, the shape of the infant psychometric function for detection has not been well described. The psychometric function describes how performance changes as a function of intensity; in the discussion that follows, the psychometric function for detection describes the proportion of correct detections as a function of signal level. Knowing the shape of this function for different stimuli will provide a more complete description of the detection process during infancy.

The mechanisms underlying reduced sensitivity in infancy are poorly understood, and the shape of the infant psychometric function could lend insight into those mechanisms. A growing body of evidence suggests that some processes important for detection are well developed by about 6 months of age. For example, anatomical (Bredberg, 1968; Igarashi and Ishii, 1979, 1980; Lavigne-Rebillard and Pujol, 1987, 1988), physiological (Abdala, 1993; Bargones and Burns, 1988; Folsom and Wynne, 1987; Salamy and McKean, 1976; Werner *et al.*, 1993; Werner *et al.*, 1994), and psychoacoustical (Olsho, 1985; Schneider *et al.*, 1990; Spetner and Olsho, 1990) data indicate that cochlear processing (and auditory filter width) is adultlike by this age. However, several other factors that could contribute to reduced sensitivity include immaturities of the conductive mechanisms, physiological noise, central auditory processes, and nonauditory factors such as response bias, attention, and memory. Each of these factors will have a different effect on the shape of the psychometric function for detection.

An immature outer or middle ear (e.g., Keefe *et al.*, 1993, 1994) would reduce sound transmission into the cochlea and would be expected to simply "shift" the infant psychometric function to the right (i.e., toward higher levels) relative to the adult function. The shift would presumably be uniform across intensity, resulting in a poorer threshold, but no change in the slope of the function. The upper asymptote of the infant function would be 1, as it is for the adult function. Further, the shift would be expected for detection in quiet but not for detection in noise because any reduction in sound transmission due to conductive mechanisms would influence both the signal and the noise. Thus threshold in noise would not change.

A progressive increase in the dynamic range of auditory neurons has been reported in nonhumans in the period just following the onset of cochlear function (Sanes and Rubel, 1988), and there is a rough correspondence between the time course of development of masked thresholds and of auditory-evoked potentials that are central in origin (Eggermont, 1985; Schneider *et al.*, 1989). These observations suggest, albeit indirectly, that immaturities of intensity coding persist beyond human infancy. Schneider *et al.* (1989) described two hypothetical auditory neural mechanisms that could con-

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tribute to infants' poor sensitivity. First, increases in neural noise, or an increase in the variability in the neural representation of intensity, would not only result in a poorer threshold, but in most cases would also lead to a decrease in the slope of the psychometric function for detection. In general, age-related changes in neural variability would not affect the upper asymptote of the function.[1] Second, nonlinear changes in the growth of excitation with intensity as a function of age could also contribute to immature thresholds in infants. If the rate of (nonlinear) growth of excitation is reduced early in development, the slope of the psychometric function would also be reduced. A change in the growth of excitation that results in a threshold change in the range of 10–20 dB, however, has only a slight effect on the slope, and may be hard to demonstrate in infant subjects. Changes in the growth of excitation with intensity would not affect the asymptote of the psychometric function.

Nonauditory factors such as response bias and attention influence adult thresholds (see, e.g., Green and Swets, 1966), and it is likely that these factors also play a role during development. Anecdotal evidence indicates that infant and adult listeners have different response biases. Infants are typically more likely to respond in a detection experiment than adults are. Age differences in response bias are important when a performance measure such as hit rate or percent correct is used. However, age differences in threshold are reported even when bias-free measures of sensitivity are used (e.g., Schneider *et al.*, 1989; Trehub *et al.*, 1980), so bias cannot completely account for the threshold difference.

Immature attention could also contribute to infants' poor thresholds. Several investigators have recently modeled the influence of general inattentiveness on the psychometric function for detection (Green, 1990; Schneider and Trehub, 1992; Viemeister and Schlauch, 1992; Wightman and Allen, 1992). In general, the models assume that the underlying psychometric function is the same for infants and adults, but that infants are inattentive on a certain proportion of trials. If an individual listener has a lapse of attention during a certain proportion of time, and she guesses on trials that occur during that time, she will be correct on half of those trials just by chance. On the remaining trials, when the listener attends, performance should be related to signal level. For a high signal level, detection should be near perfect when the listener is attending, and observed performance will then equal $1-(0.5\times$ the inattention rate). This will be the observed upper asymptote of the psychometric function. Assuming that the inattention rate is the same at all stimulus levels, the entire psychometric function can be rescaled according to the observed upper asymptote. Compared to the underlying function, the function for the inattentive listener is shallower and has a higher threshold. We refer to this model as the "general inattentiveness" model.

Immaturity of other varieties of attention, such as selective attention, may also influence infants' detection. Substantial evidence indicates that when adults detect a tone of known frequency, they selectively monitor or attend to an auditory filter centered on the signal frequency (Bargones and Werner, 1990; Dai *et al.*, 1991; Greenberg and Larkin, 1968; Macmillan and Schwartz, 1975; Penner, 1972; Scharf *et al.*, 1987; Schlauch and Hafter, 1991; Yama and Robinson, 1982). This is an optimal listening strategy under these conditions because it allows the listener to improve the signal-to-noise ratio at the test frequency by filtering out (and ignoring) irrelevant noise. Recent evidence indicates that unlike adults, infants do not selectively attend to a single filter centered on a given test frequency (Bargones and Werner, 1994). Rather, infants may attend to multiple filters simultaneously, or they may attend to a single filter with a varying center frequency. It is also possible that the infant does not attend to the task at all and that each time a signal is presented, the infant's attention is "captured" anew. Each of these listening strategies has a different influence on the shape of the psychometric function. Simultaneous monitoring of multiple filters leads to an increase in the slope of the function while monitoring a single, nonstationary filter results in a shallower function (Hubner, 1993). Both strategies lead to an increase in threshold, and neither necessarily results in a change in the upper asymptote. Depending on the underlying assumptions and the range over which the filter wanders, monitoring a single nonstationary filter can lead to a very shallow function that at best only very slowly approaches 1. Recent evidence indicates that for adults, threshold for an unattended frequency is elevated about 7 dB compared to detection of the same frequency when it is attended (Dai *et al.*, 1991) and the slope of the psychometric function may be the same for attended and unattended frequencies. Under some conditions, distinguishing among some of these attention mechanisms, or listening strategies, may be difficult; for example, the effects of monitoring a single wandering band which is occasionally remote from the signal frequency could be similar to the effects of occasional general attentiveness.

Although auditory psychometric functions have not been described for individual infants, composite, or group, psychometric functions, which average over a large number of infants each tested for only a few trials, have been published. Group psychometric functions for auditory detection in quiet (Trehub *et al.*, 1980) and in noise (Schneider *et al.*, 1989) for 6-month-old infants appear to have lower upper asymptotes, shallower slopes, and poorer thresholds than those of adults.[2] These results are consistent with the hypothesis that infants are less attentive during detection tasks than adults are. However, it is not clear whether the group function is an accurate description of the performance of individual infants.

The purpose of the current paper is to describe the psychometric function for detection for individual 6- to 9-month-old infants for several different stimuli. Threshold, slope, and asymptote of individual psychometric functions are estimated for repeated long-duration tone bursts, single long-duration tone bursts, and repeated short-duration tone bursts. Detection of each of these stimuli was examined in quiet; detection of single, long-duration tone bursts was also examined in noise. The psychometric function for repeated long-duration tones is taken as the "standard," because this is the typical stimulus for estimating infant threshold for frequency-specific stimuli. Performance for single, long-duration tones or for repeated, short-duration tones would be expected to be vulnerable to immature attention. If the infant were to have a lapse of attention for a short time, she could miss a single tone burst, and it has been argued that short-duration stimuli are less effective at capturing a young animal's attention (Gray, 1990). Thus if inattentiveness is an important contributor to infants' detection performance, its effects (reduced slope and upper asymptote, elevated threshold) should be exaggerated in the case of single or short-duration stimuli, relative to the standard case. A decrease in stimulus duration might also be expected to have a larger effect on detection for infants than for adults if neural variability is higher in infants than in adults; an especially shallow infant psychometric function slope with an upper asymptote of 1 for the short-duration stimulus relative to either of the long-duration tones would be consistent with this model. Because the effects of maturational changes in the growth of excitation with stimulus intensity would be small, slight or no reductions in infant psychometric function slope for any stimulus, with an upper asymptote of 1, would be consistent with immature growth of excitation. In any case, comparison of infant performance in quiet and in noise will provide insights into conductive mechanisms as well as the potential influence of physiological noise. Thus this set of stimuli should allow us to distinguish among many of the models that have been proposed to account for infants' poor sensitivity.

I. GENERAL METHODS

All three experiments followed the same general methods. Where differences exist, they are described with the specific methods of the experiment involved.

A. Subjects

Six- to nine-month-old infants and 18- to 30-yr-old adults participated in the studies. No change in thresholds is expected within either of these age ranges (Nozza and Wilson, 1984; Olsho *et al.*, 1988). Each subject visited the lab two to seven times. All subjects were healthy and passed a tympanometric screen for middle-ear effusion (pressure-compliance peak of at least 0.2 mmhos between 50 and −200 daPa) on each test day. No subject was at risk for hearing loss or had more than two episodes of middle ear effusion by parental or personal report. Any subject who had a recent middle ear effusion or had completed medical treatment for a middle ear effusion within one week prior to testing was excluded.

B. Stimuli

The stimulus was a 1000-Hz tone burst with a 16-ms rise/fall. When used, background noise was presented at approximately 20 dB N_0. The noise was low-pass filtered with a cutoff frequency of 2500 Hz. All stimuli were presented to the listener's right ear via an Etymotic ER1 insert earphone in a foam tip trimmed to fit various sized ear canals.

The tones were digitally generated and were attenuated, filtered, and amplified. The stimuli and the experiment were controlled by a computer. All stimuli were calibrated in a Zwislocki coupler, and all stimulus levels are reported in dB sound-pressure level.

C. Procedures

Infants were tested using the Observer-based Psychoacoustic Procedure (OPP; Olsho *et al.*, 1987). This is a one-interval paradigm in which an adult observer begins a trial when an infant is quiet and appears to be attentive. Signal and no-signal trials occur with equal probability. In a typical detection task, tones are presented on signal trials and no tone is presented on no-signal trials. Signal and no-signal trials have equal duration. The adult observer decides if a signal trial occurred or not based solely on the infant's behavior. The observer gets feedback after each trial, and the infant is reinforced for making an observable response on signal trials by the activation of a mechanical toy. In contrast to typical adult psychoacoustic testing, in OPP no information is given to the infant about when a trial is in progress, and feedback (i.e., reinforcement) is provided to the infant only when the observer correctly identifies a signal trial.

In the current experiments, adults were tested using procedures as similar to the infant procedures as possible. Instructions to adults were minimal since infants could not be verbally instructed. Adults were told to respond whenever they heard a sound that would make the animated toys light up. They were told that their goal was to make the animals light up as much as possible, so if they were not sure, they should go ahead and guess. Adults were instructed to have a "lax" criterion because previous work in our lab indicated that adults tend to be quite conservative responders in this procedure.[3]

Each session consisted of two training phases and a test phase. In the training phases, the signal was presented at a clearly audible level. In training phase 1, signals were presented on three of every four trials, and the mechanical toy was activated after each signal trial, regardless of the observer's response. The observer had to be correct on four of the last five trials and at least one no-signal trial to enter training phase 2. In training phase 2, signal and no-signal trials occurred with equal probability, and reinforcement was contingent on the observer's correctly identifying a signal trial; the observer had to be correct on four of the last five signal trials and four of the last five no-signal trials before entering the test phase. In the test phase, the signal was set at a fixed level for a full block of 30–40 trials. Levels were selected on the basis of pilot data to be in the range of the psychometric function for subjects in each age range for each stimulus.

Although the training and test levels were based on pilot data, it is possible that some of the levels were inappropriate for some subjects or that on any given day a subject was not performing optimally. To ensure that infants had a chance to perform at their best, three procedures were included.[4] First, five additional "probe trials" were randomly presented in each session. Probe trials were identical to signal trials except the level was increased by 10 dB. The infant-observer team had to be correct on at least three of the five probe trials or the session was repeated. Second, to ensure that predetermined training and test levels were appropriate, if an infant did not reach criterion in training phase 2 after two visits to the lab, slight modifications were made in the next visit. Signal level in training phase 2 was fixed at the highest level for that phase (see individual experiments), and the test level was set at the highest level of the initial test levels. Subsequent sessions followed the original procedures. Finally, if a function was nonmonotonic, an attempt was made to repeat testing at the level where the nonmonotonicity occurred. In these cases, the session with the best performance at a given level was used; this occurred in three cases.

D. Data analysis

The results were analyzed in terms of $p(C)_{\max}$, an unbiased estimate of sensitivity. Assuming that d' is criterion-free, $p(C)_{\max}$ is the value of $p(C)$ that would be observed if the observer adopted an unbiased criterion. $p(C)_{\max}$ is the probability of obtaining a Gaussian deviate that is less than $d'/2$. To decrease statistical bias in estimating d' for relatively few trials (30–40), and because $p(C)_{\max}$ is undefined for proportions of 0 and 1, proportions of 0 were changed to $1/2n$ and proportions of 1 were changed to $1-1/2n$, where n is the number of trials in the given condition (see, e.g., Macmillan and Kaplan, 1985). Psychometric functions, plotting $p(C)_{\max}$ as a function of signal level, were constructed for each individual.

Ideally the asymptote, slope, and position of each function would be estimated from a fit to all the data for each subject, for example, using probit analysis (Finney, 1970). However, with a small number of data points, it is often not possible to obtain stable fits. Therefore to quantify the functions, data from each subject were fit with three straight lines: lower asymptote, upper asymptote, and a slope.[5] The lower asymptote had a slope of 0 and an intercept of $p(C)_{\max}=0.5$ (chance performance). It included all points falling within the 95% confidence interval above 0.5 based on binomial probabilities. The upper asymptote also had a slope of 0. Its intercept was estimated by calculating the binomial standard error for the block with the best $p(C)_{\max}$ and averaging all points within the 95% confidence interval of that point. If no points fell within the 95% confidence interval and the point with best performance was at the highest level tested, the point with the best $p(C)_{\max}$ was taken as the upper asymptote. If performance at intensities above the level with best performance fell outside the 95% confidence interval and if the session could not be repeated, the nonmonotonic function was excluded. If the upper asymptote was estimated as the single highest level tested for many subjects in a given experiment (i.e., the functions did not plateau), additional subjects were tested at higher signal levels to better estimate the upper asymptote. The slope line was fit to all points falling between the upper and lower asymptotes including the point at the lowest level on the upper asymptote and the point at the highest level on the lower asymptote. This slope estimate is based on data points obtained at 5-dB intervals and is thus a first approximation of the slope. More accurate estimates would require a smaller step size. An example of the three-line fit to data for an individual infant and an individual adult are shown in Fig. 1. The dashed line in Fig. 1 is the infant's function rescaled for inattention; it will be discussed below.

In addition to estimating the upper asymptote and the slope of the function, best performance and threshold were estimated. Best performance was the highest $p(C)_{\max}$ attained, and threshold was defined as the level at which $p(C)_{\max}=0.75$.

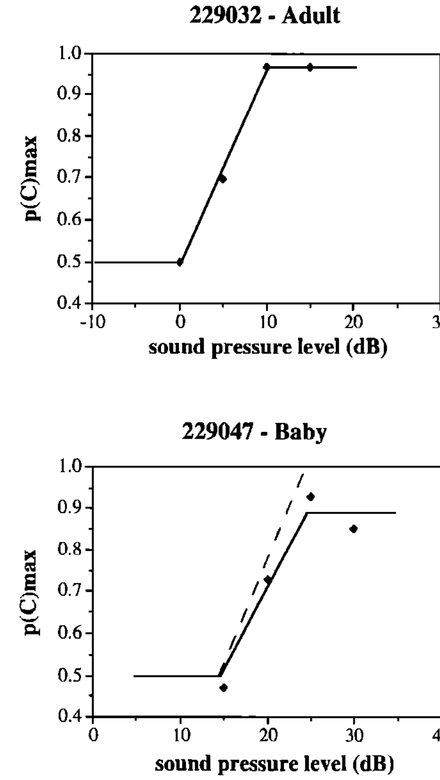

FIG. 1. Example of three-line psychometric function fits to data for an individual adult and an individual infant. The dashed line indicates the infant psychometric function rescaled for general inattentiveness (see Sec. V).

Bartlett's test for homogeneity of variance was used prior to all statistical analyses. If nonhomogeneity of variance was found ($p<0.05$), nonparametric statistics were used. This occurred for the age comparison of thresholds in experiment I, for the age comparison of slopes in experiment III, and for the age comparison of upper asymptote and best performance in all experiments. In all other cases, data were analyzed with parametric statistics. An arcsin transform of each $p(C)_{\max}$ was made prior to statistical analyses of upper asymptotes and best performance. Nonparametric, *post hoc*, multiple comparisons were completed following Daniel (1990) with a conservative experimentwise error rate of 0.05.

II. EXPERIMENT I: PSYCHOMETRIC FUNCTIONS FOR DETECTION OF REPEATED, LONG-DURATION TONE BURSTS IN QUIET

A. Method

1. Subjects

Subjects included 20 infants (mean age at first test=7 months, 12 days) and 10 adults (mean age at first test=22 yr, 7 months). Psychometric functions were obtained from the adults and ten infants within at most 63 days (infant mean 37 days, adult mean 13 days). Examination of the individual functions revealed that the upper asymptote for five of the ten infants was estimated on the basis of a single point (i.e., the functions did not plateau). Ten additional infants completed two visits within 31 days to estimate the upper asymptote. All infants completed the study before reaching the age of 9 months and 2 weeks.

In addition, 15 infants and 1 adult were excluded from the study for the following reasons: did not complete a full data set (9 infants), nonmonotonic function (4 infants, 1 adult), and did not tolerate test situation (2 infants). An additional 28 infants were scheduled for one or more visits but did not complete the study due to failed tympanogram (19) or scheduling conflict or sickness (9). The data obtained from subjects who did not complete a full data set were similar to the data obtained from subjects who did.

2. Stimuli

The signal consisted of four 1000-Hz tone bursts of 500-ms duration with 500 ms between bursts.

3. Procedure

To obtain psychometric functions, the signal was presented at 55 dB in training phase 1 and at 35, 40, or 45 dB in training phase 2; each level was randomly selected without replacement before a level was repeated. In the test phase of the first two visits, signal level was randomly set to 25 or 30 dB for infants and 10 or 15 dB for adults. After the first two sessions, test level was increased or decreased in 5-dB steps according to performance on the initial test levels. If performance at both levels was above chance, estimated by binomial probabilities, intensity was reduced. If performance was at chance at both intensities or at the lowest intensity, test level was increased. Once the level of chance performance was established, test level was increased 5 dB above the initial test levels. For example, a given infant might be tested at 20, 25, 30, and 35 dB. Each subject was tested at three to five stimulus levels in an attempt to obtain performance ranging from chance to upper asymptote.

To estimate the upper asymptote alone, signal level was 66 dB in training phase 1. In training phase 2, signal level was 46, 51, or 56 dB. Each level was randomly presented without replacement before any level was repeated. Test level was 46 dB. This level is more than 20 dB above threshold for this stimulus and would be expected to produce asymptotic performance.

Upper asymptotes estimated from psychometric functions are referred to as "full-function" asymptotes, while those estimated at 46 dB are referred to as "single-point" asymptotes.

B. Results

Individual psychometric functions for repeated, long-duration tone bursts for infants and adults are shown in Fig. 2. The infant functions appear to have lower upper asymptotes and somewhat shallower slopes compared to the adult functions; further, the functions are shifted to the right for infants, indicating that their thresholds are worse than those of adults.

Average upper asymptote and best performance for the infant and adult functions are shown in Table I. Both upper asymptote and best performance for infants were poorer than

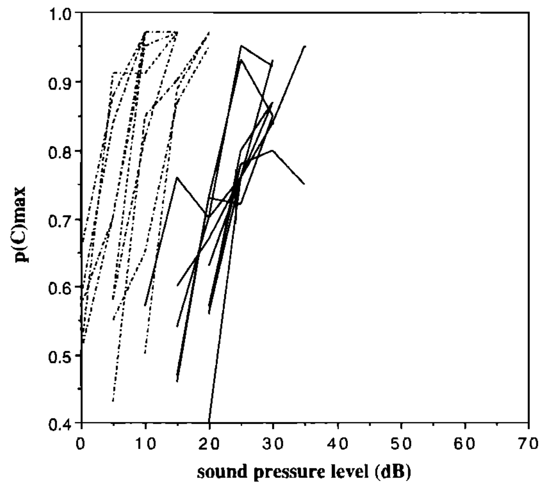

FIG. 2. Psychometric functions from experiment I. Data points for individual listeners are connected with lines. Dashed lines=adults, solid lines=infants.

for adults; these observations were confirmed with the Mann–Whitney test ($U=0.50$, $p<0.001$ and $U=1.00$, $p<0.001$, respectively).

Seven of the ten infants from whom single-point asymptotes were obtained completed a block of test trials in one of two visits, and three infants completed a block of trials in each of two visits. The highest $p(C)_{max}$ in the two visits was used in the latter cases. $p(C)_{max}$ averaged 0.92 and ranged from 0.85 to 0.97. This is an average of 2 errors in 30 trials. One infant scored 0.97. It seems likely that this represents infants' best detection performance on a 30-trial block. A few additional infants were tested at 56 dB; there was no apparent difference in performance.

Two Kruskal–Wallis one-way ANOVAs were used to compare infant single-point asymptote with the full-function upper asymptote from infants and adults. There was a significant difference among infant single-point asymptote, infant full-function asymptote, and adult (full-function) asymptote ($H=18.748$, $p<0.001$). *Post hoc*, nonparametric, paired comparisons showed that adult upper asymptote was significantly higher than either infant single-point or full-function asymptote. There was no difference, however, between the two estimates of infant upper asymptote, suggesting that the full-function estimates were accurate. Therefore the full-function estimates of upper asymptote were used to fit the functions and estimate the slope and threshold for each subject.

Average slopes of adult and infant functions are shown in Table II. Despite the appearance of the individual psychometric functions in Fig. 2, the average infant and adult slopes were not statistically different [$t(18)=-0.983$, $p>0.05$]. This suggests, in any case, that if there is a difference it is small. Previous studies report adult psychometric function slopes of about 5%/dB (Arehart *et al.*, 1990; Green and Swets, 1966; Watson *et al.*, 1972) in agreement with the present results.

Average thresholds for infant and adults are shown in Table III. The infants' average threshold was higher than that of the adults ($U=100.000$, $p<0.001$). Thresholds ob-

TABLE I. Average (s.d.) upper asymptote and best performance in $p(C)_{max}$ for adults and infants tested with four different tonal stimuli.

	Experiment I repeated, long duration in quiet	Experiment II single, long duration in quiet	Experiment II single, long duration in 20 dB N_0 noise	Experiment III repeated, short duration in quiet	Experiment III repeated, short duration in quiet (asymptote only)
Upper asymptote					
adults	0.97	0.97	0.97	0.96	...
	(0.01)	(0.01)	(0.00)	(0.01)	
infants	0.88	0.84	0.83	0.73	0.86
	(0.06)	(0.05)	(0.06)	(0.03)	(0.07)
Best performance					
adults	0.97	0.97	0.97	0.96	...
	(0.01)	(0.01)	(0.00)	(0.01)	
infants	0.89	0.85	0.85	0.75	0.88
	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)

tained here are within the range of thresholds previously reported for listeners of the same ages for 1000-Hz stimuli (Nozza and Wilson, 1984; Olsho *et al.*, 1988; Wilbur *et al.*, 1988).

III. EXPERIMENT II: PSYCHOMETRIC FUNCTIONS FOR DETECTION OF SINGLE, LONG-DURATION TONE BURSTS IN QUIET AND IN NOISE

A. Method

1. Subjects

Subjects included 18 infants (mean age at first test=7 months, 11 days) and 20 adults (mean age at first test=22 yr, 9 months). Each subject completed the experiment within at most 71 days (infant mean=28 days in quiet and 24 days in noise; adult mean=12 days in quiet, 9 days in noise), and all infants completed the study before reaching the age of 9 months and 2 weeks.

In addition, 11 infants tested in quiet and 9 infants tested in noise were excluded from the study for the following reasons: did not complete a full data set (10 in quiet, 6 in noise), did not meet training criterion (1 in noise), did not tolerate test situation (1 in quiet, 2 in noise). An additional 33 infants were scheduled for one or more visits but did not complete the study due to failed tympanogram (16) or scheduling conflicts or sickness (17).

2. Stimuli

The signal consisted of one 1000-Hz, 300-ms tone burst presented in quiet or in noise. In the noise condition, the noise was turned on at the beginning of the session and remained on throughout.

3. Procedure

In training phase 1, signal level was 55 dB in quiet and 75 dB in noise. In training phase 2, signal level was 40, 45, or 50 dB in quiet and 60, 65, or 70 dB in noise. In this phase, each signal level was randomly selected without replacement before a level was repeated. In the test phase of the first two visits, signal level in quiet was randomly set to 25 or 30 dB for infants and 10 or 15 dB for adults. In noise, signal level was randomly set to 50 or 55 dB for infants and 45 or 50 dB for adults. After the first two sessions, test level was increased or decreased in 5-dB steps according to performance on the initial test levels as described in experiment 1.[6]

B. Results

Individual psychometric functions for single, long-duration tone bursts for infants and adults are shown in Figs. 3 (in quiet) and 4 (in noise). The infant functions appear to have lower upper asymptotes and reduced slopes compared

TABLE II. Average (s.d.) slope, in %/dB, for adult functions, infant functions, and infant functions rescaled for inattention obtained with four different tonal stimuli. Results for infants in experiment III are for the psychometric functions from experiment III refit including the lowest point on the upper asymptote estimated separately (see text).

	Experiment I repeated, long duration in quiet	Experiment II single, long duration in quiet	Experiment II single, long duration in 20 dB N_0 noise	Experiment III repeated, short duration in quiet
Adults	4.8	6.3	6.3	6.2
	(1.8)	(2.3)	(2.3)	(2.2)
Infants	4.0	5.3	4.3	1.1
	(1.7)	(1.5)	(1.5)	(0.1)
Rescaled infants	5.7	8.0	6.9	1.5
	(3.1)	(2.6)	(2.6)	(0.2)

TABLE III. Average (s.d.) threshold, in dB, for adult functions, infant functions, and infant functions rescaled for inattention obtained with four different tonal stimuli. Threshold is defined as the level at which $p(C)_{max}=0.75$. Results for experiment II are for the psychometric functions refit including the lowest point on the upper asymptote estimated separately (see text).

	Experiment I repeated, long duration in quiet	Experiment II single, long duration in quiet	Experiment II single, long duration in 20 dB N_0 noise	Experiment III repeated, short duration in quiet
Adults	8.2 (3.9)	10.9 (4.5)	42.1 (1.9)	15.7 (2.7)
Infants	23.6 (1.9)	26.6 (2.6)	50.1 (2.5)	52.6 (1.7)
Rescaled infants	21.8 (2.3)	24.8 (2.8)	47.9 (2.3)	45.9 (2.4)

to the adult functions; further, the functions are shifted to the right for infants, indicating that their thresholds are higher than those of adults.

Average upper asymptote and best performance for the infant and adult functions are shown in Table I. Infant upper asymptotes were about the same in quiet and in noise and lower than the adult measures. A Kruskal–Wallis one-way ANOVA was used to analyze the upper asymptotes from infants and adults tested in quiet and in noise and showed a significant difference among groups ($H=31.721$, $p<0.001$). *Post hoc*, nonparametric, paired comparisons indicated that the upper asymptotes for infants and adults tested in quiet were not different than the upper asymptotes for infants and adults tested in noise. The upper asymptotes for adults tested in quiet and in noise were higher than the upper asymptotes for infants tested in quiet and in noise.

Infant best performance was also lower than that of adults in quiet and in noise, and best performance for both infants and adults was similar in quiet and in noise. These observations were confirmed using a Kruskal–Wallis one-way ANOVA ($H=31.834$, $p<0.001$). *Post hoc*, nonparametric, paired comparisons indicated that best performance for adults tested in quiet and in noise was higher than best performance for infants tested in quiet and in noise. Best performance for infants and adults tested in quiet were not different than best performance for infants and adults tested in noise.

Six of eight infants tested in noise and nine of ten infants tested in quiet reached an asymptotic plateau. There was no indication that performance would continue to improve at higher intensity levels, and pilot data at higher test levels were consistent with an upper asymptote of about 0.83 for a single tone burst.

Average slopes for adult and infant functions in quiet and in noise are shown in Table II. In both quiet and noise, the adult slope was somewhat steeper than the infant slope. The slopes obtained here are slightly steeper than slopes obtained for repeated, long-duration tones (experiment I). Adult slopes were compared to infant slopes using a two-way ANOVA (age×condition). Neither the interaction nor the main effect of condition were significant [$F(1,34)<1$]. Infant slopes were shallower than adult slopes [$F(1,34)=5.401$, $p<0.05$].

Average thresholds for adults and infants are shown in Table III. Infant thresholds were higher than adult thresholds in both quiet and noise. Adult thresholds were compared to

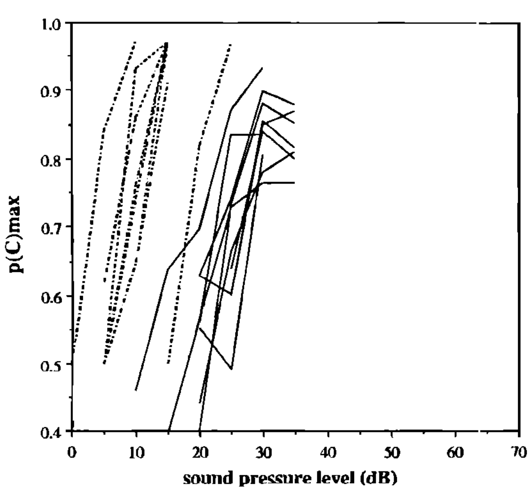

FIG. 3. Psychometric functions from experiment II for detection in quiet. Data points for individual listeners are connected with lines. Dashed lines =adults, solid lines=infants.

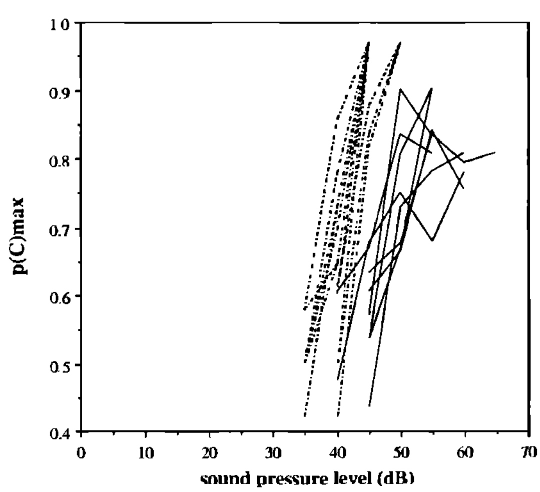

FIG. 4. Psychometric functions from experiment II for detection in noise. Data points for individual listeners are connected with lines. Dashed lines =adults, solid lines=infants.

infant thresholds using a two-way ANOVA (age×condition). The interaction was significant [$F(1,34)=16.195$, $p<0.001$] as were the main effects for condition [$F(1,34)=829.680$, $p<0.001$] and age [$F(1,34)=154.492$, $p<0.001$]. *Post hoc* analyses confirmed that infant thresholds were higher than adult thresholds in both quiet and in noise, but that they were relatively higher in quiet.

IV. EXPERIMENT III: PSYCHOMETRIC FUNCTIONS FOR DETECTION OF REPEATED, SHORT-DURATION TONE BURSTS IN QUIET

A. Method

1. Subjects

Subjects included 21 infants (mean age at first test=5 months, 28 days) and 10 adults (mean age at first test=22 yr, 11 months). Psychometric functions were obtained from the adults and ten infants within at most 88 days (infant mean 19 days, adult mean 29 days). Examination of the individual psychometric functions indicated that the upper asymptote for seven of the ten infants was estimated on the basis of a single data point (i.e., the functions did not plateau). Eleven additional infants were tested to estimate the upper asymptote only. These infants completed the study within 22 days (mean 13 days). All infants completed the experiment before reaching the age of 6 months, 14 days. In addition, 14 infants and 1 adult were excluded for the following reasons: did not complete a full data set (11 infants), nonmonotonic function (3 infants), or experimenter error (1 adult). An additional 15 infants and 3 adults were scheduled for one or more visits but did not complete the study due to a failed tympanogram (6 infants) or scheduling conflict or sickness (2 infants, 3 adults).

2. Stimuli

The signal consisted of 20, 1000-Hz tone bursts with 16-ms rise and fall and no steady-state duration. There were 444 ms between tone bursts.

3. Procedure

To obtain psychometric functions, the signal was presented at 85 dB in training phase 1. In training phase 2, signal level was randomly selected as 50.5, 60.5, or 70.5 dB. Test levels were 30.5, 37.5, 43.5, and 50.5 dB for infants and 7.5, 14.5, and 20.5 dB for adults. Order of test level was randomized across subjects. One adult was also tested at 1.5 dB.

To estimate upper asymptotes only, signal level was 85 dB in training phase 1. In training phase 2 signal level was randomly selected at 55, 65, 75, or 85 dB. All infants were first tested at 65.5 dB. If performance was less than 80% correct, the infant was tested at 70.5 and 75.5 dB in subsequent sessions. If performance was between 80% and 90% correct, the infant was subsequently tested at 60.5 and 70.5 dB, and if performance was better than 90% correct, the infant was tested at 60.5 and 55.5 dB. Test level in the second and third sessions was randomized. Asymptote was calculated as the average of the data points falling within the 95% confidence interval below the point with the highest

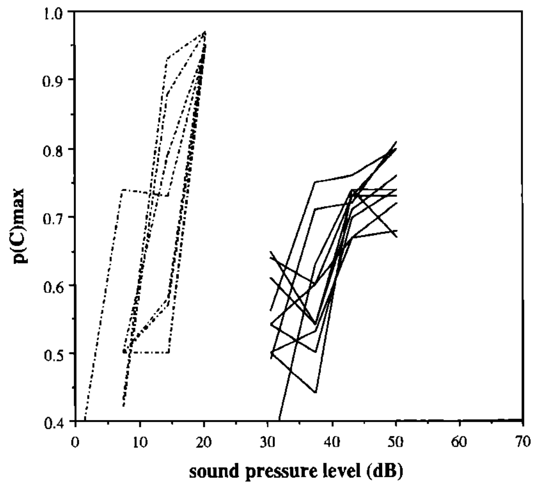

FIG. 5. Psychometric functions from experiment III. Data points for individual listeners are connected with lines. Dashed lines=adults, solid lines =infants.

$p(C)_{max}$. Thus in this experiment, both upper asymptote and best performance measures were available for the "upper asymptote" infants.

B. Results

Individual psychometric functions for repeated, short-duration tone bursts for infants and adults are shown in Fig. 5. Infant best performance is well below that of adults, and the infant functions appear shallower than the adult functions; further, the functions are shifted to the right for infants, indicating that their thresholds are worse than those of adults. Compared to functions for single or repeated long-duration tone bursts, infant functions for repeated, short-duration tone bursts appear much less mature. In particular,

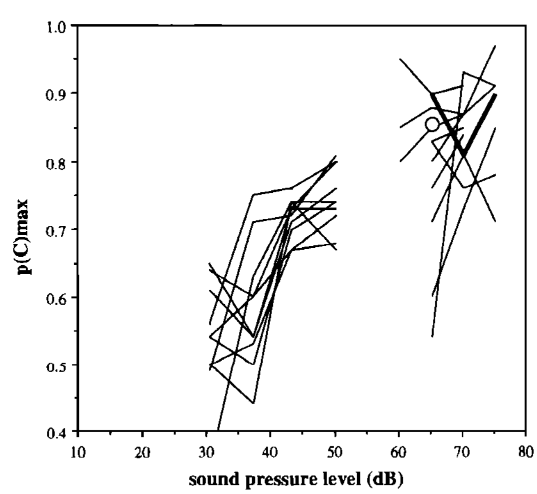

FIG. 6. Upper asymptote data for infants tested in experiment III. Data points for individual listeners are connected with lines. Data for one infant are connected with a thick line to distinguish them from surrounding data. The infant psychometric functions for the same stimulus in experiment III are replotted from Fig. 5. The open circle represents the lowest data point on the estimated infant upper asymptote for this stimulus (see text).

TABLE IV. Summary of infant psychometric function parameters relative to adult parameters (infant–adult difference).

	Experiment I repeated, long duration in quiet	Experiment II single, long duration in quiet	Experiment II single, long duration in 20 dB N_0 noise	Experiment III repeated, short duration in quiet
Upper asymptote [$p(C)$]	lower (−0.09)	lower (−0.13)	lower (−0.14)	borderline lower (−0.10)
Slope (%/dB)	not different (−0.8)	shallower (−1.0)	shallower (−2.0)	much shallower (−5.1)
Threshold (dB)	poorer (15.4)	poorer (15.7)	poorer (8.0)	much poorer (36.9)

infants' upper asymptotes rarely exceed 0.75 and thresholds appear to be extremely high relative to adults'.

The average infant and adult upper asymptote and best performance estimated from the full psychometric functions are shown in Table I. Infant upper asymptotes and best performance were lower than those of adults ($U=0.00$, $p<0.001$ and $U=0.00$, $p<0.001$, respectively).

Infant upper asymptote data are shown together with the infant psychometric functions in Fig. 6. It appears that performance continues to improve through approximately 65 dB for short-duration tone bursts. Average upper asymptote and best performance for the infants from whom only asymptotic data were obtained are listed in Table I. The upper asymptote averages 0.86 and best performance averages 0.88 compared with 0.73 and 0.75 estimated from the psychometric functions. Two Kruskal–Wallis one-way ANOVAs were used to compare the upper asymptote and best performance of infants and adults estimated from the psychometric function to those of infants who were only tested at asymptotic levels. The difference between groups was significant for both upper asymptote and best performance ($H=24.383$, $p<0.001$ and $H=24.854$, $p<0.001$, respectively). *Post hoc*, nonparametric, paired comparisons showed that both upper asymptote and best performance were higher for infants tested only at asymptotic levels than for infants from whom psychometric functions were obtained. The upper asymptote and best performance for infants tested at asymptotic levels just missed being significantly poorer than those of adults, likely because of the strict significance level imposed by the 0.05 experimentwise error rate.

For the infants tested only at asymptotic levels, asymptotic plateau was reached by 60.5 dB by two infants, 65.5 dB by five infants, 70.5 dB by two infants, and 75.5 dB by two infants. The average upper asymptote for repeated, short-duration tones was estimated as $p(C)_{max}=0.86$ beginning at 65.5 dB. This point, 0.86 at 65.5 dB, was considered the lowest intensity point on the upper asymptote for repeated, short-duration tones in fitting the infant psychometric functions. This point is shown as a large open circle in Fig. 6. The average slope for the infant functions fit including this point is listed in Table II. The slope of the infant functions is shallower than that of adult functions ($U=0.000$, $p<0.001$), and the age difference is much greater than that seen for long-duration tones.

Average threshold for infant functions fit including the lowest intensity point of the upper asymptote are shown in Table III. Infant thresholds are higher than adult thresholds [$t(18)=36.357$, $p<0.001$], and the age difference is much greater than that seen for long-duration tones.

V. DISCUSSION

Infant psychometric functions for detection of repeated, long-duration and repeated, short-duration tones in quiet and single, long-duration tones in quiet and in noise have lower upper asymptotes and higher thresholds than adult functions. The infant slope is only slightly, if at all, shallower than the adult slope for repeated, long-duration tones, but is significantly shallower than the adult slope for single, long-duration tones and shallower still for repeated short-duration tones. The difference between infant and adult thresholds is about the same for single and repeated long-duration tones, but is much greater for short-duration tones. Upper asymptote, however, is about the same, 0.83–0.88, for all stimuli. Differences between infant and adult psychometric functions estimated in the three experiments are summarized in Table IV.

The finding that the slopes and upper asymptotes of the psychometric functions obtained in quiet are similar to those obtained in noise for both infants and adults (experiment II) supports the idea that the detection task is the same in quiet and in noise (e.g., Green and Swets, 1966; Watson *et al.*, 1972). The age difference in threshold in noise is about 8 dB. This difference provides an estimate of the age difference in criterion signal-to-noise ratio which is important for detection both in quiet and in noise. The age difference in threshold is greater in quiet than in noise. Mechanisms underlying the age differences in criterion signal-to-noise ratio, slope, and asymptote will be discussed below followed by a discussion of additional factors that may contribute to the age difference in thresholds obtained in quiet.

Is there a single mechanism that can explain the differences between infant and adult psychometric functions and the differential effects of stimulus on the parameters of the infant psychometric function? Any explanation that predicts an infant upper asymptote of 1 can be eliminated, as for every stimulus, the upper asymptote of the infant psychometric function is lower than that of the adult. That would eliminate variability in the neural representation of intensity and the growth of neural excitation with increasing intensity as sole explanations.

General inattentiveness models predict a decrease in the upper asymptote of the psychometric function together with a shallower slope and a higher threshold (Green, 1990; Schneider and Trehub, 1992; Viemeister and Schlauch, 1992; Wightman and Allen, 1992). The degree to which the slope is shallower and the threshold is higher depends on the inattentiveness rate which is estimated using the upper asymptote: A less attentive listener would have a relatively lower asymptote, shallower slope, and higher threshold. These characteristics are consistent with the age differences in psychometric functions observed here. Infant upper asymptotes average about 0.85 for repeated, long-duration tones, repeated, short-duration tones, and single, long-duration tones (Table I). According to the general inattention model [observed performance$=1-(0.5\times$ inattention rate)], this suggests that infants are inattentive approximately 30% of the time for each of these stimuli.

How well the model can account for the immaturities observed in the infant psychometric functions can be assessed by rescaling the functions for inattentiveness assuming that the underlying function approaches 1 as described in the Introduction. The dashed line in Fig. 1 indicates the result for a representative infant. The functions that have been corrected for general inattention will be referred to as rescaled functions. Slopes and thresholds can then be calculated for the rescaled functions to determine if the model accounts for the age differences.

The average slope of the rescaled functions for each stimulus is listed in Table II. The slope of the rescaled function for repeated, long-duration tones in quiet and single, long-duration tones in quiet and in noise are similar to adult slopes, indicating that once general inattentiveness is taken into account, infant functions are parallel to adult functions for these stimuli. These results were confirmed with ANOVA ($p>0.05$). This is not the case for repeated, short-duration tones in quiet. The slope of the rescaled function for this stimulus is still substantially shallower than that of the adult function. This result was confirmed with the Mann–Whitney U test ($p<0.001$). The average threshold for the rescaled function for each stimulus is listed in Table III. Correcting infant thresholds for inattention accounts for approximately 2–6 dB of the threshold shift, depending on the upper asymptote and slope of the function. However, even after correction for inattention, infant thresholds are higher than those of adults. This conclusion was confirmed with statistical analysis ($p<0.001$).

Thus while the characteristics of the infant psychometric function seem qualitatively consistent with the general inattentiveness model, there are several aspects of the present data which cannot be accounted for by general inattention. First, although rescaling the infant psychometric function for long-duration tones makes them similar to adult functions in slope, rescaling the infant psychometric function for short-duration tones does not make the slope adultlike. Second, it would seem logical that single stimuli or short-duration stimuli would be more affected than repeated long-duration stimuli by general inattentiveness. There is little evidence that this was the case here; the upper asymptote of the infant psychometric function, which would be a direct measure of infant inattention rate, varies little with stimulus. Finally and most importantly, the degree of inattentiveness indicated by the upper asymptote of the infant psychometric function is not sufficient to account for the infant–adult threshold difference for any stimulus. Of course it would be ludicrous to claim that infants are perfectly attentive; nonetheless, this analysis shows that the effects of inattentiveness as it is currently modeled are simply not great enough to account for infant–adult differences in detection.

Another potentially important contributor to the maturation of auditory sensitivity is the development of listening strategies. Adults seem to have a variety of listening strategies available to them and appear to choose a given strategy depending on the listening task. For example, when adults listen for a pure tone of known frequency, they monitor the single auditory filter centered on the signal frequency (Bargones and Werner, 1990; Dai *et al.*, 1991; Greenberg and Larkin, 1968; Macmillan and Schwartz, 1975; Penner, 1972; Scharf *et al.*, 1987; Schlauch and Hafter, 1991; Yama and Robinson, 1982). In other conditions, they monitor multiple filters simultaneously or they monitor a single filter, but scan or switch filters in time. Infants do not appear to approach the task in the same way that adults do. For example, infants do not monitor a single filter centered on the signal frequency when the signal is a single pure tone of a given frequency (Bargones and Werner, 1994). Exactly what the infant is doing is unknown.

Given the finding that infants do not attend selectively to a known signal frequency, several hypotheses about infant listening strategies should be considered. Infants may simultaneously attend to multiple filters, effectively broadening the filter bandwidth and reducing the internal signal-to-noise ratio, or they may simply not monitor any auditory filter in the region of the signal frequency (i.e., they may not be "listening"). Attending to multiple filters should result in a threshold elevation, a slight *increase* in the slope of the psychometric function, and an upper asymptote of 1 (Green and Swets, 1966; Hubner, 1993; Schlauch and Hafter, 1991). This model is thus inconsistent with the age differences observed in infant and adult psychometric functions. If infants simply do not attend to any filter, or at least to any filter in the region of the signal frequency, threshold would also increase. For adults, threshold for unattended tones increases about 7 dB compared to detection of the same tones when they are attended (Dai *et al.*, 1991). Squires *et al.* (1973) similarly reported that stimulus levels had to be increased by 8 dB to obtain the same late auditory-evoked potential amplitude to unattended as opposed to attended stimuli. Because this is about the size of the age difference in threshold (signal-to-noise ratio) that needs to be explained, nonattending may explain age differences in threshold, but at least at first blush, the psychometric function for the detection of unattended tones does not appear to be shallower than that of attended tones (Dai *et al.*, 1991).

A model (Hubner, 1993) in which there is jitter in the infant's placement of the filter predicts an increase in threshold, because the signal-to-noise ratio at any filter except that centered on the signal frequency will be reduced. If the filter is assumed to wander over a range of 0.2× the signal frequency, threshold can shift up to about 8 dB depending on the assumptions about the detection process. This is close to the age difference observed in threshold in noise. Further, the model predicts a decrease in slope of the psychometric function. The asymptote of the function depends on the assumed underlying distributions, but at best, only slowly approaches 1. Overall, the data presented here are consistent with this model. The model predicts that if infants were tested at higher levels, performance would slowly increase and at very high levels the infant might respond all of the time. If the attended filter were occasionally remote from the signal frequency, the asymptote may be below 1.

The large difference between infant and adult psychometric functions for repeated, short-duration stimuli is not well explained by any of the models considered so far. As noted above, the infant psychometric function for these stimuli is especially shallow and the threshold is especially high, but the upper asymptote is about the same as that for other stimuli. While general inattentiveness cannot account for this pattern, some immaturity in listening strategy might. For example, if infants are not listening at all, short-duration tones may be especially unlikely to draw their attention. Alternatively, adult listening strategies appear to be affected by stimulus duration (Wright and Dai, 1994), and perhaps this effect is exaggerated among infants. Finally, if the effects of a fixed level of inattentiveness were combined with those of a factor that has more pronounced effects for short durations (e.g., neural variability), the observed results might be accounted for. The present results do not allow us to choose among these alternatives.

Contrary to the idea that infants do not listen "intelligently," a comparison between their thresholds for single and repeated long-duration stimuli suggests that in some cases infants use an optimal listening strategy. Signal detection theory predicts that for optimal performance, sensitivity for n independent looks, d'_n, is

$$d'_n = \sqrt{n} d'_1, \quad (1)$$

where d'_1 is the sensitivity for a single look. Because d' is proportional to signal intensity, threshold for n looks, T_n, corresponding to a fixed level of performance will be

$$T_n = T_1 - 10 \log(\sqrt{n}) \text{dB}, \quad (2)$$

where T_1 is the threshold for a single look. According to this model, thresholds for four repetitions of a tone burst should be 3 dB lower than thresholds for a single tone burst. Threshold for infants is 3 dB lower for four tones compared to one tone, and for adults it is 2.7 dB lower. This is strong evidence that both infants and adults are able to make use of multiple looks, or additional information, to improve detection. Further, it suggests that at least some aspects of the underlying detection process for infants and adults are similar.

Infant thresholds in quiet are about 16 dB worse than those of adults. This is about 8 dB worse than observed in noise and suggests that additional factors must contribute to detection in quiet. Developmental increases in sound transmission into the inner ear and decreases in physiological noise may largely account for the part of the threshold shift that is unique to signal detection in quiet.

A developmental increase in sound transmission through the outer and middle ears would result in more sound energy being transmitted into the inner ear. Keefe *et al.* (1993) recently reported that between 6 months of age and adulthood, power transfer into the middle ear increases by 3–5 dB at 1000 Hz. Further, growth of the middle ear cavities likely influences the transfer of power into the cochlea. Development of the conductive system would only influence threshold; it would not affect the slope or asymptote of the psychometric function. This is consistent with the finding that the slope and asymptote of both the infant and adult functions are the same in quiet and in noise. Thus conductive immaturities likely account for at least half of the age difference specific to detection in quiet.

It is not known whether the intensity level of bodily noises changes with age; however, it is clear that infants and adults act differently in the test room, and these actions probably result in different internal noise levels. For example, an adult typically sits quietly, without moving, and may even hold her breath in an effort to detect a very soft sound. Alternatively, infants breath normally and move relatively freely. Although an attempt is made to begin trials when the infant is quiet and not moving, it is likely that infants are "making more noise" than adults are. Using a probe-microphone system (Etymotic Research 7C), we find that the level of sound in an infant's ear canal when no external sounds are presented is about 4 dB higher than that in an adult's (unpublished observations). In quiet conditions, this type of internal noise would be expected to mask the signal if the spectral composition of internal noise overlaps with that of the signal. Physiological noise would be expected to have a primarily low-frequency spectrum; more precise measures of internal noise in infants and adults are needed to address this issue more fully. However, the finding that infant thresholds are more similar to those of adults for high frequencies than for low frequencies in quiet but not in noise (Schneider *et al.*, 1980, 1989; Trehub *et al.*, 1980) is consistent with this hypothesis.

Finally, it should be noted that the current study examined mechanisms underlying differences in detection between adults and 6- to 9-month-old infants. It is likely that the factors contributing to behavioral threshold change as the infant's auditory system matures and that other mechanisms could be important for detection among younger infants.

VI. CONCLUSIONS

(1) Infant psychometric functions for detection have reduced upper asymptotes, shallower slopes, and higher thresholds than those of adults.

(2) The characteristics of the infant psychometric function cannot be completely accounted for by lapses of attention. While immaturities in listening strategies may account for the infant psychometric function, the details of such a model have yet to be worked out. Some combination of inattentiveness and primary neural immaturity cannot be eliminated as a possible explanation.

(3) Infants and adults appear to use additional information (multiple samples) to improve detection to the same extent, and the size of the effect of increasing the number of samples is as predicted by signal detection theory. Thus some aspects of the detection process are probably similar in infants and adults.

(4) Immaturities of the conductive system and age differences in physiological noise likely contribute to the age difference in thresholds obtained in quiet.

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[1]The slope would not be affected by changes in neural variability if the relationship between d' and signal energy were a power function. However, several studies suggest that at least in adults, this relation departs significantly from a power function (see discussion by Schneider *et al.*, 1989), so it is likely that age-related changes in neural variability would result in a shallower slope. In addition, if, for example, the underlying sensory evidence distributions are exponential, the extended tails of these distributions might prevent the asymptote from approaching one (e.g., Graham, 1989).

[2]Teller *et al.* (1992) fit individual psychometric functions for visual acuity in 2-month-old babies. Infant functions had reduced upper asymptotes, shallower slopes, and poorer thresholds compared to adult functions.

[3]In experiment II, half of the adults were given the abbreviated instruction to respond whenever they heard a sound that would make the animals light up. They were not told to guess if they were not sure. There was no difference in the psychometric functions for the adults given the standard or the abbreviated instruction (α=0.05) and the results from both groups were combined.

[4]Experiment III was actually completed first and did not include these controls.

[5]Preliminary analyses indicated that different fitting procedures (probit analysis, interpolation between adjoining points, and the three-line fits) resulted in similar trends (see also Werner and Marean, 1991).

[6]Approximately 20% of the babies tested in experiment II did not receive probe trials in the test phase. All measures obtained from babies not given probes were within the same range as the measures obtained from babies given probes. Data from babies with and without probes were combined for the following analyses. In two sessions in noise, the infant-observer team was correct on only two of the five probe trials. In one case hit rate was 0.90 for the test signal and in the other, hit rate was near chance. In both cases, performance on test trials was consistent with previous data collected on the subjects (i.e., the functions were monotonic); therefore these data were included.

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