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ABSTRACT

A forced-choice observer-based testing procedure was used to determine pure-tone hearing thresholds for 2- to 4-week-old infants. Stimuli were 500-ms tone bursts of 500, 1,000, or 4,000 Hz with 500-ms intervals between tone bursts. Stimuli were presented monaurally by means of an insert earphone. Each 15-s trial consisted of 5 tone bursts, followed by a 5-s silent interval, followed by a 5-s test trial. During the test interval, either five tone bursts were presented, at the same intensity as in the first interval, or 5 s of silence were presented. An observer with no prior knowledge of trial type judged whether a sound had occurred during the test interval on the basis of the infant's behavior. Intensity varied between 25 and 70 dB SPL. For all infants at each frequency, psychometric functions were fit to the proportion of correct judgments as a function of intensity by probit analysis. Threshold calculated from this function was 56 dB at 500 Hz and 41 dB at 4,000 Hz. Threshold could not be calculated at 1,000 Hz; the observer made 0.65 correct judgments at the lowest intensity used. Results, which agree with other recent reports, suggest that the function relating sensitivity to sound frequency is not adultlike at this early age. (Author/RH)

PURE-TONE SENSITIVITY OF 2- TO 4-WEEK-OLD INFANTS

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ABSTRACT

A forced-choice observer-based testing procedure was used to determine pure-tone hearing thresholds for 2- to 4-week-old infants. Stimuli were 500-ms tone bursts of 500, 1000 or 4000 Hz with 500-ms silent intervals between tone bursts. Stimuli were presented monaurally using an insert earphone. Each 15-s trial consisted of 5 tone bursts, followed by a 5-s silent interval, followed by a 5-s test interval. During the test interval either five tone bursts were presented, at the same intensity as in the first interval or 5 s of silence was presented, with equal probability. An observer with no prior knowledge of trial type judged whether a sound had occurred during the test interval, on the basis of the infant's behavior. Intensity was varied between 25 and 70 dB SPL. For all infants at each frequency, psychometric functions were fit to the proportion of correct judgments as a function of intensity by probit analysis. Threshold calculated from this function was 56 dB at 500 Hz and 41 dB at 4000 Hz. Threshold could not be calculated at 1000 Hz: the observer made 0.65 correct judgments at the lowest intensity used. These results suggest that the function relating sensitivity to sound frequency is not adultlike at this early age, but are in good agreement with other recent reports. (Work supported by March of Dimes Birth Defects Foundation.)

BACKGROUND

It has been believed for some time that the newborn's sensitivity to sound is generally good. For example, Hecox (1975) estimated that the threshold for the auditory brainstem response (ABR) to clicks was only 10-15 dB higher in newborns than in adults. The audibility curve, showing threshold as a function of acoustic frequency, has not been well described for infants younger than 3 months of age. In this regard, the literature suggests that newborns are more sensitive to low frequencies than they are to high. For example, Hutt et al. (1969) reported higher amplitude motor responses to lower frequency sounds (125-250 Hz) in newborns, and Klein (1984) has recently shown that ABR thresholds at 500 Hz are mature by 1 month of age, while thresholds at 4000 Hz take considerably longer to mature. However, the reported newborn behavioral thresholds are greater than ABR thresholds by 30 dB or more, whereas adult behavioral thresholds are generally somewhat lower than their ABR thresholds.

The current study explored the sensitivity of young infants to pure tones using a behavioral measure. The aim was to extend the range of frequencies tested to include the range that has been studied using the ABR, and to determine whether an observer-based procedure (Olsho et al., 1987; Teller et al., 1974) could provide a more sensitive behavioral measure of hearing than the procedures previously used.

METHOD

Subjects. All infants were less than 1 month of age at testing (range =15 to 36 da, mean = 25.4 da, s.d. = 4.24), had uncomplicated medical histories and no family history of congenital hearing disorders. Infants were screened for middle ear pathology by tympanometry on the day of testing.

Stimuli and apparatus. In Experiment 1, the stimuli were tone bursts at 500, 1000 or 4000 Hz. Each tone burst was 500 ms in duration with 16-ms rise/fall times. Stimulus levels of 25, 40, 55, and 70 db SPL were used at 500 and 1000 Hz, while levels of 25, 40, 55, and 65 db SPL were used at 4000 Hz. In Experiment 2 only tone bursts at 1000 Hz were used, with levels of 5, 15, 25, and 35 dB SPL. Tones were generated by a Data Translation 280' ' D/A board. The output of the board was bandpass filtered using Kemo VBF25.13, 90 dB/octave filters. Stimulus levels were controlled by Wilsonics programmable attenuators. Rise/fall times were controlled using Coulbourn instruments S84-04 rise/fall gates. The stimuli were amplified (Crown D-75) and attenuated by a Coulbourn Instruments S85-02 manual (impedance matching) attenuator. Stimuli were presented using Etymotic ER-1 insert earphones, with a foam ear tip trimmed to fit the infant's ear canal. These devices and stimulus timing were controlled using an AT&T 6300 microprocessor. All testing was conducted in a double-walled IAC booth.

Procedure. Infant thresholds were obtained using a forced-choice, observer-based procedure. The paradigm was similar to that used in previous studies (e.g., Olsho et al., 1987) in that an observer watched the infant and decided on each trial whether a sound had occurred during a specified time interval. However, the trial structure differed from that used to test older infants and the infant received no reinforcement for responding to the sound.

The infant was held by the parent in any position in which the infant was comfortable and alert. The only other constraint on the infant's position was that the observer, who was in the booth with the parent and infant, have a clear view of the infant. The sounds presented to the infant via the insert earphone were generally inaudible to others in the booth; however, the parent and the observer also listened to masking sounds over circumaural headsets to prevent them from inadvertently influencing the infant's behavior. An infant is shown in the test procedure in Figure 1.

A single frequency was presented during each session. When the observer judged that the infant was in an alert state, he signaled for the beginning of a trial. The trial structure is illustrated in Figure 2. Each trial was 15 s long and consisted of 3 intervals. During the first interval 5 tone bursts at one of the four levels were presented, with 500 ms between bursts. The second interval, also 5 s in duration was silent. During the third interval one of two events occurred with equal probability. Either 5 tone bursts were presented at the same level as in the first interval, or 5 s of silence occurred. The observer heard a signal from the control booth over his headset at the beginning of each interval; his job was to decide, on the basis of the infant's behavior, whether or not a sound had been presented during the third interval. The observer received feedback at the conclusion of each trial.

Each session began with a training period during which the stimulus level was always 70 dB SPL and the observer was required to achieve 4 of 5 consecutive trials correct. Testing proper began as soon as this criterion had been met. During testing, stimulus level varied randomly from trial to trial. Testing continued until the infant's state was judged unacceptable (fussing, crying or sleeping). In Experiment 1, of 79 total sessions, 46 provided test trials. Of the 33 sessions in which no test trials were obtained, 29 ended because the infant was fussy, crying or sleeping; only 4 ended with the infant in an alert state but the observer unable to reach training criterion. In Experiment 2, 33 of 44 sessions provided test trials, 8 ended because the infant was fussy, crying or sleeping, and 3 ended because the observer was unable to reach training criterion.

RESULTS

The data were analyzed in two ways. First, group psychometric curves were constructed by taking the proportion of all trials correct at a given level for all infants tested at each frequency. The curves obtained in Experiment 1 are shown in Figure 3. Notice that at 500 and 4000 Hz, the proportion of correct responses increases with increasing stimulus level, as would be expected. However, these curves are much shallower than those that would be obtained from adult listeners, and while the proportion correct is close to chance (0.50) at low levels, it does not reach 1.00 within the range of levels tested here. At 1000 Hz, the curve is basically flat: the observer averaged about 0.60 correct across levels.

A psychometric function was fit to the data at each frequency, using probit analysis (Finney, 1971). A "group threshold" was calculated from the functions at 500 and 4000 Hz. No function could be found to fit the 1000-Hz data The obtained thresholds are plotted in Figure 4, along with a 4000-Hz threshold for 1-month-olds recently reported by Schneider and Judge (1988), and thresholds for 3-month-olds, 6-month-olds and adults from our laboratory (Olsho et al., 1988). Our result at 4000 Hz is quite similar to Schneider and Judge's; 1-month-olds appear to have thresholds that are 10-15 dB higher than those of 3-month-olds at both 500 and 4000 Hz.

The thresholds for 1-month-olds plotted in Figure 4 may, however, be misleading. Consider Figure 5, where the group psychometric curve at 4000 Hz is plotted along with the psychometric curves of 3 individual infants tested at that frequency. Notice that these individual curves are quite sloppy, in that they are nonmonotonic; at the same time, they give the impression of being steeper and reaching higher levels of performance than the group curve does. Averaging over these sloppy curves, which also vary in their positions along the level (dB)-axis, a smoother, but shallow group curve is obtained. Unfortunately, a shallow group curve might yield a threshold estimate that is much worse than what would be obtained if the thresholds of individual infants were calculated and averaged.

The second type of data analysis addressed the relationship between the group and individual psychometric curve estimates of sensitivity, by attempting to fit a psychometric function to the data of each infant. Of the 33 infants providing test data, 23 had psychometric functions with positive slopes, but only 12 (7 at 500 Hz, 1 at 1000 Hz, 4 at 4000 Hz) of these were considered greater than zero. Examples of the individual psychometric functions and the data points used to derive them are shown in Figure 6.

A threshold was estimated for each infant for whom an acceptable psychometric function was obtained. The average thresholds are plotted in Figure 7 along with the group thresholds at 500 and 4000 Hz previously shown. The means of the individual thresholds are much lower than the group thresholds. In fact, the average individual thresholds are about what we typically find in 3-month-old infants. However, whether the group or individual infant thresholds are considered, the difference between infant and adult thresholds is most pronounced at 4000 Hz, in agreement with Klein's report with respect to the ABR in infants younger than 1 month of age.

One potential contributor to a reduction in psychometric function slope is habituation on the part of the infant. The prediction would be that the infant would become more difficult to "read" as the session progressed and the infant habituated to the tone bursts, resulting in the psychometric function's becoming more shallow. To examine this possibility, group psychometric functions were fit at each frequency for all infants who had a positive individual psychometric function slope, using only the first 5 test trials, the first 10 test trials, the first 15 test trials, and the first 20 test trials. The resulting functions are shown in Figure 8. Note that the number of test trials had little, if any effect, on the psychometric function at 500 or 1000 Hz. However, the effect at 4000 Hz was rather dramatic: the psychometric function grew progressively steeper as the number of test trials increased to 15 and remained steep with the increase to 20 trials. Rather than habituation, this pattern suggests improvement in performance over trials.

The "barely above chance" performance of observers at 1000 Hz was puzzling, particularly in view of the fact that the one infant providing an acceptable psychometric function at 1000 Hz had a threshold of 24 dB, comparable to the average individual thresholds at the other frequencies. In order to examine possible effects of the range of stimulus levels used, in Experiment 2, an additional group of infants was tested at 1000 Hz using a lower range of stimulus levels. As Figure 9 shows, the group psychometric function for these infants is much steeper than that obtained at 1000 Hz in Experiment 1; in fact, its slope approaches those of the individual curves plotted for comparison in Figure 9. The threshold calculated from the group psychometric function fit to these data was 24.05 dB. Eight of 33 infants in this experiment provided acceptable psychometric functions; the average of the individual thresholds was 23.92 dB (s.e. = 6.02). The mean threshold has been plotted in Figure 7, along with those from Experiment 1. The one infant with an acceptable psychometric function at 1000 Hz in Experiment 1 had a threshold that was nearly identical to the mean obtained in Experiment 2.

We compared the characteristics of infants providing acceptable psychometric functions with those providing test data but no psychometric function, as well as those never reaching training criterion. These data are displayed in Table 1 for both experiments. There are no obvious differences between these three groups, although in Experiment 2 there was a tendency for a greater number of both training and test trials to be obtained from infants with acceptable psychometric functions.

CONCLUSIONS

--Behavioral pure-tone thresholds for infants younger than 1 month of age can be estimated using an observer-based procedure.

--Both group and individual thresholds at this age appear to be closer to those of adults at 500 and 1000 Hz than they are at 4000 Hz.

--Group psychometric functions can give an estimate of infant sensitivity that is poor and misleading, particularly when the range of stimulus values presented in the experiment is not well-chosen relative to the threshold.

--Judging from psychometric function slope, there is little evidence for a systematic change over 20 trials in an observer's ability to use an infant's behavior to detect sounds at either 500 or 1000 Hz. However, at 4000 Hz, it appears that the infant-observer team gets better once the number of test trials exceeds 10.

References

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Olsho, L.W., Koch, E.G., Carter, E.A., Halpin, C.F., and Spetner, N.B. (1988). Pure-tone sensitivity of human infants. Journal of the Acoustical Society of America, 84, 1316-1324.

Schneider, B.A & Judge, P. (April, 1988). Methodological insights in infant audition: Observer-based psychophysical procedures. Paper presented to the Biennial Meeting of the Society for Research in Child Development, Washington, D.C.

Teller, D.Y., Morse, R., Borton, R., & Regal, D. (1974). Visual acuity for vertical and diagonal gratings in human infants. Vision Research, 14, 1433-1439.

TABLE 1

COMPARISON OF SUBJECT AND SESSION CHARACTERISTICS ACCORDING TO SESSION OUTCOME

	N	AGE (DA)	# FEMALES	# TRAINING TRIALS	# TEST TRIALS
EXPERIMENT 1					
ACCEPTABLE FUNCTIONS	12	26.36	4	9.00	11.64
TEST TRIALS, BUT NO FUNCTION	46	26.29	19	7.36	12.40
NO TEST TRIALS	33	25.85	8	9.66	0.00
EXPERIMENT 2					
ACCEPTABLE FUNCTIONS	8	21.38	5	12.20	16.60
TEST TRIALS, BUT NO FUNCTION	33	22.06	14	8.21	14.21
NO TEST TRIALS	10	19.43	5	5.40	0.00

Figure Captions

Figure 1. Photograph illustrating test situation.

Figure 2. Stimulus configurations on signal and no-signal trials.

Figure 3. Group psychometric functions at three frequencies in Experiment 1.

Figure 4. Group thresholds at 500 and 4000 Hz for infants in Experiment 1 compared to thresholds for infants for infants of about the same age reported by Schneider & Judge (1988) and to average individual thresholds for 3- and 6-month-olds and adults reported by Olsho et al. (1988)

Figure 5. Group psychometric function at 4000 Hz in Experiment 1 compared with three individual psychometric functions. The functions are arbitrarily placed on the dB scale for visual clarity.

Figure 6. Examples of best-fitting psychometric functions for three individual infants. The functions are arbitrarily placed on the dB scale for visual clarity.

Figure 7. Average individual thresholds as a function of frequency compared to group thresholds.

Figure 8. Best fitting group psychometric functions based on 5, 10, 15 and 20 trials at three frequencies.

Figure 9. Group psychometric function at 1000 Hz in Experiment 2 compared with three individual psychometric functions. The functions are arbitrarily placed on the dB scale for visual clarity.

Figure 1

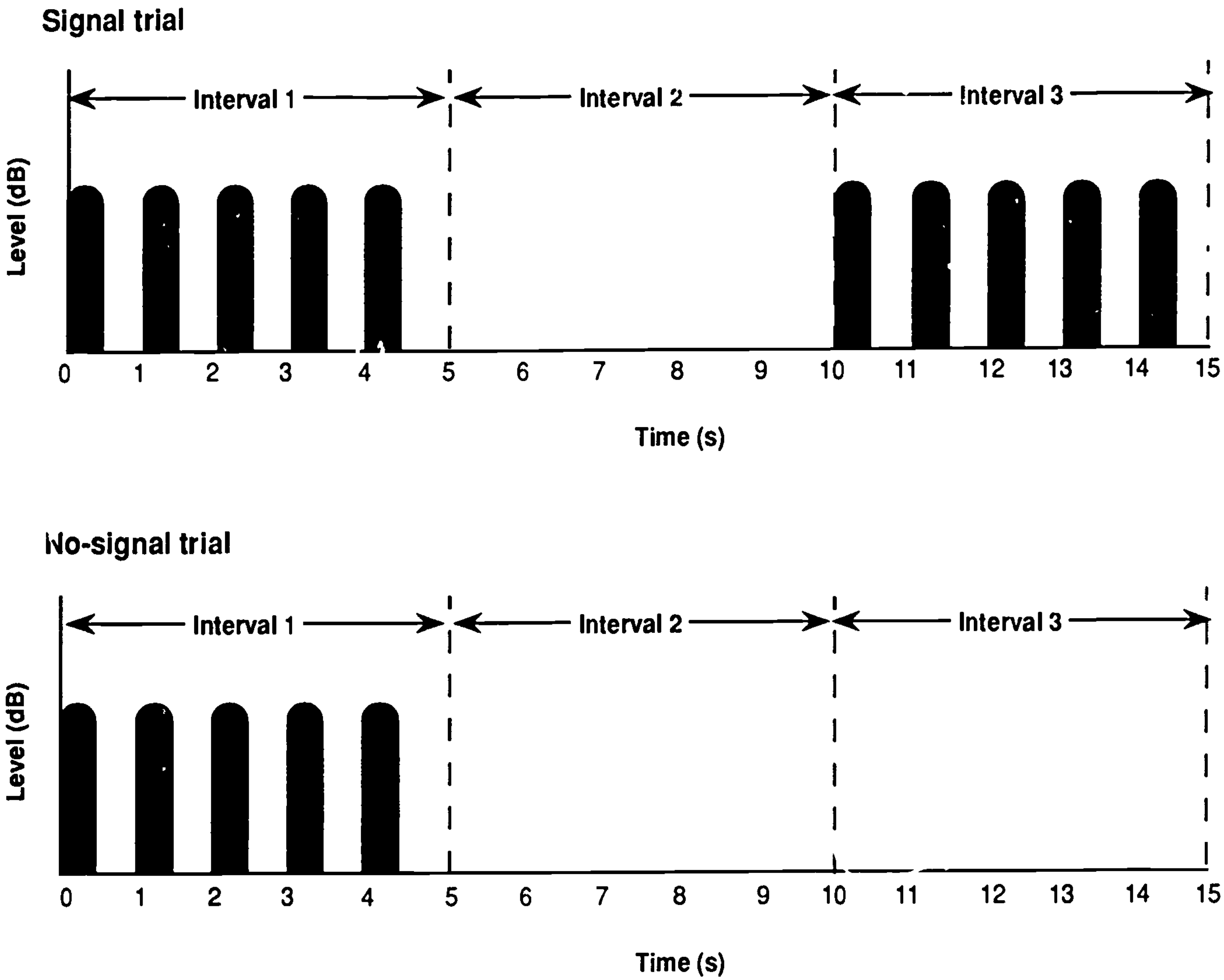

Signal trial
Interval 1
Interval 2
Interval 3
Level (dB)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (s)
No-signal trial
Interval 1
Interval 2
Interval 3
Level (dB)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (s)

Figure 2

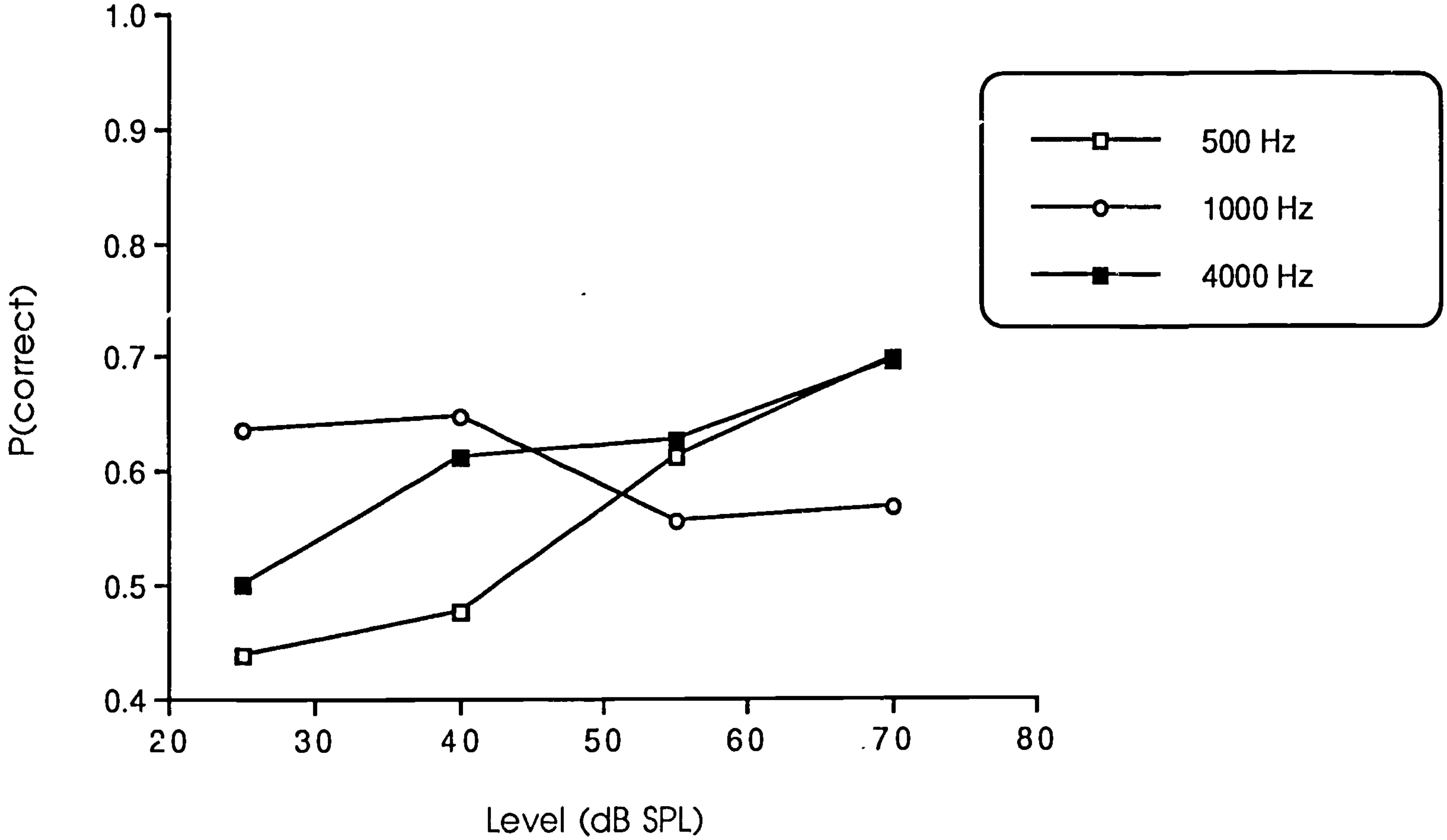
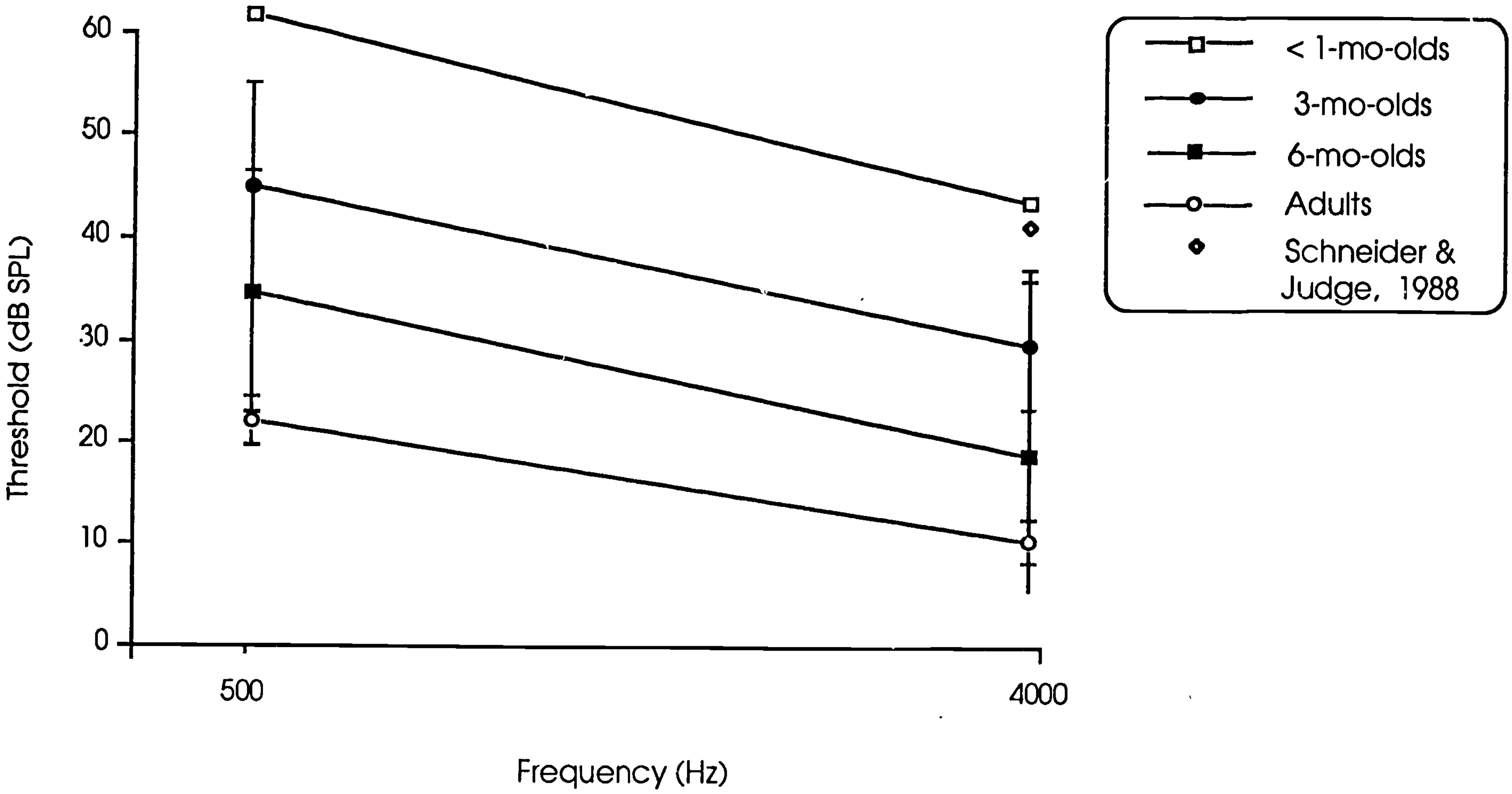

1.0
0.9
0.8
0.7
0.6
0.5
0.4
P(correct)
20
30
40
50
60
70
80
Level (dB SPL)
500 Hz
1000 Hz
4000 Hz

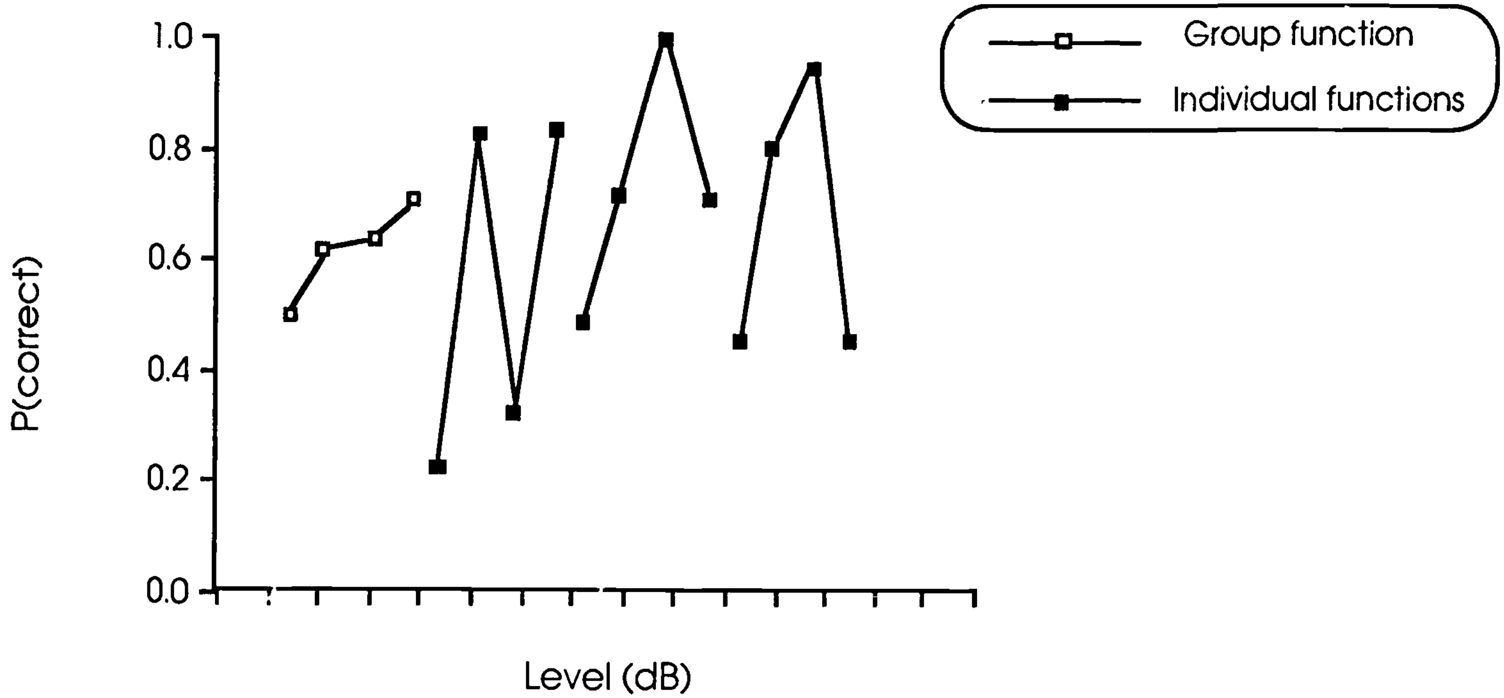
Figure 3

Figure 4



Threshold (dB SPL)
0
10
20
30
40
50
60
500
4000
Frequency (Hz)
< 1-mo-olds
3-mo-olds
6-mo-olds
Adults
Schneider & Judge, 1988

Figure 5



1.0
0.8
0.6
0.4
0.2
0.0
P(correct)
Level (dB)
Group function
Individual functions

Figure 6

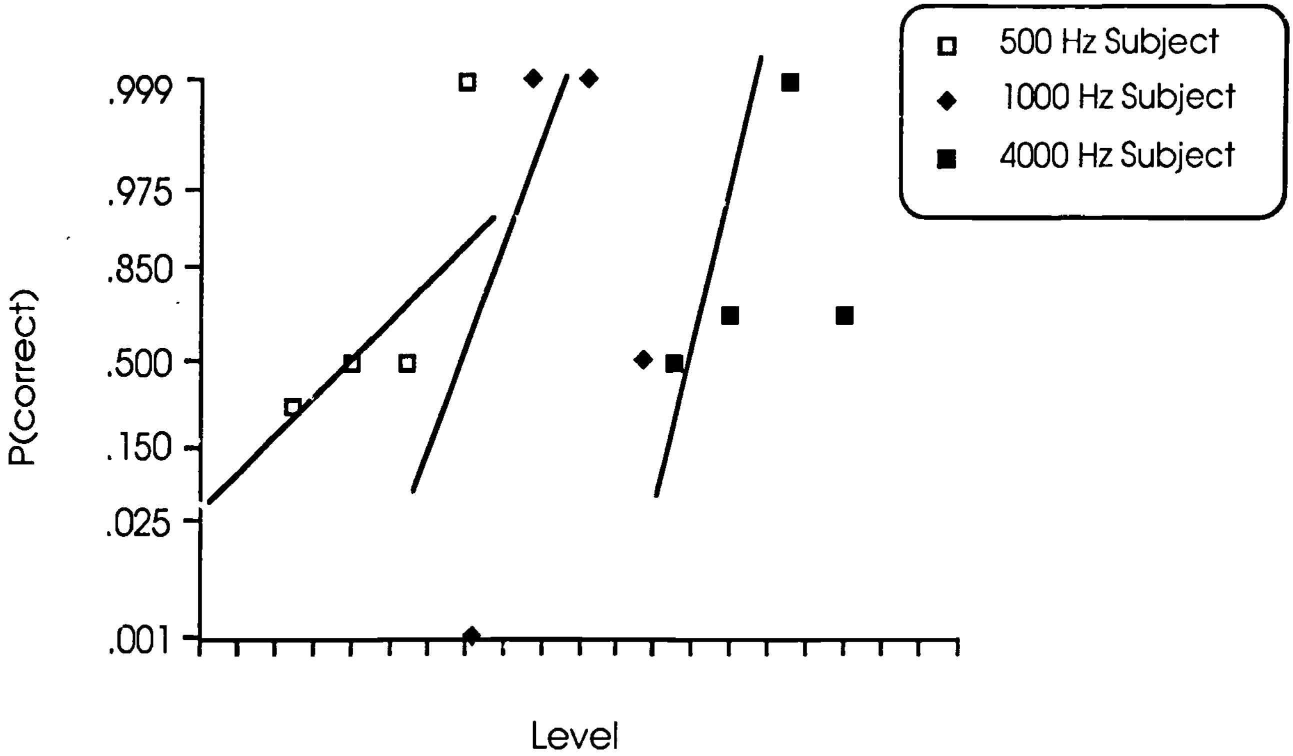

500 Hz Subject
1000 Hz Subject
4000 Hz Subject
.999
.975
.850
.500
.150
.025
.001
P(correct)
Level

Figure 7

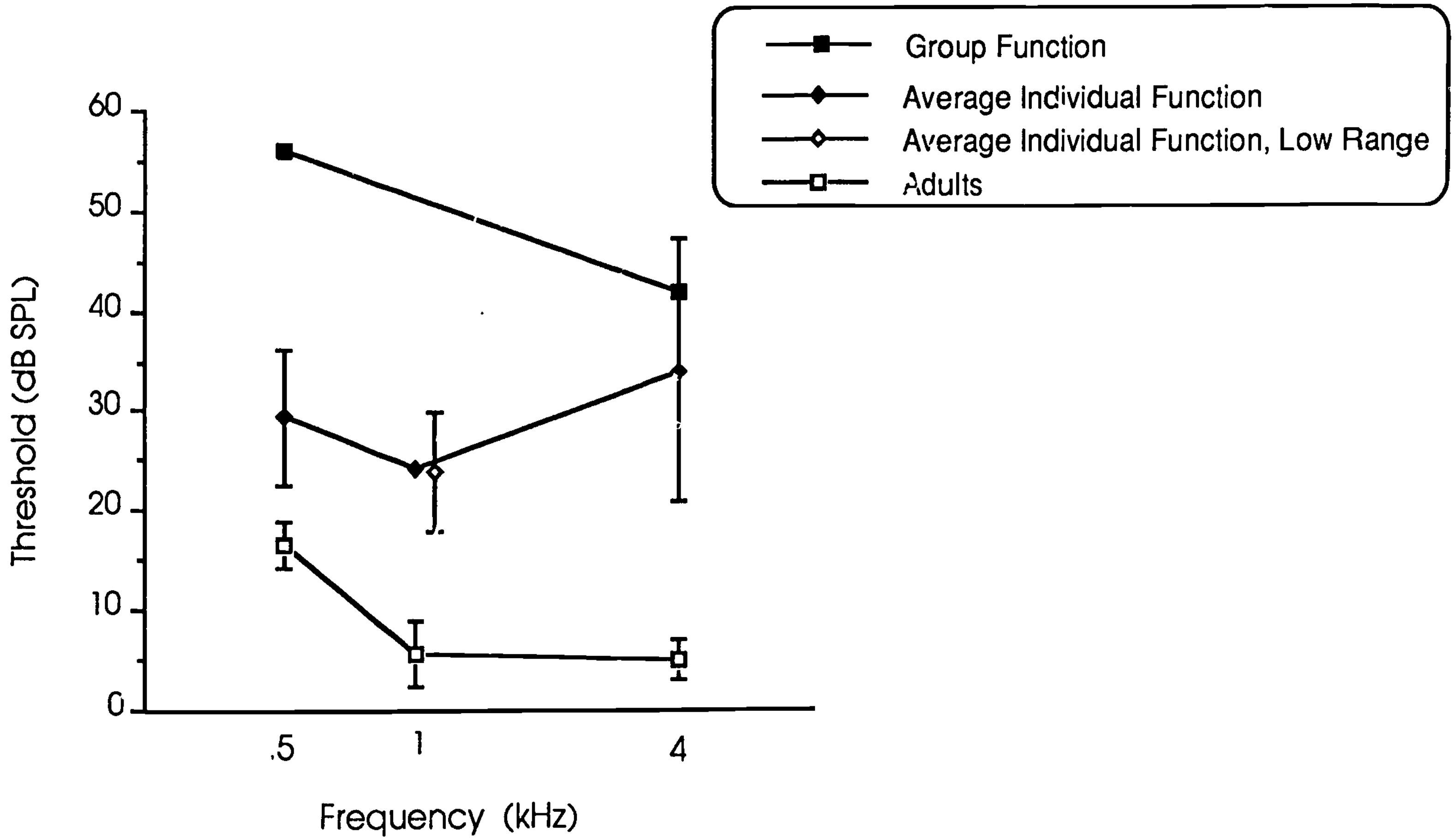
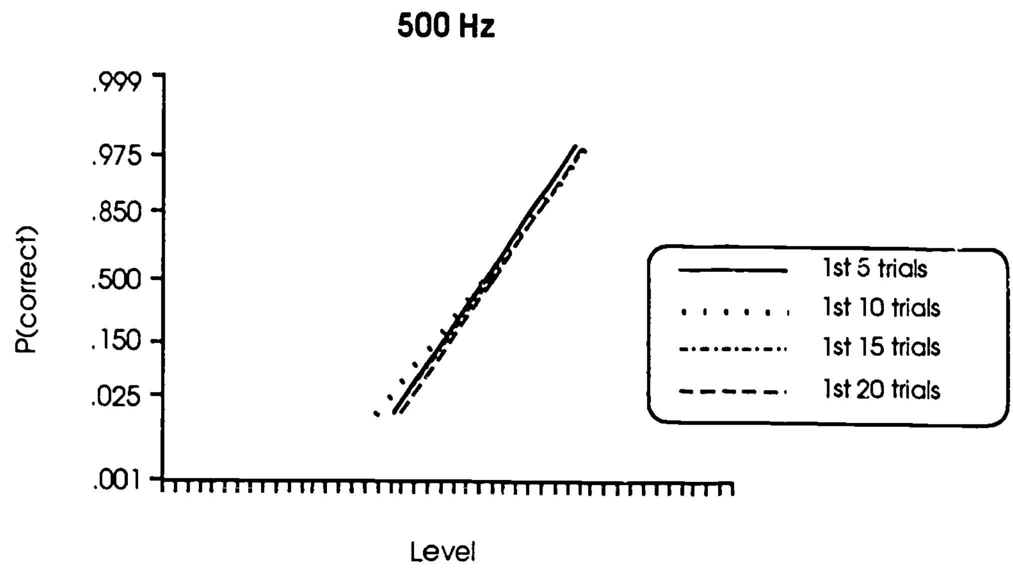
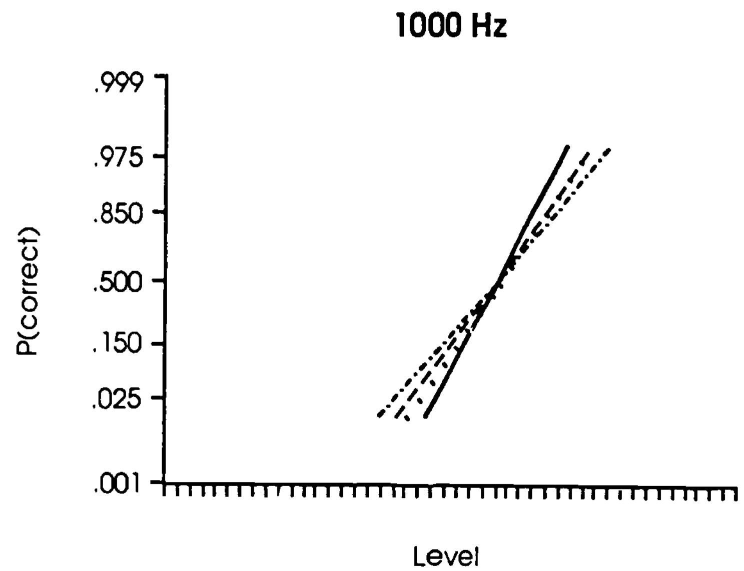

Group Function
Average Individual Function
Average Individual Function, Low Range
Adults
Threshold (dB SPL)
0
10
20
30
40
50
60
.5
1
4
Frequency (kHz)

Figure 8


500 Hz
.999
.975
.850
.500
.150
.025
.001
P(correct)
Level
1st 5 trials
1st 10 trials
1st 15 trials
1st 20 trials


1000 Hz
.999
.975
.850
.500
.150
.025
.001
P(correct)
Level

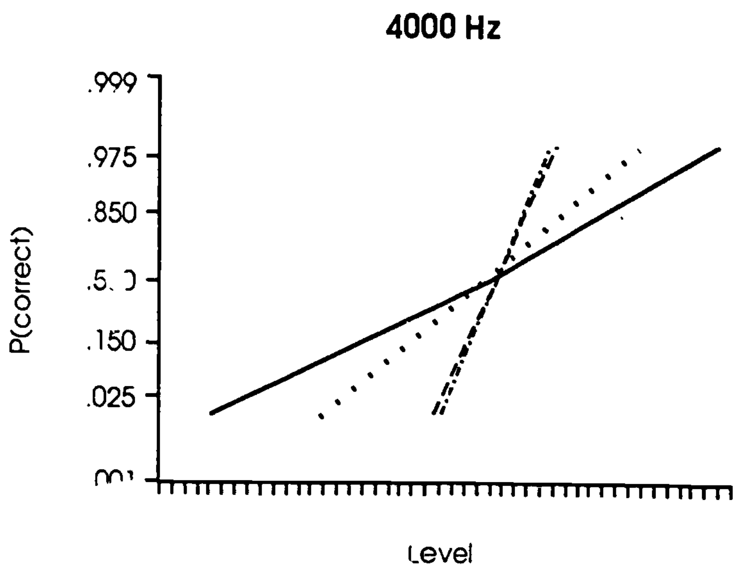
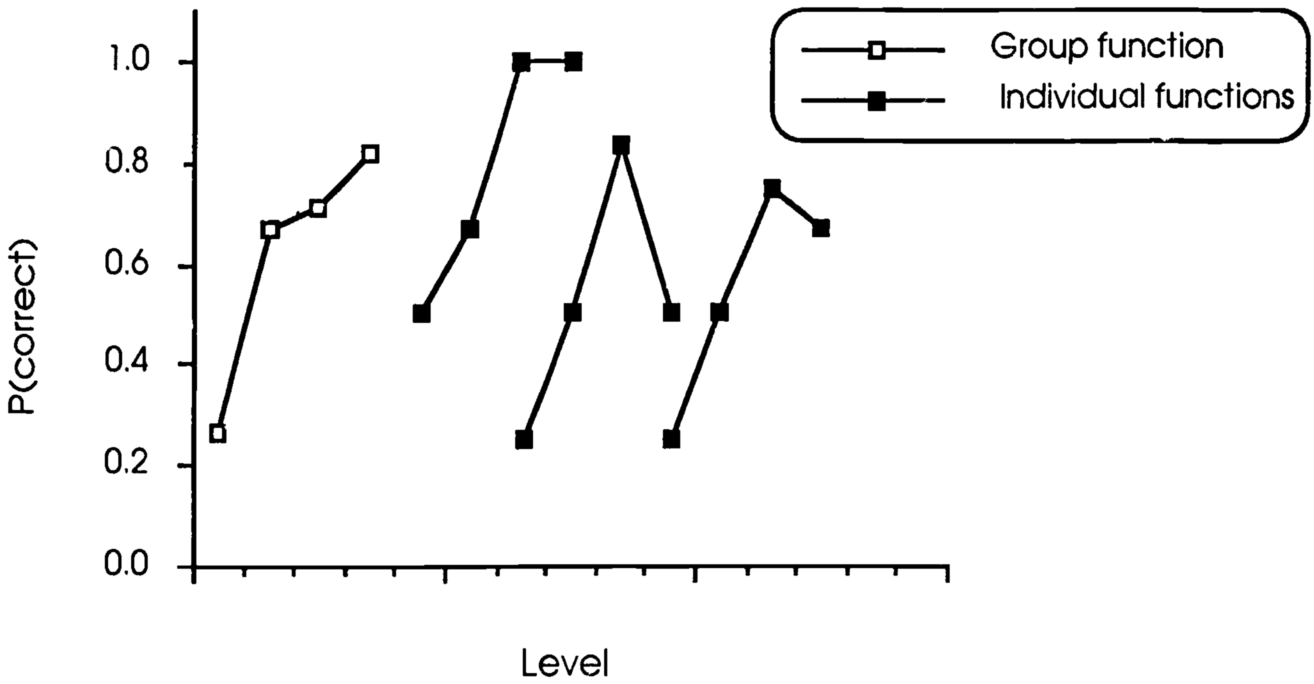

4000 Hz
.999
.975
.850
.150
.025
P(correct)
Level

Figure 9



Group function
Individual functions
1.0
0.8
0.6
0.4
0.2
0.0
P(correct)
Level