Children's frequency-selective detection of signals in noise¹

GORDON Z. GREENBERG,² NORMAN W. BRAY,² AND DANIEL S. BEASLEY³
UNIVERSITY OF ILLINOIS

Five children, median age 7 years, and six adults, median age 20 years, served as Os in a task requiring the detection of auditory signals presented against a continuous background of noise. Two-alternative, temporal-forced-choice trials of 5-sec duration were presented periodically in blocks of 50 during two or three 1-h sessions. During a block, some 70% of the signals were of 1,000 Hz and approximately 30% were probe signals of a frequency other than 1,000 Hz. After only rudimentary description of the task, the children and adults performed adequately. The results from the children and adults were similar, showing differential detection as a function of signal frequency. The demonstrated frequency selection is consistent with a sensory-filter model of the O's auditory behavior.

The results of some recent studies (Greenberg & Larkin, 1968; Greenberg, 1969) clearly show that auditory Os detecting signals of a single frequency select from the stimulus input and respond differentially as a function of the frequency of the signal. Such frequency-selective behavior might be attributed to a process in the sensory system, such as a sensory-filter, that selects from the input by attenuating differentially the various frequency components during the early stages of input processing. In fact, a filter has been used in various models of the behavior of auditory Os in this and similar situations (e.g., Green & Swets, 1966; Henning, 1967; Jeffress, 1967; Schafer, Gales, Shewmaker, & Thompson, 1950; Sherwin, Kodman, Kovaly, Prothe, & Melrose, 1956; Swets, Green, & Tanner, 1962).

If the observed frequency-selective performance of signal-detection Os reflects a basic aspect of the auditory system, such behavior should be observed in all clinically normal Os, regardless of age. Previous reports of the detection of signals presented in noise by child Os are unknown to the authors.

The present study has undertaken to explore the use of children as Os in a signal-detection task and to compare their frequency-selective behavior with that of adults performing under comparable conditions.

METHOD

Observers

Experimental Os were adults and children. The three women and three men in the adult group, ages 18 to 25 (median age 20) were tested simultaneously. The children, four boys and one girl, with ages between 6 years 4 months and 8 years 6 months (median age 7 years), were tested individually. All had clinically normal hearing as reported by the adult Os or by the parents of the children.

Procedure

The trial structure was that of the common two-alternative temporal-forced-choice experiment. Three visual indicators defined a warning interval and the two observation intervals of each trial. During one of the observation intervals, a signal was added to a continuous background of noise. The O's response on each trial was to indicate the observation interval during which the signal had been added to the noise. Trials were presented periodically.

Much of the experimental procedure followed was tailored to suit the challenge of testing children in the signal-detection situation. Because there have been few reports of children performing this type of auditory task, some aspects of the procedure are given in detail.

The definition of the signal-detection task and the instructions typically given adult Os were unsuitable for the youngsters. The experimental instructions given the children exploited the similarity between the experimental task and the noisy communications between ground control personnel and astronauts in space vehicles. The child was told he was listening for a signal like that sent by an unmanned spacecraft, although the signals used in the experiment were sent to him by a computer. His task was to tell the computer in which interval of each trial the computer had sent the signal. The children were informed that adult "ground controllers" of spacecraft flights often have considerable difficulty locating all the signals that are sent, and that the E wished to determine if children might be better able to locate a signal on each trial.

The procedure used to begin the first session was different from that used during the following sessions. Initially, with a

child, E manually controlled the occurrence and duration of noise, signal, and indicator lights. During this demonstration, the auditory stimuli were presented with an electroacoustic speaker system. The child was introduced to the noise separately, the signal separately, and to the noise plus a signal combined so that the signal was easily heard. The various visual indicators were illuminated separately in the order used for later trials. A sequence of trials with the normal timing was presented, and the continuous noise background with signals occurring during the observation intervals was delivered over the speaker system.

After E was confident the child understood the task and the sequence of events of a trial, and that the proper rapport had been established, the earphones were introduced as a way of listening that would make the task easier, and 20 practice trials were presented. During these practice trials of the first session, the signal amplitude began 4 dB higher than usual and was gradually reduced during the 20 trials to the level used during the remainder of the experiment.

A single experimental session occupying approximately 1 h was conducted on any one day. Blocks of 50 trials, lasting approximately 4 min, were separated by pauses of approximately 5 min. These block and session durations had produced no evidence of fatigue or significant diminution of interest or attention when used in preliminary studies with other children.

After each block of trials, the child was praised for successfully completing the block and rewarded with his choice of 15¢ in coin or a small bag of M&M candies. No information was given regarding the accuracy of his responses. During pauses between blocks, E occupied O by such things as discussions of matters of interest to the child, demonstrations of dynamic visual illusions, and paper and pencil games.

A session continued only as long as: the child responded to all but a very few trials; he indicated a desire to continue when questioned after each block; and E judged from all evidence that O's interest was sustained. The child was allowed to undertake the several blocks of trials in a

session at his own pace. Thus, one child completed eight data blocks in each of two sessions; another child, four blocks in the first and eight blocks in the second session; and the other children, four blocks in each of three sessions. One week separated experimental sessions.

For the children, a session consisted of a practice block of 20 trials, a practice block of 50 trials, and four or eight data blocks of 50 trials each. For the adults, a practice block of 50 trials preceded four data blocks of 50 trials each.

Throughout all interactions with the children, the E emphasized the need to respond on each and every trial. Occasionally, a child expressed concern for the accuracy of his responses. In such cases, E encouraged O to do simply the best he could, emphasizing that the primary concern of the computer and of E was that O respond on each trial. The children were not told of the presentation probabilities of signals in the two observation intervals, that the sequence of observation intervals containing the signals was random across trials, or the nature of the noise. Although such matters are frequently discussed with adult Os in other experiments, the instructions given the children in this experiment contained the minimum information necessary to define their task and obtain a response on every trial.

During the first session with the group of adult Os, the task was described and a sequence of trials was run to demonstrate the timing of events. Following a practice block of 20 trials, similar to that for the children, five full blocks of trials were presented.

The instructions given the adult Os were concise and designed to provide only the information given the children, albeit not in terms of spacecraft and computers. Three sessions, each of four data blocks, were conducted on successive days with the adult Os. The pay for each adult O was a flat hourly rate plus a bonus based on his individual performance level for each session.

Stimulus Presentation

For each trial, three 0.35-sec intervals, the warning interval at the beginning of the trial and the two observation intervals, were defined for O by three separate indicator lamps. The first observation interval began 0.5 sec after the termination of the warning interval and the second observation interval began 0.35 sec after the end of the first observation interval. The response interval of 2.75 sec began at the end of the second observation interval and continued until the beginning of the warning interval of the next trial. A signal

occurred during the latter 0.25 sec of a 0.35-sec interval. The a priori presentation probability of the signal was 0.50 for each of the two observation intervals of a trial.

To demonstrate any frequency-selective behavior, the probe-signal method (Greenberg & Larkin, 1968) was used. Two types of trials were presented. During a *primary-signal* trial, the signal presented was of 1,000 Hz. On infrequent, randomly determined positions in a trial sequence, a *probe-signal* trial occurred in which a signal of other than 1,000 Hz, a probe signal, was presented. The two types of trials differed only in the specifications of the signals presented.

During a session, probe signals were presented only after the first 50 trials for adults and only after the first 70 trials for the children. Data blocks contained both types of trials and the order of presentation of the two types of trials was determined by a table of random numbers (Rand Corporation, 1955). On any given trial, the type of trial presented was independent of the observation interval in which the signal was presented and these two events were determined by separate, consecutive sampling from the same random number source. The nominal (sampling) presentation probability was 0.60 for the primary-signal trial and 0.40 for the probe-signal trial, but a further constraint was imposed on the trial sequence such that successive probe-signal trials could not occur. Probe signals were observed to occur on approximately 30% of the trials.

The probe signals during a block of trials were all of the same frequency. During each set of four data blocks, probe signals of 850, 925, 1,075, and 1,150 Hz were presented. The sequence of probe-signal frequencies over a set of four data blocks was changed for every set within or across sessions.

For two of the children (AS and JG), primary signals were presented with $10 \log E/N_0 = 14$, where E is the signal energy and N_0 is the noise power per unit bandwidth. Primary signals were presented 1 dB higher for all other children and all the adults, with $10 \log E/N_0 = 15$. Probe signals at the various frequencies were presented with amplitudes chosen in an attempt to produce equal detectability for all the probe signals and the primary signal. The amplitude of each probe signal was adjusted in proportion to the separation of its frequency from the frequency of the primary signal (Green, McKey, & Licklider, 1959). Specifically, probe signals with frequencies below that of the primary signal were presented with amplitudes lower than that of the primary signal by 0.2 dB per 100-Hz separation from the

frequency of the primary signal. The amplitude of each probe signal with a frequency higher than that of the primary signal was determined by the same relation and was greater than that of the primary signal.

Apparatus

For each O, the earphones (Sharpe HA-10) of a binaural headset were wired in parallel and in phase. Several headsets were wired in parallel. A noise generator (Grason-Stadler Model 455-C) provided a continuous noise with an overall level of approximately 65 dB SPL. The 0.25-sec signal was added to the noise by gating an oscillator output without regard to phase and without using special devices.

RESULTS AND DISCUSSION

The results are presented in Fig. 1 for the children and in Fig. 2 for the adults. The curve for each O is drawn through the mean percent correct detections over the sessions for each of the signals of the various frequencies. The chance level of performance is 50% correct. The data points for the curve for each O are derived from the 12 to 16 50-trial data blocks for each child and from the 12 50-trial data blocks for each adult. The data points for each O represent between 36 and 64 trials for each probe-signal frequency and between 420 and 580 trials for the 1,000-Hz signals.

A comparison between these results and those of comparable experiments reported

Fig. 1. Mean percent correct detections of the signals of various frequencies for each child O and for the group (broken line).

Fig. 2. Mean percent correct detections of the signals of various frequencies for each adult O and for the group (broken line).

previously (Greenberg & Larkin, 1968; Greenberg, 1969) reveals some differences. The variability among the Os within a group, as well as that between groups in this experiment, is greater than that obtained in the previous experiments. In general, the curves in Figs. 1 and 2 are not as sharply peaked as those previously obtained. The relative flatness of the curve for the one adult O in Fig. 2 is particularly unusual. Generally, the asymmetry of the curves about the 1,000-Hz frequency is greater in the present curves than in those previously reported. In other regards, the results of this experiment are very similar to those of the earlier studies using the same range of frequencies for probe signals.

The results of the cited previous experiments were obtained from adult Os who had received extensive instructions and undergone relatively lengthy training on the task of detecting signals of a single frequency. Also, the data points determining the curves for the previous experiments are based on a larger number of trials and sessions than those in Figs. 1 and 2. We can only surmise that the differences between the results of this and

the earlier experiments are due to the obvious differences in procedure. In some exploratory studies by the authors, using comparable stimulus conditions and adult Os, the steepness of the performance curves appears to be directly related to the amount of prior experience with the task.

Other features of the results warrant comment. Overall, the performance of Child AS was deviant from that of the rest of the children although the procedure for him was the same as for Os GM and JG. However, the important feature of the present curves is the differential detection as a function of signal frequency. For example, for either group the mean difference in the performance on signals of 850 Hz and that on 1,000-Hz signals is comparable to a change in signal energy of at least 3 dB. This result was obtained in spite of the fact that the energies of the signals of various frequencies were such that all signals should have been equally detectable if there had been no frequency selection. A flat performance curve in Fig. 1 or Fig. 2 would indicate an absence of frequency selection. Obviously, both the children and the adults in this experiment demonstrated frequency selection, and a comparison between the mean curves of Figs. 1 and 2 does not indicate any systematic difference between the frequency-selective behavior of the adults and that of the children under the conditions presented.

CONCLUSION

Children were able to perform adequately the task of detecting signals presented against a background of noise with periodic presentation of trials. Performance was sustained over three 1-h sessions spaced 1 week apart. Presumably, developmental questions concerning signal detection may be examined with young Os if E arranges the task to interest the child.

When given only minimal instructions regarding the detection of signals and little pretraining, the frequency-selective performance over two or three sessions was quite similar for the children and the adults. The observed differential responding as a function of signal frequency, similar to that obtained with adult Os in other more extensive studies, indicated that children as well as adults do

select from the auditory input with regard to signal frequency. The results of this experiment are not discrepant with a sensory-filter model of the O's frequency-selective behavior.

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NOTES

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2. Address: Department of Psychology, University of Illinois, Urbana, Illinois 61801.
3. Now at Michigan State University, Lansing, Michigan 48823.

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