# Adaptive auditory signal processing*†

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An experiment was conducted to investigate adaptive auditory signal processing over series of trials in a standard two-interval temporal forced-choice detection task with stimulus uncertainty. Observer sensitivity was found to be dependent upon both the number of successive repetitions of the test stimulus and the number of correct responses in the preceding trials. The results are interpreted in terms of adaptive signal processing based upon stimulus information available in the preceding trials.

The concept of selective attention has been found to apply in many areas traditionally assumed in psychophysics to be static and orderly in nature. This is especially true of the auditory system, which is now viewed by many as a dynamic time-dependent system whose parameters are probably under the intelligent control of the O and are fixed only in terms of some maximum ranges of adaptability (Swets, Green, & Tanner, 1962; Swets & Kristofferson, 1970). However, most contemporary theories have avoided the complicated problem of specifying the adaptive character of the auditory system. In this paper we report on an experiment designed to investigate some frequency-dependent informational aspects of auditory sensitivity over short sequences of trials.

Speeth & Mathews (1961) explored the adaptability of the auditory system in terms of sequential dependencies in a simple four-alternative temporal forced-choice task. They found several kinds of sequential response biases, but no dependencies which seemed indicative of changes in sensitivity. Shipley (1961) demonstrated small, but significant, short-term sensitivity dependencies contingent upon the intensity of the previous stimulus. In both of these studies, the nature of the stimulus was invariant across trials. Swets, Shipley, McKey, & Green (1959) and Swets and Sewall (1961), in tasks involving frequency uncertainty, found sequential dependencies of the following nature:

$$P(C_{i,n} \mid C_{i,n-1}) > P(C_{i,n} \mid C_{j,n-1}), \quad i \neq j, \qquad (1)$$

and

$$P(C_{i,n} \mid C_{i,n-1}) > P(C_{i,n} \mid E_{i,n-1}), \qquad (2)$$

where $C_{i,n}$ indicates correct on Trial n, given Stimulus i, and E indicates an incorrect response. These effects, when evident, were very small and nonsignificant, seldom exceeding 1% or 2%. The size of these results is not surprising, since an efficient, adaptable system operating in a semistationary environment would exhibit only small changes in response to the information contained in each event or trial. Measurable changes would only be evident over appropriate series of several events and not in the one-trial dependencies explored by previous researchers. An experiment was designed to investigate this hypothesis.

## METHOD

Experienced female Os with normal hearing were paid to detect signals in two-alternative temporal forced-choice detection tasks. A signal was always presented in one of two visually marked observation intervals, each 100 msec in duration. The signal presented on any trial was chosen randomly from a predetermined set of two signals, with independent random generators employed for signal and interval selections. The O reported which of the two intervals contained the signal and was given feedback which indicated the correct interval, but not which stimulus had been presented. The signals were all presented monaurally in a continuous broad-band white noise, approximately 57 dB SPL. All signals were gated at positive zero-crossings of the sinusoidal waveforms, with less than a one-cycle rise or decay observed in the acoustic output of the high impedance TDH-39(300) earphone.

Each trial was 5.7 sec in duration, with the two visually marked observation intervals separated by 300 msec. Before each block of 100 trials, the signals were presented to the Os first in quiet and then in noise. The original experiment was based on approximately 3,000 trials for each of four Os. The experiment was replicated with 7,000 trials for each of three new Os. In the original experiment, the signal was either 500 or 2,000 Hz, with 10 log $(E/N_0)$ values of 9.27 and 13.01, respectively. In the replication, a 2,100-Hz signal was substituted for the 2,000-Hz signal. The signals were all approximately matched for detectability. The signal selection process was constrained in a manner which decreased the probability of a stimulus change from 0.50 to 0.33. This increased the expected number of runs of trials with the same signal, yet maintained an overall equal probability for the selection of each stimulus. The selection of the stimulus interval was independent of the stimulus and was random across trials.

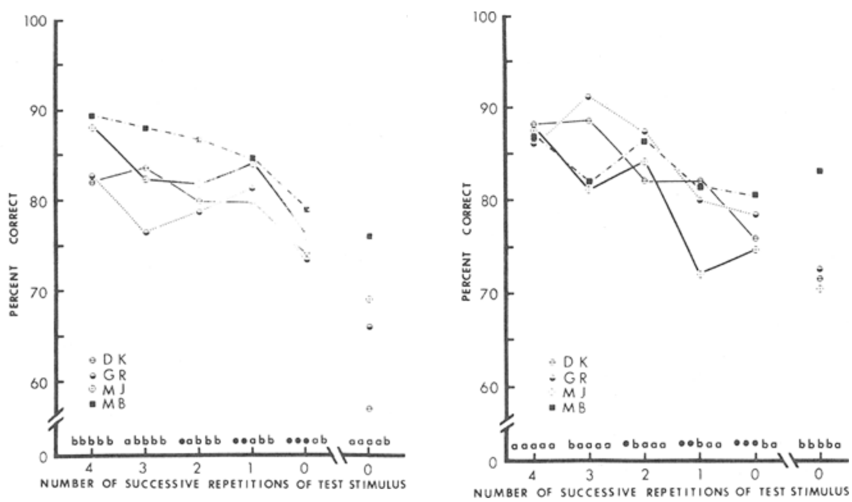


Fig. 1. Percent correct plotted as a function of the number of successive repetitions of the test stimulus for each of four Os. The test stimulus is 500 Hz in Fig. 1a and 2,000 Hz in Fig. 1b.

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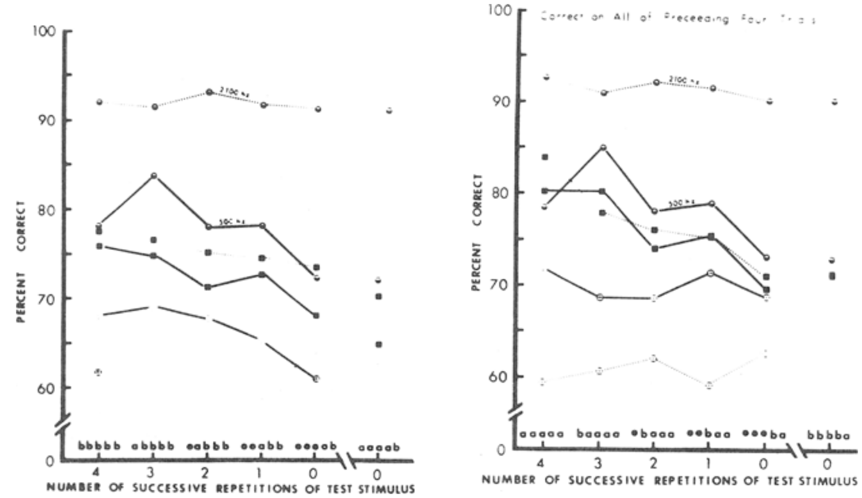


**Fig. 2. Percent correct plotted as a function of the number of repetitions of the test stimulus for three Os in the replication experiment. Solid line indicates the 500-Hz test stimulus; broken line indicates 2,100-Hz.**

## RESULTS AND DISCUSSION

Figure 1a shows the percent correct detection of the 500-Hz signal as a function of the number of prior occurrences of the 500-Hz signal for each of the four Os. The ". . . ab" condition indicates that signal "b" (500 Hz) was preceded by signal "a" (2,000 Hz). The "aaaab" condition constitutes the theoretically "worst case" for detection, since the signal on the current trial did not occur in any of the preceding four trials. There is clear evidence for a decrease in percent correct as the number of repetitions decreases, with an even further decrease to the "aaaab" condition. Figure 1b demonstrates parallel results for the 2,000-Hz signal. Similar results were also obtained from the replication experiment (Fig. 2a), except when the signal was either very detectable [$P(C) > 0.9$] or very poorly detectable [$P(C) < 0.6$]. In the former case, signal parameter information can probably add little to improve the detection process; in the latter case, little parameter information is ever available to the Os. Except for these two cases, all the chi-square statistics computed between the three- or four-reptition and the zero-repetition conditions were significant (0.10 or 0.05 level). These statistics were each based on from 1,400 to 2,200 trials. When the O has been correct on the preceding trials, there is an increased likelihood that the relevant signal information was obtained, and the sequential dependency should be enhanced. Figure 2b shows the data from the replication experiment with the condition that O has been correct on all of the preceding four trials. In general, these functions exhibit a slightly greater slope than those in Fig. 2a.

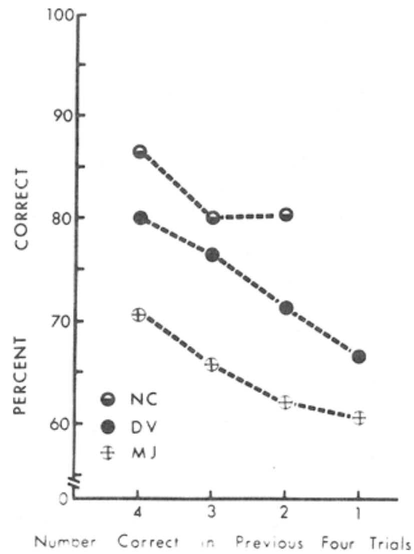


**Fig. 3. Percent correct plotted as a function of the number of correct responses in the preceding four trials, each of which contained the same stimulus as the current trial (Conditions "aaaaa" and "bbbbb").**

These data indicate a change in auditory sensitivity as a function of the number of repetitions of the stimulus and the probability of a recent stimulus detection. This latter dependency is further demonstrated in Fig. 3, which is a plot of percent correct as a function of the number of times the O has been correct in the preceding four trials, where the stimuli on the current and preceding four trials are identical, but the stimulus intervals are random. This condition is, therefore, orthogonal to the one plotted in Fig. 2a.

Several mechanisms may be postulated to account for this dependence on signal repetition. One general view is that the O is likely to have obtained a clear impression of the particular signal on a trial when he has been correct, and that impression will influence how he listens on the subsequent trial. A further notion is that this effect is cumulative, with the O's template becoming less noisy as a function of repetition. Another view might be that the occurrence of long strings of like signals effectively raises the O's estimate of the probability of the given stimulus; in the two-signal ensemble, the O simply shifts the weights he places on the outputs of his internal filters. There is experimental evidence for both of the proposed adaptive mechanisms (e.g., Shipley, 1961; Sorkin, 1965; Kinchla, 1966; Larkin & Greenberg, 1970), which are equally compatible with the results of this experiment.

It should be noted that the experiment was designed to maximize the probability of sequential dependencies. The results demonstrate that the human listener is adaptable in the frequency domain and can employ signal parameter information obtained from previous trials. While these results are not incompatable with signal detection theory, which deals only with stationary behavior, they do suggest that a general theory of listener performance in detection tasks must recognize the nonstationary properties demonstrated here.

### REFERENCES


KINCHLA, R. A. A comparison of sequential effects in detection and recognition. Experimental Psychology Series. Psychology Department, New York University, Technical Report 1, 1966.

LARKIN, W., & GREENBERG, G. Z. Selective attention in uncertain frequency detection. Perception & Psychophysics, 1970, 8, 179-184.

SHIPLEY, E. F. Dependence of successive judgments in detection tasks: Correctness of the response. Journal of the Acoustical Society of America, 1961, 33, 1142-1143 (L).

SORKIN, R. D. Uncertain signal detection with simultaneous contralateral cues. Journal of the Acoustical Society of America, 1965, 38, 207-212.

SPEETH, S. P., & MATHEWS, M. V. Sequential effects in the signal detection situation. Journal of the Acoustical Society of America, 1961, 33, 1046-1054.

SWETS, J. A., GREEN, D. M., & TANNER, W. P., JR. On the width of critical bands. Journal of the Acoustical Society of America, 1962, 34, 108-113.

SWETS, J. A., & KRISTOFFERSON, A. B. Attention. Annual Review of Psychology, 1970, 21, 339-366.

SWETS, J. A., & SEWALL, S. T. Stimulus vs. response uncertainty in recognition. Journal of the Acoustical Society of America, 1961, 33, 1586-1592.

SWETS, J. A., SHIPLEY, E. F., McKEY, M. J., & GREEN, D. M. Multiple observations of signals in noise. Journal of the Acoustical Society of America, 1959, 31, 514-521.