Intensity discrimination: Performance in three paradigms¹

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Performance in the following auditory intensity-discrimination paradigms was compared: (1) 2IFC, (2) single-interval rating with an intensity cue preceding each observation interval, and (3) single-interval rating with no cue. ROCs obtained in the single-interval conditions could be well approximated by assuming that the underlying distributions were both normal and had equal variance. No large difference was observed between performance in the cue and the no-cue conditions. The normalized separation of the means for 2IFC was approximately twice the corresponding estimate for the single-interval conditions, i.e., $d_2 = 1.91 d_1$. This is consistent with the hypothesis that the O in intensity-discrimination tasks bases his decisions on the difference between the observed input and that of a noisy stored reference. The familiar result that $d_2 = (2)^{1/2} d_1$ can be predicted for simple detection.

The application of the theory of signal detectability (TSD) has stimulated a reevaluation of some of the classical

psychophysical phenomena. One area of psychoacoustics enjoying this renewed interest is pure-tone intensity discrimination. The experiment to be presented compares performance in three paradigms for the study of intensity discrimination; each of these paradigms is amenable to straightforward interpretation within the context of TSD. For all conditions in this experiment, the intensity of the reference pulse (pedestal) was fixed, and the O was required to detect an increment in this intensity.

PROCEDURE

The three tasks used in this experiment were: (1) 2IFC, (2) single-interval rating with preceding intensity cue, (3) single-interval rating with no intensity cue. The conditions were run in the above order and feedback was used in all conditions. The E was the single O.

The pedestal or cue was a sinusoid of 950 Hz, 60 dB SPL, gated for 160 msec through a narrow bandpass filter. The signal was derived from the same oscillator and was added in-phase to the pedestal before gating. A continuous, low-level

wide-band noise with a spectrum level of 15 dB SPL was present in all conditions. Therefore, the pedestal was highly detectable.

A 2IFC trial was defined as follows: warning light (300 msec), pause (300 msec), first observation interval light (160 msec), null interval (500 msec), second observation interval light (160 msec), response interval (1,750 msec), feedback light (300 msec). A signal was presented on every trial and it was equally likely to occur in either interval.

A 4-point rating scale was used in the single-interval tasks (Egan, Schulman, & Greenberg, 1959). The timing sequence for the cue condition was similar to that used in the 2IFC task; the signal could occur, however, only in the second interval ($P_{SN} = 0.5$), and the response interval was lengthened to 3,500 msec. The timing sequence for the no-cue condition was similar to that used in the cue condition except that the cue interval (Interval 1) and the null interval were omitted.

RESULTS AND DISCUSSION

ROCs for the single-interval tasks are

Fig. 1. ROCS obtained in a single-interval intensity-discrimination task with an intensity cue preceding each observation interval. Each ROC is based upon 400 ratings. Observer: N.V.

Fig. 2. ROCS obtained in a single-interval intensity-discrimination task with no intensity cue. Each ROC is based upon 400 ratings. Observer: N.V.

shown in Fig. 1 for the cue condition and in Fig. 2 for the no-cue condition. The obtained proportions

$$P(y \leq y_c | SN) = \sum_{i=1}^c P(r_i | SN),$$

and

$$P(y \leq y_c | N),$$

($c = 1, 2, 3$) were converted to normal deviates; straight lines were fitted to these points by eye. The data are well fitted by linear functions and there appears to be no consistent deviation from unit slope. Therefore, the underlying distributions for auditory intensity discrimination can be treated as if they were Gaussian and had equal variance. This does not imply, however, that models that predict different distributions are necessarily wrong. The form of empirical ROCs simply does not permit very fine distinctions between possible underlying distributions.

The measure $d_s = 2 z(y | N)$, where $z(y | N) = -z(y | SN)$, was estimated from each ROC. The measure d_2 was computed from the 2IFC data by adding the z values corresponding to $P("1" | I)$ and $P("2" | II)$. Psychometric functions with $d_1 = d_s$ for the single interval tasks, and d_2 for 2IFC are shown in Fig. 3.

There is no large difference in asymptotic performance between the cue and no-cue conditions. Similar results have been obtained with the classical psychophysical methods of constant stimuli and single stimuli (Woodworth & Schlosberg, 1954; Pollack, 1954) and in simple detection (Greenberg, 1962).

An economical hypothesis for decision making in the intensity-discrimination conditions is that the O uses the difference between the observed input and a stored reference as his decision variable. The stored reference may be the input from the previous interval, as in the cue condition and in 2IFC, or may have been stored from previous trials, as in the no-cue condition. Evidently, the stored reference is not appreciably degraded in the no-cue condition.

Undoubtedly, the process is more complicated. The O probably uses trial-by-trial information to improve stored information and thereby introduces trial dependencies. Temporal spacing of the observations has been shown to affect performance (Tanner, 1961; Kinchla & Smyzer, 1967). Also, there is no conclusive evidence that Os employ a simple differencing strategy or equivalent procedures in such psychophysical tasks. Nevertheless, it will be shown that the

Fig. 3. Psychometric functions for three intensity discrimination paradigms. The measure $d_1 = d_s$ is plotted on the ordinate for the single-interval conditions. For 2IFC, the measure d_2 is plotted on the ordinate and each data point is based upon 400 trials. Observer: N.V.

hypothesis leads to a reasonable prediction about the relationship between performance in 2IFC and single-interval intensity discrimination and simple detection tasks.

Assume that the O computes the quantity x_i for each possible signal interval i and that $x_i: N(\mu_{SN}, \sigma^2)$ for pedestal-plus-increment (SN) intervals, and $x_i: N(\mu_N, \sigma^2)$ for pedestal-alone (N) intervals. For the 2IFC task, the hypothesis is identical to the usual assumption that the O bases his decisions on the magnitude of $(x_1 - x_2)$. Assuming independence of intervals, $(x_1 - x_2): N(\mu_{SN} - \mu_N, 2\sigma^2)$ for interval one correct, and $(x_1 - x_2): N(\mu_N - \mu_{SN}, 2\sigma^2)$ otherwise. Then, $d_2 = 2(\mu_{SN} - \mu_N)/(2\sigma^2)^{1/2} = (2)^{1/2} d'$.

In the single-interval intensity-discrimination task, the O is assumed to base his decisions on the magnitude of $(x_2 - x_s)$, where x_s is the value of x stored from the cue interval or from previous trials. Assuming $x_s: N(\mu_s, \sigma^2)$, $(x_2 - x_s): N(\mu_{SN} - \mu_s, \sigma^2)$ for SN trials, and $(x_2 - x_s): N(\mu_N - \mu_s, \sigma^2)$ for N trials, and, $d_1 = (\mu_{SN} - \mu_N)/(\sigma^2)^{1/2} = d'/(2)^{1/2}$. Thus, $d_2 = 2 d_1$. Figure 3 shows the psychometric functions to be linear and, in general, $d_2/d_1 = 1.91$.

Sorkin (1962) found that performance in a "matching" task similar to the cue condition could be better described by assuming that the O used a noisy, rather

than fixed, reference. Although this conclusion is equivalent to that based upon the present data, a direct computation of d_2/d_1 is precluded by Sorkin's use of signals that were equally likely to cause an increment or decrement in the pedestal. Leshowitz (1969) compared intensity-discrimination performance in two-interval and single-interval (no cue) rating tasks. He computed d_2/d_1 for each of 13 data points on the psychometric functions for each of the three Os. The mean d_2/d_1 was 1.75 and the range was 0.77-2.93.

The crucial assumption in the above derivation is that the O uses a noisy stored reference in computing the difference between the observed and the reference values of the variable, x . If the reference were not noisy, the O would subtract a constant from the observation; there would be no decrement in single-interval performance (i.e., $d_1 = d'$) and $d_2 = (2)^{1/2} d_1$. Of course, such an O can do equally well by simply basing his decision on the magnitude of x . Evidently, additional factors preclude the effective use of the magnitude of x by real Os in discrimination tasks; comparative judgments are made in spite of the decrement in single-interval performance.

The discussion so far has considered only intensity-discrimination tasks in which the externally presented noise has no appreciable effect on performance. In

simple detection tasks, however, the externally presented noise imposes the primary limitation on performance. The stored reference in such a task is appropriate for intensity discrimination of the (wide-band) noise, but it is inappropriate for the detection of a narrow-band, sinusoidal signal in this noise. The variability of the stored reference is probably much less than that of the observation because the O can more effectively smooth the fluctuations in intensity (or envelope) for the wide-band reference observation than he can for the narrow-band detection observation (Bos & de Boer, 1966). Assuming that the variability of the stored reference makes a negligible contribution to the total variability, $d_1 = d'$ and $d_2 = (2)^{1/2} d_1$. The data for simple detection are in reasonable agreement with this familiar prediction.

The O in a single-interval intensity-discrimination task was assumed to base his decisions on the magnitude of $(x_2 - x_s)$, i.e., he responds "yes" in a yes-no task if $(x_2 - x_s)$ exceeds a fixed criterion, x_c . We can obtain the same results by assuming that x_s is fixed and that $x_c: N(\mu_c, \sigma^2)$. With these assumptions, the proposed model is equivalent to a special case of the criterion-variance model proposed by Wickelgren (1968). The magnitude of the criterion variance in this model is almost completely arbitrary; there is no a priori reason for assuming it to be equal to that of the observations. However, it is reasonable to assume, as in the proposed model, that the variance of a cue or its stored equivalent is approximately equal to that of the observation. Clearly, the cue is subject to the same perturbing factors as the observation. The stored reference in the no-cue intensity-discrimination condition is probably at least as variable as the observations from which it was derived. For example, the O may perfectly store the previous observation and change his

criterion according to the feedback information. Let his criterion be $X_{c,N}$ when the previous interval was pedestal alone. If $X_{c,SN} = X_{c,N} + \mu_N - \mu_{SN}$, his performance will be identical to that in the cue condition.

Durlach and Braid (1969) have developed a theory of intensity resolution applicable to a wide variety of psychophysical tasks. The account of performance in the 2IFC and cue condition would be similar to that of the proposed model; they include an additional variance term for memory effects and also assume that "sensation" variance is independent of pedestal intensity. In the no-cue condition, the O compares an observation with the context of previous observations. A variance term in addition to sensation variance is included for context-coding noise. To account for the similarity in performance in the cue and no-cue tasks and also to account for $d_2 \cong 2 d_1$, the context-coding variance must be at least as large as the sensation variance. However, since only two closely spaced intensities were used in the present experiment, context-coding variance should be minimal and, according to assumptions which they make in the later development of the theory, should be much less than the sensation variance.

The primary difference between the three models is in the interpretation of the variability in the various conditions. In the proposed model, the variability in all intensity-discrimination conditions is caused mainly by sensory factors. The other models imply that variability from other sources is appreciable in the no-cue condition, if not in all conditions. Indeed, nonsensory variability may impose the primary limitation on performance in all psychophysical tasks.

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NOTES

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