Duration discrimination of acoustically defined intervals in the 1- to 8-sec range

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This experiment indicates how one's ability to distinguish between two acoustically defined durations, differing by .4 sec, diminishes as the shorter duration is increased from 1 to 8 sec. This effect is interpreted with a model in which one's "subjective temporal estimate" is a random variable whose variance is directly proportional to the actual stimulus duration, the constant of proportionality being about 6 msec²/sec.

Studies of duration discrimination have been reported which employed a "forced-choice" procedure with both acoustically (Creelman, 1962; Tanner et al, 1966) and visually (Allan et al, 1971; Tanner et al, 1966) defined durations. However, in these studies, the durations used were less than 2 sec. In contrast, the present paper uses temporal intervals ranging from 1 to 8 sec and employs a "recognition" paradigm, in which one of the durations was presented on each trial and the S attempted to discern whether it was the longer or shorter of the pair.

Specifically, on each of a series of trials, a tone came on and remained on with equal probability for either t_1 or t_2 sec. At the termination of the tone, Ss were required to indicate whether the short stimulus, t_1 , or the long stimulus, t_2 , had occurred, and, in addition, to rate their response "certain" or "uncertain." The Ss received feedback after every trial, indicating the correct response as "long" after a t_2 or "short" after a t_1 .

In the experiment reported here, the value of t_1 was varied from one test session to the next, although the absolute difference between t_1 and t_2 was held constant at .4 sec.

APPARATUS

Three Ss performed simultaneously in three isolated acoustical testing chambers, with visual cues presented on a small oscilloscope in each chamber. Responses were made by pressing one of four pushbuttons located on a table in front of each S.

A DEC PDP-12 computer was programmed to present the stimuli and record responses automatically. The auditory stimulus was a 1,000-Hz tone presented to the S binaurally through Permoflux earphones at an amplitude of about 50 dB re .0002 dynes/cm². An electronic switch provided a 10-msec rise and decay period when the tone was turned on and off to avoid switching transients, i.e., clicks.

SUBJECTS

The Ss were three nonstudent females, 25 to 40 years old, who had had no prior experience in perceptual experiments.

PROCEDURE

Several practice sessions were presented prior to the start of the experiment. At the first practice session, the following instructions were given: "This is an experiment in duration, or time, discrimination. The duration you will be asked to judge is that of a tone—so you will be asked to wear earphones. At the start of each trial, a tone will come on and stay on for one of two durations. It will either be short or it will be long. There are only two different lengths—long or short. You are to decide whether it was a long tone or a short tone. When the tone goes off, if you thought it was long, press the right key in front of you. If you think it was short, press the left key. These are clearly marked. After you have responded, the TV screen in front of you will indicate whether it was short or long. Note that a response that occurs after the correct response is indicated won't be counted. The discrimination will not be easy—often you may feel you can't really decide; but this is meant to be a difficult discrimination, so just do the best you can and don't worry about that. When 'end session' comes on the TV screen, there will be a break."

Prior to the third practice session, Ss were instructed to rate their responses in each category as "certain" or "uncertain." They were also asked to use all four response categories about equally often.

The sequence within a trial was as follows: tone on for duration t_1 ($i = 1, 2$); response period, 2 sec; feedback period, 1 sec; intertrial interval, 1.5 sec. At the start of a session, the word "ready" was displayed on the scope for 30 sec prior to the start of the first trial. Feedback consisted of the words "long" or "short," which

appeared on the scope following the response period on each trial.

Six practice sessions were followed by 23 experimental sessions in which the difference between t_1 and t_2 was always .4 sec ($t_2 - t_1 = .4$ sec). Eight values of t_1 were used: 1, 2, 3, 4, 5, 6, 7, or 8 sec. A single value of t_1 was employed within any one session, with the particular order of values chosen randomly. Both t_1 and t_2 trials occurred equally often within each session in a randomly determined sequence.

In order to keep the total session length constant, the number of trials per session varied; however, sufficient sessions were run under each condition (value of t_1) to provide a minimum of 800 trials for that condition, not including 20 warm-up trials at the start of each session. Sessions occurred at the same time daily except for weekends, and were presented in two 25-min blocks separated by a 15-min break. Ss were paid at the rate of \$2.00/h.

RESULTS

A "short" or "long" response, independent of confidence level, will be denoted by R_S and R_L , respectively. A S's response tendencies on t_1 and t_2 trials can then be summarized by the proportions of R_L responses on these trials, denoted by $\hat{p}_1$ and $\hat{p}_2$, respectively. The cap on each symbol indicates that it is an estimate of a corresponding theoretical

Table 1
Estimates of $\hat{p}_1$, $\hat{p}_2$, $\hat{p}_C$, and $\hat{d}'$
for Experiment 1

t_1	$\hat{p}_2$	$\hat{p}_1$	$\hat{p}_C$	$\hat{d}'$
Subject 1				
1	.987	.017	.985	4.37
2	.990	.038	.976	4.07
3	.983	.028	.977	3.93
4	.988	.952	.968	3.69
5	.881	.071	.905	2.64
6	.901	.088	.906	2.62
7	.764	.159	.802	1.70
8	.858	.109	.874	2.31
Subject 2				
1	.950	.022	.964	3.69
2	.891	.028	.931	3.11
3	.970	.003	.984	4.20
4	.756	.064	.846	2.26
5	.833	.165	.834	1.90
6	.713	.099	.806	1.84
7	.736	.166	.786	1.59
8	.778	.182	.798	1.68
Subject 3				
1	.977	.027	.975	3.93
2	.848	.086	.811	2.38
3	.973	.025	.974	3.76
4	.930	.058	.936	3.02
5	.909	.043	.932	3.09
6	.936	.040	.947	3.30
7	.848	.130	.859	2.17
8	.837	.147	.845	2.03

Fig. 1. Probability correct, averaged for all three Ss; the abscissa identifies the t_1 value of each condition (t_2 was always .4 sec longer than t_1).

probability, i.e., $\hat{p}_i$ is an estimate of $P(R_L | t_i)$. Similarly, $\hat{p}_C$ will denote an estimate of the probability of correctly identifying the duration of the stimulus on each trial. Finally, it will be useful to denote a S's four response alternatives as a variable R , with $R = 1, 2, 3$, or 4 , corresponding to "certain short," "uncertain short," "uncertain long," and "certain long" responses, respectively (e.g., note that R_S implies $R = 1$ or 2).

Table 1 presents values of $\hat{p}_1$, $\hat{p}_2$, and $\hat{p}_C$ for each S under each value of t_1 (1, 2, ..., 8 sec). Each value of $\hat{p}_1$ or $\hat{p}_2$ is based on 400 trials, while $\hat{p}_C$ is based on the full 800 trials under each t_1 condition. A chi-square analysis is sufficient to indicate a statistically significant ($p < .01$) effect of the t_1 value on the performance of each S. The general nature of this effect is apparent numerically in Table 1 and graphically in Fig. 1, where the average value of $\hat{p}_C$ across all three Ss is plotted against the value of t_1 and indicates the virtually linear reduction in $\hat{p}_C$ as t_1 increased from 1 to 8 sec.

DISCUSSION

Further analysis of the data is afforded by estimates of a d' discriminability measure, which are presented in Table 1. These estimates are obtained by treating p_1 and p_2 as "hit" and "false-alarm" measures in a conventional signal detection analysis (see Green & Swets, 1966); specifically, if z_1 corresponds to that value of a normal deviate exceeded with probability p_1 , then

$$\hat{d}' = \hat{z}_1 - \hat{z}_2 \quad (1)$$

Another way of looking at the data

in terms of "signal detection" measures is to plot "operating characteristic" (ROC) functions for each value of t_1 using the confidence rating responses (Green & Swets, 1966). This method basically consists of plotting $P(R \geq x | t_2)$ against $P(R \geq x | t_1)$ for $x = 4, 3$, or 2 , where $P(R \geq x | t_1)$ is the proportion of times R equalled or exceeded the value x on t_1 trials. Figure 2 presents the average form of these functions for all three Ss plotted on a probit scale. While there is a slight, but consistent, departure from the linear operating characteristic predicted by signal detection theory for such graphs, the general effects are consistent with a progressively lower level of discriminability as t_1 was increased, independent of the S's judgmental standards.

Several models of time perception have been proposed (e.g., Creelman, 1962; McGill, 1970) which characterize a S's "internal clock" process as a counter whose output can be represented by a Poisson distribution. As the interval being timed increases, the total counts produced by such a "clock" would approximate a Gaussian random variable. It will be assumed here that the Ss do have an "internal clock" of this sort and that the durations

employed in this experiment were sufficiently long to warrant a Gaussian assumption. Some empirical support for this assumption does exist, although the data were obtained under slightly differing procedures and with much briefer durations (Allan et al, 1971; Baron, 1969).

The model employed in the present analysis can be summarized as follows:

(1) A stimulus of duration t produces a "count," C , on the S's "internal clock," which is a Gaussian random variable with an expected value equal to t , $E(C) = t$, and a variance directly proportional to t , $\text{Var}(C) = \phi t$ (where ϕ is a constant of proportionality).

(2) When asked to discriminate between two values of t , the S will respond "long" (R_L) whenever C exceeds a number β , his response criterion, and will respond "short" (R_S) otherwise.

It follows from these two assumptions that a d' discriminability measure for the type of experimental task we have employed could be defined as follows:

$$d' = \frac{E(C | t_2) - E(C | t_1)}{[\text{Var}(C | t_1)]^{1/2}}$$

Fig. 2. ROC plots of confidence rating responses, averaged for all three Ss and plotted on a normal-normal scale; the top row of numbers identifies the t_1 value of each condition.

$$\frac{t_2 - t_1}{(\phi t_1)^{1/2}} \quad (2)$$

Furthermore, an expression for d' could also be written in terms of z_1 and z_2 , where z_i is that normal deviate exceeded with probability p_i ($i = 1$ or 2); specifically,

$$d' = z_2 - kz_1 \quad (3)$$

where

$$k = \frac{[\text{Var}(C | t_1)]^{1/2}}{[\text{Var}(C | t_2)]^{1/2}} \quad (4)$$

$$k = \frac{(\phi t_1)^{1/2}}{(\phi t_2)^{1/2}}$$

In terms of the "operating characteristic" representation in Fig. 2, this would imply a linear operating characteristic with d' equal to z_2 when z_1 equalled zero, and a slope of k^{-1} .

In order to simplify the present application of the model, we shall consider k to equal 1. This is essentially true when the difference between t_1 and t_2 is small relative to the value of t_1 . In any case, the conclusions to be drawn in our present analysis are not critically dependent on this simplification and would also follow from the more complicated analysis in which k was not assumed to equal 1.

Given the assumptions of the model leading to Eqs. 2, 3, and 4, as well as the simplifying assumption that $k = 1$, Eq. 1 can be rewritten as

$$\text{Var}(C) = \frac{(t_2 - t_1)^2}{(d')^2} \quad (5)$$

and Eq. 3 reduces to Eq. 1, allowing us to use the estimates of d' in Table 1, Column 4, in Eq. 5 to define an estimate of $\text{Var}(C)$, as follows:

$$\hat{\text{Var}}(C) = \frac{(.4)^2}{(\hat{d}')^2} \quad (6)$$

Values of $\hat{\text{Var}}(C)$ for each S under each t_1 value are presented graphically in Fig. 3. Since $\hat{\text{Var}}(C)$ equals ϕt , by assumption, the slope of a least-square-fitted straight line passing

Fig. 3. Variance estimates showing observed (filled circles) and theoretical (solid line) values; individual plots for each S.

through the origin is an estimate of ϕ . The values of this estimate, ϕ , for Ss 1, 2, and 3 are 5, 8, and 4 msec²/sec, respectively. In other words, this is the increment in the variance of the S's subjective estimate of time, C , produced by each second of counting. This was, on the average, about 6 msec²/sec.

The temporal discrimination model applied in this paper does not require any specific assumption concerning an underlying "Poisson process." Basically, the model simply assumes that one's subjective estimate of time is a Gaussian random variable whose expected value is the actual time and whose variance is directly proportional to that time, with ϕ being the constant of proportionality. However, it is

possible to translate the measure ϕ into the parameter of a Poisson process, λ .

First, assume that C , denoting the count on an "internal clock," is a Poisson variable, i.e., $P(C; \lambda) = e^{-\lambda}(\lambda^C/C!)$. Then the expected value and variance of C during a time period of t would equal λt . Thus, for the two durations t_1 and t_2 , the discrimination measure d could be written as

$$d = \frac{\lambda t_2 - \lambda t_1}{(\lambda t_1)^{1/2}}$$

which implies

$$\lambda = \frac{t_1 (d)^2}{(t_2 - t_1)^2}$$

A value of d was obtained by setting t_1 and t_2 at 1 and 1.4 sec, respectively, and assuming the variance at 1 sec (ϕ) equalled .006, the average value for the three Ss. Then,

$$5.13 = \frac{\lambda t_1 - \lambda t_2}{(\lambda t_1)^{1/2}}$$

and

$$\lambda = 164.$$

Since λt is the expected value of C , this estimate of λ can be interpreted to mean that the average counting rate, λ , of the Poisson process is 164 counts per second.

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