Application of a variable criterion model to auditory reaction time as a function of the type of catch trial*

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A variable criterion model has been applied to data from an RT experiment by LaBerge in which catch trial stimuli varied in similarity to a single auditory RT signal. Estimates of a sensory recruitment function and the parameters of hypothetical criterion distributions were obtained by a scaling solution. Auditory recruitment was an exponential growth function, and the criterion distributions were normal. In combination, these estimates successfully predicted the empirical RT distributions.

The writer has recently been engaged in the development of a theory which treats response evocation as a decision process. While the most recent applications have been in the area of conditioning (Grice, 1971, 1972), the first paper in the series (Grice, 1968) dealt with both conditioning and simple reaction time (RT). Central to these formulations is a concept of decision criterion or reaction threshold (T) which summarizes the state of readiness to respond. The criterion is treated as a normally distributed random variable whose mean (T) and standard deviation (σ) are subject to manipulations by a variety of experimental variables, and which also reflect individual differences. Response evocation occurs when the excitatory strength of a response exceeds the momentary value of the threshold. In conditioning, excitatory strength has been successfully treated as an additive combination of associative or habit strength (H) and sensory strength (V) (Grice, 1972). In simple RT, the associative component may be treated as preset or maximal at the start of each trial, and the analysis may be in terms of the sensory and criterion values only. In dealing with latency data, it is assumed that sensory strength undergoes recruitment according to some monotonic function until it reaches the criterion, at which point the response occurs. While Grice (1968) provisionally treated the recruitment functions as linear, there are various considerations from psychophysics and other sources (John, 1967; Grice, 1972) suggesting that they are negatively accelerated. Furthermore, the linear assumption does not lead to realistic prediction of the form of RT distributions in combination with the assumption of normally distributed thresholds. The theoretical value determining the probability of response at any given time is suprathreshold excitatory potential, E = V − T. Since this value is normally distributed, Thurstonian scaling assumptions are applicable, and theoretical calculations are applied to a scale in which σ is the unit.

Most of the RT work related to this theory has been concerned with the identification and evaluation of variables influencing the criterion. One of the variables which behaved properly in this respect is the presence or absence of catch trials in simple RT (Murray, 1970). Recently, LaBerge (1971) has reported some very interesting experiments in which he, in effect, manipulated the similarity of stimuli presented on catch trials to the RT signal. LaBerge interpreted the data as possible evidence concerning the use of distinct levels of information processing, detection, and discrimination. However, the present line of reasoning suggests a somewhat different interpretation in terms of criterion level. It is reasonable to assume that increasing similarity of RT and catch trial stimuli results in higher decision criteria with respect to the amount of sensory exposure required. The remainder of this paper is an analysis of LaBerge's data in terms of this hypothesis. It is certainly not the present intent to arrive at a definitive decision concerning the relative merits of these two rather closely related views, but merely to evaluate the adequacy of the criterion interpretation. The first step will be to obtain estimates of the two criterion parameters for each experimental condition for each S. The next step will be to obtain an estimate, in common scale units, for the sensory recruitment function of the 1,000-Hz RT signal. Finally, it will be determined how adequately this information can be used to reconstruct the empirical RT distributions.

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THEORETICAL ANALYSIS

The data analyzed are those of LaBerge's (1971) Experiment 2 and are from the distributions presented in his Figs. 2, 3, and 4. There were four experimental conditions in which the RT signal was always a 1,000-Hz tone of 80 dB SPL. In each condition, a different signal was used on the catch trials: nothing, an illuminated red square, a noise, and a 1,200-Hz tone. There were three Ss, each receiving all conditions. The other experimental details are, of course, given by LaBerge (1971).

The first step in the analysis was to arrange each of the 12 RT distributions in cumulative form, with class intervals of 10 msec. These cumulative proportions of response are assumed to estimate probability of response as a function of time since signal onset. These proportions were then transformed to their corresponding normal deviates. In this form, the transformed cumulative distributions now provide estimates of the growth of excitatory strength following stimulus onset. Any point on one of the functions estimates the distance of the recruitment function at that time to the mean of the criterion distributions in units of the σ of that distribution. That is, each point estimates E = V − T. Since the mean of the criterion distribution (T) is assumed to be a parameter for a condition, the functions estimate the recruitment of V, sensory strength. Each function is measured from a threshold, and in a unit both specific to the particular S and condition. The next step is a scaling solution which estimates the distances between the thresholds and the relative sizes of the σs.

The scaling solution used is the same as that previously used by the writer (Grice, 1971, 1972) and first introduced by Thurstone (1925, 1928). It involves plotting for adjacent conditions, functions, which the writer has called, in applications of this kind, response evocation characteristics (RECs). An REC is a plot of probability of response for one condition against probability for a second condition on normal-normal coordinates. Each point is formed by the probabilities at the same value on some dimension of increasing response strength common to the two conditions. In this instance, one distribution was plotted against another, each point representing one 10-msec class interval. This involves

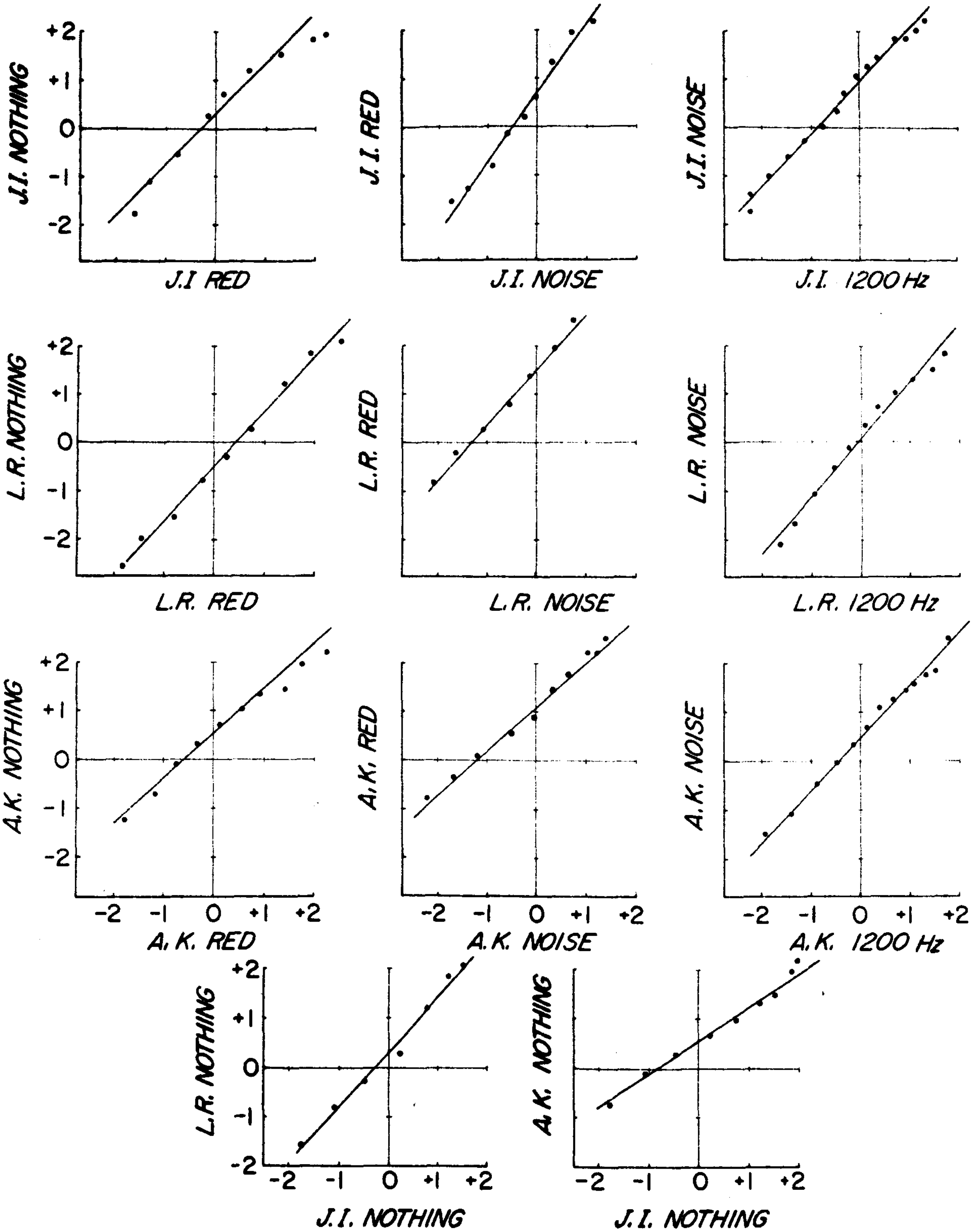

Fig. 1. RECs used in the scaling solution. The units are normal deviates corresponding to proportions in the cumulative distributions.

the assumption that the recruitment function for V is the same for all conditions. Of course, only the overlapping portions of the distributions are available for such a plot. The mathematics of the model was derived by Thurstone (1925) and is similar to that of the TSD model. Linearity of the plot implies normality on the underlying hypothetical scale. The slope of the line is the ratio of the standard deviations, σ_x/σ_y. The y-intercept is the scale separation, d, between the conditions in units of σ_y, and the x-intercept is d in units of σ_x. In the present model, d is the distance between the means of the two threshold distributions.

All RECs used in the present solution are presented in Fig. 1. The lines were fitted by the method

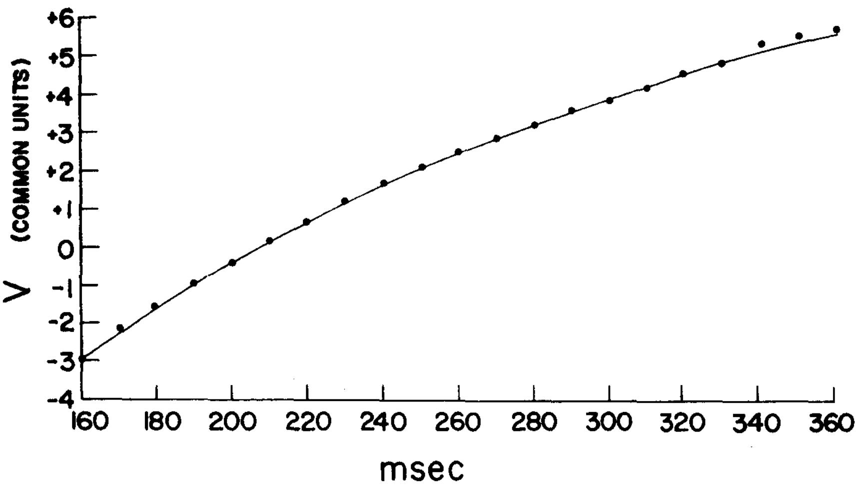

Fig. 2. Estimate of the sensory recruitment function on the common scale.

previously used by Grice (1971) with one exception. This time, we followed the suggestion of Thurstone (1928) by weighting the observations with the Müller-Urban weights.[1] This is desirable because of the low reliability of normal deviates based on very low or high proportions. The top nine plots are for within-S scaling between the experimental conditions. The lower two plots relate Ss L.R. and A.K. to S J.I. for the nothing condition. The general picture of linearity provides rather good overall support for the normal assumption. The more obvious departures from linearity are in the less reliable tail points. The 11 standard deviation ratios and d values provide the information to complete the scaling. One of the σs is arbitrarily selected as the unit for the scale, and all remaining σs and all values of d are sequentially converted to the common unit. By appropriate summation of the ds, each value of T is then expressed in common units as a distance from an arbitrarily chosen origin for the scale. In this instance, the unit is the σ of J.I.'s nothing condition and the origin is the corresponding criterion mean. The resulting values of T and σ in this scale are presented in Table 1.

The next step in the analysis is to convert each of the transformed cumulative distribution functions to the common scale. This is accomplished simply by multiplying each value by the appropriate σ and adding the value of T. In terms of the model, we now have 12 estimates of the sensory recruitment function, all in the same units and on a scale with a common origin. A single estimate of this function has been obtained by computing the weighted mean of the separate estimates at each 10-msec class interval. Since the distributions do not fully overlap, each mean is based on Ns varying from 2 to 12. In computing the means, each value was weighted by the Müller-Urban weight for the original proportion from which the scale value was derived. The means are indicated by the points plotted in Fig. 2, and describe an extremely orderly negatively accelerated function. The points have been fitted by the exponential growth function:

$$V = 10 - 30.83(10)^{-.00235t} \quad (1)$$

where t is in milliseconds. It may be noted that the final three points which lie above the fitted curve are based on merely the tails of only two distributions.

The entire model may readily be understood with reference to Fig. 2. The means of the criterion distributions are located along the ordinate at positions indicated by the values of T in Table 1. The standard deviations are the values of σ. The cumulative probability of response at any time, t_i, is the proportion of the threshold distribution below the recruitment function at t_i. This, of course, is a function of the scale distance V − T at that time. This value has been calculated throughout the function from Eq. 1 and the estimates of T for each S-condition combination. These values were then returned to the scales of the original distributions and predicted probabilities read from the normal distribution table. The result was the smooth calculated distribution functions presented in Fig. 3. The actually obtained cumulative distributions are indicated by the plotted points. Further evidence concerning the quality of the fit is presented in Table 2, where calculated and observed values of the quartiles and the semi-interquartile range (Q) are given. It will be noted that the largest miss was 7 msec, but that this was by no means typical.

DISCUSSION

It is apparent that the theory has been able to provide quite an adequate account of this complex set of data as the consequence of a hypothetical common recruitment function and criterion parameters influenced by the experimental conditions and individual differences. This approach is quite different from the current trend of accounting for RT distributions in terms of hypothetical stochastic properties of sensory processes themselves (McGill, 1967; Luce & Green, 1972). Elsewhere, the writer (Grice, 1968, 1972) has argued for the plausibility of this approach. The success of this first attempt to apply it to RT distributional phenomena suggests that it can be taken seriously.[2]

One impressive feature of the analysis is the recruitment function of Fig. 2. Regularity of this kind, even in a hypothetical function, encourages belief that some nontrivial aspect of the data is being revealed. The interpretation in terms of a sensory recruitment process will be strengthened if a sensible family of such functions can be produced when stimulus intensity is varied in similar experiments. The interpretation will be further strengthened if more general functions can be determined which are transsituational. For example, can such functions, obtained in RT experiments, also be applied in the more complex analyses of conditioning experiments?

There is also possible interest in the criterion parameters as analytic measures of the effect of the experimental variables and individual differences in strategy of dealing with

Table 1
Mean (T) and σ of Each Criterion Distribution in Common Scale Units

	S JI		S LR		S AK	
Condition	T	σ	T	σ	T	σ
Nothing	0.000	1.000	−0.279	0.897	−0.836	1.479
Red	0.300	1.046	−0.721	1.006	−0.015	1.355
Noise	1.047	1.525	0.784	1.132	1.440	1.226
1200 Hz	2.538	1.679	0.923	1.345	2.025	1.317

Table 2
Observed (O) and Calculated (C) Values (Msec) of Quartiles and Quartile Deviation (Q) for Each Distribution

S	Condition	Q_1			Median			Q_3			Q		
		O	C	O-C	O	C	O-C	O	C	O-C	O	C	O-C
JI	Nothing	197	196	+1	207	208	−1	219	221	−2	17	17	0
	Red	202	201	+1	215	214	+1	231	228	+3	19	18	+1
	Noise	207	208	−1	230	229	+1	250	251	−1	29	29	0
	1200 Hz	232	236	−4	263	262	+1	289	293	−4	38	38	0
LR	Nothing	192	192	0	204	203	+1	214	214	0	15	15	0
	Red	182	184	−2	194	195	−1	208	207	+1	17	15	+2
	Noise	207	208	−1	222	223	−1	239	239	0	21	21	0
	1200 Hz	207	208	−1	227	226	+1	249	245	+4	28	25	+3
AK	Nothing	180	177	+3	192	193	−1	211	211	0	21	23	−2
	Red	192	192	0	207	208	−1	224	226	−2	21	23	−2
	Noise	216	220	−4	230	237	−7	250	256	−6	23	24	−1
	1200 Hz	224	230	−6	247	250	−3	270	272	−2	31	28	+3
Mean Absolute Error				2.0			1.7			2.1			1.2
Mean Constant Error				−1.2			−0.8			−0.8			+0.3

them. As expected, all Ss showed their highest criteria in the presence of the most similar, 1,200-Hz, catch stimulus, and second highest with the other auditory signal, noise. With respect to criterion variability, S A.K. apparently maintained approximately equal variability across conditions, actually displaying the lowest in the noise condition. On the other hand, the other Ss showed increasing variability with similarity. Of particular interest is the performance of S L.R. in the red condition, which was actually faster than the nothing condition. This S reported using the absence of the red light as a "go" signal (LaBerge, personal communication). Now, in view of the fast RTs, it is difficult to see how this could have possibly been true. The analysis suggests a more reasonable interpretation. The excellence of the fit implies full dependence on the recruitment function of the auditory signal. Apparently, the S was made more confident by the appearance of the red light on catch trials, and was led to adopt the lower criterion indicated by the value of T in Table 1. The faster responses made in this condition are fully explained as a criterion effect.

While LaBerge's distinction between detection and discrimination is clearly a sensible way of describing the ways of processing information in this experiment, it also appears that this distinction may be described as a continuous dimension rather than distinct levels. The more difficult the discrimination, the higher the criterion must be, in terms of sensory exposure required, before the decision to respond can be reached. It seems possible that the concept of distinct processing levels may imply discontinuities, which would make improbable the application of a single function like Eq. 1 to all conditions of this experiment.

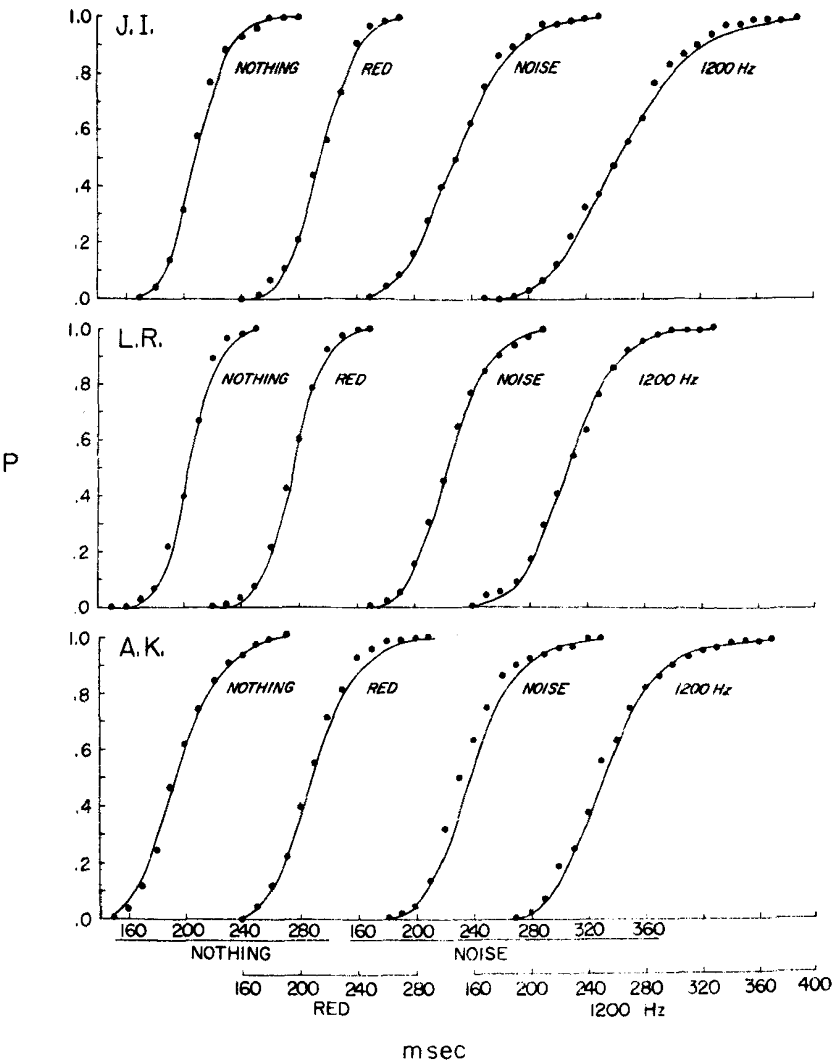

Fig. 3. Calculated cumulative RT distribution functions with points indicating the obtained distributions.

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NOTES

1. Actually, Thurstone did not use the tabled values of the Müller-Urban weights, but directly derived equivalent weights. Here, we used the tabled values (Guilford, 1936). A single weight for the two values comprising a given point was obtained by combining the tabled weights for each proportion by the relation:

$$W = \frac{1}{\frac{1}{w_1} + \frac{1}{w_2}}$$

It is suggested that this procedure may also appropriately be used in the fitting of ROCs in TSD applications.

2. It should be noted that the present model is similar to the theory proposed by John (1967). However, John does not treat the criterion as a random variable, an assumption which provides the rationale for unequal σ solutions in applications such as the present one.

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