Journal of Experimental Psychology
1972, Vol. 92, No. 3, 419–427

THE LATENCY OPERATING CHARACTERISTIC:
I. EFFECTS OF STIMULUS PROBABILITY ON CHOICE REACTION TIME[1]

JOSEPH S. LAPPIN[2] AND KENNETH DISCH
Vanderbilt University

The latency operating characteristic (LOC), defined as the trade-off relation between reaction time (RT) and discrimination accuracy, is proposed as a measure of the perceptual process that is invariant over changes in decision strategies in RT tasks. The LOC was computed from confusion matrices constructed from sets of trials on which the RT fell within a given range. The convergent validity of the LOC was supported by findings of a strong and consistent relation between speed and accuracy that was invariant under changes in stimulus and response probability. Several models of the underlying perceptual processes are discussed which lead to a good description of LOC by a set of straight lines.

When reaction time (RT) is used to measure human information processing, *S*'s decision processes are usually assumed to remain constant from one trial or condition to another. Variation in RT is assumed to reflect only the contributions of sensory, perceptual, or cognitive processes, free from variation in *S*'s decision strategies in choosing when to make his response. But there is seldom any test of this assumption and seldom any tight control on *S*'s decision processes. Typically, *S* is asked to respond as rapidly as possible without making errors. If he makes no errors, however, there is no guarantee that the response has been made as rapidly as possible. The same comment holds for both simple and choice RT tasks, even though erroneous responses are not well defined in the simple RT procedure. Without evidence on the functioning of decision processes in RT tasks, the contributions of perceptual processes cannot be unequivocally distinguished from the contributions of decision processes in RT results.

One example of a problem requiring mutual determination of both perceptual and decisional processes is the question about the effect of stimulus probability on the speed of perceptual processing. It is well known that RT is inversely related to the probability of a stimulus–response pair (Hyman, 1953). The average RT for correct responses is not, however, a sufficient measure for distinguishing the contribution of perceptual processing from that of response bias and decision criterion when stimuli are mapped one to one onto the response alternatives and when the number of errors is very low. One method intended to distinguish perceptual from response processes has been to vary separately stimulus and response probabilities by means of many-to-one mappings of stimuli onto response. Both stimulus and response biases have been found to influence RT (e.g., Bernstein, Schurman, & Forester, 1967; Dillon, 1966; LaBerge, Legrande, & Hobbie, 1969). But this method is also inadequate for isolating and measuring perceptual and decisional processes because *S*'s decision criteria may vary among stimuli with the same response. Expressing the problem in different terms, when there are more stimuli than responses the number of degrees of freedom in the stimulus–response matrix is less than the number of parameters needed to measure the relations between all the pairs of stimuli and pairs of responses. Several experiments suggest that decisional processes do indeed influence the RTs to specific stimuli: Examples are Bartz's

---

[1] This study was supported in part by funds from the Graduate Research Council at Vanderbilt University. The results were also presented at the Psychonomics Society meetings, San Antonio, November 1970.

[2] Requests for reprints should be sent to Joseph S. Lappin, Department of Psychology, Vanderbilt University, Nashville, Tennessee 37203.

(1970) demonstration that stimulus probability effects may be induced on the first trial by instructions alone and Hinrichs' (1971) finding that stimulus probability effects disappear when *S* correctly predicts the stimulus. One may note that stimulus probability has no effect on certain measures of performance in signal detection tasks (Schulman & Greenberg, 1970). This lack of convergence of the detection and RT tasks also raises the question as to whether the effects of stimulus probability on RT are truly perceptual.

A second example of the need for assessment of decision processes in RT tasks is provided by experiments to determine the relation between RT and stimulus intensity. Grice (1968) has concluded from a review of this research that decision processes are likely to exert a major influence on the RTs to stimuli of varying intensity. We will examine this problem further in a second paper in this series.

The purpose of this paper is to report an initial study of a potential method for distinguishing perceptual from decisional processes in RT tasks. The proposed method is to use the trade-off relation between RT and discrimination accuracy as the dependent measure of performance, rather than the distribution of RTs for error-free trials. The rationale for this technique is based on the proposition that a decision process determines the point in time at which perceptual processing is terminated and an overt response is selected. Thus, a given pair of RT and error-rate values reflects performance under a specific decision criterion; but the complete trade-off function between RT and error rate is presumed to reflect performance under varying decision criteria applied to a constant perceptual process. The functional relation between two dependent performance measures is thereby used to obtain a decision-free measure of the perceptual process. The same approach is used in signal detection theory: The functional relation between hit rate and false-alarm rate, the receiver operating characteristic (ROC), is used as the decision-free measure of detection, rather than any specific value of hit rate or false-alarm rate.

By analogy with the signal detection literature, we adopt a similar designation for the functional relation between RT and discrimination accuracy, "latency operating characteristic" (LOC).[3]

The LOC is of interest not only as a dependent measure for the effects of stimulus and task variables, but also as a potential measure for the process of temporal growth of perceptual information. At least four distinct models of this process have been suggested: (*a*) a two-state model (Yellott, 1971), (*b*) information transmission models (Swanson & Briggs, 1969), (*c*) sequential sampling models (Edwards, 1965; Laming, 1968), and (*d*) additive models (Pew, 1967; Shouten & Bekker, 1967). These models are distinguishable by their specification of the function relating RT and discrimination accuracy. The empirical strategy of this study was to seek measures of discrimination accuracy that were linearly related to RT in a two-choice discrimination task. That is, we wished to find measures of accuracy, A, defined on the frequencies in a 2×2 stimulus–response confusion matrix, such that $A = m(RT - k)$, where m is the slope of the LOC and k is the intercept on the RT axis. Each of the above models provides a measure of discrimination accuracy that is approximately linearly related to RT.

According to the two-state model, RTs are emitted in either of two perceptual states: a guessing state and a stimulus-controlled state, with chance or nearly perfect accuracy, respectively. Observed

---

[3] The designation LOC has been used previously by other authors, sometimes referring to a slightly different function. Thomas (1971), for example, derives the LOC from the probability density functions of RTs under signal-plus-noise and noise-alone conditions. The present usage seeks to avoid dependence of the LOC on the probability distributions of RT and does not involve a signal detection task in the strict sense. Other authors (see text below) have used the label "speed-accuracy tradeoff" or "speed-accuracy operating characteristic" to refer to functions very similar to the present LOC. Ira Bernstein had previously used the LOC designation in conversations with the first author.

distributions of correct and incorrect responses are thus presumed to consist of differential mixtures of guessing and stimulus-controlled responses. The general "fast-guess" model developed by Yellott (1971) does not generate a specific LOC; consequently, we examine the LOC only for the special case in which the probability of an all-or-none transition from a guessing state to a stimulus-controlled state is constant for any unit interval in all RT $> k$. It is easy to show that the resulting measure of accuracy that should be linearly related to RT is given by $A \equiv -\log[1 - p(D)]$, where $p(D)$ is the probability of the stimulus-controlled state, estimated by the familiar correction-for-guessing formula in which the false-alarm rate is subtracted from the hit rate.

According to information transmission models of RT, the human operator is considered as a communication channel whose processing time is linearly related to the contingent uncertainty between stimulus input and response output (e.g., Pachella, Fisher, & Karsh, 1968; Swanson & Briggs, 1969). The appropriate measure of accuracy is then given by

$$\begin{aligned} A &\equiv H_t \\ &= -\sum_{s} [p(s) \log_2 p(s)] \\ &\qquad + \sum_{s}\sum_{r} [p(r) p(s|r) \log_2 p(s|r)], \end{aligned}$$

where s and r represent stimuli and responses, respectively. The principal difference between this model and the additive model is the assumption that RT is an increasing function of the amount of information in the stimulus set. We test this assumption by comparing LOCs for conditions in which the two stimuli are equiprobable or occur with probabilities .7 and .3.

In sequential sampling models, *S* is assumed to make repeated but independent observations of an unreliable perceptual signal. Under assumptions that observations are repeated at a constant rate proportional to RT and that each observation is an identically and normally distributed random variable, the appropriate measure of accuracy may be shown to be $A \equiv (d')^2$, where d' is the familiar detectability measure of signal detection theory (see Green & Swets, 1966; Taylor, Lindsay, & Forbes, 1967). A distinction is often made between decision strategies in which *S*'s response criterion is defined on the likelihood ratio axis and strategies in which the criterion is fixed on the RT axis; the $(d')^2$ measure is appropriate for the latter case. Taylor et al. have shown that this measure gives a very good linear fit to Shouten and Bekker's (1967) "forced RT" data, where RTs were constrained to occur within a narrow range.

The additive model for the present experiments postulates a weak perceptual signal that grows in strength at a constant rate; a response emitted in the *n*th observation interval may therefore be guided by a perceptual signal that is *n* times as strong as a signal in the first observation interval. The signal detection theory version of this general model assumes that in selecting his response at any point in time, *S* must decide whether the currently available perceptual signal is an instance of one or the other of two random variables; these variables are assumed to be randomly distributed with equal variance but differing in means by an amount d'; we assume, further, that the signal strength increases at a constant amount in each successive time interval. As is clear from these assumptions, the appropriate measure of accuracy for this model is $A \equiv d'$, where d' is estimated from the 2×2 confusion matrix by assuming the hit rate and false-alarm rate to represent areas within the response criterion of two normally distributed random variables with equal variance. Another additive model yielding a similar measure of accuracy is provided by Luce's choice theory. According to this model, the conditional probability of a given stimulus is equal to the strength of the tendency for that response relative to the sum of all other response tendencies for that stimulus. As shown by Luce (1963), the appropriate measure of accuracy for an additive scale of two-choice discrimination accuracy is given by

$$A \equiv -\log \eta = 1/2 \log \left[\frac{p(r_1|s_1)}{p(r_2|s_1)} \cdot \frac{p(r_2|s_2)}{p(r_1|s_2)} \right],$$

where s_1 and s_2 represent the two alternative stimuli and r_1 and r_2 the two alternative responses. This measure turns out to be very similar to the *d′* measure for assumed underlying normal distributions of equal variance, in terms of both a very high linear correlation between the two scale values and also very similar ROC functions for varying response biases (see Luce, 1963). The measure is presented here in part because of its ease of computation relative to *d′* and in part because of the contrast in underlying rationale. These additive models have not previously been explicitly proposed as models for the perceptual process underlying RT performance. They are, however, simple and a priori reasonable models. Both Pew (1969) and Shouten and Bekker (1967) have suggested similar ideas and have provided supporting data.

Although the above models provide qualitatively different descriptions of the perceptual process, they provide quantitatively similar scales of discrimination accuracy. As will be seen below, each of the theoretical LOCs is highly correlated with RT. Additionally, all of the models share two strong postulates: (*a*) homogeneity in time and (*b*) stochastic independence of the increments in discrimination.

A primary goal of this experiment was to obtain a detailed examination of the relation between RT and discrimination accuracy. If the LOC is to be used as a valid measure of *S*'s information processing, then there must be a strong and consistent relation between speed and accuracy. As one test of this consistency, we also consider whether the LOC remains invariant under changes in stimulus probability. Variation in stimulus probability should be expected to produce changes in decision strategies and response biases (and possibly in the perceptual process). Invariance of the LOC under variation in stimulus probability would thus provide some convergent validity for the LOC as a measure of the perceptual process. This result does in fact obtain.

METHOD

Stimuli and apparatus.—Two easily discriminable stimuli—to the right or left of a fixation point—were mapped onto two highly compatible responses, right hand versus left hand. The stimuli were luminous circles, 1° in diameter and 40 min. off center to the right or left of the fixation point, which was centered in a 5½° square luminous background. The stimulus luminance was 1.5 ftl. added to a continuous background of 8.5 ftl. The stimuli were presented with an Iconix three-channel tachistoscope and associated Iconix timing, power, and logic equipment. A tape reader was used to program the stimulus position for each trial.

Procedure.—Well-practiced *S*s were asked to respond at a speed that would result in an error rate of about 25%. They were instructed to avoid guessing, but to adjust their RTs from trial to trial in order to maintain the appropriate speed and error rate.

A trial was initiated when *S* depressed both of the telegraph response keys. The stimulus always appeared 1 sec. later and remained in view until *S* responded by lifting one of the response keys. If *S* responded prior to the stimulus onset, the same trial was initiated again. The *E* recorded the stimulus, response, and RT and informed *S* of the RT and correctness of his response. The *E* then advanced the tape reader and this served as a signal that *S* could initiate the next trial when he was ready. The trials were run at a rate of about 15/min.

Two conditions were run in each session: 50–50, in which the two stimuli were equally likely, and 70–30, in which one stimulus appeared on 70% and the other on 30% of the trials. The order of the two conditions and whether the left or right stimulus was the more probable were counterbalanced across *S*s and sessions. One hundred and fifty experimental trials were run under each condition in each session; these were preceded by 30 practice trials. The two stimulus positions were randomly scheduled with the constraint that the relative frequencies were equal to the appropriate values for each block of 50 trials. Each *S* served for 10 experimental sessions, preceded by at least 2 practice sessions.

Subjects.—The *S*s were four male volunteers. Two of the *S*s were the authors, one *S* assisted with this and other RT experiments for course credit, and another was paid for his participation.

Analysis.—The LOC was recovered by data analysis, rather than by experimental operations to constrain the decision criteria or RTs. The analytic procedure is to first rank order all RTs, correct and incorrect, and then partition these into a series of blocks of some constant number of trials, except as limited by ties. In the present report, we have used blocks of 150 trials, though this number was a somewhat arbitrary compromise between maximizing the number of trials per block and optimizing the resolution of differences in RT. For each set of 150 responses, we then construct the 2 × 2 stimulus–response confusion matrix and calculate the median RT as the measure of average speed for that set of responses. Finally, we compute a set of intercepting line segments to describe the relation between discrimination accuracy and RT. The first segment is the line $A = 0$, for $0 \leq RT < k$. The second segment describes the region where the speed-accuracy trade-off obtains, i.e., $A = m(RT - k)$, for $k \leq RT \leq l$. The third segment describes the region in which discrimination accuracy was approximately perfect, for $RT > l$. (This third segment can only be fit to the H_t measures of discrimination, since perfect discrimination is not defined on the other scales.)

The interest in this analysis lies in measuring the perceptual process rather than the decision process. The method does not permit an analysis of the decision processes employed by *S*. We wish to avoid as many assumptions as possible about the decision process and, unlike previous determinations of the speed-accuracy trade-off, do not assume a stable response criterion on either the liklihood ratio or RT dimension. The experimental procedure we used, in fact, virtually guarantees that the decision criteria did not remain fixed.

RESULTS

The LOC was represented by a set of intercepting line segments which were fitted to the pairs of RT and accuracy measures by the least-squares procedure described by Bogartz (1968). There were three such lines for the H_t measure: $A = 0$, for $RT < k$; $A = m(RT - k)$, for $k \leq RT \leq l$; and $A = 1.0$ in the 50–50 condition or $A = .88129$ in the 70–30 condition, for $RT > l$. This set of lines thus has two free parameters, which may be represented by the slope, *m*, and the intercept, *k*, in the second line segment. The range of RT values to which each of the line segments was fitted were selected so as to minimize the sum of squared deviations from the lines under the restriction that the intercepts *k* and *l* did not lie within the range of RTs being fitted to the line segments at chance and perfect discrimination, respectively. The same procedure was followed for the other four measures of accuracy with the exception that the third line segment, at perfect discrimination, was not included. Under the choice theory, signal detection, and sequential sampling models, no measure is defined when either the hit rate is 1.0 or the false-alarm rate is 0; under the two-state theory, no measure is defined when both the hit rate is 1.0 and the false-alarm rate is 0. Consequently, for the latter four measures only the first two line segments were fitted to the set of points in the range of RT where perfect discrimination did not occur, and the LOC regression lines were

TABLE 1

SLOPES (*m*) AND INTERCEPTS (*k*) FOR THE SEGMENT OF THE LATENCY OPERATING CHARACTERISTIC (LOC) GIVEN BY THE EQUATION $A = m(RT - k)/100$ msec, FOR EACH *S* AND EXPERIMENTAL CONDITION

S	Cond.	$-\ln[1 - p(D)]$		H_t		$(d')^2$		d'		$-\ln \eta$	
		m	*k*	*m*	*k*	*m*	*k*	*m*	*k*	*m*	*k*
K. D.	50–50	2.21	143	.648	143	6.89	145	2.64	128	2.26	130
	70–30	2.18	155	.712	162	13.14	171	2.86	139	2.57	142
	Combined	2.16	148	.666	152	7.06	150	2.69	133	2.28	134
J. L.	50–50	2.77	156	1.027	164	10.73	163	3.24	141	2.79	143
	70–30	2.27	148	.907	163	12.93	162	2.91	133	2.68	137
	Combined	2.46	151	.740	155	16.03	171	3.60	144	3.19	146
L. S.	50–50	3.15	145	1.024	149	10.56	148	2.82	118	2.43	120
	70–30	2.05	140	.528	137	11.88	155	3.40	134	2.95	135
	Combined	3.34	151	.688	140	11.15	151	3.26	129	2.84	131
B. V.	50–50	3.09	163	.948	165	30.97	197	3.94	151	3.08	160
	70–30	2.81	160	.760	164	8.76	158	2.84	136	2.41	137
	Combined	3.06	164	.749	159	21.29	185	3.55	147	3.31	151

Note.—Slopes are given in units of A/100 msec. and intercepts in milliseconds.

TABLE 2

PROPORTION OF VARIANCE ACCOUNTED FOR BY THE LATENCY OPERATING CHARACTERISTIC (LOC) UNDER EACH MEASURE OF DISCRIMINATION ACCURACY, FOR EACH SUBJECT AND EXPERIMENTAL CONDITION

S	Cond.	$-\ln[1 - p(D)]$	H_t	$(d')^2$	d'	$-\ln \eta$
K. D.	50–50	.749	.856	.885	.850	.859
	70–30	.943	.942	.905	.942	.939
	Combined	.812	.872	.865	.870	.873
J. L.	50–50	.920	.942	.927	.952	.951
	70–30	.942	.905	.944	.912	.924
	Combined	.923	.908	.927	.938	.937
L. S.	50–50	.742	.897	.920	.915	.915
	70–30	.991	.953	.980	.982	.987
	Combined	.735	.838	.950	.944	.951
B. V.	50–50	.954	.966	.986	.972	.963
	70–30	.959	.981	.957	.942	.943
	Combined	.955	.952	.872	.941	.920
Average	50–50	.841	.915	.930	.922	.922
	70–30	.959	.945	.946	.952	.948
	Combined	.856	.892	.904	.923	.920

thus fitted to slightly differing numbers of points for the five accuracy measures.

The results of this analysis are given in Tables 1 and 2 and Fig. 1. Table 1 gives the slopes, m, and intercepts, k, of the lines $A = m(RT - k)$, describing the trade-off between speed and accuracy for each of the five accuracy measures under the two stimulus probability conditions for each *S*. Table 2 gives the proportion of variance in discrimination accuracy that is accounted for by each set of regression lines. A graphic portrayal of the relation between RT and d' is given in Fig. 1. As these results show, a strong and consistent correlation between speed and accuracy was obtained for each *S* and experimental condition.

One of the primary questions to which these results are relevant concerns the description of the functional relation between speed and accuracy. As shown in Table 2, each of the five proposed measures of discrimination accuracy provides a good linear fit to the obtained data. Although the two measures from the additive model, d' and $-\ln\eta$, account on the average for the greatest proportion of variance in discrimination accuracy, the superiority is clearly too slight and too inconsistent to warrant an acceptance of the associated model in favor of the other three alternatives. Although there are good indications of nonlinearity in the sequence of $(d')^2$ values in the combined data of *S*s, J. L. and B. V., the same trends are not found in the data of the other two *S*s. Despite the clear algebraic distinction between the d' and $(d')^2$ measures, more data will be required in order to decisively choose between the two models. More convincing evidence can be found that is contrary to the information transmission model, based on a tendency for less information to be transmitted in the 70–30 than in 50–50 condition at a given RT. This evidence is examined in more detail below.

A second major question about these data concerns the comparison of performance in the 50–50 and 70–30 conditions. According to the information transmission model, the LOC, as determined with the H_t measure of discrimination, should be the same for the two conditions; correspondingly, $-\ln\eta$, d', and $p(D)$ should be higher under the 70–30 than the 50–50 condition. Inspection of the data in Table 1 and Fig. 1 suggests, however, that the LOCs for the latter measures were invariant under the two experimental conditions, but poorer in the 70–30 condition by the H_t measure. This was examined in more detail by comparing the various measures in each successive 10-msec. band of RT from 151 to 250 msec. There were 10 such comparisons for each of the four *S*s, with some reductions due to ties. In 28 of the 40 comparisons, H_t was greater in the 50–50 than the 70–30 condition. This number is significantly greater than the expected value of 20 under the binomial distribution at $p < .01$. The comparable values for the measures $-\log\eta$, d', and p(D), respectively, were 22/37, 21/36, and 24/39; the significance level is $p > .10$ for the first two values, and $.10 > p > .05$ for the third value. Thus, when the LOC is determined with the choice theory, signal detection, and two-state measures of discrimination, variation in stimulus probability seems to have had very little effect on the speed of discrimination, contrary to the information transmission model.

The invariance of the LOC under changes in stimulus probability does not imply that *S*s behaved identically in the two conditions. Just as in previous studies of the effect of stimulus probability on RT, *S*s did respond more rapidly and with fewer errors in the 70–30 condition, where the stimulus position could be more accurately predicted. This result is shown in Table 3.

Dissussion

The principal concern of this experiment is the potential of the LOC as a measure for extracting an invariant perceptual process from RT data influenced by varying response strategies. The main test for this invariance is provided by the manipulation of stimulus

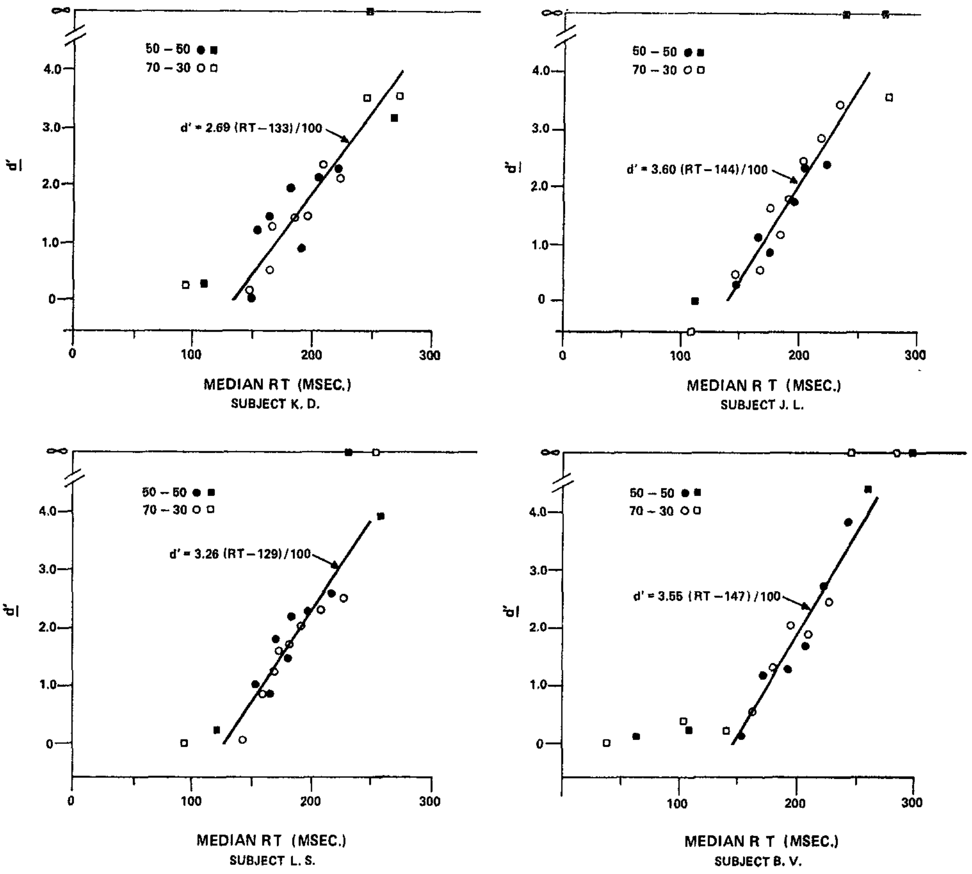

FIG. 1. The LOC functions for each *S* and experimental condition. (The lines described by the above equations were fitted to the circular data points.)

TABLE 3

Means and Standard Deviations of Distribution of Correct and Error Responses and Percentage of Errors for Each Subject and Condition

Type of response	*S*s and Cond.							
	K. D.		J. L.		L. S.		B. V.	
	50–50	70–30	50–50	70–30	50–50	70–30	50–50	70–30
Mean RT								
Correct	201	198	201	201	193	184	207	190
Error	161	167	163	159	158	157	142	137
SD								
Correct	49	52	49	53	43	48	68	68
Error	56	64	52	58	47	50	74	73
% errors	21.9	18.5	23.1	20.8	19.3	19.3	23.1	22.2

probability, and the outcome is encouraging. When one of the two stimuli was more probable, the response assigned to that stimulus was made more frequently and more rapidly, but the LOC was found to remain approximately unchanged under two levels of stimulus probability. The LOC thus appears to remove certain effects of response bias from the measure of performance in this task.

The results of this experiment indicate that the overall mean RT and error rate may be insufficient measures for distinguishing perceptual from decisional factors in RT. The extent of the influence of decisional processes in RT tasks is as yet uncertain, however. Blake, Fox, and Lappin (1970) failed to find any indication of such effects in a more complex task requiring the classification of letter pairs. A basic question may nevertheless be raised about the nature of the processes determining the distribution of RTs in error-free conditions. Some of the studies relying on the mean RT and error rate in investigating the effect of stimulus probability in particular are suspect.

What is the effect of stimulus probability? Is there really no effect on the speed of perceptual processing, but only on the speed and biasing of overt responses? For the specific task used in this experiment, stimulus probability does appear to have no effect on the underlying perceptual discrimination. (Possible superior performance for the more probable of a pair of alternative stimuli cannot be distinguished by the present analysis from the effects of the marginal response probabilities.) We must emphasize, however, that an important aspect of this task is the high degree of compatibility between stimuli and responses. Fitts (1964) has previously reported that the magnitude of the stimulus probability effect may be quite small under conditions of high stimulus–response compatibility. Yellott (1971) has also recently found little or no effect of stimulus probability on the LOC as measured with his fast-guess model. We are confident though from other work in our laboratory that the LOC is sensitive to variations in stimulus probability under conditions of lower stimulus–response compatibility, e.g., in the Sternberg (1966) memory search paradigm. The implication seems to be that stimulus probability has its effect at higher, more abstract, levels of perceptual processing.

The results of this experiment impose important constraints upon viable models of the temporal process underlying the acquisition of perceptual information. The two salient features of the four models discussed above are (*a*) homogeneity and (*b*) stochastic independence. These two strong postulates appear to be consistent with the data, although subtle departures from the theories would be hard to detect. *A simple and adequate*, though not unique, description of the process is provided by the additive models described above: that the strength of the perceptual signal increases linearly with time and that *S* selects his response at any given time according to the relative strengths of the signals associated with the two stimulus alternatives at that time.

Considerably more evidence on the validity of the LOC will be required in order to determine when the extra experimental effort should be invested in estimation of LOC parameters for the analysis of human information processing.

REFERENCES

BARTZ, A. E. Reaction time as a function of stimulus uncertainty on a single trial. *Perception & Psychophysics*, 1971, 9, 95–96.

BERNSTEIN, I. H., SCHURMAN, D. L., & FORESTER, G. Choice reaction time as a function of stimulus uncertainty, response uncertainty, and behavioral hypotheses. *Journal of Experimental Psychology*, 1967, **74**, 517–524.

BLAKE, R. R., FOX, R., & LAPPIN, J. S. Invariance in the reaction time classification of same and different letter pairs. *Journal of Experimental Psychology*, 1970, **85**, 133–137.

BOGARTZ, R. S. A least-squares method for fitting intercepting line segments to a set of data points. *Psychological Bulletin*, 1968, **70**, 749–755.

DILLON, P. J. Stimulus versus response decisions as determinants of relative frequency effect in disjunctive reaction time performance. *Journal of Experimental Psychology*, 1966, **71**, 321–330.

EDWARDS, W. Optimal strategies for seeking information: Models for statistics, choice reaction times, and human information processing. *Journal of Mathematical Psychology*, 1965, **2**, 312–329.

FITTS, P. M. Perceptual-motor skill learning. In A. W. Melton (Ed.), *Categories of human learning*. New York: Academic Press, 1964.

GREEN, D. M., & SWETS, J. *Signal detection theory and psychophysics*. New York: Wiley, 1966.

GRICE, G. R. Stimulus intensity and response evocation. *Psychological Review*, 1968, **75**, 359–373.

HINRICHS, J. V. Probability and expectancy in two-choice reaction time. *Psychonomic Science*, 1970, **21**, 227–228.

HYMAN, R. Stimulus information as a determinant of reaction time. *Journal of Experimental Psychology*, 1953, **45**, 188–196.

LABERGE, D., LEGRANDE, R., & HOBBIE, R. K. Functional identification of perceptual and response bias in choice reaction time. *Journal of Experimental Psychology*, 1969, **79**, 295–299.

LAMING, D. R. J. *Information theory of choice-reaction times*. New York: Academic Press, 1968.

LUCE, R. D. Detection and recognition. In R. D. Luce et al. (Eds.), *Handbook of mathematical psychology*. Vol. I. New York: Wiley, 1963.

PACHELLA, R. G., Fisher, D. F., & Karsh, R. Absolute judgments in speeded tasks: Quantification of the tradeoff between speed and accuracy. *Psychonomic Science*, 1968, **12**, 225–226.

PEW, R. W. The speed-accuracy operating characteristics. In W. G. Koster (Ed.), *Attention and performance, II*. Amsterdam: North-Holland, 1969.

SCHULMAN, A. I., & GREENBERG, G. Z. Operating characteristics and a priori probability of the signal. *Perception & Psychophysics*, 1970, **8**, 317–320.

SHOUTEN, J. F., & BEKKER, J. A. M. Reaction time and accuracy. In A. F. Sanders (Ed.), *Attention and performance*. Amsterdam: North-Holland, 1967.

STERNBERG, S. High-speed scanning in human memory. *Science*, 1966, **153**, 652–654.

SWANSON, J. M., & BRIGGS, G. E. Information processing as a function of speed versus accuracy. *Journal of Experimental Psychology*, 1969, **81**, 223–229.

TAYLOR, M. M., LINDSAY, P. H., & FORBES, S. M. Quantification of shared capacity processing in auditory and visual discrimination. In A. F. Sanders (Ed.), *Attention and performance*. Amsterdam: North-Holland, 1967.

THOMAS, E. A. C. Sufficient conditions for monotome hazard rate: An application to latency-probability curves. *Journal of Mathematical Psychology*, 1971, **8**, 303–332.

YELLOTT, J. I. Correction for fast guessing and the speed-accuracy tradeoff in choice reaction time. *Journal of Mathematical Psychology*, 1971, **8**, 159–199.

(Received August 14, 1971)