

## RESPONSE BIAS AND THE DISCRIMINATION OF STIMULUS DURATION<sup>1</sup>

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Pigeons discriminated stimulus duration in a psychophysical choice situation. Following presentation of any duration from a set of short durations (11 to 15 sec), responses on a red key were reinforced intermittently. Following presentation of any duration from a set of long durations (16 to 22 sec), responses on a green key were reinforced intermittently. Relative reinforcement rates were manipulated for choice responses across conditions. As relative reinforcement rates were varied, psychometric functions showed shifts in green-key responses at all durations. A signal-detection analysis showed that sensitivity remained roughly constant across conditions while response bias changed as a function of changes in relative reinforcement rate. Relative error rates tended to match relative reinforcement rates.

*Key words:* stimulus duration, signal detection, discrimination, response bias, matching function, concurrent schedules, pigeons

Although signal-detection theory was designed to provide answers to persistent problems in human psychophysics (Green and Swets, 1966; Swets, 1964) applications of the theory and its methodology are proving useful in various research areas. One such area is the study of stimulus control in animals. Several articles have shown how a detection framework may be useful for the conduct and analysis of animal experiments (Boneau and Cole, 1967; Nevin, 1969). And the detection framework has been used with animal experiments involving discrimination (*e.g.*, Hack, 1963; Nevin, 1965), stimulus generalization (*e.g.*, Blough, 1967), and psychophysics (*e.g.*, Irwin and Terman, 1970; Terman, 1970).

The methodology stresses the independent assessment and control of variables that affect sensitivity and response bias. Sensitivity, which refers to changes in performance as a function of changes in a stimulus continuum, is a function of stimulus factors (*e.g.*, Blough, 1967; Clopton, 1972; Irwin and Terman, 1970; Terman, 1970), of the reinforcement contingencies

(Stubbs, 1968), and of other factors (Nevin, 1970; Stubbs, 1968). Response criterion or bias, which refers to the probability of emission of one type of choice response over another, has been manipulated by varying the probability of presentation of the stimuli to be discriminated (*e.g.*, Clopton, 1972; Hack, 1963; Hume, 1974), and by varying the stimulus-response consequences asymmetrically (Hume, 1974; Nevin, 1965, 1970; Stubbs, 1968).

The present experiment is similar to the studies of Hume, Nevin, and Stubbs in that the stimulus-response consequences were manipulated to change response bias. The stimulus-response consequences were changed by varying the relative reinforcement rate for different choice responses. Since relative reinforcement rate is also a variable of interest in probability matching experiments (Graf, Bullock, and Bitterman, 1964; Shimp, 1966) and studies of concurrent schedules (Catania, 1966; Herrnstein, 1961), the present study was designed to make contact with these areas (*cf.* Atkinson, Bower, and Crothers, 1965).

### METHOD

#### *Subjects*

Three male White Carneaux pigeons, maintained at approximately 80% of their free-feeding weights, had experimental histories including a year's training on experiments in-

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volving discrimination of stimulus duration (Stubbs and Thomas, 1974).

### Apparatus

The experimental chamber was a Lehigh Valley Electronics pigeon chamber (LVE Model 1318C), modified by adding a third key between the two normally mounted. Each key could be transilluminated from a light source (LVE Model 1349 QL). The chamber was located in a darkened room. White noise was present both in the chamber and in the room. Switching relays and timers scheduled sessions. Data were recorded on electromagnetic counters.

### Procedure

Daily sessions lasted until a pigeon had produced 40 food presentations. On each trial of a psychophysical choice procedure, the center key was initially lit by orange light while the side keys were dark. One response on the center key changed the key color from orange to white. The white light remained on for one of 10 predetermined durations: 11, 12, 13, 14, 15, 16, 17, 18, 20, or 22 sec. The durations varied nonsystematically from trial to trial, each duration occurring equally often. At the end of the duration, the center-key light went off and two side keys went on; this change in stimuli occurred independently of behavior. The colors assigned to the side keys, one red and one green, alternated nonsystematically over trials. The consequences of side-key responses depended on the duration of the white light. After durations of 11, 12, 13, 14, or 15 sec (short durations), a response on the red key was "correct"; after durations of 16, 17, 18, 20, and 22 sec (long durations), a response on the green key was "correct". The durations were selected so that for each short duration there was a long duration of approximately equal logarithmic distance from the cutoff, 15.5 sec: thus, 11 approximately equalled 22; 12 approximately equalled 20, *etc.* (*cf.* Stubbs, 1968). Correct responses produced either a 0.5-sec food-magazine light or 4-sec access to grain; in either case, all lights except the magazine light were dark. Food was delivered intermittently according to a modified variable-ratio schedule, detailed below. Nonreinforced or "incorrect" responses produced a 7.5-sec

timeout, during which all chamber lights were off and responses had no scheduled consequences. After either food, magazine light, or timeout, a new trial began. A noncorrection procedure was used: the sequence of stimulus durations was not affected by the accuracy of choice responses. The chamber was lit by a houselight except during food, magazine light, and timeout periods.

Correct choice responses produced food subject to two restrictions. First, a variable-ratio (VR 4) schedule of reinforcement was in effect: the pigeons had to respond correctly to several durations—four on the average—before food was available. Each correct response counted toward completion of the ratio. Second, the specific choice response (a green-key response following a long duration or a red-key response following a short) that produced food was predetermined by a stepping switch and was changed nonsystematically from reinforcement to reinforcement. It was thus possible to specify the relative rate of reinforcement for each choice response and hold this relative rate constant (Stubbs and Pliskoff, 1969). Until the ratio was completed and then the preselected choice response emitted, all correct choice responses simply produced the magazine stimulus. If food was available and the animal made an error, then several problems might intervene before one where food could be produced. Thus, the actual number of problems before food typically exceeded the average ratio value of four. Table 1 presents the number of problems completed in various conditions. Interested readers may calculate the obtained number of problems per reinforcer.

The relative reinforcement rate was varied across conditions by varying the number of food presentations for green-key and red-key responses. Relative reinforcement rates, computed with respect to green-key responses, were in order 0.50, 0.75, 0.25, 0.125, 0.875, and 1.00. When the relative reinforcement rate was 0.50, 20 food presentations were produced by green-key responses and 20 by red-key responses; when the relative reinforcement rate was 0.75, 30 food presentations were produced by green-key responses, 10 by red-key responses, *etc.* The number of sessions under each condition was determined visually; conditions were changed when no systematic trends were evident in the data for at least seven sessions.

RESULTS

Figure 1 shows psychometric functions relating choice behavior to stimulus duration. Figure 1 shows the probability of a "long" or green-key response as a function of stimulus duration. Green-key probability was calculated by dividing the number of green-key responses by the total number of responses emitted at each duration. Green-key responses were incorrect at the short durations, 11 to 15 sec, since red-key responses were reinforced at these durations; green-key responses were correct (*i.e.*, reinforced) given long durations, 16 to 22 sec. Durations are plotted on a logarithmic axis (Stubbs, 1968). Probability of a long response is plotted on a normal probability axis because such an axis tends to convert ogival functions into straight-line functions (Guilford, 1954). The data are medians of the last seven sessions under each condition.

Figure 1 shows that the psychometric functions are approximately parallel straight lines, with exceptions at the relative reinforcement rate of 1.0 for all pigeons and at 0.875 for Pigeon 2. As relative reinforcement rate changed, probability of long responses changed at all durations. When green-key reinforcers increased, green-key responses increased at all durations; when green-key reinforcers decreased, green-key responses decreased.

The degree of steepness of a psychometric function indicates the degree of sensitivity of performance. Sensitivity refers to a change in

behavior as a function of changes along a stimulus dimension. Steeper functions indicate a greater change in response probability across a stimulus dimension. That the obtained functions are roughly parallel and equally steep indicates that sensitivity remained constant across conditions. The change in functions would indicate a change in response bias. Questions related to choice sensitivity and response bias can be handled more easily perhaps within the framework of signal-detection methodology. Accordingly, Figure 2 replots the data within this framework.

The top section of Figure 2 shows ROC-type plots of the conditional probabilities of green-key responses given a long duration and green-key responses given short durations. Probability of a green-key response given a long duration was calculated by dividing the number of green-key responses given durations of 16 to 22 sec by the total number of responses at these durations. Probability of a green-key response given a short duration was calculated by dividing green-key responses given durations of 11 to 15 sec by the total number of responses at these durations. The probabilities are analogous to the correct detection and false-alarm probabilities of signal-detection plots. The data are medians of the last seven sessions for each condition.

Figure 2 shows that both probability measures increased as the relative reinforcement rate increased for green-key responses: the higher the relative reinforcement rate, the

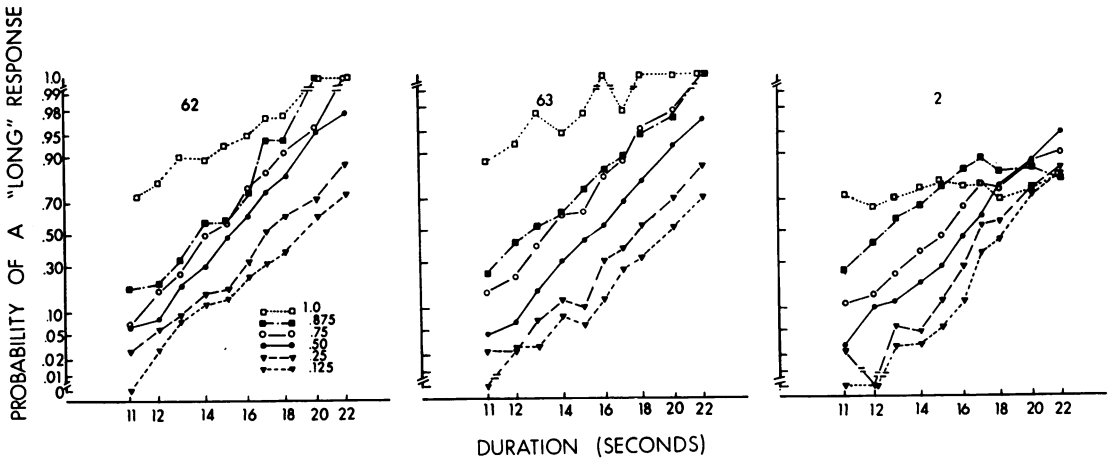


Fig. 1. The probability of a green-key or long response as a function of stimulus duration. Durations are ordered along a logarithmic coordinate; the probability of a long response is ordered along a normal probability coordinate. The different functions show performance as a function of different relative rates of reinforcement for responses.

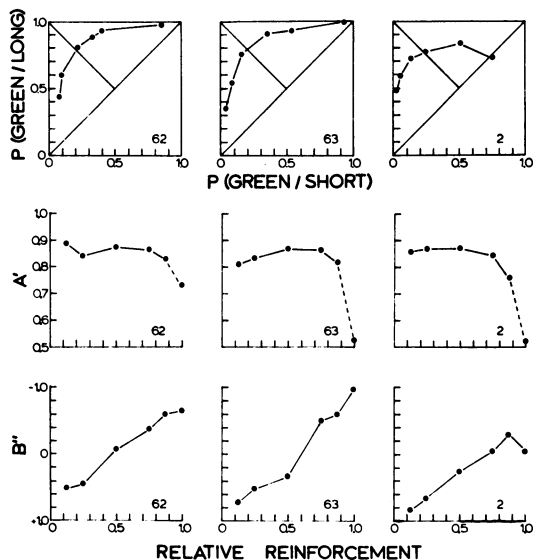


Fig. 2. Top portion: ROC type plots showing the probability of a green-key response given long and given short durations. Middle portion:  $A'$  measures, a nonparametric index of sensitivity as a function of relative reinforcement rate. Bottom portion:  $B''$  measures, a nonparametric index of response bias, as a function of relative reinforcement rate. All points are medians of the last seven sessions.

higher the probability of a green-key response, given both short and long durations. Both probability measures increased in every case except one (Pigeon 2 at the relative reinforcement rate of 1.0). Pigeons 62 and 63 showed similar performance: with a relative reinforcement rate of 0.50, the points were close to the northwest diagonal; with higher relative reinforcement rates, the points lay above the line, with lower rates below. Pigeon 2 deviated from this pattern, emitting fewer green-key responses than the other birds across all conditions. The lines between points indicate a curvilinear relation between choice behavior and relative reinforcement rate. Such a relation is common in signal-detection research and indicates that sensitivity remained constant while response bias changed, at least for Pigeons 62 and 63.

The bottom two sections of Figure 2 show  $A'$ , a nonparametric index of sensitivity, and  $B''$ , a nonparametric index of bias. The measures were computed from the formulas given by Grier (1971). Figure 2 shows that  $A'$  remained roughly constant across conditions except when the relative reinforcement rate was 1.0. The rough similarity of  $A'$  across

conditions indicates that sensitivity remained roughly constant while response bias changed. In contrast,  $B''$  showed changes that were related to changes in relative reinforcement rate. The changes indicate a shift in response bias as a function of changes in relative reinforcement rate.

Figure 2 shows median data for the last seven sessions. Table 1 shows summary data totalled across the last seven sessions. The data are raw data totals. Calculations based on the table would show similar results to those of the medians shown in Figure 2. Table 1 shows that both the total number of responses and total number of correct responses varied somewhat across conditions. The numbers change for two reasons. First, the total number increased as errors increased. Second, the number of correct problems increased due to the way food was scheduled. Once the ratio requirement was met, only one preselected response would produce food (e.g., a green-key response given a long duration). Given such a problem, if the animal made an incorrect response, a series of other problems might intervene (e.g., three short-duration stimuli) before food could be produced. Under some conditions, the pattern of errors increased the number of problems per reinforcer. When, for example, the relative reinforcement rate was 0.50, incorrect responses resulted in extra problems occurring before the next reinforcer. Under other conditions, errors occurred, but typically reinforcers were obtained when first available. When, for example, the relative reinforcement rate was 1.0, the subjects emitted most responses on the green key; thus, errors occurred, but when a reinforcer was available, the animals would virtually always emit the appropriate green-key response and never "miss" the reinforcer.

Figure 3 shows the relation between two relative performance measures and relative reinforcement rate. The upper half shows green-key (long response) probability as a function of relative reinforcement rate. Green-key probability was calculated by dividing green-key responses for all durations combined by the total number of choice responses. Figure 3 shows that green-key probability increased as a function of relative reinforcement rate. The diagonal lines represent the matching lines where green-key probability equals the relative reinforcement rate. When, for example, the relative reinforcement rate was 0.75, a

Table 1

Total number of responses across the last seven sessions of each condition. The four choice responses are (1) red-key (short) responses given short durations (11 to 15 sec); (2) green-key (long) responses given short durations; (3) green-key responses given long durations (16 to 22 sec); and (4) red-key responses given long durations.

Pigeon	Condition (relative rein- forcement rate)	Red/Short	Green/Short	Green/Long	Red/Long
62	0.50	1229	372	1296	295
	0.75	1071	481	1375	164
	0.25	1363	161	939	597
	0.125	1094	91	547	654
	0.875	683	436	1045	86
	1.0	195	1033	1195	37
63	0.50	1300	303	1234	373
	0.75	949	602	1390	154
	0.25	1520	145	878	794
	0.125	1135	49	441	737
	0.875	606	633	1133	107
	1.0	101	1197	1291	14
2	0.50	1356	229	1172	414
	0.75	1178	440	1228	403
	0.25	1441	90	916	616
	0.125	1097	29	542	581
	0.875	612	679	1072	209
	1.0	390	1015	1073	313

point on the line would indicate that green-key probability also was 0.75. The points, while showing an increasing function, do not indicate a matching relation for any subject.

The bottom half of Figure 3 shows the relative error rate as a function of relative reinforcement rate. Relative error rate was calculated as follows:

$$\frac{\frac{\text{green-key response}}{\text{durations 11 to 15 sec}}}{\frac{\text{green-key responses}}{\text{durations 11 to 15 sec}} + \frac{\text{red-key responses}}{\text{durations 16 to 22 sec}}}$$

The measure indicates the probability of an error being an incorrect response to the green key. The data indicate that the relative error rate matched relative reinforcement rate, at least for Pigeons 62 and 63. When, for example, 75% of the reinforcers were delivered for green-key responses, approximately 75% of the errors were incorrect responses on the green key. Relative error rate for Pigeon 2 was consistently lower than the corresponding relative reinforcement rate across all conditions. Divergence from matching was roughly constant across conditions, except when the relative reinforcement rate was 1.0. The points approximate the dashed line that is parallel to the matching diagonal. The data for Pigeon

2 are consistent with the data of Figures 1 and 2 showing a tendency to respond to the red key across conditions. The divergence from matching is like that observed for some subjects in research on concurrent schedules (Baum, 1974).

DISCUSSION

Pigeons discriminated stimulus duration, with performance similar to that observed in prior experiments (Stubbs, 1968; Stubbs and Thomas, 1974). The experiment adds to pre-

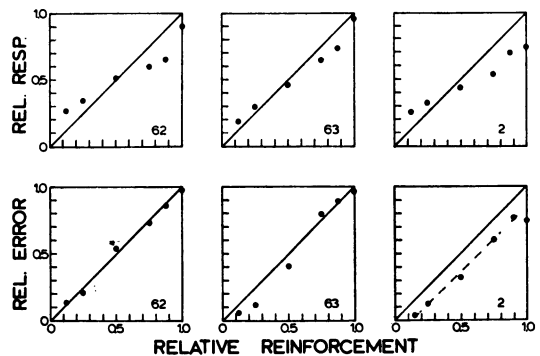


Fig. 3. Relative response rate (top) and relative error rate as a function of relative reinforcement rates. All points are medians of the last seven sessions.

vious results through a more complete manipulation of response bias. Relative reinforcement rate was varied in the present study and the effects on sensitivity and response bias were assessed. Response bias changed as a function of relative reinforcement rate while sensitivity remained relatively constant.

The experiment combined features of both traditional and detection psychophysical procedures. The basic method was the method of single stimuli (Wever and Zener, 1928), allowing for the production of psychometric functions for each condition. The use of stimulus-response consequences and the explicit manipulation of relative reinforcement rate came from signal-detection methodology and allowed the results to be compared to detection research. The traditional and signal-detection aspects of the procedure are complementary and point to the same conclusions: (1) The similar slopes of the psychometric functions on the one hand and the ROC plots and  $A'$  measures on the other, all indicate that sensitivity remained roughly constant across conditions except when the relative reinforcement rate was 1.0; (2) The raising and lowering of the functions and the changing ROC plots and  $B''$  measures all indicate a change in response bias across conditions.

Use of the method of single stimuli produces a difference between the present experiment and most animal signal-detection experiments. In most experiments, typically only two stimuli are used, one as "signal" the other as "noise" (see, however, Nevin, 1970). The particular stimuli may vary across conditions so that sensitivity can be assessed as a function of stimulus difference (*e.g.*, Hume and Irwin, 1974). In contrast, 10 stimuli were used in the present experiment; the procedure treated a distribution of five stimuli as "signal" and five as "noise". Use of stimulus distributions as "signal" and "noise" has a disadvantage: parametric measures of sensitivity and response bias cannot be used (Pastore and Scheirer, 1974). However, use of several stimuli provides some advantages. For example, performance to many stimuli can be assessed within a single session; this aspect of the procedure may be useful for some manipulations, such as the study of drug effects on performance (*e.g.*, Stubbs and Thomas, 1974). Additionally, when only two stimuli are used and choice accuracy is low, position habits may become prevalent

and interfere with the assessment of stimulus control (Blough, 1971). Use of many stimuli so that choice accuracy remains high can prevent such patterns of responding from developing (see Blough, 1971; Irwin and Terman, 1970, for discussions).

Figure 3 was constructed to see whether matching relations held between relative reinforcement rate and two performance measures: relative response rate and relative error rate. A relation between relative reinforcement and responses would indicate that the relative number of green-key (long) responses matched the relative number of reinforcers for that response class. This relation has been suggested previously (Nevin, 1969; Thomas and Legge, 1970). Figure 3 shows that such a relation did not occur. The failure of matching is probably related to the accuracy level. Nevin pointed out that matching of this sort will hold only if choice accuracy is near 50%. When accuracy is high, relative response rate will tend toward 0.50, given equal presentations of signal and noise stimuli. If, for example, accuracy is 90%, the subject would necessarily respond correctly on most trials, thus making approximately equal numbers of either choice response.

Figure 3 shows that relative error rate tended to match relative reinforcement rate. Relative error rate, in contrast to relative response rate, can show matching across a wide variety of accuracy levels. If, for example, accuracy is 90% and there are 100 presentations each of signal and noise stimuli, 75% of the reinforcers might be delivered for one response. The subject could maintain 90% accuracy and have the following pattern of errors: five of one type, 15 of the other. Thus, the relative error rate would be 0.75 (*i.e.*,  $15/(15 + 5)$ ). Since it is not dependent on accuracy level, relative error rate seems to provide a useful index of degree of response bias, as well as a measure relating performance to consequences.

The matching relation observed here makes contact with probability-matching and concurrent-schedule research. The matching principle has gained widespread attention in animal research and has been proposed as a basic principle governing the relation of behavior and its consequences (*e.g.*, Herrnstein, 1970). The present data indicate that the matching principle extends beyond basic schedule per-

formance and plays a role in complex discrimination performance.

That the matching principle extends to this research provides no mystery. In some ways, the different procedures have common features. It is easy in a few steps to transform the present procedure into a standard concurrent procedure. First, one could change stimuli such that short and long durations were indiscriminable. Since performance would be at "chance", a distinction between corrects and errors would be trivial; responses presumably would simply match relative reinforcement rate. Next, the center-key stimuli and responses could be removed because they have no discriminable effects; the animals would simply emit choice responses from trial to trial. Here, the situation is the same as a probability matching procedure. Finally, the trials aspect could be removed: the side keys could remain on and the subject could respond at any time; the procedure would now be a free-operant concurrent schedule.

While the results indicate a matching relation, it is difficult to tell how general such a matching relation might be. Dusoïr (1975) reviewed various models of response bias dealing with human performance. He indicated that many ways have been suggested to relate bias to payoffs and stimulus probability. Different experiments have produced different and seemingly contradictory evidence. No one model, according to Dusoïr, has an edge at explaining the existing results. The literature with humans suggests that statements about response bias may be limited or may be a function of the various procedural differences between different experiments. In addition, other research and formulations with animals suggest that the present matching relation may not hold in all cases (Hodos, 1970; Hume, 1974). For example, Hodos has developed a quantitative, nonparametric index of response bias. According to his model, the subject would make relatively more errors of one sort as accuracy declines, reaching a limit as accuracy approaches 0.5 when virtually all errors are of this type. My account suggests that relative error rate would match relative reinforcement across various accuracy levels. The Hodos model suggests that relative error rate would increase as accuracy nears 0.50. Research is necessary to decide the conditions under which these alternate formulations support the data.

A procedural point is instructive and perhaps will be crucial for the results of future research. This point concerns the method used here to hold relative reinforcement rate constant. Reinforcers were scheduled such that the relative reinforcement rate was fixed at a particular value (e.g., 0.75). Changes in response bias, no matter how extreme, could not change the relative distribution of reinforcers. In contrast, other experimenters have not fixed the relative amount or rate of reinforcement (e.g., Hume, 1974). For example, an experimenter might schedule one choice response to produce food according to one schedule and a second response to produce food according to a separate independent schedule; the scheduled relative reinforcement rate might be 0.75 (e.g., if the schedules are FR 4 FR 12, VR 10 VR 30, etc.). However, should biased responding develop and the animal respond almost exclusively on one key, then the obtained relative reinforcement rate would diverge from 0.75. In an extreme case where 99% of the responses occurred on one key, the obtained relative reinforcement rate might also approximate 0.99. Where response biases develop and influence relative reinforcement rate, the reinforcers could further increase bias. Lowered accuracy probably produces conditions favoring increased bias (e.g., Blough, 1971). Future research must consider not just the relation of response bias to scheduled reinforcement rate but the interactive relation between scheduled and obtained consequences and response bias (see Stubbs and Pliskoff, 1969 for a similar discussion with regard to concurrent schedules).

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