JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1979, 31, 15-22 NUMBER 1 (JANUARY)

# *REINFORCEMENT CONTINGENCIES AS DISCRIMINATIVE STIMULI: II. EFFECTS OF CHANGES IN STIMULUS PROBABILITY*

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Three pigeons were trained on a matching procedure involving a sample component and a choice component. Responding in the sample component, according to either a differential-reinforcement-of-low-rate schedule on some trials or a differential-reinforcement-of-other-behavior schedule on other trials, produced access to the choice component in which each of two keys was illuminated with a unique color. The correct choice response was defined by the contingency that was met to produce the choice. The food hopper operated for 1.5 seconds following an appropriate sample response and for 3 seconds following a correct choice response. A signal-detection analysis showed that variations in the probability of presentation of the different contingencies systematically affected response bias but not sensitivity to the contingencies as stimuli. Substitution of a blackout for food at the end of the sample component did not differentially affect performance, but elimination of the delay between sample and choice components generally increased the sensitivity measure. The findings suggest a role for reinforcement contingency discrimination in schedule-controlled responding.

*Key words:* discrimination, matching procedure, signal detection, stimulus probability, response bias, mixed schedule, key peck, pigeons

Reinforcement contingencies have been found to exert discriminative control over behavior. Rilling and McDiarmid (1965), Pliskoff and Goldiamond (1966), and Hobson (1975) used psychophysical choice techniques based on the matching-to-sample procedure described by Skinner (1950) to demonstrate the discrimination of different values of fixed-ratio (FR) schedules by pigeons. Components of reinforcement contingencies other than response number also can be discriminated. The passage of time, different frequencies of reinforcement, and different response-reinforcer relationships have been shown to control choice responses in conditional discrimination experiments (*e.g.*, Commons, 1973; Lattal, 1975; Stubbs, 1976).

Signal-detection theory (Green and Swets, 1966) provides a useful model for analyzing the discriminative properties of a variety of events with animals, including reinforcement contingencies. Signal-detection theory assumes that discrimination performance is determined jointly by variables that affect the discriminability of, or sensitivity to, the stimulus and those that affect the subject's criterion, or response bias, for reporting the presence of a stimulus. Discriminability is affected by such variables as the physical parameters of the stimulus and level of background noise, and response bias is affected by such variables as the probability of presentation of each of the possible stimuli and relative reinforcement frequency of the available responses. Receiver-operating-characteristic (ROC), or isosensitivity curves yield data that can be analyzed to isolate the effects of such variables on response bias and discriminability. A number of studies have shown these two processes to be independent of one another. For example, Rilling and McDiarmid (1965) found relatively constant response bias and systematic changes in discriminability as a function of changes in the magnitude of the difference between two FR requirements. In other experiments, the reinforcement rate for the choice alternatives (Nevin, 1970; Stubbs, 1976) and the probability of stimulus presentation on a trial (Elsmore, 1972) affected response bias but not the

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[1] This research and the manuscript preparation were supported by a NIMH postdoctoral fellowship to the author at the University of California, San Diego, and a faculty research grant from West Virginia University. I thank G. S. Reynolds for providing the facilities and equipment used in this experiment, Katie Keaton for help with the data analysis, Barry Edelstein for a review of an early draft of the paper, and especially J. A. Nevin for numerous helpful suggestions about the data analysis and manuscript. Reprints may be obtained from the author, Department of Psychology, West Virginia University, Morgantown, West Virginia 26506.

discriminability of visual and temporal stimuli.

The present experiment used signal-detection procedures and measures of bias and sensitivity to assess the effects on choice of changes in the probability of occurrence of two different reinforcement contingencies: reinforcement produced by pecking a response key and by not pecking the key. Of particular interest was the relation of the present discrimination performance to behavior controlled by concurrent schedules that arrange response-dependent reinforcement and response-delayed reinforcement.

## METHOD

### *Subjects*

Three White Carneaux pigeons, previously trained on variable-interval schedules of reinforcement, were maintained at 80% of their free-feeding weights.

### *Apparatus*

Three translucent plastic response keys and a grain magazine were located on one wall of an operant conditioning chamber with a work area of 31.0 by 32.0 by 39.5 cm. The keys were located horizontally 9.0 cm apart and 25.5 cm from the floor of the chamber. Each could be operated by a force of approximately 0.14 N. The center key was transilluminated by a yellow stimulus light and the other two keys by red or green stimulus lights. The food magazine, located behind an aperture 14.0 cm below the center key, provided access to mixed grain when illuminated. General chamber illumination was provided by a 7-W bulb. A ventilating fan and white noise masked extraneous noise. Standard electromechanical programming equipment controlled the experiment from an adjacent room.

### *Procedure*

After each bird was trained to peck all three response keys, a conditional discrimination procedure was introduced. Figure 1 shows the five steps in each trial of the procedure. As illustrated in the far-left panel, a trial began with the center key illuminated by a yellow light and the side keys dark. During this sample component, one of two schedules for pecking the yellow center key was in effect. On some trials, a 1.5-sec period of grain presentation was dependent on the absence of key pecking for 10 sec (differential-reinforcement-of-other-behavior (DRO) 10-sec schedule). On other trials, the grain presentation was dependent on the occurrence of a single key peck on the center key after a 10-sec period in which pecking did not occur (differential-reinforcement-of-low-rates (DRL) 10-sec schedule). The yellow light remained illuminated until the appropriate response requirement was met. Thus, a mixed DRL 10-sec DRO 10-sec schedule was in effect in the sample component. At all times other than during the sample component, the center key was dark.

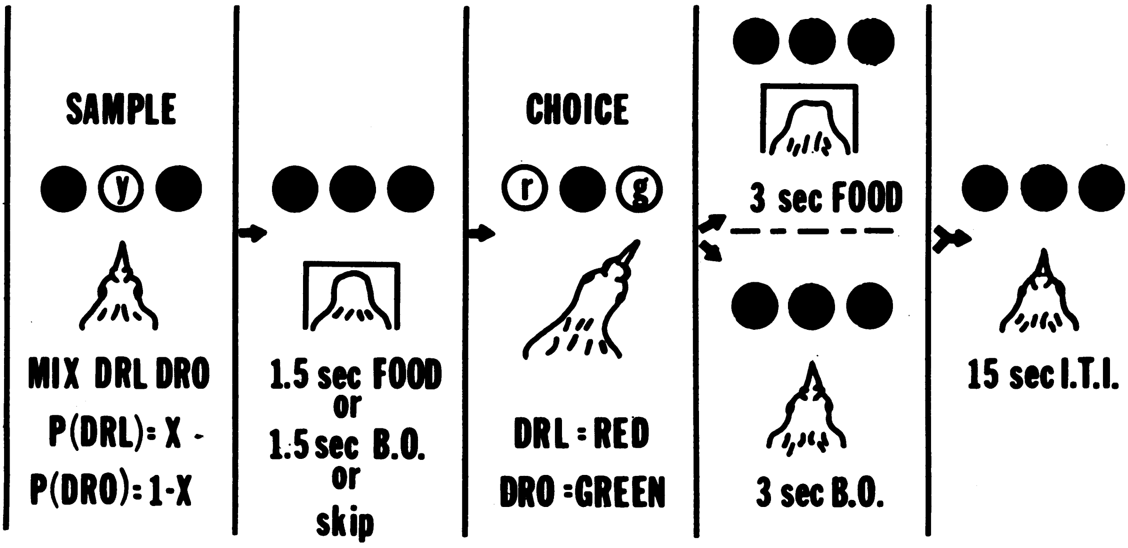

Fig. 1. Schematic diagram of a trial. The sequence of events proceeds from left to right.

After the response in the sample component was reinforced (second panel), the choice component was introduced by simultaneously illuminating the two side keys (third panel). Red and green stimulus lights, presented on the left and right choice keys, randomly alternated on different choice trials. The fourth panel in Figure 1 shows the consequences of the choice responses. If the DRL 10-sec schedule had been in effect in the preceding sample component, a response on the red side key extinguished both keylights and produced 3 sec access to grain. If the DRO 10-sec requirement had been in effect in the preceding sample component, a response on the green key extinguished both lights and produced 3 sec access to grain. Responses on the incorrect choice keys produced a 3-sec blackout (abbreviated "B.O." in the figure). A 15-sec blackout preceded initiation of the sample component for the next trial.

The DRL and DRO schedules were sequenced randomly in the sample component and the sequence was changed at irregular intervals during the experiment. A correction procedure was used in the choice component so that incorrect responses resulted in repetition of the same schedule in the sample component until a correct choice response occurred. Pecks on dark keys had no effect and rarely occurred. Each daily session was terminated after 80 correct choice responses.

The effects of different probabilities of DRL and DRO schedules in the sample component on changes in response bias and sensitivity were examined. The sequence is shown in Table 1. Changes in conditions were made when the session-to-session pattern of choice responses did not vary systematically for at least five sessions. The last two conditions of the experiment were suggested by the finding of Lattal (1975) that the likelihood of correct choice responses was related to the duration of a blackout period between the sample and choice components. In Condition 9, completion of the schedule in the sample component resulted in immediate presentation of the choice component (labelled "skip" in Figure 1). In Condition 10, a 1.5-sec blackout period was substituted for the 1.5-sec access to grain at the end of the sample component.

Table 1

Sequence of experimental conditions and numbers of sessions at each condition.

| *P of DRL in Sample Component* | *Condition* | | *Number of Sessions* | | |
|---|---|---|---|---|---|
| | *Delay Interval and Event between Sample and Choice Component* | | *Bird 120* | *Bird 212* | *Bird 555* |
| 1. 0.50 | 1.5 sec | Food | 32 | 33 | 26 |
| 2. 0.75 | 1.5 sec | Food | 15 | 15 | 15 |
| 3. 0.25 | 1.5 sec | Food | 18 | 17 | 15 |
| 4. 0.00 | 1.5 sec | Food | 5 | 6 | 6 |
| 5. 1.00 | 1.5 sec | Food | 6 | 5 | 5 |
| 6. 0.07 | 1.5 sec | Food | 15 | 15 | 15 |
| 7. 0.93 | 1.5 sec | Food | 24 | 25 | 21 |
| 8. 0.50 | 1.5 sec | Food | 16 | 16 | 16 |
| 9. 0.50 | 0 sec | — | 30 | 19 | 29 |
| 10. 0.50 | 1.5 sec | Blackout | 10 | — | 6 |

## RESULTS

Following signal-detection terminology (*cf.* Rilling and McDiarmid, 1965), the DRL, or peck, contingency in the sample component is labelled a "signal" and the DRO, or pause, contingency in the component is labelled "noise". A peck on the red key in the choice component was a "hit" if the preceding sample component contained the signal (DRL), and a "false alarm" if the preceding sample component contained the noise (DRO).

Figure 2 shows ROC curves for each of the three subjects. Each data point is the average of the last 400 trials (five sessions) at each condition. Functions based on the last five individual sessions were similar to those based on the means of those sessions, but somewhat more variable. Data from the correction trials were not included in the analysis. Displacement of the data points from the positive diagonal (solid line) and the negative diagonal (dashed line) respectively provide indices of sensitivity and response bias. Increasingly greater displacement of data points from the negative diagonal indicates greater control of the choice response by the likelihood of reinforcement of either alternative. From left to right for each bird, the filled, connected data points in the figure indicate the probability of a DRL contingency in the sample component of 0.07, 0.25, 0.50, 0.75, and 0.93. Thus, as the likelihood of the DRL contingency in the sample component increased, the likelihood of both hits and false alarms increased.

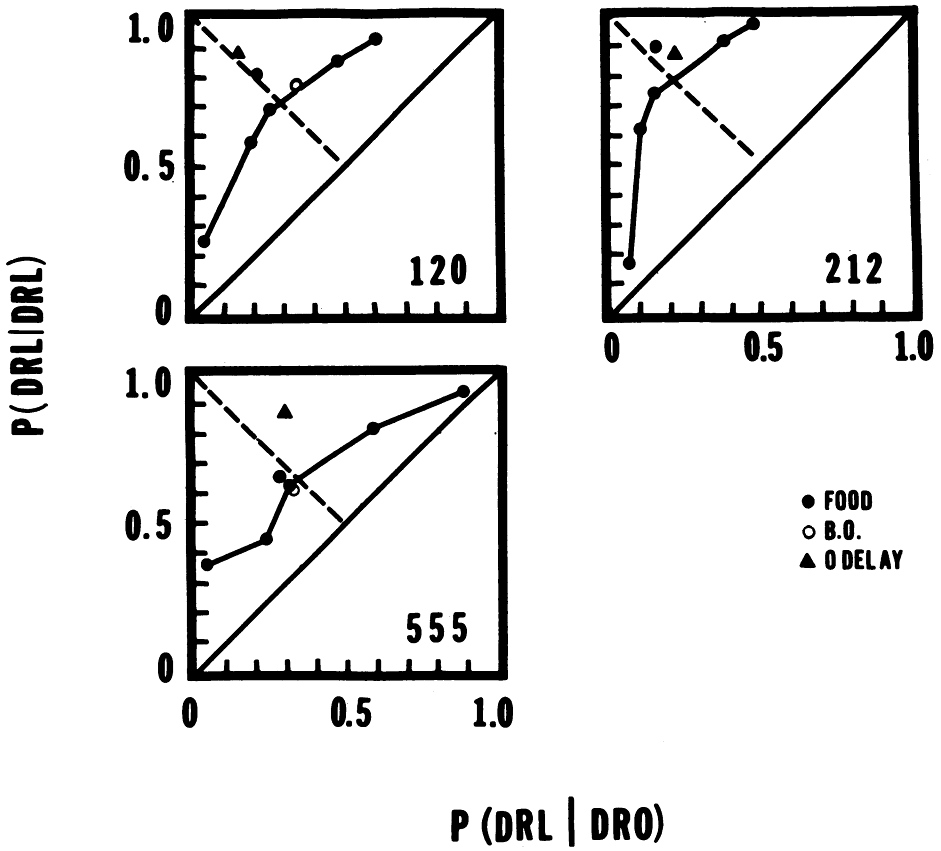

Fig. 2. Isosensitivity (ROC) curves for each subject. Data points represent the probability of a peck on the DRL choice key (red key) given a DRL or a DRO contingency in the sample component (hits and false alarms, respectively) during each condition. All points are the mean of the last five sessions at each condition.

The second exposure to the condition in which p(DRL in the sample component) = 0.50 is shown in Figure 2 by the solid, unconnected circles. For Birds 120 and 212, discrimination performance improved from the first to the second exposure to the p(DRL) = 0.50 condition. Virtually no incorrect choice responses were made during the p(DRL) = 1.00 and p(DRL) = 0.00 conditions. Substitution of the 1.5-sec blackout (open circles) for the 1.5-sec access to food between the sample and choice components did not systematically affect the performance of either Bird 120 or Bird 555, suggesting that the nature of the intervening event was not crucial in determining choice. Omission of the delay between sample and choice components (triangles) generally increased sensitivity, as indicated by the displacement of the data points from the positive diagonal (*cf.* Lattal, 1975).

Figure 3 summarizes analyses of several variables that may have contributed to discriminative performance. Both the passage of time and number of responses (or response rate) can serve as discriminative stimuli and could have affected the present performance (*cf.* Elsmore, 1972; Rilling and McDiarmid, 1965). In general, the mean number of nonreinforced responses, response rates, and component durations per sample component were somewhat greater when the DRL contingency was in the sample component. However, exceptions to these generalizations occurred in several instances without consistently affecting choice performance. Consistent side preferences did not occur, presumably because of the correction procedure.

The top two rows of Figure 4 show two standard measures of discriminability or sensitivity, d′ and A′, derived from the ROC data shown in Figure 2. The parametric index d′ was computed from Swets' (1964) tables, whereas A′ is a nonparametric index computed from Grier's (1971) formulas. There is no con-

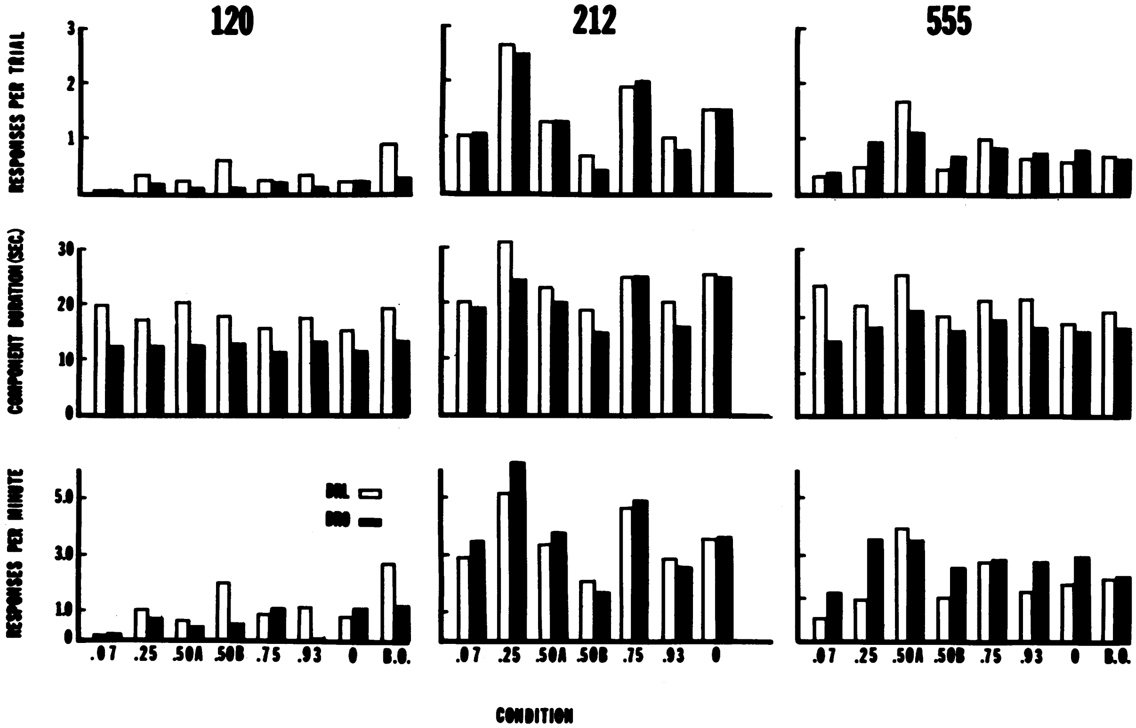

Fig. 3. Mean sample component duration, mean number of nonreinforced responses per sample component, and mean response rate (nonreinforced responses/component duration) for each bird during the last five sessions of each condition for each subject. Conditions 0.50A and 0.50B refer to the first and second exposure to the p(DRL) = 0.50 with 1.5 sec access to food between sample and choice components. Except for the zero-delay condition (0) and the blackout (B.O.) condition, there was a 1.5-sec access to food between the sample and choice components at each p(DRL) condition. Data from the p(DRL) = 0.00 and p(DRL) = 1.00 are not included.

sensus among researchers concerning which index is more appropriate for describing data such as those resported here; both are presented to illustrate that the effects on sensitivity were the same regardless of the index used. According to Green and Swets (1966), nonparametric analyses of ROC data should be used when there is, "little, if any, basis for expecting a particular kind of ROC curve" (p. 345). Nevin (personal communication) suggested that d′ permits the possibility of identifying behavioral variables correlated with asymmetries around the negative diagonal of the types observed with Birds 555 and 212. Figure 4 also shows the mean values for all three birds of d′ and A′ [the p(DRL) = 0.00 and p(DRL) = 1.00 conditions were excluded from this analysis], a conventional way of summarizing the results of signal-detection analysis. Although the means were relatively constant across the different probabilities of signal presentation, there was considerable variability from subject to subject. In the case of Bird 555, both measures of sensitivity tended to decrease with increased signal probability, whereas for Bird 212, the sensitivity measures increased somewhat as the probability of a signal increased. In all three subjects, the discriminability of the two contingencies increased during the second exposure to the p(DRL) = 0.50 condition and during the zero-delay condition (Condition 9).

The third row of Figure 4 shows the extent of response bias as measured by the index, B″ (Grier, 1970). The greater the deviation of B″ from zero, the greater the proportion of choice responses directed toward one of the two keys, with negative values indicating greater choice for the red (DRL) key and positive values, greater choice for the green (DRO) key. It is apparent that bias toward one or the other of the two keys varied systematically as a function of changes in the relative frequency of a signal being presented on a given trial.

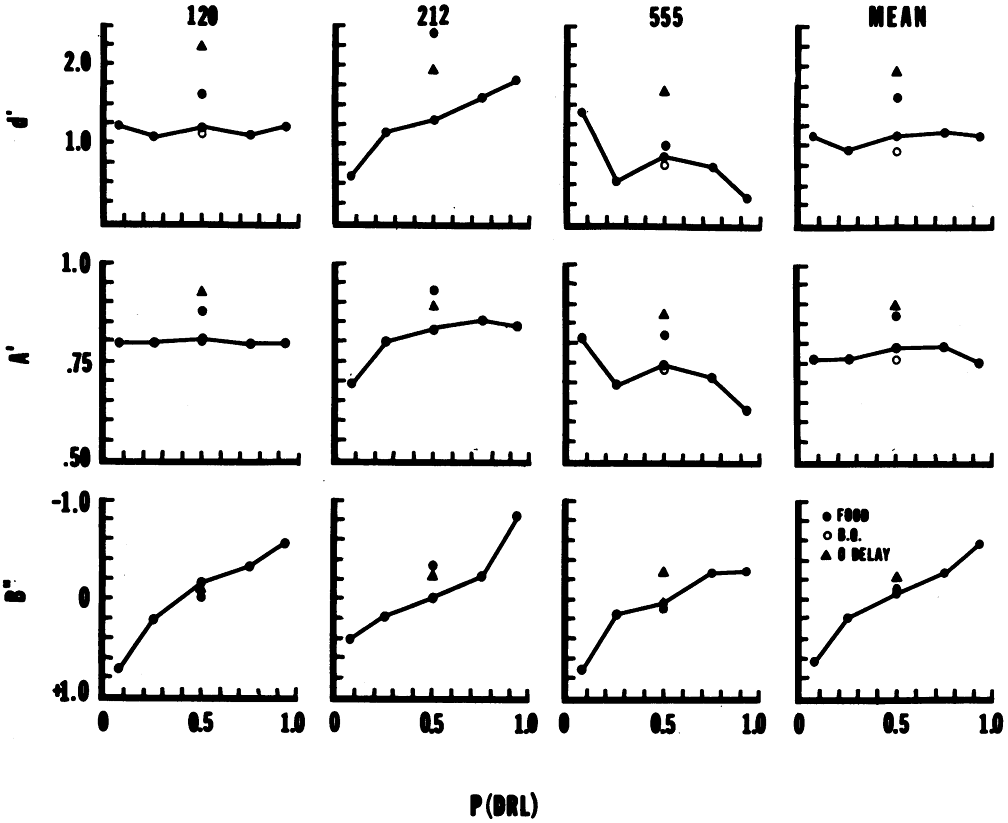

Fig. 4. The indices d', A' and B" as a function of the probability of a DRL contingency during the sample component for each bird. All points are the mean of the last five sessions at each condition. Blackout data points (open circles) overlap with data points from the 1.5-sec food access condition (filled circles) during the p(DRL) = 0.50 in the A' graphs of Birds 120, in the B" graphs for Birds 120 and 555, and the mean graph of B". Filled unconnected circles represent the second exposure to the p(DRL) = 0.50 with a 1.5-sec food access between sample and choice components.

## DISCUSSION

These results illustrate the applicability of signal-detection procedures to the analysis of the discriminative properties of response-reinforcer relations. The ROC curves in Figure 2 resemble those reported for psychophysical judgements of other types of stimuli. For example, similar ROC curves are obtained when lights of differing intensities or stimuli of differing durations are used in the sample component of conditional discrimination procedures (Elsmore, 1972; Nevin, 1970; Stubbs, 1976). Other methods of manipulating response bias, such as through changes in the probability of reinforcement of the choice responses (Nevin, 1970; Stubbs, 1976), also generate curves similar in form to those obtained in this experiment.

The data in Figure 4 elaborate these findings by showing that changes in probability of a DRL trial for the two alternatives produced systematic changes in response bias. However, corresponding *systematic* changes in sensitivity did not occur. One subject, Bird 120, showed constant sensitivity across all manipulations, and one each showed progressive increases and decreases as the probability of a DRL trial in the sample component increased.

The variability in d' and A' that occurred with Birds 555 and 212 could reflect some real differences in sensitivity to the two contingencies. However, since the changes in sensitivity were not systematic across the birds, it seems more likely that the measures were affected by idiosyncratic variables generated by the interaction between behavior and the schedules programmed in the sample component of the sort discussed by Zeiler (1977). Figure 3 shows how three outcomes of these interactions (component duration, responses per trial, and response rate) changed across the different conditions. The data in Figure 3 do not show systematic differences in the performance of Birds 212 and 555 that would account for the sensitivity differences. Thus, the cause of these differences seems to lie in other, unmeasured indirect variables or in complex interactions between the reported variables.

The basis for the increased sensitivity between the first and second $p(DRL) = 0.50$ condition also is difficult to specify. A general training effect due to repeated exposure to the discrimination task may be excluded because of the decreases in sensitivity for Birds 120 and 555 during the 1.5-sec blackout condition (Condition 10 in Table 1). Another sequence variable may be implicated, however. The condition in which $p(DRL) = 0.93$ always preceded the $p(DRL) = 0.50$ condition. During the former condition, both hits and false alarms were frequent, and introduction of the latter condition proportionally reduced the false alarm rate much more than the hit rate. Thus, the differences between the first and second $p(DRL) = 0.50$ conditions may reflect residual training effects of the frequent presentation of the DRL contingency in the sample component in the $p(DRL) = 0.93$ condition.

The direct action of reinforcement contingencies in strengthening operant responses is given primary consideration in the experimental analysis of behavior. However, the present results show that different contingencies of reinforcement can also exert discriminative control over behavior. The discriminative and response-strengthening effects of different reinforcement contingencies parallel the view of signal-detection theory that response occurrence is a joint function of the likelihood of reinforcement (payoff) and the discriminability of the stimuli. In schedules in which key pecking and pausing (*i.e.*, non-key pecking) are reinforced concurrently (*e.g.*, Rachlin and Baum, 1972; Zeiler, 1976), the rate of key pecking covaries with its relative frequency of reinforcement. This type of concurrent schedule may be compared to a yes-no signal detection task in which a key-peck response is equivalent to a report that a reinforcer is likely to be peck dependent, and a pause in responding in equivalent to a report that a reinforcer is likely to be pause dependent. As the relative frequency of reinforcement of the different responses changes, it is possible that the discriminability of the different response-reinforcer relations also changes. For example, when the frequency of reinforcement of pecking is high, the rate of pecking may be relatively rapid, in part because the organism fails to discriminate those occasions when pausing is reinforced. However, the present data suggest that this is not necessarily the case, since the discriminability of pecking and pausing did not change systematically across a wide range of response biasing values. Thus, response rate changes when pecking and pausing are reinforced concurrently are more likely related to changes in response bias variables, such as reinforcement frequency, than to consistent changes in the discrimination of the different contingencies as their relative frequency changes.

In addition to the response-reinforcer relations studied in this experiment, other variables are associated with reinforcement contingencies that might affect schedule performance through their discriminative properties. The present analysis suggests that accounts of schedule-controlled behavior should consider both discriminative and biasing effects of the various contingencies that control operant responding.

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*Received 14 August 1977.*
(*Final acceptance 16 August 1978.*)