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EFFECTS OF REINFORCEMENT SCHEDULING ON SIMULTANEOUS DISCRIMINATION PERFORMANCE[1]

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Pigeons were trained on a discrete-trials, simultaneous discrimination procedure, with confusable stimuli such that asymptotic performance was about 85% correct. Trials were terminated if no response occurred within 2 sec of stimulus onset, so that probability of responding was free to vary. The schedule of reinforcement for correct responses was varied, with the following results: (1) there was no relation between frequency of reinforcement and accuracy of responding. (2) In extinction, the probability of responding fell to low levels, but accuracy remained roughly constant. (3) When reinforcement was available after a fixed number of trials or after a fixed number of correct responses, the probability of responding increased with successive trials after reinforcement, but accuracy was generally constant. (4) When every fifth correct response was reinforced, accuracy decreased immediately after reinforcement if the birds were required to respond on every trial.

CONTENTS

Response probability is a basic datum in the analysis of behavior. It may be studied effectively in procedures which define a set of alternative behaviors on discrete trials. For example, one may examine the probability of one response rather than another in a choice situation, or of responding to one stimulus rather than another in a simultaneous discrimination. Finally, one may study the probability of responding rather than not responding in procedures which do not require a response on every trial. The latter situation is closely related to the usual single-response free-operant experiment in which rate of responding is the primary dependent variable.

The present study is concerned with the effects of reinforcement scheduling on the probability and accuracy of responding in a discrete-trial, simultaneous discrimination. Schedules of reinforcement are known to be powerful determinants of the rate and pattern of emission of a free operant, and of preference in choice experiments (*e.g.*, Shimp, 1966). The differential control of responding by stimuli associated with reinforcement and extinction may also depend on the schedule of reinforcement. As Jenkins (1965) has argued, discrete-trial procedures may be particularly appropriate in the analysis of stimulus control. Since trials terminate with the occurrence of a response, the subject cannot use the consequences of that response as a basis for subsequent responding. The effects of generalization of the consequences of responding on one trial to the following trials can be controlled by adequate randomization of the stimulus sequence. Thus, measurements of stimulus control may be kept free of confounding by the reinforcement schedule.

The basic procedure of this study was as follows. Pigeons were presented with different levels of illumination on two response keys. The brightness difference was chosen to maintain accuracy at intermediate levels, so that improvements as well as decrements could be measured. Trials were terminated after a sin-

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gle peck at either key, or after 2 sec if no peck occurred. Pecks at the brighter key, (S^D), were reinforced on various schedules analogous to interval and ratio schedules in free-operant research. This permitted simultaneous measurement of the probability of key-pecking given a trial, and the probability of correctly pecking S^D given the occurrence of a peck. Thus, it was possible to determine whether schedule variables affecting the level of performance would also affect accuracy.

EXPERIMENT I: ACCURACY AS A FUNCTION OF REINFORCEMENT FREQUENCY

The effects of reinforcement frequency on accuracy and probability of responding were investigated. Reinforcement was available on randomly selected trials without regard to events on preceding trials. The schedule is analogous to a free-responding variable-interval schedule with limited hold (Ferster and Skinner, 1957). Schedules are designated by the mean number of trials between reinforcement availabilities; for instance, RT 10 means that reinforcement was scheduled randomly every 10 trials on the average. Extinction after exposure to RT schedules was also studied.

Subjects

Four experimentally naive male White Carneaux pigeons, maintained at 80% of their free-feeding weights, ± 15 g, served.

Apparatus

A Lehigh Valley pigeon chamber contained two response keys, 1 in. in diameter and 6 in. apart center to center. A dim house light was mounted centrally above the keys, and a grain feeder positioned centrally below them. Either key could be illuminated with uniform white light; brightness was varied by lighting different numbers of bulbs behind diffusing screens. Brightnesses were calibrated with a Macbeth illuminometer and checked regularly throughout the experiment. The keys were adjusted to require the same force of pecking (about 9 g) to operate their microswitches.

Experimental sessions were programmed automatically with standard relay equipment; reinforcement availability was scheduled with a randomly wired stepping switch and a Lehigh Valley probability panel in combination. Responses were recorded on electromagnetic counters; occasional samples of latencies were recorded with a Hewlett-Packard electronic counter. Programming and recording equipment was isolated from the experimental chamber.

Preliminary Training

After the birds were adapted to the chamber and trained to eat from the grain magazine, one key was lighted and the birds were trained to peck it. After several reinforcements, it was darkened, the other key lighted, and several reinforcements given for pecks on that key. The key light was switched back and forth irregularly until about 50 reinforcements were delivered.

In the next session, a discrete-trials procedure was introduced. One or the other key was illuminated (S^D), to a luminance of 4.1 ml, and kept on until the bird pecked one of the keys. Pecks on the lighted key were reinforced with 3-sec access to grain; pecks on the dark key turned off the key light. Trials were separated by 6 sec and 60 trials were given. Over the course of the next 20 sessions, the luminance of the dark key was gradually increased to 2.6 ml. During the final sessions of preliminary training, the birds averaged 75% correct on this discrimination.

Since the present experiments were performed, Mentzer (1966) has reported brightness difference thresholds in pigeons, obtained in a similar procedure, with Weber fractions typically ranging from 0.20 to 1.00. In his research, a spot was superimposed on a uniformly lighted surround, a more favorable arrangement for brightness discrimination than the present situation, in which the brightnesses to be compared were on keys 6 in. apart. These results suggest that the present stimuli, for which the ratio of the brightness difference to the brightness of S^Δ was 0.58, constitute a difficult discrimination for the pigeon under the conditions of this experiment.

Procedure

The final procedure went into effect after this preliminary training. A trial began with illumination of both keys. A peck on the brighter key (S^D) was reinforced on the prevailing schedule with 3-sec access to grain; pecks on the dimmer key (S^Δ) were never reinforced.

The key lights were turned off when either key was pecked, or after 2 sec if no peck occurred. When a reinforcement scheduled for a particular trial was not collected, because the bird pecked S^{Δ} or failed to peck, it was cancelled. Trials were separated by 6 sec; pecking during the intertrial interval delayed the next trial for 6 sec after the peck. The S^{D} appeared equally on the left or right in a repeating 50-trial sequence, randomized with the restriction that there were no more than three consecutive S^{D} presentations on either side. The sequence advanced after each trial. Counters recorded the number of pecks to S^{D} and S^{Δ}, separated according to whether S^{D} was on the right or left.

Sessions were conducted at least five days per week if the birds were within 15 g of 80% of their free-feeding weights. There was no evidence of performance decrements after one or two sessions were missed. Sessions always began with 10 warmup trials, which were excluded from the data, followed by 50 trials if the schedule was RT 1 (continuous reinforcement), or 100 trials for all other schedules. Session length was reduced at RT 1 to prevent the birds from exceeding their weight limits. The birds were trained on the following RT schedules, listed in order of exposure, for 1000 trials (excluding warmup trials): RT 1, RT 2, RT 5, RT 2, RT 10, RT 5, RT 25, RT 10, RT 50, extinction, RT 1, RT 5, RT 50. This design exposed the birds to descending frequencies of reinforcement, with recoveries of earlier values interspersed. Three schedule values covering the entire range were repeated after extinction.

Results

The probability of key-pecking stabilized near 1.00 for all birds after a few sessions on RT 1. The probability of pecking S^{D} stabilized between 0.75 and 0.90 after the first 12 to 14 sessions. Individual differences were evident, but there were no consistent accuracy changes within subjects for the last six sessions. Examination of data from subsequent schedules indicated that, if there were any changes in behavior, they almost always occurred within the first few sessions. Accordingly, data for the final 300 trials on each schedule were used to estimate terminal response probabilities.

The results are presented in Fig. 1, which relates the probability of responding given a trial, P(R), and the probability of correctly pecking the S^{D} given a peck, P(C), to the programmed reinforcement schedule. Data taken after extinction are displaced slightly to the right. Means for the four birds before extinction are indicated by a solid line, mean data after extinction by a dashed line.

Considering first the accuracy of responding (upper panel), both mean curves have a slight trend downward as the mean number of trials between scheduled reinforcements becomes large. However, this trend is by no means consistent across subjects. After extinction, P(C) tends to be higher than on the same schedules before extinction. The variability within and between birds is large. Variance for each bird about its overall mean P(C) was calculated and found to be appreciably larger than the expected binomial variance in samples of the same size, so one cannot conclude that P(C) is constant; however, it appears that any effect of reinforcement frequency on accuracy is slight.

In general, the birds divided their responses about equally between the two keys. There was some tendency for low accuracies to be associated with moderate departures from equal responding, but complete position preferences were never observed. Adoption of a position preference obviously imposes an upper limit on P(C); however, accuracies were always below this limit.

Examination of the lower panel of Fig. 1 suggests a small and highly variable decrease in probability of responding as the value of the RT schedule increased. Probability of responding tended to be higher after extinction, as did P(C), but otherwise there were no strong correlations between these measures.

Analysis of latencies on all schedules before extinction revealed no difference between correct and incorrect responses. Latencies to S^{D} and S^{Δ} were recorded separately to the nearest $\frac{1}{60}$ sec. The data were pooled for the last three sessions on each schedule, and medians determined for each bird. Of the 36 comparisons available, the median latency to S^{D} was shorter than that to S^{Δ} 20 times, longer 15 times, and tied once. In all cases the differences were small, and the direction of difference appeared to be random with respect to birds and schedules. Latencies generally tended to increase when reinforcement was less frequently scheduled.

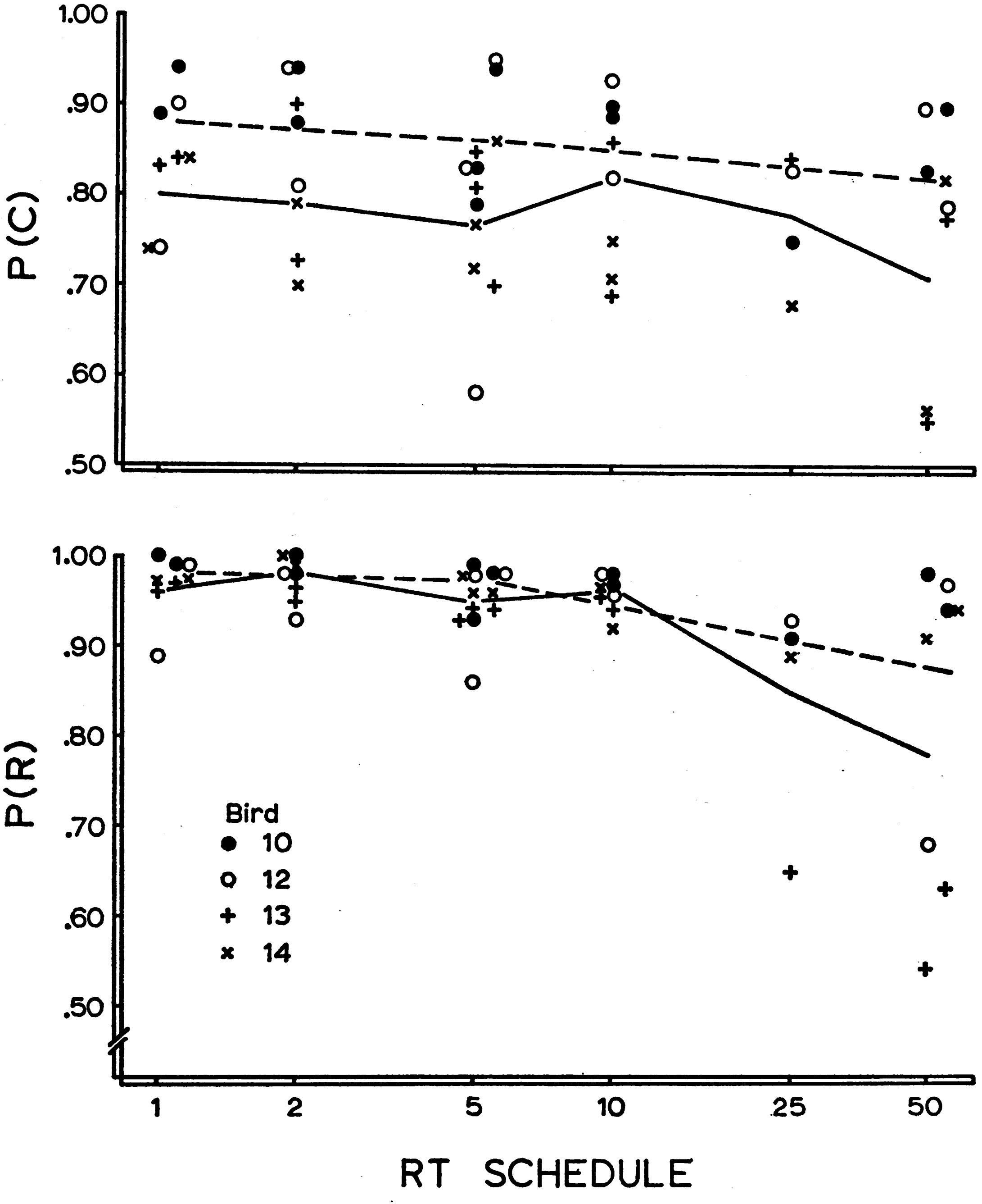

Fig. 1. Probability of responding (lower panel) and probability of responding correctly (upper panel) on a simultaneous brightness discrimination, as a function of the average number of trials between randomly scheduled reinforcements. Solid lines are mean functions before extinction; dashed lines are mean functions after extinction. Data taken after extinction are given by points displaced slightly to the right.

In summary, reinforcement frequency had little consistent effect on either probability or accuracy of responding under the conditions of this experiment.

When reinforcement was withheld for 10 sessions, response probability decreased systematically for all birds, while accuracy remained about constant. The results, averaged for all four subjects, are shown in Fig. 2. The data for single subjects suggest that the mean is a fair representation of individual performances. Table 1 summarizes responding to S^D and S^Δ for the last three sessions on RT 50, the first three sessions of extinction, and the last three extinction sessions in which the subjects actually responded. Although all four subjects exhibited slightly higher accuracies at the end of extinction than at the beginning, these terminal accuracies were generally close to terminal accuracies on RT 50. None of the accuracy differences within subjects was statistically significant by χ^2 tests. Accordingly, it seems appropriate to conclude that stimulus control was invariant during extinction of this simultaneous discrimination performance.

EXPERIMENT II: ACCURACY WITHIN DISCRETE-TRIAL ANALOGUES OF FIXED-INTERVAL AND FIXED-RATIO SCHEDULES OF REINFORCEMENT

This experiment was concerned with the effects of cyclic patterns of reinforcement and non-reinforcement on probability and accuracy of responding. Reinforcement was available on schedules analogous to fixed-interval or fixed-ratio schedules in free-operant research. In one procedure, designated FT, reinforcement was available on every nth trial, independent of behavior on the intervening trials. This is related to fixed-interval schedules with limited hold for free-operant behavior (Schoenfeld, Cumming, and Hearst, 1956). In the other procedure, designated FR, reinforcement was presented for every nth correct response. The contingency between reinforcement and prior unreinforced behavior is analogous to that in simple fixed-ratio schedules (Ferster and Skinner, 1957).

Subjects

Three experimentally naive male White Carneaux pigeons, maintained at 80% of their free-feeding weights, ± 15 g, served.

Apparatus

The apparatus was the same as in Exp. I.

Procedure

The general procedure and preliminary training were identical to Exp. I. After the subjects had attained stable accuracies with continuous reinforcement, they were exposed to FT 5, FT 10, and FR 5 schedules in that order. Each schedule was in effect for 22 sessions of 250 trials each. Five sessions of continuous reinforcement intervened between the different schedules. Each session began with 10 warmup trials, which were not included in

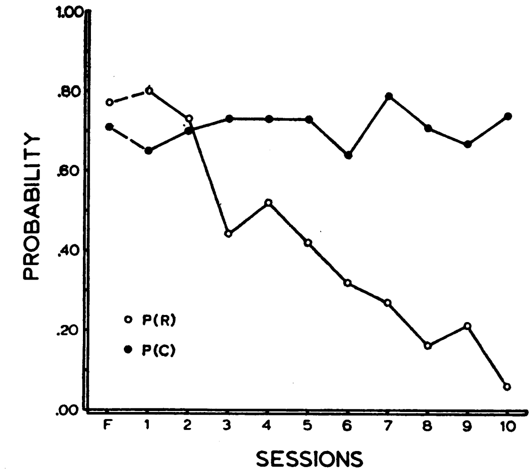

Fig. 2. Probability of responding and probability of responding correctly on a simultaneous brightness discrimination over the course of 10 sessions of extinction, averaged for four subjects. The data points over F represent final performance on the preceding intermittent reinforcement schedule.

Table 1

Responses to S^D and S^Δ, and the proportion of correct responses, P(C), before and during extinction.

Bird	*RT 50 Last 3 sessions*			*Extinction First 3 sessions*			*Extinction Last 3 sessions*		
	S^D	S^Δ	*P(C)*	S^D	S^Δ	*P(C)*	S^D	S^Δ	*P(C)*
10	229	56	0.80	125	57	0.69	43	11	0.80
12	186	20	0.90	208	32	0.87	49	5	0.91
13	88	73	0.55	66	39	0.63	22	10	0.69
14	155	120	0.56	145	118	0.55	59	40	0.60

the data. The sequence of stimuli, responses, and reinforcements was recorded on a polygraph.

On FT schedules, reinforcement was available every fifth or tenth trial. If the bird incorrectly pecked S$^{\Delta}$, or failed to peck within 2 sec on reinforcement trials, the reinforcement was missed. On FR 5, subjects were required to peck S^{D} on five trials, not necessarily consecutive, to receive reinforcement.

Results

Performance on FT and FR schedules stabilized satisfactorily within 15 sessions; data

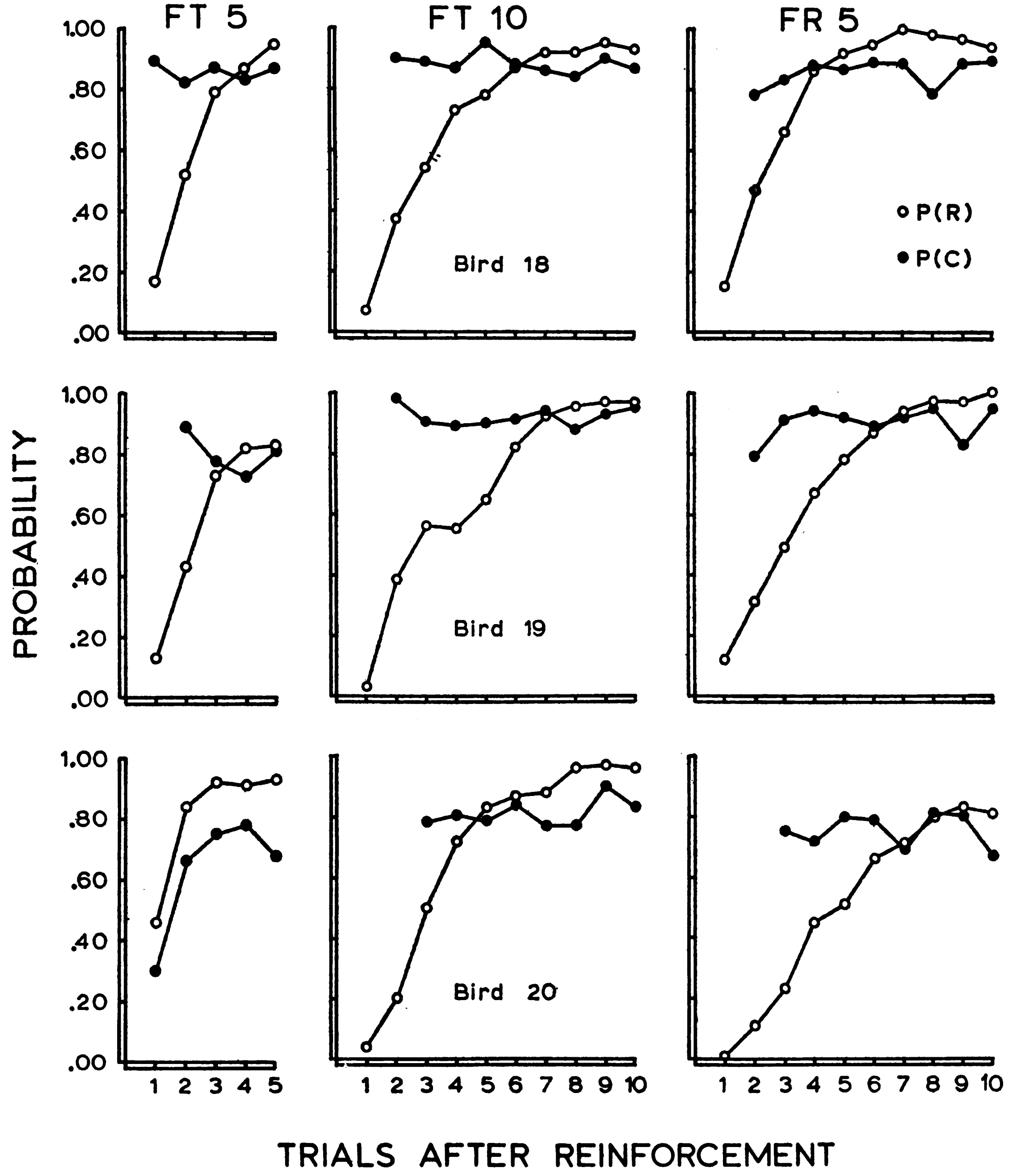

Fig. 3. Probability of responding and probability of responding correctly on a simultaneous brightness discrimination as a function of the ordinal trial number after reinforcement. Reinforcement was scheduled on every fifth trial (FT 5), every tenth trial (FT 10), or for every fifth correct response (FR 5).

for the last five sessions on each schedule were taken as descriptive of asymptotic performance. Data for all birds on all schedules are presented in Fig. 3, which relates probability of responding, P(R), and accuracy of responding, P(C), to the ordinal trial number after reinforcement. Birds rarely required more than 10 trials per reinforcement on FR 5, so the abscissa scale stops at 10. No point is plotted for P(C) if fewer than 20 responses were made on a given trial number.

On all schedules, P(R) increased systematically as a function of trials after reinforcement. In general, P(C) was constant throughout the sequence of trials after reinforcement; Bird 20 on FT 5 was the only serious exception to this constancy. The birds rarely emitted the requisite 20 responses on the first trial after reinforcement; however, examination of the available data revealed no systematic differences in P(C) on this and subsequent trials.

Coincidentally, the birds received about the same number of reinforcements per session on FT 10 and FR 5. Comparison of individual data, and data averaged across birds for these

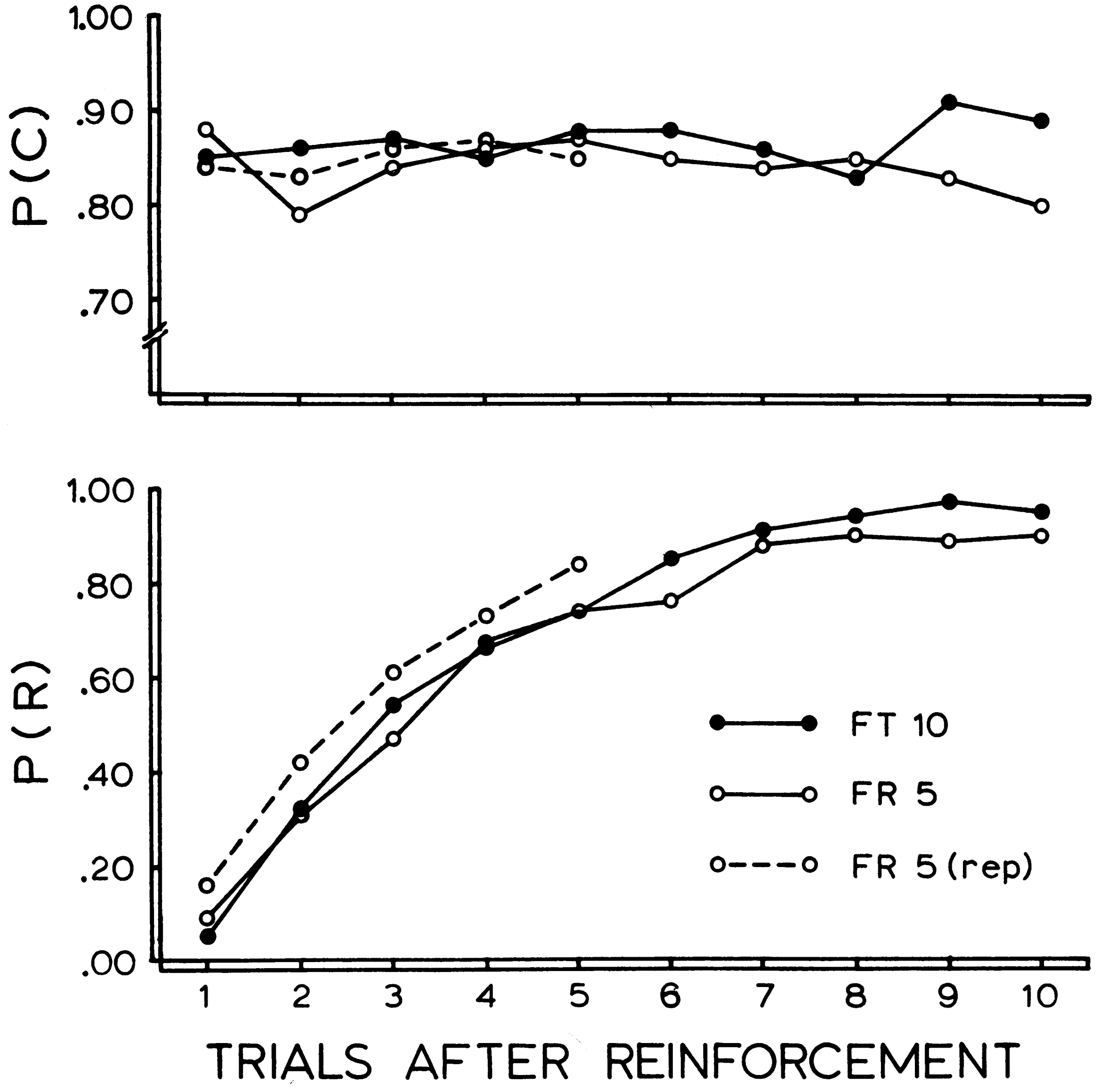

Fig. 4. Probability of responding (lower panel) and probability of responding correctly (upper panel) on a simultaneous brightness discrimination as a function of the ordinal trial number after reinforcement. Data are means for three birds on FT 10 and FR 5 schedules. Mean functions for an independent replication with four birds on FR 5 are also given.

schedules in Fig. 4, shows that both accuracy and probability of responding were virtually identical on these schedules. (The functions designated FR 5 (rep) come from a replication with other birds, to be described in connection with Exp. III.) The similarity of the P(R) functions under these schedules may be coincidental; other schedule values, or longer exposure to the contingencies, might lead to different forms of the functions. The constancy of P(C), despite large changes in P(R), is noteworthy.

EXPERIMENT III: ACCURACY DURING FORCED-CHOICE PROCEDURES

The results of Exp. II are at variance with the results of Nevin, Cumming, and Berryman (1963), who trained pigeons on a matching-to-sample task, and found that accuracy was near chance immediately after reinforcement on FR schedules, increasing systematically as the ratio progressed. These experiments differed not only in the nature of the discrimination, but also in that Nevin *et al.* required a response on every trial: stimuli remained on until the subject pecked S^D or S^Δ. The present experiment evaluated the effects of forcing a choice on every trial of the simultaneous discrimination used in the preceding experiments, with FR 5 reinforcement.

Subjects

The four pigeons used in Exp. I served after Exp. I was completed.

Apparatus

The same apparatus as in Exp. I and II was used.

Procedure

In the forced-choice procedure, stimuli remained on until a peck to S^D or S^Δ occurred; this peck turned off the stimuli and initiated the 6-sec intertrial interval. The fifth correct response was reinforced. After 20 sessions on this procedure, the FR 5 procedure of Exp. II was repeated for 20 sessions: trials terminated after 2 sec without a response, and the fifth correct response was reinforced. Throughout Exp. III, sessions consisted of 250 trials, preceded by 10 warmup trials. Counters recorded the number of pecks to S^D and S^Δ for the first five trials after reinforcement.

Results

Pooled data for the last five sessions of the forced-choice procedure with FR 5 are given in Fig. 5 for individual subjects. In every case, P(C) was lowest immediately after reinforcement. Detailed latency data were not recorded, but observation indicated that latencies immediately after reinforcement were often extremely long, on the order of 1 min.

When the response requirement was removed, the birds rarely pecked the keys immediately after reinforcement; when they did, accuracy was about the same as on subsequent trials. Results for the final five sessions, averaged across subjects, are plotted in Fig. 4 (designated FR 5 (rep)) for comparison with the results of Exp. II. The results of the earlier experiment for both P(R) and P(C) appear to be almost perfectly replicated.

The decrement in accuracy when the subjects were forced to respond on trials immediately after reinforcement agrees in direction with the results of Nevin *et al.* (1963), but is much smaller, suggesting that some additional aspect of their matching procedure may be of considerable importance.

DISCUSSION

Experiment I found no systematic relation between the frequency of reinforcement and the accuracy of the simultaneous discrimina-

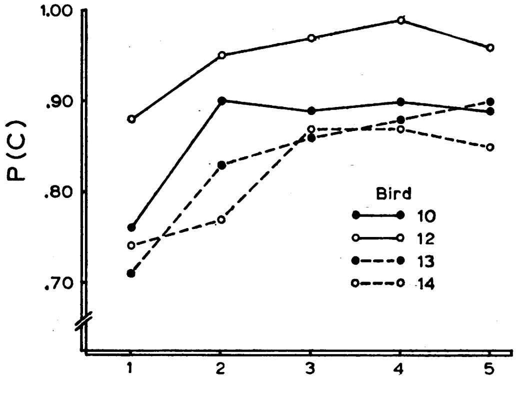

Fig. 5. Probability of responding correctly on a simultaneous brightness discrimination as a function of the ordinal trial number after reinforcement. The birds were required to respond on every trial, and every fifth correct response was reinforced.

tion performance. This is in accord with the findings of Cumming (1955), who studied the behavior of pigeons in a free-operant, successive brightness discrimination. In his study, two brightness levels alternated on the response key, with reinforcement available at variable intervals in the presence of the dimmer light. After differential responding was well established, he varied the frequency of reinforcement in S^D, and the physical difference between S^D and S^Δ. For any given $S^D - S^\Delta$ disparity, more frequent reinforcement in S^D tended to produce higher rates of responding in both stimuli, so that the ratio of rates remained about constant. In a similar experiment, Dinsmoor (1952) trained rats on a successive brightness discrimination with food reinforcement at variable intervals in S^D. He found that changes in food deprivation altered response rates in the presence of both stimuli so that their ratio remained constant. These findings of the constancy of stimulus control despite changes in the overall level of responding accord with the extinction data of Exp. I, which showed that accuracy remained constant while the probability of responding fell to low levels.

The latter result does not, however, agree with the observations of Smith and Hoy (1954), who trained rats on a successive discrimination with variable-interval reinforcement in S^D, and then changed the schedule in S^D to extinction. As the level of performance decreased, the ratio of responses in the former S^D increased slightly. This finding has been replicated with pigeons in informal studies in the Swarthmore Laboratories. The effect may result from the non-independence of successive responses in free-operant procedures. Blough (1963, 1966*a*) has shown that responses with short interresponse times may not depend on the prevailing stimulus conditions. If the subject is more likely to initiate responding in S^D than in S^Δ, and this responding leads to further responses with short interresponse times, the number of responses in S^D relative to total responses would be expected to increase. Discrete-trial procedures which permit response probability to vary, or special schedules of reinforcement designed to break up such dependencies on prior responding (*e.g.*, Blough, 1966*b*), may be better suited to the study of differential responding when performance is in transition to low levels.

Experiment II demonstrated that the accuracy of responding remained invariant within repeated cycles of reinforcement and non-reinforcement, although the reinforcement schedules effected large changes in response probability within the cycle. This result agrees with the findings of Dews (1962) in a study of fixed-interval reinforcement. He exposed pigeons to alternating 50-sec periods of S^Δ and S^D, with reinforcement at the end of the fifth S^D. Within each cycle of five alternations between reinforcements, the level of responding increased systematically in both S^Δ and S^D. When responding in S^Δ periods was compared with responding in the same periods of the 500-sec fixed interval with S^D continuously present, it was found that S^Δ reduced rate by a fixed percentage throughout the interval between reinforcements.

Experiment III demonstrated that accuracy decreased immediately after reinforcement when responding was required on every trial, as reported in research on matching to sample by Nevin *et al.* (1963) and recently replicated by Mintz, Mourer, and Weinberg (1966). When responding is forced in this way, the eventual delivery of reinforcement depends on the occurrence of responding to advance the trial sequence. This effect of responding does not, of course, depend on whether S^D or S^Δ is chosen. This nondifferential contingency may obscure the differential control of the stimuli when reinforcement is temporally remote.

The present data, taken together with the literature discussed above, support the following generalization: the differential control of behavior by stimuli correlated with reinforcement and extinction, once established, does not depend on variables which affect the overall level of performance. This generalization assumes that the measurement of stimulus control is not confounded by the programming of reinforcement, response dependencies, or contingencies other than the basic contingency between responding and reinforcement in S^D.

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