FURTHER EXPERIMENTS ON PROBABILITY-MATCHING IN THE PIGEON¹

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In a discrete-trials, two-key choice situation, probability-learning by pigeons was studied under a variety of training conditions. Matching was found in simultaneous and in successive problems, but a spatial problem produced only maximizing. In the simultaneous problem, noncorrection produced maximizing, while correction produced matching. Guidance produced maximizing when the animals were required to earn each opportunity for choice by pecking a center key on FR-5, but matching when the center key was not used. In a discrete-trials one-key situation, with latency as the measure, frequency and probability of reinforcement were varied independently. Differences in probability produced differences in latency of response, but differences in frequency did not.

Discrete-trials experiments on probability-learning in the pigeon (Bullock and Bitterman, 1962), the fish (Bitterman, Wodinsky, and Candland, 1958; Behrend and Bitterman, 1961), and the cockroach (Longo, in press) have yielded clear evidence of matching—*i.e.*, of a correspondence between choice-ratio and reinforcement-ratio. For example, pigeons trained in a two-key situation with response to red reinforced on a random 70% of trials, and response to yellow reinforced on the remaining trials, come to choose the red key on a random 70% of trials. Analogous experiments with the rat (Wodinsky, Candland, and Bitterman, 1958) and the monkey (Wilson, 1960; Meyer, 1960) have for the most part yielded only maximizing—*i.e.*, choice on almost all trials of the higher-probability alternative.⁵ When a correspondence between reinforcement-ratio and choice-ratio has, on occasion, appeared in one of these higher animals, it has been found to have a different basis than in the lower ones. For example, a correspondence found in the

rat by Hickson (1961) turned out on further analysis to be due to reinforcement-following—the rats displayed a strong tendency to choose on each trial the correct alternative of the immediately preceding trial.⁶ A correspondence found in the monkey by Wilson, Oscar, and Bitterman (in press) could be traced to the opposite strategy—a tendency to avoid on each trial the reinforced alternative of the immediately preceding trial. Systematic tendencies of this sort have not appeared in the matching of lower forms, which seems to be quite random. For example, the probability that the pigeon will choose a given alternative on any trial is independent of which of the two has been reinforced on the preceding trial.

EXPERIMENT I: MATCHING AS A FUNCTION OF TRAINING CONDITIONS

The failure to find random matching in any given species, *e.g.*, the rat, may mean that the mechanism of response-selection is different in the rat than it is in a species, *e.g.*, the pigeon, which does show random matching. Another possibility is that the experimental conditions employed for the two species have not been equated for the effects of some contextual variable which interacts with reinforcement-ratio in the determination of choice-

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⁵A unique free-operant study of probability-learning in the rat by Verhave (1961) also has given evidence of maximizing.

⁶The reinforcement-following was discovered by Bitterman in a sample of data provided by Hickson.

ratio. The interactive interpretation implies (Bitterman, 1960) that conditions can be found for the rat in which it will function like the pigeon, and that conditions can be found for the pigeon in which it will function like the rat. The purpose of the present experiment was to study probability-learning in the pigeon under a wide range of conditions which might well be expected to influence choice. The original work of Bullock and Bitterman (1962) was extended in three respects.

(1) Bullock and Bitterman used guidance after error; both key-lights were turned off and then, after a brief period of darkness (TO), the correct key alone was turned on, and the animal was reinforced for responding to it. In the present experiment, guidance was compared with noncorrection and with correction. In noncorrection, an incorrect response terminated the trial, while, in correction, each incorrect response was followed, after the TO, by the relighting of both keys, which gave the animal another choice. In correction, as in guidance, each trial terminated with a reinforced response, which permitted exact control of the reinforcement-ratio; but no such control was possible, of course, in noncorrection. Work with the fish has shown matching in guidance but maximizing in noncorrection (Bitterman *et al.*, 1958; Behrend and Bitterman, 1961).

(2) In the work of Bullock and Bitterman, each trial began with the presentation of the two colored keys, between which the animal was required to choose. In the present experiment, a condition was studied in which each trial began with the presentation of a white center key (CK), five pecks at which turned it off and turned on the two colored keys (one on each side of the CK). The CK-condition was expected to reduce spatial biases and to increase the motivational significance of erroneous choice.

(3) The matching reported by Bullock and Bitterman was found in work with a visual problem (red *vs.* yellow). Their pilot work with a spatial problem (involving two red keys and differential reinforcement of position) did not produce evidence of matching. In the present experiment, the spatial problem was examined further under conditions (CK-correction) which were found to give the best matching in a visual problem. Work with

the fish has yielded matching in spatial as well as in visual problems (Bitterman *et al.*, 1958; Behrend and Bitterman, 1961), and spatial matching has been found also in the cockroach. This, however, has not yet been studied under visual conditions (Longo, *in press*).

Subjects

Twenty-one White Carneaux cocks were maintained at 75% of their free-feeding weights by the technique of Bullock, Roberts, and Bitterman (1961). Eleven of the Ss were experimentally naive, and the rest had had experience only in a single-key situation in which different key-colors were associated with different amounts of reward.

Apparatus

The Ss were tested in a small picnic chest. The front wall contained three Lehigh Valley Electronics pigeon keys (3 in. apart) and the opening of a Gerbrands grain-magazine 7 in. below the CK. Experimental contingencies were programmed automatically, and responses were recorded with a Gerbrands polygraph.

Procedure

The 10 experienced birds were trained on a 0:100 simultaneous red-green discrimination, half with red-positive and the rest with green-positive. For five NoCK birds, the guidance procedure of Bullock and Bitterman was used. The two keys were presented after a 6-sec intertrial interval (ITI) in darkness, with each color half the time on the left and half the time on the right (in Gellermann orders). Each correct response was followed by access to grain for 4 sec (key-lights out, white mag-light on), and then by the ITI. Each incorrect response was followed by a 6-sec TO in darkness and then by the presentation of the positive key alone; response to that key produced the mag and then the ITI. For five CK birds, the ITI was followed by the presentation of a white CK, the fifth peck at which turned off the CK and presented the discriminanda. In this stage of the experiment, the CK did not intervene between erroneous choice and guidance. The TO was followed immediately by presentation of the positive key alone. Throughout the experiment, 40 trials per day were given.

After the Ss had mastered the 0:100 problem (which they did very rapidly), they were transferred to the 70:30 problem under non-correction conditions. The previously negative stimulus was reinforced on 28 of each day's trials, and the previously positive stimulus on the remaining 12 trials, the sequence random, with the restriction that there must be at least one minority reinforcement in each block of five trials. When performance had stabilized, the conditions were changed from non-correction to correction and to guidance, in different orders for different birds, with the reinforcement-ratio remaining at 70:30. In correction, both keys were presented after error, and there was no limit to the number of repetitive errors which could be made on each trial. Few errors were made, as the animals learned quickly to shift sides after each initial error. The programmer provided for intervening *CK* in correction (which it did not in guidance); i.e., each presentation of the discriminanda after error was earned by response to the *CK* on the FR-5 schedule.

Because the *CK*-guidance condition produced deviant results, the programmer was modified to permit intervening *CK* in guidance, and six naive birds (after magazine and key training) were put on the 70:30 *CK* problem, both with correction and with guidance (in different orders for different birds). After enough information had been obtained, the same birds were trained on a *CK*-correction spatial problem with two yellow keys reinforced, first in the ratio 70:30, and then in the ratio 50:50.

The remaining five naive birds, after magazine and key training, were put on a 100:0-0:100 successive problem with *CK* and correction. Three birds were reinforced for pecking the right-hand key when both keys were green and the left-hand key when both were blue. The other two were reinforced for choosing the right-hand key when both were red and the left-hand key when both were yellow. Each of the two colors was presented on 20 of each day's 40 trials, the two pairs being alternated in accordance with Gellermann orders. After errorless performance had been achieved, the reinforcement-ratio was changed to 70:30-30:70. In the case of the green *vs.* blue animals, for example, response to the right-hand key was rewarded on 14 (70%) and response to left-hand key on six

(30%) of the 20 green trials. Response to the left-hand key was rewarded on 14 (70%) and response to the right-hand key on six (30%) of the 20 blue trials. In such a problem, of course, the two positions and the two colors are equally often rewarded.

Fig. 1. The performance of two pigeons in the simultaneous color discrimination of Experiment I. Response to green was consistently reinforced in the first three blocks of trials, after which the animals were shifted to a 70:30 problem with red as the majority color. The arrows show the points at which new conditions were introduced. NC, noncorrection; C, correction; G, guidance. No. 9 was trained with center key and No. 10 without center key.

Results

The results for two of the 10 experienced birds, both trained first to green-positive in the simultaneous problem, one with *CK* and the other with *NoCK*, are presented in Fig. 1. The performances of these two birds are representative of the group except in one respect. Shifted from 0:100 guidance to 70:30 noncorrection, four of the remaining eight birds (three *CK* and one *NoCK*) failed to show a shift in preference, continuing on 100% of trials to choose the positive color of the 0:100 problem. Only when the conditions were changed from noncorrection to correc-

tion or to guidance did these animals show a shift in preference. The other four animals did, like those whose performances are shown in Fig. 1, shift their preferences in noncorrection, and uniformly maximized, choosing the 70% color on about 100% of trials. Furthermore, when the *NoCK* animals subsequently were returned to noncorrection after training under conditions (such as correction) that did produce matching, they maximized again (see the curve for No. 10).

The curve for No. 10 also illustrates the general finding that both correction and guidance produced matching in *NoCK*. The curve for No. 9 illustrates that only correction produced matching in *CK*. (In correction, of course, only the first choice on each trial is represented in the tabulations, repetitive errors being omitted.) In *CK*-guidance, there was a pronounced tendency to maximize. This finding was duplicated in subsequent work with naive birds and a programmer which permitted intervening *CK*; *i.e.*, whether or not *CK* intervened between error and guidance, *CK*-guidance produced maximizing.

Fig. 2. Summary of the results for the 70:30 simultaneous color discrimination of Experiment I. Each point marks the mean preferences of five Ss. The vertical line through each point represents the range of individual values.

The results for the simultaneous problem are summarized in Fig. 2 in terms of the mean percentage of response to the 70% color in each of the last eight sessions of training under each condition. The vertical line through each point represents the range of individual values. The first curve shows maximizing in noncorrection-*NoCK*. Parallel data for noncorrection-*CK* are, unfortunately, unavailable. The noncorrection condition was not repeated for the *CK* animals after the initial 70:30 training (as it was for the *NoCK* animals) because interest centered on replicating the

phenomenon of maximizing in guidance, but the failure of noncorrection to produce matching in *CK* is quite evident from the results of the initial 70:30 training. Figure 2 also shows maximizing in *CK*-guidance. Matching was produced in *NoCK*-guidance, *NoCK*-correction, and (best of all) in *CK*-correction.

Table 1

Asymptotic levels of preference for the original majority side developed by each of six Ss trained first in a 70:30 spatial problem and then in a 50:50 problem (*CK-C*).

S	70:30	50:50
1	70	25
2	70	30
3	92	85
4	90	50
5	85	60
6	85	50

In the spatial problem, by contrast, *CK*-correction did not produce good matching. The results are given in Table 1. In the 70:30 problem, four of the six birds tested showed preferences for the 70% side which substantially exceeded 70%. Shifted to the 50:50 problem, each animal showed a reduced preference for the original majority side; while the mean preference of the group for that side became exactly 50%, individual values varied widely. (The tabulations are based only on the initial choice made on each trial, repetitive errors being omitted.)

The results for the successive problem (again *CK*-correction) are summarized in

Fig. 3. Summary of the results for the successive color discrimination of Experiment I. The points are means for five Ss, and the vertical line through each represents the range. The arrows show the points at which new conditions were introduced.

Fig. 3, which is plotted in terms of the mean percentage of left choices for each color separately. The vertical line through each point shows the range of individual preferences. (Again the computations reflect only the initial choice made on each trial.) The curves of Fig. 3 well represent the curves for each of the five Ss in the group. In the 100:0 training, the animals learned always to go left when the keys were of one color (*A*) and never to go left when the keys were of the alternative color (*B*). With the shift to 70:30 training, the mean percentage of left-key responses fell to 70% when the color was *A* and rose to about 25% when the color was *B*.

Discussion

Of the eight main conditions studied (*simultaneous CK-noncorrection*, *sim-CK-correction*, *sim-CK-guidance*, *sim-NoCK-noncorrection*, *sim-NoCK-correction*, *sim-NoCK-guidance*, *spatial-CK-correction*, and *successive-CK-correction*) four failed to produce matching. The failure in the two noncorrection cases is in accord with the results of previous work on the fish (Bitterman *et al.*, 1958; Behrend and Bitterman, 1961). To produce matching in either species, apparently, it is necessary to employ a technique which guarantees reinforcement for response to the minority stimulus. The failure in the case of *CK-guidance* was quite unexpected. It might be suggested that *CK* facilitates discrimination between two-key (choice) and one-key (guidance) presentations, with the result that choices are not influenced by guidance. This explanation would not account for maximizing with non-intervening *CK*. The failure in the spatial problem was not entirely unexpected in view of the negative results of Bullock and Bitterman (1962), but it is nevertheless difficult to understand. Fish and cockroach certainly match in spatial problems. The pigeon matches nicely in the successive problem, which may be thought of as two concurrent color-differentiated spatial problems. Perhaps the pigeon (in the situation employed here) is more susceptible than the other species (in their situations) to postural biases, the effects of which are minimized as behavior is brought increasingly under exteroceptive control.

These results make clear, in any event, that there is still no general understanding of

matching and the failure of matching in the pigeon. It is hoped that these results will be of some value in guiding the search for matching in species in which the phenomenon has not yet been found.

EXPERIMENT II: PROBABILITY VS. FREQUENCY OF REINFORCEMENT

Under all conditions which have produced matching in pigeon, fish, and cockroach, probability and frequency of reinforcement have been confounded. In 70:30 correction, for example, the probability of reward for initial choice of the 70% alternative is 70%, and 70% of the reinforcements earned by the animal are earned for choice of that alternative. The results of some preliminary tests with the fish (Behrend and Bitterman, 1961) suggest that frequency alone is not the determining factor, but no unconfounded manipulation of probability has yet been reported. In the present experiment with the pigeon, the effects of the two variables are compared in a one-key situation, with latency rather than choice as the measure. The one-key situation was used because there seemed to be no really adequate way of separating the effects of the two variables in a choice-situation. The results do not, then, give us any unequivocal information about the determination of choice in the two-key situation, but only as to whether the pigeon is at all capable of discriminating probability independently of frequency.

Subjects

Seven White Carneaux cocks, with several months of prior training on an oddity problem in a three-key situation, had been and continued to be maintained at 75% of their free-feeding weights.

Apparatus

Similar to that used in the choice-experiment, the front wall of this compartment presented only one pigeon key. The programming was not, as it was in the previous experiment, entirely automatic. During the *ITI*, the experimenter determined, with one toggle-switch, the color of the key-light and, with another switch, whether or not response was to be reinforced. Response-times were read from Standard Electric 0.01-sec clocks.

Procedure

Each *S* had 20 trials per day with a red key on a random half of the trials and a green key on the remaining trials (in Gellermann orders). The first response to each color turned off the key-light and caused the magazine to be presented for 4 sec, after which there was an ITI of 3 sec. After four days of this training, a 70:30 reinforcement ratio was introduced. Response to one color was reinforced on seven of 10 trials and response to the other on three of 10 trials. As had been expected on the basis of a prior experiment (unpublished), in which different amounts of reinforcement were associated with the two key-colors, no difference in the latency of response to the two colors appeared in the course of this training. The number of responses required on each trial therefore was increased gradually (to 10 in some *Ss* and to 20 in others) until a clear difference in latency did appear in each *S*. When the FR requirement was introduced, two times were recorded on each trial—the latency of the first response and the time required to run the ratio.

With one color reinforced on seven of 10 trials and the other color reinforced on three of 10 trials in the first phase, probability and frequency of reinforcement were confounded. In the second phase, probability of response was equated for some *Ss* while frequency of reinforcement varied as before. There were 14 trials with the previous 70% color of which seven were reinforced, and six trials with the previous 30% color of which three were reinforced. Three of the *Ss* (Group I) were shifted to this equal-probability condition in Phase 2, while the remaining four (Group II) stayed on the confounded problem.

In the third phase, all *Ss* were shifted to an equal-frequency condition in which the probability of reinforcement was 70% for the original 70% color and about 23% for the original 30% color. Of the 40 trials given each *S* in each pair of days (20 trials per day), there were 10 with one color and 30 with the other color; seven of the trials with each color were reinforced.

Results

The results are summarized in Fig. 4 in terms of the latency of the first response on each trial. At no point in the experiment did

Fig. 4. Mean log latency of initial response to each color in Experiment II. In Phase 1, both groups were trained on a confounded 70:30 problem. In Phase 2, probability of reinforcement for response to the two colors was equated for Group I, while Group II remained on the confounded problem. In Phase 3, frequency of reinforcement for response to the two colors was equated and probability of reinforcement alone was varied for both groups. The first arrow shows the start of Phase 2 and the second arrow the start of Phase 3.

any of the animals discriminate the two colors in terms of the time required to run the ratio. Although the FR was necessary to produce evidence of discrimination between the two colors, the discrimination was manifested only in the latency of the initial response. In this respect, the present results are identical with those of the previous experiment with this technique in which amount (2 *vs* 14 sec access to grain), rather than probability of reinforcement, was studied.

The first four points in Fig. 4 are for the last four days of Phase 1 (frequency and probability confounded), during which all seven *Ss* responded with a higher latency to the 30% color than to the 70% color. The first arrow denotes the first day of Phase 2, and the second arrow the first day of Phase 3. In Phase 2, differential response to the two colors disappeared in each animal of Group I (for which the probability-ratio became 50:50 while the frequency-ratio remained 70:30); latency of response to the previous 30% color decreased and latency of response to the previous 70% color increased. The performance of Group II (which continued on the confounded problem) remained essentially unchanged in the second phase. In Phase 3 (with

equal frequency and a 70:23 probability-ratio for both groups), each animal responded differentially to the two colors, the discrimination becoming even sharper than before.

Discussion

These data suggest that the pigeon is sensitive to probability as distinct from frequency of reinforcement. They do not mean, of course, that the so-called probability-matching, which the pigeon shows in certain choice-situations, is in fact based on the discrimination of probability. They do, however, rule out an interpretation of the pigeon-rat difference in terms of the inability of the pigeon to discriminate probability.

The relation between the determinants of latency in the single-key situation and the determinants of choice in the two-key situation might be sought in an experiment with the rat patterned after the present one with the pigeon. If the results for the rat were like those obtained here, it would follow that the single-key situation does not reflect the operation of the variable which gives different behavior in the two-key situation. Different one-key results for the rat might, however, provide some clue to the source of the two-key difference.

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