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PROBABILITY-MATCHING IN THE FISH

By ERIKA R. BEHREND and M. E. BITTERMAN, Bryn Mawr College

The only animal other than man which has yielded unequivocal evidence of probability-matching is the African mouthbreeder, *Tilapia macrocephala*.¹ In the first of two exploratory investigations reported several years ago, a small number of these fish were trained on a simultaneous horizontal-vertical discrimination with response to one of the stimuli reinforced on a random 70% of trials and response to the other reinforced on the remaining 30% of trials. This distribution of reinforcements was ensured by the use of a 'guidance' procedure: if on any trial the unreinforced stimulus was chosen initially, it was removed, and *S* was permitted to earn a reinforcement for response to the other. Under these conditions, each animal in the group developed a stable tendency to choose the more frequently reinforced stimulus approximately 70% of the time. In the second experiment, the same animals were trained with two gray stimuli on a 70:30 spatial problem. Again, matching developed, although the preference for the more frequently reinforced position shifted rapidly from 70% to 100% when guidance was abandoned in favor of a pure noncorrectional method. Analogous experiments with rats and with monkeys have yielded no indication of matching. These animals maximize; that is, they tend to choose the more frequently reinforced stimulus almost 100% of the time.² The experiments reported in the present paper were designed to provide further information on the course of probability-learning in the mouthbreeder and the conditions under which matching occurs.

A secondary concern of the present work was with the course of habit-reversal after inconsistent reinforcement. The results for mammals are

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¹ M. E. Bitterman, Jerome Wodinsky, and D. K. Candland, Some comparative psychology, this JOURNAL, 71, 1958, 94-110.

² Bitterman, Wodinsky, and Candland, *op. cit.*, 103-108; Allen Parducci and James Polt, Correction *vs.* noncorrection with changing reinforcement schedules, *J. comp. physiol. Psychol.*, 51, 1958, 492-495; W. A. Wilson, Jr., and A. R. Rollin, Two-choice behavior of rhesus monkeys in a noncontingent situation, *J. exp. Psychol.*, 58, 1959, 174-180; Wilson, Two-choice behavior of monkeys, *ibid.*, 59, 1960, 207-208; D. R. Meyer, The effects of differential probabilities of reinforcement on discrimination learning by monkeys, *J. comp. physiol. Psychol.*, 53, 1960, 173-175.

suggestive of the paradoxical effect of partial reinforcement on resistance to extinction; for example, rats reverse less rapidly after 67:0 than after 100:0 training,³ and monkeys reverse less rapidly after 60:40 than after 60:0 training.⁴ Since mouthbreeders do not show the paradoxical effect in simple instrumental training—their initial resistance to extinction is *reduced* by partial reinforcement⁵—there was reason to be curious about the readiness with which they would reverse a preference established with inconsistent reinforcement.

METHOD

Subjects. The 16 animals used were not experimentally naïve. All had had rather extensive training in a simple instrumental (single-target) situation and some limited extinction-experience.

Apparatus. The technique employed was an extension of that described by Longo and Bitterman.⁶ Two interchangeable targets of light metal—in this case, one black and one white—were introduced into *S*'s individual 2-gal. living tank, as shown in Fig. 1. The targets were mounted on light rods inserted into the needle-holders of crystal phonograph-cartridges. The outputs of these cartridges were amplified and used to operate a set of relays. (Such a system is extremely sensitive to contact of fish and target, which, of course, is precisely what it was designed to detect.) The reinforcement was a pellet of food (Aronson's mixture) dropped into the water by an automatic feeder. Either of the two targets, or both of them together, could be introduced into the water, or withdrawn from it, by *E*, as indicated in Fig. 1. The fish was brought to the experimental situation in its living tank, the long sides and the back of which were painted in such a way that they admitted only diffuse light. The front of the tank, which was of clear glass, was set before a gray-painted background against which the targets were seen.

Procedure. After several days of pretraining in the new situation, during which the animals learned to strike at both targets readily, there were two days of 50:50 training with guidance, during which the preferences of the animals were established. Then the animals were divided into two groups of 8 *S*s each, matched for the direction and strength of preference, and experimental training was begun. The problem was a confounded brightness-position discrimination (the black target always in one position and the white target always in the other). With minor exceptions (to be noted later) there were 20 massed trials per day. In some stages

³ J. H. Grosslight, J. F. Hall, and Winfield, Reinforcement schedules in habit reversal—a confirmation, *J. exp. Psychol.*, 48, 1954, 173-174.

⁴ C. B. Elam and D. W. Tyler, Reversal-learning following partial reinforcement, this JOURNAL, 71, 1958, 583-586.

⁵ Jerome Wodinsky and M. E. Bitterman, Partial reinforcement in the fish, this JOURNAL, 72, 1959, 184-199; Resistance to extinction in the fish after extensive training with partial reinforcement, this JOURNAL, 73, 1960, 429-434. Nicholas Longo and M. E. Bitterman, The effect of partial reinforcement with spaced practice on resistance to extinction in the fish, *J. comp. physiol. Psychol.*, 53, 1960, 169-172.

⁶ Longo and Bitterman, Improved apparatus for the study of learning in fish, this JOURNAL, 72, 1959, 616-620.

of training, guidance was used and in other stages it was not. Guidance involved the withdrawal of both targets after an unreinforced response and the reintroduction only of the target which was positive on that trial. In the final stage of training, guided choices of this kind sometimes were scheduled quite independently of erroneous choices.

RESULTS

Experiment 1. In the first experiment, both groups were trained, with guidance, against the preferences demonstrated in pretraining.

One group was put on the 100:0 problem, and the second group was put on the 70:30 problem. For the 70:30 group, reinforcements of the minority stimulus were

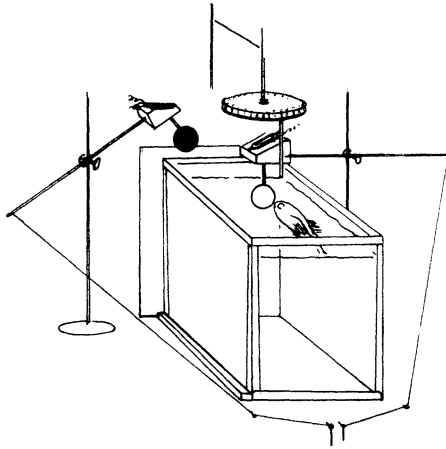


FIG. 1. DIAGRAM OF THE EXPERIMENTAL SITUATION

randomized over blocks of 10 trials, with the restrictions (1) that there could be no more than two such reinforcements in succession, and (2) that there should be at least one in each block of five trials. On Day 25, both groups were shifted to the 0:100 problem, the former minority stimulus now being consistently reinforced. Training on this problem continued through Day 38.

Plotted in Fig. 2 are the daily percentages of preference for the stimulus more frequently reinforced at the outset of training. The curves begin at a low level, because the animals were trained against their original preferences, and then rise rapidly, the 100:0 curve to a very high level, and the 70:30 curve to the 70% level. The matching shown by the 70:30 curve is not merely a group effect, but an individual phenomenon; the preferences of individual *Ss* averaged over Days 4-24 range from 59-76% with a mean of 68%. The individual preferences for the 100:0

group averaged over Days 7-24 range from 93-99% with a mean of 96%.

Shifted to the 0:100 problem, both groups reversed rapidly. After the first day or two on the new problem, their performance was almost identical. Since the curve for the 100:0 group begins at a higher level, its initial rate of change is greater, but there is no hint of cross-over. Unfortunately, there is no directly analogous mammalian experiment which may be compared with this one, but extrapolation from available mammalian data suggests that the results of a directly analogous experiment would be rather different than those pictured here.

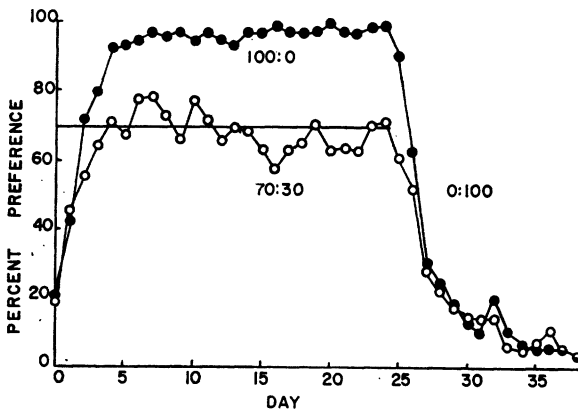


FIG. 2. PERFORMANCE IN EXPERIMENT I
(One group was trained on the 100:0 problem, a second group on the 70:30 problem, then both were shifted to the 0:100 problem. Guidance was used throughout.)

Experiment II. Earlier findings for the 70:30 problem having been confirmed in the first experiment, the next step was to extend the search for matching to other probability-ratios.

In this experiment, the original groups of fish were split to form two new groups, equated for original group-membership and for performance in the first stage of the experiment. One of the new groups was put on the 20:80 problem and the second on the 40:60 problem for 22 days, after which both groups were shifted to the 50:50 problem for 17 days. Guidance was used throughout. In the 20:80 training, one reinforcement of the minority stimulus was scheduled at random for each block of five trials. In the 40:60 training, there were two such reinforcements in each block of five trials and no more than two in succession. In the 50:50 training, the positive stimulus was designated according to selected Gellermann-orders.

The performance of the animals in the second experiment is plotted

in Fig. 3.⁷ The points for Day 38 show the performance of the two groups on the last day of 0:100 training. Thereafter, the two curves separate, approaching different asymptotes in negatively accelerated fashion. The 20:80 group tends at asymptote to choose the minority stimulus approximately 20% of the time. Over Days 48-60, the individual preferences range from 11-23% with a mean of 19%. The curve for the 40:60 group tends somewhat to undershoot the 40% level, the mean for Days 48-60 being 34% and individual scores ranging from 30-48%. There is no overlapping whatsoever between the two groups, either in daily means

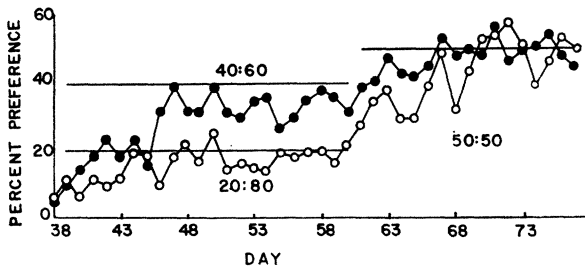


FIG. 3. PERFORMANCE IN EXPERIMENT II

(One group was trained on the 20:80 problem, a second group on the 40:60 problem, then both were shifted to the 50:50 problem. Guidance was used throughout.)

or in terms of individual preference-levels. It should be noted that an increase in preference for the minority stimulus as animals are shifted from 0:100 to 20:80 or 40:60 means a decrease in the number of initial reinforcements, although (with guidance) the total number of reinforcements remains the same.

During the period of 50:50 training, the mean preferences of both groups shift once more, this time to the 50% level. The change in ratio of reinforcement is reflected in the performance of each animal in each of the two groups. Individual preferences averaged over Days 67-77 range from 31-69%. Confronted with insoluble problems of this sort, mammals develop strong preferences for one or the other of the stimuli. Group curves may run along at the 50% level, but only because the two stimuli are fixated by equal numbers of Ss.⁸

In Fig. 4, the average deviation of individual asymptotic preferences

⁷ The curves are based on the data for 7 Ss in each group, 2 Ss having been lost in the course of the experiment.

⁸ Meyer, *op. cit.*, 174.

about asymptotic preferences for the group are plotted for the probability-ratios studied in Experiments I and II. As the curve shows, variability decreases monotonically as the ratio deviates from 50:50.

Experiment III. For the third experiment, two new groups of animals were constituted, matched for performance in the second phase of Experiment II, and both groups now were trained, *without guidance*, against

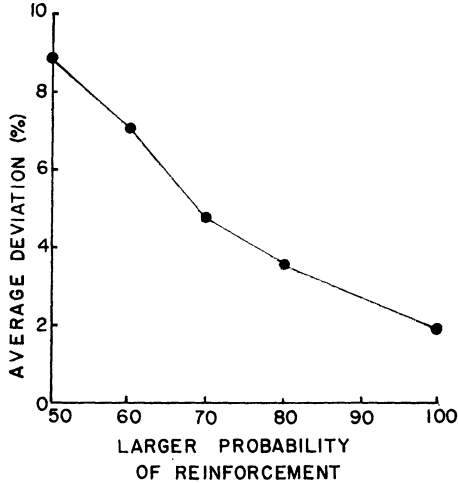


FIG. 4. PRECISION OF MATCHING AS A FUNCTION OF PROBABILITY-RATIO

(The measure of precision is the average deviation of the preferences of individual *Ss* from the mean preference of the group. The curve is based on the data of the first two experiments.)

whatever preference was manifested in that performance, one on the 100:0 problem and one on the 70:30 problem.

The purpose of the work was to check on the earlier conclusion of Bitterman, Wodinsky, and Candland that guidance is essential for matching.⁹ After 21 days, both groups were shifted to the 0:100 problem. With the use of a noncorrection method, the amount of food earned by *S* depended on its choices; total daily intake was equated in supplementary feedings, the number of pellets given each *S* being equal to the number of errors plus two.

The performance of the two groups is plotted in Fig. 5. The first point is for the last day of the previous experiment, and it is below the chance-

⁹ Bitterman, Wodinsky, and Candland, *op. cit.*, 106.

level because the initially preferred stimulus was the minority stimulus. Thereafter, both curves rise in negatively accelerated fashion to a high level. That is, the 70:30 group maximizes rather than matches, a result which confirms the earlier conclusion. Before the point of shift, the performances of the two groups are, in fact, statistically indistinguishable. After the shift, too, the two groups perform in comparable fashion; that is, inconsistent reinforcement neither increases nor decreases the difficulty

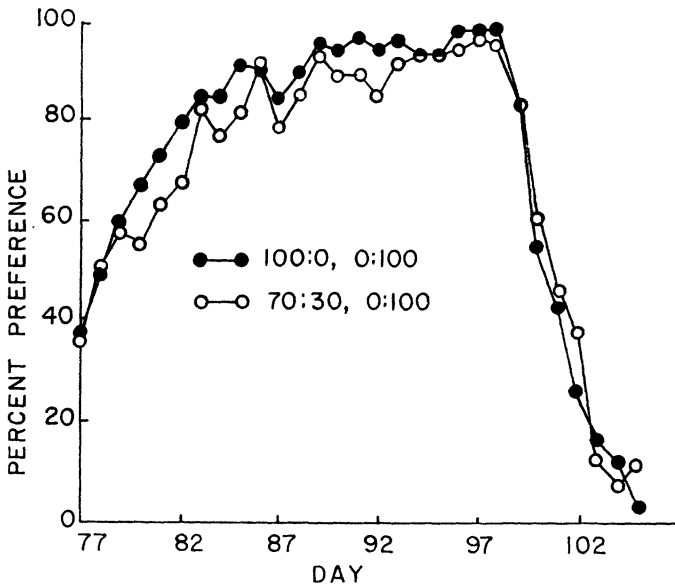


FIG. 5. PERFORMANCE IN EXPERIMENT III

(One group was trained on the 100:0 problem, a second group on the 70:30 problem, without guidance after error in either case. Then both were shifted to the 0:100 problem.)

of habit-reversal. Again, a directly analogous mammalian experiment is not available, but existing data suggests that such an experiment would yield rather different results.

Experiment IV. Matching appears when guidance is used but not in simple, noncorrectional training. Will any procedure which ensures a certain distribution of reinforcements between two stimuli produce a corresponding distribution of choices? The fourth experiment was designed to answer this question.

In the first stage of the experiment, a procedure used by Ramond in work with the rat was adopted.¹⁰ Each animal was given 21 trials per day: seven choice-trials on which preference was measured, with both levers being presented and either response reinforced; and 14 guided trials with the two targets individually, which brought the total number of reinforcements to 14 for one of the targets and 7 for the other. For each animal, the majority stimulus was the one *against* which it had been trained in the previous experiment.

The results are shown in the first portion of Fig. 6. Each of the 14 animals developed a substantial preference for one of the two targets (8

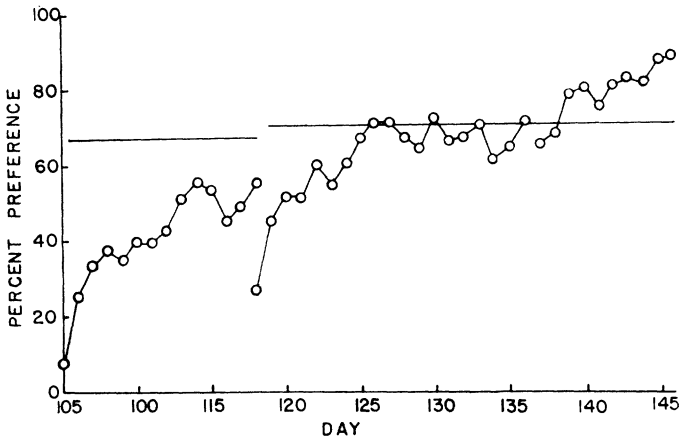


FIG. 6. PERFORMANCE IN EXPERIMENT IV

(In the first stage of training, all responses were reinforced, and guided trials were used to produce a 66:33 reinforcement-ratio. In the second stage, choices were reinforced on a 50:50 basis, and additional guided trials were used to produce a 70:30 reinforcement-ratio. In the third stage, choices were reinforced on a 100:0 basis, and guided trials were used to maintain the over-all 70:30 reinforcement-ratio.)

for the majority target and 6 for the minority target), the curve for the group as a whole therefore showing no preference. Under similar conditions, Ramond's rats developed a transient group-preference for the majority target which disappeared with further training, but not even a *transient* group-preference was shown by the fish. Whatever this difference may mean, the results for the fish indicate that controlling the distribution of reinforcements with guided trials is not enough to produce matching.

¹⁰ C. K. Ramond, Performance in selective learning as a function of hunger, *J. exp. Psychol.*, 48, 1954, 265-270.

The second stage of this experiment was designed to test the hypothesis that guided reinforcements would be effective only if they directly followed unrewarded choices. All animals were given 20 trials per day. Ten were 50:50 choice-trials with guidance following unreinforced choices. The rest were randomly interspersed guided trials, one to the target preferred in the preceding phase of the experiment and nine to the other target. If the animals were influenced by *all* guidances, they should match at the 70% level, because there were, in all, 14 reinforcements to one target and 6 reinforcements to the other. If only the guidances which followed unreinforced choices were effective, the animals should match at the 50% level.

The results are plotted in the middle portion of Fig. 6. As the curve shows, matching at the 70% level appeared. Averaged over Days 126-136, the individual preferences for the more frequently reinforced stimulus range from 41-81% with a mean of 68%. (Without one animal which began with a very strong preference for the minority stimulus, the range of individual preferences is 61-81% and the mean is 70%. The preference of the deviant animal for the majority stimulus increased progressively from day to day to reach the 70% level on Day 136.) The results suggest that all of the guided reinforcements were effective, not only those which immediately followed unreinforced choices.

In the third stage of the experiment, each animal again was given 20 trials per day. Ten were 100:0 choice-trials with guidance after error, the majority stimulus of the previous stage being consistently reinforced. The rest were randomly interspersed guided trials so distributed as to maintain a 70:30 ratio of reinforcement; that is, there were four reinforcements for the target which was consistently reinforced on the choice-trials and six reinforcements for the other target.

The results are plotted in the third portion of Fig. 6. From the matching of the second stage of the experiment, there is an unmistakable shift to maximizing in the third, with every fish showing a marked and progressive increase in preference for the majority stimulus. The conclusion suggests itself that some inconsistency of reinforcement on choice-trials is essential if supplementary guided reinforcements are to influence choice.

SUMMARY AND CONCLUSIONS

In a series of experiments with a confounded visual-spatial discrimination, probability-learning in the African mouthbreeder was studied. When guidance was used to control the distribution of reinforcements between two stimuli—*i.e.* when, after each unreinforced response, the positive stimulus alone was introduced and the animal reinforced for response to it—probability-matching appeared in 80:20, 70:30, 60:40, and 50:50 problems. Precision of matching, as measured by the deviation of individual

preferences from group-values, increased progressively as the ratio of reinforcement decreased from 100:0 to 50:50. The results confirm and extend earlier findings on probability-learning in the mouthbreeder, lending emphasis to what seems to be an important functional difference between fish and mammal.

With guidance eliminated—*i.e.* when a simple noncorrectional method was employed—matching gave way to maximizing. Matching also disappeared when nonreinforcement was eliminated and the ratio of reinforcement maintained with guided trials alone—*i.e.* with reinforced responses to individually presented stimuli; nor could matching be demonstrated when a given stimulus was consistently positive on choice-trials and an intermediate ratio of reinforcement was maintained with interspersed guided trials. Some inconsistency of reinforcement apparently is necessary on choice-trials if the fish is to develop a preference-ratio corresponding to the over-all ratio of reinforcement. When 50:50 choice-trials were mixed with guided trials to give an over-all 70:30 ratio of reinforcement, a 70:30 distribution of choices developed. Clearly, the context in which reinforcement is given has considerable importance. Results of this sort highlight the limitations of the so-called mathematical theories which have been developed to deal with behavior in choice-situations.¹¹

In two experiments, the ease of habit-reversal after 100:0 as compared with 70:30 training was studied, in one case when the use of guidance had led to different pre-reversal asymptotes, and in another case when the elimination of guidance had led to maximizing in both groups. In neither experiment was reversal retarded by inconsistent reinforcement. Directly analogous mammalian experiments are needed to assess the relation of these results to the data on extinction following partial reinforcement in simple instrumental situations.

¹¹R. R. Bush and Frederick Mosteller, *Stochastic Models for Learning*, 1955, 1-365; R. R. Bush and W. K. Estes, (eds.), *Studies in Mathematical Learning Theory*, 1959, 1-432.