COLOR ALTERNATION LEARNING IN THE PIGEON UNDER FIXED-RATIO SCHEDULES OF REINFORCEMENT¹

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Pigeons were trained on a non-spatial delayed alternation task in which the correct stimulus was that color not responded to on the preceding trial. Subjects required to emit either 15 or 30 pecks to the correct stimulus within a trial learned the task, those required to emit only one or five pecks did not. Also, alternation was learned more easily after an incorrect than after a correct trial. Later experiments showed that a minimum fixed-ratio value was required for successful color alternation to occur, even though no fixed-ratio requirement was necessary when a position cue was available. The mechanism of the fixed-ratio effects derived from the pigeons' tendency to repeat their response in the presence of the color reinforced on the last trial. Whereas subjects trained on larger fixed-ratios corrected this error tendency within a trial, subjects trained on smaller fixed ratios did not.

Experiment I: *Acquisition of Color Alternation with Various Fixed-Ratio Schedules of Reinforcement*

Experiment II: *Transfer of Color Alternation to New Color Combinations*

Experiment III: *Transfer of Color Alternation between Different Fixed-Ratio Schedules of Reinforcement*

Experiment IV: *Differences in Accuracy after Correct and Incorrect Trials as a Function of Positional Cues and Reinforcement Value*

General Discussion

While a variety of selective attention effects indicate that not all stimuli differentially correlated with reinforcement come to control behavior, it has generally been assumed that a necessary condition for the acquisition of stimulus control is that differential reinforcement occur in the presence of the stimulus. A learning task that does not satisfy the condition of temporal contiguity between stimulus and reinforced response in any obvious sense is the delayed alternation problem. The delayed al-

ternation procedure not only requires the subjects to respond on the basis of some previous event no longer physically present, but it also requires that the response just reinforced be avoided on the next trial. Thus, if stimulus control occurs only under the condition of temporal contiguity between stimulus and reinforced response, either animals should be incapable of learning delayed alternation or some further analysis is required of the actual stimulus effective in that learning problem.

A frequent interpretation of successful alternation acquisition has been that the subjects have acquired some form of mediational behavior that allows the stimulus from the previous trial to be carried over to the point of the response. When the alternation problem involves spatial cues, such mediational behavior often includes postural orientation toward the appropriate response position (*e.g.*, Hearst, 1962). Mediation in terms of behavioral chains is less plausible, however, for alternation problems employing non-spatial cues. There is often no obvious means whereby the cue from the previous trial can be said to be behaviorally mediated. Thus, an examination of acquisition of non-spatial delayed alternation should more clearly establish the temporal conditions under which stimulus control does or does not occur.

The first question that must be asked of non-spatial delayed alternation is whether animals can learn it. Of previous studies of this problem (all confined to primate subjects),

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some have reported that none of their subjects learned the problem (Schusterman, 1962; Ettlinger and Wegener, 1958). Others have reported that only some of their subjects learned the problem and then only with large numbers of training trials (Nissen and Taylor, 1939; Pribram and Mishkin, 1956; Pribram, 1961; Mishkin, Vest, Waxler, and Rosvold, 1969). Thus, non-spatial alternation must be considered extremely difficult for animals to learn, and some further analysis is needed of the procedural variables that may facilitate its learning.

The present experiment investigated whether non-primate subjects, in this case pigeons, could successfully learn to alternate between a pair of colors. In addition, four values of fixed-ratio (FR) schedule of reinforcement were examined, both to vary the number of responses per reinforcement, and to allow an examination of the pattern of responding when several pecks are required within a single trial.

EXPERIMENT I: ACQUISITION OF COLOR ALTERNATION WITH VARIOUS FIXED-RATIO SCHEDULES OF REINFORCEMENT

METHOD

Subjects

Eight White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. Subjects 5, 6, 7, and 8 had been trained previously, only on an auditory discrimination. Subjects 273, 295, 462, and 467 had been trained on a variety of simple color discriminations but had no experience on any type of delayed response or alternation training.

Apparatus

The apparatus was an operant conditioning chamber converted from an aluminum picnic cooler. The bird's chamber was a 12-in. (30.5-cm) cube, and was equipped with an overhead houselight and constant white noise input to mask outside noise. On the front panel, two Gerbrands pigeon keys 0.75 in. (1.9 cm) in diameter were mounted 4 in. (10 cm) apart, center to center, and 9 in. (23 cm) off the floor, with each key requiring the application of at least 0.15 N for operation. Behind each

key were two 7.5-w Christmas tree light bulbs, one of which was illuminated behind each key each trial. Each peck on either of the keys produced a click resulting from the activation of a relay located just behind the front panel. Directly between and 5.25 in. (13 cm) below the keys was a 2 by 1.75 in. (5 cm by 4.5 cm) aperture through which the birds were fed when a food magazine was activated. The electrical scheduling equipment for the conditioning chamber was located in the next room.

Procedure

Each of the four FR schedules of reinforcement was presented to two subjects. For a given value of FR, that number of correct or incorrect pecks would produce a completed trial. Correct and incorrect pecks were counted separately so that whichever reached the designated FR value first determined whether the trial was regarded as correct or incorrect. The FR values used were FR 1 for Subjects 8 and 462, FR 5 for Subjects 7 and 467, FR 15 for Subjects 273 and 295, and FR 30 for Subjects 5 and 6. All subjects were given one session on each of the smaller FR values before being placed on their respective schedule, in order to shape the pecking behavior for the larger values.

Each subject was run daily, with the sessions terminating after a fixed number of reinforcements. For Sessions 1 to 6, this number was 50; for Sessions 7 to 8, 60; and thereafter 70. Each reinforcement consisted of 2.8-sec access to the food magazine, with 0.2 sec of blackout following the reinforcement before the keylights were illuminated for the beginning of the next trial. An incorrect trial resulted in a 3-sec blackout of all lights, so that the time between trials was always 3 sec regardless of whether the trial was correct or incorrect.

The stimuli used during alternation acquisition were red and green lights, each appearing behind only one of the keys on a given trial, with the color behind a given key changing randomly after every correct trial. After an incorrect trial, the positions of the colors remained unchanged. The color designated as correct on the first trial of a session was randomly varied. Afterwards, the stimulus designated correct on a given trial was always the color not pecked on the preceding trial, regardless of whether the preceding trial was correct or incorrect.

All subjects were run with no changes in the above procedure until either 30 days after the first day with 80% correct trials or until it became clear that no further improvement would occur. Subjects 7, 8, and 462 fulfilled the latter criterion and were then shifted to the FR 15 schedule. Subject 467 was continued on the FR 5.

RESULTS

The percentage of correct trials is shown in Fig. 1. The performance of the FR 15 and FR 30 subjects quickly diverges from that of the FR 1 and FR 5 subjects, with the former subjects clearly having learned the task. In contrast, none of the FR 1 or FR 5 subjects learned to alternate between the colors, even though all of these subjects stabilized around 65% correct. As will be seen in Fig. 2, this performance, apparently greater than chance, is due to the positions of the colors remaining unchanged after incorrect trials.

The second portion of Fig. 1 represents the changes occurring for the subjects in the FR 1 and FR 5 groups after their change to FR 15. For all subjects, changing the FR value produced an increase in accuracy comparable to that of the subjects originally trained on the larger FRs. For Subject 467, however, which was continued on FR 5, alternation accuracy increased only slightly.

As regards the comparison of the FR 15 and FR 30 conditions, the first portion of Fig. 1 shows that the FR 15 subjects learned the task

more quickly. This is perhaps misleading, however, in that subsequent data not on the graph showed that asymptotic performance of both groups of subjects was approximately the same, 90 to 95% correct.

Figure 2 shows, from a different perspective, the improvement of the birds shifted to the FR 15 in that accuracy after a correct trial is separated from accuracy after an incorrect trial. For the last 15 days of training before the change to the FR 15, the two measures are remarkably different. Although only the slightest evidence of learning is revealed after a correct trial, the birds are 80 to 90% accurate after an incorrect trial. Also, the change in FR produced a very regular increase in accuracy after a correct trial, but accuracy after an incorrect trial changed little if any.

Also to be noted from Fig. 2 is that Subject 7, which was initially trained on FR 5, showed an immediate increase in accuracy when placed on FR 15, indicating that it learned something about color alternation from training on FR 5. In contrast is Subject 467, which was continued on the FR 5, whose alternation accuracy after a preceding correct trial increased, but extremely slowly.

Of importance to any interpretation of the above FR effects is the distribution of the birds' responses. The first noteworthy observation is that the subjects trained on the smaller FRs exhibited substantial position biases. In spite of equal numbers of reinforcements being given for each of the two response positions, at least 80% of the errors of three of the FR 1 and FR 5 subjects were emitted to a

Fig. 1. Accuracy of performance during alternation training as a function of FR schedule of reinforcement.

Fig. 2. Accuracy of alternation performance separated into that after a correct trial and that after an incorrect trial.

single position, with this preferred position varying with the individual subject. For the fourth subject, 467, there were transient position biases, with the position preference drifting back and forth between the two alternatives. In contrast, the errors of all FR 15 and FR 30 subjects were distributed relatively evenly between the two response positions. Similarly, when Subjects 8, 462, and 7 were transferred to the FR 15, their position biases were considerably reduced, although they continued to emit between 60 and 80% of their errors to their favored position.

A second facet of the response distribution was that the birds frequently emitted more pecks during the trial than required by their respective FR schedules. That is, the birds often shifted their response from one color to the other within a trial, with these changeovers usually occurring in the first few pecks of a trial. Moreover, the number of such changeovers varied with the FR schedule. The larger FR values produced many more such changeovers, even when this number was corrected for the number of opportunities for changeovers to occur. The number of changeovers was further correlated with learning proficiency for the FR 15 and FR 30 subjects, in that this number increased most during the period of most rapid learning.

DISCUSSION

The success of the pigeons in learning color alternation is clearly determined by the number of pecks required during a trial. All subjects trained on FR 15 and FR 30 learned the task, while no subject learned when trained on FR 1 or FR 5. A possible explanation for this effect is the greater effort required by the larger FR values. That is, a larger work requirement may cause the pigeon to attend to the cue of color pecked on the last trial, with this cue not being attended to with a small work requirement. Such an interpretation is supported by the substantial position biases that occurred for the FR 1 and FR 5 subjects, but not for the FR 15 or FR 30 subjects.

An alternative interpretation of the FR effects is suggested by the distribution of pecks within individual trials. A major feature of alternation acquisition was the tendency of the subjects to shift their response between keys within trials. As alternation became more accurate, the subjects often began responding to

the color in the presence of which reinforcement had just been delivered, and then switched to the correct color before the full FR requirement was completed. The smaller FRs did not allow for such switching, in that the first few pecks of a trial determined whether that trial was designated as correct or incorrect. Thus, a possible explanation for the FR effects is that the initial pecks of a trial have a different probability of being correct than subsequent pecks within the same trial. A plausible interpretation for this difference then could be the tendency of the subjects to repeat the response for which they were just reinforced. Experiment III is addressed to separating these two alternative explanations.

EXPERIMENT II: TRANSFER OF COLOR ALTERNATION TO NEW COLOR COMBINATIONS

A question posed by the success of the pigeons in Exp. I is what exactly was learned for successful alternation to occur? This question is emphasized by previous findings that even primate subjects have difficulty learning non-spatial alternation, *e.g.*, Nissen and Taylor (1939), and the finding in Exp. I that learning occurred only when large FR requirements were imposed. To answer this question, Exp. II introduced various combinations of novel color stimuli, sometimes in combination with the original stimuli, so that the behavior actually controlled by individual training stimuli might be independently examined.

At least three different modes of behavior for solving the alternation problem can be readily distinguished. First, the birds could learn to alternate between the stimuli, independently of the specific stimuli used. This possibility is suggested by earlier work with primates in which an alternation accuracy of 65 to 70% was obtained, even though the specific stimulus pairs were changed every few trials (Behar, 1961). This hypothesis would predict substantial transfer to any new pairings of colors.

A second alternative is that the birds learn only to avoid the color to which their response was just reinforced. Then, the color pecked on the preceding trial serves not as a cue for pecking the alternative color but rather as a cue for avoiding the color just responded to. This hypothesis would predict greater accuracy dec-

rements for new pairings involving two new stimuli than for new pairings with only one new stimulus. Also, assuming that the cue function of the stimuli are only gradually learned, it would predict that for the pairings with only one new stimulus, accuracy after a correct response on the old stimulus should be high and accuracy after a correct response on the new stimulus should be low.

The third hypothesis is that the birds have learned a pair of stimulus-response chains, *i.e.*, SD_{red} -Response_{green} and SD_{green} -Response_{red}. This hypothesis would predict that the introduction of any new pairings, regardless of whether they contained one of the old stimuli, would reduce the accuracy to a chance level.

METHOD

The subjects and apparatus were the same as in Exp. I. All subjects were continued on an FR 15 schedule of reinforcement, with the exceptions of Subjects 5 and 6, which continued on FR 30.

Procedure

After all subjects, except 467, had finished the training in Exp. I, transfer tests to new pairs of colors were begun, consisting of all possible combinations of red, yellow, green, and blue, taken two at a time. For Subjects 8, 295, and 5 (Group I), the order of testing was yellow-green, red-yellow, blue-green, red-blue, and yellow-blue. For Subjects 7, 462, 273, and 6 (Group II), the order was yellow-blue, red-blue, blue-green, red-yellow, and yellow-green. Each subject received five successive days of training on each pair, with three days of retraining on the original red-green alternation occurring between exposures to new pairs.

RESULTS

Figure 3 and Table 1 present the alternation accuracy for each transfer condition, and for each red-green retraining period separating transfer conditions. Only trials after a preceding correct trial are presented there, in that trials after incorrect trials were found to be insensitive to the change to the new color pairings. Presumably this was due to the position cue that was present only after incorrect trials.

If the individual transfer conditions in Fig. 3 are examined, considerable transfer occurs to the red-blue and yellow-green conditions,

Fig. 3. Accuracy of alternation after a preceding correct trial for five transfer conditions and the retraining between transfer conditions.

while only slight transfer occurs to the red-yellow and blue-green. The interpretation of these data is complicated by the fact that the yellow-blue condition, the pairing with two new stimuli, produced an accuracy intermediate between these two classes. Moreover, from Table 1, the ranking of transfer performance on the five conditions is different for the two groups, indicating that the order of presentation may be a significant variable.

Apart from the overall accuracy on the various transfer conditions, the finding most relevant to an interpretation of alternation learning is the difference in performance after correct responses to old stimuli (red, green) and after correct responses to new stimuli (yellow,

Table 1

Percentage correct for trials after a preceding correct trial for each subject on each transfer condition, with percentages calculated from all five days of testing on each condition.

Order	Pairing	Group I			
		8	295	5	x
1	Y-G	80.7	79.7	89.8	83.4
2	R-Y	63.2	54.8	58.5	58.8
3	B-G	55.4	51.3	56.6	54.4
4	R-B	82.0	79.4	66.3	75.9
5	Y-B	81.1	87.2	73.6	80.6

Order	Pairing	Group II				
		7	462	273	6	x
1	Y-B	64.1	71.3	77.2	72.7	71.3
2	R-B	79.8	79.2	91.6	85.2	83.9
3	B-G	54.8	54.2	53.7	60.9	55.9
4	R-Y	62.4	58.8	59.9	58.1	59.8
5	Y-G	68.5	66.8	85.3	87.5	77.0

blue) for those transfer pairings involving one old and one new stimulus. Table 2 presents these data for each subject on each transfer condition. When this difference score is averaged across all transfer conditions for each subject, five of the seven subjects show a higher accuracy after a correct response to an old color than after a correct response to a new color. If individual transfer conditions are examined, moreover, most of this accuracy difference is contributed by the yellow-green and red-blue pairings. When these data were analyzed with a student's *t* test for difference scores, the mean difference score across subjects is statistically significant for the combined yellow-green and red-blue pairings (prob. $t_{(6)} = 3.47$ less than 0.01), but is not significant for the combined blue-green, red-yellow pairings (prob. $t_{(6)} = 0.59$ greater than 0.05). Thus, it is only when a high overall accuracy is attained on a transfer condition that the difference between performance after responses on old and after responses on new stimuli is apparent.

Table 2

Percentage correct of trials after a correct response on an old stimulus (red, green) minus percentage correct of trials after a correct response on a new stimulus (yellow, blue). Data are presented for each subject for each transfer condition having one old and one new stimulus.

Pairing	Group I			x
	8	295	5	
Y-G	-3.8	4.2	-1.0	-0.2
R-Y	-2.8	-12.9	-0.6	-5.4
B-G	9.2	-11.9	19.6	5.6
R-B	15.8	10.5	5.6	10.6
x	4.6	-2.5	5.9	2.7

Pairing	Group II			x
	7	462	273	
R-B	26.8	-4.0	11.3	-2.7
B-G	5.6	-8.3	9.0	-0.6
R-Y	1.1	16.3	12.8	-10.9
Y-G	10.0	15.9	9.5	6.0
x	10.9	5.0	10.7	-2.1

DISCUSSION

The hypothesis most supported by the above results is that the birds have learned to avoid responding to the color reinforced on the preceding trial. The evidence supporting this hypothesis is that accuracy is higher for trials after correct responses to old stimuli than for trials after correct responses to new stimuli,

with this difference being larger the greater the amount of transfer to a particular color combination. Thus, the color last pecked serves less to cue the next response to the alternative color than to cue not responding to the same color.

The hypothesis that alternation acquisition consists at least partially of learning a pair of response chains cannot be fairly evaluated by the present data. While the considerable transfer that was shown to three of the five novel color pairings argues against this interpretation, stimulus generalization between the colors cannot be excluded as an explanation for this transfer.

A second consideration from the above results is the unexpected ordering of amount of transfer to the respective color pairings. Yellow-blue, the pairing with two new stimuli, resulted in substantially more transfer than either red-yellow or blue-green, which contained one old and one new stimulus. This result can be explained by the hypothesis that the pigeons regarded red and yellow, and blue and green, as partially equivalent in some sense. Then, the transfer tasks of yellow-green, red-blue, and to a lesser extent yellow-blue, are only slightly different from the original red-green training pair. The difficulty of red-yellow and blue-green is also then explained, in that a new discrimination must be made between them. Support for this hypothesis comes from the effects of red-yellow and blue-green training on transfer to yellow-green and red-blue, respectively. Presumably, causing the animal to discriminate red from yellow and blue from green should cause it to judge them less equivalent later on. Consequently, there should be less transfer to red-blue after blue-green training than before such training. Similarly, there should be less transfer to yellow-green after red-yellow training. This hypothesis is tested by a comparison of the differences in red-blue and yellow-green transfer produced by the different orders of presentation for the two groups of subjects. From the group means presented in Table 1, this hypothesis is supported, in that yellow-green transfer is greater for Group I than for Group II and red-blue transfer is greater for Group II than for Group I. Unfortunately, an interpretation of these results is complicated by the failure of these effects to occur for several of the individual subjects.

EXPERIMENT III: TRANSFER OF COLOR ALTERNATION BETWEEN FIXED-RATIO SCHEDULES OF REINFORCEMENT

Because the FR value so determines success in color alternation learning, the best approach to analyzing such learning is apparently a closer examination of the FR differences. Since Exp. I showed that smaller FR values did not produce learning of the task, a major question is whether animals previously trained on the larger FR values will transfer alternation to smaller FR values. If transfer does occur, it would suggest that although smaller FR values do not cause the pigeons to attend initially to stimuli such as the color pecked on the last trial, once developed, such behavior will continue with smaller FR values. On the other hand, if the FR effect is the result of the pigeons' tendency to repeat their just-reinforced response, transfer should not occur.

METHOD

The subjects, apparatus, and details of procedure were unchanged from those of Exp. I.

Reduction of FR Value

Three of the birds (7, 462, 8) were shifted gradually from the FR 15 to smaller FR values. Additional decreases in FR value occurred when the subject attained the criterion of 80% accuracy for three consecutive days. The details of these shifts are presented in the Results. Also during this time, Subject 467, which had not successfully learned the color alternation on the FR 5, was shifted directly to the FR 15, in an effort to replicate the effects of this shift seen with Subject 7 in Exp. I. Training on this phase continued for 40 daily sessions.

Threshold Determination

Phase II was designed to determine the minimum FR value required for a specified level of accuracy. Each subject began on the FR value last used in Phase I. Then, if a bird's accuracy for a given day's performance was 80% or above, the FR value for the next day was decreased by one. If the accuracy was below 80%, the next day's FR value was increased by one. This training continued for 53 sessions.

RESULTS

Reduction in FR Value

Figure 4 shows the effects of introducing smaller FR values. As in Exp. I, the change in FR had little effect on trials after an incorrect trial, but a substantial effect on trials after a correct trial.

If only accuracy after correct trials is considered, it is clear from Fig. 4 that decreasing the FR decreased alternation accuracy. For Subjects 7 and 462, there was a similar effect: recovery from the first change, but no recovery from the second. Thus, for these two subjects, an FR value can be reached that does not allow a high accuracy, and the size of this FR value varies with the individual subject. This latter point is especially emphasized by Subject 8. Shifted immediately from FR 15 to FR 5, its initial performance after the switch was at a chance level only, but then improved with training such that at the end of FR 5 training it was 80% accurate.

Also to be noted from Fig. 4 is the performance of Subject 467, which was shifted from FR 5 to FR 15. As was the case for Subject 7 in Exp. I (see Fig. 2), Subject 467 was 60 to 65% accurate after a preceding correct trial on FR 5 (after over 100 training sessions), but immediately began at an 80% accuracy with the change to FR 15.

Fig. 4. Accuracy of alternation divided into that after correct trials and that after incorrect trials, as a function of changing FR schedules of reinforcement.

Threshold Determination

Under the tracking procedure, if a minimum FR value does exist, the function of FR value used should oscillate between some two points. Figure 5 shows that this oscillation generally occurred for all four subjects tested. To be noted is the function of Subject 467. This phase of training was begun with it performing on the FR 15, so that its progress can be seen for the entire transition from FR 15 to FR 5.

Because the data shown in Fig. 5 are based on accuracy for all trials, and because accuracy of trials after an incorrect trial was shown to be insensitive to FR changes, it is useful to examine the effects of the FR changes on responding after a correct trial alone. Table 3 shows the accuracy of these responses for the various FR values given to each bird. In order to minimize the slight improvement over days seen in Fig. 5, these data include only those sessions after the first 20 days of exposure to the tracking procedure. All subjects show a monotonic relation between FR size and response accuracy.

A final observation from the tracking procedure is how the pattern of the birds' responding changed with variation of the FR schedule. Table 4 shows various characteristics of the response pattern of a single subject, 462,

Fig. 5. Value of FR schedule as a function of days of training during the tracking of the FR threshold for 80% accuracy.

Table 3

Percentage correct for trials after a preceding correct trial for each value of FR given to each subject. The number of training sessions given to each FR value is shown in parentheses, with the data taken only from the last 33 sessions of training.

FR value	Subject			
	7	8	462	467
12				
11			80.4 (6)	
10			77.9 (11)	
9	84.1 (4)		75.9 (11)	87.0 (1)
8	77.9 (9)		69.6 (5)	82.6 (3)
7	76.6 (13)			80.3 (13)
6	70.4 (7)			72.9 (14)
5		84.5 (6)		
4		79.0 (16)		
3		71.0 (11)		
2				

which, with the exception noted, is representative of all four subjects. Shown in Row 1 is a measure of position bias. For Subject 462, there is a consistent but small position preference that slightly increased with reductions in FR value. However, the degree of position preference is the single measure shown in Table 4, which is not representative of all subjects. For Subject 7, there was a larger position bias (65 to 70%) that remained relatively unchanged with FR reductions; for Subject 467, the degree of position bias decreased with reductions in FR value. Thus, unlike Exp. I, no

Table 4

Measures of response patterning for Subject 462, as a function of FR value. Trials with changeovers are defined as trials in which more pecks were emitted than required by the FR schedule. Excessive pecks are defined as total pecks minus pecks required by FR schedule.

Measure	FR value			
	11	10	9	8
Percentage of total pecks to left position	55.4	52.2	54.8	60.1
Percentage of trials during which changeovers occurred	24.2	19.9	19.4	14.0
Average number of excessive pecks for trials during which changeovers occurred	2.03	2.23	2.07	2.25
Percentage occurrence of changeovers for trials after a correct trial	27.8	21.2	20.6	15.7
Percentage occurrence of changeovers for trials after an incorrect trial	10.7	15.1	11.3	8.3

consistent correlation between position bias and alternation accuracy was present.

Rows 2 to 5 reveal the pattern of responding when more pecks were emitted in a trial than were required by the FR schedule, *i.e.*, when the subject changed from one color to the other within a trial. Row 2 shows the percentage of trials during which more pecks were emitted than the FR schedule required. For all subjects, this measure decreases regularly with reductions in FR value. Row 3 shows the average number of excessive pecks for those trials during which excessive pecks occurred. Unlike the measure in Row 2, the measure in Row 3 changes little, if any, with FR reductions. Rows 4 and 5 again show the percentage of trials during which changeovers occurred, but now as a function of the reinforcement value of the preceding trial. Row 4 shows this percentage for trials after a correct trial, and Row 5 for trials after an incorrect trial. Both measures decrease as a function of FR reduction, but for all subjects the measure for trials after correct trials is much greater than for trials after incorrect trials. (It should be recalled that accuracy after incorrect trials is almost always higher.)

DISCUSSION

This experiment clearly established that successful color alternation cannot occur with small FR values, even when such values are gradually introduced. One possible interpretation of the FR effects this finding eliminates is that larger FR values cause the animal to attend more strongly to cues generally too weak to control behavior. Such an explanation would predict that once the cues were attended to they would continue to control behavior, a prediction clearly rejected by the results. Moreover, the behavioral correlates of FR reduction provide still stronger rejection of the selective attention hypothesis. Unlike Exp. I, in which the FR differences were correlated with the presence or absence of position biases, position bias in this experiment was either absent, or was not strong enough to account for the poor performance with small FR values. More strongly correlated with FR reduction than position bias was the tendency of the subjects to change from one color to the other within a trial. Whenever this tendency was high, accuracy was high, and *vice-versa*. Moreover, this tendency was much greater after a

correct trial than after an incorrect trial (see Table 4). The one hypothesis that accounts for these results is that larger FR values are required to overcome perseveration to the just-reinforced stimulus.

Also supporting the perseveration hypothesis is the performance of subjects shifted from FR 5 to FR 15. As shown by the immediate increase in accuracy after the switch to the FR 15, color alternation learning did occur from FR 5 training. However, the poor performance during FR 5 training reveals that some mechanism reduces alternation accuracy when small FR values are used. Again the most plausible explanation for this performance deficit is the tendency of the subjects to repeat their just-reinforced response.

EXPERIMENT IV: DIFFERENCES IN ACCURACY AFTER CORRECT AND INCORRECT TRIALS AS A FUNCTION OF POSITIONAL CUES AND REINFORCEMENT VALUE

A consistent finding in Exp. I, II, and III was the difference in performance obtained after preceding correct and incorrect trials. During color alternation acquisition, transfer to new colors, and transfer to smaller FR values, alternation after incorrect trials was much more successful than after correct trials. The first three experiments allow two possible interpretations for this difference. Perseveration occurring to the just-reinforced stimulus is a possible explanation, in that such perseverative tendencies should be absent after incorrect trials. This is supported by Exp. III, in which the tendency to change between colors within trials was found to be much greater after correct than after incorrect trials. A second alternative is that the procedure used in the first three experiments allowed the usage of positional cues after incorrect trials but not after correct trials. This is noteworthy in that previous experiments have shown that a variety of organisms can easily learn spatial delayed alternation (*e.g.*, Hearst, 1962; Livesay and Trender, 1966), while non-spatial delayed alternation has been learned only with great difficulty.

To separate the effects of the use of the position cue from those of reinforcement value, the present experiment again presented the two transfer tasks found above to yield the

largest difference in performance after correct and incorrect trials, but this time with the position cue after incorrect trials removed. Thus, if a difference in performance after correct and incorrect trials occurs with the position cue removed, it must be considered an effect of reinforcement value *per se*.

METHOD

The subjects were 295, 273, 5, and 6. The apparatus and procedural details were unchanged from Exp. I.

The subjects had previously been trained extensively on either FR 15 or FR 30. They were continued on the color alternation task, but now with the position cue after incorrect trials removed. The color not pecked on the last trial was still designated correct, but the position of the colors changed randomly after all trials, not just after correct trials.

Ten days of retraining with an intertrial interval of 3 sec were then given, followed by 32 days of training in which intertrial intervals ranging from 3 to 25 sec were used, in order that a larger number of incorrect trials would occur, insuring that the subjects had been exposed to the change in procedure a large number of times. For this training, Subjects 295 and 273 remained on an FR 15 schedule, and Subjects 5 and 6 remained on FR 30.

Transfer to Blue-Green

The subjects were trained for five more days on the red-green alternation with the position cue after incorrect trials removed and with a 3-sec intertrial interval. The new color pairing blue-green was then substituted for five days with no other changes in procedure.

Transfer to FR 5

After completion of the blue-green transfer testing, the subjects were returned to their lofts for 45 days, during which time the experiment was discontinued. The subjects were then returned to the red-green alternation problem for retraining with the position cue after incorrect trials again removed. Subjects 295 and 273 continued on FR 15 and Subjects 5 and 6 on FR 30. After six days of such training, the subjects were immediately switched to FR 5, with no other changes being made. This training continued for 10 sessions.

RESULTS

Transfer to Blue-Green

The blue-green pair was chosen for the transfer test because Exp. II had shown virtually no transfer to that pair. This allowed an evaluation of the effects of removing the position cue using stimuli for which little prior alternation learning had occurred. The results of the transfer testing are shown in Fig. 6. Also shown are results for the same four subjects when tested for blue-green transfer in Exp. II when the position cue was present after an incorrect trial. The results are averaged because they are typical of all subjects. The primary difference between the two tests is for performance after incorrect trials. Performance after a correct trial is essentially the same for both tests, showing only a small amount of transfer and improvement for the five days of testing. Performance after an incorrect trial, however, was much more accurate for Test 1, in which the position cue was present. It should be especially noted that even in Test 2, when no position cue was present, there was a significant superiority for performance after incorrect trials. Although performance on the first day of testing was the same for the two types of trials, for all subjects alternation after an incorrect trial was learned more quickly.

Fig. 6. Alternation accuracy after preceding correct and after preceding incorrect trials during two transfer tests using the blue-green transfer condition, with the tests differing only in the use of a position cue after incorrect trials for test 1.

Transfer to FR 5

The results of FR reduction are shown in Fig. 7. Presented first are the last four days of red-green retraining with the larger FR values, and then the results of the switch to the FR 5. Again, the average values presented are typical of all subjects. For the larger FR values, there is no significant difference between responding after correct and incorrect trials. Also, an improvement across days is observed, presumably due to the recovery from the forgetting that occurred during the 45-day period in which the experiment was discontinued.

Fig. 7. Alternation accuracy after preceding correct and incorrect trials for the last four sessions on FR 15 and FR 30 schedules, and for 10 days of transfer testing using the FR 5.

The switch to FR 5 produced different results, however. There, accuracy after a preceding correct trial was only slightly better than chance, while accuracy after an incorrect trial ranged from 67 to 78%.

DISCUSSION

Experiment IV showed that the differences found in the first three experiments between accuracy after correct and after incorrect trials resulted from two factors: the usage of positional cues after incorrect trials, and the effects of reinforcement value *per se*. The latter factor further supports the interpretation of the FR effects presented in Exp. III, namely, that the FR differences derived from the pigeons' tendency to repeat their just-reinforced response. As the perseveration notion would predict, the performance difference after correct and after incorrect trials was especially pronounced with the switch to smaller FR values.

GENERAL DISCUSSION

The present study indicated that qualitative differences in pigeons' complex learning performance can be produced simply by changing the response requirement. All subjects learned the non-spatial alternation problem, but only when an appropriate response requirement was employed. In view of previous findings, which have found non-spatial alternation to be extremely difficult for primate subjects, the role of the response requirement as a determinant of alternation performance for those subjects merits further investigation as well.

The interpretation of the present FR effects derives from the tendency of the pigeons to repeat their response to the stimulus reinforced on the last trial. Whereas subjects trained on larger FRs corrected this error tendency within a trial, subjects trained on smaller FRs did not, in that their initial perseveration at the beginning of a trial was counted as an incorrect trial. The evidence for this interpretation is substantial: (1) the correlation between FR value and the number of changeovers within trials; (2) the failure of the pigeons to perform accurately with small FR values even when such values were gradually introduced; (3) alternation learning did occur with small FRs (as evidenced by the results of the shift from FR 5 to FR 15 for Subject 7 in Exp. I and Subject 467 in Exp. III), whereas alternation performance with small FRs was somehow reduced in accuracy; (4) the difference found in Exp. IV between alternation after correct and incorrect trials, coupled with the observation in Exp. III that the tendency to changeover between colors within a trial was much greater after correct than after incorrect trials. Further support comes from Exp. II, which showed that the color last pecked does not cue the next response to the alternative color, but rather cues not responding to the same color again. Apparently, the mechanism of alternation acquisition is learning to inhibit the error tendency of repeating the response just reinforced.

If the overcoming of perseveration to the just-reinforced response is accepted as the mechanism of the FR effect, a possible implication is that the FR effect is specific to the alternation problem. It should be noted, however, that for other complex discrimination problems (*e.g.*, matching to sample, learning

set, successive discrimination reversals) there are inherent sources of perseveration as well, e.g., previous conditioning in discrimination reversal learning, general error factors in learning set acquisition. Thus, FR schedules might enhance learning proficiency in those situations as well.

In support of the generality of the FR effects is a study by Gonzalez, Bainbridge, and Bitterman (1966), which varied the number of bar presses per trial required of rats in a discrete trial go, no-go alternation problem. They found that subjects trained on FR 10 learned the alternation sequence much more rapidly than those on FR 1. A similar result was obtained by the present author (Williams, 1970) when varying the FR schedule in a successive discrimination reversal problem. Pigeons trained on FR 15 made many fewer errors to criterion than those trained on FR 1, with this difference being greater the more difficult the discrimination.

If the explanation of the FR effects is indeed the opportunity to inhibit error-producing response tendencies, the present results further indicate the need for great caution in using tasks such as color alternation as tools of the comparative psychology of learning. Since many tasks used for cross-species comparisons (e.g., learning set, successive reversal learning) are generally considered to involve the ability to inhibit non-reinforced response tendencies, the present experiment raises a critical question—that differences among species on such tasks may merely reflect the different dimensions of the responses required of the different species, e.g., a WGTA object choice by a monkey is not necessarily equivalent to a key press of a pigeon. Since there presumably exists for each of these subjects a function relating FR value and learning proficiency, comparisons of their relative learning proficiency can be justified only when equivalent FR values are used for each subject. Consequently, by changing the type of response used in comparative learning tasks, completely different results might be obtained.

A final observation from this experiment is its import for the study of stimulus control. Clearly, behavior can be controlled by non-spatial stimuli no longer physically present. Further, the major problem with establishing

such control is competition for control from stimuli that are physically present, i.e., the pigeons often repeated their response to the color just reinforced. The fact that such perseveration did occur also argues against any mediation of the delay interval by behavioral chaining. That is, behavioral chaining is incompatible with the variable behavior that often occurred before the choice between colors (see Table 4). For the notion of chaining to be empirically meaningful, it must imply an invariant sequence of events between the offset of the stimuli of one trial and the terminal response emitted in the next trial, a condition that the frequent occurrence of perseveration does not satisfy.

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