FACTORS AFFECTING CONDITIONAL DISCRIMINATION LEARNING BY PIGEONS

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In Experiment 1 (within subjects) and Experiment 2 (between subjects) it was shown that the sequential training of pigeons on a color discrimination and then on its reversal, each in a different floor-tilt/texture context, failed to produce conditional control of discriminative performance by those contexts. Daily alternation between the two problems (with correlated contexts) was successful, however. In each of these experiments conditional control was better reflected in generalization test performance in extinction than during sessions of training with reinforcement.

Key words: conditional discrimination, sequential training, key peck, pigeons

Consider an experiment with pigeons in which pecking at a key lighted red is reinforced while pecking at a blue one is extinguished. The red light is a discriminative stimulus that "sets the occasion" for the response by indicating the availability of reinforcement. This three-term contingency between stimuli, responses, and outcomes defines discriminative stimulus control from a conceptual or procedural point of view (Skinner, 1938). Behavioral evidence of discriminative stimulus control consists of differential responding to the different key colors. Next, add another stimulus, the houselight in the operant chamber. When the houselight is on, the aforementioned three-term contingency is in force; when the houselight is off, it is not and some other contingency replaces it. As Sidman (1986) pointed out, this constitutes a four-term contingency that provides a conceptual definition of conditional stimulus control. Conditional stimuli are said to control responding indirectly by virtue of the significance that they impart to other stimuli. Cumming and Berryman (1965) proposed that a conditional cue functions as a "selector of discriminations," that is, it provides "instructional control." Behavioral evidence of conditional stimulus control consists of differential discriminative stimulus control in the presence of different conditional stimuli.

Now consider another hypothetical experiment. Pigeons are trained to peck a key, by

reinforcing that response when the houselight is on; the houselight off accompanies extinction. Next, add another stimulus, a colored light on the response key. When the keylight is blue the contingency between the houselight, key pecking, and reinforcement is in force; when the keylight is red, it is not. From this description, it would appear that the houselight is the discriminative stimulus and the key color is the conditional cue which serves to indicate the significance of the houselight. Yet when we described the previous experiment we designated the key colors as discriminative and the houselight cues as conditional. But the two experiments are one and the same! Thus the conceptual definition of conditional stimulus control cannot specify which stimulus plays a conditional and which plays a discriminative role.

Somehow the initial description of the hypothetical experiment seems more "natural" than the alternative. We expect the discriminative stimulus for pigeons to be a localized cue projected on the response key, because that has become the standard practice. It needn't be done that way, but perhaps there is good reason (other than tradition) for doing so. A way out of our conceptual dilemma might exist if it could be demonstrated that different physical characteristics predispose a given stimulus to serve in one functional capacity rather than the other. Evidence that this may be so comes from an experiment recently reported by Thomas, McKelvie, and Mah (1985, Experiment 4). In this experiment pigeons acquired a successive discrimination in four training ses-

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sions in which a vertical line on the response key accompanied variable-interval (VI) reinforcement while a horizontal line accompanied extinction; during the next four sessions this discrimination was reversed. For Group 1 a houselight was on and a pure tone was present during original training; the houselight was off and white noise was present during the reversal. For Group 2 the contexts were key colors on which white lines were superimposed, blue for original training and red for reversal training. Line angle generalization testing was carried out in extinction on the next day with the two contexts alternated in successive blocks of test trials. For Group 1 the contexts exerted strong conditional control, with gradients peaking at vertical or horizontal depending on the context present. In Group 2 the key colors were ineffective as contextual (conditional) cues; the gradients peaked at horizontal, the reversal S+, regardless of the key color present. Clearly, the mere presence of even a highly salient stimulus when a three-term contingency is in effect contrasted with the absence of that stimulus when an alternative contingency is in effect does not suffice to imbue that stimulus with the functional properties of a conditional cue. We need to determine why this is so, or conversely, what it is about stimuli that acquire this capacity that enables them to do so.

Another experiment reported by Thomas *et al.* (1985, Experiment 2) indicated that only the visual components of the contexts used with Group 1 accounted for their effectiveness. In seeking to explain why the houselight (on or off) was such an effective conditional cue in their experiments, Thomas *et al.* suggested that animals may be predisposed to associate a learning experience with the physical location in which that learning has taken place. It would not be surprising if pigeons used global visual cues to identify locations where they had obtained food. Perhaps other global environmental cues would also suffice to identify the learning environment and might therefore serve effectively as conditional cues. Experiment 1 in this paper was designed initially to determine whether the floor-tilt dimension would acquire conditional stimulus control over discriminations based on the color of the response key. Riccio, Urda, and Thomas (1966) demonstrated discriminative stimulus control by this dimension in the form of decremental gen-

eralization gradients following training under a single floor-tilt condition. In this respect, floor tilt, a global stimulus, functioned similarly to such localized discriminative stimuli as key color and line angle. Would it also function as a conditional cue? What type of training procedure would be required to produce this outcome? As far as we know, conditional stimulus control has never been demonstrated in the operant free-response situation with pigeons except with visual conditional cues. It would be useful to determine whether nonvisual cues can function in this manner, and it seems appropriate to ask this question using cues that are sufficiently salient to function effectively in other ways.

EXPERIMENT 1

METHOD

Subjects

The subjects were 9 experimentally naive pigeons obtained from a local supplier and maintained at 80% of their free-feeding weights. They were housed in individual cages in a colony room with a 16-hr/8-hr light/dark cycle. Light onset was at 7:00 a.m.; sessions were conducted daily starting at 3:00 p.m.

Apparatus

The apparatus was the same as that used by Thomas, McKelvie, Ranney, and Moye (1981). Key stimuli were produced by IEE projectors (Series 0010) with No. 1815 lamps operated at 12V. Kodak Wratten filters Nos. 75, 74, 99, 73, and 72B produced nominal peak-transmitted wavelengths of 490 nm, 538 nm, 555 nm, 576 nm, and 606 nm, respectively. The key was the only source of illumination in the experimental chambers. A white-noise generator provided masking noise. Reinforcement was 3 s of access to a food hopper filled with mixed grain. Recording and control were accomplished with the use of a Commodore Pet Professional® computer (Model 2001) with a locally designed and constructed interface. Cardboard floor inserts which covered the entire floor were used in the flat-floor condition. In the tilt-floor condition, the floor was covered with hardware cloth and was propped up by two blocks under the right side (facing the intelligence panel) such that its inclination was 20°. Thus floor

tilt and texture were purposely confounded in order to make the context manipulation more salient.

Procedure

Half of the birds received initial and Problem 1 training under the flat-floor condition and half under the tilt-floor condition. On Day 1 all birds were magazine trained, the key peck was shaped while the key was illuminated by a 490-nm (blue) light, and each bird was allowed to earn 60 reinforcers on a VI schedule with a gradually increasing mean interreinforcement interval. On Day 2 the subjects were given single-stimulus training with the 490-nm keylight until 60 reinforcers were earned on a VI 30-s schedule. Starting on Day 3 the birds received the first of four sessions of (multiple schedule) successive discrimination training in which 490 nm (blue) was S+ (signaling VI 30-s reinforcement) and 606 nm (red) was S- (signaling extinction). Component stimulus presentations ("trials") were of 55-s duration, separated by 5-s blackouts during which reinforcement was unavailable. The S+ and S- presentations were arranged in an unsystematic order, except that each block of 10 trials contained five presentations of S+ and five presentations of S-.

After four sessions of Problem 1 (blue S+, red S-) training, on the next day the birds received reversal training. This was carried out in a single session that was extended until the birds met a criterion of at least 90% of responses during S+ in a block of 10 trials. This Problem 2 reversal training (red S+, blue S-) was carried out under the floor-tilt context condition alternative to that used with Problem 1. On the next day, all subjects were tested for wavelength generalization during extinction. The five test stimuli, 490, 538, 555, 576, and 606 nm, were randomized into blocks and eight different randomized blocks were presented to each subject. Stimulus presentations were of 30-s duration separated by 5-s blackouts. All subjects started the test in Context 1 (i.e., the context that had been present during training on Problem 1). After every two blocks of wavelength test stimuli a 15-s blackout was introduced during which the birds were removed from the operant chambers, the floor context condition changed, the birds returned, and the test continued. One subject failed to respond after the floor tilt was altered during the test;

this subject was eliminated from the experiment.

On the day following the generalization test, the birds were retrained under Problem 1/Context 1 conditions, receiving the first of 20 sessions in which the two problems, along with their paired contexts, were alternated on a daily basis. This procedure was called conditional serial discrimination reversal (CSDR) training by Thomas and McKelvie (1982) who used it to establish conditional control over a wavelength discrimination and its reversal by vertical and horizontal lines on the response key. On the day after the 20th session of CSDR training, the birds received a second wavelength generalization test in extinction administered under the same conditions as the first.

RESULTS AND DISCUSSION

Because there were no differences in training or testing caused by the counterbalancing of conditions, the data were pooled over the different subgroups. All subjects performed well on Problem 1, and the percentage of responses to S+ on the fourth day of discrimination training ranged from 88% to 98%. With the start of reversal training, all subjects showed an immediate disruption of key pecking, and with most subjects the key peck had to be reshaped, indicating that the floor-tilt/texture cue had gained discriminative control. Reshaping was done in the presence of the new S+; all subjects met the reversal criterion in 7 to 10 blocks of training trials, and there were no differences in subsequent performance between subjects for which key pecking was reshaped and those for which it was not.

For each subject separate generalization gradients were generated, based on responding in each context; the two gradients for each subject are presented in Figure 1. The mean gradients based on pooled data from all 8 subjects are also presented in the figure. The pooled data are representative of individual performances. Virtually every gradient from every subject peaked at 606 nm, the Problem 2 S+. Such responding, which is in accordance with the set of contingencies that were in effect in immediately preceding training, has been called "recency" by Thomas et al. (1981) in accordance with the traditional literature on memory. There is no suggestion in the gradients that the floor-tilt and texture contexts were associated with the different problems; that is,

SINGLE REVERSAL TRAINING

Fig. 1. Individual and group generalization gradients, showing rate of responding as a function of wavelength, for the subjects under the single-reversal condition. C₁ and C₂ refer to Context 1 and Context 2, respectively. During prior conditioning, the wavelength of 490 nm had functioned as S+ in the presence of Context 1, and the wavelength of 606 nm had functioned as S+ in the presence of Context 2.

they exercised no conditional control over discriminative responding. The recency finding is the typical result in single-reversal experiments when the contextual cues are ineffective (Thomas *et al.*, 1985).

Unlike the single-reversal procedure, the CSDR procedure permits an assessment of conditional control during acquisition, based on the responses occasioned by the discriminative stimuli in a given session before the first

reinforcer of that session is delivered. In the present experiment, this measure was not systematically recorded; however observation indicated that at the beginning of each session the subjects responded quite similarly in the presence of 490 and 606 nm, and those response rates diverged as the session progressed. In the last few sessions the subjects emitted about 90% of total responses on the S+ each day, ending each session with virtually no re-

sponding on the key that displayed S-. Yet in the first 10 min of Session 20 of CSDR training the subjects averaged only 72% of total responses on S+ (range, 65% to 82%). In view of the way in which the subjects performed at the start of each training session, the observed improvement across sessions might be explained by assuming that the birds had become increasingly sensitive to reinforcement as a discriminative stimulus for subsequent responding. Had this been the case, one might expect to see a precipitous improvement in performance subsequent to the delivery of the first reinforcer in each session. Beale (1970) reported such a pattern of behavior in a serial-reversal study in which no conditional cues were available. In the present case, however, inspection of daily records on a minute-by-minute basis revealed that within-session improvement was as often gradual as precipitous.

Given the pattern of responding observed within sessions during CSDR training, the results of generalization testing were somewhat surprising. The generalization gradients of each subject in each context are presented in Figure 2, along with gradients based upon means across subjects for each of the two context conditions. Figure 2 illustrates for all subjects a high level of conditional control over discriminative performance by the floor-tilt and texture contexts. Every gradient peaked at the S+ value appropriate to each context, although there often was substantial responding on the alternative S+. If the birds had started the test responding nearly equivalently to both S+ values (just as they had done during reinforced training sessions), and the contexts exerted increasing control as testing progressed, this would account for the form of the gradients obtained. Analysis of changes in the gradients over the course of testing in extinction indicated that this was what had occurred. Figure 3 shows the mean relative generalization gradient of the 8 subjects based upon the first presentation of each of the five test stimuli. The transformation to relative gradients was used to equate the contribution of each subject to the group average. The gradients were obtained in Context 1 for all subjects, yet they reveal virtually equivalent responding on both S+ stimuli at the start of testing.

Although the floor-tilt and texture cues were sufficiently salient to disrupt key pecking when they were changed for reversal training, they

did not gain conditional control over discriminative responding in the single-reversal paradigm. Note that this paradigm, and in particular four sessions of training on Problem 1 followed by reversal training in a single session, was the procedure used by Thomas et al. (1981), which was the first study to demonstrate conditional control by houselight cues.

Conditional control by the floor-tilt/texture cues was demonstrated following 20 sessions of CSDR training in this experiment. As far as we are aware, this is the first demonstration with pigeons in an operant free-response paradigm of conditional control by nonvisual stimuli. Thomas et al. (1985) showed that auditory cues (i.e., tone vs. white noise) failed to gain conditional control with the single-reversal procedure, but they did not try the CSDR procedure with those cues. It remains to be determined whether auditory cues would acquire conditional control with a procedure designed to enhance their salience.

Perhaps the most surprising result of Experiment 1 is the strong demonstration of conditional control by floor tilt and texture despite the fact that there was little indication of conditional stimulus control from CSDR training performance. Several points should be made about this result. In the Thomas and McKelvie (1982) CSDR study conditional control was revealed in performance during training; however, the conditional cues were lines projected on the response key, and 40 sessions of CSDR training, rather than 20, were administered. Perhaps additional training would have revealed conditional control in training performance in the present experimental situation as well. The fact remains that the generalization test in extinction provided a more sensitive measure of conditional control than did within-session changes in performance. It is unclear why during testing in extinction, as well as during training with reinforcement, the context exerted increasing influence as the session progressed. This is a most unusual "warm-up" effect in that it depends upon exposure to the training or test stimuli and/or on time spent in the experimental apparatus but not on exposure to the reinforcement contingencies. For present purposes it is sufficient to note that the changes in performance that occurred during generalization testing revealed relationships that had been learned during reinforced training because no reinforcement

CSDR TRAINING

Fig. 2. Generalization gradients (individual and group average) for subjects under the conditional serial discrimination reversal (CSDR) condition. During prior conditioning, the wavelength of 490 nm had functioned as S+ in the presence of Context 1, and the wavelength of 606 nm had functioned as S+ in the presence of Context 2.

was delivered during generalization test sessions.

Before concluding that the subjects in Experiment 1 had learned the conditional relationship between floor tilt/texture and the two key colors because of the opportunities for stimulus comparison afforded by the CSDR procedure, two potential confounds must be considered. First, testing for generalization in the two contexts may have sensitized the subjects to the contextual cues so that they learned

about them more readily afterwards. Second, the 20 sessions of additional training might have resulted in conditional stimulus control even if the CSDR procedure had not been used. The latter possibility must be taken particularly seriously because none of our published or unpublished studies using the single-reversal procedure has used extensive training.

To eliminate these potential confounds as well as to permit a direct comparison between single-reversal and CSDR procedures, Ex-

FIRST FIVE TRIALS

Fig. 3. Relative generalization gradient based on group means taken over the first five test trials in the presence of Context 1.

periment 2 was performed. The training conditions used were the same as in Experiment 1 except that separate groups were exposed to the two different procedures. Each group was given 30 sessions of discrimination training, 15 on each of the color discrimination problems. This exceeds the total number of discrimination training sessions used in both phases of Experiment 1.

EXPERIMENT 2

METHOD

Subjects and Apparatus

The subjects were 16 experimentally naive pigeons maintained as in Experiment 1. The apparatus was the same as that used in Experiment 1.

Procedure

The subjects were assigned randomly to the two groups ($n = 8$). Preliminary training was the same as in Experiment 1. For half of each group, the training context was the flat floor;

for half it was the tilted one. Key pecking was hand-shaped and the key was illuminated by 490 nm (the S+ of Problem 1). After their first day of discrimination training (blue S+, red S-) the subjects in the single-reversal group received 14 additional training sessions under the same conditions. Then they received 15 sessions of training on the reversal problem (red S+, blue S-) under the alternative floor-tilt/texture condition. At the start of the first session of reversal training several response-independent food-hopper presentations were given in the presence of the new S+ in order to elicit responding. For those subjects with which this was unsuccessful, training was interrupted and key pecking was reshaped in the presence of the new S+; then scheduled training resumed. There were no subsequent differences in performance between subjects for which key pecking was reshaped and those for which it was not.

For subjects in the CSDR group, after the first training session on Problem 1, both the problem and the context were reversed on the next session and for every session thereafter to a total of 30 discrimination training sessions. On the first reversal session, retraining was occasionally necessary.

On the day after their 30th session of discrimination training both groups were tested for wavelength generalization in extinction following the same procedure as in Experiment 1.

RESULTS AND DISCUSSION

Because there were no differences in training or testing that were attributable to the counterbalancing of conditions, the data were pooled over the different subgroups. The single-reversal group performed well on both discriminations. For the last sessions of Problem 1 and Problem 2 training the data yielded means of 97.8% (range, 92% to 100%) and 95.6% (range, 84% to 100%), respectively, of total responses on S+. The CSDR group performed somewhat less well. For the last sessions of Problem 1 and Problem 2 training the data yielded means of 89.6% (range, 73% to 100%) and 88.6% (range, 70% to 100%), respectively, of total responses on S+. Virtually all responses on S- occurred at the start of training sessions and most subjects responded substantially on this stimulus during the first

Fig. 4. Generalization gradients based on individuals' data and upon group averages for subjects in the single-reversal group. C₁ and C₂ refer to Context 1 and Context 2, respectively.

one or two times it was presented, even after 30 sessions of CSDR training.

In order to compare statistically the discrimination performance of the two groups, the discrimination index for each subject for each problem (i.e., S+ responding as percentage of total responses) was entered into a 2×2 analysis of variance. The result indicated that the single-alternation group performed significantly better, $F(1, 14) = 7.81, p < .05$. There was no difference between performance on Problem 1 versus Problem 2 ($F < 1$).

Figures 4 and 5 present the individual and group average generalization gradients of the subjects in the single-reversal and CSDR groups, respectively. No subject in the single-reversal group showed evidence of conditional discrimination learning. Instead they all showed recency with maximal responding on the 606-nm key, the Problem 2 S+, regardless of the floor-tilt context present. On the other hand, most subjects in the CSDR group showed evidence of conditional discrimination learning. As in Experiment 1, the subjects in this

Fig. 5. Generalization gradients based on individuals' data and on group averages for subjects in the CSDR (conditional serial discrimination reversal) group. C₁ and C₂ refer to Context 1 and Context 2, respectively.

group tended to respond at a considerable level on the alternative S+, particularly at the start of the test session. Two of the subjects ceased responding after the floor tilt was manipulated in testing. There was no need to replace these subjects because the generalization test results of the two groups were so different.

Experiment 2 replicated the results of Experiment 1 while eliminating the two confounds previously described. Prior exposure to a previous generalization test in which floor

tilt and texture are varied is not necessary for the demonstration of conditional control following CSDR training. On the other hand, such experience may have contributed to the greater regularity of the gradients obtained in Experiment 1, perhaps by reducing the disruptive effect of the birds being removed from the operant chambers and then returned with the floor position altered. The results obtained with the single-reversal group are unequivocal; not one of these subjects learned the con-

ditional relationship between the floor-tilt/texture cues and the wavelength discriminations.

It is particularly noteworthy that the single-reversal condition led to greater discriminative control but less conditional control than did the CSDR procedure. Clearly, each alternation between training stimuli permits comparison between them, which should facilitate the formation of a discrimination. The CSDR procedure permits repeated comparison of the conditional cues whereas the single-reversal procedure does not. On the other hand, the colored light discriminative cues alternate on a minute-by-minute basis with both procedures so the opportunities for the beneficial effects of stimulus comparison on discriminative control are comparable. The CSDR procedure, however, maximizes the opportunities for interference between the two problems because the color that was S+ yesterday is S- today (and vice versa). This occurs only once for a given subject with the single-reversal procedure. It is not surprising that the conditional cues function more effectively under the CSDR procedure, because this procedure provides for elimination of a strong conflict between incompatible response tendencies. Perhaps the really surprising finding is that the subjects learn about the conditional relationship at all in the single-reversal paradigm, but they do when houselights or other global visual cues are used as contexts. In this paradigm, learning about the contexts can be categorized as "incidental," because subjects can easily learn a color discrimination and its reversal in the absence of any context change (see Thomas *et al.*, 1981). Indeed Thomas (1985) has used the term "implicit conditional control" to describe the learning that occurs in the single-reversal paradigm because that learning can only be revealed in subsequent generalization testing in extinction under both context conditions.

GENERAL DISCUSSION

It was pointed out in the introduction that the conceptual definition of conditional stimulus control as a four-term contingency is incomplete because it fails to specify which stimulus plays a discriminative, as opposed to a conditional, role. It was suggested that different physical stimulus characteristics might in-

fluence this determination. Experiment 1 was designed to test the notion that the houselight condition, on or off, was a particularly effective conditional cue because it was a global environmental stimulus that defined the physical location in which food could be produced by discriminative responding. One might expect the floor tilt and texture to provide similar information, yet they were ineffective as conditional cues in the single-reversal paradigm. Thus the basis or bases for the effectiveness of houselight as a conditional cue remain unknown.

In order to achieve an understanding of the process of conditional stimulus control in the free-operant situation with pigeons, we must answer these related but different questions: (a) What stimuli or combinations of stimuli permit the development of conditional relationships, and (b) when such relationships are established, which stimulus will play a discriminative and which will play a conditional role? Is it possible that each of the stimuli plays both of these roles, that is, affecting responding directly via its discriminative role and indirectly via its conditional role with respect to the other stimulus? To these questions we can now add another: (c) What training conditions are necessary for the formation of a conditional relationship between particular stimuli? We can now state that the training procedure required depends on the conditional stimuli that are employed. The present experiments revealed that CSDR training was necessary for floor tilt and texture to gain conditional control. Yet Thomas and Goldberg (1985) directly compared single-reversal and CSDR procedures in an experiment with houselight conditional cues and key color discriminative cues and found equal (and excellent) conditional control with both procedures. A third group in their experiment, exposed to all four combinations of houselight and key color conditions on a minute-by-minute basis within sessions, performed more poorly. Thus, increasing the opportunities for subjects to compare the potential conditional stimuli does not always help, and may even hinder the development of conditional control. The present paper provides few answers with regard to an understanding of conditional stimulus control, but should contribute toward that ultimate goal by more clearly articulating the relevant questions.

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Received March 24, 1987

Final acceptance May 15, 1987