*REPEATED ACQUISITION OF BEHAVIORAL CHAINS:
RESPONSE SEQUENCES OR CONDITIONAL
DISCRIMINATIONS?*

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The purpose of this study was to determine whether pigeons learn a sequence of positional responses or a series of conditional discriminations under a repeated-acquisition-of-behavioral-chains procedure. Three pigeons were trained under a repeated-acquisition procedure in which three different key colors served as stimuli correlated with the three steps in a chain. The order of presentation of the three stimuli was altered during the latter part of each test session after acquisition had occurred. If the pigeons had acquired a response sequence, the pattern of responding should remain the same as in the initial portion of the test session. However, if the pigeons had acquired a conditional discrimination, the response pattern should change in accordance with the changed order of the key colors. Although the results of this study do not rule out the possibility that the subjects acquired, to some degree, a response sequence, the results suggest that the behavior of pigeons under a repeated-acquisition-of-behavioral-chains procedure is controlled primarily by conditional discriminative stimuli.

Key words: repeated-acquisition procedure, response sequence, conditional discrimination, discriminative stimuli, behavioral chains, key peck, pigeons

In 1968, Boren and Devine reported the development of a procedure that allowed for the repeated acquisition of behavioral chains in rhesus monkeys. Thompson (1973) later adapted this procedure for use with pigeons. The training of pigeons under this repeated-acquisition procedure resulted in a steady state of total errors committed across sessions, as well as stable within-session error reduction. This stable baseline has subsequently allowed the repeated determination of the effects of pharmacological and toxicological chemicals on the acquisition of different response chains (Harting & McMillan, 1976a; McMillan, 1979; Moerschbaeher & Thompson, 1980; Thompson, 1973, 1974, 1975; Thompson, Moerschbaeher, & Winsauer, 1983).

In his initial report on repeated-acquisition schedules, Thompson stated that the task of the subjects was to "... learn a new four-response sequence (chain) by pecking the correct key in each group of colors" (1973, p. 507). Since this initial report, it has generally been assumed that during training under the repeated-acquisition procedure the subjects learn to make a sequence of responses. How-

ever, according to Kelleher, "A sequence of responses (or response sequence) is a pattern of changes in response frequency or response topography that regularly recurs in the absence of correlated changes in exteroceptive stimulus conditions" (1966, p. 163). Thus, the establishment of a response sequence with the repeated-acquisition procedure would seem to imply that the subjects are learning to respond in a specific positional order such that each response in the sequence serves to set the occasion for the subsequent response.

Under the repeated-acquisition procedure, subjects typically are trained in a three-key pigeon chamber in which all three keys are simultaneously illuminated with one of four colors of light (e.g., yellow, green, red, and white). Each color represents a step in the chain (e.g., the keys are illuminated with yellow light in the first step of the chain, with green light the second step of the chain, with red light in the third, and with white light in the fourth or last step in the chain). During the presentation of each color, one key is designated as the correct key and a response on this key advances the chain. A response on either of the other keys produces a timeout in which the houselight and keylights are extinguished and responses have no programmed consequences. At the beginning of each session, a new four-response chain is introduced.

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According to the usual assumptions, subjects acquire a sequence of positional responses (e.g., left-right-center-right). However, because the key colors change with each correct response, it is possible that what the subjects acquire is not a sequence of responses but rather a conditional discrimination (e.g., yellow, peck left key; green, peck right key; etc.).

The answer to the question of whether the subjects are acquiring response sequences or conditional discriminations hinges on the degree of control exerted by the key colors. There is little doubt that the key colors can serve both discriminative and conditioned-reinforcing functions (Gollub, 1977; Kelleher, 1966). However, it is not clear whether the key colors function only to signal the current step in the chain or whether they also serve as discriminative stimuli to control the position at which the pigeon responds.

The purpose of this study was to determine the control exerted by the key colors in the repeated-acquisition procedure. Control was determined by placing the two stimulus functions of the key colors in opposition to each other and recording which of the alternatives controlled the behavior of the subjects. The data obtained from these studies support the interpretation that the key colors in the repeated-acquisition procedure function primarily as conditional discriminative stimuli.

METHOD

Subjects

Three adult male White Carneau pigeons served as subjects. They were individually housed in a large colony room and given continuous access to water and grit. They were maintained at 80% of their free-feeding weights for the duration of the study. The subjects were given supplementary feedings as needed after completion of the sessions to maintain this weight. The 80% weights ranged from 390 to 440 g.

The subjects had extensive previous experience with the repeated-acquisition procedure (approximately 12 months). During this time, the subjects had been tested with various drugs including morphine, cocaine, naloxone, and delta-9-tetrahydrocannabinol to determine the effects of the drugs on the repeated acquisition of behavioral chains. The last drug administration occurred 1 week before the first test session of the present study was conducted.

Apparatus

The experimental chamber was a pigeon test cage (Gerbrands Model G-7313) enclosed in a sound- and light-attenuating cubicle (Gerbrands Model G-7211). The chamber was equipped with three response keys that could be illuminated with colored lights. A response was defined as an opening of the key contacts that required a minimum force of 0.05 N. Two 28-V, DC lights provided illumination of the chamber, except during the feeding cycle and the timeout periods. The number and position of responses were recorded and the behavioral contingencies were controlled by a Tandy TRS-IV® microcomputer.

Procedure

The repeated-acquisition procedure used in this study was similar to that of Thompson (1973) with the major exception being that the behavioral chain was three steps instead of four steps in length. For each session, the subjects were placed in the experimental chamber in the absence of the houselights and the keylights. After 5 min, the houselights and keylights were turned on and the session was initiated. The first key color (correlated with the first step in the chain) was red. A response on the designated correct key caused the keylights to change to green. A response on either of the other keys was designated as an error and caused the houselights and the keylights to extinguish for 5 s. Responses during this timeout period had no programmed consequences. Because an error did not advance the chain, the keylights remained the same color until a correct response was emitted. These contingencies were continued for each of the steps in the chain.

The order of presentation of the keylights was red, then green, then blue. The subjects were required to complete the three-step chain five times (fixed-ratio 5) to gain 3-s access to the reinforcer (mixed grain). During reinforcer delivery, the houselights and keylights were extinguished, and the lights above the food hopper were illuminated. For each completion of the chain (with the exception of the fifth completion), the hopper was raised and the hopper lights were turned on for approximately 0.5 s while the houselights and keylights were extinguished. After the completion of the chain the hopper was raised for 3 s to allow the pigeon time to eat.

The sessions lasted for 45 min or until the

subjects earned 30 reinforcers (3-s presentations of grain), whichever occurred first. Each session was divided into blocks of five reinforcers, resulting in six blocks within the session. If all five reinforcers were obtained, the number of correct responses in each block would have been 75. In each block the number of correct responses, the number of errors, and the location (i.e., to which key position the subject had responded) was recorded. Response rate was also determined.

The number of differing three-response chains used for training (maintenance) sessions was restricted by two criteria. The first criterion was that the same key could not be correct for two consecutive steps in the chain. The second criterion was that the three responses could not be in a continuous order such as left (L)-center (C)-right (R). Ten three-response chains were developed within these criteria and all 10 chains were used during the training sessions (one chain per session). For four of these chains it was necessary for the subjects to respond on each of the three keys in order to receive the reinforcer. The four chains were L-R-C, C-L-R, R-L-C, and C-R-L. Because the subjects did not repeat a key during these chains, these patterns were used during test sessions so that the results would be as free from ambiguity as possible.

For each *test* session, the last block was used as a test block because accuracy increased from 40% to 50% in the first block to an asymptotic level of approximately 90% accuracy by this time in the session. During the test block, the stimulus order was changed so as to determine whether the pattern of responding of the subject was appropriate for having learned a response sequence or whether the pattern was controlled by the discriminative stimuli. Thus, if the subject had acquired a sequence of position responses of L-R-C in the presence of the red, green, and blue lights, and the order of color presentation was then changed to green-blue-red, the pattern of responding would be expected to remain L-R-C. If, however, the subject had learned a conditional discrimination, the pattern of responding would be expected to follow the color change (i.e., right-green, center-blue, left-red).

During training sessions, correct responses advanced the chain, and incorrect responses (errors) produced a 5-s timeout and did not advance the chain. During the test blocks it was necessary to advance the chain to present

each of the stimulus conditions to the subjects. To meet this requirement, and to minimize the feedback to the subjects as to whether their response was correct or incorrect when the order of the key color changed, each response during the test block advanced the chain (i.e., every response was correct).

Performance under this procedure was characterized by intrasubject variability during the test block of the second test session, perhaps because all responses were reinforced. To minimize the possibility of reinforcement of responses early in a test block changing performance later in the test block, the number of reinforcers that could be earned during the test block was reduced from five to one for the third and subsequent test sessions. This reduction in the number of reinforcers resulted in a decrease in the number of responses emitted by the subjects from a total of 75 to a total of 15 responses.

Each test session in which the order of the key colors was changed was separated from the subsequent test session by at least two training sessions in which the order of key colors was not changed. Subjects P177 and P170 participated in five test sessions, and Subject P110 participated in the first three test sessions. The first two of these sessions were those in which the subjects could earn five reinforcers during the test block. Subject P110 was excluded from the last two test sessions due to a chipped beak and did not participate in any sessions until its beak was healed (10 days).

The behavior of the subjects continued to be variable under this procedure so the contingencies were changed again in an attempt to reduce variability. For the next phase of the study, a response on any key resulted in both a 5-s timeout and the advancement of the chain. Thus, the subjects were exposed to conditions for each response which had been associated with both correct and incorrect responding. This contingency greatly decreased the variability. This second phase of the study continued through the completion of five test sessions. Each test session was again separated from the previous test session by a minimum of two training sessions.

After the second phase of the study had been completed, a third phase was initiated. For this phase of the study, the contingencies remained the same as in the training sessions, while the stimulus order was again changed during the

last block of the test sessions. During 50% of these test blocks, responses that were appropriate for the position sequence were correct and advanced the chain. For the remaining half of the test blocks, responses that were consistent with the conditional discrimination were correct and resulted in the advancement of the chain. As an example, if the order of the chain had been red-center, green-right, and blue-left, and during the test block the stimulus order was changed to green-blue-red, then for a session in which the sequence was correct the order of the chain was green-center, blue-right, and red-left. For the session in which the conditional discrimination was correct the order of the chain was green-right, blue-left, and red-center. A response on the designated correct key (position or color) in each link advanced the chain, whereas a response on either of the other keys, or an error, produced a 5-s timeout and did not advance the chain.

The purpose of this third phase was to evaluate further the control of behavior by the color versus the position sequence. The reasoning was that if the stimulus order were changed, but the sequence of correct key positions for responses required to produce the reinforcer remained the same, the birds should make a large number of errors if key color were controlling behavior because they would be acquiring a new conditional discrimination during the test block. However, if the stimulus order were changed and the positional order of the correct keys were also changed such that the key color and the correct response position remain paired, then the subjects should commit few errors.

This phase consisted of eight test sessions, four for each condition, each separated by a minimum of two training sessions. The subjects could earn only one reinforcer during the test block. However, although the number of correct responses they could emit was limited to 15, they were not limited in the number of errors that could be emitted. The identical stimulus order was used for each pair of test blocks in which the sequence or the conditional discrimination was correct during the test block. The positional order of responding during the initial five blocks of the sessions was also the same. Thus, the only difference during the test blocks was whether the subject's pecks would be reinforced for following the positional sequence or the conditional discrimination colors.

RESULTS

Figure 1 illustrates the effects of changing the discriminative stimulus order and allowing each response to advance the chain for each of the 3 birds in each individual test session (Phase 1). Prior to the changes in discriminative stimulus order, all birds had acquired the appropriate behavior as shown by the high percentage of responses on the correct key (86%–100%) during the block of trials immediately prior to the test block (percentages are shown for each bird for each test session in Figure 1).

Figure 1 reveals that Subject P170 typically emitted the greatest percentage of its responses on the key appropriate for the conditional discrimination (filled bars). Exceptions were the pattern of responding during the third stimulus for the first test block (sequence, unfilled bars) and during the second (other, hatched bars) and third stimuli of the second test block. The other 2 subjects' response patterns, however, appear to have been controlled by both key color and the sequence of the key positions without a clear difference in the degree of control by the two stimuli. It is also apparent that, occasionally, responding occurred predominantly on the third key (hatched bars), which was not associated with stimulus control by key color or key sequence.

The effects of changing the stimulus order with each response producing a 5-s timeout and advancing the chain (Phase 2) are illustrated in Figure 2. Again, during the block of trials immediately preceding the test block, most responses occurred on the correct key (78%–100% correct with over 90% correct for most blocks).

Inspection of Figure 2 reveals that all subjects responded predominantly on the keys appropriate for the conditional discrimination when the stimulus order was changed and the responses produced a 5-s timeout and advanced the chain. However, there were instances for individual stimuli of a chain in which a subject responded more frequently on the key associated with neither the sequence nor the conditional discrimination. These instances occurred for Subject P170 on Test 4 with the second stimulus, for Subject P177 on Test 4 with the third stimulus, and for Subject P110 at least once in each test. However, there was only one instance in which a subject re-

Fig. 1. The percentage of responses emitted by P170 (left panels), P177 (middle panels), and P110 (right panels) on the sequence-appropriate key (SQ, open bars), the conditional-discrimination-appropriate key (SP, filled bars), and the third, or other, key (OTH, hatched bars) during each of the chain stimuli. The initial sequence of positional responses is also indicated (e.g., SQ = LRC) as is the order of the key colors (e.g., OR = GBR) during the test block for each test session. The percentages shown near the key color order represent the percentage of responses on the correct key during the final acquisition block before the test block. During some test blocks the relative position of one of the keys did not change. Thus, this key was correct for both sequence and conditional discrimination responding. This situation is denoted by the phrase "same key" and indicates that it is not possible to determine whether the key color or the sequence controlled responding on this key. The top two graphs for each subject show the percentage of 75 responses emitted on each key, and the remaining graphs represent the percentage of 15 responses emitted on each key. The order of graphs denotes the order of testing, with the first test represented by the top graph and the last test represented by the bottom graph.

Fig. 2. The effects of each response producing a 5-s timeout and advancement of the chain on the percentage of responses emitted by the subjects on the three response keys. Data are graphed as in Figure 1.

sponded a greater percentage of the time on the sequence-appropriate key: Subject P177 on Test 4 with the first stimulus.

During the five test blocks there were three stimuli in the total of 15 in which the sequence-appropriate key and the key appropriate for the conditional discrimination were the same. For the remaining 12 stimuli, Subjects P177, P170, and P110 emitted a larger proportion of their responses on the key appropriate for

the conditional discrimination during 11, 10, and 9 of the 12 stimuli, respectively. It can also be seen that the conditional-discrimination-appropriate key was the only key on which the subjects responded during each stimulus of the chain during every test session. In only one case did any of the subjects respond on the sequence-appropriate key in each of the three stimuli of a chain. This result occurred for Subject P110 in Test 3. Subject P110 had an

Table 1

The percentage correct, percentage errors, and number of errors committed during the sequence-correct and conditional-discrimination-correct test blocks. On the left- and right-hand panels of the table the numbers from left to right indicate the percentage correct during the block preceding the test block (bracketed numbers), percentage correct during the test block, percentage of total errors on the conditional discrimination or sequence key, respectively, percentage of total errors committed on the "other" key, and total number of errors committed during the test block.

Subject	Test	Sequence correct					Conditional discrimination correct				
		% Correct		Errors			% Correct		Errors		
		BL	Test	SP	Other	Total	BL	Test	SQ	Other	Total
P170	1	[96]	37	92	8	26	[91]	83	100	0	3
	2	[100]	19	77	23	66	[91]	83	33	67	3
	3	[96]	19	82	18	62	[94]	58	73	27	11
	4	[97]	17	64	36	72	[91]	60	0	100	10
P177	1	[85]	28	51	49	39	[99]	65	75	25	8
	2	[100]	20	63	37	59	[100]	68	43	57	7
	3	[100]	29	50	50	36	[100]	60	60	40	10
	4	[94]	33	87	13	30	[91]	63	56	44	9
P110	1	[89]	29	73	27	37	[91]	25	53	47	45
	2	[91]	26	74	26	43	[82]	50	73	27	15
	3	[88]	16	79	21	80	[90]	100	0	0	0
	4	[94]	23	65	35	51	[99]	54	15	85	13

accuracy of only 78% for the block that preceded the test block for this session. Thus, the subject's behavior may not have been stable at the time of this test block.

The results of the third phase of the study, in which behavior was reinforced only after conditional-discrimination- or sequence-appropriate responding, are presented in Table 1. This table shows the total percentage of responding on the correct key as well as the percentage of errors committed on each key for each of the test sessions. Again, it can be seen that the pigeons usually responded on the correct key during the block immediately prior to the test block (82%–100% correct responding).

The data from this table show that for each of the subjects, the percentage correct was much greater, and thus the number of errors committed was much smaller, during the sessions in which the conditional discrimination was correct than for the sessions in which the sequence was correct. An exception to this statement is the result for P110 during the first discrimination-correct session. This subject made only 25% correct responses during this discrimination-correct session as compared to 29% correct during the paired sequence-correct session. For the remaining test sessions, however, this pigeon made a greater percentage of correct responses during the sessions in

which the discrimination was correct than when the sequence was correct.

The data from all three phases of the study are summarized in Table 2, which shows on which key responding occurred most frequently during each stimulus. The table shows that responding was most frequent on the key associated with acquisition of conditional discriminations rather than with the acquisition of position sequences. In fact, responding was as likely to occur on the key associated with neither conditional discriminations nor response sequences as it was on the response-sequence key. It should also be noted that, because the test stimuli in which the sequence-appropriate and discrimination-appropriate keys were the same are not counted in the results for this table, the number of times that the subjects responded predominantly on the other key is underestimated.

DISCUSSION

The results obtained in these experiments suggest that the subjects acquired a conditional discrimination during training under the repeated-acquisition procedure. Their pattern of responding during the test blocks was, for the most part, controlled by the discriminative-stimulus properties of the key colors rather

Table 2

Sources of stimulus control summed across experiments and birds. "Key color" indicates that more responses occurred on the conditional-stimulus key than on either of the other two keys. "Key sequence" indicates that more responses occurred on the sequence key than on either of the other two keys. "Other" indicates that more responses occurred on the key not associated with either the conditional stimulus or the sequence. Data were not entered when responding was equal at the two keys with the highest number of responses or when the conditional-stimulus key and the sequence key were the same for a step in the chain.

	Key color	Key se- quence	Other
Phase 1 (all responses advance the chain)	20	8	1
Phase 2 (all responses advance the chain and produce a timeout)	30	1	8
Phase 3 (sequence responses reinforced)	25	3	4
Phase 3 (conditional stimulus responses reinforced)	27	3	2
Totals	102	15	15

than by the sequence of key positions. This result was more readily apparent from the data of the second phase of the study than from the data obtained in the first phase, even though nondifferential contingencies of reinforcement were in effect in both phases. The difference in the contingencies of the first and second phase was the addition of the 5-s timeout that was interposed between the response and the change in the color of the keylights during the second phase. Why the addition of the timeout resulted in an increase in the degree of behavioral control by the discriminative stimuli is not clear. However, it is possible that this timeout caused a bias away from control by the positional sequence of the keys due to the temporal interruption between successive responses. Thus, the subjects' behavior may have also been controlled by the positional order of the response keys, but sequential control was disrupted by the 5-s timeout between responses.

An alternative explanation is that the change in the order of presentation of the chain stimuli during the first phase of the study caused a disruption in the behavior of the subjects such that they committed a number of errors. Thus, the subjects would have come into contact with the changed contingencies. Because the con-

sequence of their behavior during this phase was immediate (i.e., immediate advancement of the chain), the new contingencies may have interfered with control of behavior by the previous contingencies. In the second phase of the study, however, the response-produced 5-s timeout may have resulted in a decrease in the association of the response with the advancement of the chain. Thus, there would have been less interference with the previously established behavioral contingencies and a correspondingly greater degree of behavioral control by the color of the response keys.

The data obtained during the third phase of the study suggest that the behavior of the subjects was controlled primarily by the discriminative stimuli. Only if the subjects had to relearn a discrimination would one expect to observe the large number of errors that were committed during the sessions in which the position sequence was correct. This large number of errors occurred even though the subjects were strongly biased to respond on the sequence-appropriate key due to the advancement of the chain for these responses and the 5-s timeout for responses on either of the other two keys. Conversely, the few errors that were made when the conditional-discrimination-appropriate key was correct suggests that the subjects did not have to learn a new positional response sequence during the sessions in which the conditional discrimination was correct. Rather, they were responding on the key correlated with the discriminative stimulus (i.e., the key position associated with the color of the response keys).

It was stated previously that to establish a response sequence it is necessary for the behavior of the subjects to come to be controlled by the position of the last correct response. Under a tandem schedule the keylights remain the same color throughout the session, and, thus, the only discriminative stimulus that can control correct responding is the position of the previous correct response. Under these conditions the subject must learn a response sequence in order to gain consistent access to the reinforcer. It has been found that far more errors, and greater variability in the number of errors, occur when a tandem schedule is used instead of a chain schedule in repeated acquisition (Harting & McMillan, 1976b; McMillan, 1979; Thompson, 1975). These results suggest that the keylights in a conditional discrimination exert greater control over re-

sponding than do the stimuli generated by the position at which a previous response occurred.

There have been a number of studies in which the effects of drugs have been determined under the repeated-acquisition procedure. Typically, these studies have shown dose-dependent increases in errors after drug treatment (Harting & McMillan, 1976a; Moerschbaecher & Thompson, 1980; Thompson, 1973, 1974, 1975; Thompson et al., 1983). In some of these studies, the drug effects were quite different under chain- and tandem-acquisition baselines (McMillan & Harting, 1976a; Thompson, 1975). These differential drug effects may relate to the baseline variability generated under chain and tandem schedules, to the baseline error rate, or to differences in the way in which behavior is controlled by exteroceptive stimuli under chain schedules that are not present under tandem schedules. Our data suggest that the behavior of pigeons under chain-acquisition schedules is controlled primarily by exteroceptive conditional discriminative stimuli rather than by cues generated by sequential position responding. These data thus imply that different behavioral processes might be involved in stimulus control under chain and tandem repeated-acquisition schedules, which might explain the differential behavioral effects of drugs found under these two schedules.

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