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CONTROL OF PIGEONS' KEYPECKING BY A CONDITIONAL CLOCK

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This study attempted to determine if animals' conditioned responding could be controlled by an analog of the familiar 12-hour clock in which the significance of a reading is conditional upon other stimuli. The periodic availability of grain reinforcement for food-deprived pigeons' keypecking was signaled by a conditional line tilt clock. The orientation of lines on the key during successive thirds of odd numbered intervals was horizontal, oblique, then vertical. Reinforcement was available during vertical. The orientation during successive thirds of even numbered intervals was vertical, oblique, then horizontal. Reinforcement was available during horizontal. The houselight was illuminated only during odd numbered intervals. Thus, vertical and horizontal signaled either nonreinforcement or reinforcement, conditional upon whether the houselight was on or off. Under these conditions most pecking occurred during the final third of all intervals. Clock control of pecking was demonstrated during two types of tests. In one, the clock was sped up or slowed down by shortening and lengthening the fixed interval. These manipulations did not affect the usual temporal pattern of responding; pecking still occurred only during the last portion of the interval. In the other type of test, the usual order of presentation of the line tilts was changed. This manipulation did affect the temporal pattern of pecking. The birds seemed to learn two types of conditional discriminations: one between houselight, line tilts, and reinforcement availability; the other between certain orders of events in the clock sequence and the availability of reinforcement.

Several studies (e.g., Baron & Galizio, 1976; Caplan, Karpicke, & Rilling, 1973; Donahoe, 1970; Ferster & Skinner, 1957; Kendall, 1972; Segal, 1962) have demonstrated stimulus control of responding by a clock (i.e., a fixed, repetitive sequence of arbitrary environmental stimuli). In these studies responding was most frequent during the clock reading associated with periodic reinforcement availability.

One important type of external clock—what we call a "conditional clock"—has received scant study. An example of such a clock is the familiar 12-hr clock. This clock is conditional in that a reading, depending

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upon whether it is a.m. or p.m., can signal two different events. Apparently the only study of conditional clocks was a limited one performed by Ferster and Skinner (1957). They exposed pigeons to a periodic food reinforcement schedule. The clock, which consisted of continuous change in the length of a slit of light, ran throughout the period. At the start of the interval the slit was intermediate. It lengthened as the interval progressed until halfway through the period, at which point it changed to the smallest length. Then it gradually lengthened to the intermediate size, at which time reinforcement became available. This sequence was repeated during each interval. This clock was conditional because the same stimulus (intermediate length slit) was associated with both the start (nonreinforcement) and end (reinforcement) of the interval.

After exposure to the conditional clock the pigeons pecked most frequently near the time of reinforcement. Control of pecking by the changes in the length of the line also was revealed when the birds were subsequently exposed to a simple clock under which the line grew from short to long over the interval.

The present experiments were a further study of control by conditional clocks. Rather than using a continuous clock, we used a discrete clock. Rather than allowing unprogrammed stimuli to serve as the conditional cue, we provided explicit ones. The clock worked as follows. A fixed-interval food reinforcement schedule was divided into three equal subintervals (thirds). During the first third of the first fixed interval of a session, horizontal lines appeared on the pecking key. Oblique lines appeared during the middle third; vertical lines appeared during the last third, at the end of which reinforcement was available. During the first third of the next fixed interval, vertical lines again appeared. Oblique lines (identical to those of the preceding interval) appeared during the middle third. Horizontal lines occurred during the last third, at the end of which reinforcement again was available. The next fixed interval began with horizontal lines, and so forth. The houselight was illuminated only during the odd numbered intervals. To the human observer the lines appeared to move clockwise during the light (odd) intervals and counterclockwise during dark (even) intervals. The clock was conditional because whether vertical or horizontal lines signaled reinforcement availability depended on whether the houselight was on or off.

In the study of clock control of behavior one must demonstrate that the clock stimuli rather than unprogrammed temporally varying stimuli control behavior. An elegant test of clock control is to run the clock in reverse and determine if the typical temporal pattern of responding reverses. To demonstrate control by our conditional clock we reversed the usual sequence of line tilts during light and dark intervals. Thus, the normal sequence of stimuli during light (horizontal, oblique, vertical) was changed to vertical, oblique, horizontal. Similarly, the order of line tilts during dark was reversed. If the clock rather than unprogrammed temporally varying stimuli controlled responding we expected a reversal of the usual scalloped pattern of pecking to accompany the reversal in the order of the clock stimuli.

EXPERIMENT 1

Method

Subjects

One homing pigeon (BW1) and two Silver King pigeons (SK107 and SK105) were housed in individual cages in a naturally illuminated room. They were maintained at approximately 85% of free-feeding weight throughout the experiment by mixed grain obtained during and after experimental sessions. Water and grit were available continuously in the home cages. Each bird previously had participated in a number of experiments, including exposure to fixed-interval reinforcement schedules.

Apparatus

A commercial operant chamber for pigeons (Tech Serv Model No. 1519) was used as the experimental space. One wall of this lightproof, sound-attenuating, ventilated chamber contained three plastic pecking keys arranged in a row, and a grain feeder. Only the center key was used in the present experiment. A force of about .2 N was required to operate the response-sensing microswitch of this key. A Series 10 Industrial Electronics Engineers' projector was mounted behind the key and illuminated (with 3-W lamps) the key at various times with three black vertical, oblique, or horizontal lines on a white background (Tech Serv film pattern No. 715). The feeder was located directly below the center key and permitted timed access to mixed grain illuminated by a 3-W lamp. A 3-W houselight was located above the center key. Experimental conditions and data recording were implemented by solid state and electromechanical circuits and a cumulative recorder.

Procedure

All birds received experimental sessions at approximately the same time (mornings) each day, seven days per week, for the duration of the experiment. As all birds had experimental experience, no preliminary feeder or keypeck training was necessary.

Baseline. Baseline sessions consisted of an even number of 150-sec fixed intervals (FIs). During the first and subsequent odd numbered of these, the key was illuminated during successive thirds (50-sec periods) of the FI period by horizontal, oblique, and vertical line orientations. During the second and subsequent even numbered FIs, the key was illuminated during successive thirds by line tilts of vertical, oblique, and horizontal. The houselight was illuminated during odd numbered FIs and turned off during even numbered FIs. Reinforcement (5-sec access to mixed grain) was produced by the first peck that occurred after the FI period had elapsed. The key light remained on during the reinforcement period. The first 12 FIs of each session were considered as warm-up; beginning with the 13th FI, the number of keypecks during each third of odd and even numbered FIs was recorded. Normally, keypecking during 14 intervals was recorded.

The first exposure to baseline conditions lasted 40 sessions by which time visual inspection indicated that performance had stabilized. Then the first of four clock reversal tests occurred. This test was followed by additional baseline sessions, interspersed with the other three tests sessions

TABLE 1

Summary of Procedures

Conditions, in order of occurrence	Number of sessions
EXPERIMENT 1	
Baseline	40
Clock reversal test — free food	1
Baseline	19
Clock reversal test — free food	1
Baseline	5
Free food test	1
Baseline	4
Free food test	1
Baseline	3
Clock reversal test — extinction	1
Baseline	6
Clock reversal test — extinction	1
EXPERIMENT 2	
Baseline	5
Partial reversal in odd FIs	1
Baseline	4
Partial reversal in even FIs	1
Baseline	5
Partial reversal in odd FIs	1
Baseline	11
Partial reversal in even FIs	1
Baseline	7
Shorter FI test	1
Baseline	13
Longer FI test	1
Baseline	4
Partial reversal test in odd FIs	1
Baseline	13
Partial reversal test in even FIs	1

(see Table 1 for details). Typically, about three to five baseline sessions intervened between the test sessions; sometimes more sessions were given if performance appeared unstable, if there had been an equipment malfunction, etc.

Clock reversal tests. These sessions were identical to baseline sessions with two exceptions. First, beginning with the 13th interval the houselight was turned off during odd numbered intervals and on during even numbered intervals. Thus, the line tilts moved counterclockwise during light and clockwise during dark, the opposite of baseline training. During the first two test sessions grain was delivered at the end of each FI independently of keypecking. Two control tests (see Table 1) were conducted to assess the effects of free food presentations. During the other two reversal tests no reinforcement was delivered; the next FI began immediately and automatically at the end of a completed FI.

Results and Discussion

An index of curvature (Fry, Kelleher, & Cook, 1960) was calculated for the test sessions and for the three baseline sessions preceding each test. A separate index was calculated for odd and even numbered FIs. This measure was calculated as follows:

$$I = \frac{(n\text{-}1)\, R_n - 2 \sum_{i=1}^{n-1} R_i}{nR_2} \qquad (1)$$

where, n is the number of subintervals into which the FI period is divided (three here) and R_i is the number of pecks in the ith subinterval. A constant rate of pecking across the subintervals gives $I = 0$. Positively accelerated, scalloped pecking patterns give values greater than 0. The maximum value, when $i = 3$ and when all pecks occur during the final subinterval, is +.67. The minimum value, with $i = 3$ and when all pecks occur during the first third, is -.67.

Figure 1 shows I values (multiplied by 100) during odd and even FIs for baseline and test sessions. During baseline sessions the value of I was generally at or near the maximum value of +.67 during both odd (light) and even (dark) FIs for all birds, indicating that most pecking occurred during the final third of the FI. During the clock reversal test sessions the value of I

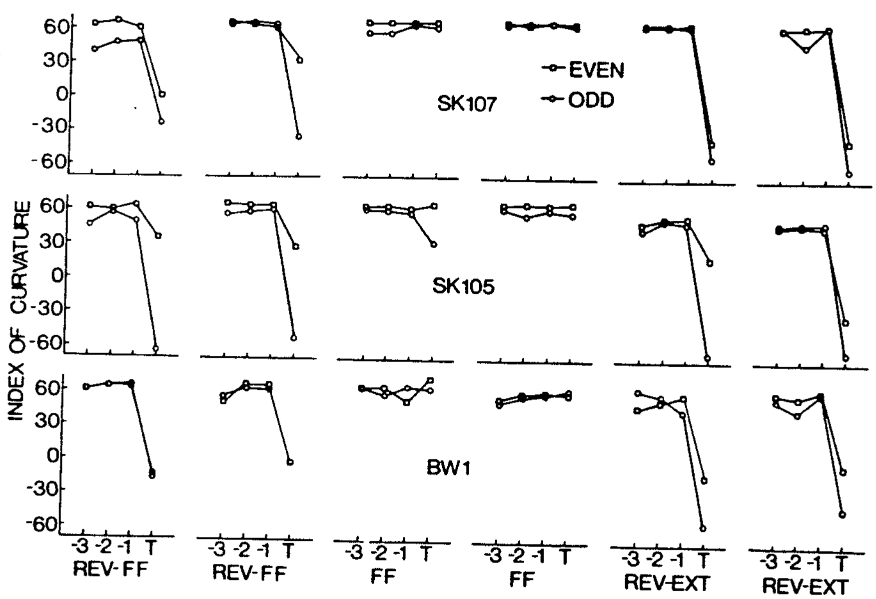

Figure 1. Index of curvature values (x100) during odd and even FIs for the three subjects for the three baseline sessions (-3, -2, -1) preceding the six test (T) sessions. The first and second test sessions were clock reversal tests in which free food was given at the end of each FI (REV-FF). During the third and fourth tests free food was given at the end of each FI(FF). The fifth and sixth test sessions were clock reversal tests in which no food was given (REV-EXT).

generally decreased, indicating proportionally less pecking during the final portion of the FI. In many cases, especially during the odd numbered intervals, the value of I became negative, indicating that most of the pecking occurred during the first third of the FI.

Had unprogrammed temporally varying stimuli been responsible for the scalloped pattern of pecking during baseline training, then reversing the order of the then irrelevant clock stimuli should not have resulted in a reversal of the usual temporal pattern of responding. On the other hand, there seems to be some evidence that some cues besides the line tilt clock also participated in the control of pecking. Had the clock alone controlled pecking, the clock reversal should have resulted in a total reversal of the temporal pattern of pecking. Such a complete reversal (to a -.67 index) only occurred during a fraction of the reversal test sessions and then only during the odd (dark) intervals. As can be seen in Table 2, which shows response sums across the four clock reversal tests, considerable responding occurred during the final as well as the first third of the FI during the clock reversal tests.

TABLE 2

Total Pecks During Clock Reversal Tests

Bird	Odd intervals Thirds:	1	2	3	Even intervals Thirds:	1	2	3
SK107		764	59	127		808	231	780
SK105		1357	29	75		891	160	1577
BW1		3308	218	1578		3215	462	2522

Data from the four clock reversal replications shown in Figure 1 were subjected to a repeated measures analysis of variance (ANOVA). The baseline (mean I values of .592, .614, .622) vs. test day (mean I value of -.219) factor was significant, $F(3,6) = 703.68$, $p < .001$. A post hoc Duncan's multiple range test performed on this factor at the 5% level of significance indicated that test days differed significantly from each baseline session. The odd vs. even interval main effect was not significant, $F(1,2) = 7.95$, $p = .106$. The replications factor was not significant, $F(3,6) = 4.40$, $p = .058$. The odd vs. even by baseline vs. test days interaction was significant, $F(3,6) = 5.85$, $p = .033$.

Figure 1 also shows data from the two control tests in which food was delivered independently of responding at the end of each FI. Free food deliveries had no effect on the index of curvature values.

EXPERIMENT 2

Two other manipulations were carried out to further substantiate conditional clock control of keypecking. In one procedure subjects trained under the conditional clock procedure with one FI value were exposed to both longer and shorter FI values. These changes in effect either sped up or slowed down the clock. If unprogrammed temporally varying stimuli rather than the programmed clock stimuli controlled pecking then there should be little transfer to these new FI values. On the other hand, if the clock stimuli controlled responding, such transfer should occur readily.

The second procedure, like that in Experiment 1, involved a change in the temporal order of the clock stimuli. However, in this procedure the order of only two of the three clock stimuli was reversed. Again, as in Experiment 1, we expected that this reversal would affect the usual temporal pattern of responding.

Method

Subjects and Apparatus

These were the same as in Experiment 1.

Procedure

This experiment followed Experiment 1 immediately and began with baseline sessions identical to those in Experiment 1. That is, light was on during odd numbered FIs and off during even numbered FIs. During odd intervals the key was illuminated during successive 50-sec subintervals by horizontal, oblique, and vertical lines. During even intervals the lines occurred in the order vertical, oblique, then horizontal. As in Experiment 1 pecks were recorded beginning with the 13th interval.

Two types of tests for clock control were interspersed, as summarized in Table 1, among baseline sessions. All tests began during the 13th interval.

Partial reversal tests. Six of these tests were given. During three, the order of the first two clock stimuli during the odd numbered (light) FIs was reversed; the lines appeared in the order oblique, horizontal, then vertical rather than horizontal, oblique, then vertical. During the other three tests, the order of the first two clock stimuli during even numbered (dark) FIs was reversed so that the order was oblique, vertical, then horizontal rather than vertical, oblique, then horizontal.

Length of FI tests. During two test sessions the FI was changed from 150 sec to 30 sec (shorter FI test) and to 300 sec (longer FI test). In the former test, the subintervals were 10 sec; in the latter, 100 sec.

Results and Discussion

Partial Reversal Tests

Data from the six partial reversal tests were compared to those from the immediately preceding baseline sessions. Data from both the baseline and test sessions were treated as follows. The number of pecks during the first and second subintervals of the FIs (odd or even during alternate tests, see Table 1) for which the presentation order was reversed was divided by the number of pecks during the third subinterval. Similarly, the number of pecks during the first and second subintervals of the corresponding (i.e. odd or even) FIs of the baseline session was divided by the number of pecks

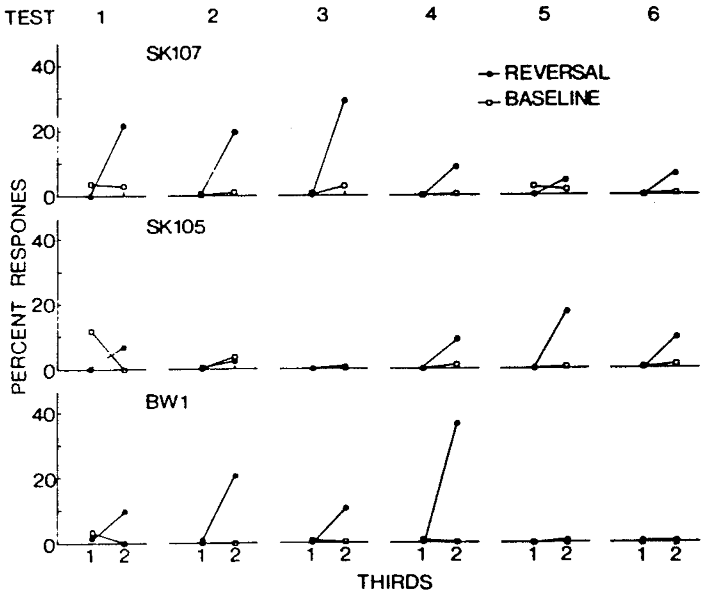

Figure 2. Pecks during the first and second thirds of the FI expressed as a percentage of responses made during the final third of the FI for the six partial reversal tests and the baseline session preceding each test.

during the final third. This transformation controlled for any differences in overall rate of pecking on baseline and test days. These data, expressed as percentages, are shown in Figure 2.

During the baseline sessions preceding the tests there generally was little pecking during the first and second thirds of the FI. Thus, percentage of responses during these thirds was low. Further, there was no systematic difference between pecking during the first and second third. During test sessions most pecking occurred during the second subinterval. That is, during odd (light) intervals more pecking occurred during horizontal when it was in the second ordinal position, as it was during tests, than when it was in the first third, as it was during baseline sessions. Similarly, during even (dark) intervals more pecking occurred during vertical when it occurred in the second rather than the first third.

Since clocks are ordered sequences of stimuli, this finding that the order of line tilts affects the temporal pattern of pecking shows again that the line tilt clock stimuli controlled pecking.

The data shown in Figure 2 were subjected to an ANOVA. First, a difference score (percentage of pecks during second third minus percentage of pecks during first third) was found for baseline and reversal days in each replication. These difference scores were then analyzed in a two-factor repeated measures ANOVA, the factors being baseline vs. reversal and replications. The former factor (baseline mean = 0.55; reversal mean = +11.36) was significant, $F(1,2) = 29.38$, $p = .032$. Replications was not significant, $F(5,10) = .55$, $p = .74$.

Length of FI Tests

Figure 3 presents the results of the test sessions in which the FI was changed from the normal 150 sec to 30 sec and 300 sec. This figure shows rate of pecking during successive thirds of the FI for each test and for the preceding baseline session. Manipulating the length of the FI had little effect on the temporal pattern of responding. Again, this is the expected outcome if the clock stimuli rather than unprogrammed temporally varying stimuli were controlling keypecking.

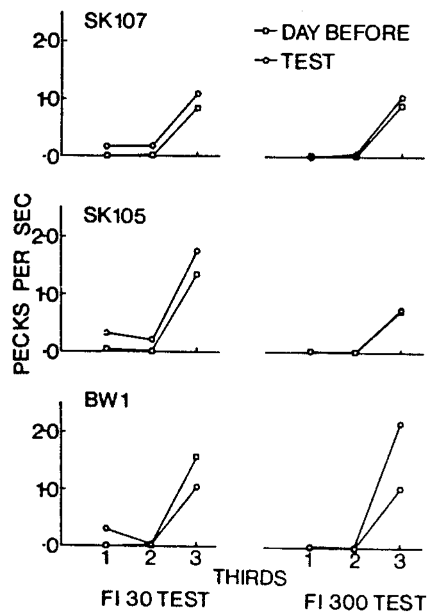

Figure 3. Rate of pecking during successive thirds of FIs during two test sessions when FI value was 30 and 300 sec. Data from the baseline session (FI 150 sec) preceding each test are also shown.

DISCUSSION

When reinforcement is scheduled periodically as in the present experiments one must show that responding is controlled by the programmed clock stimuli rather than by unprogrammed temporally varying stimuli. This was accomplished in two ways in the present study. First, the length of the FI was varied. Had unprogrammed temporally varying stimuli rather than the line tilt clock stimuli controlled responding, one would have expected little transfer of control to longer and shorter intervals. Instead, control transferred well. Secondly, the order of the clock stimuli was varied. Both complete and partial reversals of the usual order of line tilt affected the typical pattern of responding.

Given that the line tilt clock stimuli controlled responding one can ask questions about the nature of this control. The results of the tests in which the clock was completely reversed and the ones in which the FI length was varied suggest that the birds had learned a conditional discrimination between the presence of certain line tilts and the presence or absence of the houselight. If the birds had learned that reinforcement was available during vertical when the light was on and during horizontal when the light was off, one would expect the frequent responding observed in the first third of the interval during the clock reversal test. One would expect also the lack of effect of varying the FI length because this manipulation left the relation between the line tilts and light intact.

Learning a conditional discrimination between vertical and horizontal tilts and houselight, however, does not account for the considerable responding that occurred during the final third of the FIs during the complete clock reversal tests or for the results of the partial clock reversal tests. Changing the usual order in light from horizontal then oblique to oblique then horizontal and similarly reversing vertical and oblique in dark resulted in more responding during the second third of the FI as compared to baseline. It thus appears that the birds had learned, in addition to the relation between houselight and vertical and horizontal, that food was available during the stimulus that followed oblique but not during the stimulus that followed reinforcement. Such a successive conditional discrimination (vertical and horizontal positive after oblique but negative after reinforcement) implies that the birds remembered reinforcement and/or oblique after their termination. Thus memory processes may play a role in control by conditional clocks. (Since *ordering* of stimuli is an essential defining feature of clocks this finding that the birds had learned something about the order of the clock stimuli is also convincing evidence of clock control of responding.)

Successive conditional discrimination learning accounts for the finding that responding occurred during the final third of the FI during the complete clock reversal tests but does not explain the increased responding found during the first third of the FIs during these tests. Thus, during exposure to the conditional clock birds seem to learn two conditional discriminations: a simultaneous conditional discrimination between vertical and horizontal and houselight and a successive conditional discrimination between vertical and horizontal and the preceding stimulus—reinforcement or oblique.

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