SIGN-TRACKING WITH AN INTERFOOD CLOCK

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Food was presented to pigeons, irrespective of their behavior. The fixed 60-s interfood interval was segmented into ten 6-s periods, each signaled by a distinctive stimulus color, ordered by wavelength. This "interfood clock" reliably generated and maintained successively higher rates of key pecking at stimuli successively closer to food. Under extinction, key pecking ceased. When the standard stimulus sequence was changed to a different sequence for each bird, accelerated responding again emerged and was sustained under each of the new color sequences. However, responding was neither maintained nor acquired when each successive interfood interval provided a different random sequence of the ten stimuli. Thus, the interfood clock generated and maintained sign-tracking under stimulus control, and the resulting behavior was attributable neither to stimulus generalization nor to a simple temporal gradient.

Key words: clock stimuli, sign-tracking, autoshaping, key peck, pigeons

Brown and Jenkins (1968) demonstrated that food-deprived pigeons come to peck a visual stimulus that occurs just prior to response-independent food presentation. Gibbon and Balsam (1981) proposed that this ability to control responding was correlated with the relative duration of the trial with respect to the interfood interval or "cycle" (i.e., the C/T ratio, where C and T are cycle and trial durations). They supported their view by presenting acquisition scores for groups exposed to various temporal ratios. Food-contiguous stimuli that occurred for only a short portion of an interfood interval generated responding within a few trials, but those stimuli that occurred for almost half the interfood interval required extensive exposure before they controlled key pecks. Those stimuli longer than approximately half the interval did not control reliable key pecking.

The importance of temporal factors in associative learning is becoming increasingly apparent. For example, Gibbon and Balsam (1981) contend that traditionally emphasized

factors such as probability of reinforcement are not relevant as such. The obtained relationships can be shown to be functions of the predictive value of the trial stimulus as indexed by the C/T ratio. Jenkins, Barnes, and Barrera (1981) have offered a comparable view, contending that the most useful formulation is simply in terms of the ratio of overall waiting time to waiting time during the trial stimulus.

A position emphasizing the importance of temporal parameters has also been advanced to account for conditioned-reinforcement effects in operant situations (Fantino & Navarick, 1974). It suggests that the effectiveness of a stimulus as a conditioned reinforcer can best be predicted by the relative reduction in time to primary reinforcement signaled by the onset of that stimulus as compared to the average time to reinforcement that accompanies the contextual stimuli.

Procedures that provide trials segmented into sequences of discrete stimuli are potentially important for the examination of temporal factors in sign-tracking. The antecedent stimuli in a sequence of stimuli preceding response-independent food presentation have been shown to control directed key pecks (Newlin & LoLordo, 1976; Ricci, 1973; Wasserman, Carr, & Deich, 1978). Ricci partitioned a trial stimulus into four discriminable components, with trials separated by a variable intertrial

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interval that averaged 240 seconds. In one group, four 7.5-s stimuli preceded food presentation, whereas a second group received four 30-s stimuli preceding food. Accelerated responding across trial-stimulus segments occurred in both groups.

Ricci's data are consistent with Gibbon and Balsam's (1981) findings. In both the single-trial stimulus and segmented-trial stimulus paradigm, the stimuli that accompanied successively earlier portions of an interfood interval resulted in successively weaker responding. Responding in a segmented trial could therefore be viewed as a relatively continuous, within-subject index of the ability of various temporal portions of an interfood interval to control responding in a sign-tracking procedure.

The present study assessed the behavior controlled by an interfood clock. The procedure provided 10 distinct 6-s stimuli during a fixed 60-s interfood interval. By providing differentiable stimulus periods of equal length all the way back to the start of the interfood interval, the schedule did not simply dichotomize the schedule into a period signaling the absence of food and a period signaling imminent food presentation.

METHOD

Subjects

Ten domestic pigeons obtained from a local supplier were housed in individual cages where they had free access to water. All were maintained at approximately 80% of their ad lib weights with pelletized laying mash. The study began with 2 birds that had been used in a previous experiment; 3 experimentally naive birds were then started approximately 3 weeks later and were exposed to the same conditions. In Phase 5, 2 additional experimentally naive birds were added; 3 naive birds were used in a control condition.

Apparatus

The experimental chamber interior was a 30-cm cube. An unfinished aluminum stimulus panel served as one side of the chamber; the other sides were painted white. The stim-

ulus panel had a feeder aperture 5 cm in diameter medially located 8 cm above the floor. Three response keys, 2 cm in diameter, were located 9 cm apart, 19 cm above the floor. Only the center key was used. The key required a force of approximately 15 g (0.15 N) to operate. The frosted Plexiglas key could be transilluminated by a stimulus projector containing color filters. The filters were the following Roscolux theatrical gels: pink (34), red (26), orange (23), amber (20), yellow (12), green (91), turquoise (73), blue (68), and violet (58). A Lee color-correcting filter (218) was used to produce white. A 7-W houselight was located on the stimulus panel 4 cm from the right wall and 8 cm above the floor. Ventilation was provided by an exhaust fan mounted on the outside of the chamber. A white-noise generator provided ambient masking noise in the running room. Stimulus events were controlled and responses and interevent times were recorded by a computer system (Doyle & Palya, 1980).

Procedure

Prior to the experiment, the naive birds were exposed to a manually operated food magazine until they approached and ate from the food hopper within 3 s on three consecutive food presentations. The experiment involved six phases as outlined in Table 1. Each session typically contained 20 to 30 food presentations, as determined by each bird's body weight that day.

In Phase 1 (the baseline procedure) the five original birds were exposed to 57 sessions in which a fixed 60-s interfood interval was segmented into ten 6-s time periods, each designated by a different key color. The color

Table 1
Number of Sessions for each Bird in each Phase

<i>Phases</i>	90*	96*	17	83	978	26	31
1 Interfood Clock	57	57	57	57	57		
2 Extinction	11	11	11	11	11		
3 Interfood Clock	27	27	27	27	27		
4 Unique Interfood Clock	44	44	23	23	24		
5 Random Interfood Clock	11	50	11	11	11	18	18
6 Interfood Clock	35	35	35	35	35	35	50

*not experimentally naive

Table 2
Sequence of Colors for each Bird in Phase 4

<i>Bird</i>	<i>Stimulus Order</i>
90	green, orange, violet, yellow, white, turquoise, amber, blue, red, pink
96	amber, yellow, red, green, pink, turquoise, violet, blue, orange, white
83	pink, green, orange, yellow, violet, blue, turquoise, red, amber, white
978	violet, pink, red, blue, turquoise, green, orange, yellow, white, amber
17	turquoise, orange, amber, blue, red, violet, pink, white, green, yellow

sequence was white, pink, red, orange, amber, yellow, green, turquoise, blue, and violet, so that dominant wavelength decreased as proximity to reinforcement increased. A 3-s food presentation immediately followed the offset of the 10th stimulus. The houselight was off during food presentation. The 10-stimulus sequence repeated immediately following food offset, with no intertrial interval.

The second phase was extinction. The number and order of the stimuli remained the same as during the initial baseline procedure, but food presentations no longer followed the last of the 10 stimuli. A 3-s timeout, during which the houselight and magazine light were out, was substituted for food delivery.

The baseline procedure was reinstated in Phase 3. This phase was identical in all respects to the initial interfood-clock procedure.

In Phase 4 each bird was exposed to a new and unique color sequence as shown in Table 2. Other than a change in the stimulus sequence, all other conditions were identical to the initial baseline conditions.

In Phase 5 the birds were exposed to a randomly ordered sequence of colors between each food presentation. The 10 colors were each presented once for 6 s in a random order during each 60-s interfood interval. The random ordering was generated by the control computer (Doyle & Palya, 1980). Two naive birds were added to the study at this phase to determine if key pecking could be acquired with a randomized interfood clock.

Finally, the initial baseline procedure was again put into effect. Phase 6 was identical to Phases 1 and 3. A control condition was also implemented with 3 naive birds. These birds were exposed to 15 sessions of an interfood clock with the first nine stimulus periods ran-

domized and the final stimulus always violet.

RESULTS

The interfood clock generated and maintained responding. Generally, the response rate progressively increased across the stimuli in the second half of the interfood interval.

The three frames of Figure 1 show the acquisition of responding for the 3 naive birds as designated by their insets. The consecutive clock stimuli are represented from left to right across the *x* axis. This axis depicts the effect of stimuli successively closer to food presentation. Consecutive trials are represented from front to back along the *z* axis. This axis depicts the effect of increasing exposure to the schedule. The trial number at the beginning of each session depicted is provided along the axis. The number of responses occurring during a particular stimulus of a particular trial is depicted by the height of the *y* axis at that intersection. As can be seen, there was an initial period of no key pecking punctuated by an occasional peck. Consistent pecking subsequently originated during the stimulus immediately before food presentation. Within a few trials thereafter, pecking occurred at all 10 stimuli, in all 3 naive birds. However, responding did not propagate backwards consecutively through the interval. The stimuli in the middle of the interval were typically the last to control responding. Pecking at the initial and middle stimuli of the interfood clock subsequently dropped out or remained low, with the exception of Bird 83 noted below.

In general, the loss of responding to early stimuli was graded in terms of the temporal position of the stimulus in the interfood interval. The earlier the stimulus occurred in the interval, the sooner the loss began, the more

Fig. 1. Acquisition of responding for the 3 naive birds as designated by the insets. The consecutive clock stimuli are represented from left to right across the *x* axis. This axis depicts the effect of stimuli successively closer to food presentation. Consecutive trials are represented from front to back along the *z* axis. This axis depicts the effect of increasing exposure to the schedule. The trial number at the beginning of each session depicted is provided along the *z* axis. The number of responses occurring during a particular stimulus of a particular trial is depicted by the height of the *y* axis at that intersection.

sharply the rate declined, and the lower was its asymptotic rate.

Pecking at the final stimuli was well maintained over the 57 sessions of Phase 1. Each frame in Figure 2 depicts the asymptotic distribution of pecking at the 10 stimuli for the bird designated by its inset. The early trials of each session were excluded because atypically flat distributions were frequently noted during the first trial or so of a session. Tie bars indicate ± 1 standard deviation in the session-to-session averages. With an exception noted below, responding began in the interfood interval before the seventh stimulus, with successively higher rates on each subsequent stimulus. The characteristic pattern of successively higher rates on stimuli successively closer to food

emerged following only a few sessions of exposure to the schedule, and was essentially the same in both the naive birds and the birds with previous experimental histories. The final stimuli maintained rates on the order of three responses per second.

Bird 83 was an exception. This pigeon tended to bite the edge of the key throughout the second half of the interfood interval, such that key operations poorly indexed the rates that were indicated by occasional informal observations.

In the extinction phase (Phase 2) responding reached near zero levels within a few sessions. Figure 3 presents the behavior occurring under extinction, using the same format as Figure 1. Consecutive stimuli are arranged left

Fig. 2. Asymptotic distributions of each pigeon's pecking at the 10 stimuli of the interfood clock. The data are the mean response rates for each stimulus averaged over the last five sessions of Phase 1, excluding the first five trials of each session. Tie bars indicate ± 1 standard deviation in the session-to-session averages.

to right. Consecutive trials are arranged front to back. The trial number at the beginning of each session depicted is provided along the axis. The last five sessions of the preceding baseline phase are presented first, followed by the extinction sessions. (The baseline data depicted in this figure are the raw data underlying the summary provided in Figure 2.) As can be seen, consistent responding endured for about three extinction sessions in 3 birds and

less than one session in 2 birds. Extinction typically resulted in an initial increase in variability with responding less confined to the final stimuli, as would be expected. Examples of spontaneous recovery can be seen in the records of Birds 90, 83, and 978.

Both a relative and an absolute extinction criterion were used to index resistance to extinction so that comparisons could be made between the rate and the resistance to extinction that accompanied each stimulus. These indices provided the number of trials that elapsed before the extinction criterion was met during each of the 10 stimuli for each bird. The relative extinction criterion assessed the number of trials that elapsed before the median of five consecutive trials was less than 1% of the mean rate for that stimulus over the last 5 days of the preceding baseline phase. The relative criterion showed that responding was maintained longer the later the stimuli occurred in the interval, and roughly corresponded with the response rate previously maintained by each stimulus. The absolute extinction criterion assessed the number of trials that elapsed before 10 consecutive trials occurred without a key peck. This extinction measure also showed that the resistance to extinction roughly paralleled the preextinction response rates. A more stringent criterion (25 trials without a response) showed greater variability between birds and a greater tendency for responding to cease first in the presence of the middle stimuli, then the initial stimuli, and finally in the presence of the terminal stimuli.

When the baseline procedures were reinstated in Phase 3, responding recovered. Within 10 trials high rates accompanied the final stimuli in all birds, and within one session the characteristic response pattern of Phase 1 reappeared.

The color sequence of the 10 stimuli was arbitrarily scrambled for each bird in Phase 4 to assess the importance of stimulus generalization in control by the interfood clock of the characteristic pattern of responding. Figure 4 presents the asymptotic rates on each of the stimuli when each bird had a unique sequence of 10 stimuli, using the same format as in Figure 2. The same basic pattern of respond-

Fig. 3. Extinction of responding in the 5 birds as designated by the insets. The last five sessions of the preceding baseline phase are presented first, followed by the extinction sessions. Consecutive stimuli are arranged left to right. Consecutive trials are arranged front to back. The trial number at the beginning of each session depicted is provided along the z axis.

Fig. 4. Asymptotic distributions of pecking at the 10 stimuli of the unique interfood clock. The data are the mean response rates for each stimulus averaged over the last five sessions of Phase 4, excluding the first five trials of each session. Tie bars indicate ± 1 standard deviation in the session-to-session averages.

ing emerged as had occurred in Phases 1 and 3 even though the stimuli were not ordered in terms of their dominant hue. Bird 83 was a partial exception, but stimulus generalization can provide no account of that bird's idiosyncratic pattern of responding only in the third quarter of the interfood interval. This was presumably a consequence of its particular response topography, discussed earlier.

During Phase 5, stimulus sequences were randomized in each interfood interval. Four of

the 5 original birds' responding virtually ceased with 11 sessions (about 0.5 responses per minute). The response rate for the remaining bird (96) slowly declined to about 0.7 responses per second over the course of 50 sessions. For this bird, response rates on each consecutive stimulus increased until the middle of the interfood interval, and then decreased as the remainder of the interval elapsed. Two naive birds were added to the study at this phase. Key pecking was not acquired by these birds in the 18 sessions of exposure to the randomized stimulus sequences. The 3 naive birds of the control condition that had been exposed to an interfood clock with the first nine stimuli randomized and the final stimulus always violet, pecked only at the final stimulus. The rates on the violet stimulus were 0.3, 1.1, and 1.6 responses per second for these 3 birds.

In the final phase, the 7 birds in the main study were exposed to the original baseline schedule. As can be seen in Figure 5, for the most part the characteristic response pattern again emerged. One of the birds (31) that had been added to the study in Phase 5, and had had 18 sessions of a randomized interfood clock, only slowly acquired pecking, pecked at a low rate, and required 50 sessions to stabilize. The bird that bit the edge of the key (83) reacquired its characteristic response pattern.

DISCUSSION

An interfood clock composed of 10 equally long stimulus components was found to generate and maintain successively higher rates on the successively later stimuli of the interval. The key pecking was viewed as sign-tracking in that: The pecking was reliably acquired and maintained without a response contingency; pecking was under the control of stimuli with fixed relationships to food; the behavior was directed onto those signaling stimuli; and key pecking was abolished when the stimulus contingency was removed without altering food presentations.

The present study provided a direct, single-subject measure of temporal control within an

Fig. 5. Asymptotic distributions of pecking at the 10 stimuli of the unique interfood clock. The data are the mean response rates for each stimulus averaged over the last five sessions of Phase 5, excluding the first five trials of each session. Tie bars indicate ± 1 standard deviation in the session-to-session averages.

interfood interval. The effect was reliable within birds and general across birds. The consistent behavioral effect of this procedure suggests that this schedule of stimulus contingency could be used to assess a variety of factors affecting timing or stimulus control in behavior patterns maintained with only stimulus contingencies.

It was notable that substantial responding was chronically maintained on stimuli other than the stimulus directly contiguous with food presentation (Brown, Hemmes, Coleman, Hassin, & Goldhammer, 1982). Responding began about midway through the interval and accelerated to approximately three responses per second in the presence of the final stimulus. The effect is not inconsistent with positions emphasizing temporal control in sign-tracking such as those of Gibbon and Balsam (1981) or Jenkins et al. (1981), but neither is it explicitly predicted by either of them.

If responding on all but the final stimulus had ceased, it would have been consistent with the traditional notions of least effort, discrimination, and stimulus control. This view has been most clearly stated by Ferster and Skinner (1957, p. 266) to predict the distributions of operant behavior under clocked fixed-interval schedules. However Gibbon and Balsam (1981) have also considered the possibility that the functional ITI includes all stimuli other than the positive trial.

Given that pecking consistently occurred on stimuli other than the final stimulus in the fixed interfood interval, a variety of mechanisms can be advanced to account for the early responding. Imprecision of an internal clock, or temporal generalization, is not applicable when explicit temporally correlated stimulus changes are available. This potential explanation was also evaluated empirically by randomizing the stimuli during each trial. If only temporal cues were responsible for responding during the interfood interval, then the same characteristic response pattern should have occurred when each bird was exposed to randomized stimuli distributed within the constant interfood interval. This was especially the case when key pecking was maintained immediately before food presentation and only

the first nine stimuli were randomized in each trial. The inability to generate or maintain responding on the noncontiguous stimuli under those conditions showed that simple temporal control was not a viable explanation.

Stimulus generalization was a possible explanation for the early responding when the stimulus sequence was systematically ordered with respect to hue. However, Phase 4 directly tested this potential explanation through arbitrary alteration of the color sequence. The emergence of the same characteristic response pattern when each bird was exposed to a different stimulus sequence indicated that the obtained effect was not the result of the stimuli controlling similar responding only by virtue of their hue similarity. As a result, stimulus generalization was also excluded as a plausible explanation.

A higher-order conditioning view (e.g., Rashotte, 1981) could propose that the final stimulus acquires the ability to elicit responding and act as a reinforcer by virtue of being contiguous with primary reinforcement. The penultimate stimulus then comes to elicit responding and act as a reinforcer, in turn, by virtue of being contiguous with the final stimulus. This process could be repeatedly invoked for successively earlier stimuli to whatever extent was necessary to account for the obtained data. In principle, higher-order conditioning could be continued indefinitely, in that it is not clear whether a loss of strength across successive levels is always to be expected. Unfortunately, there is a critical absence of specific predictions. The number of levels attainable, their stability, and the factors that determine the number of levels are all unspecified. Simple combinations of higher-order conditioning with post hoc appeals to inhibition and discrimination provide little predictive power because almost any data could be seen as the result of some combination of those processes.

One aspect of the present study is inconsistent with a higher-order conditioning interpretation. Higher-order conditioning implies an underlying order to acquisition. Initially the final stimulus should be conditioned, next the penultimate stimulus, and so on. Figure 2 provides no evidence of consecutive condition-

ing of responding on successively earlier stimuli. The middle stimuli were the last to control pecking. It would seem that any gain provided by using higher-order conditioning as an explanation for the present results would be lost by the necessity of invoking a yet to be understood mechanism that controls, as a minimum, the expression of higher-order conditioning of pecking.

Alternatively, it could be pointed out that a relatively large change in the predictability of food is occasioned by the onset of a stimulus that immediately precedes food presentation and that this information value results in sign-tracking (see Hearst & Jenkins, 1974). It would follow from this information view that the onset of a stimulus in a series of stimuli preceding food would come to control approach (Allaway, 1971). The problem, of course, is that of independently specifying which stimuli in a clock are informative of impending food and which signal only a continuance of the no-food intertrial interval.

The predictive weakness in both the higher-order conditioning and information views with respect to the effect of an interfood clock could be mitigated by using Gibbon and Balsam's (1981) function to specify which stimuli will become positive and will control approach. This position would contend that higher-order conditioning will extend to the approximate midpoint of the interfood interval, or that stimuli that accompany the second half of the interfood interval provide relatively positive information concerning the subsequent food presentation.

Responding to clock stimuli not contiguous with food could be viewed from yet another perspective. Hearst and Jenkins (1974) label this view the expectancy releaser theory. It would suggest that the fixed interfood interval induced an increasing readiness to perform consummatory responses as the interval elapsed and that the clock functioned primarily to direct the expression of the increasing behavioral potential as key pecks.

Killeen (1979) and Staddon and Simmelhag (1971) have shown that fixed interfood intervals generate consistent changes in several behavior patterns that are correlated with

relative time in the interval, even when those patterns are not required for reinforcement, are not elicited by stimuli preceding the reinforcer, and do not occur in approximate contiguity with food. The obtained systematic increase in rate across an interfood clock may have resulted in part from a similar effect conditioned to the temporally correlated stimuli. Phase 5 and the control condition demonstrated that the behavior in the present study was not a simple function of temporal control, for the correlation between the clock stimuli and the passage of time in the interfood interval proved to be necessary. This correlation may have served to associatively steer temporally "released" pecks to the key, or to control the topography of the released behavior as key pecks rather than as other patterns such as orientation toward the magazine (Staddon & Simmelhag, 1971).

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