STIMULUS CONTROL OF RESPONDENT AND OPERANT KEY PECKING: A SINGLE KEY PROCEDURE

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Pigeons' responses to a uniformly illuminated response key were either reinforced on a variable-interval one-minute schedule of reinforcement or extinguished for one-minute periods. When 1.5 second signals were presented at the beginning of each component, so as to differentially predict reinforcement, the pigeons pecked at the signals, at rates higher than rates during the remainder of the component. When the brief signals were not differentially predictive of reinforcement, pecking in their presence decreased to near zero levels. Similar results were obtained with signals based upon colors and upon line orientations. Changes in rates of (unreinforced) pecking occurred during the signal whether pigeons responded differentially during the remainder of the component or not. Experiment II demonstrated that the presence of the signal correlated with extinction was not necessary for pecking to develop at the signal which preceded the component in which responding was intermittently reinforced. The experiments demonstrated a clear dissociation of respondent control from operant control of a response. In addition, operant behavior was shown to be relatively insensitive to differing rates of reinforcement, as compared to the sensitivity of respondent behavior to differing rates of reinforcement produced by the very same operant behavior.

Key words: elicited and operant responding, stimulus control, trace stimuli, mixed schedules, key peck, pigeons

Considerable evidence has accumulated which suggests that the stimuli associated with the various components of a multiple schedule have an eliciting, as well as a discriminative function (Gamzu & Schwartz, 1973; Gamzu & Williams, 1973; Ricci, 1973; Schwartz, 1973). The alternation of two stimuli which are differentially predictive of food appears to be a sufficient condition for the development of elicited pecking directed at the stimulus correlated with the higher frequency of reinforcement.

The recognition of stimulus-reinforcer dependencies in multiple schedules of reinforcement led to the development of the additivity theory of behavioral contrast (Gamzu & Schwartz, 1973). The theory proposes that behavioral contrast—response rate increases in one component (S+) of the schedule resulting from a reduction in the frequency of reinforcement in another component (S-)—occurs be-

cause a differential stimulus-reinforcer dependency is imposed upon an already existing response-reinforcer dependency. The two sources of control are said to interact additively to generate a higher response rate than either dependency alone.

Support for this view of contrast is provided by studies that have demonstrated that operant and elicited pecking can be spatially separated (Keller, 1974; Schwartz, 1973, 1975; Schwartz, Hamilton, & Silberberg, 1975; Speelman, 1976). For example, Keller (1974) exposed pigeons to a sequence of multiple schedules in which the discriminative stimuli were located either on the food key or displaced upon a second signal key. When the discriminative stimuli were located on the food key, contrast was observed when the reinforcement schedule in one of two components was changed to extinction. When the discriminative stimuli were presented on the separate signal key, the rate of responding on the food key did not increase. However, the pigeons began pecking the signal key whenever the stimulus associated with reinforcement was present. When both food key and signal key responses were added together contrast was obtained.

The present series of experiments attempted

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to separate elicited and operant pecking in time with a single key procedure rather than spatially with a two key procedure. Such separation more closely resembles multiple schedule performances and would make possible the analysis of the dynamics of superimposed respondent-operant behavior.

EXPERIMENT I

The purpose of Experiment I was to demonstrate that brief signals that precede periods of intermittently reinforced pecking, maintained by unequal reinforcement densities, will acquire control of key pecking even when responding is never reinforced in their presence.

Subjects

Six adult male, experimentally naive, Silver King pigeons, obtained from the Palmetto Pigeon Plant, Sumter, South Carolina were maintained at 80% of their free-feeding weights. Water and grit were always available in the home cage.

Apparatus

The experimental apparatus was a standard pigeon test chamber (Gerbrand's Model #E5610) containing three clear response keys; only the center key was used. Pecks of at least .15 N were recorded and operated a feedback relay mounted behind the front panel. The reinforcer was 4-sec access to mixed grain delivered by a food hopper located directly below the center key. Light from an Industrial Electronic Engineers Inc. projector transilluminated the key. The houselight remained on during sessions except during reinforcement cycles when both the houselight and keylight were turned off and the food hopper was illuminated. Masking noise was provided by a white noise generator and an exhaust fan. Relay and solid state programming and recording equipment was located in an adjacent room.

Procedure

The sequences of stimuli for the various conditions in Experiment I are presented in Table 1. In Condition I, pigeons' responses were reinforced on a mixed variable-interval 1-min variable-interval 1-min (VI 1-min VI 1-min) schedule of reinforcement in the presence of a white key. The values of the 20 intervals

that made up the constant-probability VI schedules were derived from Catania and Reynolds (1968). Components, indistinguishable from the subjects' viewpoint and each associated with its own VI schedule, alternated every 60 sec. Sessions were terminated after 60 components were presented. No responses were reinforced for 1.5 sec following a component change. Responses in these intervals were counted separately in order to provide a baseline against which to assess the effect of adding a signal.

For Birds 1, 2, and 3, after 50 sessions of mixed VI 1-min VI 1-min, the key was illuminated by red light during the first 1.5 sec of half the components and by a green light during the first 1.5 sec of the remaining 30 components (Condition II). Thus, the key color during each component was either red or green for 1.5 sec and white for 58.5 sec. Responses in white continued to be reinforced on VI 1-min. At no time did responses in the presence of either the red or green signal directly produce access to grain. For Birds 4, 5, and 6, black horizontal and vertical lines on a white background were used as signals.

In Condition III the reinforcement schedule in white following green for Birds 1, 2, and 3, and in white following vertical for Birds 4 and 5, and in white following horizontal for Bird 6, was changed to extinction with all other contingencies remaining in effect.

Birds 1, 2, and 3 were exposed to Condition IV in order to assess the degree of stimulus control exerted by the signals. In Condition IV, the duration of the green signal was increased to one minute and the duration of white following green was reduced to zero; i.e., the component which consisted of 1.5 sec of green followed by 58.5 sec of white was changed to 60 sec of green. Extinction remained in effect throughout the component.

For Birds 4 and 5 the cycle of conditions was I, II, III, II, and I; for Bird 6 the cycle was I, II, III, and II.

The number of sessions at each condition is presented in Table 2. The numbers in parenthesis refer to the number of sessions the bird was reexposed to the condition.

RESULTS

Figure 1 shows response rates per session for Birds 1, 2, and 3 for the last 5 sessions of

Table 1
Sequence of Conditions for Experiment 1

Condition I								
Birds 1, 2, 3, 4, 5, 6								
Color	W	W	W	W				
Schedule (min)	EXT	VI 1	EXT	VI 1				
Duration (sec)	1.5	58.5	1.5	58.5				
Condition II								
Birds 1, 2, 3				Birds 4, 5, 6				
Color	R	W	G	W	H	W	V	W
Schedule (min)	EXT	VI 1	EXT	VI 1	EXT	VI 1	EXT	VI 1
Duration (sec)	1.5	58.5	1.5	58.5	1.5	58.5	1.5	58.5
Condition III								
Birds 1, 2, 3				Birds 4, 5				
Color	R	W	G	W	H	W	V	W
Schedule (min)	EXT	VI 1	EXT	EXT	EXT	VI 1	EXT	EXT
Duration (sec)	1.5	58.5	1.5	58.5	1.5	58.5	1.5	58.5
Bird 6								
Color	H	W	V	W				
Schedule (min)	EXT	EXT	EXT	VI 1				
Duration (sec)	1.5	58.5	1.5	58.5				
Condition IV								
Birds 1, 2, 3								
Color	R	W	G					
Schedule (min)	EXT	VI 1	EXT					
Duration (sec)	1.5	58.5	60.0					

Condition I and all sessions of Conditions II, III, and IV. For Condition I, the response rate in the first 1.5 sec of each component is shown separately. Although the 1.5-sec interval in each component of Condition I was associated with a white key, one was designated red and the other green, on the basis of what color was to be added to that component in Condition II.

During mixed VI 1-min VI 1-min (Condition I), response rates were essentially equal in each component. The response rate in the first 1.5 sec of each component was almost indistinguishable from the rate in the remainder of the component event though responding in the 1.5-sec intervals was not reinforced.

Changing the key color from white to red or green for the first 1.5 sec of each component reduced responding in those intervals to near zero levels. Responding in the white stimuli was unaffected. However, when the reinforcement schedule in white following green (W_G) was changed to extinction, the rate in the 1.5-sec red signal which preceded the white component in which responses were still inter-

mittently reinforced, increased dramatically. Little change in responding occurred in the green signal. After a considerable number of sessions the pigeons began to differentially respond to white. The major change occurred in the response rate during W_G . Little change occurred in the rate in white following red (W_R).

The red and green trace stimuli exerted control over pecking in their presence before they exerted control over response rates in white. In addition, in Condition III the rate in red came to exceed the rate in white.

Increasing the duration of the green signal

Table 2
Number of Sessions at Each Condition for Experiment 1

Subject	Condition			
	1	2	3	4
1	50	5	23	5
2	50	5	24	5
3	50	5	25	5
4	50 (5)	5 (10)	22	
5	50 (5)	5 (10)	22	
6	50	5 (15)	22	

Note. The numbers in parentheses represent the number of sessions the bird was reexposed to the condition.

Fig. 1. Responses per minute for the last five sessions of Condition I, and all sessions of Conditions II, III, and IV. Filled circles, solid lines represent response rates in white following red (W_R); filled circles, dashed lines, the rate in white following green (W_G); unfilled circles, solid lines, the rate in red (R); and unfilled circles, dashed lines, the rate in green (G). In Condition I unfilled circles represent response rates in the first 1.5 sec of each white component.

had very little effect upon responding in green. In Condition IV response rates remained at a near zero level even though green was available for 30.0 instead of .75 min a session. The rate in red decreased, however, and the rate in white following red increased. Casual observation indicated that the decrease in the red rate was primarily due to the pigeons moving away from the response key during the green component. At the onset of the red signal the bird approached the key, but did not arrive quickly enough to peck at it.

Figure 2 shows responses per minute for the last five sessions of Condition I and all sessions of Conditions II, III, and return to Condition II for Birds 4, 5, and 6.

As in Figure 1 the mixed VI 1-min VI 1-min (Condition I) rates were approximately equal. Adding the signals to the first 1.5 seconds of each component, without altering the reinforcement frequency in either component, produced effects similar to those observed with color. That is, the response rate in the first 1.5 seconds of each component decreased substantially. However, rates were somewhat higher than the rates of responding to the red and green signals in the corresponding condition. Changing the reinforcement schedule in white following vertical (W_V) (Birds 4 and 5) or white following horizontal (W_H) (Bird 6) to extinction, resulted in differential responding to the signals. Response rates in the signal which preceded the reinforced component increased to a level above both the baseline signal rate and the rate in the white components during any condition. Unlike the data of Birds 1, 2, or 3, little or no differential responding developed in the presence of W_H and W_V (Note the differences in the scale along the y axis). Secondly, when pigeons began responding on keys with line stimuli they responded to both the horizontal and vertical signals. However, the rates in the signal which predicted extinction quickly decreased again while responding in the presence of the signal which predicted reinforcement continued to increase and was maintained at very high levels. Responding in the signal predicting extinction was maintained at a much higher rate than that observed when red and green lights were used as signals. When the reinforcement schedule was returned to VI 1-min VI 1-min responding to both signals decreased to baseline levels. Little systematic change in re-

sponse rates was observed in the presence of either W_H or W_V .

Within component rates for W_H and W_V for Birds 4, 5, and 6 were calculated in four intervals. The first three intervals were 15 sec in duration, the fourth, 13.5 sec. With few exceptions the within component response rates were fairly close to the overall session rates. Standard deviations ranged from .4 to 5.1 responses per minute and rate changes appeared to fluctuate unsystematically except for Bird 4. For this pigeon, rate fluctuations were greatest during Condition III and the second exposure to Condition II.

In contrast the postsignal pause (measured from the offset of the signal to first response in white) changed systematically as the conditions were changed. First, in 9 of 10 cases the average postsignal pause increased when signals were added to the mixed VI 1-min VI 1-min schedule and decreased when the signals were removed. Second, in all cases the postsignal pause following the signal which predicted reinforcement decreased when the differential condition was introduced and increased when the pigeons returned to the non-differential condition.

DISCUSSION

The results of Experiment I clearly demonstrated that pigeons will differentially peck at signals which differentially predict periods of intermittently reinforced responding. In addition, the rate at which the pigeons pecked at the signal dramatically exceeded the rate at which pecking occurred during the periods when it was reinforced.

It is clear (Figure 2) that the differential pecking to the brief stimuli was dependent upon the differential stimulus-reinforcer relation created by changing the reinforcement schedule in one of the white components to extinction. When the differential stimulus-reinforcer relation was removed, the rate of pecking in the signal which preceded the reinforced component returned to near zero levels. Further, the control exerted by the green signal over a low rate of responding was not limited to that signal's brief duration, for that signal also controlled a near zero response rate when its duration was extended to 60 sec. Perhaps the procedure is an alternative way of errorlessly establishing stimulus control (Terrace, 1963), similar to that of Wessels (1973) and

Fig. 2. Responses per minute for the last five sessions of Condition I, and all sessions of Conditions II and III. Filled circles, solid lines represent the rate in white following vertical (W_V); filled circles, dashed lines, the rates in white following horizontal (W_H); unfilled circles, solid lines, the rate in vertical (V); and unfilled circles, dashed lines, the rate in horizontal (H). In Condition I unfilled circles represent rates in the first 1.5 sec of each white component.

Wilkie and Ramer (1974). However, because the appropriate control tests for transfer were not conducted, a conclusive answer on this point awaits further research.

The red and green stimuli (with respect to white) exerted strong control over responding during the first 1.5 sec of the component, even when they were first introduced in Condition II. They immediately controlled a near zero rate of responding which persisted for 5 sessions, a result that presumably followed from the lack of reinforcement in their presence. Similar effects were noted for line orientation although the degree of control was not as strong. Other differences between line orientation stimuli and colored lights were also observed. First, W_R and W_G exerted a greater degree of stimulus control over responding than did W_H and W_V . One explanation for this difference in stimulus control is that the background illumination of the key was white when the line orientations were presented. The presence of white light during and following the brief stimuli may have interfered with the acquisition of stimulus control.

Second, differential responding to the horizontal and vertical lines developed in the absence of differential responding in white. When colored lights were used as signals they exerted control on responding in white, but always after the lights exerted control of responding in their presence.

Third, when pigeons pecked at the horizontal or vertical lines in Condition III, they began pecking at both signals. Thus the rate in the signal preceding the extinction component temporarily increased (Figure 2). When colored lights were used only the rate in the color preceding the reinforced component increased. Similar differences in acquisition of stimulus control by color and line orientation have been reported previously (Carter & Eckerman, 1975).

EXPERIMENT II

Experiment I showed that altering the stimulus-reinforcer relation which existed during the baseline conditions resulted in the pigeons pecking at the signal which preceded the component in which responding was reinforced. However, it is not clear whether both signals were necessary for pecking to develop. If a respondent conditioning process is involved, then the presence of a signal preceding extinction

should be needed only for the establishment of differential control in the white components and not for the development of pecking to the signal predictive of reinforcement. Suppose Experiment I is repeated without the signal which preceded extinction, i.e., suppose that 1.5 sec of red is followed by 58.5 sec of white, then by 1.5 sec of white instead of 1.5 sec of green, and finally by 58.5 sec of white. If reinforcers are equally likely in white then the red signal will not be differentially predictive of food and should not control a high rate of pecking. However, if the probability of reinforcement in the first minute of white is greater than the probability of reinforcement in the second minute of white, the red signal will be differentially predictive of food and should control pecking. These possibilities were examined in the experiment reported below.

Subjects

Birds 4 and 5 of Experiment I, previously trained with line tilt signals were used as subjects. Subjects were maintained at 80% of their ad-lib weights. Water and grit were always available in the home cage.

Apparatus

Same as in Experiment I.

Procedure

Birds 4 and 5 were first re-exposed to the mixed VI 1-min VI 1-min procedure (Condition I, Experiment I) in order to assess whether continued exposure to the schedule had allowed some uncontrolled feature of the situation to gain control over responding. After 5 sessions either a red (Bird 4) or green (Bird 5) signal was added to the first 1.5 sec of one of the components. Components alternated simply, so in effect the 1.5-sec signal was followed by 1 min and 58.5 sec of white. The key color of the first 1.5 sec of the second component remained white and no responses in this interval were reinforced. The signal was followed by 58.5 sec of white in the presence of which a VI 1-min schedule of reinforcement was in effect; then by 1.5 sec of white in which responses were extinguished, then by 58.5 sec of white in which responses were reinforced on a VI 1-min schedule (Condition II). After 5 sessions of exposure to this condition, the schedule in the second 58.5 sec white compo-

nent was changed to extinction for 25 sessions for Bird 4 and 16 sessions for Bird 5 (Condition III). For Bird 5 only, the schedule in the second white component was returned to VI 1-min for 13 sessions (Condition II).

RESULTS

Figure 3 shows responses per minute per session for Birds 4 and 5 for the five sessions of the nondifferential condition, all sessions of the differential condition, and for Bird 5, the

return to the nondifferential condition. Note that for Bird 4 the green signal and for Bird 5 the red signal was omitted. As in Experiment I there was very little responding to the signal when the rate of reinforcement was constant throughout white. However, when responding in the second minute of white was not reinforced, both pigeons began pecking at the signal. When the differential stimulus-reinforcer dependency was removed (Bird 5) pecking quickly decreased to the baseline level. For

Fig. 3. Responses per minute for the last five sessions of Condition II (Left Panel), all sessions of Condition III and for Bird 5, all sessions of the return to the nondifferential condition (Condition II). Filled circles, solid lines represent response rates in white following red (W_R); filled circles, dashed lines, the rate in white following green (W_G); unfilled circles, solid lines, the rate in the red signal (R), and unfilled circles, dashed lines the rate in the green signal (G).

both birds the rates in white were essentially equal. For Bird 4, during the first few sessions of the differential condition, the rate in the second 58.5-sec white component (EXT) was slightly higher than the rate in the 58.5-sec component associated with the VI 1-min reinforcement schedule. The divergence in response rates developed because the VI tape-timer stopped scheduling the shortest programmed interreinforcement interval. Consequently, pausing began to develop following reinforcement delivery. When the difficulty was corrected the rates quickly converged.

Within-components rates in white were also calculated. As in Experiment II, each 58.5-sec white component was divided into four intervals, the first three were 15 sec in duration and the fourth 13.5 sec. With the exception of the first 15-sec interval in the white component immediately following the signal, the response rates in white were fairly constant. Standard deviations ranged from 1.1 to 7.4 responses per minute. The two largest fluctuations occurred in the rates in the first minute of white following the signal. Part of this fluctuation was due to a rate increase occurring in the first 15 sec that was due to response-bursting in the signal. Birds would begin a burst near the end of a signal presentation and continue for a second or two after the onset of the white stimulus. The fact that the postsignal pause decreased in the differential condition supports this interpretation. The rate in the first 1.5-sec interval of the second component was very similar to the overall and local rate in white during the remainder of the component.

DISCUSSION

Experiment II demonstrated that the presence of a signal preceding the period of extinction was not necessary for elicited pecking to develop. What appears to be necessary is a shift in the distribution of reinforcers which results in an increased correlation between the signal and food. This finding is quite consistent with the respondent conditioning literature (Gamzu & Williams, 1971; Rescorla, 1967, 1968).

GENERAL DISCUSSION

The present experiments clearly show that elicited and operant pecking can be separated even though both types of responses are di-

rected at a single key within the same experimental session. The two kinds of pecking were easily discriminable on the basis of rate differences within a condition and on the basis of differential rate changes across conditions. Pecking at the brief stimuli and during white was fairly independent; i.e., there was little evidence that operant reinforced relations in white gained control over brief stimulus pecking or that pecking rates during the brief stimuli interacted with pecking in white. In summary, there was a clear dissociation, both in rate of development and magnitude of effect, of operant discrimination and differential respondent pecking.

The present experiments differ from other sign tracking experiments in that operant responses produced the reinforcers that maintained the respondent behavior. Consequently the effect of a change in the rate of reinforcement simultaneously altered the response-reinforcer relation maintaining operant behavior and the stimulus-reinforcer relation maintaining respondent behavior. The two kinds of behavior were differentially sensitive to reinforcement rate changes. A reinforcement rate difference sufficient to establish and maintain respondent behavior was not reflected in the rate of operant behavior. The results suggest that respondent behavior is more sensitive to differing rates of reinforcement at least when the respondent and operant behavior are topographically similar. Whether the difference in sensitivity can be demonstrated with topographically dissimilar responses remains to be seen.

While all two-key multiple schedule studies have been able, to some degree, to separate operant and elicited pecks, no two-key study has yet demonstrated the magnitude of the rate differences obtained in the present experiment. There are several possible reasons for these rate differences. First, the time base in two-key studies is markedly different from that of the present study. In two-key procedures the signal key is illuminated whenever the operant key is. Thus signal time equals time in S+. Considering that most signal-key pecks occur at the beginning of the S+ component (Schwartz et al., 1975) using total time in S+ to calculate signal rate will result in a much lower response rate than if the first 1.5 sec of S+ is used as the time base. Secondly, in the two-key situation the pigeon cannot peck at two keys

simultaneously. If pigeons are pecking at the signal key then reinforcers for food-key pecks cannot be delivered even if available. Thus it is possible that sustained signal-key pecking will lower the reinforcement rate and consequently the frequency of elicited pecks. (Williams & Williams, 1969). Third, because pigeons are allowed to switch between keys, the actual sequence of stimulus presentations can be quite different from that programmed. As a result the intertrial interval between signal presentations during S+ can be quite short. In the single-key procedure, the minimum interval between presentations of the signal predicting reinforcement is two minutes, a procedure more conducive to the development of elicited pecking (Terrace, Gibbon, Farrell, & Baldock, 1975).

The results of the present experiments may also be relevant to the errorless discrimination experiments of Terrace (1963). In the present experiments stimulus control by the red and green signals was established almost immediately in Condition II even though the subjects had been rapidly pecking at white for 50 sessions. In Terrace's experiment control by a 5-sec green signal was rapidly established by first introducing the green signal at zero intensity and then gradually increasing its intensity. In Terrace's experiment 5 sec of green was followed by 3 min of red in which responding was intermittently reinforced. Terrace argued that few responses were made to green because of the manner in which it was introduced, i.e., at a short duration and low intensity. The present experiments suggest the role of the relationship between the signal and the distribution of reinforcers not only in its presence but also following its termination. The low rates of pecking in Terrace's experiments may have been due to a lack of a differential stimulus-reinforcer relation and not to the presence of a dark key.

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