Specification of the stimulus-reinforcer relation in multiple schedules: Delay and probability of reinforcement

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Control of pigeons' keypecking by a stimulus-reinforcer contingency was investigated in the context of a four-component multiple schedule. In each of three experiments, pigeons were exposed to a schedule consisting of two two-component sequences. Discriminative stimuli identifying each sequence were present only in Component 1, which was 4, 6, or 8 sec in duration, while reinforcers could be earned only in Component 2 (30 sec in duration). Control by a stimulus-reinforcer contingency was sought during Component 1 by arranging a differential relation between Component 1 cues and schedule of reinforcement in Component 2. In Experiment 1, rate of keypecking during Component 1 varied with the presence and absence of a stimulus-reinforcer contingency. When a contingency was introduced, rate of keypecking increased during the Component 1 cue associated with the availability of reinforcement in Component 2. In Experiment 2, the stimulus-reinforcer contingency was manipulated parametrically by varying the correlation between Component 1 cues and Component 2 schedules of reinforcement. Responding in Component 1 varied as a function of strength of the stimulus-reinforcer contingency. The relatively high rates of Component 1 responding observed in Experiments 1 and 2 pose difficulties for conceptions of stimulus-reinforcer control based on probability of reinforcement. In these two experiments, the stimulus-associated probabilities of reinforcement in Component 1 were invariant at zero. An alternate dimension of stimulus-reinforcer control was explored in Experiment 3, in which Component 1 cues were differentially associated with delay to reinforcement in Component 2, while probability of reinforcement was held constant across components. When the stimulus-reinforcer contingency was in force, rate of responding in Component 1 varied inversely with delay to reinforcement in Component 2. In a quantitative analysis of data from Experiments 2 and 3, relative rate of responding during Component 1 was strongly correlated with two measures of relative delay to reinforcement.

The acquisition and maintenance of keypecking in pigeons under autoshaping procedures (Brown & Jenkins, 1968; Williams & Williams, 1969) suggest that responses sensitive to operant contingencies can also be controlled by a stimulus-reinforcer (S-S^R) contingency. Subsequent to this early work, many studies have been reported in which keypecking was shown to vary when some dimension of S-S^R relation was changed (e.g., Gamzu & Schwartz, 1973; Gamzu & Williams, 1971, 1973; Gibbon, Locurto, & Terrace, 1975; Hemmes, 1973). An issue which is becoming increasingly evident in this literature is a lack of consensus on the manner in which the S-S^R relation is specified. Gamzu and Schwartz (1973), for example, reported that rate of keypecking under a response-independent multiple schedule varied with relative rate of stimulus-associated food presentation.

Gamzu and Williams (1973) reported that acquisition of autoshaped keypecking depended upon the presence of a positive correlation between the trial stimulus and food presentation. These results demonstrated the applicability of Rescorla's (1967) contingency analysis of classical conditioning to the phenomenon of autoshaping. According to this analysis, stimulus-contingent keypecking should vary with the conditional probability of food in the presence vs. absence of the trial stimulus (CS).

While this analysis can account for data such as those presented by Gamzu and Williams (1971, 1973), Gibbon et al. (1975) demonstrated that conditional probability of food presentation does not fully account for variation in the probability of keypecking under autoshaping procedures. In their study, three groups of pigeons were exposed to an autoshaping procedure under which the conditional probability of food in the presence of the CS was .25. Food was never presented in the absence of the CS. The groups differed in terms of the frequency of trial presentation. Although the conditional probability of food presentation given the CS was the same across

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groups, acquisition of keypecking was much more rapid when trials were widely spaced. These and other data (e.g., Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Terrace, Gibbon, Farrell, & Baldock, 1975) indicate that a valid index of contingency for the autoshaping situation must include the temporal dimension. This issue has been discussed in detail by Gibbon and his associates (Gibbon & Balsam, 1981; Gibbon, Berryman, & Thompson, 1974) and by Jenkins, Barnes, and Barrera (1981), who have proposed contingency indices based on temporal parameters.

In the present study, probabilistic and temporal dimensions of an S-SR contingency were investigated using a paradigm which differs from autoshaping in several potentially important ways. The paradigm, termed here the "temporal separation procedure," was developed independently by the present authors (Coleman, Brown, & Hemmes, Note 1) and by Marcucella (1981). Unlike autoshaping, the temporal separation procedure includes both S-SR and R-SR contingencies. The procedure is a multiple schedule composed of two fixed two-component sequences. Responses are never reinforced in the first component of either sequence, while primary reinforcers can be earned in the second component according to a response-dependent schedule. Component 1 of each sequence is signaled by a unique key color, while Component 2 of either sequence is cued by a white keylight. Under this procedure, control of behavior by R-SR contingencies may be examined in the second component, while control by S-SR contingencies is sought in the first component. The S-SR contingency is manipulated through differential pairing of Component 1 stimuli with Component 2 schedules of reinforcement.

A variation of the present design has been employed previously to demonstrate dissociation of S-SR and R-SR factors. Ellison and Konorski (1964, 1965) exposed dogs to a discrete-trial two-component procedure. One component, containing a signaled fixed-ratio (FR) 9 schedule for leverpressing, preceded a second component containing a fixed-time (FT) schedule that terminated after 8 sec with food delivery. Terminal performance revealed the restriction of leverpressing to the FR component, and salivation to the FT component. Evidence for dissociation of S-SR and R-SR factors was based on the assumption that these two response systems are differentially controlled by instrumental and classical processes, an assumption which may not hold (Miller & Carmona, 1967; Sheffield, 1965). In the present study, dissociation of factors does not depend upon assumptions regarding properties of different response systems but, rather, upon the argument that behavior control lawfully follows from different classes of manipulations (cf. McSweeney, Ettinger, & Norman, 1981). The strategy employed here was to separate these manipu-

lations temporally, in a manner analogous to previously employed spatial separation procedures (e.g., Keller, 1974; Spealman, 1976).

An important feature of the temporal separation procedure for the present investigation is the absence of reinforcement in Component 1 of either sequence. In virtually every analysis of S-SR control of keypecking, a contingency was specified in terms of reinforcers simultaneous, or at least contiguous, with the CS vs. reinforcers occurring in the absence of the CS. Although the formulations proposed by Jenkins et al. (1981) and by Gibbon and Balsam (1981) might be modified to account for S-SR control in Component 1 of the temporal separation procedure, they do not do so in their present versions.

In this paper, we report a series of three experiments in which the temporal separation procedure was used to assess several ways of specifying an S-SR contingency, including rate and probability of reinforcement, and a temporal parameter—delay of reinforcement. The results implicate delay to reinforcement as the behaviorally effective dimension, with at least two measures of this temporal contingency correlating strongly with rate of responding in Component 1.

EXPERIMENT 1

In Experiment 1, the stimulus-reinforcer contingency with respect to Component 1 cues was varied by manipulating the probability of reinforcement associated with Component 2 of one sequence. The purpose of this experiment was to evaluate the efficacy of the temporal separation procedure as an assay of stimulus-reinforcer control of keypecking. In addition, the experiment should provide evidence regarding the adequacy of several approaches to specifying the S-SR contingency.

Method

Subjects. Four experimentally naive White Carneaux hen culls were maintained at 80% of ad-lib weight.

Apparatus. The experiment was conducted in a standard three-key pigeon chamber (BRS/LVE). The center key could be transilluminated with various stimuli provided by display projectors (BRS/LVE IC-901), but the left and right keys remained dark. Responses directed toward a dark key were not recorded and had no programmed consequence. Masking noise was provided by a fan in the chamber and white noise in the small room containing the chamber. The experiment was controlled by electromechanical equipment located in an adjacent room.

Procedure. Following magazine training and hand-shaping to peck a white center key, the birds were placed on a VI 30-sec schedule until 50 reinforcers were earned. During each of the next two sessions, the birds earned 50 reinforcers according to a VI 60-sec schedule. Reinforcers consisted of access to mixed grain for 3 sec.

After this preliminary training, all birds were exposed to three experimental phases, during which the following conditions were held constant. Sessions contained 50 two-component sequences. Component 1 and Component 2 durations were 8 and 30 sec, respectively. Component 2 was always signaled by a white light, while Component 1 cues varied; for half of the sequences, Com-

Table 1
Schedules of Reinforcement in Component 2, Experiment 1

Phase	Sessions	Sequence	
		Red	Green
1	60	VI 1-min	VI 1-min
2	85	VI 1-min	Ext
3	40	VI 1-min	VI 1-min

Note—Schedules are shown for Birds 2084 and 2533; for the other two birds (2430 and 5395), the roles of red and green cues were reversed.

ponent 1 was signaled by a red key, and for the other half, by a green key. Sequences alternated within sessions according to a fixed random order, with the restriction that neither sequence occur more than three times in succession. The random order of presentation of red and green sequences was reversed on alternate sessions, and entry into the random order varied nonsystematically across sessions. Responses in Component 1 were never reinforced during this or subsequent experiments.

Conditions that were in force in Component 2 during the three experimental phases are described in Table 1. Baseline levels of responding in both components were established during Phase 1. In that phase, reinforcement was available according to a VI 1-min schedule during Component 2 of both sequences. The primary feature of Phase 1 was the absence of an S-S^R contingency between Component 1 cues and the reinforcement schedule in Component 2.

An S-S^R contingency was introduced in Phase 2, during which the schedule of reinforcement in Component 2 of one sequence (the negative sequence) was converted from VI to Ext, while the other sequence (the positive sequence) remained unchanged. For two birds (2430 and 5395), the red sequence was converted; for the other two birds (2084 and 2533), the green sequence was converted. During Phase 3, the S-S^R contingency established in Phase 2 was eliminated by a return to the baseline condition for all birds.

Results

The results for each bird are presented in Figure 1, which shows mean response rate plotted over five-session blocks during the three experimental phases. Upper panels for each bird depict performance during Component 1, and lower panels show corresponding performance during Component 2. The dashed, vertical lines separate phases. The figures show that rate differences between sequences emerged in both components during Phase 2.

The data of primary interest are rates of responding during Component 1. The results in that component were straightforward: Rates of responding were very low for all birds during 60 baseline sessions. With the introduction of the S-S^R contingency in Phase 2, all birds showed an increase in Component 1 response rate in the sequence containing the VI schedule in Component 2. For B5395, this increase was present, but very small. Return to baseline conditions during Phase 3 resulted in recovery of baseline performance.

Differentiation of responding during Phase 2 was also observed in Component 2. By the end of this phase, all birds showed higher rates of responding in the VI than in the Ext sequence. The rate differ-

ence gradually diminished following reinstatement of baseline conditions. Since no differential information was provided by the key light in Component 2, a question is raised about the source of behavioral control in Phase 2. Two possible sources are: (1) control via stored information generated in Component 1, and (2) cues based on reinforcer presentations during Component 2. The latter alternative was assessed by comparing performances in Component 2 with and without reinforcers. These data are presented in Figure 2, which is based on measurements from cumulative records of the last five sessions under Phase 2. As can be seen, there was little systematic difference in rate of responding during a positive sequence, regardless of whether reinforcers occurred or not. In addition, even in the absence of reinforcers, rates of responding were consistently higher during positive sequences than during negative sequences. The absence of control by reinforcer cues suggests that differential responding in Component 2 is attributable to events occurring during Component 1.

In general, the degree of stimulus control in Component 1 covaried among subjects with control in Component 2. To assess this relationship during the final 15 sessions of Phase 2, differences in rates of responding in positive vs. negative sequences were

Figure 1. Rates of responding for the four birds in Experiment 1 during red (×) and green (♦) sequences. Upper and lower panels depict Component 1 and Component 2 performance, respectively, in five-session blocks. Dashed vertical lines separate baseline, differential reinforcement, and return-to-baseline procedures. Note difference in ordinate scales between components.

Figure 2. Component 2 rate measures based upon cumulative records for four birds during the last five sessions in Phase 2, Experiment 1. Measures are plotted for positive components containing one or more reinforcer deliveries (x), positive components containing no reinforcer deliveries (O), and negative components (Δ).

computed for both Component 1 and Component 2. The correlation between Component 1 and Component 2 on this measure of stimulus control was .98.

Discussion

Experiment 1 produced strong evidence for S-SR control over keypecking in Component 1. Introduction of an S-SR contingency with respect to Component 1 cues produced an increase in rate of keypecking in the positive sequence. Peck rate returned to baseline levels when the S-SR contingency was removed in Phase 3. Similar data were reported by Marcucella (1981). These results, together with the stimulus-specificity of performance changes, indicate that the S-SR contingency, rather than adventitious reinforcement of Component 1 keypecks by Component 2 reinforcers, was responsible for the behavioral effect. Therefore, it seems reasonable to apply the results of this experiment to an analysis of control by a stimulus-reinforcer relation.

The behavioral changes that occurred in Component 1 across experimental phases impose an important constraint on the way in which the S-SR con-

tiguency may be defined. Consistent with the relativistic spirit of contingency theory, differential responding in Component 1 emerged, and was maintained, only when Component 1 cues were associated with differing densities of reinforcement in Component 2. These findings may be compared with those of Gamzu and Schwartz (1973), who also manipulated an S-SR contingency within the context of a multiple schedule. Using a two-component multiple schedule of response-independent reinforcement, Gamzu and Schwartz found that differential responding across components occurred only when the density of reinforcement in one component was high relative to density in the second component. In addition, absolute rates of responding varied with the presence vs. absence of the S-SR contingency. As in the present study, absolute rate of responding in the presence of the distinctive cues was very low when the cues were associated with identical schedules of reinforcement, and relatively high when the stimuli signaled differing densities of reinforcement. While the results of both studies are best understood in terms of relative, rather than absolute, rates of reinforcement, the

present study demonstrates that the members of the contingency (the stimuli and reinforcers) need not be temporally contiguous. From Gamzu and Schwartz's data, one might predict that no change in pecking would occur during Component 1 of the temporal separation procedure, since relative rates of reinforcement during Component 1 stimuli were invariant at zero. The development of differential responding during Component 1 implies a looser linkage between stimulus and reinforcer occurrences than has been assumed in some models of stimulus-reinforcer control (e.g., Gibbon, Berryman, & Thompson, 1974). This issue will be considered in greater detail below.

Although not of primary interest in the present study, systematic behavioral effects were also observed in Component 2. All four birds showed differential responding during Phase 2, and a gradual recovery of nondifferential responding when baseline conditions were reinstated in Phase 3. Because explicit key cues did not distinguish conditions in Component 2, and because control by reinforcer cues was ruled out (Figure 2), events during Component 1 remain as the only plausible source of differentiation in Component 2. The observed correlation in stimulus control between Components 1 and 2 is relevant here. An inference from that correlation is that Component 2 differentiation was supported by memory of Component 1 stimulus events, or was mediated by differential behavior generated during Component 1 (Blough, 1959; Cumming & Berryman, 1965). Thus, while differential responding in Component 2 depends upon differential reinforcement in that component, stimulus control of the rate difference is attributable to events occurring in Component 1.

EXPERIMENT 2

Experiment 1 produced differential rates of pecking in Component 1 in the presence of an S-SR contingency, but not in its absence. In Experiment 2, the S-SR relation in Component 1 was manipulated parametrically. Experiment 2 also eliminated the relationship, present in Experiment 1, between presence of an S-SR contingency in Component 1 and overall density of reinforcement in Component 2. In the first experiment, addition of an S-SR contingency to Component 1 was accomplished by removing reinforcement availability from Component 2 of one sequence. In Experiment 2, manipulation of the S-SR contingency was accomplished by varying the correlation between Component 1 cues and schedule of reinforcement in Component 2, such that the overall density of reinforcement in Component 2 remained unchanged.

Method

Subjects. Six experimentally naive White Carneaux hen culls were maintained at 80% of ad-lib weight. Two subjects were assigned randomly to each of three experimental conditions.

Apparatus. The experiment was conducted in a pigeon chamber with the same overall dimensions and intelligence panel as that used for Experiment 1. The center key was illuminated with various stimuli provided by a display projector (BRS/LVE IC-901), and the side keys remained dark and nonoperational. Sound masking was provided by white noise and a fan in the chamber. Electro-mechanical programming and recording equipment were located in an adjacent room.

Procedure. After all subjects were magazine trained and shaped to peck a white center key, they were exposed to two sessions of continuous reinforcement, with 100 reinforcers delivered per session. During the following two ½-h sessions, a random interval (RI) 30-sec schedule ($p = .1$, $t = 3$ sec) was in effect. Once set up, a reinforcer was held until collected or until the next reinforcer was set up. Next, birds were run on RI 60-sec ($p = .05$) sessions, which were 50 min in duration, until they earned at least half of the reinforcers set up during two consecutive sessions. During the next 30 sessions, subjects were exposed to a multiple schedule containing two identical two-component sequences. In each sequence, Component 1, cued by a white cross on a black background, lasted 6 sec and was associated with an extinction schedule. As in Experiment 1, Component 2 immediately followed Component 1; it was always cued by a white keylight, and it terminated after 30 sec. A probability generator ($p = .5$) was sampled at the onset of each Component 2 period to determine whether an RI 60-sec schedule or Ext would be in effect. Sessions during this and all subsequent conditions terminated after 100 two-component sequences had been presented in strict alternation.

Following pretraining, all animals were exposed to a zero correlation condition (Phase 1). Under this condition, sequences were differentially cued by red and green keylights during Component 1; however, Component 2 schedules (RI 60-sec or Ext) continued to be determined by a probability gate set at $p = .5$. Thus, the correlation between Component 1 cues and the availability of reinforcement in Component 2 was zero. The subjects were given 5 sessions (B9565, B5231, B1467, and B2420) or 35 sessions (B2034 and B10686) of exposure to the zero correlation and then moved to a nonzero correlation (Phase 2). The degree of correlation may be expressed in terms of the association between Component 1 colors and Component 2 schedules. Four subjects were exposed to a perfect correlation; that is, one Component 1 cue was always followed by the RI schedule, while the other cue was always followed by Ext. For two birds (B9565 and B2034), the red Component 1 cue was associated with the RI schedule and the green cue was associated with extinction. For birds B5231 and B10686, the roles of red and green cues were reversed. Two other birds were exposed to an attenuated correlation between Component 1 colors and Component 2 schedules. Under these conditions, one color was followed by an RI schedule in Component 2 75% of the time and by Ext 25% of the time. For one bird (B1467), red was associated with RI in Component 2 75% of the time. For the other bird (B2420), green was associated with RI 75% of the time. After 60 sessions of exposure to Phase 2, all pigeons were exposed to 40 sessions, during which the correlation between Component 1 colors and Component 2 schedules was zero (Phase 3).

Results and Discussion

The results are presented in Figure 3, which shows mean rate of responding in five-session blocks for each experimental condition. The format of the figure for individual birds is the same as that in Figure 1—rates in Component 1 are displayed in the upper portion of the panel, and rates in Component 2 are shown in the lower portion. The two birds in each column were exposed to identical sequences of experimental conditions. The dashed, vertical lines separate data from successive conditions, and the numbers between the dashed lines (.5, .75, and 1.0)

Figure 3. Rates of responding for six birds during all phases of Experiment 2, plotted in five-session blocks. Component 1 rates during red (x) and green (•) sequences are shown in the upper panel for each bird, and Component 2 rates are shown in the lower panel. Dashed vertical lines separate baseline, differential reinforcement, and return-to-baseline phases.

indicate the proportion of trials during which a particular Component 1 cue was associated with the RI schedule.

Rate during Component 1 varied systematically with the degree of programmed relationship between Component 1 key color and Component 2 reinforcement schedule. When the relationship was zero (i.e., $p = .5$) during the first condition, Component 1 peck rate remained at or near zero for as long as 30 sessions (B2034 and B10686). When a nonzero correlation between Component 1 colors and Component 2 schedules was programmed in Phase 2, keypeck rate increased across sessions in the Component 1 more likely to be followed by RI 60-sec in Component 2, but not in the Component 1 more likely to be followed by Ext. Although the pattern of rate changes during Phase 2 differed among birds, all but one (B2034) showed higher rates at the end than at the outset of Phase 2. In the 1.0 condition, no systematic difference appeared in the behavior of birds receiving differing amounts of prior exposure to the zero correlation.

For the birds that did acquire keypecking during Component 1, level of responding depended upon the magnitude of the correlation. During the last five sessions of Phase 2, three of four birds exposed to the perfect correlation showed higher Component 1 rates than either of the birds exposed to the attenuated correlation (B1467 and B2420). When all birds were returned to the zero correlation condition in Phase 3, Component 1 response rates returned to the control levels observed during Phase 1. For those three birds that responded under the perfect correlation conditions, the return to control levels took place gradually over the 40 sessions of Phase 3, whereas the two birds exposed to the attenuated correlation showed an abrupt reduction in rate. Thus, correlation effects were discernible in Phase 3 as well as in Phase 2. Moreover, the fact that Component 1 rates in Phase 3 returned to Phase 1 levels precludes an account of Phase 2 performance in terms of adventitious reinforcement.

The present results replicate the finding of Experiment 1 that keypeck tendency in Component 1 of the

temporal separation procedure is sensitive to an S-SR contingency, and extends those results by showing that the level of responding attained in Component 1 is a graded effect of the degree of the contingency.

As in Experiment 1, differential responding was observed during Component 2 during the present experiment. Inspection of Figure 3 shows that differentiation varied regularly with treatment condition. Rate differences were largest under the 1.0 correlation conditions, smaller under the .75 condition, and smallest under the 0 condition.

The data obtained in Component 1 of this experiment may be compared with those of Gamzu and Williams (1973), who manipulated the probability of reinforcement associated with signal and no-signal periods in an autoshaping procedure. Their birds acquired pecking only when reinforcer probability was higher in the presence of the signal than in its absence. The S-SR contingency in designs of this type may be specified by "discretizing" time to create trials which are used to compute a phi coefficient representing the degree of S-SR relation (Gibbon, Berryman, & Thompson, 1974). However, as with the relative rate measure discussed in Experiment 1, such probability-based measures would predict nondifferential pecking in the present study during Component 1, in which probability of reinforcement was always zero. The relationship obtained in the present study between performance in Component 1 and schedule in Component 2 again indicates that representations of the S-SR contingency which require simultaneity of stimulus events may need to be modified. This issue was explored in Experiment 3.

EXPERIMENT 3

An alternative construction of the S-SR relation that allows a weaker linkage between stimulus and reinforcer events is one that focuses upon temporal factors. The fact that temporal measures of the S-SR relation have received strong support from studies of autoshaping (e.g., Gibbon et al., 1977) suggests their application in the present procedure. A formulation that is consistent with the results of Experiments 1 and 2 can be based on the delay to reinforcement signaled by one Component 1 cue relative to that signaled by the other Component 1 cue. In those experiments, the tendency for keypecking to develop during a Component 1 cue varied inversely with the relative delay to reinforcement associated with that component. However, relative delay to reinforcement was confounded with rate of reinforcement during Component 2 in both of the preceding experiments. Experiment 3 was designed to examine relative delay of reinforcement independently of relative rate of reinforcement. That is, differences in delays to reinforcement signaled by Component 1 cues were

varied, while overall probability of reinforcement in Component 2 was held constant between sequences.

Method

Subjects. Six naive White Carneaux hen culls were maintained on a 23-h schedule of food deprivation. The birds' body weights were initially maintained at 80% ($\pm 2.5\%$) of ad-lib weight; however, as described below, this criterion was subsequently raised for five subjects.

Apparatus. A pigeon chamber identical to that described for Experiment 1 was used. Sound masking and programming equipment were similar to those described for Experiments 1 and 2.

Procedure. Following magazine training, keypecking was manually shaped on the center key, which was illuminated by a white light. The birds were then exposed to the following sequence of schedules: continuous reinforcement (one session), RI 30 sec ($t = 3$ sec, $p = .1$, one session), and RI 60 sec ($p = .05$, three sessions). Sessions terminated after the birds had earned 100, 100, and 60 reinforcers, respectively. During these and all subsequent procedures, the houselight and keylight remained illuminated except during reinforcer delivery when only the hopper was illuminated.

The birds were next given extended pretraining under a 4-ply multiple schedule similar to those used in Experiments 1 and 2. During these and all subsequent sessions, Component 1 of both sequences was 4 sec in duration and Component 2 was 30 sec long. Responses were never reinforced during Component 1. For this procedure only, the key was illuminated by a white plus on a black background during Component 1 of each sequence. In Component 2, the keylight was white and an RI 60-sec schedule was in effect in both sequences. Thus, under this procedure, the two sequences were identical, although data were collected independently for each. Hopper duration was reduced to 2 sec to prevent the birds from gaining weight. The procedure remained in effect for 31 to 34 sessions. During the next 5 sessions, Component 1 cues were changed from the plus sign to a red key in one sequence and to a green key in the other. For the first three sessions, an RI 60-sec schedule was in effect during Component 2 of both sequences. For the next two sessions, the schedule was changed to RI 10 sec.

During two experimental phases, an S-SR contingency was introduced for Component 1 cues by varying the delay and/or density of reinforcement programmed for each sequence. All birds were exposed to a delay (D) condition under which only delay of reinforcement differed between sequences. Each bird was also exposed to one of two comparison conditions (Conditions H and L), under which both delay and density of reinforcement differed between sequences. During Phase 1, two birds were assigned to each of the three conditions. Assignments were random, with the exception that one bird (B3257) was deliberately assigned to Condition L (the condition under which the fewest reinforcers could be earned) because of its tendency to gain weight.

The schedules in effect under each experimental condition are described in Table 2. Under Condition D, RI 10 sec and RI 60 sec were presented consecutively during Component 2 of both sequences; however, the order of presentation of these schedules differed between components. This resulted in a sequence in which delay to reinforcement was relatively short (RI 10 $\rightarrow$ RI 60) and one in which delay was relatively long (RI 60 $\rightarrow$ RI 10). However, since RI 10-sec and RI 60-sec schedules were each in effect approximately half of the time in both sequences, density of reinforcement did not vary across sequences under Condition D.

The schedule used in Component 2 has been termed "traveling RI" (Coleman, Brown, & Hemmes, Note 1). Under this schedule, a probability gate is sampled at the beginning of each 3-sec bin in Component 2. Output from the gate causes the RI schedule to switch from the one initially programmed for that component (e.g., from RI 10 when the traveling RI is designated RI 10 $\rightarrow$ RI 60) to the other RI schedule. Thus, a switch can occur as early as the beginning of the component, or might never occur on some oc-

Table 2
Summary of Conditions in Effect During Phases 1 and 2 for Each Sequence

Subject	Component 1 Cue	Phase 1		Phase 2	
		Condition	Component 2 Schedule	Condition	Component 2 Schedule
236	Green	D	RI 10→RI 60	L	RI 60
	Red		RI 60→RI 10		RI 60→RI 10
9840	Red	D	RI 10→RI 60	H	RI 10→RI 60
	Green		RI 60→RI 10		RI 10
4181	Green	H	RI 10	D	RI 60→RI 10
	Red		RI 10→RI 60		RI 10→RI 60
4872	Red	H	RI 10	D	RI 60→RI 10
	Green		RI 10→RI 60		RI 10→RI 60
2748	Red	L	RI 60→RI 10	D	RI 60→RI 10
	Green		RI 60		RI 10→RI 60
3257	Green	L	RI 60→RI 10	D	RI 60→RI 10
	Red		RI 60		RI 10→RI 60

Note—Schedule units are seconds.

casions. Once a switch occurs, however, a second switch cannot occur. The probability gate is set for a value which arranges for the switch to occur, on the average, halfway through the component. In the present experiment, it was necessary to use two probability values, $p = .10$ and $p = .15$, with $p = .10$ being used on 1 of 5 days. The order in which the two values were used was randomized within 5-day blocks.

Two comparison conditions also employed the traveling RI procedure. For both conditions, the initial RI value in Component 2 was the same across components. Differential conditions were arranged by switching the RI value in only one sequence. Thus, in Condition H, the Component 1 cue of one sequence was associated with an RI 10-sec schedule in Component 2, and the other Component 1 cue was associated with RI 10→RI 60. This procedure produced a higher overall density of reinforcement in Component 2 than that arranged under the delay condition. Lower overall densities of reinforcement were arranged under Condition L in which RI 60 sec was programmed in Component 2 of one sequence while RI 60→RI 10 was arranged for the other component. Unlike Condition D, in which density of reinforcement was constant across components, delay and density of reinforcement both varied between components in comparison conditions H and L.

The association of key color in Component 1 and schedule in Component 2 was balanced across subjects in each condition. Early in Phase 1 (session 1 for Birds 4181 and 9840, and session 2 for Birds 236, 2748, 4872, and 3257), hopper duration was reduced to 1.5 sec because of the tendency for some subjects to gain weight. In addition, a new weight criterion was established: subjects were run only if their weights were below 90% of free-feeding weight. For one subject (B3257), the criterion remained at 80%, since this bird typically failed to respond when its weight exceeded that value. Phase 1 continued for 50 sessions.

During Phase 2, each bird was assigned to a new condition (see Table 2). All birds previously exposed to conditions H and L were now assigned to Condition D. One bird from Condition D was assigned to Condition H in Phase 2, while the other bird was assigned to Condition L. In all cases, the transition from Phase 1 to Phase 2 conditions involved a change in the schedule associated with one sequence only. The conditions imposed in Phase 2 were such that performance reversals were expected in Component 1 for all subjects. That is, the sequence which in Phase 1 was predicted to produce the higher rate of Component 1 pecking (i.e., the sequence containing the shorter delay and/or higher density of reinforcement) was expected to generate the lower rate of Component 1 pecking during Phase 2. For example, for the bird switched from Condition D to Condition H, the sequence associated with the shorter delay (RI 10→60 in Component 2) remained unchanged, while the schedule in the sequence associated with the

longer delay was changed from RI 60→RI 10 to RI 10 sec. Thus, the Component 1 cue previously associated with the shorter delay was now associated with the longer delay and lower density of reinforcement. Similar changes were made for the birds previously exposed to Conditions H and L. Recall that these birds were all assigned to Condition D during Phase 2. Following this change, the Component 1 cue previously associated with the higher density and shorter delay of reinforcement was now associated with the longer delay to reinforcement. These changes are summarized in Table 2.

Results and Discussion

Data from Component 1 for individual subjects under both experimental phases are presented in Figure 4. Regardless of when it was introduced (i.e., during Phase 1 or Phase 2), the delay condition (Condition D) resulted in strongly differentiated responding during Component 1. All birds showed high rates of responding during the Component 1 cue associated with the shorter delay to reinforcement in Component 2 (RI 10→RI 60), and very low rates during the sequence in which RI 60→RI 10 was programmed. Despite these large between-sequence differences in Component 1 responding, average rate of reinforcement during Component 2 did not differ between sequences under the delay condition (see Table 3). These results strongly implicate delay to reinforcement as the controlling dimension of the S-SR contingency imposed by the temporal separation procedure.

A somewhat different picture emerges for the comparison conditions (Conditions H and L), under which both density and delay of reinforcement were correlated with Component 1 cues. The three birds exposed to Condition H showed no evidence of differential control by the prevailing S-SR contingency. (Bird 9840 showed gradual loss of control by the prior experimental condition until nondifferential responding developed.) Differential responding in Component 1 did develop under Condition L. Two birds (B236 and B2748) responded at higher rates during the Component 1 cue associated with the

Figure 4. Rate of response in Experiment 3 plotted in five-session blocks. Component 1 rates during red (X) and green (•) sequences are shown in the upper panel for each bird, and Component 2 rates are shown in the lower panel. Dashed vertical lines separate Phases 1 and 2.

higher density and shorter delay to reinforcement in Component 2 (during which an RI 10-sec schedule was in effect). Interestingly, the absolute rates of responding shown by each bird during Component 1 were lower when the bird was exposed to Condition L than when it was exposed to the delay condition. This was true regardless of order of exposure to the two conditions.

Although both density and delay of reinforcement differed between sequences under Conditions H and L, these conditions produced less differential control

than did Condition D, under which only delay to reinforcement differed between components. This result might be understood in terms of the schedule parameters employed in the comparison and delay conditions. For example, under the delay condition, the schedule of reinforcement programmed to occur immediately after the offset of a Component 1 cue differed between sequences. Under the comparison conditions, the same schedule generally followed Component 1 offset in both sequences. Schedule differences did not occur, on the average, until 15 sec after Component 1 offset. This delay between Component 1 offset and Component 2 schedule differences may account for the relatively weak S-SR control that developed in Component 1 under the comparison conditions.

Although Component 1 behavior was strongly differentiated across sequences under the delay condition, Figure 4 shows very little differential responding during Component 2. This is not surprising, since overall rate of reinforcement in Component 2 did not differ across sequences. A greater tendency toward differential responding in Compo-

Table 3
Average Rate of Reinforcer Delivery (Reinforcers per Minute)
in Component 2 During the Last Five Sessions

Subject	Component 2 Schedule	
	RI 10→60	RI 60→10
236	3.48	3.46
9840	3.69	3.65
4181	3.26	3.26
4872	3.20	3.58
2748	3.60	3.51
3257	3.52	3.72

Table 4
Relative Rate of Responding During RI 10 Segments
of a Traveling RI Schedule

Subject	Condition	Schedule	Relative Rate
236	D	RI 10→60	.51
		RI 60→10	.50
9840	D	RI 10→60	.53
		RI 60→10	.52
4181	D	RI 10→60	.53
		RI 60→10	.51
4872	D	RI 10→60	.53
		RI 60→10	.52
2748	D	RI 10→60	.49
		RI 60→10	.51
3257	D	RI 10→60	.51
		RI 60→10	.53
9840	H	RI 10→60	.52
4181	H	RI 10→60	.55
4872	H	RI 10→60	.52
236	L	RI 60→10	.49
2748	L	RI 60→10	.50
3257	L	RI 60→10	.46

nent 2 occurred under the comparison conditions; birds responded at higher rates during the Component 2 associated with higher density and shorter delay to reinforcement.

Density of reinforcement differed within Component 2 when the traveling RI procedure arranged a switch between RI 10 and 60 sec. Nevertheless, rate of responding did not strongly track rate of reinforcement. This can be seen in Table 4, in which relative rate of responding during the RI 10-sec segment of one sequence was computed by dividing the absolute rate of responding during the RI 10-sec segment by that value plus rate of responding during the RI 60-sec segment of the same sequence. Thus, a ratio of .50 would be obtained when rates of responding were identical during the RI 10-sec and RI 60-sec segments in a sequence. The ratios presented in Table 4, which are based on mean rates of responding during the last 5 days of exposure to an experimental condition, indicate only a slight tendency toward higher rates during RI 10-sec segments than during RI 60-sec segments. Generally, the ratio was higher for the RI 10→60 sequence. While this may reflect a schedule parameter effect, it could also indicate the tendency for response rate to decline during the course of Component 2.

GENERAL DISCUSSION

For each of the three experiments described in this report, we propose that responding in Component 1 may be understood in terms of the relative delays to reinforcement signaled by each component cue. This relationship is plotted for Experiments 2 and 3 in the left panel of Figure 5. Relative response rate and relative delay to reinforcement in the component sig-

naled by the red key are shown for each bird. Open and closed data points represent results in Experiments 2 and 3, respectively. Relative rate was computed as rate in the red Component 1 divided by the sum of the rates in both initial components for the last five sessions of a condition. Relative delay is the median delay to the first reinforcer from all onsets of the red component in a session divided by the sum of the medians from the red, green, and white cues. Any reinforcers subsequent to the first in a component were ignored. Since no data were available, delays were obtained by computer simulation for Experiment 2. The data for that study indicate a negative correlation between relative rate and delay measures ($r = -.95$). The 12 data points for Experiment 3 represent both treatments to which the six birds were exposed. The correlation between relative rate and relative delay was $-.84$.

An alternative measure, which also captures the role of relative delays to reinforcement, is provided both by scalar expectancy theory (Gibbon, 1981; Gibbon & Balsam, 1981) and the relative waiting time hypothesis (Jenkins et al., 1981). In this measure, which was derived from acquisition performance in autoshaping procedures, response tendency depends upon the delay to reinforcement from a signal for food relative to the overall interreinforcer interval. An analysis similar to waiting time was applied to the data of Experiments 2 and 3 by taking as the signal the Component 1 cue associated with the shorter median delay to reinforcement, or in the case of the zero correlation condition of Experiment 2, averaging the median delays from Component 1 of both sequences. Median interreinforcer intervals were obtained by computer simulation. Relative "waiting" times in the right panel of Figure 5 represent the ratio of the delay of reinforcement from the signal to the sum of that delay plus the interreinforcer interval.¹ Relative response rate correlated negatively with relative waiting time in both Experiment 2 ($r = -.90$) and Experiment 3 ($r = -.61$). The outlying data point in Experiment 3 represents the bird

Figure 5. Relative rate of response during the red Component 1 cue as a function of relative delay (left panel) and relative waiting time (right panel) measures for Experiment 2 (open circles) and 3 (closed circles).

(B3257) whose high body weight and low rates entailed a modified running schedule. With the data for that subject omitted, the correlations for wait and delay measures in Experiment 3 rose to $-.85$ and $-.89$, respectively.

The relative delay measure and a relative waiting time analysis differ in assumptions about the number of stimulus events participating in the stimulus-reinforcer relation, that is, all vs. one. Data relevant to this issue come from a study by Marcucella (1981), who used a procedure similar to that in Experiment 1, except that Component 1 of the negative sequence was uncued; that is, the key remained the same color, as in Component 2. Marcucella found that keypecking emerged in Component 1 of the positive sequence whether Component 1 in the negative sequence was differentially cued or not, a finding readily accommodated by a waiting time analysis, as modified for the present study, but not by the relative delay measure. However, an interesting problem arises in extending a waiting time metric to the present results. As defined in scalar expectancy theory (Gibbon & Balsam, 1981), the signal for food is the cue that is contiguous with food. In a strict application of the theory, the food signal in the temporal separation procedure is the Component 2 cue. The status of Component 1 cues, as background or negative trials, is unclear, but in either case no pecking is predicted during Component 1 in this construction. Thus, extending the waiting time analysis to procedures of the present sort requires a relaxation of strict stimulus-reinforcer contiguity in specifying which signal comes to control responding. At the same time, this makes a waiting time approach more similar to the relative delay analysis, according to which the stimulus-reinforcer relation may involve recruitment of all cues, ordered on the basis of their relative temporal distances from reinforcement. The present results, together with other phenomena such as trace conditioning (Bruner-Iturbide, 1981; Lucas, Deich, & Wasserman, 1981), demonstrate control of responding in the presence of cues distant from reinforcement. They suggest, therefore, that the pigeon is sensitive to temporally defined stimulus-reinforcer relations involving stimuli in addition to the one contiguous with reinforcement.

The difference between the delay and waiting time approaches to the stimulus-reinforcer relation may be understood in terms of the properties of the organism's timing mechanism (Roberts, 1981). For example, in specifying different numbers of stimulus events, the relative delay and relative waiting time proposals differ in the number of clocks engaged, or in the number of temporal intervals being processed. Scalar expectancy theory assumes that, at least during pre-acquisition, the signal clock stops upon cessation of the signal with or without reinforcement and accumulates signal duration only. The present delay analysis has assumed either that the clock does not

stop until reinforcer delivery or that the total interval from signal onset to reinforcer delivery is accumulated in a separate buffer. These considerations suggest that refinements of a temporal interpretation of the stimulus-reinforcer relation may well depend upon the more fundamental issue of timing itself.

Relative delay measures do not account for all of the systematic variance in the present data. For example, differences in delays to reinforcement between initial components were greater for Condition L than for Condition D in Experiment 3, yet higher rates of responding were uniformly exhibited in the latter condition. However, average delay to reinforcement from either initial component was longer in Condition L than in Condition D. It is possible that the effect of relative delay to reinforcement is modulated by average delay to reinforcement or overall reinforcement density. That is, longer absolute delays may attenuate the effect of differences between delays to reinforcement. This speculation receives some support from the observed increase in overall response rates during Component 1 from Experiments 1 to 3. The rate increase may be understood as arising from the shorter absolute delays to reinforcement as Component 1 durations decreased (Experiments 1-3) and rate of reinforcement increased (Experiments 1 and 2 vs. 3) across experiments.

There is no direct support in the present study for the interaction of absolute and relative delays. However, data recently collected in this laboratory by the fourth author are confirmatory, indicating a decline in response rates in Component 1 as the duration of that component is increased, under conditions similar to those of Experiments 1 and 2. Moreover, the same kind of interaction has been described in choice procedures in which different delays to reinforcement are programmed in the terminal links of a concurrent chain schedule. Evidence from such procedures (e.g., Fantino, 1977) indicates that a given difference in delay exerts diminishing effects upon preference as absolute delay from the onset of the choice problem increases. The relation of choice data to the present study is not mere coincidence. Fantino (1977) has shown that behavior in the concurrent chains situation may be described in terms of the relative reduction in delay to reinforcement afforded by each choice alternative. It is interesting to note that the terms in the delay reduction measure are relative waiting times, but expressed as differences, rather than ratios, between signaled delays and interreinforcer times. It is possible that the appearance of similar terms as factors in the temporal separation and concurrent chains procedures reflects the influence of common stimulus-reinforcer relations.

REFERENCE NOTE

1. Coleman, D. A., Brown, B. L., & Hemmes, N. S. *Stimulus-reinforcer control by differential delay of reinforcement*. Paper

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NOTE

1. This metric differs from the relative wait time measure proposed by Gibbon and Balsam and by Jenkins (delay/inter-reinforcer time). However, the two measures are nearly linearly related over the present range of values. The bounded wait time ratio was used to facilitate comparison with the bounded relative delay measure.

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