HOMOGENEOUS CHAINS, HETEROGENEOUS CHAINS, AND DELAY OF REINFORCEMENT

KENNON A. LATTAL AND CYNTHIA L. CRAWFORD-GODBAY

WEST VIRGINIA UNIVERSITY

Three pigeons responded on two-component chain schedules in which the required response topography in the initial and terminal links was similar (a homogeneous chain) or dissimilar (a heterogeneous chain). Key-peck responding in the initial link under a variable-interval 60-second (VI 60) schedule produced a terminal link in which, in different conditions, either key pecking or foot treading was reinforced according to a VI 60 schedule. Multiple VI 60 VI 60 schedules, in which the responses required in the chain schedules were maintained by primary reinforcement in the two components, preceded and followed each type of chain. These multiple schedules were used to ensure that both responses occurred reliably prior to introducing the chain schedule. Key-peck response rates in the initial link of the chain consistently were higher during the homogeneous chain than during the heterogeneous chain. These results illustrate that intervening events during a period separating an operant response from primary reinforcement influence that operant, independently of the delay between the response and reinforcement.

Key words: homogeneous chain, heterogeneous chain, delay of reinforcement, chain schedule, variable-interval schedule, key peck, treadle press, pigeons

A response chain is an ordered sequence of responses in which each response in the sequence serves as or produces the discriminative stimulus for the response that follows. Kelleher and Gollub (1962) identified chained schedules of reinforcement as a more general classification of such response sequences. They distinguished between chained schedules that involve a single response topography that produces successive exteroceptive stimuli and chained schedules in which the different exteroceptive stimuli of the chain control different response topographies. The former are described as homogeneous chains and the latter as heterogeneous chains.

Most experimental analyses of chained schedules have involved the use of homogeneous chains (e.g., Gollub, 1977; Kelleher & Gollub, 1962) because the problems of interest have concerned the relative strength of responding in successive components of the

chain. One exception is the work of D'Andrea (1969), which examined the acquisition and extinction of heterogeneous chains under different schedules of reinforcement. Another is the observation by Kelly (1974), who reported differences in response rates and patterns under random-ratio schedules as a function of different eating patterns of rhesus monkeys. High-rate, pause-free responding occurred in 2 monkeys with a pattern of storing several food pellets in their buccal pouches. Lower-rate responding with more frequent pausing was characteristic of 2 other monkeys that consistently mouthed and chewed their food pellets one at a time.

Signaled delay-of-reinforcement procedures may be described as two-component chained schedules in which responding in the initial component (S2) produces a terminal component (S1) that ends with food delivery (Ferster, 1953; Kelleher & Gollub, 1962). In several experiments, comparisons have been made between signaled delay procedures in which the same or different response topographies were required in the two components or in which one response topography was required in S2 and responding in S1 was not required. Neither Ferster (1953, Experiment 5) nor Pierce, Hanford, and Zimmerman (1972) reported systematic differences in key-peck or

This research was supported by a grant from the National Science Foundation to West Virginia University, K. A. Lattal, principal investigator. The data were collected by Cynthia L. Crawford-Godbey as part of a master's thesis at West Virginia University. We thank Suzanne Gleeson for her helpful comments on the manuscript. Reprints may be obtained from K. A. Lattal, Department of Psychology, West Virginia University, Morgantown, West Virginia 26506-6040.

bar-press response rates, respectively, in S2 as a function of either a fixed-time (FT) or a fixed-interval (FI) schedule in S1 (see also Ferster & Skinner, 1957, p. 684). These indifferencees were found even though the different schedules in S1 controlled different rates of the key-peck or bar-press responses. Pierce et al. also compared a chain variable-interval (VI) FT with a chain VI differential-reinforcement-of-other-responses (DRO) schedule. Again, there were no systematic differences between responding in the S2 component when the temporal values of the DRO and FT were the same. In other experiments, blackouts, which presumably control responses topographically different from those in S2, have been introduced during S1. Ferster (1953) observed no differences in response rates during S2 as a function of blackout or other stimuli in S1.

Catania (1971, Experiment 2) compared the effects of different response requirements in S1 and in tandem schedules in which completion of a VI requirement on one response key (either Key B or Key A) followed by a sequence of responses on one of the keys (Key A) resulted in food presentation. The Key B–Key A sequence might be considered a heterogeneous chain in that responses in different locations were required, even though the required response in both locations was a key peck and the S2 and S1 stimuli were the same. However, neither a Key B–Key B nor a Key A–Key B response sequence was studied, so comparisons of homogeneous and heterogeneous chains were precluded.

Other than Kelly's (1974) observations and the several experiments comparing different stimuli during delay-of-reinforcement intervals, we know of no systematic comparisons of the effects of different response requirements in S1 and S2. A comparison of homogeneous and heterogeneous response chains was undertaken here to assess more systematically a possible role of responding in S1 in response maintenance in S2. If more responding in S2 occurs during homogeneous than during heterogeneous chained schedules, it would suggest that changes in response-reinforcer temporal contiguity may not alone account for responding in the initial component of two-component chained schedules used so widely in the analysis of reinforcement delay.

METHOD

Subjects

Three adult male White Carneaux pigeons, housed individually with free access to water and grit, served. One bird (3356) was maintained at ± 20 g of 70% of its free-feeding weight. The other birds were maintained at ± 20 g of 80% of their free-feeding body weights. Each had a prior history on schedules of reinforcement of key-peck responding.

Apparatus

An operant conditioning chamber 30 by 30 by 33 cm was used. A 2.0-cm-diameter translucent response key was mounted on the work panel, 7.5 cm from the right edge and 19.5 cm above the floor. It was transilluminated by a 7-W red or green light bulb during key-peck components. A force of approximately 0.15 N was required to operate the key. An Environmental Services Corporation retractable treadle (rat lever) 1.0 by 1.3 by 3.8 cm was located 2.5 cm from the left edge of the panel and 1.9 cm above the floor. The treadle was extended only during treadle-press components. A force of approximately 1.2 N was required to operate the treadle. Illumination of the chamber was provided by a 7-W white light bulb mounted behind a piece of white plastic, 4.0 cm in diameter, located at the right bottom of the front panel. A 5 by 5-cm aperture, through which a food hopper filled with grain was made available during reinforcement, was centered on the work panel 3.5 cm above the chamber floor. Reinforcement was 3-s access to mixed pigeon grain, during which the grain hopper was illuminated by a 7-W white light bulb. A white noise generator and a ventilating fan masked extraneous noise. A separate room housed supporting relay and recording circuitry.

Procedure

For each subject, the treadle-press response was initially hand shaped, and then each treadle press was reinforced until steady responding occurred for at least two sessions of 60 reinforcers each. A VI 15-s schedule then was introduced. The mean interreinforcer interval was increased over several days to VI 60-s in 15-s steps. Interreinforcer intervals for this and all other VI schedules were arranged accord-

ing to the constant-probability distribution described by Fleshler and Hoffman (1962).

After stable treadle-press performance was observed under the VI 60 schedule, several conditions were compared. Each subject first was trained on a two-component multiple schedule in which responding in the two components was reinforced according to independent VI 60 schedules. The components alternated after each reinforcement. In one multiple schedule, different responses, key pecking or treadling, were required in the alternate components. The keylight was illuminated red during the component in which key pecking was reinforced (hereafter referred to as the "key component"); the treadle was retracted and thus inoperative during this component. During the component in which treadle pressing was reinforced (hereafter referred to as the "treadle component"), the treadle was extended into the chamber and the keylight was dark. This schedule will be described as the multiple key-treadle or heterogeneous multiple schedule. In the other multiple schedule, the same key-peck response was required in both components. The keylight was illuminated red in one component and green in the other. This multiple schedule will be described as the multiple key-key or homogeneous multiple schedule.

In the homogeneous (key-key) chain schedule, responding on the red key (S2) produced, on the average of once every 60 s, a change to green illumination of the same key. Key-peck responding on the green key produced food according to a VI 60 schedule. After food delivery, the key again was illuminated red and the cycle repeated. In the heterogeneous (key-treadle) chain schedule, responding on the red key (S2), on the average of once every 60 s, produced extension of the retracted treadle into the chamber and extinguished the keylight. Treadling then produced food according to a VI 60 schedule. At the onset of food delivery, the treadle was retracted; after food delivery, the keylight was illuminated red and the cycle repeated.

The sequence of these four conditions—multiple key-key, multiple key-treadle, chain key-key, and chain key-treadle—to which each bird was exposed is shown in Table 1. Subjects 3356 and 3867 were exposed to the schedules in one order and Subject 3523 was

Table 1

Sequence of conditions, response requirement during S1 (T = treadle; K = key peck on a green key), number of sessions to stability in each condition, mean S1 intervals for the last five stable sessions, and mean and range of reinforcement (S^R) frequency during the last five sessions of each condition for each subject.

Sub- ject	Con- dition num- ber	Schedule	Re- sponse in S1	Ses- sions to stability	$\bar{x}$ Dura- tion of S1 (min)	$\bar{x}$ S ^R per min
3356	1	mult	T	43	1.0	1.0
	2	chain	T	8	2.8	0.1
	3	mult	T	24	0.8	1.1
	4	mult	K	33	0.8	1.1
	5	chain	K	53	0.9	0.5
	6	mult	K	19	1.0	1.0
3867	1	mult	T	28	1.1	1.0
	2	chain	T	24	0.9	0.5
	3	mult	T	7	1.1	1.1
	4	mult	K	20	0.9	1.1
	5	chain	K	56	0.8	0.6
	6	mult	K	10	1.1	1.1
3523	1	mult	K	33	1.0	1.0
	2	chain	K	30	0.7	0.6
	3	mult	K	8	0.7	1.2
	4	mult	T	24	1.0	1.1
	5	chain	T	20	1.3	0.4
	6	mult	T	22	1.0	1.0

exposed to the schedules in another order. The multiple schedules were used to ensure development of sustained responding in both components prior to introducing the chain schedule. The homogeneous chain schedules were preceded and followed by the homogeneous multiple schedules, and the heterogeneous chain schedules were preceded and followed by the heterogeneous multiple schedules. The VI 60 schedules in both the multiple and chain schedules were identical.

Each condition was in effect until stable responding was observed. Stability was defined as not more than 10% variation from the mean response rate in both components over five consecutive sessions and no apparent increasing or decreasing trends. Under key-treadle conditions, a constant was added to the treadle rates to bring them to the level of key-peck rates in determining stability. During the first presentation of any condition, a minimum of 15 sessions was required before stability could be established. During the con-

Fig. 1. Response rates of the 3 pigeons in each of the last five sessions at each condition. The sequence of conditions above the axes for Bird 3356 also describes the sequence for Bird 3867. S1 and S2 denote the stimulus conditions of the final and initial links, respectively, of the chain schedule; as noted, these stimuli were used in both multiple and chain schedules, in successive conditions.

ditions shown in Table 1, sessions were conducted 6 days per week and were defined by the delivery of 60 reinforcers during the multiple schedules and 30 reinforcers during the chain schedules. The one exception was for Subject 3356, whose responding was severely disrupted under the chain key-treadle.

Under this condition for this subject, sessions were terminated after approximately 120 min and the condition was terminated prior to attaining the stability criterion.

RESULTS

Figure 1 shows the response rates for each subject in each of the last five sessions of the different conditions. During the multiple-schedule baseline conditions, response rates in either component of the multiple key-key schedule were similar and in the multiple key-treadle schedule were consistently higher in the key than in the treadle component. With the change from multiple key-key to chain key-key, key-peck response rates in the initial (S2) component decreased relative to the multiple key-key baseline in all 3 subjects, although the reduction with Bird 3523 was slight. Also, within the key-key chain, a consistent differential response rate (S1 vs. S2) was shown by all birds. The same procedural change produced less consistent effects across subjects in the absolute response rates in the terminal (S1) component. Relative to the multiple key-key baseline, these rates increased with Bird 3523 and decreased with the other 2 subjects.

Relative to response rates in the multiple key-treadle schedule, key-peck response rates in S2 during the chain key-treadle were reduced substantially in all 3 subjects. Key-peck response rates in S2 were sufficiently reduced in this condition with Bird 3356 that many sessions were terminated prior to collecting the 30 reinforcers allotted during each session, as noted previously. The change from multiple key-treadle to chain key-treadle reduced absolute response rates in S1 for Bird 3523, but had little systematic effect on the S1 responding of the other 2 subjects.

The comparison of greatest interest was between the S2 response rates in the chain key-key and in the chain key-treadle conditions. For each subject, responding was reduced considerably more in the latter schedule both in absolute terms and relative to the response rates in the preceding multiple baseline condition. This occurred even though the schedules in both of these chain schedules were identical.

Table 1 provides the mean duration of S1 during the last five sessions of each condition.

Bird 3356 showed large differences in the duration of S1 during the key and treadle components under the chain schedules because of its low rate of responding during S1 in the chain key-treadle condition. The mean duration of S1 during the chain key-key also was somewhat shorter than that during the chain key-treadle for Bird 3523, but the mean duration of S1 was approximately equal during the two chain schedules for Bird 3867. Thus, an account of the differences in S2 key-peck response rates in the key-key and chain key-treadle schedules in terms of simple delay effects is precluded by these results for Bird 3867. Table 1 also shows the mean and range of reinforcement frequency during the last five sessions of each condition. The reinforcement frequency during the chain schedules was less than or equal to half that during the multiple schedules. For 2 birds the reinforcement rates were approximately the same in the chain key-treadle and in the chain key-key schedules, excluding differences in reinforcement frequency as the controlling variable of S1 response rates.

DISCUSSION

Response rates in S2 differed under homogeneous and heterogeneous chain schedules in which responding in S1 was required to produce reinforcement. Neither differences in reinforcement frequency between the homogeneous and heterogeneous chains nor differences in S1 duration could account for all of the results. These findings constitute an exception to the delay-of-reinforcement experiments described previously that "... provide no evidence to suggest that the effect of delayed reinforcement ... depends on whether the reinforcer ... is produced by a subsequent response of the same or a different operant class" (Catania, 1971, p. 284; cf. Neuringer, 1969). Chain schedules have at various times been offered as a valid method of assessing conditioned-reinforcement effects (Gollub, 1977; Kelleher & Gollub, 1962). The present results also suggest that the effectiveness of S1 as a conditioned reinforcer, as measured by rate of response in S2, varies not only as a function of parameters of the schedule (Kelleher & Gollub, 1962), but also as a function of the required response topography.

Other observations are suggested by the

present data. The present experiment differed in several ways from the earlier experiments described in the introduction. Neither Ferster (1953) nor Ferster and Skinner (1957) provided quantitative data in their analyses; rather, they provided only qualitative descriptions of effects or sample cumulative records. Pierce et al. (1972) provided a quantitative analysis but, unlike most of the other studies cited, they used rats as subjects. In those three studies, responding during S2 was compared under a condition in which a topographically similar response to that in S2 was maintained by an FI schedule in S1 and under conditions in which unlimited variability in response topography during S1 was possible (FT or blackout) or in which the only restriction on topography was that the response in S2 not occur in S1 (DRO schedule). Pierce et al. and Ferster and Skinner found differing response rates in S1 when FI and FT were in effect, but they did not report what the animals were doing during the FT schedules. Ferster observed his animals to be engaging in repetitive stereotyped movements during S1 when the key-peck response that was required in S2 was not required in S1. By contrast, in the present experiment the heterogeneous chain required an explicit treadle-press response that, on observation, appears difficult for a pigeon to make relative to the key-peck response. A role for "easy" versus "difficult" responses in accounting for the differences between these results seems possible, but its assessment must await further experimental analysis.

Response generalization between the two components is another plausible basis for the present results. However, it is not known whether key-peck responding during S2 is facilitated by the requirement of key pecking in S1, whether S2 key pecking is disrupted by the treadle-press requirement in S1, or whether some combination of these two processes controls the S1 responding. Further experimental analyses of the contribution of response generalization might include the use of responses other than treading or key pecking in the two components to determine whether the contribution of generalization is similar for different responses. In addition, it would be valuable to know whether treadle pressing during S2 would vary as a function of key-peck versus treadle-press contingencies in S1.

Regardless of the mechanisms whereby S2

responding is influenced by intervening events in S1, the results have implications for studies of delay of reinforcement. The chained schedules of this experiment may be considered a type of signaled delay of reinforcement in that a time period intervened between completion of the S2 requirement and reinforcement (cf. Kelleher & Gollub, 1962; Neuringer, 1969). Also, although most conventional delay-of-reinforcement procedures use fixed time periods as the delay interval, variable delays are equally useful. For example, Bryan (1978) found no systematic differences in response maintenance by VI schedules that included either fixed or variable delays of equal mean value. In the context of reinforcement delay, the present results illustrate that intervening events during a time period separating an operant from reinforcement can influence the rate of occurrence of that operant, independently of the delay between the response and reinforcement when variables like delay duration and stimuli are held constant. Thus, in attributing an observed change in responding to the change in temporal contiguity that implicitly defines delay of reinforcement, the nature of the intervening responding also must be considered.

As noted in the introduction, data on chained schedules of reinforcement have been obtained almost exclusively from homogeneous chains. Most reports of heterogeneous chains are limited to descriptions of complex behavioral sequences, perhaps the most well known of these being that emitted by Barnabus the Rat (Pierrel & Sherman, 1963). Also well known among a more restricted audience are the adventitious heterogeneous chains reported and carefully studied by Laties, Weiss, Clark, and Reynolds (1965) in rats during differential-reinforcement-of-low-rate schedule performance. Kelleher and Gollub (1962) note that "most chaining procedures are mixtures of homogeneous and heterogeneous chains. . . any homogeneous chain that terminates with food presentation and eating is technically a heterogeneous chain" (p. 546). The role of such heterogeneous chains in schedule-maintained responding has been

generally ignored (Kelly, 1974). However, we hope that the present description of their contribution to the analysis of delay of reinforcement provides an example of how a more general analysis of these chains might proceed and contribute to an understanding of schedule performance.

REFERENCES

- Bryan, A. J. (1978). *Stimulus and schedule effects in delay of reinforcement*. Unpublished doctoral dissertation, West Virginia University.
- Catania, A. C. (1971). Reinforcement schedules: The role of responses preceding the one that produces the reinforcer. *Journal of the Experimental Analysis of Behavior*, **15**, 271-287.
- D'Andrea, T. (1969). Extinction of a heterogeneous chain after several reinforcement schedules. *Journal of the Experimental Analysis of Behavior*, **12**, 127-135.
- Ferster, C. B. (1953). Sustained behavior under delayed reinforcement. *Journal of Experimental Psychology*, **45**, 218-224.
- Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement*. New York: Appleton-Century-Crofts.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, **5**, 529-530.
- Gollub, L. (1977). Conditioned reinforcement: Schedule effects. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 288-312). Englewood Cliffs, NJ: Prentice-Hall.
- Kelleher, R. T., & Gollub, L. R. (1962). A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, **5**, 543-597.
- Kelly, D. D. (1974). Two unlike patterns of random-ratio responding associated with different eating habits in rhesus monkeys. *Journal of the Experimental Analysis of Behavior*, **22**, 169-177.
- Laties, V. G., Weiss, B., Clark, R. L., & Reynolds, M. D. (1965). Overt "mediating" behavior during temporally spaced responding. *Journal of the Experimental Analysis of Behavior*, **8**, 107-116.
- Neuringer, A. J. (1969). Delayed reinforcement versus reinforcement after a fixed interval. *Journal of the Experimental Analysis of Behavior*, **12**, 375-383.
- Pierce, C. H., Hanford, P. V., & Zimmerman, J. (1972). Effects of different delay of reinforcement procedures on variable-interval responding. *Journal of the Experimental Analysis of Behavior*, **18**, 141-146.
- Pierrel, R., & Sherman, J. G. (1963, February). Barnabus, a rat with college training. *Brown Alumni Monthly*, pp. 8-14.

Received June 27, 1984

Final acceptance July 25, 1985