JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1974, 21, 425-432 NUMBER 3 (MAY)

STIMULUS CONTROL OF RESPONDING DURING A FIXED-INTERVAL REINFORCEMENT SCHEDULE[1]

DONALD M. WILKIE

UNIVERSITY OF BRITISH COLUMBIA

During training sessions, pecks by pigeons on a response key illuminated by a vertical line of white light resulted in reinforcement and an ensuing blackout according to a fixed-interval schedule. Training sessions were followed by dimensional stimulus control test sessions during which the orientation of the line present throughout the fixed interval was varied. Inverted U-shaped (excitatory) gradients of responding, with maximum responding occurring in the presence of the vertical line, were observed during the terminal part of the fixed interval. U-shaped (inhibitory) gradients of responding, with minimum responding occurring in the presence of the vertical line, were observed during the early part of the fixed interval when the preceding interval had terminated with reinforcement and blackout but not when the preceding interval had terminated with blackout only. These results suggest that the dimensional control by the stimulus present throughout the fixed interval is of a conditional variety. Whether the fixed-interval stimulus exerts inhibitory or excitatory dimensional control depends upon the presence and absence, respectively, of stimuli associated with reinforcement.

Operant behavior that occurs in the presence of a particular stimulus may or may not be controlled by that stimulus. A stimulus is said to control an operant behavior if stimulus value and response probability covary in a regular fashion. Whether or not a stimulus controls a behavior is ascertained by stimulus variation procedures. One stimulus variation procedure consists of varying a dimension of a stimulus. If responding varies as a dimension of a stimulus is varied, *dimensional stimulus control* is said to exist.

While stimuli present in an organism's environment do not always exert dimensional control over operant responding (*e.g.*, Jenkins and Harrison, 1960), when such control does occur it takes on one of two general forms. The results of Honig, Boneau, Burstein, and Pennypacker's (1963) experiment illustrate the two varieties of dimensional control. For one group of pigeons, pecking in the presence of a white keylight was reinforced while pecking in the presence of a black vertical line on the white key was not reinforced. The relationship between reinforcement availability and the stimuli was reversed for the subjects in the second group. Once differential responding in the presence of the two stimuli was established, subjects in both groups were given a test in which different line orientations were presented. Responding by the subjects of the first group took the form of a U-shaped gradient, with least responding occurring in the presence of the vertical line. For the other subjects, responding took the form of an inverted U-shaped gradient, with maximum responding occurring in the presence of the vertical line. These forms of stimulus control are commonly called "inhibitory" and "excitatory" dimension control (see, however, Hearst, Besley, and Farthing (1970) regarding this use of terms) and are typically observed when stimuli are differentially associated with non-reinforcement and reinforcement respectively.

The purpose of the present research was to examine dimensional stimulus control during fixed-interval (FI) reinforcement schedules. During an FI schedule, reinforcement is made available after the passage of a fixed period of time since the preceding reinforcement. Performance under an FI schedule appears to depend on the length of exposure to the schedule and the duration of the interval. During longer intervals (*e.g.*, Ferster and Skinner,

[1]This research was supported by grant 26-9873 from the University of British Columbia Committee on Research and grant A8353 from the National Research Council of Canada. I wish to thank C. Curry, D. Ramer, and C. Wilson for their assistance and comments. Reprints may be obtained from the author, Department of Psychology, University of British Columbia, Vancouver 8, British Columbia, Canada.

1957), or after a limited amount of exposure to an FI (*e.g.*, Cumming and Schoenfeld, 1958), a "scalloped" pattern of responding—little or no responding immediately after reinforcement, followed by positive acceleration in responding until the end of the interval—is typical. After extended exposure to shorter intervals, a "break-and-run" pattern—little or no responding immediately after reinforcement followed by a rapid transition to a constant rate of responding—is observed (*e.g.*, Schneider, 1969).

A basic feature of the FI schedule is the regular temporal juxtaposition of a period of reinforcement non-availability early in the interval with a period of reinforcement availability at the end of the interval. Since the stimulus present throughout the FI is regularly associated with these periods of reinforcement non-availability and availability, and since these are conditions that normally result in inhibitory and excitatory dimensional control, it may be, as suggested by Staddon (1969), that the FI stimulus exerts inhibitory dimensional control early in the interval and excitatory dimensional control later in the interval. That is, if a dimension of the stimulus present throughout the FI was varied, one might observe a U-shaped gradient of responding during the first part of the interval and an inverted U-shaped gradient during later parts of the FI. The present research attempted to determine if dimensional control by the FI stimulus is of such a variety.

EXPERIMENT I

In this experiment, pigeons' key pecking in the presence of a vertical line was reinforced according to an FI schedule. Jenkins and Harrison (1960) found that unless a stimulus associated with reinforcement was alternated with a stimulus during which reinforcement was unavailable, the former stimulus did not control responding. To ensure that the line stimulus present throughout the FI in the present experiment controlled responding, a stimulus associated with non-reinforcement was arranged to follow each FI reinforcement.

After FI training, dimensional control by the FI stimulus was assessed. Lines of different orientation were presented throughout the FI. To make training and test conditions as similar as possible, reinforcement for responding in the presence of all line orientations was provided during test conditions. Responding in the presence of the different line orientations during different parts of the FI was recorded.

Method

Subjects

Three pigeons with no previous experimental history served. Two of the birds (S1 and S3) were Silver Kings; the other was a White King. The subjects were maintained at approximately 80% free-feeding weight throughout the experiment by grain obtained during experimental sessions and post-session supplemental feeding as required. Free access to water and grit in the homecage was provided.

Apparatus

A commercial operant chamber for pigeons (Tech Serv., Inc. Model PS-004) was used as the experimental space. A clear plastic response key was mounted on one wall of the chamber directly above a solenoid-operated grain feeder. Operation of the key required a peck having a force of about 0.2 N. A Series 10 Industrial Electronics Engineers' stimulus display cell, which projected a 2.54-cm by 0.32-cm white line in various orientations, was mounted directly behind the response key. During feeder operation, the display cell was turned off and a 7-W lamp illuminated the grain in the feeder. The feeder lamp and display cell were the only sources of illumination in the chamber. Solid-state logic circuits were used to arrange experimental events and operate recording counters.

Procedure

Before the start of the experiment proper, key pecking in the presence of a vertical (0°) line on the response key was autoshaped (*cf.* Brown and Jenkins, 1968). The subjects then received daily sessions in which key pecking was reinforced according to an FI schedule. During each FI, the response key was transilluminated by a 0° line. Reinforcement consisted of 5.0-sec access to mixed grain. Each reinforcement was followed by a 1.0-min blackout during which the stimulus display cell remained off and key pecks had no consequences. Each FI was timed from termination of the blackout condition. For S1, the duration

of the FI was 6.0 min; for the other two subjects, the duration was 3.0 min. Sessions were approximately 1 hr in duration for S2 and S3 and approximately 2 hr in duration for S1. Sessions began and ended during the blackout condition. During each session, response rate during successive thirds of the FI was recorded.

Training sessions continued until responding under the FI schedule appeared by visual inspection to be stable. Subjects S1, S2, and S3 received 32, 45, and 21 training sessions respectively. The training sessions were followed by four test sessions, on successive days, in which control of responding by the line-tilt dimension was assessed. During these sessions, reinforcement continued to be made available according to the FI schedule and a blackout continued to follow each reinforcement. During these sessions, however, the line orientation on the response key was varied during different intervals. Each session consisted of 15 intervals. Each of five different line tilts (±45, ±22.5, and 0 degrees from vertical) was presented three times. Thus, the 0° line occurred during three intervals, the −22.5° line during three, and so forth. The order in which the different line tilts were presented was randomized during each session within the restriction that each line tilt had to occur three times per session. During each test session, response rate during successive thirds of the FI was recorded.

Results

During the terminal training sessions, all three subjects displayed an approximately linear increase in response rate over successive thirds of the FI.

Table 1 and Figure 1 show the test session results. Table 2 shows response rate, averaged over all four test sessions, during successive thirds of the FI in the presence of the different line tilts. During the first third of the FI, responding was in the form of a U-shaped gradient, with minimum responding occurring in the presence of the vertical line. During the last third of the FI, responding took the form of an inverted U-shaped gradient, with maximum responding occurring in the presence of the vertical orientation. During the middle third of the FI, response rates were more-or-less the same in the presence of the different orientations. Nonparametric trend analysis (Ferguson, 1965) of the averaged data for the three subjects revealed two significant trends: a bitonic trend in responding during the first third of the FI ($S = +16$, $p < 0.05$) and a bitonic trend in responding during the last third of the FI ($S = -20$, $p < 0.05$).

Figure 1 shows response rate during the first and last third of the FI in the presence of the different line tilts for each of the four test sessions. During each test session for each subject, gradients of an approximately U- and inverted U-shaped form were observed.

Table 1

Responses per minute during successive thirds of the FI in the presence of different line tilts. Data are averages of all four test sessions.

		Line Tilt				
Subject	*Third of FI*	*−45*	*−22.5*	*0*	*+22.5*	*+45*
S1	1	55.3	37.0	20.3	55.5	54.0
	2	97.0	86.3	99.5	107.5	101.5
	3	138.5	141.0	173.8	129.0	126.3
S2	1	8.3	7.0	3.4	5.9	7.9
	2	18.9	16.6	16.8	17.0	18.4
	3	28.2	30.9	37.4	27.8	25.9
S3	1	30.0	32.2	9.9	24.8	27.2
	2	52.9	60.6	61.2	51.2	54.9
	3	69.9	76.3	95.0	70.5	70.1

Discussion

The test-session data confirm Staddon's (1969) prediction that dimensional control by the FI stimulus is of an inhibitory variety early in the FI and of an excitatory variety during later portions of the FI. This finding differs from the results of an experiment performed by Konick and Thomas (1968). They reinforced key pecking in the presence of a 555-nm light according to an FI 1-min schedule. Reinforcement was followed by a blackout averaging 30 sec in duration. After training, several wavelengths were presented during a test for stimulus control. Blackouts but not reinforcement were arranged every 1 min during the test. They reported an inverted U-shaped gradient of responding, with most responding occurring in the presence of 555 nm in all parts of the FI.

One way to account for the temporal change observed here in the type of dimensional control exerted by the FI stimulus, and to reconcile these results with those of Konick and Thomas, is to consider the dimensional control

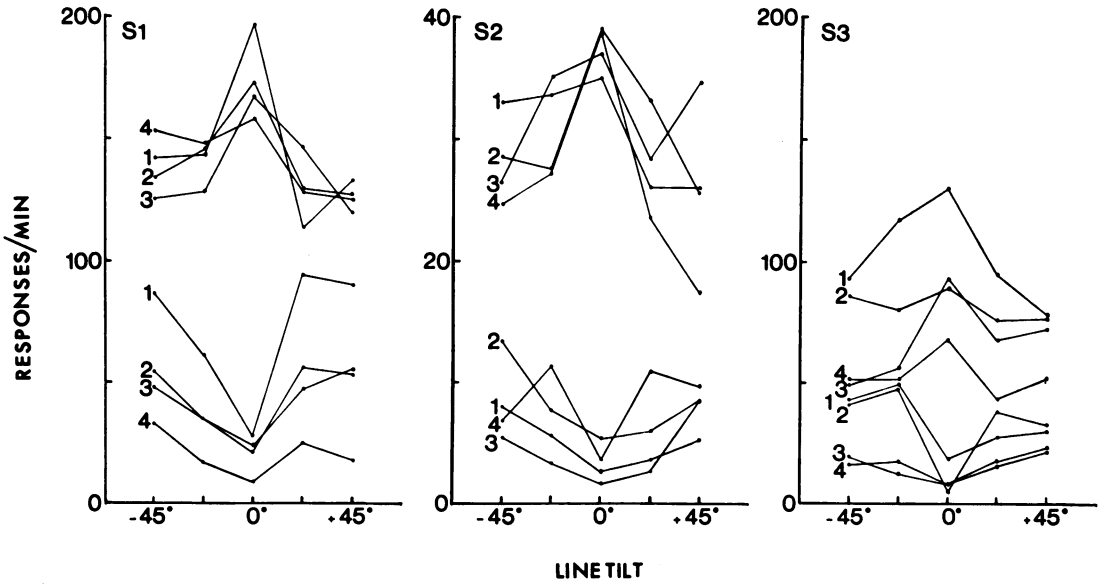

Fig. 1. Response rate in the presence of the different line tilts during the first (lower four gradients) and last (upper four gradients) third of the FI. Number beside each gradient refers to test session number.

exerted by the FI stimulus as a type of conditional stimulus control. At the start of the interval, when reinforcement is unavailable, the FI stimulus and other stimuli associated with the beginning of the interval are present. At the end of the interval, when reinforcement is available, the FI stimulus is unchanged, but the other stimuli have terminated or changed in value. Thus, in order for the FI stimulus to be inhibitory, the stimuli associated with the early part of the FI would need to be present. If these stimuli were related to the occurrence of reinforcement at the end of the preceding interval, one could account for the inhibitory dimensional control observed in the first part of the FI in the present experiment and the non-occurrence of this type of control in Konick and Thomas' experiment. Apart from the use of a shorter FI and wavelength as the FI stimulus, the only essential difference in procedure between their experiment and the present one was the omission of reinforcement during the stimulus control test session.

To examine the validity of the notion that FI stimulus control is of a conditional variety, Experiment II was performed.

EXPERIMENT II

Pigeons' key pecking in the presence of a vertical line was again reinforced according to an FI schedule. The subjects then received test sessions in which the effects of reinforcement omission upon control by the stimulus present throughout the FI was assessed. If reinforcement-associated stimuli are determinants of the inhibitory dimensional control by the FI stimulus early in the FI, then omitting reinforcement should abolish this type of stimulus control during the first part of the FI.

METHOD

Subjects

Three pigeons served. Two (S1 and S3) had previously served in Experiment 1. The third bird (S4), a Red King, had previously served in an experiment in which key pecking in the presence of red and green stimuli had been reinforced according to a variable-interval schedule. The birds were maintained at about 80% of their free-feeding weights throughout the experiment.

Apparatus

The apparatus was identical to that used in Experiment 1.

Procedure

Each subject received five test sessions interspersed among training sessions. Subjects S1, S3, and S4 received 59, 49, and 58 training sessions respectively. Session durations were approximately 2 hr, 1 hr, and 3 hr, for Subjects

S1, S3, and S4. Sessions began and ended during the blackout condition. During daily training sessions, key pecking in the presence of a 0° white line was reinforced according to either an FI 3-min (Subject S3 and S4) or FI 6-min (Subject S1) schedule. A 1-min blackout followed each reinforcement. Response rate during successive thirds of the FI was recorded during each session.

Test sessions for Subject S1 occurred after the thirtieth, forty-first, forty-fifth, forty-ninth, and fifty-ninth training session. Test sessions occurred after the twentieth, thirty-first, thirty-fifth, thirty-ninth, and forty-ninth training session for Subject S3 and the thirty-fourth, fortieth, forty-sixth, fifty-second, and fifty-eighth training session for Subject S4. The first hour of each test session was identical to a training session: key pecking in the presence of the 0° line resulted in reinforcement and the ensuing blackout according to the FI schedule. Twenty additional intervals followed. During each of the odd-numbered intervals, the 0° line was present on the response key. One half of these intervals ended in response-produced reinforcement. A 1.0-min blackout followed reinforcement. The remaining intervals ended in a response-produced blackout of 5.0 sec, which was immediately followed by the regular 1.0-min blackout. During the even-numbered intervals, the key was transilluminated by either a 0°, ±22.5°, or ±45° line. Each orientation occurred twice per session, once after an odd 0° interval had ended in reinforcement and once after an odd 0° interval had ended in a blackout. Each even-numbered interval ended with reinforcement and an ensuing 1.0-min blackout. The order of occurrence of odd intervals ending in reinforcement and blackout and the order of occurrence of the different line tilts during the even intervals was randomized within the constraints imposed by the conditions described above. During each test session, response rate during successive thirds of the 10 even-numbered intervals was recorded.

Results

Test session results are shown in Figure 2. Responding in the presence of the different line tilts following 0° intervals that ended in reinforcement is shown in the left-hand panels. Response rate gradients during the first and last third of the FI for Subjects S3 and S1 are similar to those observed in Experiment I. Subject S4 showed little evidence of either a U-shaped gradient of responding during the first third of the FI or an inverted-U shaped gradient of responding during the last third of the FI. What trend there was in this subject's responding, however, appears to be consistent with the data for S3 and S1. It is interesting to note that Subject S4 exhibited little change in response rate during successive thirds of the FI for both training and test sessions. Its previous exposure to variable-

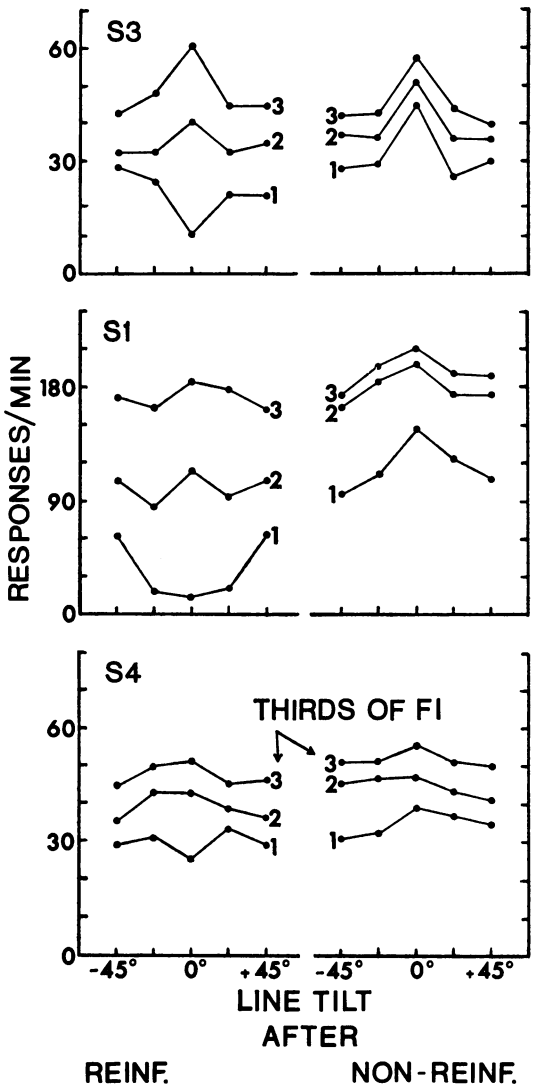

Fig. 2. Response rate in the presence of the different line tilts during successive thirds of FIs that followed 0° intervals ending in reinforcement (left-hand panels) or non-reinforcement (right-hand panels). Rate is averaged over five test sessions.

interval reinforcement schedules may, in part, have been responsible for the atypical FI performance.

Nonparametric trend analysis of test-session responding in the presence of the different line tilts following 0° intervals that ended in reinforcement revealed a significant bitonic trend during the last third of the FI ($S = -16$, $p < 0.05$). Responding during the first third of the FI did not contain a significant bitonic trend. When the data of Subject S4 were excluded from the analysis, the bitonic trend in responding during the first third of the FI was significant ($S = +12$, $p < 0.05$).

Response rate in the presence of the various line tilts following 0° intervals ending in non-reinforcement is shown in the right-hand panels of Figure 2. Gradients with peak responding during the presence of the 0° line occurred during all three portions of the FI for Subjects S3 and S1. Again, the gradients for Subject S4 are considerably flatter than those of the other subjects. Nonparametric trend analysis of responding in the presence of the different line tilts following 0° intervals that ended in non-reinforcement revealed a significant bitonic trend during the first ($S = -16$, $p < 0.05$), second ($S = -12$, $p < 0.05$), and last ($S = -22$, $p < 0.05$) third of the FI.

The effects of reinforcement omission on response rate during the succeeding FI can be seen by comparing response rates in the left- and right-hand panels of Figure 2. Response rate, particularly in the presence of the vertical line orientation during the first third of the FI, and particularly for Subjects S3 and S1, was higher during intervals following reinforcement omission than following reinforcement.

Discussion

Reinforcement has been shown to be a critical determinant of inhibitory dimensional control by the FI-correlated stimulus during the early part of the FI. The present results reconcile those of Experiment I and those of Konick and Thomas (1968), and lend support to the notion that control by the FI stimulus is conditional in nature.

The results also replicate previous experiments (*e.g.*, Staddon and Innis, 1969) that have demonstrated the reinforcement omission effect and have shown this effect to be primarily the result of rate changes early in the following interval. The size of this effect seems to depend on the similarity of the stimulus present during the interval following omission to the stimulus present during the interval terminating in non-reinforcement.

GENERAL DISCUSSION

The change over time in the type of dimensional control exerted by the FI-associated stimulus that was observed in the present experiments can be characterized as a form of conditional stimulus control. Whether the FI stimulus is an occasion for non-reinforcement (and inhibitory dimensional control) or reinforcement (and excitatory dimensional control) depends on the presence or absence of reinforcement-associated stimuli. While this account of FI stimulus control obviously suffers at present from the failure to identify the reinforcement-associated stimuli involved, a notion such as this would appear to be necessary to account for these results.

Inhibitory gradients of key pecking such as observed here during the early part of the FI are usually interpreted as being the result of an interaction between pecking and responses antagonistic to pecking (*cf.* Jenkins, 1965; Terrace, 1972, 1973). During the stimulus associated with non-reinforcement for pecking, responses antagonistic to pecking are believed to occur. While little attention has been paid to observing and measuring these antagonistic responses or to questions concerning why and how they develop, some investigators (*e.g.*, Terrace, 1972) have suggested that they consist of such behavior as turning away from the response key, and that they are conditioned by the negative reinforcement associated with the cessation of non-reinforced pecking. When the stimulus associated with non-reinforcement for pecking is varied in some dimension, the antagonistic responses are believed to decrease in frequency, with the result that pecking increases in frequency. In terms of such an analysis, the present results indicate that the antagonistic responses that occur during the first part of the FI are jointly controlled by antecedent reinforcement-associated stimuli and the stimulus present throughout the FI. When either controlling stimulus is varied (reinforcement omitted or FI stimulus varied) the frequency of antagonistic responding during the initial part of the interval, and hence the frequency of pecking, is affected.

The present experiments do not answer the question of whether pecking during the early part of the FI is always jointly controlled by reinforcement-associated stimuli and the FI stimulus. It may be that the latter source of control operates only when the FI stimulus has been differentially associated with reinforcement availability, as was the case here, or when the FI stimulus is one, such as wavelength for pigeons, that controls responding in the absence of differential reinforcement (*cf.* Terrace, 1966). The results of Malone (1971), who conducted an experiment similar to Experiment I except that blackouts after reinforcement were not used during training or testing, suggests that this might be the case. Malone reported no inhibitory, U-shaped gradient of responding in the presence of different line tilts during the early part of the FI. He did report, however, that a novel red keylight superimposed on a line tilt did "disinhibit" (*i.e.,* increase) responding early in the FI. Similar effects have been noted in several other experiments (*e.g.,* Hinrichs, 1968). Such findings would appear to indicate that antagonistic responses always occur at the start of the FI but that they are controlled by the FI stimulus only in certain situations.

The finding that the FI stimulus exerts inhibitory dimensional control for a period of time after reinforcement is consistent with Terrace's (1972) theory that the development of inhibitory dimensional control by a stimulus as a result of the occurrence of antagonistic responses is responsible for the byproducts that often accompany discrimination training in which reinforcement is made differentially available in the presence of certain stimuli. Several of the byproducts observed during discrimination training have also been observed during FI schedules. For example, the divergence of response rate in the early and late parts of the FI during the development of performance on FI schedules has been classified as behavioral contrast (*e.g.,* Reynolds, 1961; Schneider, 1969). This rate interaction would, according to Terrace's account, be the result of inhibitory control exerted by the FI stimulus during the post-reinforcement period. The inhibitory nature of the control by the FI stimulus at the start of the interval would also be responsible, according to Terrace's hypothesis, for the fact that the FI stimulus at the start of the interval elicits attack behavior (Richards and Rilling, 1972), acts as a negative reinforcer (Brown and Flory, 1972), and as a punishing stimulus (*cf.* Dews, 1970).

REFERENCES

Brown, T. G. and Flory, R. K. Schedule-induced escape from fixed-interval reinforcement. *Journal of the Experimental Analysis of Behavior,* 1972, **17,** 395-403.

Brown, P. L. and Jenkins, H. M. Auto-shaping of the pigeon's keypeck. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 1-8.

Cumming, W. W. and Schoenfeld, W. N. Behavior under extended exposure to a high-value fixed-interval schedule. *Journal of the Experimental Analysis of Behavior,* 1958, **1,** 245-263.

Dews, P. B. The theory of fixed-interval responding. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules.* New York: Appleton-Century-Crofts, 1970. Pp. 43-61.

Ferguson, G. A. *Nonparametric trend analysis.* Montreal: McGill University Press, 1965.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement.* New York: Appleton-Century-Crofts, 1957.

Hearst, E., Besley, S., and Farthing, G. W. Inhibition and the stimulus control of operant behavior. *Journal of the Experimental Analysis of Behavior,* 1970, **14,** 373-409.

Hinrichs, J. V. Disinhibition of delay in fixed-interval instrumental conditioning. *Psychonomic Science,* 1968, **12,** 313-314.

Honig, W. K., Boneau, C. A., Burstein, K. R., and Pennypacker, H. S. Positive and negative generalization gradients obtained after equivalent training conditions. *Journal of Comparative and Physiological Psychology,* 1963, **56,** 111-116.

Jenkins, H. M. Generalization gradients and the concept of inhibition. In D. I. Mostofsky (Ed.), *Stimulus generalization.* Stanford: Stanford University Press, 1965. Pp. 56-61.

Jenkins, H. M. and Harrison, R. H. Effect of discrimination training on auditory generalization. *Journal of Experimental Psychology,* 1960, **59,** 246-253.

Konick, D. S. and Thomas, D. R. Stimulus generalization following fixed-interval training. *Journal of Experimental Psychology,* 1968, **77,** 689-691.

Malone, J. C. Properties of the fixed-interval S^D. *Psychonomic Science,* 1971, **23,** 57-59.

Reynolds, G. S. Behavioral contrast. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 57-71.

Richards, R. W. and Rilling, M. Aversive aspects of a fixed-interval schedule of food reinforcement. *Journal of the Experimental Analysis of Behavior,* 1972, **17,** 405-411.

Schneider, B. A. A two-state analysis of fixed-interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 677-687.

Staddon, J. E. R. Inhibition and the operant. Review of G. von Békésy, *Sensory inhibition,* and F. Ratliff, *Mach bands: quantitative studies on neural networks in the retina. Journal of the Experimental Analysis of Behavior,* 1969, **12,** 481-487.

Staddon, J. E. R. and Innis, N. K. Reinforcement omission on fixed-interval schedules. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 689-700.

Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant behavior: areas of research and application.* New York: Appleton-Century-Crofts, 1966. Pp. 271-374.

Terrace, H. S. By-products of discrimination learning. In G. H. Bower (Ed.), *The psychology of learning and motivation: advances in research and theory* (Volume 5). New York: Academic Press, 1972. Pp. 195-265.

Terrace, H. S. Conditioned inhibition in successive discrimination learning. *Transactions of the New York Academy of Sciences,* 1973, **35,** 39-50.

Received 6 June 1973.
(Final Acceptance 10 December 1973.)