JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1974, 21, 215-221 NUMBER 2 (MARCH)

EFFECTS OF RESPONSE RATE, REINFORCEMENT FREQUENCY, AND THE DURATION OF A STIMULUS PRECEDING RESPONSE-INDEPENDENT FOOD[1]

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Food-reinforced key pecking in the pigeon was maintained under a four-component multiple schedule. In two components, responding was maintained at high rates under a random-ratio schedule. In the other two components, responding was maintained at low rates under a schedule that specified a minimum interresponse time. For both high and low response rates, one of the schedule components was associated with a high reinforcement frequency and the other components with a lower reinforcement frequency. During performance under these schedules, a stimulus terminated by access to response-independent food was periodically presented. The duration of this pre-food stimulus was 5, 30, 60, or 120 sec. Changes in rate of key pecking during the pre-food stimulus were systematically related to baseline response rate and the duration of the stimulus. Both high and low response rates were increased during the 5-sec stimulus. At longer stimulus durations, low response rates were unaffected and high response rates were decreased during the stimulus. For two of three pigeons, high response rates maintained under a lower frequency of reinforcement tended to be decreased more than high response rates maintained under a higher reinforcement frequency. In general, the magnitude of decrease in high response rates was inversely related to the duration of the pre-food stimulus.

Estes and Skinner (1941) found that ongoing responding maintained under a schedule of food delivery was suppressed in the presence of a stimulus that regularly preceded an unavoidable shock. This general procedure of superimposing a stimulus terminating with a noxious stimulus on a baseline of ongoing behavior is called the Estes-Skinner procedure, and the associated phenomenon of reduced responding during the superimposed stimulus is called conditioned suppression. Subsequent study of the Estes-Skinner procedure has demonstrated that the magnitude of suppression is related to the intensity of the shock (Annau and Kamin, 1961), the relative proportion of total session time spent during the pre-shock stimulus (Carlton and Didamo, 1960; Stein, Sidman, and Brady, 1958), and the response rate and reinforcement frequency associated with baseline performance (Blackman, 1968*a*, 1968*b*).

Results from several experiments have suggested that under a variety of conditions, the variables controlling the direction and magnitude of changes in responding during a stimulus terminating with a positive reinforcer presented under the Estes-Skinner procedure are similar to those controlling the direction and magnitude of changes in responding during a pre-shock stimulus under the same procedure. Several investigators have reported that responding maintained under a variable-interval schedule of food presentation in the rat and squirrel monkey was suppressed in the presence of a relatively brief stimulus (6 to 30 sec) that regularly preceded response-independent presentations of food, water, and intracranial stimulation (Azrin and Hake, 1969; Meltzer and Brahlek, 1970; Miczek and Grossman, 1971). Under these same conditions, responding was not systematically affected during relatively longer durations of the stimulus (120 to 180 sec) that regularly preceded response-independent presentations of the reinforcer (Meltzer and Brahlek, 1970; Miczek and Grossman, 1971).

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[1] This paper is based on a dissertation submitted to the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the Ph.D. degree. It was supported in part by grants MH 18022 and MH 23685 from NIMH, Fogle C. Clark, principal investigator. I thank Dr. Clark for his support and comments during the conduct of this experiment and Doctors W. H. Morse and P. B. Dews for comments on the manuscript. Reprints may be obtained from the author, Laboratory of Psychobiology, Harvard Medical School, 25 Shattuck Street, Boston, Massachusetts 02115.

In addition to reports of suppressed responding during stimuli preceding response-independent presentations of positive reinforcers, there has been at least one report of increased responding during a pre-food stimulus. When responding was maintained under a food schedule that selectively reinforced a specified minimum interresponse time, ongoing responding in the rhesus monkey was not affected during a 20-sec and 40-sec pre-food stimulus but was markedly increased during an 80-sec pre-food stimulus (Henton and Brady, 1970).

In all of the above experiments, moderate rates of responding were reduced during presentations of either pre-food or pre-shock stimuli, and the magnitude of reduction was inversely related to stimulus duration (*e.g.*, Miczek and Grossman, 1971; Stein *et al.*, 1958). In addition, increases of low rates of responding maintained by a schedule that selectively reinforces spaced responding have been reported during either a pre-food or pre-shock stimulus (Blackman, 1968*a;* Henton and Brady, 1970). The purpose of the present experiment was to examine systematically relationships between direction and magnitude of changes in ongoing responding during a pre-food stimulus under varying response rates and reinforcement frequencies, and to compare these relationships with those reported by Blackman (1968*b*), who used shock presented under the Estes-Skinner procedure.

Using response-pacing techniques (Ferster and Skinner, 1957) to manipulate response rate and reinforcement frequency independently, Blackman (1968*b*) found that (1) with comparable reinforcement frequencies, high response rates were decreased more than low response rates during a 1.0-min pre-shock stimulus, and (2) with comparable response rates, responding maintained by a lower reinforcement frequency was decreased more during the same pre-shock stimulus. In the present experiment, responding was maintained at high rates under a random-ratio schedule and at low rates under a schedule that reinforced minimum interresponse times (IRTs). For both high and low response rates, there were multiple schedule components associated with high and low reinforcement frequencies. The magnitude of change in responding during a pre-food stimulus was measured for all conditions.

METHOD

Subjects

Three experimentally naive adult male Silver King pigeons were maintained at 75% of free-feeding weight. Water and grit were continuously available in individual home cages.

Apparatus

A stainless steel and Plexiglas chamber, 30 cm deep, 30 cm long, and 25 cm wide, enclosed in a larger ventilated sound-attenuated box was used. The response key (Grason-Stadler Model E8670A) was centered on one chamber wall 22 cm above the floor and required a force of at least 0.15 N for activation. Water and grit were available in the test chamber. Stimuli were projected on a screen immediately behind the response key by an inline projector (Industrial Electronics Engineers). The chamber was illuminated by a 3-W incandescent lamp at all times except during operation of the grain magazine and during scheduled blackout periods. Reinforcement duration was 5-sec access to grain. An audible click from a relay mounted behind the response key accompanied each effective peck. White noise masked extraneous noises.

Procedure

Preliminary training. Following feeder training with the response key darkened, all three birds received food presentations for each key peck occurring in the presence of four different key colors; green, blue, yellow, and red. A blackout period separated each stimulus presentation. This training lasted for 14 sessions.

Baseline training. The purpose of baseline discrimination training was to bring comparably high and low response rates under stimulus control of key colors associated with comparably high and low reinforcement frequencies. Thus, there would be conditions of higher response rate and higher reinforcement frequency (high resp:high reinf), of higher response rate and lower reinforcement frequency (high resp:low reinf), of lower response rate and higher reinforcement frequency (low resp: high reinf), and of lower response rate and lower reinforcement frequency (low resp:low reinf). Two schedules were used. The schedule controlling lower response rates reinforced interresponse times; after irregular time periods, the first response separated from the preceding response by 3-sec or more resulted in food presentation. In the presence of the green key color, the average time for food availability was 2 min (low resp:low reinf), and in the presence of the yellow key color, the average time for food availability was 1 min (low resp: high reinf). The schedule controlling higher response rates was random ratio. Reinforcement density was determined by the probability of reinforcement following a response, and probability values were empirically selected such that higher response rates were maintained under higher or lower reinforcement frequency. When the key color was red, the probability of reinforcement for a given response was 0.01 and the resulting average reinforcement frequency was one or more reinforcements per minute (high resp:high reinf). When the key color was blue, the probability of reinforcement was 0.006 and the resulting average reinforcement frequency was 0.6 to 0.7 reinforcements per minute (high resp:low reinf). Key color presentations were 45 min each, blackout periods were 2 min each, and each key color occurred once daily in a fixed order. The key color sequence was green, blue, yellow, and red. There were 45 training sessions under final baseline conditions.

Presentation of stimuli preceding response-independent food presentations. Following baseline training, a flickering keylight was introduced periodically during presentations of each key color. During flicker periods, the keylight was briefly interrupted one time per second. Five-minute periods of flickering keylight alternated with 5-min periods of constant keylight for each key color for five sessions. Schedule conditions were unchanged during the 5-min flicker periods.

After sessions of presenting the flickering key color without presentations of response-independent food, 5-sec access to response-independent food occurred at the end of the flicker period (pre-food stimulus). Duration of the pre-food stimulus was over a range from 5 sec to 120 sec. The sequence was as follows: 5 sec (35 sessions), 30 sec (30 sessions), 60 sec (15 sessions), 120 sec (15 sessions), and 30 sec (15 sessions). There were 10 presentations of the 5-sec pre-food stimulus and five presentations of each longer pre-food stimulus for each key color. The pre-food stimulus and response-independent food presentations were omitted for seven sessions between the 30-sec and 60-sec stimuli in order to recover original schedule performance. Beginning with the 60-sec pre-food stimulus, for Birds 1 and 3, the random-ratio schedule during blue (high resp:low reinf) was changed to $p = 0.0056$ and during red (high resp:high reinf) to $p = 0.009$. These changes were to maintain reinforcement frequency at previous levels.

RESULTS

Figure 1 shows mean response rate during both the constant key color (open circles) and pre-food stimulus (closed circles), and reinforcement frequency during the constant key color (open triangles) in each schedule component for the last seven sessions at each pre-food stimulus duration. Response rate and reinforcement frequency for the flicker-only condition are not shown, but were within the range shown for the constant key color. Reinforcement frequency during the pre-food stimulus is not shown, but it depended upon changes in response rate. At brief stimulus durations, reinforcement frequency during the stimulus varied from 0.0 reinforcements per minute for low response rates to about 5.0 reinforcements per minute for high response rates. At longer durations of the pre-food stimulus, reinforcement frequency during the stimulus was approximately equal to that during the constant key color for both response rates.

Figure 1 shows that responding in all schedule components was increased during the 5-sec pre-food stimulus. As the duration of the pre-food stimulus increased, higher response rates first decreased and then increased. In most cases, even at the 120-sec pre-food stimulus, high response rates remained somewhat lower during the stimulus than during the constant key color. In the case of low response rates, responding during the pre-food stimulus at durations greater than 5 sec was not systematically affected across all birds. When the duration of the pre-food stimulus was changed from 120 sec to 30 sec (not shown), the range of response rates during the constant key color remained unchanged and the range of response rates during the stimulus returned to the level shown for the initial presentation of the 30-sec stimulus.

With respect to reinforcement frequency, Figure 1 shows that high response rates maintained by a low reinforcement frequency

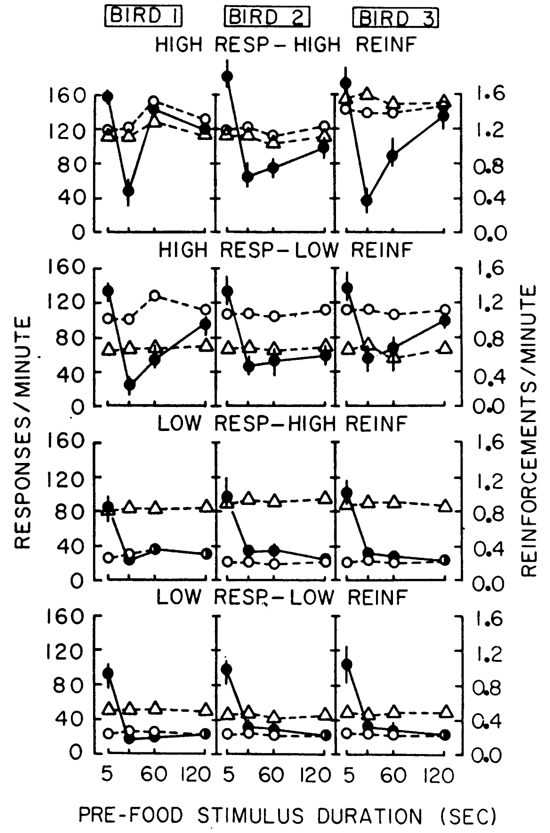

Fig. 1. Mean response rate and reinforcement frequency as a function of pre-food stimulus duration for each schedule component (rows) in each subject (columns). Points are for the last seven sessions at each stimulus duration. Vertical lines indicate the range of daily values. Open circles show responses per minute during the constant key color, closed circles show responses per minute during the pre-food stimulus, and open triangles show reinforcements per minute during the constant key color.

tended to be slightly more suppressed during the 30- and 60-sec pre-food stimuli than comparably high response rates maintained by a high reinforcement frequency. There was no discernible effect of reinforcement frequency on the magnitude of increase in either response rate during the 5-sec stimulus or on small changes in low response rates at longer stimulus durations. In terms of overall changes in responding during the pre-food stimulus, then, the most important variables were clearly response rate and stimulus duration.

Figure 2 summarizes changes in response rate in terms of a ratio that compares responding during the pre-food stimulus with responding during an equal time-period preceding the pre-food stimulus (Annau and Kamin, 1961). The value of the ratio is above 0.50 when responding was increased during the pre-food stimulus and below 0.50 when responding was decreased during the stimulus. Figure 2 shows that all responding was increased during the 5-sec stimulus but that the low rate responding was increased more than high rate responding. High rate responding (frames 1 and 2) was decreased during the 30-sec stimulus. As the stimulus duration was further increased, the magnitude of suppression for high response rates decreased. Greater suppression in the second frame than in the first reflects the small effect of reinforcement frequency on the magnitude of suppression for high response rates. In contrast to the suppression of high response rates at intermediate stimulus durations, low response rates (frames 3 and 4) were not systematically affected across subjects. Ratio values returned to near their previous levels when the stimulus duration was changed from 120 sec to 30 sec (filled points).

Figure 3 shows representative cumulative records of performance at each pre-food stimulus duration during each schedule component for Bird 2. There was steady responding both before and after presentation of the stimulus and response-independent food in all schedule components. Thus, there was no effect of the stimulus on either rate or temporal distribution of responding in the presence of the constant key color. However, there were changes in both the rate (summarized above) and temporal distribution of responding during intermediate durations of the stimulus. Moreover, these changes were related to the baseline rate of responding. Responding maintained at high rates was generally decelerated during 30- and 60-sec stimuli for all birds at both reinforcement frequencies. The pattern of low rate responding was also changed during presentations of the pre-food stimulus, but not consistently. That is, there were instances of decelerated responding, accelerated responding, and steady responding, all occurring within a given schedule component. It is interesting to note, however, that some change in the pattern of low rate responding consistently occurred, even though the overall rate of responding during the stimulus was relatively unchanged. The pattern of steady responding during the 5-sec and 120-sec stimuli was the same for all birds in all schedule components, even though

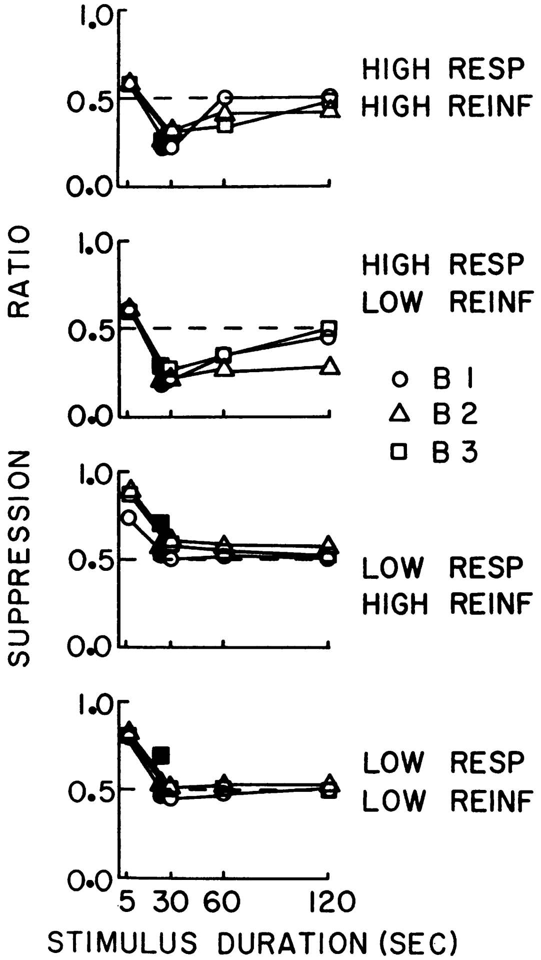

Fig. 2. Suppression ratio values as a function of pre-food stimulus duration within each schedule component (rows) for each subject. Points represent the mean suppression ratio over the last seven sessions of each stimulus duration. Open points are for initial exposures at each duration; closed points are for the second exposure at the 30-sec duration. Ranges of values are within the space covered by individual points.

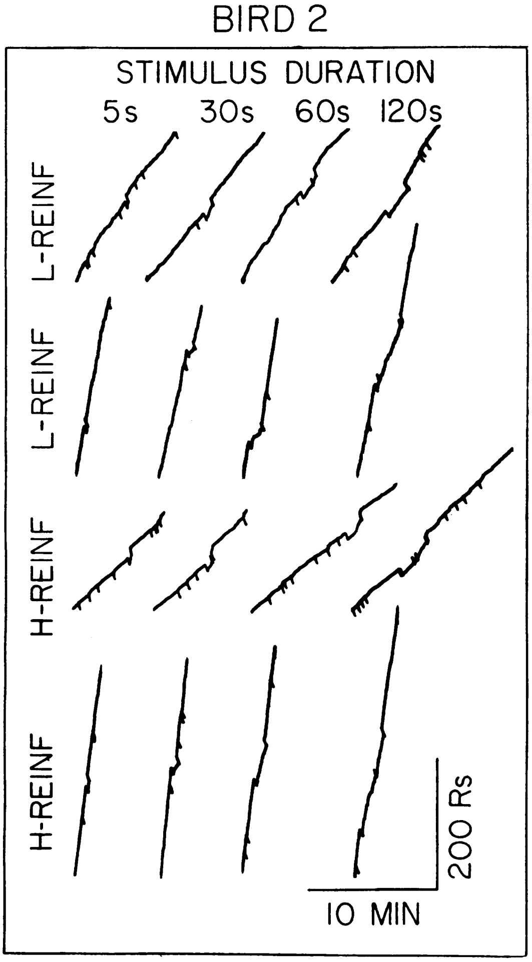

Fig. 3. Representative portions of cumulative records at each pre-food stimulus duration (columns) during each schedule component (rows). The different reinforcement frequencies are labelled H (high) and L (low). Brief deflections of the response pen indicate presentations of response-produced food. Extended downward deflections of the response pen indicate periods of the pre-food stimulus. Return of the response pen indicates presentation of response-independent food.

the rates of responding differed as a function of stimulus duration.

DISCUSSION

The direction and magnitude of changes in the rate of food reinforced key pecking during a stimulus terminated with the presentation of response-independent food were determined primarily by the base rate of responding and the duration of the pre-food stimulus. There was also a small effect of base reinforcement frequency on the magnitude of change in high response rates during pre-food stimuli of intermediate duration.

Previous studies using positive reinforcers instead of shock under the Estes-Skinner procedure have found for rats and monkeys that rates of responding may be increased, decreased, or unaffected during the stimulus preceding response-independent presentations of the reinforcer (Azrin and Hake, 1969; Henton and Brady, 1970). Subsequent similar studies have shown that when responding is decreased during the pre-food stimulus, the magnitude of decrease is inversely related to the stimulus duration (Miczek and Grossman, 1971). Results from the present experiment confirm the relationship between magnitude of change in responding during a pre-food stimulus and the duration of the stimulus. Moreover, the present results suggest that earlier differences in the direction of change in responding during a pre-food stimulus resulted from various baseline response rates, stimulus durations, and, possibly, baseline reinforcement frequencies in the different experiments.

In addition to demonstrating systematic relationships between baseline variables and changes in response rate during a pre-food stimulus, the present results indicate a similarity between these relationships and those reported when shock is presented under the Estes-Skinner procedure (Blackman, 1968*a*, *b*). In both cases, when reinforcement frequencies were comparable, high response rates were disrupted more during the stimulus than were low response rates. Also in both cases, reinforcement frequency determined the magnitude of change in comparably high response rates, but not in comparably low response rates. Reinforcement frequency did not have as great an effect on changes in high response rate during pre-food stimuli as it did during pre-shock stimuli, however. It is not clear whether this difference is due to differences between food and shock or differences between the present procedure and that of Blackman (1968*b*). It is evident, however, that important variables controlling changes in responding during pre-food and pre-shock stimuli are similar. This similarity is conceptually related to studies on response-produced shock (McKearney, 1968, 1969, 1970; Morse and Kelleher, 1970) and the postponement of food (Smith and Clark, 1972). In each of these cases, when schedules of food and shock presentation were the same, performance was similar.

Previous interpretations of decreased responding during both pre-food and pre-shock stimuli have utilized concepts that rely on either motivational states (*cf.* Azrin and Hake, 1969) or classically conditioned incompatible responses (*cf.* Kamin, 1965; Miczek and Grossman, 1971). Neither of these interpretations alone has been sufficient to account for various changes in responding during pre-shock stimuli, however, and the same criticisms apply when food is presented instead of shock (*cf.* Blackman, 1972). In the case of changes in responding during pre-shock stimuli, Blackman (1972) suggested an alternative interpretation based on the concept of stimulus control. According to this interpretation, any behavior that is under stimulus control is disrupted during a pre-shock stimulus. In the case of increased responding during a pre-shock stimulus, which has been reported only with a baseline schedule of spaced responding (Blackman, 1968*a*), Blackman (1972) suggests that the increase results from disruption of unmeasured collateral behavior that presumably provides discriminative stimuli and mediates the "timing" requirement for reinforcement. In his experiment, Blackman (1968*a*) observed that increased responding during the pre-shock stimulus was accompanied by disruption of unrecorded collateral behavior. Results from other experiments have suggested that collateral behavior may mediate the "timing" requirement for reinforcement under space-responding schedules (Hodos, Ross, and Brady, 1962; Laties, Weiss, Clark, and Reynolds, 1965). Other experiments have also suggested that under certain conditions, noxious stimuli may produce a deterioration of discriminative behavior (Blackman, 1970; Hearst, 1965).

Because the stimulus-control interpretation of changes in responding during a pre-shock stimulus is not specifically directed at either positive or negative reinforcers, it may apply to changes in responding during pre-food stimuli as well. There are difficulties with both applications, however. Even if behavior controlled by a specific stimulus is disrupted during a different, pre-shock, stimulus it is not necessarily true that behavior presumably controlled by inferred discriminative stimuli is affected in the same way. The discriminative properties of response-produced stimuli and their controlling relationship with behavior should be demonstrated each time such discriminative properties are inferred. In the absence of such a demonstration it might be more useful to maintain a distinction between the schedule control of behavior and the stimulus control of behavior, and to reserve the concept of stimulus control to those situations in which stimuli are readily identified.

The stimulus-control interpretation does not directly account for the effects of reinforcement frequency and stimulus duration. Nor does it specify behavioral mechanisms that underlie the hypothesized disruption of stimulus control. A more complete interpretation will have to identify precise interactions between properties of ongoing schedule-controlled behavior and the effects of presenting response-independent stimuli. Morse and Kelleher (1970) emphasized this type of analysis of the general effects of reinforcement and Davis and Kreuter (1972) suggested such an approach to understanding the dynamics of conditioned suppression. In the present experiment, sustained high rates of responding were reduced during pre-food stimuli at durations during which low rates of responding resulting from a required minimum interresponse time were either increased or unaffected. Clearly, the pattern of ongoing schedule-controlled responding is an important determinant of the magnitude of change in response rate during pre-food and pre-shock stimuli.

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Received 19 March 1973.
(Final Acceptance 24 October 1973.)