JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1974, 21, 389-408 NUMBER 3 (MAY)

RESPONSE STRENGTH IN MULTIPLE SCHEDULES[1]

JOHN A. NEVIN

UNIVERSITY OF NEW HAMPSHIRE

In several different experiments, pigeons were trained with one schedule or condition of food reinforcement for pecking in the presence of one key color, and a different schedule or condition in the presence of a second key color. After responding in both of these multiple schedule components stabilized, response-independent food was presented during dark-key periods between components, and the rates of pecking in both schedule components decreased. The decrease in responding relative to baseline depended on the frequency, magnitude, delay, or response-rate contingencies of reinforcement prevailing in that component. When reinforcement was terminated, decreases in responding relative to baseline rates were ordered in the same way as with response-independent food. The relations between component response rates were power functions. Internal consistencies in the data, in conjunction with parallel findings in the literature, suggest that the concept of response strength summarizes the effects of diverse procedures, where response strength is identified with relative resistance to change. The exponent of the power function relating response rates may provide the basis for scaling response strength.

CONTENTS

Introduction
Frequency of Reinforcement
  Experiment I: Response-independent food
  Experiment II: Extinction
Magnitude of Reinforcement
  Experiment III: Response-independent food
Delay of Reinforcement
  Experiment IV: Response-independent food and extinction
Contingencies on Response Rate
  Experiment V: Response-independent food and extinction
General Discussion

INTRODUCTION

Reinforcement is routinely said to "strengthen" operant behavior, and extinction is said to "weaken" it. The actual observations, of course, are that response rate increases with reinforcement and decreases during extinction. The description in terms of response strength implies that there are several properties of behavior that vary together with response rate. For example, Kling (1971) stated:

> "The term *response strength* refers to the speed, intensity, or persistence with which responses occur. The term is not just a synonym for one of these dependent variables; it implies something more than is measured by any of them. For example, Skinner (1938) spoke of the "strength" of an operant as it is reflected in response rate and in the number of responses emitted in extinction. However, because rate and resistance to extinction rarely are perfectly correlated, it is obvious that response strength must refer to something that is related to both, but identical with neither." (p. 596.)

The study of operant behavior in relation to schedules of reinforcement has made little use of the notion of response strength in this sense. The first problem with the term, identified by Kling, is the frequent lack of correlation between two presumably fundamental measures of behavior: response rate and

---

[1] The studies reported here were supported by NIMH Grant 08515 to Swarthmore College, and Grants 16252 and 18624 to Columbia University. Preparation of this manuscript was supported by NIMH Grant 23824 to the University of New Hampshire. I am indebted to Sara Shettleworth, Suzanne Roth, Roberta Welte, Dudley Anderson, Lynda Farrell, and Charlotte Mandell for their assistance in conducting the research and their comments on the findings as they developed. Reprints may be obtained from the author at Department of Psychology, Conant Hall, University of New Hampshire, Durham, New Hampshire 03824.

resistance to extinction. The problem is exemplified by Wilson's (1954) study of fixed-interval (FI) reinforcement. He trained independent groups of rats at different FI values, and obtained an orderly monotonic decreasing function relating average maintained response rate to the length of the interval. However, when reinforcement was discontinued, the average number of responses during extinction was not monotonically related to the value of the FI during training, but exhibited a maximum at FI 1-min. Perhaps as a consequence of findings of this sort, the notion of strength has received little attention in the literature on intermittent reinforcement. Instead, research has concentrated on elucidating the variables responsible for the properties of maintained performances, while extinction responding has been discussed primarily in terms of the similarity of conditions prevailing during reinforcement and non-reinforcement (*e.g.*, Ferster and Skinner, 1957).

As the study of maintained performance progressed, a second problem arose: namely, that response rate was itself a conditionable dimension of behavior. Consider, for example, the differences in behavior maintained by variable-ratio (VR) schedules, and differential-reinforcement-of-low-rate (DRL) schedules. In the former case, responding occurs at a high steady rate, whereas in the latter, it occurs at a low steady rate. These different performances may be understood as the outcomes of different contingencies between various interresponse times (IRTs) and reinforcement, in conjunction with contingencies relating the obtained rate of reinforcement to the rate of responding (Morse, 1966). However they may differ, both performances may be seen as the terminal products of related contingencies, and thus, perhaps, equally "strong". An alternative view might hold that the two sets of contingencies serve to define two different responses that cannot be compared at all. In DRL schedules, for example, the experimenter-defined response—that is, the behavioral event on which reinforcement depends—is not merely the measured bar press, key peck, *etc.*, but also the prior passage of the DRL interval. In VR schedules, the response definition does not involve a temporal dimension, so that the two performances involve qualitatively different responses.

Some of the difficulties outlined above arise from an implicit identification of the strength of responding with its absolute rate. An alternative approach is to examine the way in which responding changes, relative to its baseline rate, when some parameter of the experiment is varied. Extinction—the termination of reinforcement—is only one way of examining such changes. Other variables that alter the rate of responding may give results that accord with the effects of extinction. To the extent that similar changes are effected by different variables, and the results bear some orderly relation to the conditions of reinforcement used to establish the baseline performance, the concept of response strength provides a useful summary of the findings.

Two-component multiple schedules of reinforcement are particularly convenient for examining the changes in responding effected by different procedures in relation to the conditions of reinforcement for individual subjects. In multiple schedules, two successive stimulus conditions are correlated with independent schedules or conditions of reinforcement. Each stimulus and its correlated schedule defines a component of the multiple schedule. After prolonged training, the average rate of responding in each component will stabilize at a level that is determined both by the conditions of reinforcement prevailing in that component, and by those in the alternated component. If, at this point, some variable that reduces the rates of responding is introduced uniformly with respect to both components, the component performance that undergoes the smaller reduction, relative to its stabilized baseline, may be identified as the stronger of the two performances. It will be shown empirically that this identification is consistent across several operations that decrease response rates, and that the same internal consistency holds for a variety of different reinforcement conditions.

The present paper considers multiple schedules using variable-interval schedules of food reinforcement in both components, where the components differ in one of the following ways: frequency of reinforcement per unit time, magnitude of reinforcement, delay of reinforcement, or contingencies on response rates at the time of reinforcement. The operations used to decrease response rates are, in the studies reported here, simple extinction

—the withholding of food—or the introduction of response-independent food during periods separating the schedule components. A review of related studies suggests that comparable data are obtained with satiation, or with the introduction of stimuli preceding unavoidable shocks.

FREQUENCY OF REINFORCEMENT

The frequency of reinforcement per unit time is a potent determinant of performance in single, multiple, and concurrent schedules, and its effects have been examined parametrically in many studies (for review, see Catania and Reynolds, 1968, and Herrnstein, 1970). Accordingly, the present researches began with the examination of responding in multiple schedules where the components differed in frequency of reinforcement.

EXPERIMENT I

This experiment was designed to explore changes in responding in a three-component multiple schedule, where key pecking was reinforced with food at different, constant frequencies during two components, while the frequency of response-independent food in the third component was varied systematically. Some of the data have been published by Herrnstein (1970).

METHOD

Subjects

Pigeons 479, 481, 482, and 483, which had previously served in a multiple-schedule study (Nevin, 1968), were maintained within 15 g of 80% of their free-feeding weights.

Apparatus

The experiment was conducted in a standard single-key Lehigh Valley pigeon chamber with red and green keylights, houselight, and grain feeder. Scheduling and recording were accomplished by conventional electromechanical equipment in an adjacent room.

Procedure

Each session consisted of a fixed number of schedule cycles, during which the key was dark for the first 30 sec, followed by red or green illumination for 60 sec. Red and green alternated irregularly from cycle to cycle, with the restriction that there were no more than three consecutive presentations of one color, and the colors appeared equally often. Thus, the key was red for one-third of the session, green for one-third of the session, and dark for one-third of the session. The houselight was on continuously. Experimental sessions were conducted daily with few exceptions; the number of cycles per session was adjusted from time to time to maintain the subjects at their 80% weights. An arithmetic VI 1-min schedule was correlated with green and an arithmetic VI 3-min schedule with red. When the key was dark, a separate tape timer ran continuously, and presented food at variable intervals. In all cases, feeder presentations lasted 3 sec. The number of food presentations per hour during dark-key periods was the independent variable. Values of 60, 180, 360, and 20 food presentations per hour were scheduled for a total of 6 to 10 hr each, in that order. Approximately 5 hr of training with no food during dark-key periods intervened between values of the dark-key schedule.

RESULTS

The average rate of responding in the presence of green and red for the last 5 hr of baseline training and throughout the remainder of the experiment is shown in Figure 1. As expected, the average rate of responding when the key was green (VI 1-min reinforcement) was always higher than when the key was red (VI 3-min reinforcement). The introduction of food during dark-key periods decreased responding to both green and red, with larger decrements resulting from more frequent food presentation. Response rates during the first hour after response-independent food was introduced differed little from those during the last hour before returning to baseline conditions. Because of this slight difference, and because continued training with free food often changed the obtained frequencies of peck-contingent reinforcement when the key was lighted, performance during the first hour of exposure to response-independent food was taken as the major dependent variable in this and subsequent experiments using the same general procedure.[2]

---

[2] Complete tables of individual data are available from the author.

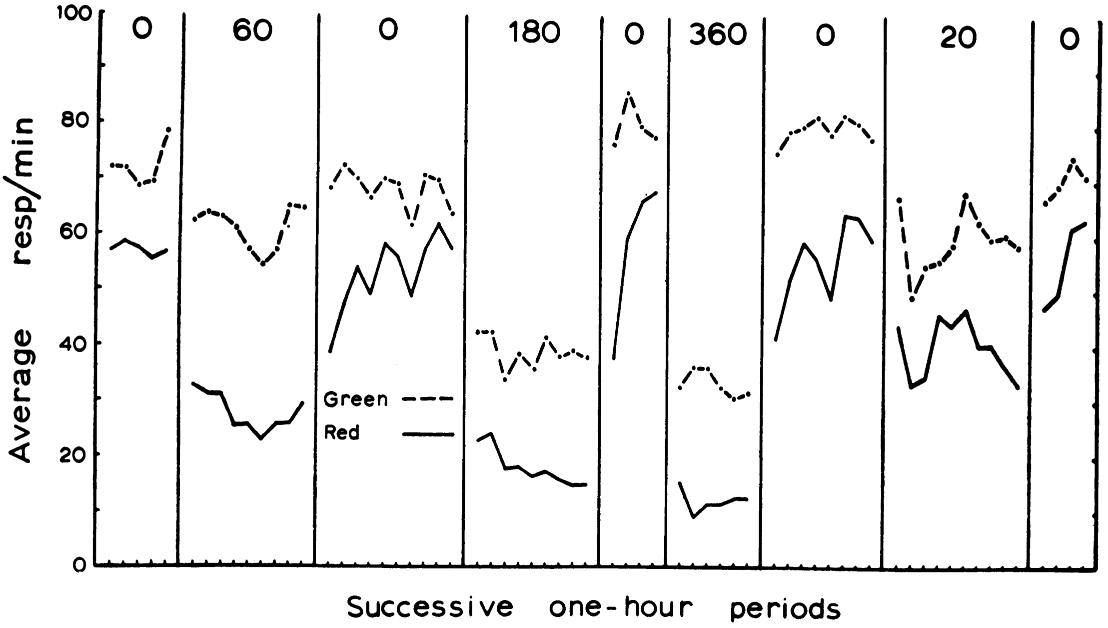

Fig. 1. Average rate of key pecking by pigeons during successive 1-hr periods of training on a multiple schedule with VI 1-min reinforcement in the presence of green, VI 3-min reinforcement in the presence of red, and response-independent food when the key was dark. The number of food presentations per hour of dark-key time is specified in each panel.

The rate of responding in the presence of red and green during the first hour with response-independent food was expressed as a proportion of the baseline response rate in each component averaged for the immediately preceding 3 hr. The resulting proportions, which are termed relative response rates throughout this paper, are presented for each subject as a function of the frequency of response-independent food in Figure 2. In every case, except for Bird 482 with 20 and 60 food presentations per hour, the relative response rate in the presence of red was less than that in green. Typically, the decrements in responding and the separation between rates in the presence of red and green were evident within 10 to 20 min after food was introduced during dark-key periods.

These results are consistent with the common finding that responding in one schedule component depends on the relative frequency of reinforcement produced by responding in that component, and that the source and contingencies of reinforcement in the other component do not alter the relationship (*e.g.*, Nevin, 1968; Rachlin and Baum, 1972). In the present case, relative reinforcement was always higher in the presence of green, and was less affected by the introduction of any given frequency of response-independent food. This aspect of the findings may be clar-

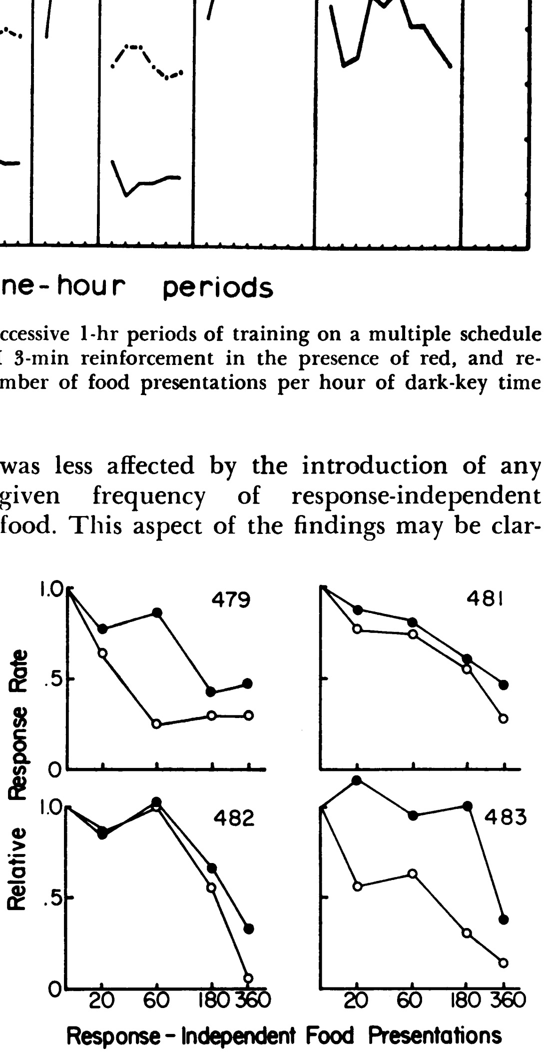

Fig. 2. Rate of responding to a green key (filled circles), correlated with VI 1-min reinforcement, or to a red key (unfilled circles), correlated with a VI 3-min schedule, relative to baseline rate of responding, as functions of the frequency of response-independent food. On the abscissa, food presentation frequencies are spaced logarithmically, and displaced arbitrarily from zero.

ified by consideration of Figure 3, which plots the average rate of responding in each component during the first hour with response-independent food as a function of the frequency of reinforcement in that component, divided by the sum of that frequency and the frequency of food presentations when the key was dark (note that the frequency of food reinforcement in the other schedule component is ignored in this computation). The two functions run roughly parallel, and are similar to Nevin's (1968) data for average response rates in the VI 3-min component of a multiple VI 3-min DRO schedule. Thus, no new concepts are required to account for these particular findings. The utility of some more general concept, such as response strength, will emerge from the correspondence of these results with those of other studies employing quite different procedures.

EXPERIMENT II

Extinction after multiple-schedule training has been studied by Gollub and Urban (1958). They employed a multiple VI 3-min VI 9-min schedule of food reinforcement with pigeons as subjects. During subsequent extinction, they found that responding in the presence of the stimulus formerly correlated with VI 3-min reinforcement declined slowly, relative to that in the presence of the stimulus formerly correlated with VI 9-min, so that the rate difference increased. Gollub and Urban (1958) employed unusually long components during training (15 and 45 min) and extinction (12.5 min). The following study, conducted by Sara Shettleworth in the author's laboratory, provides a systematic replication of their findings with brief components.

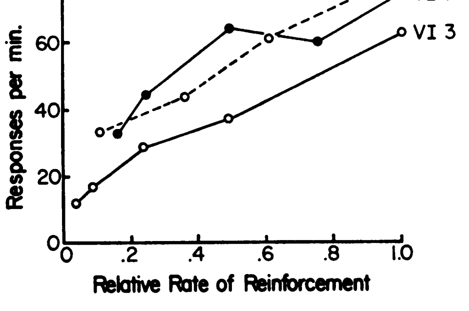

Fig. 3. Average rate of responding in the VI 1-min and VI 3-min components of a multiple schedule, as functions of the rate of reinforcement in each component relative to the sum of that rate and the rate of response-independent food when the key was dark. Data from an earlier study are plotted for comparison.

METHOD

Subjects

Pigeons 15, 16, and 17, which served in a study reported by Nevin and Shettleworth (1966), were maintained within 15 g of 80% of their free-feeding weights.

Apparatus

The same as in Experiment I.

Procedure

Red and green keylights alternated regularly throughout daily 90-min sessions. When the key was green, an arithmetic VI 2-min schedule of food reinforcement was in effect; when the key was red, an arithmetic VI 6-min schedule was in effect. Component durations were varied during 75 training sessions (data at an early stage of training are presented by Nevin and Shettleworth, 1966). During the final 10 sessions, components alternated every 30 sec. A single, continuous extinction session lasting 5.5 hr was administered on the day immediately after the last training session. Rates of responding to both red and green were recorded every 30 min.

RESULTS

Figure 4 presents, at the left, response rates during the last baseline session (F) and throughout extinction. All three subjects exhibit enhanced differences in response rates early in extinction, relative to baseline responding, with increases in the presence of green (formerly correlated with VI 2-min) and decreases in the presence of red (formerly correlated with VI 6-min). The separation is especially noteworthy for Bird 16, which had not exhibited differential responding to the component stimuli at any time from the start of training. The enhancement of responding at the onset of extinction has been noted before (*e.g.,* Morse, 1966); here, it appears to be confined to the stimulus correlated with more frequent reinforcement.

The right column of Figure 4 presents the extinction data expressed as proportions of the rate of responding in the initial 30 min.

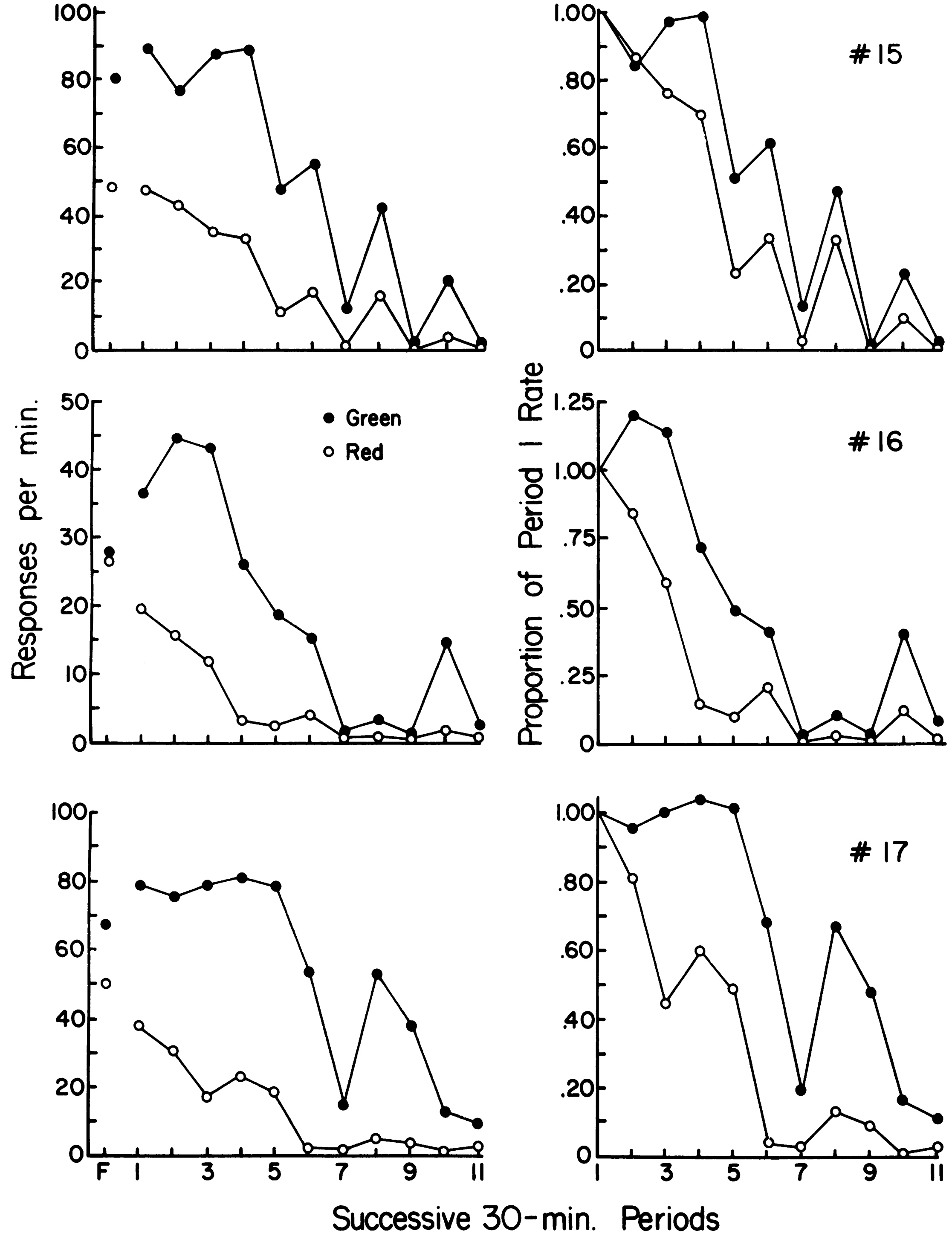

Fig. 4. Response rates at the end of training on a multiple schedule with VI 2-min reinforcement in the presence of green, and VI 6-min reinforcement in the presence of red (F), and during a single 5.5-hr session of extinction, are shown in the left panels. On the right, rates of responding during extinction are shown relative to responding in the first 30-min period. Note that scale values on the ordinate differ for Bird 16.

Even after the initial separation has been removed by this computation, responding declines relatively less rapidly in the presence of green. This finding is consistent with the Gollub and Urban (1958) results, despite rather different conditions of experimentation.

DISCUSSION

The findings described above demonstrate that responding maintained by relatively more frequent reinforcement is less affected by the introduction of response-independent food, and is more resistant to extinction, than is responding maintained by less frequent reinforcement. The same sort of differentiation may be observed when response rates decrease as a consequence of satiation. C. Eckerman (1968) trained pigeons on multiple VI 1-min VI 5-min schedules until their performance stabilized, and then prefed various amounts of grain before conducting experimental sessions. As the amount of prefeeding increased, rates of responding in both components decreased. Relative to baseline levels, the reduction was always greater in the VI 5-min component than in the VI 1-min component. The same sort of effect was observed by Carlton (1961), who trained rats on multiple FR 1 FI 2-min (or VI 2-min) schedules, and varied hours of deprivation. As deprivation was reduced, response rates decreased in both components, with the larger decrease in the component correlated with intermittent reinforcement.

Another procedure that gives comparable results is conditioned suppression. Lyon (1963) trained pigeons on a multiple VI 1-min VI 4-min schedule and presented a stimulus correlated with unavoidable shock for various periods during both components. For all durations of the preshock stimulus, responding was suppressed more, relative to its baseline level, in the VI 4-min component than in the VI 1-min component. Blackman (1968*b*) repeated this finding in a procedure that controlled the baseline response rate by means of pacing schedules. Blackman (1968*b*, Experiment II) trained rats on multiple schedules with different VI schedules in the two components but with identical pacing requirements, so that the baseline response rates were equated. He then introduced a stimulus correlated with unavoidable shock during both components, and observed greater suppression in the component correlated with less frequent reinforcement. This effect was general to several VI schedule values and pacing requirements.

Thus, the effects of satiation and conditioned suppression procedures on multiple-schedule performances are consistent with the effects of response-independent food and extinction: performance in the component correlated with relatively more frequent reinforcement is relatively less reduced by variables that are arranged uniformly with respect to both components. The greater relative resistance to change established by more frequent reinforcement is taken here as indicating greater response strength.

MAGNITUDE OF REINFORCEMENT
EXPERIMENT III

Magnitude of reinforcement has a number of effects that are strikingly parallel to those of frequency of reinforcement. For example, Shettleworth and Nevin (1965) varied the relative amount of food in two components of a multiple schedule, and duplicated Reynolds' (1963) findings with relative frequency of reinforcement. Also, Rachlin and Baum (1969) varied the magnitude of signalled reinforcement, and found the same reduction in the rate of a concurrent response maintained by a VI schedule as did Catania (1963) when he varied the frequency of signalled reinforcement. Accordingly, it is reasonable to expect that differential magnitude of reinforcement in the components of a multiple schedule will affect response strength in the same way as differential frequency of reinforcement.

METHOD

Subjects

Pigeons 1 and 2, both having extensive histories in luminance discriminations with white light, were maintained within 15 g of 80% of their free-feeding body weights.

Apparatus

A standard Lehigh Valley two-key pigeon chamber served as the experimental space. The experiment was programmed and data recorded by standard electromechanical equipment.

Procedure

The left key was lighted red, or the right key green, for 1-min periods in irregular order. When the left key was lighted, an arithmetic VI 1-min schedule of reinforcement for key pecking was in effect; the duration of grain presentations was 7.5 sec. When the right key was lighted, the same VI 1-min schedule was in effect, with grain presentation for 2.5 sec. In both components, the program tape stopped when reinforcement became available, and reinforcements not collected during the components in which they were scheduled were cancelled. The 1-min component timer stopped during reinforcement. Each session began with a 30-sec period with both keys dark, and 30-sec dark-key periods always intervened between components. Sessions consisted of 25 components with the left key lighted and 25 with the right key lighted. This procedure was in effect for 49 sessions, except that response-independent food was presented during dark-key periods on an arithmetic VI 1-min schedule during Session 40 (thus providing 60 food presentations per hour) and on a VI 10-sec schedule during Session 47 (360 food presentations per hour). The duration of access to response-independent food was always 4 sec. In Session 50, the baseline schedules were changed to VI 3-min in both components. Response-independent food was presented on a VI 1-min schedule during dark-key periods in Session 63, and on a VI 10-sec schedule in Session 70. Bird 1 was stolen from the laboratory after its sixty-third session, and consequently did not complete the experiment.

RESULTS

Bird 1 exhibited no consistent difference in response rates with 7.5-sec and 2.5-sec reinforcement durations, while Bird 2 consistently responded at a higher rate in the component with 7.5-sec reinforcement. In both cases, response-independent food during dark-key periods reduced response rates below baseline, more so for the component with the shorter duration. These results are summarized in Figure 5, which presents responding during sessions with response-independent food as proportions of the average rates for the three preceding baseline sessions. Note that in every case except Bird 2, VI 3-min with 360 free food presentations per hour, the relative rate of responding in the presence of green (correlated with 2.5-sec reinforcement) is lower than in red (correlated with 7.5-sec reinforcement). Also note that the responding maintained by VI 3-min reinforcement is more sharply reduced by a given free-food schedule than when the baseline schedule was VI 1-min, again with one exception.

DISCUSSION

The finding that free food had a generally greater effect when baseline schedules were VI 3-min than when they were VI 1-min is, of course, consistent with the findings of Experiment I. But it represents an important extension in that it suggests that comparisons made across successive experimental conditions agree with those made within a single session across components of a multiple schedule.

The finding that performance maintained by the larger magnitude of reinforcement was less affected than performance maintained by a smaller magnitude is consistent with expectations based on the functional similarities of magnitude and frequency of reinforcement, and the results of Experiment I. It is also consistent with the data on resistance to extinction reported by Shettleworth and Nevin (1965), who trained pigeons on multiple schedules with various magnitudes of reinforcement in the two components, and then terminated reinforcement after training to asymptote with 9-sec and 1-sec reinforce-

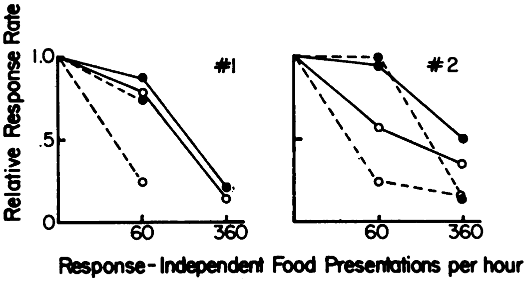

Fig. 5. Rate of responding during 1-hr sessions with response-independent food, relative to preceding baseline rates. Filled circles represent responding in the presence of red, correlated with 7.5-sec reinforcement duration, and unfilled circles represent responding in the presence of green, correlated with 2.5-sec reinforcement. Solid lines connect points obtained with VI 1-min schedules, and dashed lines connect points obtained with VI 3-min schedules. Abscissa as in Figure 2.

ment durations. They observed that responding during extinction decreased more slowly, relative to baseline levels, in the former 9-sec reinforcement component than in the former 1-sec reinforcement component.

Another supportive line of evidence comes from the work of Millenson and de Villiers (1972). They studied conditioned suppression of responding by rats in alternated sessions with VI 15-sec reinforcement, with 32% or 8% sucrose. Distinctive stimuli were correlated with these conditions; thus, the procedure may be construed as a multiple schedule with unusually long periods between components. They found that responding was relatively less suppressed when 32% sucrose served as the reinforcer than in sessions with 8% sucrose. This result is similar to the differential suppression observed with schedules differing in frequency of reinforcement. Overall, then, it is reasonable to conclude that larger magnitudes of reinforcement are analogous to higher frequencies of reinforcement in establishing greater response strength.

DELAY OF REINFORCEMENT

EXPERIMENT IV

Another important parameter of reinforcement is the delay between occurrence of the response and presentation of the reinforcer. The quantitative studies of delay of reinforcement for free-operant behavior suggest that it too may function like frequency of reinforcement. For example, Chung and Herrnstein (1967) arranged concurrent variable-interval schedules with equal frequencies of reinforcement but different delays, and found that their subjects roughly matched the proportion of pecks on one key to the relative immediacy of reinforcement on that key, where immediacy was defined as the reciprocal of delay. The result is similar to the matching of relative frequency of reinforcement (*e.g.*, Herrnstein, 1961) or relative magnitude of reinforcement (*e.g.*, Neuringer, 1967) that is commonly observed in concurrent-schedule studies. Accordingly, it seemed likely that response strength in a multiple schedule would depend on immediacy of reinforcement in the same way as on frequency and magnitude. This experiment was designed to explore the effects of response-independent reinforcement and extinction on responding in a multiple schedule with several delay values, to determine if there was any relation between differential delay of reinforcement and differential response strength.

METHOD

Subjects

Birds 19 and 20, both with extensive histories on luminance discriminations, were maintained within 15 g of 80% of their free-feeding weights.

Apparatus

The same as in Experiment III.

Procedure

As in Experiment III, the left key was lighted red, or the right key green, for 1-min periods in irregular order. Thirty second dark-key periods began each daily session and intervened between periods with a key lighted. When either key was lighted, an arithmetic VI 1-min schedule was in effect. When reinforcement became available, the tape stopped, and the next key peck initiated a blackout (key and chamber lights out), followed after a fixed delay by presentation of grain for 4 sec, with the chamber light on. After grain presentation, the key was lighted again. The 1-min component timer stopped during the delay interval and reinforcement; thus, reinforcement per unit time with a lighted key was the same for both components. Sessions consisted of 25 components with the left key lighted and 25 components with the right key lighted.

Over the course of the experiment, various delay values were arranged in the two components, such that their sum was always 10 sec. The longer delay was in effect for a block of sessions first on one key and then on the other, to control for position preferences. Each pair of delay values was in effect for between 12 and 25 sessions to establish stable baseline performances. Response-independent food was scheduled during dark-key periods for single sessions, either 60 or 360 times per hour of dark-key time. At least six baseline sessions intervened between response-independent food sessions. The delay values explored in this way were 2.5 and 7.5 sec, 9.0 and 1.0 sec, 5.0 and 5.0 sec (in which case there was no reversal across keys and colors, because the delays were equal), and 0.4 and 9.6 sec, in that order. The last condition was followed by seven sessions of extinction in which the components alternated as usual with dark-key periods but pecking had no consequences and blackout and food were never presented.

RESULTS

The baseline rate of responding proved to be insensitive to the delay value correlated with the multiple-schedule components. Although the rate of responding was generally higher in the component with the shorter delay, the difference was not large and was not systematically related to the difference between delay values. The baseline rates for each subject, averaged across replications with key colors and positions reversed for the last three sessions preceding each introduction of response-independent food, are presented in Figure 6. The figure shows that, although the rate of responding was generally higher in the component with the shorter delay (*e.g.*, 1 sec *versus* 9 sec, 2.5 sec *versus* 7.5 sec), the difference was not large and was not systematically related to the delay values or the difference between them.

Despite the absence of a clear effect of delay on baseline performance, a differential effect of delay was evident when food was introduced during dark-key periods. Figure 7 presents the rates of responding for each subject, expressed as proportions of the average rates for the immediately preceding three sessions, averaged across replications with key colors and positions reversed, for each session with response-independent food. Response rates decreased as the frequency of free food increased, as in Experiments I and III, with the larger decrease occurring in the component correlated with the longer delay. The difference in relative rates was slight when the delays were 2.5 and 7.5 sec, but was fairly large and consistent when the difference between delays was greater.

Extinction followed after training with 0.4 sec delay in green and 9.6 sec delay in red. The results are presented in Figure 8, in terms of daily response rates relative to the means of the preceding three baseline sessions. Bird 20's rate decreased systematically as extinction progressed, with a larger decrease in the presence of red than in green. Bird 19 gave exceedingly irregular data, with responding after seven sessions of extinction at a higher level than when extinction began. Throughout extinction, though, relative response rates were lower in red than in green. Thus, these data give some support to the findings with response-independent food.

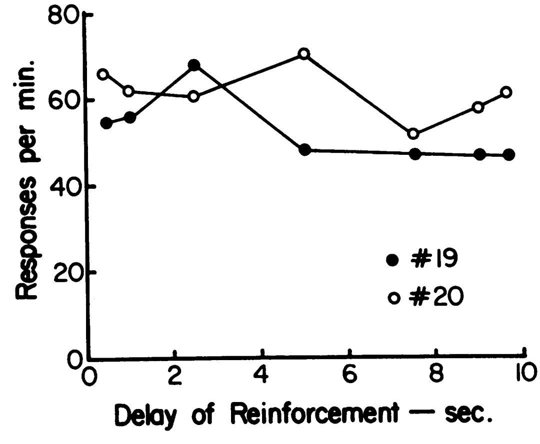

Fig. 6. Rate of responding in components of a multiple VI 1-min VI 1-min schedule, as a function of the delay of reinforcement prevailing in a component. Each data point is an average of the rate of responding to red on the left key, and green on the right key, at each delay value.

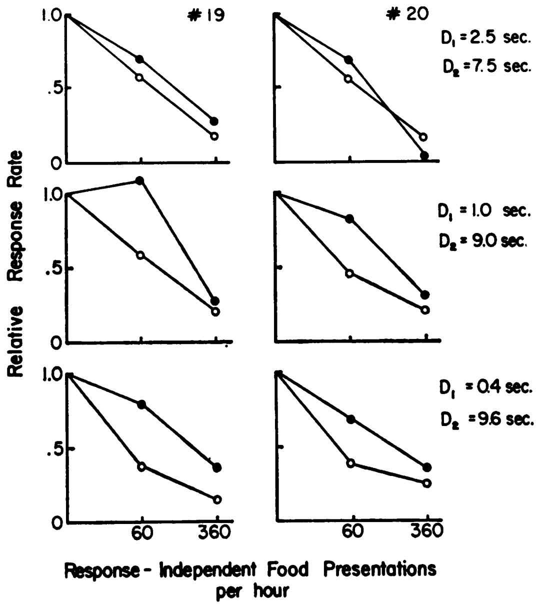

Fig. 7. Rate of responding in a component of a multiple schedule during 1-hr sessions with response-independent food, relative to baseline rates, when different delays of reinforcement were arranged in the two components. Filled circles give data for the shorter delay (D_1), and unfilled circles represent the longer delay (D_2), averaged for replications with green on the right key and red on the left key. Abscissa as in Figure 2.

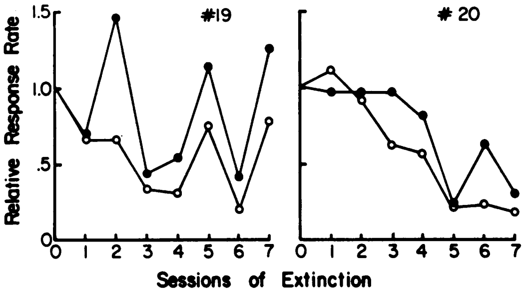

Fig. 8. Rates of responding during extinction, relative to pre-extinction baseline rates, in the presence of stimuli correlated with 0.4-sec delay (filled circles) or 9.6-sec delay (unfilled circles).

Discussion

The findings that performance maintained by the shorter delay of reinforcement was relatively less affected by introduction of free food, and was relatively greater during extinction, are consistent with the findings of the experiments described above, and thus contribute to the overall pattern of results suggesting functional equivalence of frequency, magnitude, and delay of reinforcement in the determination of responding. The identification of response strength with the relative resistance of responding to change by variables that generally lower response rates is enhanced by this internal consistency.

The effects of response-independent food are especially noteworthy in view of the absence of any systematic effect of reinforcement delay on baseline response rates. This general lack of effect agrees with the findings of Richards (1972), who arranged different delays of reinforcement in one component of a multiple schedule for independent groups of subjects and observed only a slight effect of delay on response rate with the range of delays examined here.

CONTINGENCIES ON RESPONSE RATE

EXPERIMENT V

The introduction to this paper noted that the evaluation of response strength was seriously complicated by the fact that response rate is a conditionable dimension of behavior, and that the schedules employed in conditioning response rate may have the effect of establishing qualitatively different performances that cannot be ordered with respect to strength. All of the studies described above, and all those reviewed, employed VI schedules (or VI pacing in the case of Blackman, 1968*b*) in both components of the multiple schedule. It may be that the consistent differential effects of response-independent food, extinction, and other operations depend upon the use of similar contingencies of reinforcement in the two components; in other words, the notion of strength may be meaningful only in comparing performances maintained by the same schedule contingencies. The next experiment investigated the effects of different contingencies on response rate superimposed on different frequencies of reinforcement. Either rapid or slow responding at the time of reinforcement was required in combination with either high or low frequencies of VI reinforcement in a multiple schedule. Stable performances were established by prolonged training, and the effects of response-independent food and extinction were examined.

Method

Subjects

The four pigeons from Experiment I served. They were maintained within 15 g of their previously determined 80% weights.

Apparatus

The same single-key chamber was employed as in Experiment I.

Procedure

Sessions were arranged as in Experiment I, except that red and green keylights alternated regularly for 60-sec periods, separated by 30 sec with the key dark. Sessions were always 60 min long, and were conducted daily.

Throughout the experiment, an arithmetic VI 1-min schedule was correlated with green and an arithmetic VI 3-min schedule with red. The rate of responding to either red or green was controlled separately by the following contingencies. In one component, only responses terminating interresponse times longer than 3 sec were reinforced if the VI tape had scheduled a reinforcement; no responses were reinforced at other times. This is a tandem VI DRL schedule, which characteristically maintains low, steady response rates. In the other component, a limited hold was imposed and a short ratio requirement added. When the VI tape scheduled a reinforcement, three responses were required to occur within 3 sec in order to produce food. If this requirement was not met, the reinforcement was lost. This schedule, which will be designated VI DRH, in effect requires the maintenance of a high steady rate of responding.

Birds 479 and 482 were initially trained with VI 1-min DRH in green, and VI 3-min DRL in red, so that the rate-controlling contingencies acted to enhance the rate differences expected with VI 1-min and VI 3-min schedules. Birds 481 and 483 were initially trained with VI 1-min DRL in green, and VI 3-min DRH in red, so that the rate-controlling contingencies opposed the effects of reinforcement frequency. After 35 sessions to establish stable baseline performances, response-independent food was introduced while the key was dark. Values of 60 and 360 food presentations per hour were employed in that order, with baseline recovery intervening. The first exposure to 60 food presentations per hour lasted for 14 sessions. Subsequently, response-independent food presentations were limited to a single session, because obtained rates of reinforcement were altered drastically when response rates changed under the schedule contingencies studied, and longer-term data were not interpretable. Baseline performances were recovered a second time, and then extinguished by withholding food reinforcement for seven sessions. Conditions were then reversed for the pairs of pigeons, so that Birds 479 and 482 were trained with VI 1-min DRL and VI 3-min DRH, while Birds 481 and 483 were trained with VI 1-min DRH and VI 3-min DRL. After 60 sessions of training on these baseline schedules, the subjects were exposed to the same sequence of dark-key reinforcement, baseline recovery, and extinction.

RESULTS

Baseline performance data for each subject are presented in Table 1. For every subject, higher rates were maintained by the DRH contingency than by the DRL contingency, regardless of the reinforcement frequencies arranged by the VI schedule in the two components. The differential control by the response-rate contingencies was examined quantitatively by calculating the ratio of the rate of responding in the VI 1-min component (green key) to the sum of response rates in the two components. This measure will equal 0.50 if the component rates are equal. The average value for VI 1-min DRL, relative to the sum of rates, is 0.33, while the average value for VI 1-min DRH, relative to the sum of rates, is 0.67. An equivalent statement is that, on the average, the DRH contingency maintained a response rate double that maintained by DRL, regardless of the reinforcement frequencies arranged to satisfy either contingency.

A second point of interest is that the average obtained frequencies of reinforcement, although somewhat below the scheduled frequencies of 60 and 20 reinforcements per hour, did not differ consistently across the various schedule combinations and did not depart appreciably from the scheduled 3:1 ratio. Individual data varied considerably about the average values, but were generally repeatable within subjects.

Individual response rates during sessions with response-independent food are presented as percentages of baseline rates in Figure 9. In the right column, the relative rates show a clear separation, with VI 1-min DRL performances exhibiting far less reduction than VI 3-min DRH when response-independent food was introduced. In the left column, though, this consistency breaks down: for Birds 482 and 483, VI 1-min DRH performance is less affected by the introduction of food during dark-key periods, while for Birds 479 and 481 the ordering is reversed. The reversal cannot be explained by the order of exposure to the schedules, because the birds exhibiting reversals were exposed to those conditions in different orders. There is no obvious correlation between the variations within and across subjects in Figure 9, and the data in Table 1 on obtained reinforcement.

Comparisons across columns reveal consistency with previous results. Whenever comparisons are made between schedules involving the same reinforcement contingencies on response rate, but different frequencies of reinforcement, the relative rate of responding in the component with the higher frequency of reinforcement is always greater than that in the component with the lower frequency of rein-

Table 1

Baseline rates of responding, and obtained reinforcements per hour, in multiple-schedule components with different scheduled frequencies of reinforcement and different required response rates. The first line for each subject gives baseline data for the three sessions preceding the session with 60 response-independent food presentations per hour, and the second line gives data for the three sessions preceding 360 response-independent food presentations per hour. Also shown for each subject is the ratio of the response rate in green to the sum of response rates in the two components. Means are also presented for each measure.

	Key Colors and Schedules									
	Green VI 1-min DRH		*Red VI 3-min DRL*			*Green VI 1-min DRL*		*Red VI 3-min DRH*		
Bird #	$\frac{Resp}{min}$	$\frac{Rft}{hr}$	$\frac{Resp}{min}$	$\frac{Rft}{hr}$	$\frac{G}{G+R}$	$\frac{Resp}{min}$	$\frac{Rft}{hr}$	$\frac{Resp}{min}$	$\frac{Rft}{hr}$	$\frac{G}{G+R}$
479	94.4	60	21.5	18	0.81	37.6	50	67.6	14	0.36
	101.1	66	25.7	18	0.80	33.3	45	62.9	13	0.35
481	68.5	44	27.5	20	0.71	19.2	55	56.1	19	0.25
	70.3	45	30.0	13	0.70	19.2	60	66.4	21	0.22
482	74.4	59	43.6	13	0.63	32.0	47	77.4	22	0.29
	85.1	63	40.9	14	0.68	28.6	61	72.4	21	0.28
483	55.3	27	49.2	17	0.53	41.5	53	53.1	7	0.44
	57.8	22	52.2	12	0.53	44.2	55	54.6	9	0.45
Means	75.8	48	36.3	16	0.67	32.0	53	63.8	16	0.33

forcement, regardless of whether the contingencies required high rates (DRH) or low rates (DRL). Comparisons between schedules with the same reinforcement frequency but different contingencies are also instructive. For Birds 479, 481, and 482, the relative rate in the DRL component is consistently above the relative rate in the DRH component when VI 1-min reinforcement was scheduled. Only Birds 479 and 481 are consistent in this regard when VI 3-min reinforcement was scheduled.

The effects of extinction were generally parallel to those of response-independent food during dark-key periods, as indicated by the relative response rate data for successive extinction sessions in Figure 10. Although there is some variability, once again there is a clear separation in the rate of extinction, relative to baseline, in the right column, while only Birds 482 and 483 exhibit the same clear separation in the left column. Comparisons across columns after exposure to schedules with the same contingencies but different frequencies of reinforcement indicate that the performance based on the higher frequency of reinforcement was relatively more resistant to extinction. When frequency of reinforcement was equated but the response-rate contingencies differed, DRL performance was relatively more resistant to extinction than DRH for Birds 479, 481, and 482 when responding had been maintained by VI 1-min reinforcement, as in the comparisons above (Figure 9). This difference was less clear or absent when performance was maintained by VI 3-min reinforcement.

The similarity of the data obtained with food presentations when the key was dark and with extinction is shown by the average data in Figure 11. The left panel plots the average relative rate of responding as a function of the frequency of response-independent food, while the right panel presents the average relative response rates during extinction. The ordering of the four functions representing the four combinations of reinforcement frequency and contingency is the same in both panels.

DISCUSSION

These data suggest that when reinforcement contingencies are the same (DRL or DRH), performances maintained by VI 1-min reinforcement are stronger than those maintained by VI 3-min reinforcement, in agreement with Experiments I, II, and III. Moreover, for at least two subjects, performances maintained by DRL contingencies were

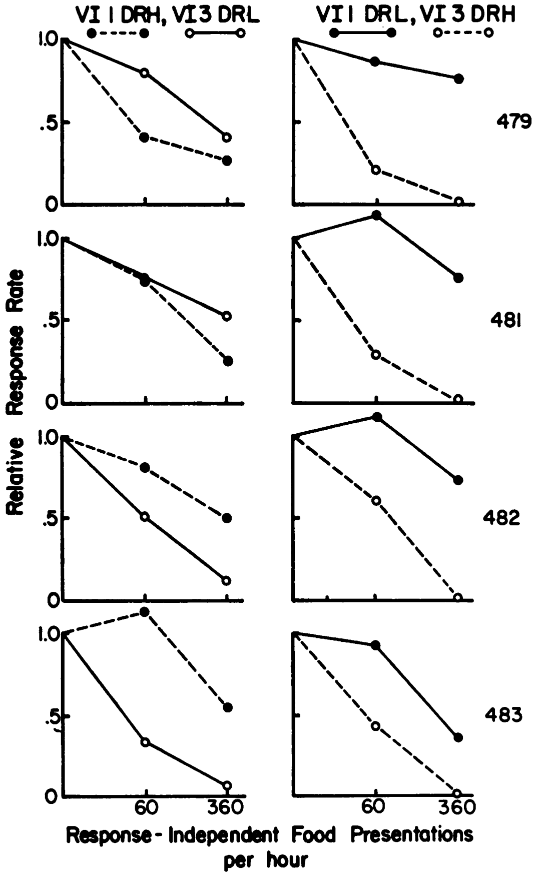

Fig. 9. Rate of responding in multiple-schedule components correlated with different reinforcement frequencies and contingencies, during 1-hr sessions with response-independent food. Data are expressed as proportions of baseline response rates. In the left column, individual data are presented for performance on *mult* VI 1-min DRH VI 3-min DRL. On the right, data are *mult* VI 1-min DRL VI 3-min DRH. Data points are coded as indicated at the top of each column. Abscissa as in Figure 2.

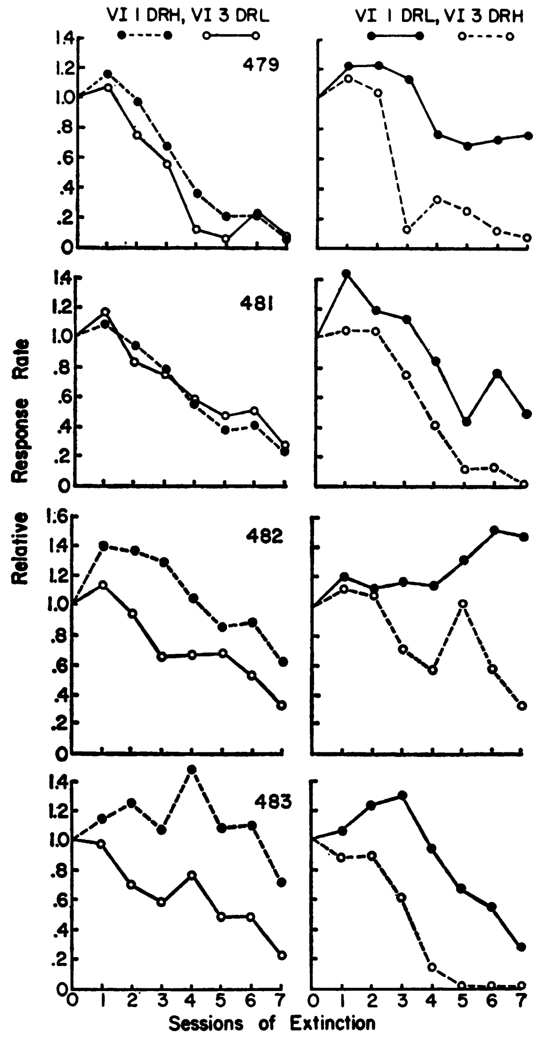

Fig. 10. Rates of responding during extinction after training on multiple schedules, relative to pre-extinction baseline. Data are arranged and coded as in Figure 9.

stronger than for DRH when reinforcement frequency was equated. Because the effects of DRL and DRH contingencies on response strength were not expected, the experiment was not designed to isolate them. To do so, it would be best to arrange identical reinforcement frequencies in conjunction with different contingencies in the two components of a multiple schedule, so that comparisons could be made without the variability introduced by intervals of nearly three months between the conditions being compared.

Although the present data permit only weak conclusions about the role of rate-controlling contingencies in the determination of response strength, the interpretation that DRL leads to stronger performance than DRH is consistent with the findings of Blackman (1968*a,b*), who studied the effects of a stimulus preceding unavoidable shock on multiple schedule performances differing in the contingencies on response rate. Blackman (1968*a*) demonstrated that DRL responding in the presence of a preshock stimulus, relative to baseline levels, was greater at all shock intensities than responding relative to a baseline maintained by a fixed-interval schedule with short limited hold. Blackman's (1968*b*) second study employed VI schedules with various

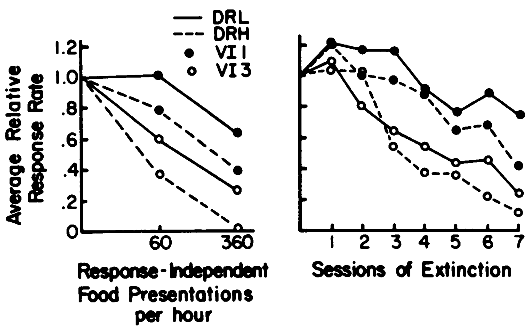

Fig. 11. Average relative response rates in relation to response-independent food (left panel) or extinction (right panel). Data are from Figures 10 and 11, and are coded as in those figures.

pacing requirements in multiple schedules, and demonstrated that performances maintained by relatively low-rate pacing requirements were less suppressed in the presence of a preshock stimulus than those maintained by a high-rate pacing requirement. As noted above, in the discussion of response strength in relation to reinforcement frequency, the findings of conditioned suppression studies were entirely in accord with those employing response-independent food and extinction. Therefore, Blackman's findings that high-rate performances are more readily suppressed than low-rate performances support the suggestion of the present data that high-rate performances are more easily reduced by response-independent food or extinction than are low-rate performances. Taken together, these results indicate that high-rate requirements generate weaker performance than low-rate requirements.

GENERAL DISCUSSION

The broad agreement in the findings reported and reviewed here suggests the operation of a common variable, which in most general terms may be called the strength of a discriminated operant. A discriminated operant is defined by the three-term contingency between a discriminative stimulus, a response, and a reinforcer. A strong operant may be identified in relation to a second operant by the higher rate of occurrence of its response, relative to its baseline rate, when a single operation is applied uniformly to reduce both rates. The relative measure of responding serves at least in part to resolve the problem of measurement when different response rates are required, and reveals internal consistency in the variables determining response strength.

The concept of strength is not, perhaps, a logical necessity. Agreements in the effects of diverse operations can be noted without invoking a common variable. However, the identification of a common variable such as response strength provides an economical summary of a large number of findings. Moreover, if this variable can be quantified, the effects of otherwise incommensurable conditions defining the discriminated operant can be ordered on a common scale.

An approach to the quantification of response strength is suggested by the relation between response rates measured independently in the two components of a multiple schedule. Nevin (1974) studied multiple VI VI schedules with brief components, arranged concurrently with a fixed-interval schedule on a second key, and found that response rates on the multiple key changed systematically as a function of time within the concurrent FI. When the response rate in one VI component was plotted in relation to the response rate in the other VI component during successive periods within the FI, a power function was found to provide an acceptable first-order description of the relation between response rates. A similar relation between response rates emerged in several of the studies described above. To show this, Figure 12 presents the average response rate in one component of the multiple schedule in relation to the average response rate in the other component for Experiments I, II, and V (Experiments III and IV did not provide sufficient data with constant conditions of reinforcement to make the function form clear). In the upper panel of Figure 12, the filled data points show the average rate of responding in the presence of green in relation to the rate in the presence of red during successive half-hour periods of extinction, after training with VI 2-min reinforcement in green and VI 6-min reinforcement in red (Experiment II). The unfilled data points show the average rate of responding in the presence of green, correlated with VI 1-min reinforcement, in relation to the average rate of responding in the presence of red, correlated with VI 3-min reinforcement, during the first hour after each of the four schedules of response-independent food presentation was introduced (Experiment I). Average baseline response rates are also plotted as the uppermost data point. Except for one point taken during extinction, the data of both studies are reasonably well described by power functions with similar slopes. In the lower panel of Figure 12, the data of Experiment V are presented in the same form. The filled data points are average response rates established by training with VI 1-min DRH schedules in the presence of green, and VI 3-min DRL schedules in the presence of red, for the sessions with response-independent food (squares) and for the seven successive sessions of experimental extinction (circles). The unfilled data points are averages for the same subjects trained with VI 1-min DRL schedules in the presence of green and VI 3-min DRH schedules in the presence of red. For each pair of schedules, the data are adequately described by power functions, and the covariations in responding produced by response-independent food and extinction fall along a single line. There is a substantial difference in the slopes of the relations for the two pairs of schedules.

The power function relating response rates may be interpreted in relation to the notion of operant strength, as follows: when the relation between response rates has an exponent less than 1.0, it implies that changes in the rate of the operant represented along the abscissa are always relatively larger than the corresponding changes in the rate of the operant represented along the ordinate. This is exactly equivalent to the identification of strength with the change in responding relative to its asymptotic baseline. Thus, the relative strengths of two operants may be measured by the exponent of the function relating their response rates: the greater the departure of the exponent from 1.0, the greater the difference in strength.

The nature of the relationship between the exponent and the conditions of reinforcement in the component schedules is a matter for empirical research. Nevin's (1974) data show that the exponent is inversely related to the relative frequency of reinforcement in the two components: thus, the difference in strength is directly related to the relative frequency of reinforcement. The present data suggest that comparable relations may hold for the relative magnitude of reinforcement, and for the relative immediacy of reinforcement (although in both cases there were insufficient data points to define power functions). They also suggest that DRL contingencies generate stronger performances than DRH, although the reasoning here is more complex. In Experiment V, DRL and DRH contingencies were arranged in tandem with VI 1-min and VI 3-min reinforcement schedules. If the strength of responding established by each of the component schedules is the sum of strengths attributable to the frequency and contingencies of reinforcement, and if the exponents of the power functions in Figure 12 are ordinally related to the differences in response strengths maintained by the components of the multiple schedule, we can write the inequality:

$$(S(\mathrm{VI}\ 1) + S(\mathrm{DRL})) - (S(\mathrm{VI}\ 3) + S(\mathrm{DRH})) >$$
$$(S(\mathrm{VI}\ 1) + S(\mathrm{DRH})) - (S(\mathrm{VI}\ 3) + S(\mathrm{DRL}))$$

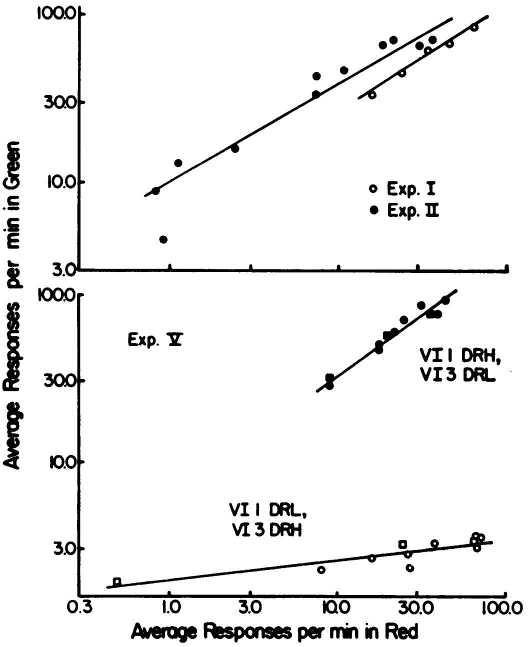

Fig. 12. Average rate of responding in one component of the multiple schedules studied in Experiments I, II, and V, as a function of the average rate of responding in the other component. In the upper panel, unfilled circles give data from Experiment I, when the frequency of response-independent food was varied, and filled circles give data from Experiment II, during extinction. In the lower panel, squares give data for response-independent food, and circles give data for extinction, for the designated schedules and contingencies of reinforcement in Experiment V.

where, for each term, S designates the strength attributable to the schedule variable indicated in parentheses. Subtracting out the terms representing the VI schedules on both sides, the inequality reduces to:

$$S(DRL) - S(DRH) > S(DRH) - S(DRL)$$

which implies

$$S(DRL) > S(DRH).$$

This sort of analysis may be applied to other experimentally arranged combinations of reinforcement variables (*e.g.*, frequency, magnitude, and delay) and the adequacy of a simple additive model of this sort may thus be tested. If it is successful, response strength is not only an economical summary term, but a variable that can be quantified from the relative resistance of responding to change, and scaled in relation to experimental variables.

Although the analysis presented here is based on performance trained to asymptote with intermittent reinforcement, it demonstrates that asymptotic response strength depends on the parameters of magnitude and delay of reinforcement in the same general way as has long been assumed for the acquisition of a new response with regular reinforcement (*e.g.*, Hull, 1943; Logan, 1960). However, the assessment of operant strength is more complex when regular reinforcement is arranged. Consider, for example, the effects of intermittent reinforcement, compared with regular reinforcement. Carlton's (1961) data, cited above, demonstrate that regularly reinforced responding is relatively more resistant to satiation effects than is intermittently reinforced responding. Brady and Hunt (1955) reported that conditioned suppression is less readily established and more easily extinguished in groups of subjects trained with regular or short ratio reinforcement schedules, than when moderate to long interval schedules are used. These data are consistent with the notion that regular reinforcement established greater response strength than intermittent reinforcement. In the results presented and reviewed above, the effects of extinction were also consistent with the effects of satiation and conditioned suppression: more frequently reinforced responding was relatively less affected by extinction. At the regular-reinforcement end of the reinforcement frequency continuum, however, this agreement breaks down. It is well known that subjects receiving intermittent reinforcement during training exhibit greater subsequent resistance to extinction than subjects receiving regular reinforcement. Although nearly all of the relevant research has used independent groups, the finding is repeatable with single subjects (*e.g.*, Hearst, 1961), and must be considered as a major counterexample to the consistencies reported here.

Before this problem is taken to be decisive against the present interpretation of response strength, some complicating factors must be noted. The widely accepted discrimination hypothesis of extinction (*cf.* Kimble, 1961) holds that responding after termination of reinforcement is a function of the discriminability of non-reinforcement. If non-reinforcement is more readily discriminated in one schedule component than the other, extinction does not constitute an operation applied equally to both operants, and thus does not satisfy the conditions that are required for the assessment of differential response strength. This problem may not be serious when both components involve relatively infrequent intermittent reinforcement. It may therefore be necessary to study operant strength based on intermittent reinforcement schedules, rather than on the superficially simpler, traditional regular reinforcement schedule.

Although the present approach to the study of response strength may have to be confined to intermittently reinforced operants if extinction is to be included among the operations used to assess strength, it is not restricted to the case where two operants are trained to asymptote. The same approach can be applied to determine the relation between response strength and the number of reinforcements, and/or the duration of training, a matter of central concern to learning theory (*e.g.*, Hull, 1943). For example, response-independent reinforcers could be presented after varying numbers of reinforcements during acquisition of an intermittently reinforced operant, and the results compared with data on resistance to extinction as a function of the number of intermittently scheduled reinforcements (*e.g.*, Wilson, 1954).

Another process to which the analysis may be applied is stimulus generalization. Several experimenters have noted that when a gradient of generalization is obtained during extinction, responding decreases relatively more rapidly as the test stimulus values depart increasingly from the training value (*e.g.*, Hearst, 1969; for review see Nevin, 1973). This differential change in responding, indicated by the sharpening of the relative gradient during extinction, leads to the paradox that stimulus control appears to improve in the absence of reinforcement. According to Lea and Morgan (1972), this result indicates the inappropriateness of relative measures of responding. The present analysis of response strength suggests that, on the contrary, a relatively smaller decrement in responding at the training stimulus, and the consequent sharpening of the gradient, is exactly consistent with the traditional view that response strength is maximal at the training stimulus.

A major theoretical problem in stimulus generalization is the assessment of conditions of "excitation" and "inhibition" responsible for the peak shift that follows discrimination training with S+ alternating with S— on the same continuum. Catania, Silverman, and Stubbs (1974) have demonstrated that overall gradient height is reduced and the usual peak shift is eliminated by concurrent presentation of a stimulus correlated with a second schedule of reinforcement during training. Terrace (1966) observed the same sort of changes in generalization gradients obtained successively during extended discrimination training. In present terms, these findings demonstrate that responding to the S+ value is relatively less resistant to reduction, and therefore is stronger, than responding at the shifted peak. This interpretation is of course consistent with the traditional Spence (1937) theory of discrimination and generalization, and it may well be that a shift from absolute or relative response rates to scaled response strengths will facilitate theoretical unification of the stimulus control literature (*cf.* Blough, 1965).

Another area of interest in traditional learning theory, as well as the current experimental analysis of behavior, is conditioned reinforcement. Many of the data on conditioned reinforcement for operant behavior have been obtained with chained schedules, in which responding during an initial link produces a terminal-link stimulus that is correlated with unconditioned reinforcement. In this situation, Ferster and Skinner (1957) and Fischer and Fantino (1968) demonstrated that initial-link responding in chain VI VI schedules is relatively more reduced by satiation than is terminal-link responding. In present terms, this implies that initial-link performance, which is based at least in part on conditioned reinforcement, is weaker than terminal-link performance, an interpretation that accords with the view that conditioned reinforcers are less effective than the unconditioned reinforcers on which they are based (*e.g.*, Kelleher and Gollub, 1962). Indeed, the data of Fischer and Fantino (1968) indicate that the relation between initial-link and terminal-link response rates is a power function (*cf.* Nevin, 1974). This result suggests the possibility of scaling the effectiveness of conditioned reinforcement in relation to the conditions of pairing with unconditioned reinforcement. It may even be possible to go a step further, and arrive at a predictive formulation of conditioned reinforcement. Wyckoff (1959) suggested that the effectiveness of a conditioned reinforcer was an increasing function of its "cue strength", where cue strength was defined by reference to the probability of responding in the presence of the stimulus serving as the conditioned reinforcer (in a two-link chained schedule, this would constitute the terminal link of the chain). As Kelleher and Gollub (1962) correctly noted, Wyckoff's formulation cannot explain chained schedule performances with terminal-link rates lower than initial-link rates. If, however, cue strength is defined in terms of response strength—that is, the relative resistance of responding to change, rather than its absolute value—this difficulty may be overcome. The results of Experiment V, for example, have been interpreted above as demonstrating that DRL contingencies established greater response strength than DRH. One would therefore predict that the discriminative stimulus correlated with DRL would be a more effective conditioned reinforcer than a stimulus correlated with DRH, when frequency of food reinforcement was equated, regardless of the response rates controlled by those stimuli. If supported, this prediction would be consistent with the general ideas proposed by Wyckoff (1959) and would suggest a new approach to the study of conditioned reinforcement.

The foregoing discussion should suffice to show that the conceptualization of response strength in terms of relative resistance of responding to change can lead to a coherent quantitative summary of the relations between asymptotic operant behavior and the conditions of reinforcement. The same logic and research methods may also permit an integrative, theoretical account of many behavioral phenomena of central concern to the psychology of learning.

REFERENCES

Blackman, D. Conditioned suppression or facilitation as a function of the behavioral baseline. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 53-61. (*a*)

Blackman, D. Response rate, reinforcement frequency, and conditioned suppression. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 503-516. (*b*)

Blough, D. S. Definition and measurement in generalization research. In D. I. Mostofsky (Ed.), *Stimulus generalization.* Stanford: Stanford University Press, 1965. Pp. 30-37.

Brady, J. V. and Hunt, H. F. An experimental approach to the analysis of emotional behavior. *Journal of Psychology,* 1955, **40,** 313-324.

Carlton, P. L. The interacting effects of deprivation and reinforcement schedule. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 379-381.

Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 253-263.

Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 327-382.

Catania, A. C., Silverman, P. J., and Stubbs, D. A. Concurrent performances: stimulus-control gradients during schedules of signalled and unsignalled concurrent reinforcement. *Journal of the Experimental Analysis of Behavior,* 1974, **21,** 99-107.

Chung, S. H. and Herrnstein, R. J. Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1967, **10,** 67-74.

Eckerman, C. *Deprivation conditions and chained schedule and multiple schedule performance.* Paper presented at the meetings of the American Psychological Association, 1968.

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

Fischer, K. and Fantino, E. The dissociation of discriminative and conditioned reinforcing functions of stimuli with changes in deprivation. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 703-710.

Gollub, L. R. and Urban, J. T. The accentuation of a rate difference during extinction. *Journal of the Experimental Analysis of Behavior,* 1958, **1,** 365-369.

Hearst, E. Resistance-to-extinction functions in the single organism. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 133-144.

Hearst, E. Stimulus intensity dynamism and auditory generalization for approach and avoidance behavior in rats. *Journal of Comparative and Physiological Psychology,* 1969, **68,** 111-117.

Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 267-272.

Herrnstein, R. J. Secondary reinforcement and rate of primary reinforcement. *Journal of the Experimental Analysis of Behavior,* 1964, **7,** 27-36.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior,* 1970, **13,** 243-266.

Hull, C. L. *Principles of behavior.* New York: Appleton-Century-Crofts, 1943.

Kelleher, R. T. and Gollub, L. R. A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior,* 1962, **5,** 543-597.

Kimble, G. A. *Hilgard and Marquis' conditioning and learning,* Second edition. New York: Appleton-Century-Crofts, 1961.

Kling, J. W. Learning: introductory survey. In J. W. Kling and L. A. Riggs (Eds.), *Experimental psychology.* New York: Holt, Rinehart, and Winston, 1971. Pp. 551-613.

Lea, S. E. G. and Morgan, M. J. The measurement of rate-dependent changes in responding. In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement: behavior analyses.* New York: Academic Press, 1972. Pp. 129-145.

Logan, F. A. *Incentive: how the conditions of reinforcement affect the performance of rats.* New Haven: Yale University Press, 1960.

Lyon, D. O. Frequency of reinforcement as a parameter of conditioned suppression. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 95-98.

Millenson, J. R. and de Villiers, P. A. Motivational properties of conditioned anxiety. In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement: behavioral analyses.* New York: Academic Press, 1972. Pp. 97-128.

Morse, W. H. Intermittent reinforcement. In W. K. Honig (Ed.) *Operant behavior: areas of research and application.* New York: Appleton-Century-Crofts, 1966. Pp. 52-108.

Neuringer, A. J. Effects of reinforcement magnitude on choice and rate of responding. *Journal of the Experimental Analysis of Behavior,* 1967, **10,** 417-424.

Nevin, J. A. Differential reinforcement and stimulus control of not responding. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 715-726.

Nevin, J. A. On the form of the relation between response rates in a multiple schedule. *Journal of the Experimental Analysis of Behavior,* 1974, (*in press*).

Nevin, J. A. Stimulus control. In J. A. Nevin (Ed.), *The study of behavior: learning, motivation, emotion, instinct.* Glenview, Ill.: Scott, Foresman, and Co., 1973. Pp. 114-152.

Nevin, J. A. and Shettleworth, S. An analysis of contrast effects in multiple schedules. *Journal of the Experimental Analysis of Behavior,* 1966, **9,** 305-315.

Rachlin, H. and Baum, W. M. Response rate as a function of amount of reinforcement for a signalled concurrent response. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 11-16.

Rachlin, H. and Baum, W. M. Effects of alternative reinforcement: does the source matter? *Journal of the Experimental Analysis of Behavior,* 1972, **18,** 231-241.

Reynolds, G. S. Some limitations on behavioral contrast and induction during successive discrimination. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 131-139.

Richards, R. W. Reinforcement delay: some effects on behavioral contrast. *Journal of the Experimental Analysis of Behavior,* 1972, **17,** 381-394.

Shettleworth, S. and Nevin, J. A. Relative rate of response and relative magnitude of reinforcement in multiple schedules. *Journal of the Experimental Analysis of Behavior,* 1965, **8,** 199-202.

Skinner, B. F. *The behavior of organisms.* New York: Appleton-Century-Crofts, 1938.

Spence, K. W. The differential response of animals to stimuli differing within a single dimension. *Psychological Review,* 1937, **44,** 430-444.

Terrace, H. S. Behavioral contrast and the peak shift: effects of extended discrimination training. *Journal of the Experimental Analysis of Behavior,* 1966, **9,** 613-617.

Wilson, M. P. Periodic reinforcement interval and number of periodic reinforcements as parameters of response strength. *Journal of Comparative and Physiological Psychology,* 1954, **47,** 51-56.

Wyckoff, L. B. Toward a quantitative theory of secondary reinforcement. *Psychological Review,* 1959, **66,** 68-78.

Receiver 11 July 1973.
(*Final Acceptance 29 November 1973.*)