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REINFORCEMENT SCHEDULES: RETROACTIVE AND PROACTIVE EFFECTS OF REINFORCERS INSERTED INTO FIXED-INTERVAL PERFORMANCES

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The responding maintained by a reinforcer depends on the relation of the reinforcer not merely to the response that produces it but also to other preceding responses. Early responses in a sequence that ends in a reinforcing consequence make smaller contributions to later response rates than more recent ones, by virtue of the longer delays that separate them from the reinforcer. This study shows that the relation between a response and a later reinforcer contributes to responding only if no other reinforcers intervene; in other words, each reinforcer blocks responses that precede it from the effects of later reinforcers. Pigeons' pecks were maintained by fixed-interval (FI) schedules of food reinforcement. When FI 60-s (short) and FI 75-s (long) schedules began simultaneously within constant 150-s cycles, long FIs did not affect short-FI performances, but short FIs eliminated the first 60 s of long-FI performances. Removing either short-FI reinforcers or short-FI stimuli showed that short-FI reinforcers and not short-FI stimuli blocked the first 60 s of the long-FI performance from the retroactive effects of the long-FI reinforcer. With FI 15-s and FI 75-s schedules, the short-FI reinforcer was followed by reduced long-FI responding, but a schedule that prevented discrimination based on time since a reinforcer eliminated this proactive effect of the short-FI reinforcer. In other words, the retroactive effects were reinforcer effects whereas the proactive effects were discriminative effects. Quantitative descriptions of variable-interval performances, in which reinforcer effects may operate in the absence of temporal discriminative effects, can be derived from these relations.

Key words: fixed-interval schedules, variable-interval rate function, reinforcer delay, inhibition by reinforcement, topographical tagging, discriminative control, matching law, key pecks, pigeons

Interval schedules of reinforcement allow a response to produce a reinforcer after a specified time has elapsed since some environmental event such as the onset of a stimulus or the delivery of a previous reinforcer. In variable-interval (VI) schedules, successive intervals vary in duration, whereas in fixed-interval (FI) schedules, they are constant. In interval schedules, temporal discriminations may be based on different reinforcement probabilities at different times within an interval. A VI schedule that maintains a constant reinforcement probability as time elapses within an interval (e.g., a random-interval schedule) prevents such discriminations from developing. To the extent that the schedule does this, the performances it maintains are behaviorally simpler than those maintained by other interval schedules. This may explain why VI schedules have been preferred to FI schedules for quantitative analyses of response–reinforcer relations.

When responding is maintained by a VI schedule of reinforcement, rate of responding is a monotonically increasing, negatively accelerated function of the rate of reinforcement provided by the schedule (Catania & Reynolds, 1968). In other words, as overall reinforcement rate increases, a given increment in reinforcement rate produces diminishing returns, in the sense that it produces smaller increments in responding. This response–reinforcer relation, sometimes called the input–output function for VI schedules, has been expressed in the following equation:

$$R = kr/(r + c) \qquad (1)$$

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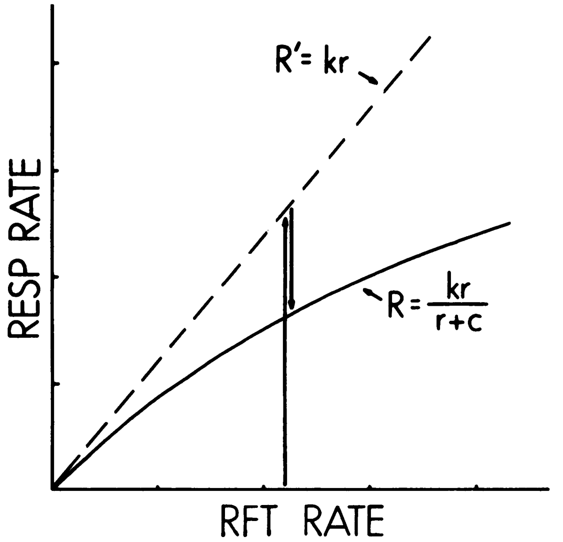


Fig. 1. The response–reinforcer input-output function as a product of a linear excitatory function ($R' = kr$) and a reciprocal inhibitory function ($I = 1/(r + c)$). RESP = response; RFT = reinforcement.

where R is rate of responding, r is rate of reinforcement, and k and c are constants; k is a dimensional constant that depends on units of measurement and c determines the degree of negative acceleration (cf. Catania, 1973; Herrnstein, 1970).

The constant c in Equation 1 has been given various interpretations. One is that it represents the effects of all other reinforcers in the situation besides those maintaining the selected response; in this interpretation the equation is a derivative of the matching law, which states that the ratio of a given response to total responses is proportional to the ratio of the reinforcers maintaining that response to total reinforcers (de Villiers & Herrnstein, 1976; Herrnstein, 1970). By this account, as the scheduled reinforcers increase in number they make up a larger proportion of the total reinforcers, and therefore R asymptotically approaches its maximum, k, as $r/(r + c)$ asymptotically approaches its maximum, 1.0.

But another interpretation of Equation 1, illustrated in Figure 1 (cf. Catania, 1973, Figure 2), treats it as the product of a linear excitatory effect of reinforcers and a reciprocal inhibitory effect (the vocabulary of excitation and inhibition is restricted here to a descriptive usage, the limitations of which have been discussed in detail in Catania, 1969, pp. 740–743; cf. Brown & Jenkins, 1967; Hearst, Besley, & Farthing, 1970). The account assumes first that each reinforcer adds a fixed increment to total responding, as given by the linear relation, $R' = kr$ (dashed line in Figure 1; cf. the reflex reserve of Skinner, 1938), and second that each added reinforcer also reduces the effectiveness of all other reinforcers, as given by the inhibitory relation, $I = 1/(r + c)$. The inhibitory effect multiplies the excitatory one, and Equation 1 is therefore derived by way of the product of the two functions: $R = R'I = kr/(r + c)$.

The inhibitory relation is consistent with findings from concurrent performances; when a reinforcer increases the rate of the response it reinforces it simultaneously reduces the rate of responses maintained by other reinforcers (Catania, 1969). This relation is easiest to see in concurrent schedules, because such schedules separate the excitatory effects produced by reinforcing one response from the inhibitory effects on other, concurrent responses. But the inhibitory effects of reinforcers with varied sources imply that the same relation holds when all reinforcers are arranged for a single response (e.g., Catania, 1973; Deluty, 1976; Rachlin & Baum, 1972).

The account that follows relates the inhibitory effects of reinforcers to another property of schedule performances. If the last response in a sequence of responses produces a reinforcer, the effect of that reinforcer depends on its relation to all of the responses in the sequence and not only on its relation to the response that produced it. But the effect is manifested only in later responding. Particular later responses therefore cannot be unambiguously attributed to particular earlier response–reinforcer relations.

Consider a pigeon in a standard experimental chamber in which pecks on a key may produce a reinforcer. The pigeon pecks twice and its second peck produces the reinforcer. Several additional pecks then follow. These subsequent pecks depend on the reinforcer, but which ones are to be attributed to its relation to the second peck (which produced it) and which to its relation, albeit after a delay, to the first peck?

The contribution to subsequent responding of each peck that precedes a reinforcer can be assessed by the method of topographical tagging (Catania, 1971). This procedure uses response location to identify the sources of responding. In the above case, for example, requiring the first of the two pecks to occur on a different key may shift some proportion of subsequent pecks to that other key without altering the total output of responses. The procedure has shown that, when a response sequence ends in a reinforcer, subsequent responding is determined by the relation of all responses in the sequence to the reinforcer; furthermore, the contribution of each response, according to a delay-of-reinforcement gradient, depends on the time that separates it from the reinforcer (Catania, 1971; Catania & Keller, 1981; Dews, 1962).

One way in which one reinforcer may reduce the effect of another reinforcer is by blocking it from its relation to earlier responding, as illustrated in Figure 2. In A, a reinforcer occurs at the end of a time interval; each of the responses leading up to that reinforcer contributes to future responding in proportion to the delay gradient shown during the preceding time interval. In B, a second reinforcer occurs in the middle of the time interval; the responses leading up to it similarly contribute to future responding. In C, both reinforcers occur within the same time interval; both contribute to future responding according to their separate gradients, but the earlier reinforcer reduces the effect of the later one by truncating its gradient. The total responding generated in C therefore is not given by summing A and B; the contribution from the later reinforcer shown by the shaded area must be subtracted. In other words, the area of C is smaller than that of A plus that of B; the shaded area shows the magnitude of the difference.

Without the truncation, each reinforcer would make a fixed contribution to responding, implying a linear relation between response rates and reinforcement rates. The truncation is one way in which added reinforcers may modify that linear relation. The experiments that follow are concerned with demonstrating such an effect of added reinforcers within FI schedules and with showing how some quantitative properties of VI performances may be derived from it. (The experiments are presented in the order in which they were conducted, but they did not necessarily follow each other consecutively; they were typically separated by pilot studies or by the exploration of other research lines that turned out not to be productive.)

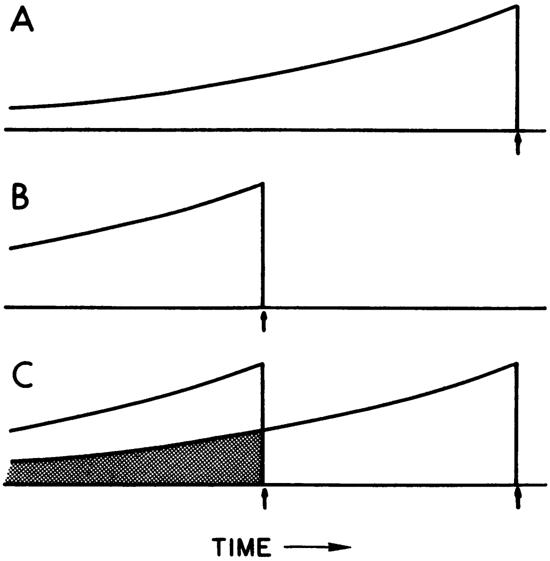


Fig. 2. Hypothetical truncation of delay gradients. A shows the effect of a reinforcer late in an interval and B of one midway through the interval; when the two are combined in a single interval, as in C, the early reinforcer cuts off the tail of the gradient maintained by the later reinforcer (shaded area).

EXPERIMENT 1: THE BLOCKING BY ONE REINFORCER OF THE EFFECT ON RESPONDING OF A LATER REINFORCER

With pigeons and many other nonhuman organisms given some history of FI responding, the rate of the reinforced response typically increases as time passes within the interval. The different response rates maintained at different times can be attributed to temporal discrimination with respect to the time since the start of the interval; the temporal discrimination is established because responses at different times in the interval are separated by different delays from the reinforcer at the end of the interval (see Dews, 1962).

The demonstration of a phenomenon comparable to that illustrated in Figure 2 requires an experimental preparation that establishes consistent temporal relations among several events: responses at particular times within an interval, the reinforcer at the end of the interval, and any additional reinforcer interpolated between them. The FI schedule provides such a preparation (cf. Eckerman & McGourty, 1969; Farmer & Schoenfeld, 1966a, 1966b).

The strategy of Experiment 1 was to examine what happened to the early responding within intervals of an FI schedule when an additional reinforcer was inserted between that responding and the reinforcer at the end of the interval. This was accomplished by adding a second shorter FI schedule to the original FI schedule. When the two schedules operated together, they always began simultaneously, so that the reinforcer arranged by the shorter schedule occurred at a consistent time within the intervals of the longer one. The performances maintained with the two FI schedules operating together were compared with those when each operated alone. A further comparison was that between the two FI schedules operating for a single response and the two schedules operating respectively for two spatially separated responses.

METHOD

Subjects

Three adult male Silver King pigeons, numbered 25, 26, and 30, were maintained at about 80% of their free-feeding weights. They were housed in individual cages with free access to water and grit in a temperature-controlled room with a 12-hr-on 12-hr-off light-dark cycle. Each had histories in autoshaping procedures, classroom demonstrations of shaping and of discrimination learning, and several weeks of preliminary training to an informal criterion of stability based on visual inspection of cumulative records on the FI schedules of Experiment 1.

Apparatus

Sessions were conducted in a three-key pigeon chamber in which the center key was dark and inoperative at all times. The left and right Gerbrands pigeon keys were mounted 15.0 cm apart, center to center, about 23 cm above the floor. The two keys were matched to operate at a minimum force of about 0.14 N. Each could be lit from behind by an Industrial Electronics Engineers® in-line projector. The stimuli projected on the keys consisted of a red field, of three vertical white lines (0.24 cm wide and spaced 0.24 cm apart), or of the red field with the lines superimposed. When a key was lit, each effective peck produced a click from a relay mounted behind the panel.

A standard Gerbrands pigeon feeder was centered below the keys. During food deliveries, the feeder was lit and keylights were turned off; a houselight at the upper right on the panel remained on. The houselight provided general illumination throughout each session. Events were scheduled and recorded by electromechanical equipment located in an adjoining room.

Procedure

Experiment 1 involved FI 60-s (short FI) and FI 75-s (long FI) schedules. While the short FI operated on a key, the key was lit red; while the long FI operated, the key was lit with vertical lines. Each FI was arranged with a 15-s limited hold (this contingency rarely made contact with behavior, and did so primarily during the preliminary FI sessions preceding Experiment 1).

The schedules operated within a constant 150-s schedule cycle; in other words, the onsets of successive intervals were always separated by 150 s. Intervals were scheduled from the beginning of a cycle, when the appropriate stimuli appeared on the keys; after reinforcers, the houselight remained lit through the end of the cycle. The reinforcer consisted of mixed grain presented in 4-s operations of the feeder.

Experimental conditions included the short or the long FI schedule operating alone and the two schedules operating simultaneously either on the same or on different keys. The conditions are shown schematically in Figure 3, each in the context of the 150-s schedule cycle. With the short FI alone (A), the key was lit red until delivery of the reinforcer (arrow) and was dark for the rest of the cycle. With the long FI alone (B), the key was lit with lines until delivery of the reinforcer and was dark for the rest of the cycle. With both FI schedules on a single key (C), the cycle began with red and lines superimposed on the key; after the short-FI reinforcer (first arrow), red was terminated but the lines remained until delivery of the long-FI reinforcer (second arrow), and the key then became dark. With the two FI schedules operating on two keys (D), the stimuli were presented on the respective keys until the respective FI schedules had ended.

Arrangements C and D might be described in the vocabulary of conjoint and concurrent schedules, but that vocabulary is ambiguous about correlated stimuli; thus, the schedules will be referred to as single short FI (A) or

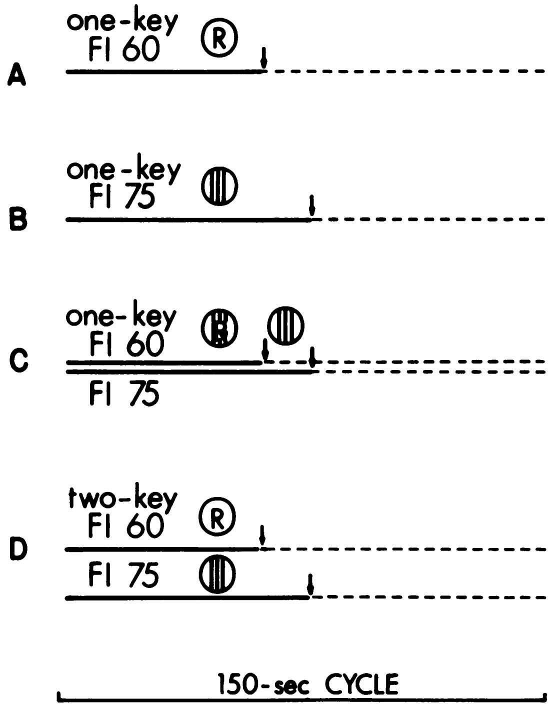


Fig. 3. Schematic diagrams of procedure: All schedules operated within repeating 150-s cycles during which the houselight was always on. In A, a single FI 60-s schedule operates in the presence of a red keylight. In B, a single FI 75-s schedule operates in the presence of vertical lines. In C, the two schedules operate together on a single key. In D, they operate together on two separate keys.

long FI (B) schedules, or as combined one-key (C) or two-key (D) schedules.

Depending on whether single or combined schedules were arranged, each cycle included either one (A and B) or two (C and D) reinforcers. The 4-s reinforcers affected neither the 150-s cycle timer nor, when two schedules operated simultaneously, the timing of an interval that had not yet ended; they were excluded, however, from all calculations of response rate.

The succession of conditions counterbalanced the two possible left and right arrangements of the four schedule combinations of Figure 3, as summarized in Table 1: The short FI alone, the long FI alone, and the two FIs together on a single key were scheduled both on the left and on the right, and the FIs on two keys were scheduled with the long FI both on the left and on the right. Daily sessions for each pigeon consisted of thirty 150-s cycles; each condition lasted for seven consecutive daily sessions.

Table 1

Sequence of fixed-interval (FI) schedules in Experiment 1.

Left key	Right key
FI 60 s (red)	—
—	FI 60 s (red)
—	FI 75 s (lines)
FI 75 s (lines)	—
FI 75 s (lines)	FI 60 s (red)
FI 60 s (red)	FI 75 s (lines)
FI 60 s (red) FI 75 s (lines)	—
—	FI 60 s (red) FI 75 s (lines)
FI 60 s (red)	FI 75 s (lines)
FI 75 s (lines)	FI 60 s (red)
FI 75 s (lines)	—
—	FI 75 s (lines)
—	FI 60 s (red)
FI 60 s (red)	—

RESULTS

For each pigeon the data for each condition are summarized in Figure 4. In each graph, response rates, shown for successive 15-s segments of each schedule, are arithmetic means across the last three sessions of each condition with that schedule. For example, data for FI 60-s alone are based on four presentations of the schedule (first two and last two conditions in Table 1). Thus, most points are based on 12 sessions (three sessions at the end of each of four conditions); points for the long FI and short FI on a single key are based on only six sessions (three sessions at the end of each of two conditions).

Data from the short-FI schedule, FI 60 s, are shown in the left column; with both schedules on one key (filled triangles), the dashed line extends the data to the last 15 s of the long-FI schedule. Response rates increased as time passed within the interval, but these rates were not systematically affected by whether the short FI operated alone (unfilled circles) or together with the long FI either on a different key (filled circles) or on the same key (filled triangles). In other words, the performance maintained by the short-FI reinforcer appeared to be unaffected by the later availability of a long-FI reinforcer.

Data from the long-FI schedule, FI 75 s, are shown in the middle column. When the schedule operated alone, response rates increased as time passed within the interval (unfilled circles). In this case, however, the other

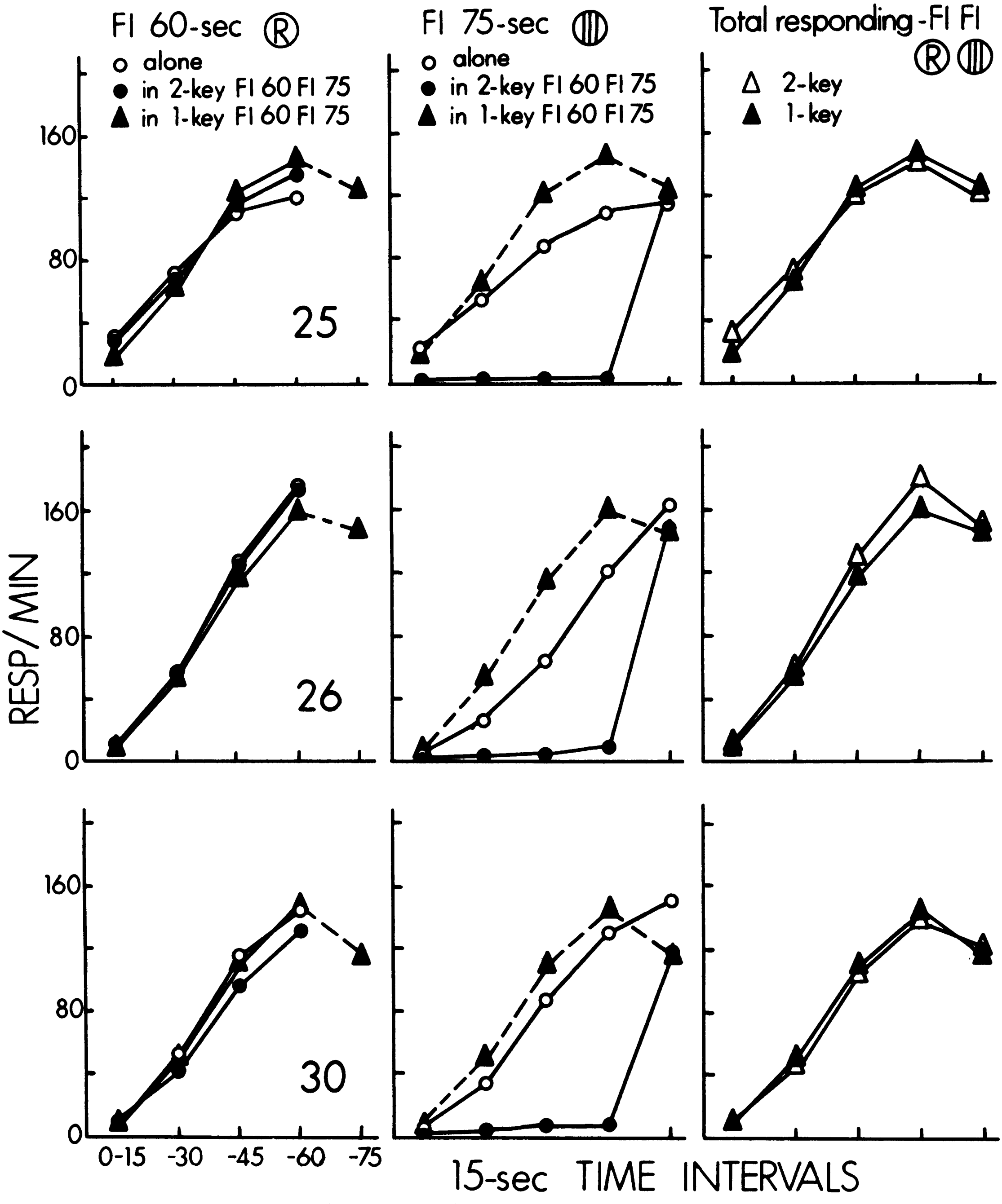


Fig. 4. The effects of FI 60-s and FI 75-s schedules. The rows present data from each of 3 pigeons (arithmetic means across the last three sessions of the procedures shown in Table 1). The left column shows data from FI 60-s, the middle column shows data from FI 75-s, and the right column shows data summed across the FI 60-s and FI 75-s schedules. Details in text.

FI made a difference. With the short FI operating on the other key, rates became low during the first 60 s of the long FI (filled circles). With the short FI operating on the same key, rates in general were higher than those with the long FI operating alone; the difference, though small for Pigeon 30, was consistent across the 3 birds (filled triangles). The data with both schedules on a single key are necessarily the same in the left and middle columns and are shown for FI 75-s with dashed lines to leave open the question of whether those rates should be attributed to the long FI or to the short one.

For Pigeons 26 and 30, rates during the last 15 s of the long FI were higher when the schedule operated alone than when it operated together with the short FI. Latencies to the first peck after the short-FI reinforcer were not collected during Experiment 1, but data collected from comparable procedures with these pigeons during later sessions indicated that such rate differences can be attributed at least in part to the pause after the short-FI reinforcer. Response rates calculated with such latencies subtracted from the time base typically approximated more closely those obtained when the long-FI schedule operated alone (but see Experiment 3 for an examination of the proactive effects of a short-FI reinforcer on long-FI performance).

The right column of Figure 4 shows the total response rates maintained by the two FI schedules together. The two-key data (unfilled triangles) show sums from the left and middle columns for the two separate keys (filled circles). The one-key data (filled triangles) are the same as those in the other two columns. The two data sets are similar, implying that the one-key performance simply combined in a single location the performances maintained in separate locations when the schedules operated on two keys, without systematically altering the response output maintained by the two reinforcers.

Summations of the two single-key performances (unfilled circles from left and middle columns), not plotted, would not have superimposed themselves on the other data. In fact, the coordinates of Figure 4 would not have accommodated such summed rates. For example, during the fourth 15-s period of the short FI alone and the same period within the long FI alone, Pigeon 25 pecked at respective rates of about 120 and 110 responses per minute; the sum, 230 responses per minute, considerably exceeds the rate of about 140 responses per minute maintained at this time when the two schedules operated together and could not be plotted without extending the y-axis. In general, the response rates maintained when the two FI schedules operated together were substantially lower than the sums of their rates when they operated separately.

Variability

The data in Figure 4 were averaged across the conditions of Table 1. Various statistical analyses throughout the course of the present experiments suggested that fluctuations in overall rates of responding contributed more to the total variance than did changes in the form of the functions relating response rates to time within an interval. The analyses, however, were applied only to limited sets of data, and assumptions about independence of measures and underlying variance distributions probably were not met. Thus, Figures 5 and 6 are provided instead, to make the point graphically with data obtained from sessions of the FI 75-s schedule operating alone.

Figures 5 and 6 show arithmetic means from the last three of seven sessions of FI 75 s on either the left or the right key in 12 conditions: four arranged during Experiment 1, four during Experiment 2, and four following these two experiments. The six left-key conditions are shown in the left column and the six right-key conditions in the right column for each bird. Figure 5 presents absolute rates of responding (responses per minute) and demonstrates that roughly equivalent response rates were maintained by FI 75 s on the left key and on the right key. Figure 6 presents the same data transformed into rates relative to the mean rate over the last three sessions of each condition. With some exceptions (especially the fourth left-key condition for Pigeon 25 and the first left-key condition for Pigeon 30), the variability evident in Figure 5 is substantially reduced by the transformation to relative rates.

DISCUSSION

One interpretation of the data in Figure 4 is that the short FI virtually eliminated the first 60 s of the long-FI performance without itself being affected by the long FI. Essentially the same short-FI performance was maintained when this schedule operated alone as when the long FI operated on a second key. In the latter circumstance, furthermore, the long FI maintained low response rates during its first 60 s. Thus, given the similarity of the total response rates maintained by the one-key and two-key procedures (right column, Figure

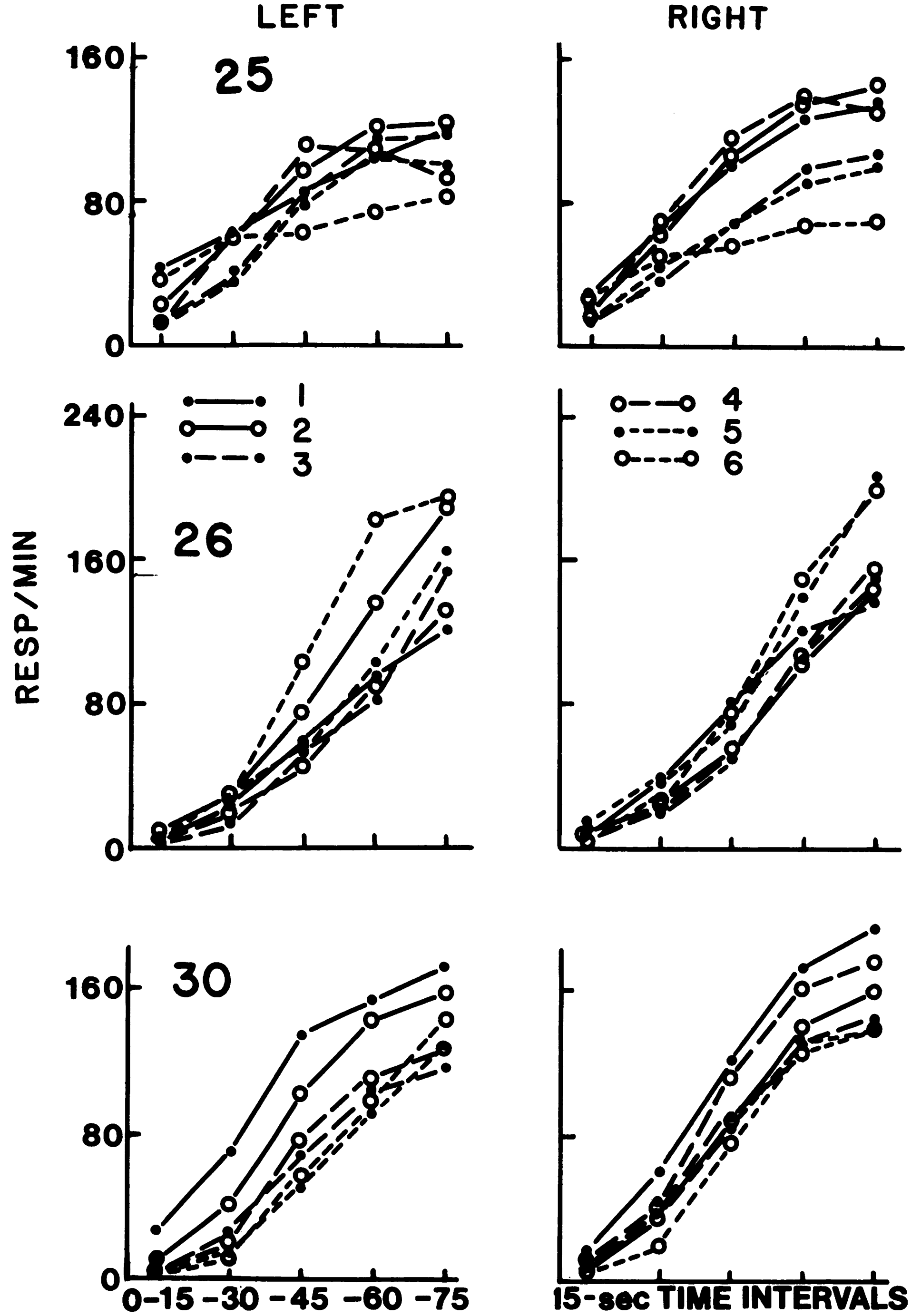


Fig. 5. Absolute response rates over the last three sessions of six determinations of FI 75-s performance on left and right keys for each pigeon.

4), the performance maintained with both schedules operating on a single key can be regarded as the simple combination on one key of the separate two-key performances. If this view is correct, responding during the first 60 s of the single-key performance must have depended mainly on the short-FI reinforcer, as it did when the performances were separated

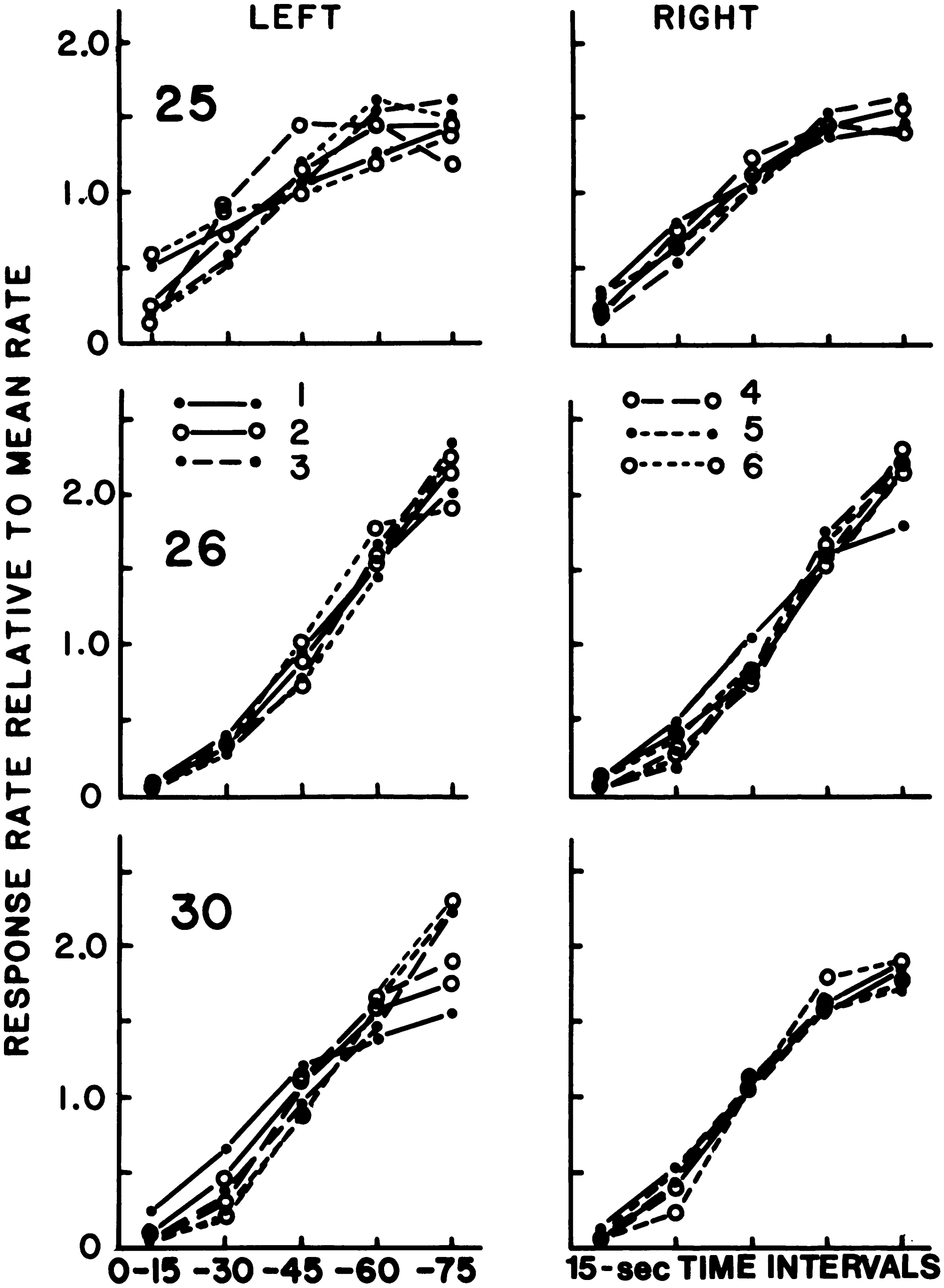


Fig. 6. Response rates relative to overall mean rates in successive determinations of FI 75-s performance on left and right keys for each pigeon.

on two keys. Thus, very little of it can be attributed to the long-FI reinforcer.

By this interpretation, the one-key and two-key FI FI performances are both consistent with a single truncating effect of the short-FI reinforcer. But what are the alternatives? Perhaps the short-FI reinforcer had different effects on long-FI performance in the two procedures. If so, the first 60 s of responding in the one-key procedure must have included responses that depended on long-FI as well as short-FI reinforcers. But then short-FI responding must have been reduced in the one-key FI FI procedure relative to that maintained in the other procedures. Otherwise, the short-FI response rates in the one-key proce-

Table 2

Sequence of schedules in Experiment 2.

Left key	Right key
—	FI 75 s (lines)
FI 75 s (lines)	—
FI 60 s FI 75 s (lines)	—
FI 75 s (lines)	FI 60 s (lines)
—	FI 60 s FI 75 s (lines)
FI 60 s (lines)	FI 75 s (lines)
—	FI 75 s (lines)
FI 75 s (lines)	—
***************	***************
FI 60 s (red) FI 75 s (lines)	—
—	FI 60 s (red) FI 75 s (lines)
—	EXT 60 s (red) FI 75 s (lines)
EXT 60 s (red) FI 75 s (lines)	—
EXT 60 s (red)	FI 75 s (lines)
FI 75 s (lines)	EXT 60 s (red)
—	EXT 60 s (red) FI 75 s (lines)
FI 75 s (lines)	EXT 60 s (red)
EXT 60 s (red) FI 75 s (lines)	—
EXT 60 s (red)	FI 75 s (lines)

dure (left column, Figure 4) would have exceeded those in the other procedures, because they would have included the additional responses maintained by the long-FI reinforcers.

At this point, trade-offs between long-FI and short-FI responses that might occur in one-key but not in two-key FI FI procedures could be assumed. Even without such additional assumptions, however, the account is already less parsimonious than one in terms of a truncating effect of short-FI reinforcers. Any account in terms other than those of such a truncation faces a dilemma. It must postulate different processes operating in the two procedures while simultaneously accounting for the invariant short-FI and total output functions produced by them (left and right columns of Figure 4). It weakens the account to assume that different processes might generate such invariances merely by coincidence.

The truncating effect is merely what is illustrated by the low rates during the first 60 s of the long FI in the two-key procedure (filled circles in the middle column of Figure 4). As a behavioral phenomenon, it calls for further analysis. In particular, it is necessary to distinguish experimentally between hypothetical retroactive blocking effects such as those implied by Figure 2 and possible discriminative stimulus functions of the red key and of short-FI reinforcers.

EXPERIMENT 2: DISTINGUISHING A DISCRIMINATIVE STIMULUS EFFECT FROM A RETROACTIVE BLOCKING EFFECT

Adding the short-FI schedule to the long-FI schedule not only inserted a reinforcer between the early responses of the long FI and the later long-FI reinforcer but it also introduced stimuli that may have had discriminative functions. These included both the red key correlated with the short FI and the short-FI reinforcer itself. For example, the long-FI reinforcer was never available while a red key was lit; thus, low long-FI response rates might have been expected in the presence of a red key. Similarly, within a cycle the long-FI reinforcer never preceded the short-FI reinforcer; thus, low long-FI rates might have been expected at times when the short-FI reinforcer had not yet occurred.

Experiment 2 examined some of the effects of these stimuli by systematically replicating Experiment 1, first with the short-FI reinforcer but without the red key and then with the red key but without the short-FI reinforcer.

METHOD

The same birds were studied, and the details of procedure were as in Experiment 1, with exceptions that follow. The experiment consisted of two sequences of conditions. In the first, lines identical to those of the long FI were substituted for red as the short-FI stimulus. The combined schedules, both now correlated with lines, operated either on one or on two keys. These conditions were preceded and followed by FI 75 s operating alone.

In the second sequence, a 60-s extinction schedule (EXT 60 s) was substituted for the FI 60-s schedule that had been correlated with the red key. When the EXT 60-s schedule was in effect, red was presented on the relevant key at the beginning of each cycle and was removed independently of behavior and without the delivery of a reinforcer 60 s later. This sequence examined the four possible combinations of the long FI with the EXT schedule (one key or two key and FI left or FI right).

Successive conditions, each maintained for seven consecutive daily sessions, are summarized in Table 2; asterisks separate the two sequences. Thirty-five sessions of other FI pro-

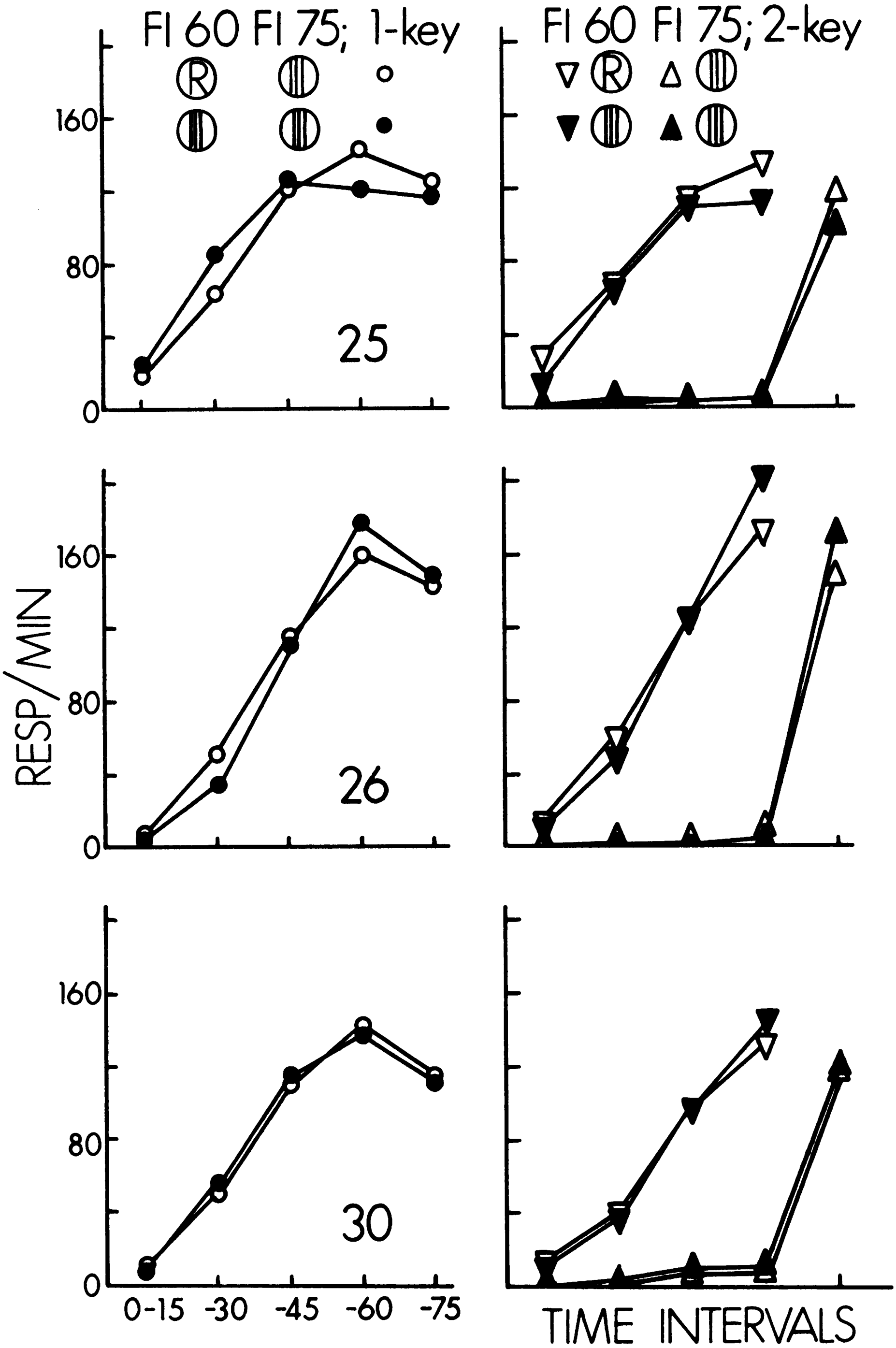
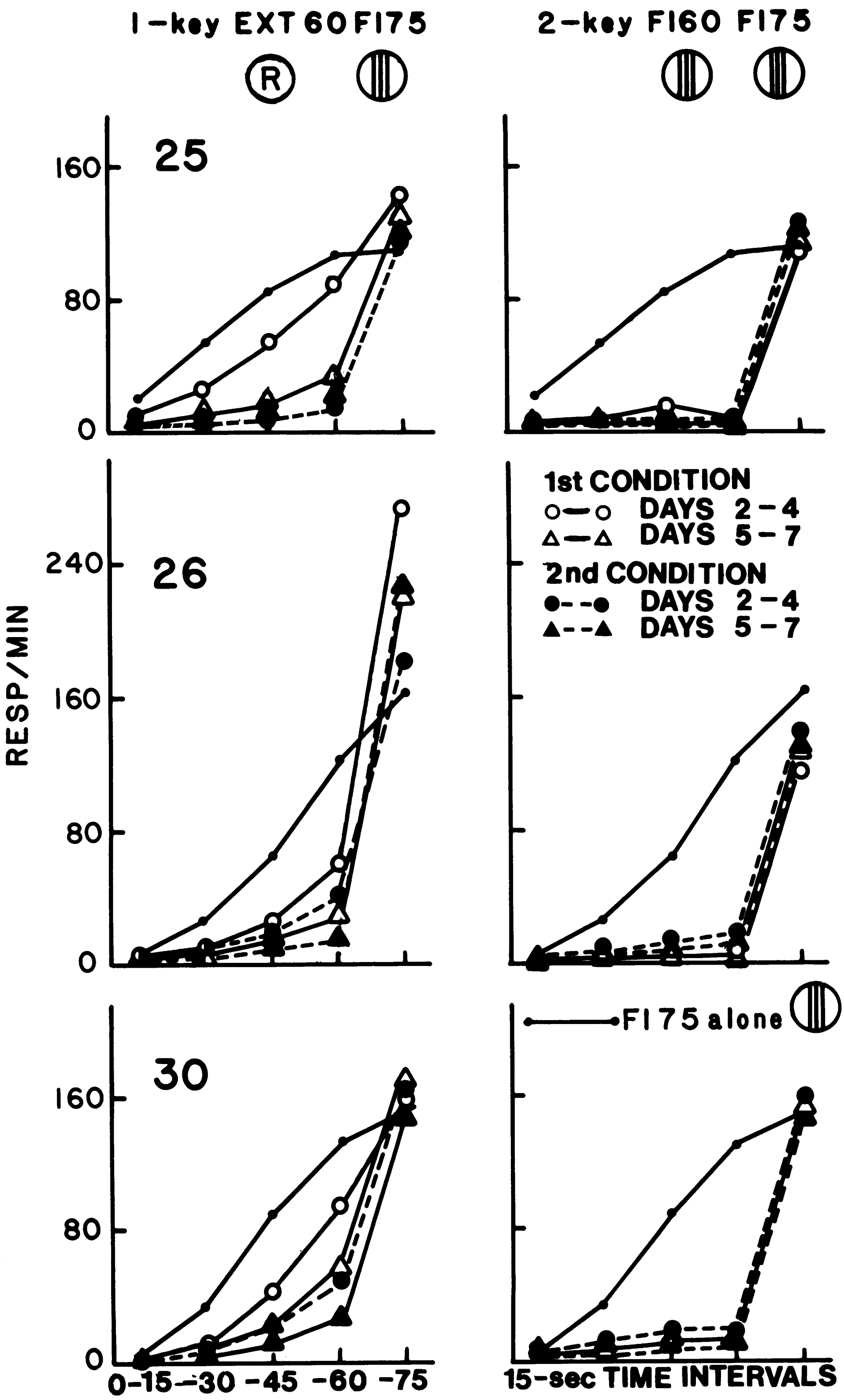


Fig. 7. Removing the discriminative stimulus (first sequence of procedures, Table 2). Data, in the left column for the one-key procedure and in the right column for the two-key procedure, are shown as filled symbols. The comparable data from Experiment 1 are shown as unfilled symbols.


1-key EXT 60 FI 75
R
2-key FI 60 FI 75
25
26
30
RESP/MIN
0
80
160
240
1st CONDITION
○—○ DAYS 2-4
△—△ DAYS 5-7
2nd CONDITION
●--● DAYS 2-4
▲--▲ DAYS 5-7
•——• FI 75 alone
0-15 -30 -45 -60 -75
15-sec TIME INTERVALS

cedures intervened between those of Table 1 and those of Table 2, and 90 sessions of other procedures intervened between the first and second sequences of Table 2. The first 14 of the latter sessions included an unsystematic exploration of the effects of an EXT 60-s schedule on a red key. For this reason, and because lines had just been correlated with both FI 60-s and FI 75-s schedules, the subsequent sessions involved various combinations of FI 60 s (red) and FI 75 s (lines) and were arranged primarily to ensure that discriminative control by both stimuli was comparable to that during Experiment 1.

RESULTS

Data from the first sequence, which substituted lines for the red stimulus of the short-FI schedule, are presented in Figure 7. Eliminating red as a stimulus distinguishing the short from the long FI had no systematic effects in either the one-key procedure (left column) or the two-key procedure (right column). The largest differences between performances with and without the red stimulus were for Pigeons 25 and 26 in the second and fourth 15-s periods with both schedules on one key and in the last 15-s period with the short-FI schedule on one of two keys; these differences were in opposite directions for the 2 birds. The short-FI reinforcer alone, in the absence of a correlated red stimulus, was sufficient to produce the truncating effects of Figure 4.

The effects of eliminating the reinforcer at the end of the short-FI schedule were more complex. The left column of Figure 8 shows data from the one-key procedure. Response rates decreased in the presence of the red EXT 60-s stimulus, but they did so more slowly and less completely than in preceding conditions with an FI 60-s schedule. The figure compares the effect of the red EXT stimulus superimposed on the long-FI schedule on one key (left column) with that of the short-FI schedule operating on a different key and without a red stimulus (right column). Comparison with both FI schedules on a single key would have been inappropriate, because that schedule combination did not produce directly observed decreases in early long-FI responding; the decreases were inferred indirectly from other data.

Both schedule combinations in Figure 8 were arranged twice, shown as first and second conditions. In each case, the data have been averaged across the two symmetrical left and right procedures and, excluding the first session of each condition, across two three-session blocks (Sessions 2 to 4 and 5 to 7) from each condition.

The left column shows that the red EXT stimulus only gradually acquired its control over the first 60 s of the long-FI performance. Even after 28 sessions (14 sessions per key), responding had not reached rates as low as those obtained during the corresponding period in the two-key procedure. The right column shows that even without the correlated red stimulus, the insertion on a second key of the short-FI reinforcer rapidly truncated responding on the long-FI schedule during the first 60 s. The effect across Sessions 2 to 4 of the first condition was of about the same magnitude as that across Sessions 5 to 7 of the second condition (essentially identical results were obtained when the short-FI schedule was correlated with red instead of with lines; cf. the middle column of Figure 4, filled circles).

Rates maintained by the long FI when the red EXT stimulus was presented on a second key are shown in Figure 9. Response rates on the red key (not shown) were negligible. This procedure was arranged twice (early and late in Figure 9: cf. Table 2). Except perhaps for Pigeon 30, there was no evidence that the red EXT stimulus on the second key exerted discriminative control over long-FI performance during the sessions of these conditions. Even if the lower rates in the later sessions for Pigeon 30 (filled circles) are interpreted as evidence for discriminative control by the red stimulus, the effect is not comparable in magnitude to the truncation demonstrated in Experiment 1. It also should be noted that each

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Fig. 8. Response rates during successive 15-s segments of FI 75 s, showing the effects of removing the FI 60-s reinforcer in the one-key procedure, and of removing the red discriminative stimulus in the two-key procedure. The data in the left column show the gradual acquisition of the discriminative effects of the red EXT 60-s stimulus over days and conditions. In contrast, the right column shows the rapid effects, without the red stimulus, of adding the FI 60-s reinforcer contingent on responses on a second key (cf. FI 75 s, right column, Figure 7). Data from conditions of Experiment 2 in which the conventional FI 75-s schedule operated alone are shown in both columns to facilitate the comparison.

pigeon entered these procedures having earlier had a brief history with a red EXT 60-s stimulus (see Method section); thus, Figures 8 and 9 underestimate the difference between the effects of the FI 60-s and of the EXT 60-s schedules.

DISCUSSION

Substituting the long-FI stimulus (lines) for the short-FI stimulus (red) did not alter the effects of the short-FI reinforcer on the long-FI performance. But removing the short-FI reinforcer did alter the effects of the short-FI stimulus (red). One possible conclusion is that the effects of Experiment 1 depended on the short-FI reinforcer rather than on the short-FI stimulus; changing the former made a difference whereas changing the latter did not. This account seems the most parsimonious, but again it is necessary to consider the alternatives.

It is reasonable to assume that the stimuli within each procedure had various discriminative functions. In the two-key procedure, for example, they probably determined both response rates at different times within an interval and the key that was pecked. It is also reasonable to assume that these discriminative functions varied from one procedure to another. When red was correlated with EXT in the two-key procedure, for example, the pigeons presumably looked at that key less often than when reinforcers had been scheduled for pecks on it, thereby reducing the likelihood that the stimulus would exert discriminative control over pecks on the other key. On such grounds, it could be argued that different phenomena entered into the data produced by Experiments 1 and 2.

An account in such terms, however, must face the difficulty of dealing with the invariances in data across procedures while postulating different processes that generated them. For example, consider the argument that red and lines determined which key was pecked in the original two-key procedure. When lines were substituted for red (Figure 7, right column), performance was essentially unaffected. But then which key was pecked no longer could have been determined by the key stimuli, be-

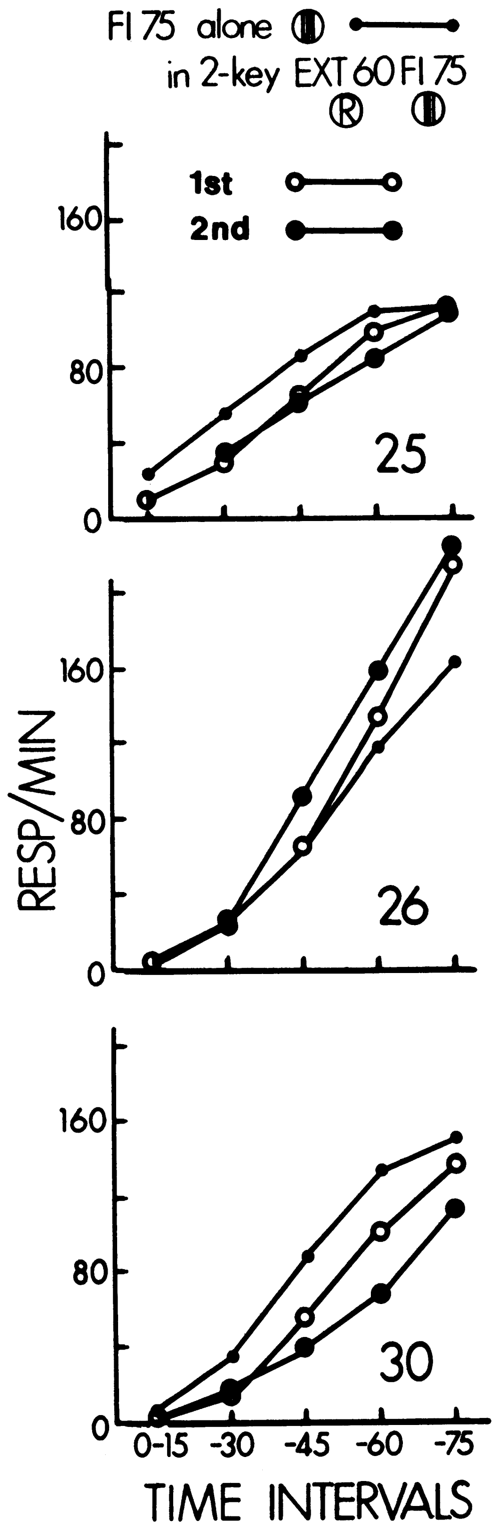

Fig. 9. Effects on FI 75-s responding of removing the FI 60-s reinforcer on a second key. Responding on the red EXT key (not shown) was negligible. The FI 75-s data from Experiment 2 (conventional schedule, operating alone) are shown to provide a reference level (cf. Figure 8).

cause each cycle began with the same stimulus (lines) appearing on both keys. Thus, the key that was pecked must have been determined in some other way by the allocation of the long-FI and short-FI schedules to the two keys. It is evident that within a small number of sessions the location of the short FI schedule was sufficient to determine the location of pecking even without a correlated visual stimulus.

Consider then the argument that looking at red on a second key was maintained when red was correlated with a short FI schedule but not when it was correlated with EXT. It might follow that red would have exerted discriminative control in the former case but not in the latter. Furthermore, the similar data obtained with lines substituted for red (Figure 7, right column) are easily accommodated by noting that another key lit, whether with lines or with red, could plausibly have functioned as a discriminative stimulus controlling response rates on the first key.

Yet even when red and lines were arranged on a single key, thereby eliminating the role of looking elsewhere, the acquisition of discriminative control was slow (Figure 8, left column) and thus not comparable to that in the analogous procedures in Experiment 1. Thus, it is now necessary to deal with why discriminative control developed rapidly in some contexts but not in others. It is perhaps reasonable to suppose that a correlated reinforcer (in this case, the short-FI reinforcer) might facilitate the development of stimulus control. But the invariances in the data must still be preserved, so this elaboration will again add to the complexity of the account.

It is possible at this point to argue that discriminative control by the stimuli on the short-FI key did determine the truncation of the long-FI performance in the two-key procedures simply by moving responding away from the long-FI key during the first 60 s of that schedule. A similar effect could not have been expected from the EXT 60-s schedule. But the invariance of the short-FI performances still remains (Figure 4, left column), leaving the inferred truncation in the one-key procedure to be accounted for in a different way. Again, the choice is to assume either that the long-FI reinforcer contributed to the first 60 s of responding in the one-key but not in the two-key procedure or that the short-FI reinforcer truncated that responding. If the former assumption is chosen, a stronger case for the short-FI invariance than an appeal to coincidence must be provided. If the latter, the one-key data may then stand as a proper demonstration of the phenomenon at issue even though the two-key data are rejected.

Perhaps the simplest conclusion, however, is that although discriminative control did vary across procedures it did not interact with the variables that determined the total response output at different times within intervals. This is all that is needed to remain consistent with the argument that the effects of Experiment 1 depended on the short-FI reinforcer rather than on the short-FI stimulus.

EXPERIMENT 3: THE PROACTIVE EFFECT OF ONE REINFORCER ON THE RESPONDING MAINTAINED BY ANOTHER

By truncating the first 60 s of the long-FI performance, the short-FI reinforcer acted retroactively, in that it affected responding that occurred ahead of its position in the interval. More precisely, this reinforcer, occurring at a given time within some intervals, affected responding at earlier times within comparable intervals that came later. This is the only sense in which the vocabulary of retroaction can be applied to behavioral phenomena, because an event cannot affect behavior that has already occurred. It is also inappropriate to speak of such inhibitory phenomena in terms of effects on memory. For example, Killeen and Smith (1984) discuss phenomena analogous to those of the present experiments in terms of "the erasure of memory by reinforcement" (cf. Jans & Catania, 1980). Temporally differentiated responding in one interval, however, demonstrates that the events of earlier intervals have been remembered.

If there also were proactive effects of the short-FI reinforcer, they were not easily seen, because this reinforcer occurred relatively late within the intervals of the long-FI schedule. In Experiment 3, therefore, an FI 15-s schedule replaced the FI 60-s schedule of the prior experiments. With this arrangement, retroactive effects of the short-FI reinforcer were confined to the first 15 s of the long-FI schedule, but proactive effects could operate over the remaining 60 s of that schedule.

First, the performances maintained by FI

Table 3

Sequence of schedules in Experiment 3.

Left key	Right key	Sessions
FI 75 s (lines)	—	7
—	FI 75 s (lines)	17
—	FI 15 s (red)	13
FI 15 s (red)	—	7
FI 15 s (red)	FI 75 s (lines)	12
FI 75 s (lines)	FI 15 s (red)	7
—	FI 15 s (red) FI 75 s (lines)	7
FI 15 s (red) FI 75 s (lines)	—	7
FI 75 s (lines)	—	7
—	FI 75 s (lines)	8
—	FI 15 s (red)	7
FI 15 s (red)	—	8
**********	**********	
FI 15 s (lines)	—	7
FI 15 s (lines) FI 75 s (lines)	—	7
FI 15 s (lines)	FI 75 s (lines)	12
—	FI 15 s (lines) FI 75 s (lines)	7
FI 75 s (lines)	FI 15 s (lines)	7
—	FI 15 s (lines)	7
FI 15 s (lines)	—	7
**********	**********	
FI 75 s (lines)	—	7
—	FI 75 s (lines)	8
—	EXT 15 s (red) FI 75 s (lines)	14
EXT 15 s (red) FI 75 s (lines)	—	12
FI 75 s (lines)	EXT 15 s (red)	10
EXT 15 s (red)	FI 75 s (lines)	10
EXT 15 s (red) FI 75 s (lines)	—	16
—	EXT 15 s (red) FI 75 s (lines)	8

15-s and FI 75-s schedules operating either alone or together were examined with procedures analogous to those of Experiment 1; then the respective contributions of the short-FI stimulus and the short-FI reinforcer to those performances were examined with procedures analogous to those of Experiment 2.

METHOD

The experimental conditions summarized in Table 3 were preceded by 191 sessions of other FI procedures that followed Experiment 2. These included sessions with FI 30 s as the red-key short-FI schedule. Less than halfway through those sessions, Pigeon 25 became ill and died, and Pigeon 32, with an experimental history of FI schedules, was substituted. The short interval was later changed from 60 to 15 s. After some history with FI 75 s (lines) and FI 15 s (red), Experiment 3 followed, with other details as in Experiments 1 and 2.

Three sequences of sessions followed each other without interruption. In the first sequence, the short-FI and long-FI schedules were arranged either alone or together on one or on two keys, as in Experiment 1. In the second and the third sequences, lines were first substituted for red as the short-FI stimulus and then a 15-s period of extinction (EXT 15 s) correlated with red was substituted for the FI 15-s schedule, as in Experiment 2. The sequences are separated by asterisks in Table 3.

Some conditions were maintained for more than seven consecutive sessions, in most cases because the laboratory personnel responsible for changing experimental conditions were temporarily unavailable. The second FI 75-s condition of the first sequence was extended after an apparatus failure, and additional sessions were also arranged for the first FI 15-s condition. In the last sequence of conditions, extra sessions were included to allow additional time for stimulus control to develop when control was not evident within seven sessions.

RESULTS

The data from the experimental sequences of Experiment 3 are shown separately for each pigeon in Figure 10 (note the different y axis scale for Pigeon 32). Each point represents an arithmetic mean averaged across the last three sessions of each arrangement of a condition, including symmetrical left and right configurations (the figure would have looked essentially the same if data from the last three of only seven sessions had been plotted). The left column presents data obtained with the long-FI and the short-FI schedules arranged either alone or together on either one or two keys. The middle column presents data obtained with lines substituted for red, the short-FI stimulus. The right column presents data obtained when EXT 15 s was substituted for FI 15 s as the schedule correlated with red.

As shown in the left column, introducing the short-FI schedule on either the same or a different key reduced subsequent responding maintained by the long-FI schedule relative to the rates it maintained when operating alone (unfilled circles). As in Experiment 1, response rates maintained by the short-FI schedule operating alone (filled circle) did not differ systematically from those when it operated to-

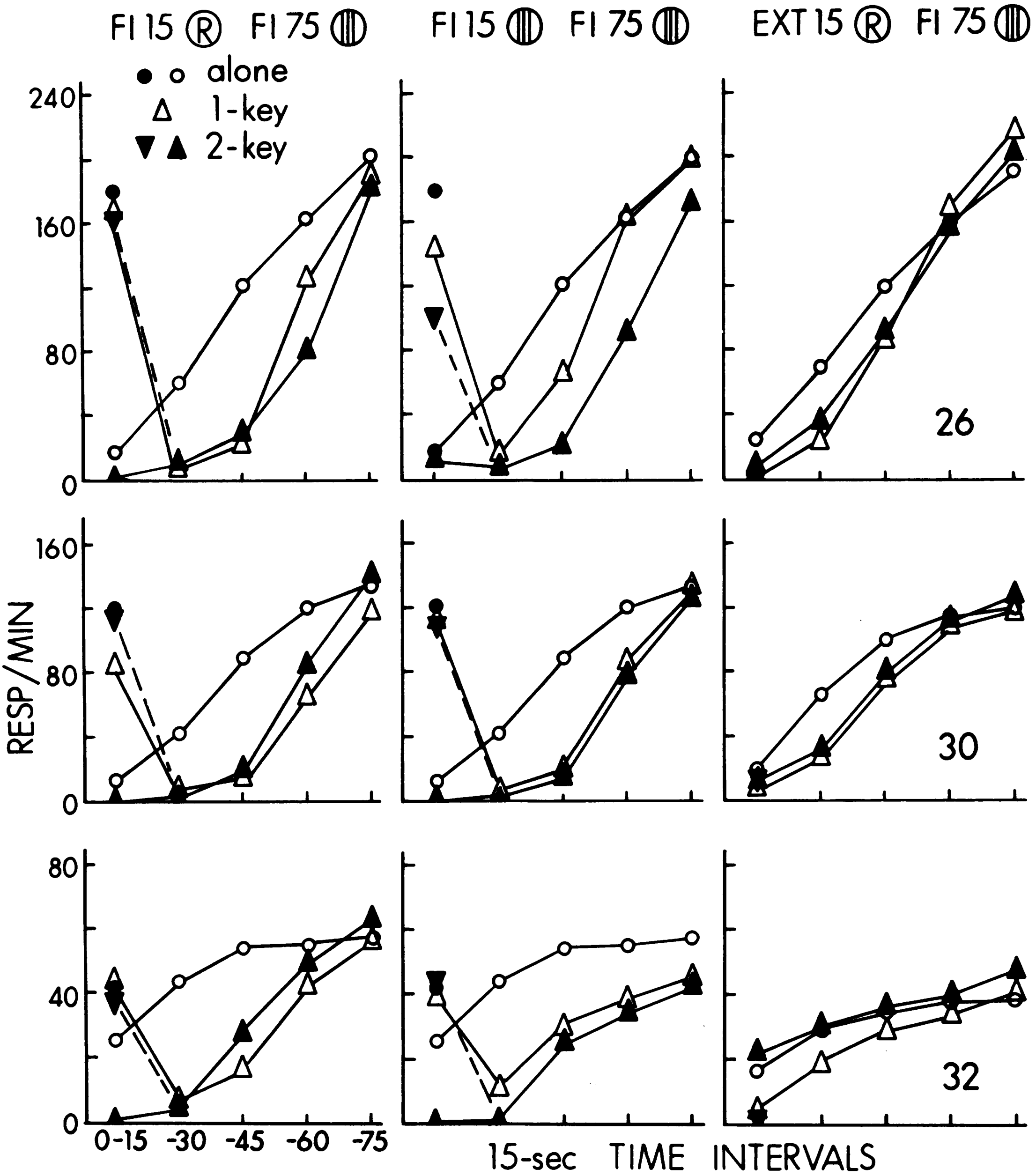

Fig. 10. Proactive effects of the FI 15-s reinforcer on the FI 75-s performance in the procedures of Table 3. The columns show the effects of each schedule combination (cf. Figure 4), of removing the red FI 15-s stimulus (cf. Figure 7), and of removing the FI 15-s reinforcer (cf. Figures 8 and 9). Details in text.

gether with the long-FI schedule, and those maintained by the one-key procedure (unfilled triangles) did not differ systematically from the total outputs in the two-key procedure (filled triangles, including the short-FI value connected by the dashed line).

As shown in the middle column, substituting lines for red as the short-FI stimulus did not substantially alter the relations among the long-FI and short-FI performances. Long-FI rates that followed the short-FI reinforcer were higher in the one-key (unfilled triangles) than in the two-key (filled triangles) procedure for all pigeons, though only marginally so for Pigeon 30. Nevertheless, these rates were still systematically lower than those maintained when the long-FI schedule operated alone (unfilled circles).

As shown in the right column, removing the short-FI reinforcer eliminated or at least attenuated the effect of the short-FI stimulus. After longer exposure to these schedules than to those of the preceding conditions (cf. Table 3), the red stimulus alone, on either the same key or a different key, was not followed by decreases in subsequent long-FI responding comparable to those produced in the other conditions. To the extent that Figure 10 implicates the short-FI reinforcer rather than the short-FI stimulus in the reduction of subsequent long-FI responding, the pattern of results is similar to that obtained in Experiments 1 and 2.

An incomplete set of data comparable to those in Figure 10 was obtained with FI 30 s (red) prior to the death of Pigeon 25 (see Method section); the proactive effects with FI 30 s were similar to, although of somewhat smaller magnitude, than those shown with FI 15 s in the figure.

Discussion

The proactive effect, like the retroactive one, seems to depend on the short-FI reinforcer rather than the short-FI stimulus. But because the relation is proactive, the possibility that the short-FI reinforcer served a discriminative function requires further analysis. An event that follows responses, as in the retroactive effect, cannot serve as a discriminative stimulus controlling those responses, but one that precedes those responses can.

Parenthetically, it might be argued in the case of FI 60 s as the short-FI schedule (Figure 4) that the short-FI reinforcer late in one interval could have exerted discriminative control over responding early in the interval of the next cycle. But such an account is not plausible, because the availability of the reinforcers in the next interval, on which such control must have been based, was consistently correlated with other events that were temporally less remote (e.g., key onset at the start of the next cycle).

In the case of the proactive effects of FI 15 s (Figure 10), however, the argument for a discriminative function need not appeal to control extending across cycles from one interval to the next. In this case the short-FI reinforcer was followed by responding that was maintained by the later long-FI reinforcer in the same cycle, and it was closer in time to that later reinforcer than was the key onset at the start of the cycle. The question of whether the proactive effect is reducible to a discriminative function of the short-FI reinforcer therefore remains open.

EXPERIMENT 4: ASSESSING PROACTIVE DISCRIMINATIVE EFFECTS

The discriminative functions of a reinforcer can be assessed by changing the contingencies upon which those discriminative functions may have been based. For example, if different response rates at different times within an interval are based on consistent temporal relations among the reinforcer and other events within the interval, the temporal discrimination can be abolished by eliminating those temporal consistencies. This rationale was the basis for Experiment 4. To the extent that the short-FI reinforcer is consistently followed by periods of time during which further responding is not reinforced, it can become a discriminative stimulus controlling low rates of responding. If so, this temporal discriminative control should be vulnerable to the substitution of a roughly uniform probability that a response will be reinforced throughout these time periods. This substitution was accomplished by inserting the short-FI reinforcer into longer variable intervals rather than into longer fixed intervals.

Another way to assess the discriminative functions of a reinforcer is to vary its properties. For example, a brief response-produced stimulus could be substituted for each short-FI feeder operation so as to maintain stimulus control while removing reinforcing effects. But the results of this procedure are interpretable only if the stimulus control exerted by the brief stimulus is similar to that exerted by the feeder. Dissimilar effects might come about for either of two reasons: because stimulus control varies with superficial stimulus properties (e.g., relative intensities, different locations) or because

Table 4

Sequence of schedules (lines, right key only) in Experiment 4.

Schedules (VI: frequencies of variable intervals)		Sessions
FI 75 s		37
(EXT)	– VI (________; 16 × 30 s; 8 × 45 s; 4 × 60 s; 4 × 75 s)	21
FI 15 s	– VI (________; 16 × 30 s; 8 × 45 s; 4 × 60 s; 4 × 75 s)	21
(EXT)	– VI (________; 16 × 30 s; 8 × 45 s; 4 × 60 s; 4 × 75 s)	12
(EXT)	– VI (16 × 20 s; 8 × 30 s; 4 × 45 s; 2 × 60 s; 2 × 75 s)	14
FI 15 s	– VI (16 × 20 s; 8 × 30 s; 4 × 45 s; 2 × 60 s; 2 × 75 s)	14
(EXT)	– VI (16 × 20 s; 8 × 30 s; 4 × 45 s; 2 × 60 s; 2 × 75 s)	7

the reinforcer effects were not discriminative in the first place. The procedure used in the present experiment avoids this ambiguity.

METHOD

Experiment 4 followed Experiment 3 after 236 sessions of other FI procedures; these included schedules with a brief stimulus (a response-produced 4-s green keylight) substituted for the short-FI reinforcer. Beginning during those procedures, Purina® pigeon chow was substituted for mixed grain as the reinforcer.

In Experiment 4, daily sessions for each pigeon consisted of 32 cycles of 150 s each, and all schedules were arranged on the right key and correlated with lines. The sequence of schedules is summarized in Table 4. The schedules are described below; other details were as in the preceding experiments.

After sessions of FI 75 s, variable-interval (VI) schedules were arranged. As in the earlier experiments, all intervals began with key onset at the beginning of the 150-s cycle. The VI schedule arranged one reinforcer within each cycle; after the reinforcer at the end of the interval, the key became dark but the houselight remained on throughout the remainder of the cycle (the 15-s limited hold made no contact with behavior during the VI sessions). Table 4 describes each schedule by showing how many times each interval occurred within a session. Intervals were arranged in an irregularly ordered sequence, and successive sessions for each pigeon began at different places within that sequence.

The first VI schedule included intervals of 30, 45, 60, and 75 s. The 30-s interval occurred 16 times, the 45-s interval occurred eight times, and the 60-s and 75-s intervals each occurred four times within the 32-cycle session. In this schedule, the probability with which a response was reinforced was .50 at 30 s (16 of 32 intervals), at 45 s (8 of the remaining 16 intervals), and at 60 s (four of the remaining eight intervals); the probability was necessarily 1.0 at 75 s (cf. the statistic, reinforcers per opportunity: Catania & Reynolds, 1968).

In the next condition, an FI 15-s schedule was superimposed on the VI schedule. This was not equivalent to adding a 15-s interval to the VI schedule, because the FI schedule made its reinforcer available for the first response after 15 s within every cycle. In other words, in this condition, two reinforcers were arranged within each cycle: one at 15 s (the FI schedule) and the other at some later time that varied from cycle to cycle (the VI schedule). After this condition, additional sessions followed with the VI schedule operating alone.

The next condition arranged a VI schedule that added a 20-s interval to those of the first VI schedule. The 20-s interval occurred in 16 of the 32 cycles of the session, and the frequencies of the other intervals were halved. Thus, the probability with which a response was reinforced was again .50 at all but 75 s, the longest interval. After sessions with this VI schedule, the FI 15-s schedule was again superimposed, so that two reinforcers were arranged within each cycle. The final condition was a return to the VI schedule operating alone.

The FI reinforcer did not affect the timing of the variable intervals (although it was subtracted from total time in the calculation of response rates), and the minimum time devoted to the FI was 19 s (FI 15 s plus a 4-s reinforcer). Thus, the maximum time from the end of the FI reinforcer to the earliest possible VI reinforcer was 11 s when the shortest interval of the VI schedule was 30 s and 1 s when it was 20 s. In practice, when FI 15 s was

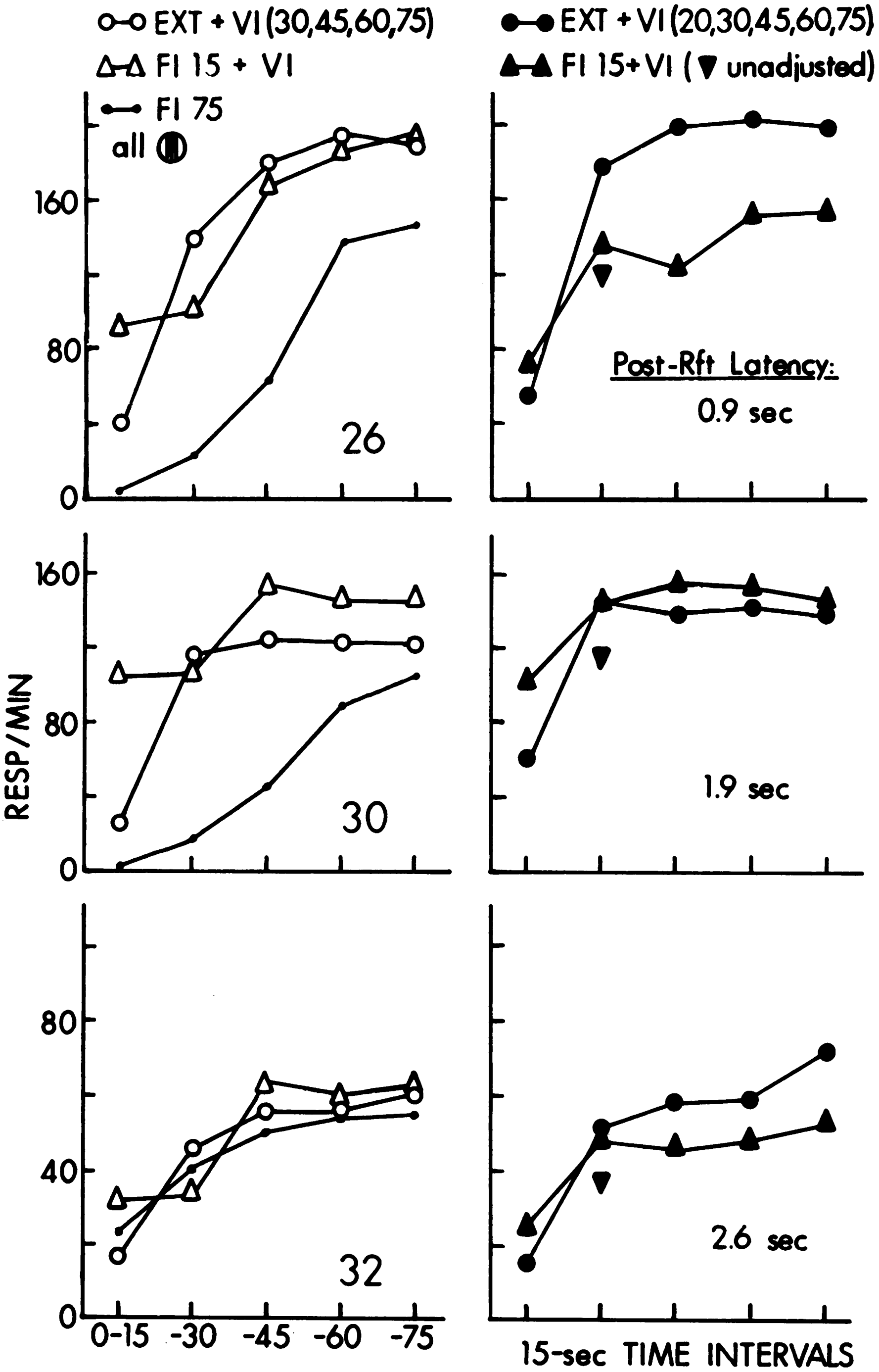

Fig. 11. Eliminating the discriminative effects of the FI 15-s reinforcer with VI scheduling of later reinforcers. In the right column, the latency after the FI 15-s reinforcer (shown for each pigeon as post-rft latency) was excluded from the calculation of subsequent response rates; the uncorrected rates are shown by the unconnected apex-down filled triangles. Details in text.

superimposed on the latter VI schedule, the 20-s interval typically made the first peck after the FI reinforcer eligible to produce the VI reinforcer.

RESULTS

Figure 11 shows response rates as a function of time within an interval when the shortest interval of the VI schedule was 30 s (left column) and when it was 20 s (right column), with and without the FI reinforcer (triangles vs. circles). The filled circles (right column) are from the first of the two presentations of the VI schedule with the 20-s interval (cf. Table 4); the second presentation, arranged mainly because the FI reinforcer reduced overall response rates for Pigeon 26 (filled triangles), generated similar data. In general, response rates increased as time passed within intervals, and rates during the first 15 s of an interval were higher with than without the FI reinforcer (first triangle and first circle of each function).

Most of the rate increase within each interval occurred during the first 30 s. After this time, rates were roughly constant; the two cases of systematically increasing rates (Pigeon 26, unfilled triangles, and Pigeon 32, filled circles) are offset by two cases of systematically decreasing rates (Pigeon 30, unfilled and filled triangles). These roughly constant rates indicate that the reinforcement probabilities of .50 at 30, 45, and 60 s functionally approximated a constant-probability or random-interval VI schedule even though these opportunities were spaced at 15-s intervals and were followed by an increase to a probability of 1.0 at 75 s.

With 30 s as the shortest interval of the VI schedule (left column), the introduction of the FI 15-s reinforcer reduced response rates in the time period that immediately followed (15 to 30 s; second unfilled triangle vs second unfilled circle). This reduction might be treated as a proactive inhibitory effect, except that a duration of about 10 s preceding the next opportunity for a reinforcer (at 30 s) might still have been sufficient to maintain temporal discriminative control.

With 20 s as the shortest interval of the VI schedule (right column), the introduction of the FI 15-s reinforcer also reduced response rates in the time period that immediately followed (unconnected apex-down filled triangle vs. second filled circle). But, as shown by the connected triangles, the reduction was effectively eliminated by subtracting from the calculations of response rate for each bird the latencies from the end of the FI reinforcer to the next peck (shown in Figure 11 as post-rft latencies); these latencies were comparable to postreinforcer latencies obtained in other studies (see especially Harzem, Lowe, & Priddle-Higson, 1978). The effects of postreinforcer latencies on response rate were not of a magnitude consistent with the proactive rate reductions of Figure 10, which were observed over periods of 30 to 45 rather than 1 to 3 s.

For Pigeon 26, and to a lesser extent for Pigeon 32, overall rates were lower with than without the FI reinforcer added to the second VI schedule (filled triangles and circles). As in the prior experiments, however, the form of the function relating response rate to time in the interval is more important than absolute response rates (cf. Figures 5 and 6). The filled triangles of Figure 11 show that, once responding began after the FI reinforcer, it continued at a roughly constant rate throughout the remaining time of the VI schedule for all birds.

DISCUSSION

Making the probability of the VI reinforcer constant following the FI reinforcer eliminated the contingencies that had maintained a temporal discrimination based on the time since the FI reinforcer. Without such temporal discriminative control, the FI reinforcer no longer had its proactive inhibitory effect, in that roughly constant rates were maintained throughout the remainder of the variable intervals. The lower rates maintained by the FI reinforcer over the first 15 s of each interval (first filled triangle of each function in Figure 11) are attributable to temporal discrimination based on the time since the beginning of the cycle.

To the extent that the performances maintained by VI schedules need not involve temporal discriminations, they are in this respect behaviorally simpler than those maintained by FI schedules (this does not rule out the possibility that FI schedules may be behaviorally simpler than VI schedules in other ways; e.g., in the temporal consistencies of delay gradients). The findings of Experiment 4 are consistent with the view that the effect of a temporal discrimination in interval performances is to reduce responding. This reduction, however, is necessarily proactive and thus must be distinguished from the retroactive effects of added reinforcers within intervals.

GENERAL DISCUSSION

These experiments have been presented as evidence for a retroactive inhibitory effect of reinforcers that is not reducible to a discriminative effect of those reinforcers, at least within the range of schedule parameters that have been explored. There are undoubtedly other interpretations of the data (especially those that may treat the retroactive effect in terms of differential facilitation of stimulus control by varying response–reinforcer contingencies within the several schedules). But the credibility of an interpretation depends not only on the internal consistency of the data set from which it is derived but also on its relation to other accounts and findings. The present retroactive effect is consistent with quantitative treatments of response–reinforcer relations (cf. Keller, 1980; Myerson & Miezin, 1980). It also has features in common with other phenomena that have been discussed in terms of blocking, overshadowing, or both (especially Williams, 1975; but see also Mackintosh, 1974; St. Claire-Smith, 1979).

A discussion of the varieties of blocking and overshadowing is beyond the scope of the present account. It is probably worth noting, however, that just as an account in terms of inhibition cannot proceed effectively without an unambiguous specification of both what is inhibited and what does the inhibiting, an account in terms of blocking must specify both what is blocked and what does the blocking. There exist various possibilities (e.g., see Davison & Jenkins, 1985, on how reinforcers may mask the discrimination of contingencies), and it may be important to explore further the contingencies involved in the present procedures (e.g., by determining the effects of response-independent rather than response-produced reinforcers inserted into FI performance).

Although the present experiments mostly involved FI schedules, they have implications for the form of the VI input–output function. If temporal discrimination plays a negligible role in determining the response rate maintained by a VI schedule (as in a random-interval schedule), each reinforcer will contribute to subsequent responding in proportion to the area under the delay gradient that precedes it (cf. Figure 3), but the gradient for each reinforcer will be truncated by the preceding reinforcer. Thus, the VI function can be derived by integrating over successive delay gradients that are truncated according to the distribution of interreinforcement intervals arranged by the VI schedule.

One plausible form of the delay gradient is an exponential decay function. Figure 12 provides an example of the derivation of the VI function based on such a delay gradient. The decay function shows the contribution to subsequent responding, $p(t)$, produced when a reinforcer follows a response by time t; k and c are constants. The interreinforcement time function shows the probability, $q(t)$, of an interval of duration t, with the parameter r determined by the value of the VI schedule. The total output can then be approximated by weighting the decay function by the distribution of interreinforcement intervals or, in other words, by multiplying the two functions, as shown in the third line of Figure 12. The output R, derived in the fourth line, is the integral of this product. The solution to the integration is the VI input–output function of Figure 1.

One corollary of this account is that the derivation cannot be extended from VI to FI schedules, because the derivation includes no terms relevant to the temporal discriminations that inevitably emerge as components of FI performance. But if temporal discriminations must be excluded, the retroactive inhibitory effect also cannot be generalized to situations in which a reinforcer follows responses that occur in the presence of two or more nontemporal discriminative stimuli (e.g., as in multiple schedules; cf. Innis, 1978; Kello, Innis, & Staddon, 1975; Staddon, 1969; Williams, 1976, 1979, 1981). Like the rate reductions produced by temporal discriminative control, those produced by other types of stimuli are not comparable to those produced retroactively by reinforcers, and it is not clear how discriminative effects might interact with the retroactive effects.

Responding maintained by a schedule that operates in the presence of one stimulus may survive interruption by another stimulus if the other stimulus is correlated with extinction (e.g., see the FI performances in Dews, 1962), but it may not do so if the other stimulus is correlated with other reinforcers. From this it might follow that delay gradients will be less truncated in the former than in the latter arrangement, and thus that more responding will be maintained when the first schedule alternates with extinction than when it alternates with another schedule that provides reinforcers.

The phenomenon just described has of course been called behavioral contrast, and by this account its magnitude would be expected to vary substantially with the way in which reinforcers are distributed within components. Furthermore, if the retroactive inhibitory effect is modified when it operates across different discriminative stimuli, different effects would be anticipated when no more than one reinforcer can occur within a component than when two or more reinforcers can occur. For example, as component durations shorten, fewer truncations and therefore higher response rates might be anticipated within components. A further analysis of the present phenomenon as it operates across different discriminative stimuli therefore may clarify the interactions within multiple schedules.

The speculative extrapolations could be extended, but it is probably premature to carry them much further. More fundamental problems remain. For example, is the delay gradient appropriately described as an exponential decay function? Even if that function is appropriate, how can its treatment as a continuous function be justified? Responses occur discontinuously, and rate of responding typically varies throughout the time that precedes a reinforcer. What then is the rationale for continuous integration under such circumstances? A more satisfactory account would show how the relevant functions could be derived from the interactions between responses and gradients in transitions from one set of schedules to another (e.g., see Myerson & Miezin, 1980).

Decay function: $p(t) = ke^{-ct}$

Interrft time function: $q(t) = re^{-rt}$

$$p(t)\cdot q(t) = ke^{-ct}\cdot re^{-rt} = kre^{-t(r+c)}$$

$$R = kr\int e^{-t(r+c)}dt = kr\left[\frac{-e^{-t}}{r+c}\right]_0^{\infty} = kr\left(\frac{1}{r+c}\right)$$

$$\therefore\ R = \frac{kr}{r+c}$$

Fig. 12. Derivation of the VI reinforcement function from an exponential delay gradient (decay function) multiplied by the distribution of interreinforcement intervals (interrft time function). The equations represent the integration under functions such as those illustrated in Figure 2, with successive intervals truncated at times corresponding to those that would be generated by a random-interval schedule.

Such an account would be particularly appropriate in the case of concurrent schedules. With pecks on two keys, for example, sequences of the two different responses will typically precede the reinforcers arranged by each schedule. The delay gradients for each schedule will therefore each maintain both responses, and their respective contributions to subsequent responding will therefore vary with changes in either relative response rates or relative reinforcement rates. Thus, the account must not only show how the integration should proceed in a given instance; it must also show how changes in response allocation will lead to an equilibrium performance (a successful analysis will presumably share some features with the derivation of concurrent matching from momentary maximizing, as in Shimp, 1966).

Another approach is through computer simulation. Such a simulation might give the responses that precede a reinforcer a weighting based upon the delay between each response and the reinforcer, and then use a summation of these weightings to assign a probability to future responding. But the simulation would have to include some feature that prevented runaway response rates, in which higher rates produce shorter delays and thus higher weightings that in turn produce still higher rates. One possible solution is to assign to the emission of each response a cost that reduces future response probability. Another is to introduce different functions that operate at different delays between responses and a reinforcer, with response probability jointly determined by these functions. One might operate at the delays explored in the present research; the other might operate only at relatively short delays, perhaps even restricted only to the final response preceding the reinforcer. The latter function, probably most critical when responses and reinforcers are contiguous or nearly so, may be involved with the organism's sensitivity to response–reinforcer contingencies (cf. Catania & Keller, 1981) and thus may determine whether the effect of the reinforcer is restricted to the response class that produced it or extends to other behavior. But such computer simulations and other theoretical elaborations will still be based upon a relatively limited data set. This has been primarily an experimental analysis rather than a quantitative one. The mathematical development is only a first approximation, and its extension may depend upon more detailed experimental studies of the effects of delayed reinforcers.

This account began with a molar relation, the input–output function for the variable-interval reinforcement of a response. It then considered some molecular effects of reinforcers delivered within fixed intervals, identifying some behavioral processes that operated at the level of particular sequential relations among responses and reinforcers. Some properties of these basic processes led to an account of the molar relation. To the extent that the molar relation has been properly derived from the molecular processes, it can be said that the input–output function has been explained in terms of these processes.

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