RESPONSE-INDEPENDENT EVENTS IN THE BEHAVIOR STREAM

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The metaphor of the behavior stream provides a framework for studying the effects of response-independent food presentations intruded into an environment in which operant responding of pigeons was maintained by variable-interval schedules. In the first two experiments, response rates were reduced when response-independent food was intruded during the variable-interval schedule according to a concomitantly present fixed-time schedule. These reductions were not always an orderly function of the percentage of response-dependent food. Negatively accelerated patterns of key pecking across the fixed-time period occurred in Experiment 1 under the concomitant fixed-time variable-interval schedules. In Experiment 2, positively and negatively accelerated and linear response patterns occurred even though the schedules were similar to those used in Experiment 1. The variable findings in the first two experiments led to three subsequent experiments that were designed to further illuminate the controlling variables of the effects of intruded response-independent events. When the fixed and variable schedules were correlated with distinct operanda by employing a concurrent fixed-interval variable-interval schedule (Experiment 3) or with distinct discriminative stimuli (Experiments 4 and 5), negatively accelerated response patterns were obtained. Even in these latter cases, however, the response patterns were a joint function of the physical separation of the two schedules and the ratio of fixed-time or fixed-interval to variable-interval schedule food presentations. The results of the five experiments are discussed in terms of the contributions of both reinforcement variables and discriminative stimuli in determining the effects of intruding response-independent food into a stream of operant behavior.
Key words: concurrent schedule, conjoint schedule, concomitant schedule, temporal control, response patterns, key peck, pigeons

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As living organisms move through time and space, they encounter a mixture of events, some that occur as a result of their actions and others that occur independently of those actions. The dynamic interplay between both types of events and behavior was recognized by Schoenfeld and his colleagues, who, reflecting earlier ideas such as Heraclitus's *panta rhei* and James's metaphor for consciousness, conceived of behavior as being like a stream, "nothing jointed, it flows" (James, 1890, p. 239). Farmer and Schoenfeld (1966) proposed that both respondent and operant conditioning paradigms involve the analysis of events intruded into the behavior stream and subsequently observed that

> Any stimulus (whether called "neutral," or "reinforcing," or "conditional," or "discriminative," or whatever) . . . may be intruded into an organism's behavior stream at the discretion of the experimenter; and the effects of the intrusion upon any response or stream segment, whether operant or not, and whether prechosen for observation or not, will depend upon many parameters. Among the latter parameters will be the temporal reference of that stimulus to the response, the degree of necessity-sufficiency between them, and the response composition of the behavior stream. (Schoenfeld & Farmer, 1970, p. 218)

One type of intruded event is the response-independent presentation of food. Such events have been intruded into a stream of behavior in three ways. First, they have been intruded when a particular response was not prechosen for analysis, as in Skinner's (1948) original investigation of superstitious behavior. Second, they have replaced response-dependent food presentations after steady-state responding was established (Herrnstein, 1966; Zeiler, 1968). And, finally, response-in-

dependent food presentations have been intruded into, which is to say combined with, a stream of prechosen responding that continues to be maintained by a schedule of response-dependent reinforcement (e.g., Schoenfeld & Farmer, 1970). The behavioral effects of this latter procedure were the concern of the present experiments.

The concomitant presence of both response-dependent and response-independent events gives rise to two classes of variables that may affect subsequent behavior. First, the response-reinforcer relation is no longer the simple dependency between responding and the presentation of food that it is when a schedule of response-dependent food is in effect. As the proportions of response-dependent and response-independent food vary, so will the temporal relations between responding and those food presentations. Second, these varying temporal relations may affect responding both directly and as a function of the discriminative stimulus control of responding that may result from both the detection of the different response–food relations that occur (cf. Killeen, 1978; Lattal, 1975) and the interfood intervals of either schedule, to the extent that they are distinct (cf. Lund, 1976). These latter temporal stimuli in particular may affect local response rates and, as a result, overall response rates. The results of several studies illustrate the operation of these variables when response-independent events are intruded and bring us to the present experiments.

When response-independent food arranged according to variable-time (VT) schedules is intruded into a stream of responding maintained by a variable-interval (VI) schedule, the rate of responding is approximately proportional to the proportion of food arranged by either of the two schedules (e.g., Imam & Lattal, 1988; Kopp & Van Haaren, 1982, Experiment 1; Lattal, 1974; Rachlin & Baum, 1972; Schoenfeld & Farmer, 1970). This relation is less consistent when other combinations of response-dependent and response-independent food are studied. For example, Lattal and Bryan (1976, Experiment 1) found that fixed-interval (FI) response rates either increased or were unchanged when a VT 150-s schedule was intruded. Further increases in VT food rate, however, did proportionally lower response

rates (Lattal & Bryan, Experiment 1). Similarly, Lattal and Bryan (Experiment 3) did not find systematic effects on FI response rates when fixed-time (FT) schedules with different interfood intervals were intruded. Zeiler (1977) also found variable effects on response rates when response-independent food, delivered according to FT schedules, was intruded during a VI schedule. Response rates of 2 subjects generally increased as the proportion of FT food decreased; however, the rates of a 3rd subject were unrelated to changing proportions of FT and VI food (cf. Kopp & Van Haaren, 1982, Experiment 2).

The fact that Lattal and Bryan (1976) did not always find response rates changing in proportion to the ratio of response-dependent to response-independent food was related to the temporal patterns of responding that occurred when VT or FT schedules were intruded on FI-schedule-maintained responding. When the VT schedule was intruded, the positively accelerated response patterns characteristic of FI performance changed to linear ones, thereby lowering the local rate at the end of the FI and elevating response rates early in the FI. As a result, the net effect was either no change or an increase in overall response rate despite a reduction in the proportion of response-dependent food. Similarly, when FT schedules were intruded during FI, response patterns became positively accelerated within each FT period, the outcome being that overall response rates were not always an orderly function of the proportion of response-dependent food presentations. Zeiler (1977) did not report response patterns when FT schedules were intruded during VI, but one possibility is that the insensitivity of the responding of 1 subject to the changing proportions of VI and FT food was related to changing response patterns engendered by the FT schedules.

In the present experiments we investigated further the manner in which reinforcement and discriminative stimulus variables combine to control responding when response-independent events are intruded into a stream of operant behavior maintained by a VI schedule of reinforcement. In the first two experiments we examined changes in response rates and patterns engendered by varying the rates of food presentation arranged by FT and VI schedules. In the next

three we attempted to isolate some of the controlling variables of the effects observed in the first two experiments.

EXPERIMENT 1

Key pecking maintained by VI schedules that arranged different rates of reinforcement was studied as a function of intruded food arranged by an FT schedule of fixed value.

METHOD

Subjects

Three male White Carneau pigeons, each with an unknown prior history of responding on schedules of reinforcement, were maintained at 80% of their free-feeding weights by limiting access to food.

Apparatus

An operant conditioning chamber made of hardware cloth and enclosed in a sound-attenuating chamber was used. The work area was approximately 30 cm high by 30 cm wide by 30 cm long. A single response key was centered on the front aluminum work panel 20 cm from the chamber floor. The key was transilluminated by a single 110-V AC colored bulb at all times except during food delivery. Food was defined as 3-s (for Pigeons 4067 and 4533) or 5-s (for Pigeon WC3) access to mixed grain in a Gerbrands food hopper located behind a feeder aperture (5 cm square) centered on the work panel with its lower edge approximately 6 cm from the floor. Food delivered as a result of either the VI or FT schedule was presented through the same hopper. The aperture was lit by a 110-V AC white light during food delivery. General chamber illumination was provided by a 110-V AC houselight located in the lower right corner of the work panel. The houselight remained on throughout the session, except during food delivery. White noise and a ventilation fan in the chamber masked extraneous noise. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure

Following training to key peck, a VI schedule, consisting of 20 intervals generated using the progression suggested by Fleshler and Hoffman (1962), was effected. The average interreinforcer interval was increased gradually over several sessions until the terminal value was reached. When responding showed no systematic trends, the effects of combinations of different VI and FT schedules were studied as detailed below. In each case, the two schedules operated independently of one another. Whenever food was scheduled from the FT schedule while VI food was being presented (which occurred only rarely), the former was delivered immediately after the hopper was deactivated.

The conditions, numbers of sessions at each, and their sequence are shown in Table 1. Following training on VI 300-s schedules, concomitant[1] FT 150-s VI ts schedules were studied. The average VI interreinforcer interval, t, was changed from 300 to 600 to 1,800 s over successive conditions for Pigeons 4067 and 4533. These values represent ratios of response-independent to response-dependent food of 2:1, 4:1, and 12:1, or percentages of response-dependent reinforcers of 33, 25, and 8, respectively. In a final condition for these 2 pigeons, the FT 150-s schedule was changed to an FI 150-s schedule to assess the effect of adding the response-food dependency. For Pigeon WC4, the effects of adding and removing a concomitantly available FT 150-s schedule were studied. Except for the last condition, which terminated for 2 subjects after only a few sessions because of the investigator's departure from the laboratory, conditions were in effect for at least 20 sessions and until no systematic trends in response rates and patterns were observed over the last six sessions. Some conditions were in effect beyond the first point of stability to assess longer term effects of the schedules. Sessions

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[1] The procedure has been described in terms of the intrusion of response-independent food presentations into a stream of operant behavior maintained by VI schedules. Because this description is rather general and cumbersome for precise, repeated use, we have followed the rationale of Imam and Lattal (1992) and describe combinations of response-dependent and response-independent food-delivery schedules as concomitant schedules. Such a label, as Imam and Lattal note, distinguishes the combinations from conjoint schedules, where two response-dependent reinforcement schedules are correlated with the same operandum simultaneously, and concurrent schedules, where two distinct operants are specified.

Table 1

Sequence of conditions and numbers of sessions in each condition for each pigeon in Experiment 1. Also shown are the means and ranges of the number of food delivery presentations (S^R) under both the VI and FT schedules and response rates (total responses divided by total time in session) for each of the 3 birds during the last six sessions of each condition.

Subject	Schedule	Number of sessions	M FT or FI S^R	VI S^R	Response rate	
					M	Range
4067	VI 300 s	30		18	59	57–63
	FT 150 s VI 300 s	35	36	18	55	41–65
	FT 150 s VI 600 s	36	36	9	53	45–64
	FT 150 s VI 1,800 s	22	34	3	53	49–55
	FI 150 s VI 1,800 s	8	37	3	74	65–85
4533	VI 300 s	53		18	80	77–82
	FT 150 s VI 300 s	36	36	18	54	47–59
	FT 150 s VI 600 s	35	32	9	45	42–50
	FT 150 s VI 1,800 s	26	36	3	17	14–21
	FI 150 s VI 1,800 s	5	37	3	32	22–50
WC4	VI 300 s	31		18	27	26–32
	FT 150 s VI 300 s	45	38	18	14	11–18
	VI 300 s	23		18	18	15–24

ended after the first FT food after 5,400 s (90 min) had elapsed and occurred at the same time each day, 6 days a week.

RESULTS

Table 1 shows response rates (total responses divided by total time in session less food time) for each pigeon averaged over the last six sessions of each condition. Intruding the FT schedule reduced average response rates from the first condition (VI schedule alone) for each pigeon, although these reductions for Pigeon 4067 were modest. As the rate of VI reinforcement was reduced while the FT food rate was held constant, average response rates decreased for Pigeon 4533 but were relatively unchanged for Pigeon 4067 even when, during the concomitant VI 1,800-s FT 150-s schedule, only three response-dependent reinforcers occurred in each session. When the FT schedule was removed, either by returning to the VI 300-s schedule alone (Pigeon WC4) or by changing the FT schedule to an FI schedule (Pigeons 4067 and 4533, last condition), response rates increased relative to those controlled by the preceding concomitant schedule.

Key-peck response rates in successive tenths of the fixed interfood interval during each condition are shown for each pigeon in Figure 1. These same data are shown as percentages of total responses in Figure 2. During VI 300 s, responses were recorded in a manner similar to that used during the concomitant schedules, but response-independent food did not occur. Response rates were the same across successive tenths of the FT sham period during VI 300 s. For each of the 3 birds, intruding the FT schedules changed the distributions of key-peck responses. During each of the concomitant schedules, the number of responses across successive portions of the FT period decreased, implying a negatively accelerated cumulative response pattern. That is, response rates were highest in the first tenth of the interval following an FT food delivery and were lower in the other nine tenths of the interval. There were two forms of this negatively accelerated response pattern. All pigeons responded rapidly immediately after an FT food delivery, but thereafter Pigeons 4533 and WC4 responded at a more even rate and Pigeon 4067 responded at progressively lower rates across the FT period. The negatively accelerated response pattern was most marked with Pigeon 4067 during the concomitant VI 1,800-s FT 150-s schedule, when it responded at rates of 87 and 22 responses per minute in the first and last tenths of the FT period. Informal but regular observations during the concomitant schedules revealed that as each FT period progressed, Pigeon 4067 in particular oriented toward the food hopper and sometimes
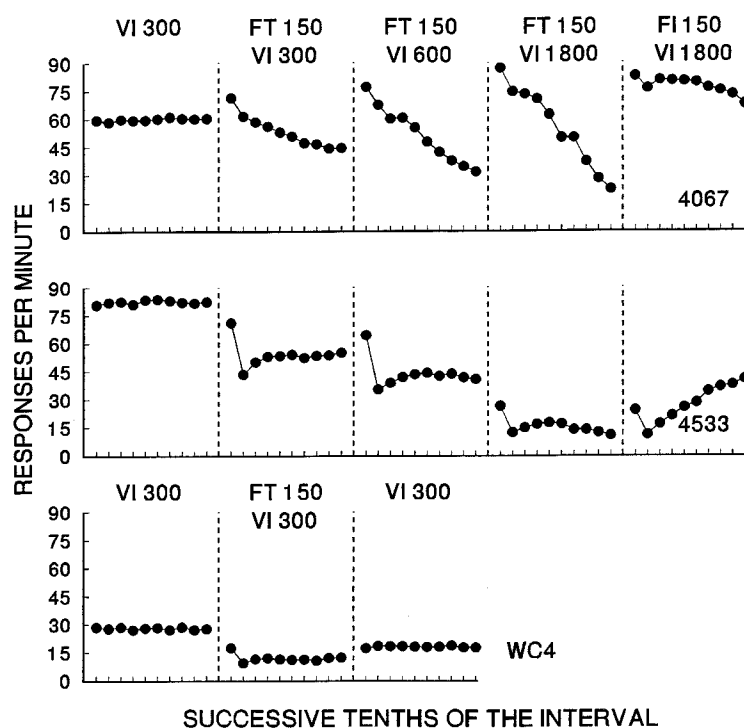
Fig. 1.   Response rates (responses per minute) during successive tenths of the FT period for each subject during each condition of Experiment 1. Each data point is an average over the last six sessions of each condition. All schedule parameters are in seconds.

actually placed its head in the hopper aperture (although grain could not be obtained from the hopper because its aperture was protected by a device described by Catania, 1965, to prevent such behavior). Similar feeder-orienting responses also occurred for Pigeons 4533 and WC4.

For Pigeon 4533 the concomitant VI 1,800-s FI 150-s schedule led to positively accelerated response patterns across the fixed interval after only a few sessions. The distribution of responses across the fixed period by Pigeon 4067 was more even (i.e., linear cumulative record) than in the preceding concomitant FT VI schedules, but the experiment was terminated before positively accelerated responding developed.

The cumulative records in Figure 3 illustrate the moment-to-moment changes in responding for Pigeon 4067 that are summarized in Figures 1 and 2. These records show that responding was similar throughout the session and that as the rate of VI food decreased both the frequency and degree of negatively accelerated response patterns increased.

DISCUSSION

As in several previous studies, intruding response-independent food reduced response rates relative to those maintained by a VI schedule; however, the relation between response rate and the proportion of response-dependent reinforcers was variable. This latter finding is similar to that reported by Zeiler (1977) with concomitant FT VI schedules.

The negatively accelerated response patterns across the FT were an unexpected finding that suggests both detection of the two different response/food-delivery relations and control of responding by the temporal distribution of food presentations through the FT schedule. Because the negatively accelerated response patterns were so striking and different from responding under the VI schedule, it seemed important to attempt a replication of these findings.
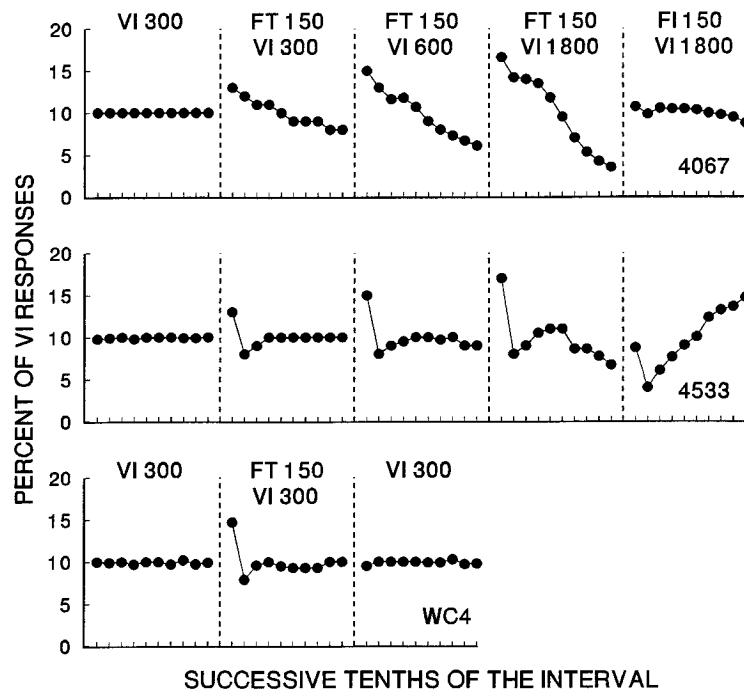
Fig. 2. Percentage of total responses in successive tenths of the fixed interfood interval for each subject in Experiment 1. Each data point is an average over the last six sessions of each condition. All schedule parameters are in seconds.

EXPERIMENT 2

In the first experiment, the FT value was held constant as the VI value was systematically decreased. In the second experiment, VI-maintained key pecking was studied over a range of interfood intervals that were arranged by varying concomitantly available FT schedules to further examine the effects of intruded response-independent food on operant behavior.

METHOD

Subjects and Apparatus

Each of 3 experimentally naive male White Carneau pigeons was maintained at 80% of its ad libitum body weight.

The apparatus was similar to that used in the first experiment except that the chamber was made of wood rather than of hardware cloth and the internal dimensions of the work area were 38 cm high by 33 cm long by 30 cm wide, with proportional changes in the location of the response key (25 cm above the chamber floor) and food hopper aperture

(lower edge 8 cm above the chamber floor). Food was 3-s access to mixed grain.

Procedure

The initial training and general features of the schedules were the same as described in the first paragraph of the Procedure section of Experiment 1. The schedules in effect, the numbers of sessions in each, and the sequence of conditions are shown in Table 2. Following training on VI 180-s (Pigeon 4773) or VI 300-s (Pigeons 4050 and 8421) schedules, concomitant FT VI schedules were effected. The first FT interfood interval was decreased by halving the current value in two successive conditions. The resulting FT value then was doubled successively in each of the next two conditions. The ratios of response-independent to response-dependent food in these conditions, then, were 2:1, 4:1, 8:1, 4:1, and 2:1, or percentages of response-dependent food of 33%, 20%, 11%, 20%, and 33%. The VI schedule then was reinstated, which was followed in turn by FT alone. Then, one or more concomitant FT VI schedules with
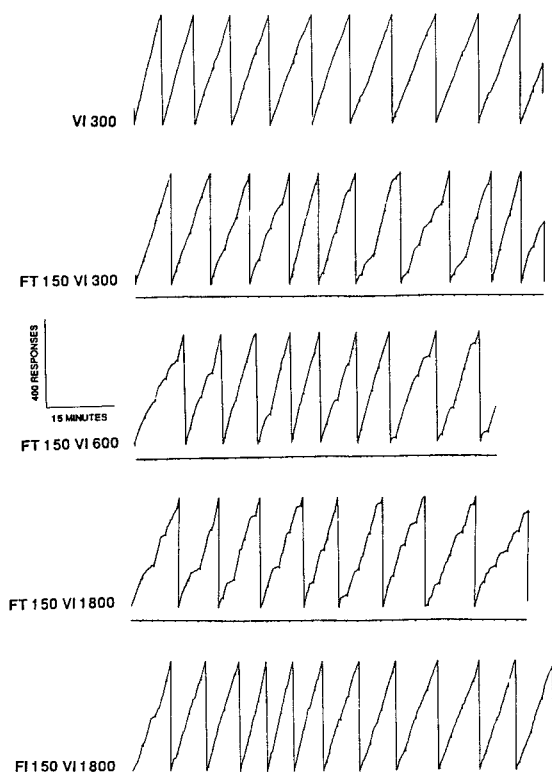
Fig. 3. Sample cumulative records illustrating the patterns of responding during VI and concomitant FT VI schedules for Pigeon 4067. All food presentations are shown as deflections of the response pen, and only response-independent food presentations are shown as deflections of the lower event pen (where appropriate). Each record is from one of the last six sessions of each condition. The FT 150-s VI 600-s session was briefer than usual on the day shown here. The reason for this shorter session is not known.

Table 2

Sequence of conditions (schedules) and numbers of sessions at each condition for each pigeon in Experiment 2. Where more than one schedule is listed on a single line, the two schedules were in effect concomitantly.

Subject	Schedule	Number of sessions
4773	VI 180 s	62
	FT 90 s VI 180 s	7
	FT 45 s VI 180 s	25
	FT 22.5 s VI 180 s	10
	FT 45 s VI 180 s	25
	FT 90 s VI 180 s	27
	VI 180 s	12
	FT 90 s	12
	FT 90 s VI 600 s	12
	FT 90 s VI 1,200 s	30
	FT 90 s	15
	FT 90 s VI 1,200 s	25
	FT 90 s	12
	FI 90 s	15
4050	VI 300 s	92
	FT 150 s VI 300 s	24
	FT 75 s VI 300 s	34
	FT 37.5 s VI 300 s	17
	FT 75 s VI 300 s	20
	FT 150 s VI 300 s	10
	VI 300 s	12
	FT 150 s	41
	FT 150 s VI 1,200 s	15
	FT 150 s	21
	FI 150 s	12
8421	VI 300 s	49
	FT 150 s VI 300 s	9
	FT 75 s VI 300 s	35
	FT 37.5 s VI 300 s	25
	FT 75 s VI 300 s	23
	FT 150 s VI 300 s	35
	VI 300 s	30
	FT 150 s	20
	FT 150 s VI 1,200 s	16
	FT 150 s	20
	FI 150 s	12

different VI food rates were studied in alternating blocks of sessions with FT schedules. An FI schedule was studied last. Conditions were changed when no systematic trends were observed in response rates and patterns. Sessions ended following the first FT reinforcer after 3,600 s and occurred at the same time each day, 5 days per week.

RESULTS

Figure 4 shows key-peck response rates for each pigeon during the first seven conditions as a function of the percentage of response-dependent food. In general, response rates were highest when all of the food was response dependent and lowest when the percentage of response-dependent food was low-est. Between these two extremes, however, the response-rate function varied among pigeons. For Pigeon 4773, response rate was an increasing function of the percentage of response-dependent food. For Pigeon 4050, response rates did not change systematically until the percentage of response-dependent food presentations was at its lowest value, at which point the response rates dropped. Response rates of Pigeon 8421 decreased reliably only with repeated exposure to FT alone (see Figure 5).

Figure 5 shows, in sequence, the average response rates during each of the last four
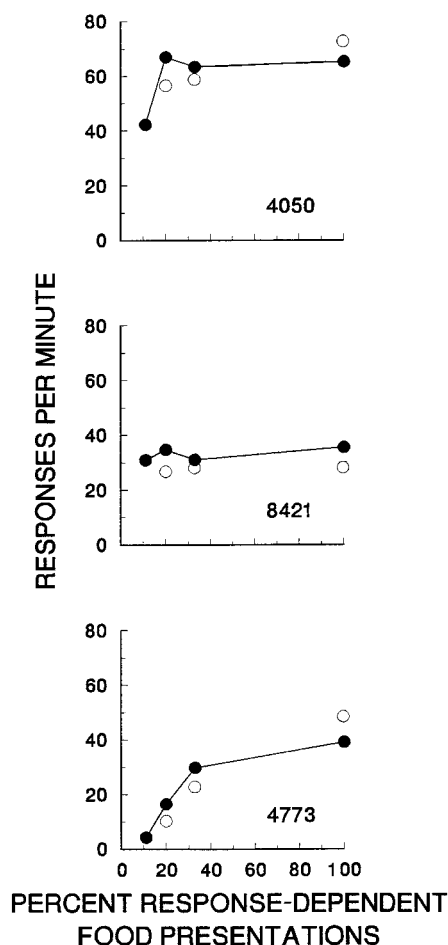
Fig. 4. Response rates (responses per minute) as a function of the proportions of total food presentations that were response dependent for each subject during each of the first seven conditions of Experiment 2. Response rates are averages over the last seven sessions of each condition. The closed and open points show data from initial and replication conditions, respectively.

(Pigeons 4050 and 8421) or seven (Pigeon 4773) conditions of the experiment. Response rates were lowest when FT was in effect, rose when VI was added to FT, declined again when VI was removed, and then increased when FT was changed to FI.

The same ratio of FT to VI food arranged in different ways did not necessarily have the same effects on response rates, as can be seen by comparing the data in Figures 4 and 5. Pigeon 4050 responded at similar rates under concomitant FT 150 s VI 1,200 s and concomitant FT 37.5 s VI 180 s, which both arranged food ratios of 8:1 favoring FT. Pigeon 8421

responded more rapidly when an 8:1 ratio was arranged by concomitant FT 37.5 s VI 300 s as compared to the concomitant FT 150-s VI 1,200-s schedule. Pigeon 4773 responded more rapidly when a ratio of 7.5:1 was arranged by a concomitant FT 150-s VI 600-s schedule than it did when an 8:1 ratio was arranged by concomitant FT 22.5 s VI 180 s. Pigeon 4773 also responded more rapidly when FT was intruded into VI 600 s than when it was intruded into VI 1,200 s. Changing from FT to FI increased response rates.

Figures 6 and 7 show the proportion of total responses in successive fourths of the FT during, respectively, the first seven and the remaining conditions of the experiment. As in Experiment 1, data were recorded in sham intervals when the VI was in effect. Responding was distributed evenly across the fixed period when the VI schedule was in effect. Response patterns under the concomitant schedules were more variable across subjects than in the first experiment. Pigeon 4773 responded slowly in the first quarter of the interval, highest in the second quarter, and progressively more slowly through the third and fourth quarters. Except for the low proportion of responses in the first quarter of the interval, these response distributions represent a negatively accelerated response pattern, a point to which we will return in Experiments 4 and 5 below. The patterns from the other 2 pigeons ranged between linear and positively accelerated across the FT period, linear to slightly positively accelerated (Pigeon 4050 in concomitant FT 37.5 s VI 300 s and Pigeon 8421 in concomitant FT 150 s VI 300 s) until the shortest FT value was reached and positively accelerated thereafter, except during the VI condition. Pigeon 4773 continued to exhibit the pattern described above during the first two FT and concomitant schedules shown in Figure 7. When the VI was changed to 1,200 s, the proportion of responses in the first bin increased so that the pattern more closely resembled those in the first experiment. The response patterns of the other pigeons were similar to those seen under the conditions shown in Figure 6.

DISCUSSION

The effects of the different proportions of response-dependent food on response rates were variable across subjects, as they were in
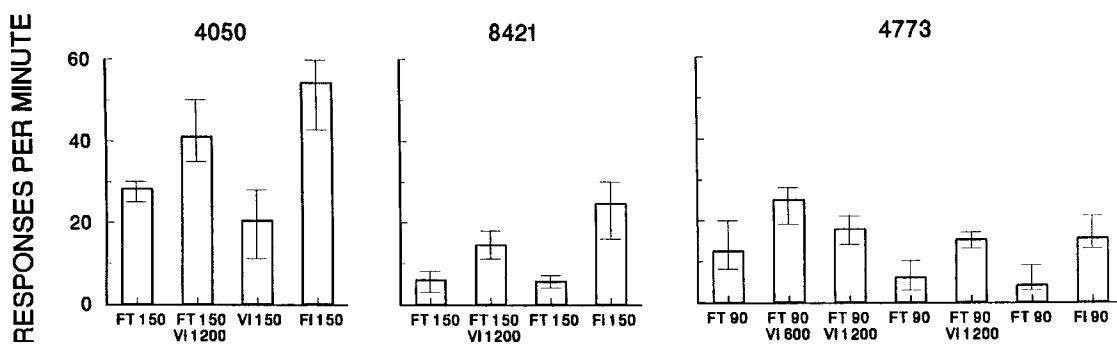
Fig. 5. Response rates (responses per minute) as a function of the proportions of total food presentations that were response dependent for each subject during each of the last five (Pigeons 4050 and 8421) or seven (Pigeon 4773) conditions of Experiment 2. Response rates are averages over the last seven sessions of each condition. All schedule parameters are in seconds. The error bars represent the ranges of response rates.
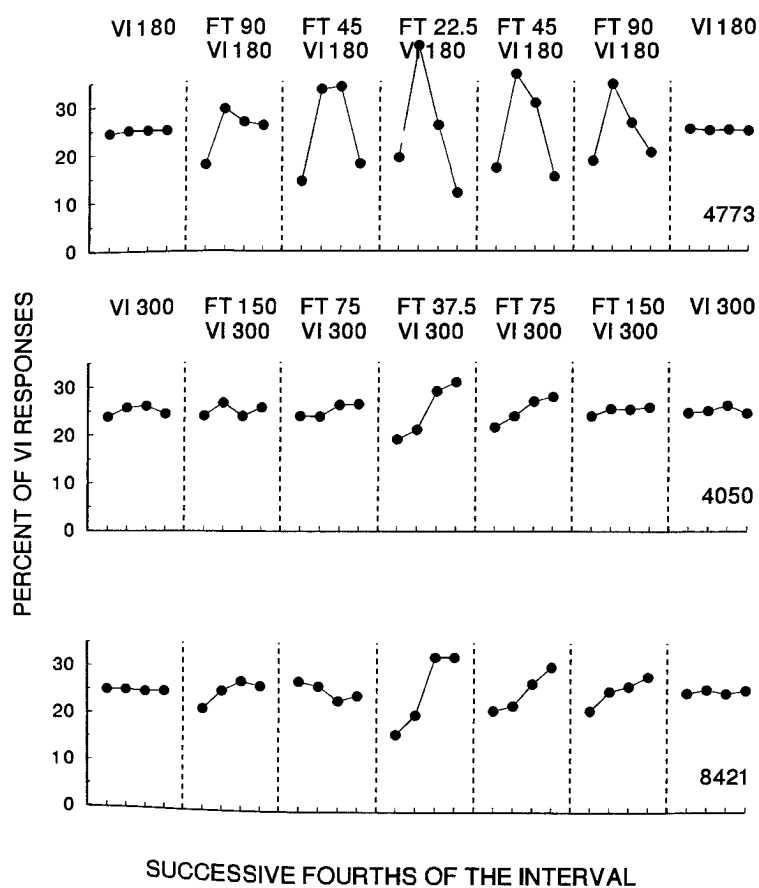

SUCCESSIVE FOURTHS OF THE INTERVAL

Fig. 6. Percentage of total responses in successive quarters of the FT period for each subject in each of the first seven conditions of Experiment 2. Each data point is usually an average over the last seven sessions of each condition; however, in a few instances the data are based on less than seven sessions because of incomplete bin data due to recording difficulties in some of those last seven sessions. Beginning with the first panel on the left, data shown in each panel are based on the following numbers of sessions: Pigeon 4773: 7, 2, 5, 4, 2, 7, 7; Pigeon 4050: 7, 3, 7, 7, 7, 7, 7; Pigeon 8421: 7, 7, 1, 2, 7, 7, 7. All schedule parameters are in seconds.
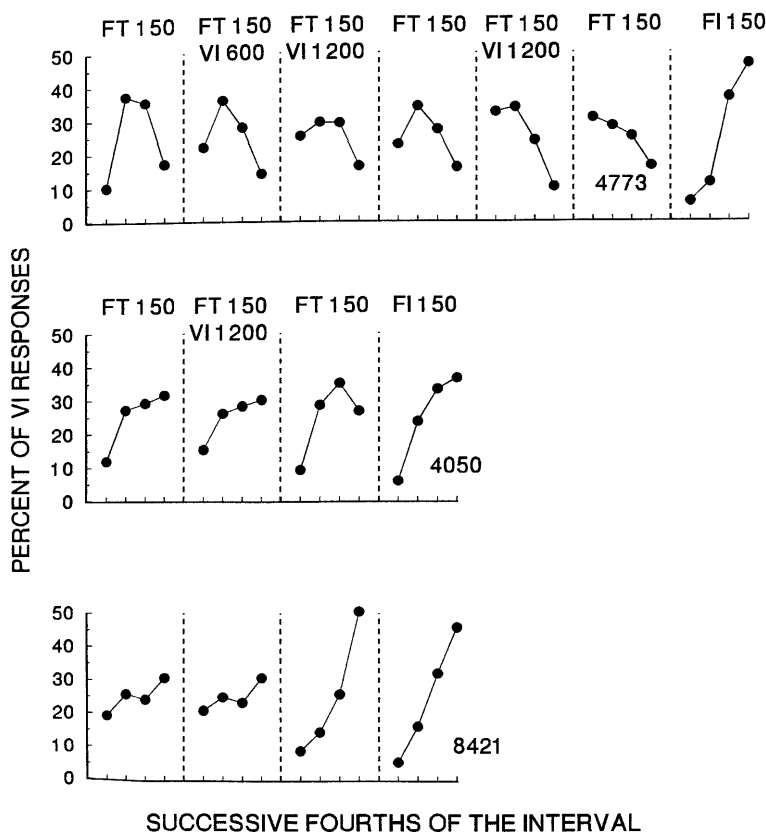
Fig. 7.   Percentage of total responses in successive quarters of the FT period for each subject in each of the last seven (for Pigeon 4773) or five (for Pigeons 4050 and 8421) conditions of the experiment. All schedule parameters are in seconds.

the first experiment above and in Zeiler (1977). An orderly relation between these two variables was found for Pigeon 4773, but for the other 2 pigeons the response rates remained relatively unchanged from the VI-schedule-alone condition until the proportion of response-dependent reinforcers was low or zero, at which point response rates dropped. The higher response rates when VI 600-s or VI 1,200-s schedules were in effect concomitantly with FT compared to those when FT was in effect alone suggest that key pecking of these subjects was affected by even relatively rare response-food dependencies.

Key-peck response patterns across the FT were more variable than those observed in Experiment 1. Excluding the first fourth of the interval, the patterns of Pigeon 4773 resembled the negatively accelerated patterns found in the first experiment. The first fourth of the interval included postfood paus-

es, which may have contributed to the relatively infrequent responding in this interval. During the first two concomitant schedules, the patterns of the other 2 pigeons changed from those seen in VI, but in divergent ways. During and after the FT 37.5-s schedule, responding was positively accelerated. In this second experiment, then, temporal control was manifest as both negatively or positively accelerated responding across the FT period, with the degree of temporal control being a function of the FT value.

In comparing the results of the first two experiments, the differences in response patterns despite similar contingencies in both are not surprising, given the absence of any programmed dependency between responding and food delivery under that schedule. Given this opportunity for variability in responding, perhaps more surprising are the similarities in the results. In neither experi-

ment did overall response rates increase as a function of the large increase in overall food-delivery rate when the FT schedules were intruded. Rather, response rates decreased or did not change as the proportions of VI and FT food changed. Response rates seemingly were not as reliably related to the proportions of VI and FT food presentations as has been found when VT schedules are intruded into a stream of VI-maintained responding. Finally, in both experiments, response patterns changed from linear to something else as a function of the intruded FT schedule. Furthermore, the patterns changed as a function of both the temporal parameters of the schedules and the presence or absence of the FT schedule.

Zeiler (1968) concluded that response rates and response patterns are controlled independently by the response–reinforcer dependency and the temporal distributions of food presentations, respectively. Zeiler's conclusion was based on an analysis of transitions between simple interval and time schedules. The results of Experiments 1 and 2 suggest a more complex relation between response rates and response patterns when response-independent food is added to a stream of operant behavior. The temporal distribution of those presentations may affect not only response patterns, but in so doing also may influence overall response rates as a function of the changes that they cause in local response rates, all of which contribute to the overall response-rate measure. The precise relation between local and overall response rates depends on how and how much local rates change as a function of the intruded FT food. For example, if there are proportional decreases and increases in response rates at the beginning and end of the FT period, respectively, then the average rates will not change from the baseline without the intruded food. It is when the local response rates do not, so to speak, balance out across the FT that overall response rates may not correspond systematically to the proportions of VI and FT food. One final observation in relation to the response rate and pattern data is in terms of using resistance of response rates to intruded response-independent events as an index of response strength or behavioral momentum. Although such events typically have been intruded during a blackout between multiple

schedule components (e.g., Nevin, 1974), it also is conceivable that such response-independent events might be intruded directly into the stream of operant behavior rather than into a blackout between components. The inconsistent relations between response rates and the percentage of response-dependent events found here suggest that this procedure may vary in utility as an index of response strength or behavioral momentum as a function of how (i.e., by what schedule) the response-independent events are intruded.

In the first two experiments, both the correlation of responses with FT food presentations and the proportions of food arranged by the two schedules seemed to play a role in determining the effects of response-independent food in the behavior stream. The correlation of a response that has not been prechosen with FT food delivery was most striking in the first experiment, in which orienting to the feeder developed and was maintained as a function of the FT schedule to some degree with each subject. With Pigeons 4050 and 8421, at least during and after the concomitant VI 300-s FT 37.5-s condition, the positively accelerated response patterns suggest that key pecking itself was functioning as an operant controlled by the FT schedule. In Experiment 1, the response patterns of each animal were more negatively accelerated as the VI schedule was made more lean (hereafter, relatively longer and shorter interfood intervals will be described as leaner and richer, respectively). In Experiment 2, responding by different subjects was either more positively or negatively accelerated as the FT schedule became richer.

These two variables, the correlation of a well-defined response with the intruded schedule and the proportions of food presentations from the operant and intruded schedule, were assessed in the next three experiments, which constituted an analysis of variables that might contribute to an interesting behavioral effect that had been observed in a somewhat different context. As a result, it was of interest to hold some variables constant while varying others. Concurrent schedules were used in all three experiments to demarcate more clearly the VI and FT (or, in some cases, FI) schedules. The concurrent schedules, then, were used not to replicate directly the contingencies investigated in Ex-

periments 1 and 2 but rather as analytic tools to hold constant some variables that were deemed potentially important in determining response patterns while systematically manipulating others. Thus, the procedures in the following experiments should be considered as analogues or models of the procedures in the first two experiments, implemented with the goal of better understanding the controlling variables that operate when response-independent events are intruded into a stream of operant behavior.

EXPERIMENT 3

There are no other reports of operant response patterns across FT interfood periods when concomitant VI schedules are in effect. Zeiler (1968) reported positively accelerated responding across the FT period when an FT schedule was in effect alone following experience on either VI, FI, or VT schedules. Neuringer (1970) provided examples of negatively accelerated responding on both VT and FT schedules alone, but his analysis was confined to the presentation of two representative cumulative records illustrating the effects. Within those records, there was considerable variability in the patterns. Nevin (1971, 1974), however, observed negatively accelerated response patterns consistently during VI schedules when FI schedules, in which a prechosen response was reinforced, were in effect concurrently.

Nevin (1971) trained pigeons on concurrent FI VI schedules in which the two schedules were available simultaneously on two different response keys. The distribution of VI responses across the FI was negatively accelerated and linear, respectively, when an FI 50-s or an FI 200-s schedule was available concurrently. These two response patterns occurred independently of the VI schedule values, and even when equal relative reinforcement rates were in effect with different absolute reinforcement rates (e.g., concurrent FI 50 s VI 90 s vs. concurrent FI 200 s VI 360 s). In Nevin's (1971, 1974) experiments, the two schedules were distinct from one another because each was correlated with a distinct operandum, and a changeover delay (COD) temporally separated responding on one schedule and food delivery on the other. In Experiment 3 the effects of

a prechosen response, reinforced according to an FI schedule, on VI response patterns on a second operandum were compared to those when no prechosen response was required during the comparable FT food schedule.

METHOD

Subjects and Apparatus

Each of 3 male White Carneau pigeons with previous reinforcement schedule experience was maintained at 80% of its free-feeding weight.

An operant conditioning chamber with a work area 38 cm high by 33 cm long by 30 cm wide was used. Two response keys were located on the front work panel with their bases 23 cm from the floor and 6.5 cm on each side of the panel midline. Each key was transilluminated by a white 110-V AC light at all times except during reinforcement. Food consisted of 3-s access to mixed grain in a food hopper that was located behind a feeder aperture (5 cm square) centered between the two keys and with its lower edge 8 cm from the floor. The aperture was lit by a white 110-V AC light during food delivery. General chamber illumination was provided by a 110-V AC houselight located in the lower right corner of the work panel. The houselight remained on throughout the session, except during food delivery. White noise and a ventilation fan masked extraneous noise. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure

Because each bird was experienced with reinforcement schedules, a two-key concurrent schedule was implemented at the outset of the experiment. The left key was correlated with the VI schedule in all conditions, and the right key was correlated with an FI schedule in some conditions. In other conditions the right key remained illuminated but an FT schedule, by definition not correlated with an operandum, was in effect. With the VI schedule, the first left-key peck after the lapse of the interreinforcer interval was followed by food. The VI reinforcers were programmed according to the constant probability distribution suggested by Fleshler and Hoffman (1962). With the FI schedule, the first right-

Table 3

Conditions, ratios of FI or FT to VI food presentations, and number of sessions per condition for each pigeon in Experiment 3. The sequence of the experimental conditions is indicated in parentheses.

Condition	Ratio of FI or FT to VI food	Number of sessions		
		Pigeon B1	Pigeon B2	Pigeon B3
Concurrent FI 30 s VI 360 s[a]	12:1	15 (2)	12 (2)	10 (1)
Concurrent FI 180 s VI 360 s	2:1	10 (1)	10 (1)	10 (2)
Concurrent FI 180 s VI 1,080 s	6:1	10, 10 (4, 7)	14, 12 (3, 7)	10, 15 (3, 7)
Concurrent FI 180 s VI 2,160 s	12:1	11 (3)	15 (4)	10 (4)
Concurrent FT 180 s VI 1,080 s	6:1	12 (5)	10 (6)	10 (6)
Concurrent FT 180 s VI 2,160 s	12:1	10 (6)	10 (5)	13 (5)

[a] Condition analyzed in Experiment 5.

key peck after a fixed period was followed by food. Changes from one key to the other started a 2-s COD, which postponed for 2 s the availability of any reinforcer scheduled on the changed-to key; a peck after the COD was required to collect the assigned reinforcer. Under the FT schedules, food was delivered at regular periods independently of key pecks, as in Experiments 1 and 2. Pecks on the right key when the FT schedule was in effect started a 2-s COD so that VI reinforcers were delayed from pecks on the right key but FT food presentations were independent of VI responding.

Table 3 shows, for each pigeon, the values of the component schedules, the sequence of conditions, and the number of sessions for each condition. The ratio of FI (or FT) to VI food also is shown. When a condition was studied twice, the numbers of sessions in effect during both the first and second exposures are shown. The table shows the sequence of the first and second exposures. One schedule component was always a VI while the other component arranged, at different times in the experiment, either response-dependent (FI) or response-independent (FT) food. The FI or FT schedule remained constant at 180 s while the VI schedule was changed across conditions (VI 360 s, VI 1,080 s, and VI 2,160 s). Thus, FI or FT food was 2, 6, or 12 times more frequent than VI food. (The results of the concurrent FI 30-s VI 360-s schedule are described in Experiment 5.) The order of conditions varied across subjects. Conditions were changed when systematic directional trends in response rates were not observed after a minimum of 10 sessions at each condition (cf. Nevin, 1971). Sessions occurred 5 days per week, at the same time each day, and they terminated after 22 food presentations on the fixed schedule.

RESULTS

Response rates of each subject on both keys during the last six sessions of each condition are shown in Figure 8. Response rates on the right key were consistently higher when the FI was in effect than when the FT was in effect. For each pigeon, left-key response rates controlled by VI 1,080 s and VI 2,160 s were similar when either FI or FT was in effect. Decreases in the VI food rate usually decreased VI response rates and did not systematically change response rates on the right key.

Figure 9 shows the logarithms of the response-rate ratios (FI responses divided by VI responses) as a function of the logarithms of the food-delivery-rate ratios in the two components (FI reinforcers divided by VI reinforcers). Each data point represents values from one of the six stable sessions for each subject shown in Figure 8. Similar data from concomitant FT VI schedules are not shown because the ratio of food deliveries varied over a narrow range, limiting the scope of any prediction. The solid lines were fit by the method of least squares, with the equation of each line given beside it. Slopes of less than 1.0 were obtained consistently, indicating that response ratios were less sensitive to reinforcement ratios than is implied by strict matching. The matching relation also implies an intercept (k) equal to 1.0 (and log k equal to 0). When a food-delivery ratio of 1.0 is not accompanied by a response ratio also equal to 1.0, the intercept differs from 1.0, and preferences are biased toward one of the alter-
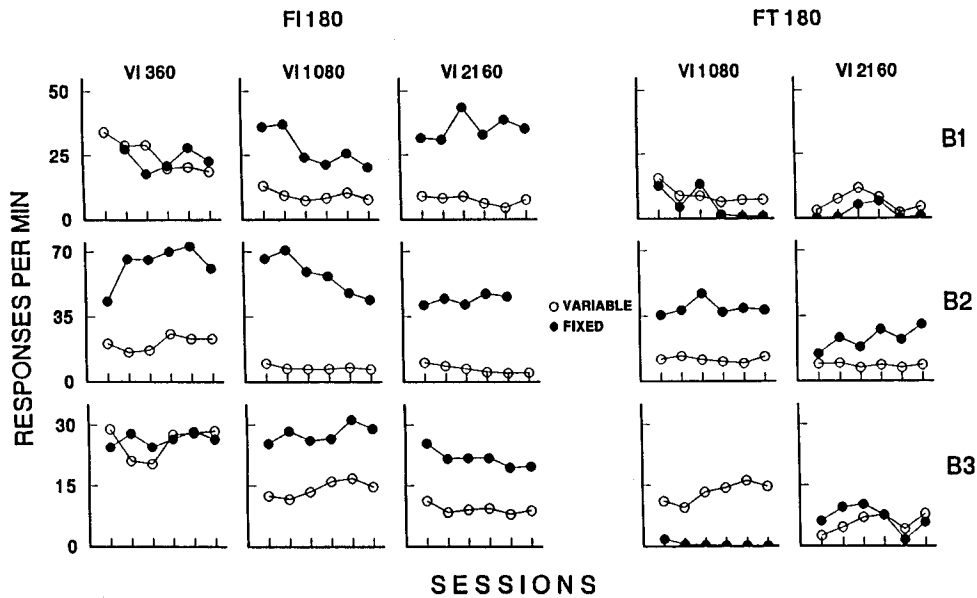
Fig. 8. Response rates for each subject during the last six sessions of each condition in Experiment 3. The conditions involving a concurrently available VI and FI schedule are shown in the graphs on the left and those involving a concomitantly available FT and VI schedule are shown in the graphs on the right. One data point is missing for Pigeon B1 during the concurrent FI 180-s VI 360-s condition and for Pigeon B2 during the concurrent FI 180-s VI 2,160-s condition. All schedule parameters are in seconds.

natives. The pecking of Pigeons B1 and B3 was biased in favor of the VI component (k was equal to 0.81 and 0.89, respectively). For Pigeon B2, pecking was biased toward the FI component (k was equal to 2.69). The proportion of the variance of response ratios that is accounted for by the food-delivery ratios is indicated by r^2.

Figure 10 shows the percentage of responses in successive tenths of the fixed interfood intervals. When a concurrent FI VI schedule was in effect, negatively accelerated response patterns occurred with the two larger ratios of FI to VI food. When the ratio of fixed to variable food was 2:1 (concurrent FI 180 s VI 360 s), the distributions of responses across the fixed time period were not systematic across subjects: For Pigeons B1 and B2, responding after the first tenth of the interval was evenly distributed in successive tenths of the interval; for Pigeon B3, response rate was highest at the beginning of the interval and decreased across the remainder of the intervals. When the ratio of fixed to variable food was 6:1 (concurrent FI 180 s VI 1,080 s), the patterns were accentuated. A similar pattern continued when the ratio

of fixed to variable food was increased to 12:1 (concurrent FI 180 s VI 2,160 s).

In contrast to concurrent FI VI schedules, concomitant FT VI schedules generated less consistent response patterns across the FT (Figure 10). Under concomitant FT 180 s VI 1080 s, Pigeons B1 and B3 showed nearly uniform key-peck responding across the FT, while a negatively accelerated pattern was observed for Pigeon B2. Under concomitant FT 180 s VI 2160 s, a pattern of negatively accelerated response rate across the FT developed for Pigeon B3, while no change was observed from the previous condition in the response patterns of Pigeons B1 and B2. In each case where negatively accelerated responding occurred, it was less marked than that obtained under the equivalent-valued FI schedule.

DISCUSSION

The reinforcement of a prechosen alternative response during a fixed interfood interval makes a pattern of negatively accelerated VI schedule responding more likely and more pronounced than that which occurs in the absence of such a response. These find-
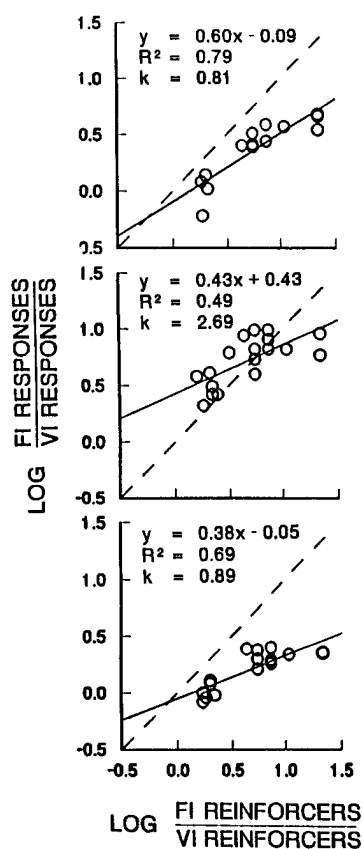
Fig. 9. Logarithms of ratios of responses (FI:VI) as a function of the logarithm of food-delivery rate ratios in the FI and VI components of the concurrent schedule for each pigeon in Experiment 3 (Pigeon B1's data are shown in the top graph and Pigeon B3's are shown in the bottom graph). Each data point is an average of the last six sessions of each condition. All schedule parameters are in seconds.

ings implicate a response–food dependency in the control of negatively accelerated response patterns of the sort reported in Experiment 1. The response–food dependency on the fixed schedule requires that responding be distributed on both operanda for optimal food access. As a result, responding on the FI operandum comes under temporal control. Eliminating the response–food dependency from the fixed schedule renders the operandum irrelevant, creating, as noted above, a single-key procedure identical to that studied in the first two experiments. In the latter case, the degree of negative acceleration was diminished but did not disappear entirely. The continued negatively accelerated

response patterns during the schedules involving FT components may be due in part to the previous history with FI schedules. In each case, the concomitant FT VI schedules occurred after all of the concurrent FI VI conditions. The degree of negative acceleration was greater during the condition that immediately followed the last concurrent schedule and was less in the condition following the concomitant FT VI schedule.

The results of Experiment 3 also suggest that the ratio of response-dependent to response-independent food may be a factor in determining the patterns of responding when response-independent reinforcers are intruded at fixed points in time. In the case of the concurrent FI VI, a ratio of 2:1 favoring FI produced only minimally negatively accelerated response patterns in comparison to that produced by the larger ratios. Furthermore, the pattern of responding changed from linear to negatively accelerated with Pigeon B3 at the most extreme food ratio (12:1) favoring FT (see also Figure 14 below, in which the results of a 12:1 ratio, achieved with a concurrent FI 30-s VI 360-s schedule, are analyzed). With Pigeon B2, the pattern became increasingly negatively accelerated as the ratios increasingly favored the FT schedule. The contribution of the ratio of food from the different schedules was examined in greater detail in the next two experiments.

EXPERIMENT 4

In Experiment 4 the ratios of response-dependent to response-independent food were varied across several combinations of rates of food arranged by VI and FT schedules. Because the spatio-temporal separation of the schedules affects response patterns, a schedule requiring a changeover response (Findley, 1958) was used to distinguish the two schedules. Thus, although food occurred independently of responding in the presence of the FT discriminative stimulus, the food depended on a response on the changeover operandum.

METHOD

Subjects and Apparatus

Each of 3 White Carneau pigeons with prior reinforcement schedule experience was maintained at 80% of its free-feeding weight.

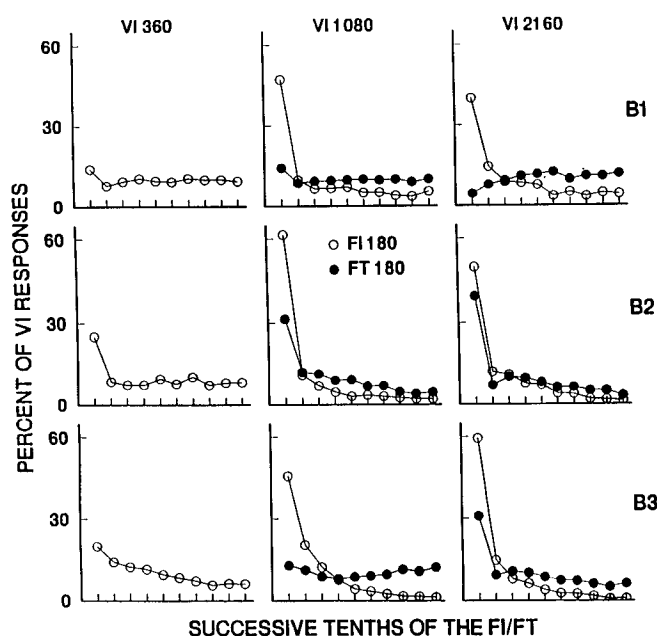The apparatus was similar to that used in the

Fig. 10. Distribution of VI responses across successive tenths of the fixed interreinforcer intervals for each subject in Experiment 3. Each data point is an average of the last six sessions of each condition. All schedule parameters are in seconds.

third experiment, except in the following ways. The two keys were located 27 cm from the chamber floor and were separated by 5 cm; the right key was located 8.5 cm from the right side wall, and the left key was located on the panel midline and 15 cm directly above the top of the feeder aperture; a blue light illuminated the right key and either a red or a white light illuminated the left key, depending on whether the schedule in effect was FT or VI.

Procedure

Because key pecking had been established previously, each pigeon was exposed directly to a concurrent FT VI schedule arranged using a changeover-key procedure. Both schedule components were correlated with a different color on the left key (main key). A single peck on the right, changeover, key changed the key color and schedule on the main key. When the main key was transilluminated red or white, FT or VI, respectively, was in effect. Both components operated independently in that the interfood intervals of each schedule continued to time (until a reinforcer for that schedule was assigned) when either schedule was in effect. Once food was scheduled in a given component, it remained available until

collected. A COD prevented the delivery of food within 2 s of a changeover.

The FT and VI values, the sequence of conditions, and the ratios of FT to VI food for each condition are shown in Table 4. When a condition was in effect twice, the number of sessions for each exposure is shown. The sequence numbers of the first and second exposures are shown. The order of conditions differed for each subject. Conditions were changed after a minimum of 10 sessions and when the percentage of time spent in the FT component met two stability criteria. First, for any six consecutive sessions, the mean of the first three sessions could not differ more than 3% of the mean of the last three sessions. Second, an absence of directional trends over the six sessions was required. Sessions were conducted at the same time 5 days per week, and each session lasted until the next available food delivery after 2,700 s occurred, thereby ensuring that the session ended after an FT food delivery.

RESULTS

The time allocated to each component during each of the last six sessions of each condition is shown in Figure 11. For each

Table 4

Conditions, ratio of FT to VI food presentations, and number of sessions per condition for each bird in Experiments 4 and 5. The sequence of conditions is indicated in parentheses.

Condition	Ratio of FT to VI food	Number of sessions		
		Pigeon B4	Pigeon B5	Pigeon B6
Experiment 4				
Concurrent FT 60 s VI 20 s	1:3	19 (7)	10 (8)	10 (2)
Concurrent FT 60 s VI 60 s	1:1	13, 11 (5, 8)	12, 16 (6, 9)	15 (10)
Concurrent FT 60 s VI 180 s	3:1	10 (6)	15 (7)	12 (11)
Concurrent FT 120 s VI 40 s	1:3	10 (3)	12 (3)	14 (3)
Concurrent FT 120 s VI 120 s	1:1	11 (1)	10, 12 (1, 5)	12, 14 (1, 5)
Concurrent FT 120 s VI 360 s	3:1	11, 10 (2, 13)	11, 10 (2, 15)	14, 13 (2, 14)
Concurrent FT 240 s VI 80 s	1:3	10 (11)	10 (12)	10 (8)
Concurrent FT 240 s VI 240 s	1:1	11 (9)	17 (10)	15, 18 (6, 9)
Concurrent FT 240 s VI 720 s	3:1	10 (10)	26 (11)	21 (7)
Experiment 5				
Concurrent FT 30 s VI 90 s	3:1	20 (12)	10 (13)	10 (13)
Concurrent FT 30 S VI 360 s	6:1	14 (4)	11 (4)	12 (4)
Concurrent FT 30 s VI 720 s	9:1	10 (14)	19 (14)	13 (15)
Concurrent FT 240 s VI 360 s	3:2	10 (15)	21 (17)	18 (16)
Concurrent FT 480 s VI 720 s	3:2	21 (16)	12 (16)	19 (17)

bird, the time allocated to the two components was directly related to the relative rate of FT and VI food, regardless of the absolute schedule values. When the interfood intervals of the two schedules were equal, more time was allocated to the VI. In Figure 12, the logarithms of the time allocated to either component are shown as a function of the logarithms of the food ratios. The solid lines were fit by the method of least squares. The equation describing each line is presented in the upper left corner of each graph, along with r^2 and the antilogarithm of the intercept (k).

In general, for each pigeon, the data conformed to the matching relation, but with a bias toward the VI. The proportion of the variance accounted for by the line of best fit was $\geq .90$ for each pigeon.

The distribution of VI responses across successive tenths of the FT is shown in Figure 13. When the ratio of FT to VI food was 1:3 (concurrent FT 60 s VI 20 s, concurrent FT 120 s VI 40 s, and concurrent FT 240 s VI 80 s), approximately linear VI response patterns followed by a peak in responding after the FT interval had lapsed (Bin 11) were obtained.
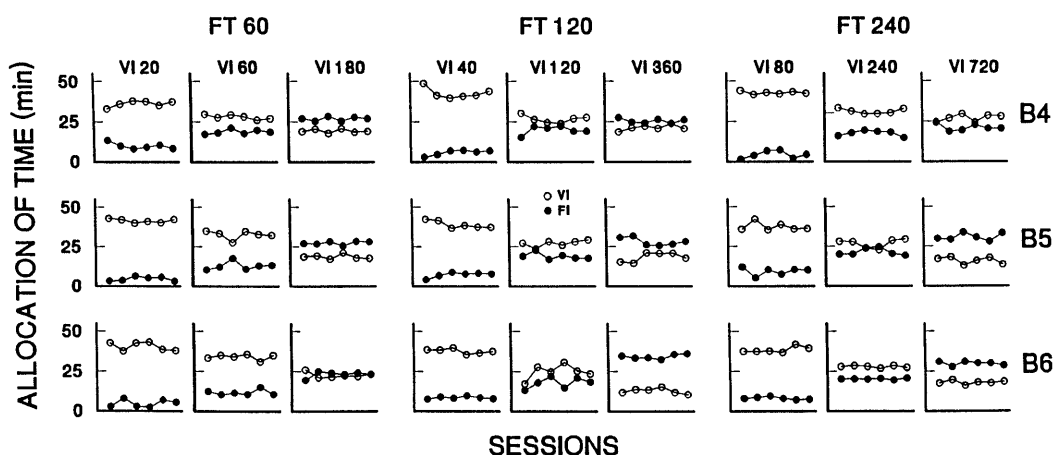

Fig. 11.   Time allocated (in minutes) to each component during each of the last six sessions of each condition for each pigeon in Experiment 4. All schedule parameters are in seconds.
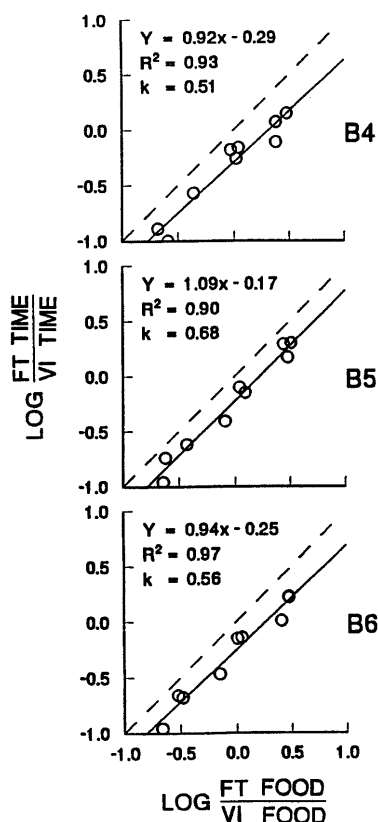
Fig. 12. Logarithms of the ratios of time spent in each component (FT:VI) as a function of the logarithm of the food ratios in the FT and VI components of the concurrent schedule for each subject in Experiment 4. Each data point is the average of the last six sessions of each condition. All schedule parameters are in seconds.

For Pigeons B5 and B6, the percentages of VI responses after the FT period had elapsed decreased as the absolute rate of FT and VI food increased.

When the ratio of FT to VI food was 1:1, the patterns of VI responses remained linear throughout most of the FT period, but with slight peaks in the percentage of responses at different points during the interval depending on the FT and VI absolute values. Under concurrent FT 60 s VI 60 s, all pigeons key pecked more often either near the beginning or at the end of the FT period. Under concurrent FT 120 s VI 120 s, most responding occurred after the FT had lapsed, as indicated by the elevated data point in Bin 11. Under concurrent FT 240 s VI 240 s, VI response rate was slightly higher at the beginning of the FT interval and was slightly lower in Bin 11.

When the ratio of FT to VI food was 3:1 (concurrent FT 60 s VI 180 s, concurrent 120 s VI 360 s, and concurrent FT 240 s VI 720 s), negatively accelerated VI response patterns occurred. The degree of negative acceleration tended to be greater with the higher absolute rates of FT and VI food (concurrent FT 60 s VI 180 s). Under this latter schedule, Pigeons B4 and B5 did not begin VI responding until the second tenth of the interval, that is, after about 3 s, likely reflecting a combination of postfood pausing and time spent changing over from the FT to the VI schedule.
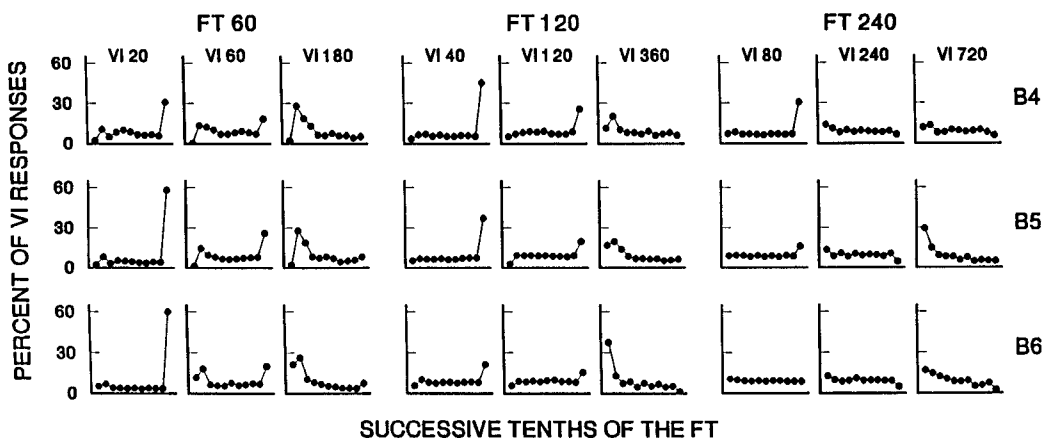

Fig. 13. Percentage of total VI responses in successive tenths of the FT period for each subject in Experiment 4. The 11th bin in each graph shows the percentage of total responses that occurred after the FT had lapsed but before the animal next changed over to that schedule. Each data point is the average of the last six sessions of each condition. All schedule parameters are in seconds.

DISCUSSION

When the FT value was constant, negatively accelerated response patterns were more likely when the VI schedule was leaner. Such patterns also were more likely when the FT schedule was richer. These results confirm and extend the general observations in Experiments 1 through 3 that ratios of FT to VI food favoring the FT are more likely to result in deviations from equal responding across the fixed period. However, equivalent ratios generated by different values of the two schedules did not yield the same patterns, suggesting that the negatively accelerated response patterns also depend on the absolute values of the FT schedule. For example, both the concurrent FT 60-s VI 120-s and the FT 240-s VI 720-s schedules yielded food-presentation ratios of 3:1 favoring the FT schedule, but negatively accelerated responding was more marked when the former schedule was in effect. The role of the absolute values of the schedules in yielding negatively accelerated response patterns was examined further in the final experiment.

EXPERIMENT 5

The effects of absolute FT values on response patterns were studied by combining the result of several manipulations in Experiment 5 with data from Experiments 3 and 4. First, the effects of variations in the rate of VI food were studied as a function of a rich FT schedule held constant at 30 s. Second, the effects on response patterns were studied as a function of constant VI schedules while the FT schedule value was varied from rich to lean.

METHOD

Subjects and Apparatus

Pigeons B4, B5, and B6 from Experiment 4 were studied.

The apparatus was the same as that in the second experiment.

Procedure

The same changeover-key procedure described in Experiment 4 was used. The sequence of conditions, the ratios of FT to VI food, and the number of sessions for each experimental condition are shown in Table 4.

In the first three conditions, the FT remained constant at 30 s and the VI was varied from 90 s to 360 s to 720 s across conditions. In the next two conditions, the values of both FT and VI schedules were changed (concurrent FT 240 s VI 360 s, concurrent FT 480 s VI 720 s) but the ratio of FT to VI food was constant at .60. The stability criterion described in Experiment 4 also was used in this experiment.

RESULTS

Figure 14 shows the distribution of VI responses across successive tenths of the FT when the FT was fixed at 30 s and the absolute VI food rate varied across sessions. Data from the concurrent FI 30-s VI 360-s schedule obtained with the two-key concurrent schedule described in Experiment 3 are included for comparison. The same general pattern occurred in each condition, regardless of the absolute rate of VI food and therefore regardless of the ratios of FT to VI food. Responding was infrequent or did not occur in the first bin, accelerated rapidly to a peak in Bin 3 or 4, and then rapidly decelerated to food delivery. Comparing across subjects, negatively accelerated response patterns occurred in both concurrent FT 30-s VI 360-s and concurrent FI 30-s VI 360-s schedules. Patterns similar to the ones shown in Figure 4 were seen in Experiment 2 with Pigeon 4773 and during the concurrent FT 60-s VI 180-s condition of Experiment 4. In the present experiment in particular the interfood intervals were 30 s so that the size of each bin was only 3 s. As a result, pausing or changing over to the alternative schedule after FT food reduces the number of responses in the first and perhaps subsequent bins, reflected in the data as low or 0% responses.

Figures 15 and 16 show the distribution of VI responses across the FT when it was varied while holding the VI constant. Data previously collected in Experiment 4 and presented in Figure 13 (in which data are presented as the concurrent FT 120-s VI 360-s and concurrent FT 240-s VI 720-s conditions) and Figure 14 (in which data are presented as the concurrent FT 30-s VI 360-s and concurrent FT 30-s VI 720-s conditions) are included. In general, response patterns were more negatively accelerated when the richer FT schedules were in effect. Consistent differences in
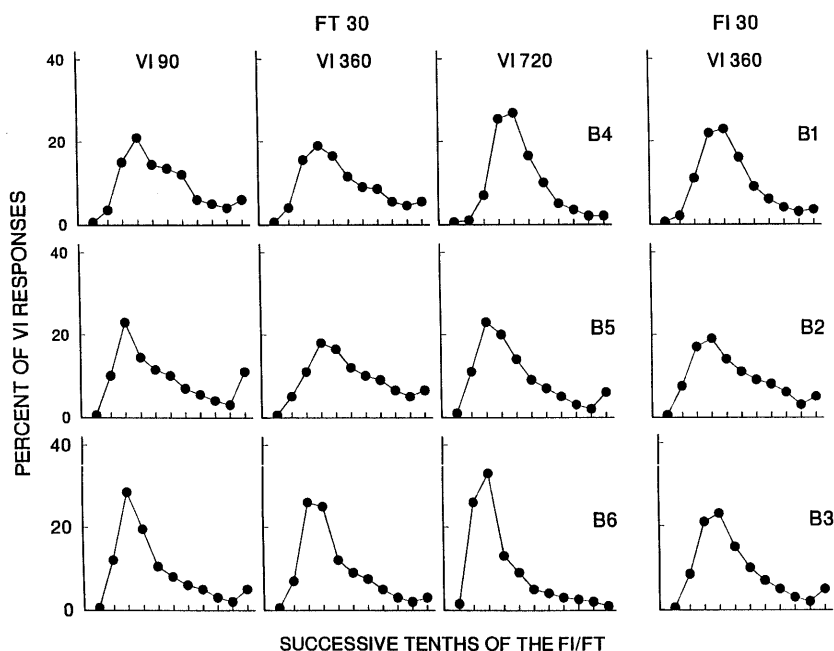
Fig. 14. Percentage of total VI responses in successive tenths of the FT 30-s component for each subject in Experiment 5 as a function of VI schedule value. The 11th bin in each graph depicts the proportion of total responses that occurred after the FT had lapsed but before the pigeon changed over to the FT component. The distribution of VI responses over successive tenths of the FI 30-s component for each subject in Experiment 3 is also shown in the graphs on the extreme right. Each data point is the average of the last six sessions of each condition. All schedule parameters are in seconds.

patterns as a function of the VI value were not observed.

DISCUSSION

Short FT (Experiment 5) and FI (Experiment 3) interfood intervals engendered similar negatively accelerated response patterns independently of the ratio of FT to VI food, suggesting the importance of absolute FT food rates in the appearance of such patterns. The effect of the absolute FT value on the development of negatively accelerated responding is illustrated further by the results shown in Figures 15 and 16, in which negatively accelerated response patterns were generally more pronounced when FT interfood intervals were shorter under constant VI schedules. Of course, in these figures the FT to VI food ratios also increasingly favored the FT.

The results of Experiments 4 and 5 together suggest that a rich FT schedule, in either relative or absolute terms, makes temporal control of responding more likely, provided that the behavior correlated with either schedule is distinct. One qualification, however, is that when both schedules are lean, temporal control of responding by the FT schedule is diminished. The results of these two experiments, using a procedure in which the distinctiveness of the schedules is more precisely specified, also help to clarify the relations between the schedule values and response patterns observed in Experiments 1 and 2. In Experiment 1, negatively accelerated responding became more pronounced as the VI schedule was made leaner. In Experiment 2, the response patterns of both Pigeons 4050 and 8421 displayed the most positively accelerated responding when the richest FT schedule (37.5 s) was in effect. With Pigeon 4773, the greatest proportion of the responses in the second quarter and the lowest proportion of responses in the fourth quarter of the fixed period also occurred when FT food delivery was most frequent.

The diminished temporal control shown in Experiments 4 and 5 with lean VI and FT schedules makes the strong temporal control found in Experiment 1, in which quite lean
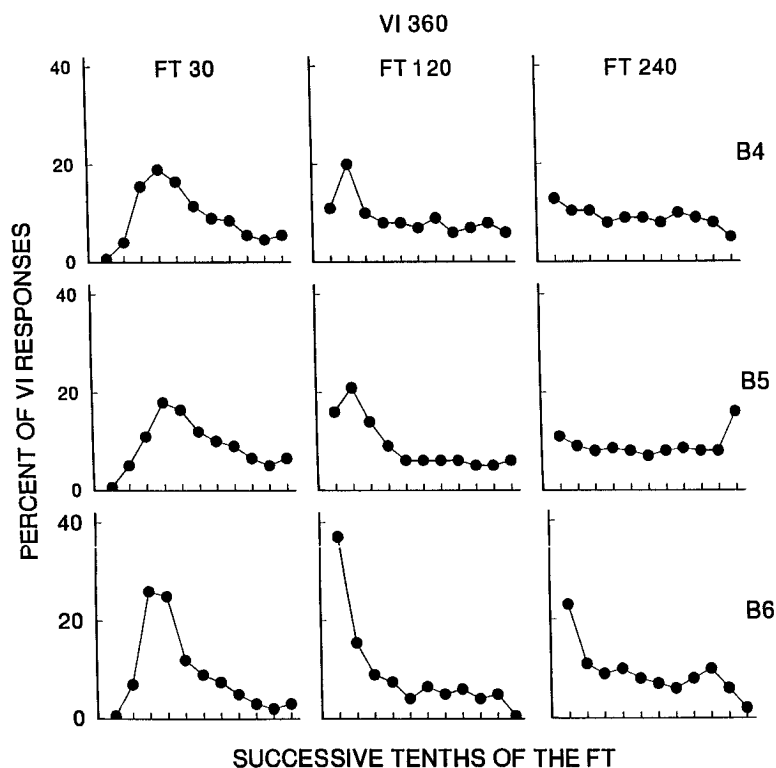
Fig. 15.   Percentage of total VI responses in successive tenths of the FT component for each subject under concurrent FT 30-s VI 360-s, FT 120-s VI 360-s, and FT 240-s VI 360-s schedules in Experiment 5. The 11th bin in each graph depicts the proportion of total responses that occurred after the FT had lapsed but before the pigeon changed over to the FT component. Each data point is the average of the last six sessions of each condition. All schedule parameters are in seconds.

FT and VI schedules were employed, even more surprising. This latter finding reinforces the conclusion that, although the values of the component schedules were important, other variables such as the distinctiveness of the responses correlated with each schedule, either by accident or by design, also play a role in determining the effects of intruded response-independent events.

GENERAL DISCUSSION

The effects observed in the first two experiments were analyzed in the last three in terms of the contributions of variables related to both reinforcement and stimulus control. The reinforcement variable of interest here, the response–food relation, was manipulated by varying the proportions and rates of response-dependent food presentations. Response rates were not consistently related to the proportions of VI food presentations

when the concomitant schedule was an FT, but relative response rates were more consistent with relative food rates under concurrent FI VI, in which a constant relation was maintained between each operant and its reinforcer. The ratio of FT to VI food strongly influenced response patterns. This ratio may in turn have its effects as a result of, or at least in concert with, discriminative processes that operate when response-independent food is intruded into a stream of operant behavior.

Both the response–food relation and the temporal aspects of the food schedule were potential sources of discriminative stimulus control of responding in the present experiments. To the extent that response-dependent and response-independent food presentations are detected as distinct, they may control responding differentially through a discriminative, as distinct from a reinforcement, process. For example, Burgess and Wearden (1986) proposed a model for de-
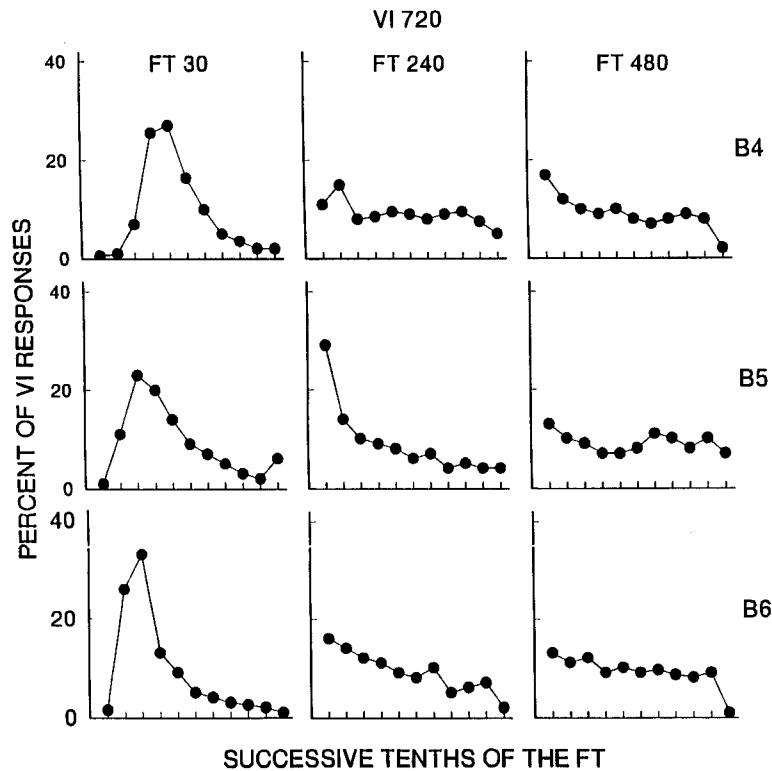
Fig. 16.   Percentage of total VI responses in successive tenths of the FT component for each subject under concurrent FT 30-s VI 720-s, FT 240-s VI 720-s, and FT 480-s VI 720-s schedules in Experiment 5. The 11th bin in each graph depicts the proportion of total responses that occurred after the FT had lapsed but before the pigeon changed over to the FT component. Each data point is the average of the last six sessions of each condition. All schedule parameters are in seconds.

scribing the effects of intruded response-independent food that relies heavily on quantifying the discriminative properties of the response–reinforcer relation. The difficulty with the model is that it does not suggest an index of the discrimination that is independent of response rates. Nonetheless, a discriminative process like that suggested by Burgess and Wearden may have operated during Experiment 1, in which distinct responses developed during the two concomitant schedules and negatively accelerated keypeck response distributions were obtained. In Experiment 3 the two response–reinforcer relations were the same for both the FI and the VI components of the concurrent pair, but each was correlated with a topographically distinct operant response; again, the response patterns during VI may suggest discriminative control of responding as a function of the food source location, that is, the two response keys.

The control of behavior may depend in part "on the degree to which differential reinforcement contingencies are associated with responding at values along the [temporal] dimension" (Lund, 1976, p. 156). In reinforcement schedules, temporal control can be said to occur when the temporal distribution of responding is controlled by the temporal distribution of reinforcers. As noted in the discussion sections of Experiments 1 and 2, when reinforcers occur at fixed temporal points, two types of distributions of responses within the interreinforcer interval offer evidence for temporal control. The most common is a positively accelerated distribution of responses across the interreinforcer interval of the sort often observed on FI schedules (but see also Ferster & Skinner, 1957, and Schneider, 1969, for descriptions of break-and-run FI patterns). Break-and-run patterns still can be considered positively accelerated; it is only that a pause in responding is fol-

lowed by an *abrupt* acceleration to the terminal response rate. Temporal control also is manifest by a negatively accelerated distribution of responses across the interreinforcer interval. Examples of both types of temporal control were seen in the present experiments.

Lund (1976, Experiment 1) showed how temporal control over a single key-peck response develops as a function of the distribution of interfood intervals. He gradually transformed FI schedules to VI schedules by systematically varying the probability of FI and VI components in a mixed schedule. As the probability of a FI component increased, that is, as responding increasingly was differentially reinforced with respect to time, response patterns became increasingly positively accelerated. In Experiment 3, temporal stimulus control of VI responding by the FI schedule, as evidenced by the degree of negatively accelerated response patterns, increased as the relative rate of FI reinforcement increased. Similar temporal control with FT schedules was observed when the FT schedule was correlated with a distinct stimulus in Experiment 4. In Experiment 5, in which the FT schedule was rich, negatively accelerated response patterns were observed across several different-valued VI schedules. The present results, in conjunction with Lund's earlier findings, suggest that temporal stimulus control by an intruded event is more likely the more regularly that that event occurs relative to the other events. Whether the expression of that temporal stimulus control is a positively or negatively accelerated response pattern may depend on other variables, such as the presence or absence of distinct responses correlated with each schedule.

Whether the discrimination of the response–food relation and the temporal control of responding by the fixed schedule are distinct behavioral processes cannot be answered unequivocally on the basis of the present experiments. We think it likely that the detection of the response–food relation in Experiments 1 and 3 was the basis for at least a portion of the temporal control manifested by the subjects in those experiments because of the distinct responses that were correlated with the component schedules. In the case of Pigeons 4050 and 8421 in Experiment 2,

which both developed positively accelerated patterns of key pecking, the temporal control may have been more directly a function of the temporal placement of the reinforcers and less a function of detection of the response–food relations as such. The pecking of these pigeons was relatively insensitive to the changing proportions of FT and VI food, which might be taken as support for a failure to discriminate the VI and FT food except for two reasons. First, the response rates of Pigeon 4067 in Experiment 1 were not sensitive to the changing proportions of response-dependent food, but its response patterns were markedly negatively accelerated, suggesting control by the FT schedule of another response, as previously noted. Second, the picture is further complicated by the interplay between local and overall response rates as discussed at the conclusion of the second experiment. This analysis simply underlines the complexity of disentangling controlling variables in the in vivo arrangements of Experiments 1 and 2 and the value of procedures like those used in the last three experiments in terms of isolating controlling variables.

Another source of discriminative control of responding in the present experiments is the food itself. The same food type, mixed grain, was arranged by both schedules. When a response is reinforced, the reinforcer can function as a discriminative stimulus that evokes further responding (cf. Cruse, Vitulli, & Dertke, 1966). When an identical food presentation to the reinforcer is intruded as a response-independent event, it too may evoke the operant response. One obvious way of distinguishing the events is by making them physically distinct—dry rat pellets and condensed milk, for example. Other ways of making the food distinct were included in the present experiments. In Experiment 3 the same type of food was correlated with different operanda, and in Experiments 4 and 5 the two events were made distinct by correlating distinct stimuli with each one, with the effect that temporal patterning developed and was maintained.

The reinforcement and stimulus variables described above operate in concert with one another to yield the in vivo effects of response-independent events intruded into the behavior stream. Other types of variables that will influence the effects of intruded events

include the composition of the behavior stream, as the experiments reviewed in the introduction suggest, and the nature of the intruded event itself. Intruded response-independent events in natural settings are likely to be more diverse than the ones studied here, not necessarily similar to events that function as reinforcers, and sometimes may be negative (i.e., aversive) rather than neutral or positive. For example, foraging animals may encounter prey that inflict injury on them, an event that can occur independently of the foraging animal's behavior but may profoundly influence the animal's future actions. Yet many, if not most, intruded response-independent events are without behavioral effect. If it were otherwise, the organism's behavior would be capricious, changing constantly in response to randomly occurring events and perhaps at the expense of changing in response to the consequences of its actions. The detection, or lack thereof, of such intruded response-independent events and their differential effects on behavior, as revealed in the present experiments, therefore constitutes an important element in the understanding of adaptive behavior.

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