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FIXED AND VARIABLE SCHEDULES OF RESPONSE-INDEPENDENT REINFORCEMENT[1]

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After response-dependent reinforcement established key-pecking as the predominant response, pigeons received schedules in which reinforcements occurred without reference to responding. These response-independent schedules involved either a reinforcement every 5 min, or reinforcements at irregular intervals that averaged 5 min. The response-independent schedules generated characteristic patterns of responding. The fixed schedule produced positively accelerated responding between reinforcements, and the variable schedule produced either steady rates, erratic, or negatively accelerated patterns. The patterns developed independent of the distribution of responses existing when the schedule was first imposed. The rate of responding varied for the three birds, but, for all, response-independent schedules decreased the rates below the level maintained by response-dependent reinforcement. Although the rate of responding was affected primarily by the events contiguous with reinforcement, the pattern of responding appeared to be determined mainly by the presentation of reinforcements in relation to time.

Responses immediately preceding reinforcement become more probable in the future whether or not the availability of reinforcement depends on them. By having reinforcement dependent on a certain response the experimenter controls the behavior that will be strengthened. Responses can be predicted because the schedule prescribes the specific events that occur just before a reinforcement. In the absence of such specification the experimenter cannot state in advance the behavior that will become most probable. Since any response may precede reinforcement, and whatever happens to occur will become more probable in the future, reinforcement is adventitiously rather than deliberately correlated with a particular response (Morse and Skinner, 1957; Skinner, 1948). The phenomenon of adventitious strengthening emphasizes that reinforcement operates on ongoing responding to determine subsequent behavior.

Response-dependent reinforcement not only alters response probabilities but also determines the distribution of a substantial number of responses over time (Ferster and Skinner, 1957; Morse, 1966). Distinctive patterns of responses occur between reinforcements. Although similar to response-dependent reinforcement in affecting the probability of responses, information about the ability of response-independent reinforcement to control patterns of responding is limited. Herrnstein and Morse (1957*b*) and Appel and Hiss (1962) combined a schedule of response-dependent reinforcement with one providing reinforcements after regular time intervals without reference to responses. They reported that responding was positively accelerated. There are no known published studies of either response-independent reinforcement presented at variable times, or on the temporal distribution of responses with schedules of response-independent reinforcement used alone. In the present experiment, the only requirement for reinforcement was elapsed time, but the schedules differed in whether reinforcements occurred regularly (fixed-time) or irregularly (variable-time). The purpose of varying reinforcement regularity was to observe the temporal distribution of responses occurring with different response-independent schedules.

Response-independent reinforcement is studied more easily if the response is known, rather than if the experimenter must wait for some behavior to emerge through adventitious

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reinforcement. Several experimenters trained animals to produce a certain response by making reinforcement dependent on it, and then studied the response under schedules not involving the dependency (Appel and Hiss, 1962; Herrnstein, 1966; Herrnstein and Morse, 1957*b*). The present experiment utilized a similar procedure.

METHOD

Subjects

Three adult White Carneaux pigeons were maintained at 80% of their free-feeding weights. All three had served previously in experiments involving the differential reinforcement of responding to three simultaneously presented stimuli. Birds 16 and 45 had received fixed-ratio schedules, and Bird 14 had received variable-interval and variable-ratio schedules.

Apparatus

The experimental chamber was similar to the unit described by Ferster and Skinner (1957). A standard response key (R. Gerbrands Co.), operated by a peck with a minimum force of 12 g, was transilluminated by either blue or orange 7-w lamps. A 2-in. square opening located 3 in. below the key provided occasional access to mixed grain for 3 sec. Two 6-w white lamps illuminated the opening during food presentation. White noise masked extraneous sounds. Standard relay programming and recording equipment was located in an adjoining room.

Procedure

Experimental sessions were conducted daily from Monday through Friday. Each session ended after 35 reinforcements.

The blue and orange lights were presented alternately. All reinforcements occurred in the presence of the blue stimulus. The orange stimulus came on after each reinforcement and lasted for 1 min.

The schedules of reinforcement were either fixed-interval, variable-interval, fixed-time, or variable-time. With fixed-interval schedules, a reinforcement followed the first response after 5 min in the presence of the blue stimulus (FI 5-min). With variable-interval schedules, a reinforcement followed a response after irregular periods in the presence of the blue stimulus. The mean interval between reinforcements was about 5-min (VI 5-min). The schedules of response-independent reinforcement (fixed- and variable-time) corresponded to those involving a response dependency. Reinforcements occurred after either a fixed time of 5 min in blue (FT 5-min), or after variable times averaging 5 min (VT 5-min). The tape controlling both variable schedules contained 14 different intervals; their order, in seconds, was: 100, 556, 24, 43, 562, 52, 246, 664, 26, 78, 212, 675, 64, 454. After every six or seven intervals, an interval of 300 sec was interpolated.

Since they correlated the blue light and the operation of the grain feeder without reference to responding, the response-independent schedules were Pavlovian conditioning procedures. The blue light was the conditioned stimulus, and the operation of the feeder was the unconditioned stimulus. The orange light provided a distinctive intertrial stimulus.

Table 1 shows the order of schedules and the number of days with each. Bird 14 started with the fixed response-dependent schedule (FI 5-min) and then had the fixed response-independent schedule (FT 5-min). Starting

Table 1
Sequence of Schedules

Bird 14		*Bird 16*		*Bird 45*	
Schedule	*Days*	*Schedule*	*Days*	*Schedule*	*Days*
FI 5-min	16	VI 5-min	11	VI 5-min	8
FT 5-min	3	FT 5-min	21	FT 5-min	11
VI 5-min	16	FI 5-min	14	FI 5-min	10
FT 5-min	23	VT 5-min	10	VT 5-min	9
FI 5-min	15	VI 5-min	20	VI 5-min	19
VT 5-min	10	FT 5-min	10	FT 5-min	10
VI 5-min	19	FI 5-min	12	FI 5-min	12
FT 5-min	10	VT 5-min	10	VT 5-min	10
FI 5-min	13	FT 5-min	8	FT 5-min	8
VT 5-min	10				
FT 5-min	2				

with the third schedule for Bird 14 and the first for Birds 16 and 45, all birds had the same sequence. The fixed response-independent schedule (FT) followed the variable response-dependent schedule (VI), and the variable response-independent schedule (VT) followed the fixed response-dependent schedule (FI). The last schedule for all birds involved a change directly from variable to fixed response-independent reinforcement (VT to FT).

RESULTS

Various conditions preceded the response-independent schedules. The sequences used were: FI to FT (only Bird 14), VI to FT, FI to VT, and VT to FT. These will be considered in the order in which they were imposed. Since there was little or no responding in the presence of the orange stimulus after the first few days of the experiment, only behavior in the presence of the blue stimulus is considered.

Bird 14 had FI and FT as the first two schedules. Figure 1 shows the behavior on the last day of FI and the final (third) day of FT. The two notable features of these data are the rates and the patterns of responding. The FI schedule produced considerably more responding than did FT: the number of responses per session decreased progressively over the three days of FT. Despite the marked differences in response rate, similar patterns of responding occurred in the individual intervals of either condition. Both revealed a pause after reinforcement followed by positively accelerated responding extending to the next reinforcement. The change from response-dependent FI reinforcement to response-independent FT reinforcement changed the rate but left the pattern stable.

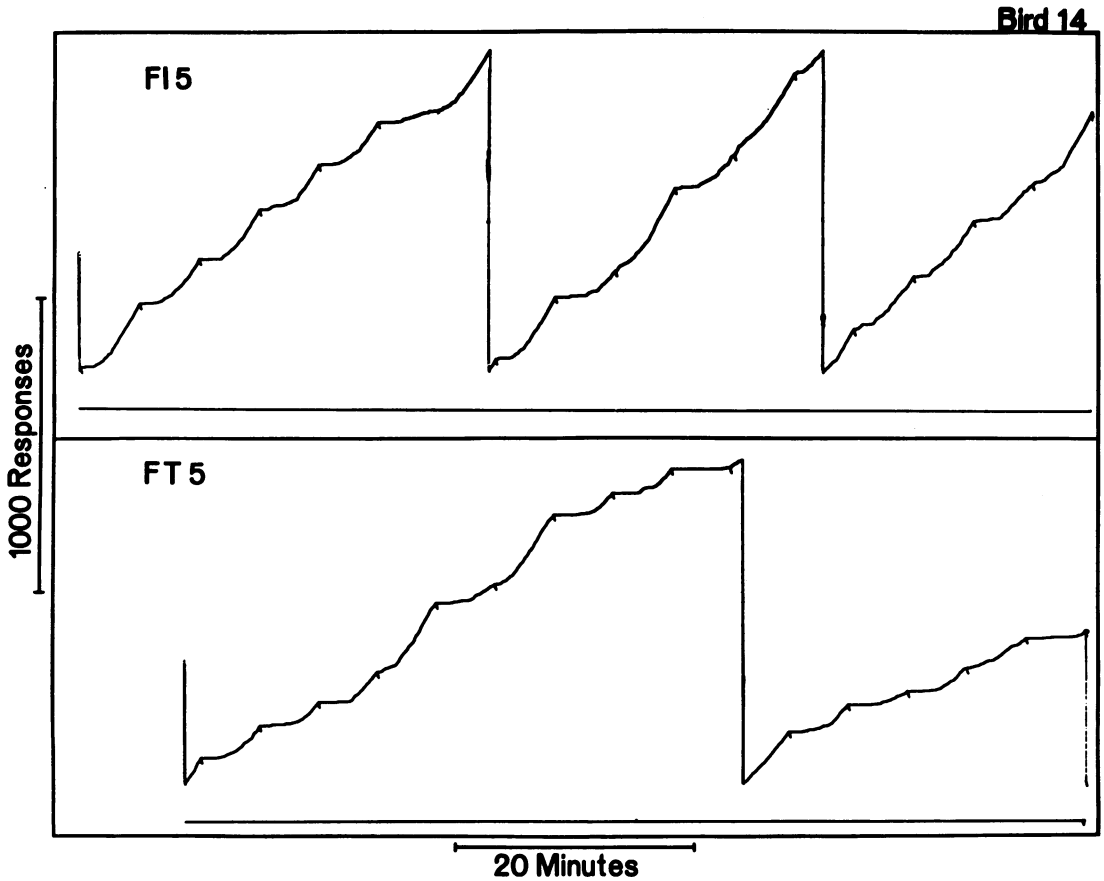

Fig. 1. Cumulative records of Bird 14 for the last day of the fixed response-dependent schedule (FI 5-min) and the third day of the fixed response-independent schedule (FT 5-min). The records are for the final portion of each session. Diagonal offsets of the pen indicate delivery of food. The recorder stopped during food presentations and while the orange stimulus was on. The response pen reset after 1100 responses.

The FT schedule maintained the temporal distribution of responses established by FI.

All other changes involved switches from variable to fixed or fixed to variable schedules and revealed that response-independent schedules established characteristic patterns even when they followed a schedule that controlled a different pattern. A single summary statistic expressing the temporal distribution of responses during intervals (positively accelerated, negatively accelerated, or steady responding) is the quarter-life of each interval (Herrnstein and Morse, 1957*a*). The quarter-life may be defined as the proportion of the interval required for the emission of the first quarter of the total number of responses made in the interval. Responding at a steady rate results in a quarter-life of 0.25, positive acceleration produces a quarter-life greater than 0.25, and negative acceleration results in a quarter-life less than 0.25.

Figure 2 shows the quarter-life for each session for the FT schedules following VI and the VT schedules following FI, together with the quarter-life for the last session of the response-dependent schedule preceding each

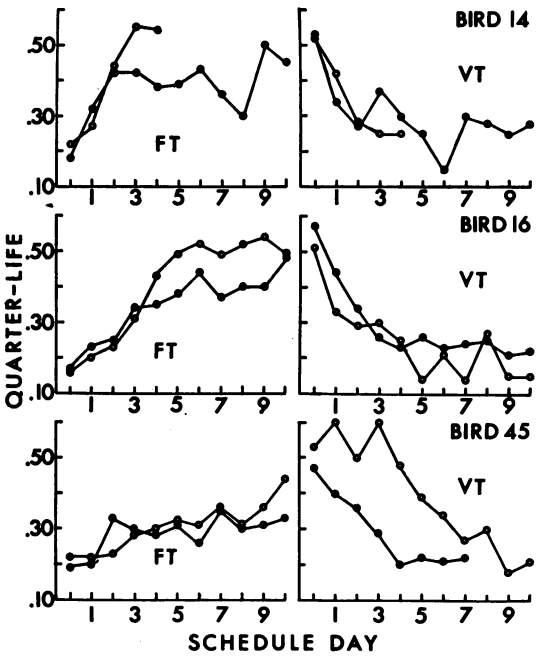

Fig. 2. Quarter-life in the presence of the blue stimulus for each session of FT and VT together with that for the last day of the immediately preceding response-dependent schedule. Filled points are for the first exposure to a schedule, unfilled points are for the second exposure.

response-independent schedule. Only responses and time in the presence of the blue stimulus provided the quarter-life data. All intervals entered into these computations for FI and FT, and all of the 5-min intervals provided the data for VI and VT. The statistic was computed from responses cumulated over each entire session on the basis of Gollub's (1964) report that such a procedure yields results corresponding closely to the mean quarter-life for individual intervals.

For Birds 14 and 16, the quarter-life on the first day of each response-independent schedule changed from that of the preceding session with the response-dependent schedule (VI always preceded FT and FI preceded VT). For Bird 45, the quarter-life changed by the first or second day of the first exposures to VT and FT and by the third or fourth day of the second exposures. Considering all of the birds, FT shifted the quarter-life from below 0.25 to at least 0.35 and often to near or above 0.50 and VT changed the quarter-life from above 0.47 to 0.25 or lower. The FT schedule produced positive acceleration, whereas VT most characteristically resulted in either steady responding or negative acceleration.

Figure 3 shows the effects on the rate of responding of changes from VI to FT and from FI to VT. Bird 14 responded less with successive days of each response-independent schedule. With the first FT the rate declined rapidly until the fourth day and then stayed at a low level through Day 14 (only the first 10 days are shown). The number of responses per session ranged from 2 to 66 on Days 15-23. The next response-independent schedule was VT. Responding decreased rapidly over the first four days and remained at a rate of about 0.01 resp/sec for the next six sessions. Responding stopped completely after the fourth day with subsequent response-independent schedules. Bird 16 was less dramatically affected than was Bird 14. Except for the first exposure to VT, in which the rate was fairly consistent over the 10 days, the number of responses dropped steadily and gradually but was substantial by the last day. The rate was still 0.18 resp/sec by Day 21 of the first response-independent schedule (FT). Bird 45 revealed rates different from either Birds 14 or 16. Responding declined to below 0.01 resp/sec with successive days with both the first FT and the first VT. The rates stabilized

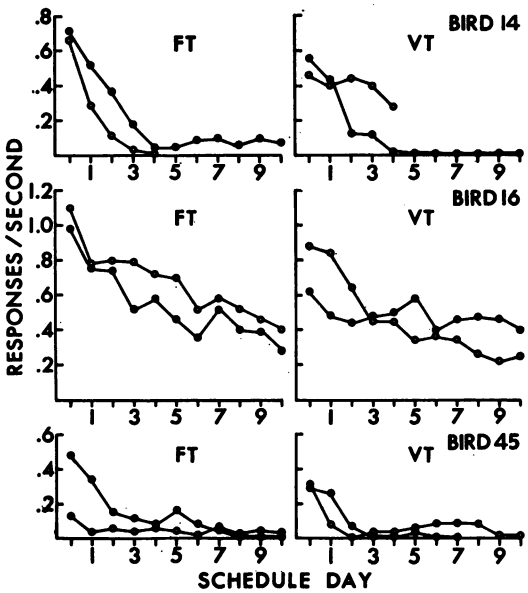

Fig. 3. Response rate in the presence of the blue stimulus for each session of FT and VT together with that for the last day of the immediately preceding response-dependent schedule. Filled points are for the first exposure to a schedule, unfilled points are for the second exposure.

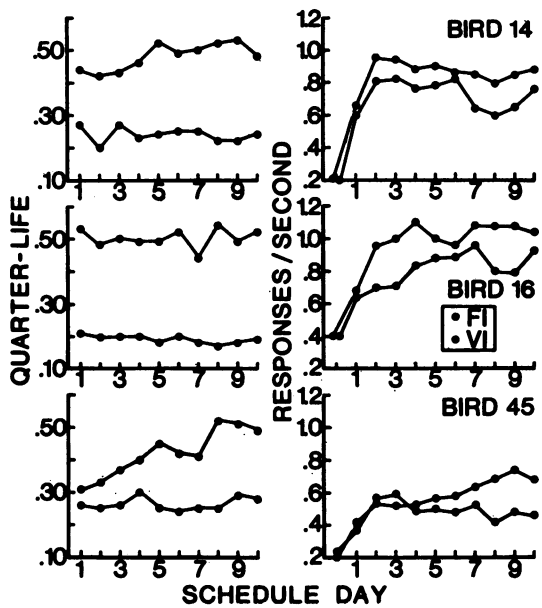

Fig. 4. Quarter-life and response rate in the presence of the blue stimulus for the first 10 sessions of the last exposure to FI and VI. The first point on each quarter-life graph is for the first day of FI and VI. The first point on each response rate graph is for the last day of the preceding schedule.

at between 0.01 resp/sec and 0.09 resp/sec after the first day of the second exposure to both schedules. In summary, response-independent schedules affected the rate of responding differently for the three birds. Bird 14 eventually stopped responding, Bird 16 responded less with successive days but maintained a substantial rate by the last day, and Bird 45 stabilized at a low rate. All birds eventually responded much less with the response-independent schedules than they did on the last day with each response-dependent schedule.

Figure 4 shows the quarter-life and response rate on the first 10 days of the last FI and VI schedules. The data are not strictly comparable to those for the corresponding response-independent schedules because FT and VT followed schedules that differed both in response dependency and regularity of reinforcement, and FI and VI followed schedules that differed from them only in the dependency of reinforcement on responses. Thus, the rates and the patterns at the beginning of each response-dependent schedule were different from those at the beginning of the corresponding response-independent schedule. The rates rose and remained at a substantial level with both FI and VI. The positive acceleration established by FT persisted and often increased with FI; the negative acceleration or steady rate of responding established with VT continued with VI.

Cumulative records revealed that the summaries provided in Fig. 2, 3, and 4 represented individual intervals. Figure 5 shows three complete sessions for Bird 16 under FT (first exposure). The top record is for the first day of FT. Except for a decrease in rate, the behavior was like that on the preceding day with VI. There was no sign of positive acceleration in individual intervals; instead, responding was either steady or negatively accelerated. The second record is that of the sixth day. Positive acceleration occurred in most intervals, and the response rate was down from that of the first day. The third record is for the sixteenth day. Positive acceleration persisted despite a sharply decreased rate of responding.

Figure 6 shows three complete sessions under VT (second exposure) for Bird 16. The clearest comparisons of behavior under VT with that under FT are provided by the behavior in the 5-min reinforcement intervals of VT. On the first day (top record) there was

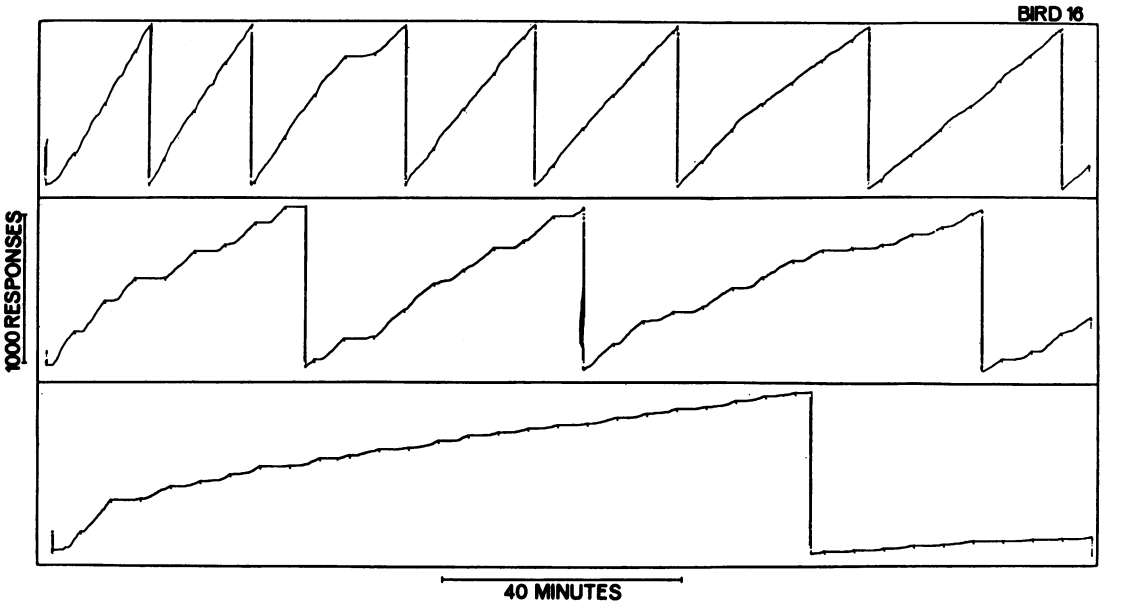

Fig. 5. Cumulative records of Bird 16 for the first (top record), sixth (middle record), and sixteenth (bottom record) days of FT. Each record is the complete session. The recording is as in Fig. 1.

distinct positive acceleration in these intervals as well as in most others. Positive acceleration was infrequent in the next record (fourth day); the typical pattern was a steady rate or some negative acceleration. The overall rate of responding was less than on the first day. The third record (eighth day) shows considerably less responding overall with most intervals either erratic or negatively accelerated. The bottom record shows the complete session for the last day of VI. Negatively accelerated intervals prevailed. Such patterns were not peculiar to VT, therefore, but were common with either type of variable schedule. The major differences between response-dependent and response-independent reinforcement were in the rates of responding and in the greater frequency of within-interval pauses after a number of days with VT.

As the final procedure, the three birds were switched directly from VT to FT. Bird 14 had ceased responding before the last day of VT and did not respond at all with FT. Figure 7 shows the first hours of the last day of VT, the third (Bird 45) and fifth (Bird 16) days of FT, and the last day of FT. Responding during the intervals on the last day of VT was usually erratic and generally negatively accelerated for Bird 16 and was either S-shaped or steady for Bird 45. The change to FT produced positive acceleration with the response rate much lower for Bird 45 than for Bird 16. The rate increased for Bird 16 with the change from VT to FT. The erratic responding and pausing present on the last day of VT disappeared with FT.

DISCUSSION

The two schedules of response-independent reinforcement established different patterns of responding. The regular presentations of reinforcement according to a fixed-time schedule produced intervals of positively accelerated responding. The irregular presentation of reinforcement according to a variable-time schedule resulted in intervals of either steady, erratic, or negatively accelerated responding. At the same time that these patterns developed, the rate of responding decreased. These two aspects of behavior, pattern and rate, were independent to the extent that patterns developed and persisted while the number of responses declined.

The decrement in responding with either fixed or variable response-independent schedules, and the maintained high level of responding with both response-dependent schedules, indicates that the dependency between responding and reinforcement determined response rate. When the schedules were response-dependent, and thereby ensured a

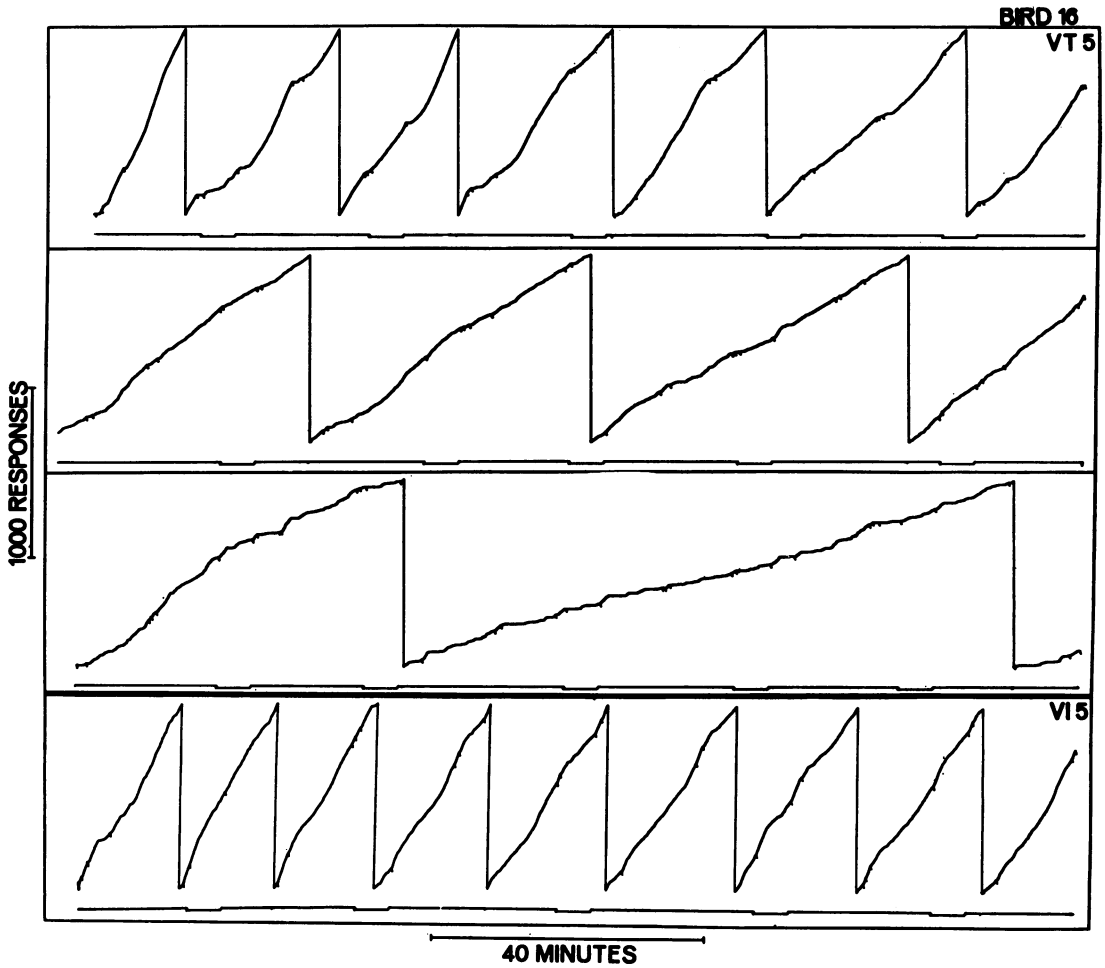

Fig. 6. Cumulative records of Bird 16 for the first (top record), fourth (second record), and eighth (third record) days of VT and the last day the bird was exposed to VI (bottom). Each record is the complete session. The recording is as in Fig. 1 except that the event pen was offset from horizontal during the 5-min reinforcement intervals.

close temporal contiguity of key-pecking and reinforcement, the rate was high. When the schedules were response-independent, and therefore did not guarantee that a key-peck immediately preceded reinforcement, the rate declined. Decrement in the rate of a response established by response-dependent reinforcement after a shift to a response-independent schedule has been observed in other studies (Herrnstein, 1966). It is consistent with the observation that the behavior in closest contiguity to reinforcement becomes predominant (Skinner, 1948). Whenever procedures fail to guarantee the contiguity of a response with reinforcement, competing behavior may occur at the moment of reinforcement and thereby become more probable in the future.

These data illustrate the difference in behavior produced by procedures requiring a certain response before reinforcement as opposed to procedures omitting such a requirement. Even response-dependent schedules, however, allow events at the time of reinforcement to vary. For example, simple schedules such as fixed- and variable-interval do not specify response topography, the maximum intensity of the response, the terminal interresponse time, or other behavior that might occur concurrently with the response programmed to produce reinforcement. Whatever does occur will probably increase in the future. To the extent that this generalization is true, a complete specification of the effects of reinforcement needs to include both the

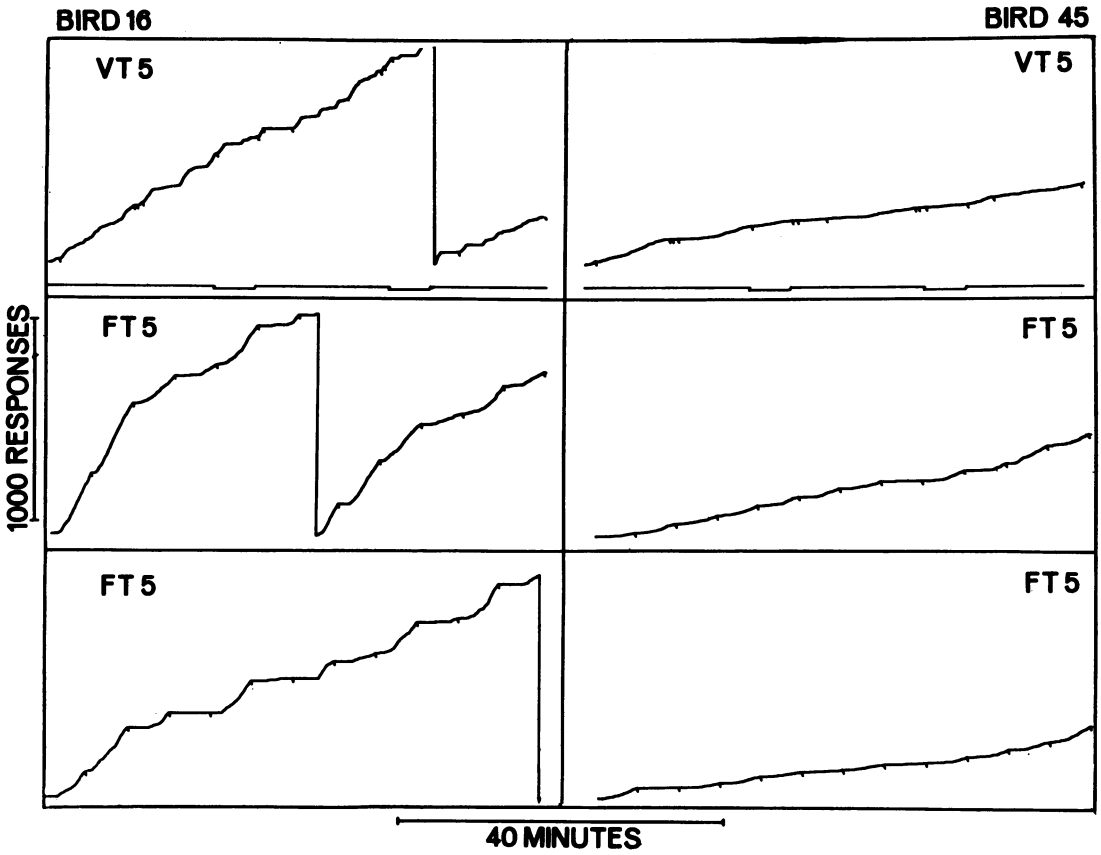

Fig. 7. Cumulative records of Birds 16 and 45. The top records are the last day of VT 5-min, the middle records are the third (Bird 45) and the fifth (Bird 16) days of FT 5-min, and the bottom records are the last day of FT 5-min. Each record is for the first hour of the sessions. The recording is as in Fig. 5.

behavior that may occur, and is therefore reinforced adventitiously, and the behavior that must occur and is therefore reinforced deliberately. Adventitious reinforcement, *i.e.*, the strengthening of behavior because it happens to occur contiguously with or in close temporal proximity to reinforcement, may explain between- and within-subject variability in response rate, topography, and other aspects of behavior not deliberately controlled by the experimenter.

The temporal distribution of responses was controlled by scheduling reinforcement in relation to time. Positively accelerated responding occurred with fixed schedules of either response-independent reinforcement or response-dependent reinforcement, and different patterns occurred with the variable schedules. These patterns, therefore, depended on the temporal programming of reinforcement and not on the response-reinforcement dependency. The between-subject variability in response rate did not carry over to the patterns of responding; the patterns developed whether the rates were substantial or low. Appel and Hiss (1962) reported positively accelerated responding when fixed-interval and fixed-time schedules were each correlated with a distinctive stimulus. Herrnstein and Morse (1957*b*) obtained similar results with a fixed-time schedule imposed simultaneously with a response-dependent schedule that by itself maintained responding at a low, steady rate. Positive acceleration appears to be characteristic of behavior under fixed-time schedules in a variety of contexts.

The patterns observed with the fixed-interval schedule, pausing after reinforcement followed by positive acceleration, were like those usually found with similar schedules (Morse, 1966). The patterns with variable-interval reinforcement departed somewhat from expec-

tations. Ferster and Skinner (1957) observed steady rates with variable-intervals both larger and smaller than the VI 5-min of the present experiment; they reported negative acceleration only when their schedules contained some individual intervals more than six times larger than the mean. There is no firm explanation for the shapes of the curves observed in the present experiment. Because the patterns appeared before response-independent or fixed-interval schedules were introduced, they cannot be attributed to a history of exposure to other programs. The birds behaved similarly with the variable-time schedule. Since the same tape programmed all variable schedules and every sixth or seventh interval was 5-min, the particular sequence of a relatively small number of different individual intervals may have generated the patterns.

Examination of cumulative records showed a variable relation of key-pecks to reinforcements with both response-independent schedules. Sometimes the operation of the grain magazine followed key-pecks immediately, and at other times the food appeared during periods without pecks. That characteristic patterns developed despite this variability indicates that the behavior at the moment of reinforcement need not be stereotyped to produce certain temporal distributions of responses. Furthermore, if the adventitious reinforcement of responses that competed with key-pecking caused the decline in pecking with response-independent reinforcement, then the development of the patterns concurrently with the decrement in pecking supports the conclusion that the patterns were independent of the behavior occurring contiguous with reinforcement. Although the occasional contiguity of pecking and reinforcement may have had a role in shaping the patterns of responses, the consistency of the patterns, together with the inconsistency of behavior at the moment of reinforcement, implies that this was not the sole determinant.

Dews (1962, 1966) suggested that a temporal gradient of reinforcement determines positive acceleration with fixed-interval schedules. This hypothesis, that there is a declining, retroactive, rate-enhancing effect of reinforcement, is compatible with both the temporal patterning and the eventual cessation of responses observed with the fixed-time schedules of the present experiment. The response contiguous with the presentation of reinforcement is strengthened most and may eventually predominate. Before that point is reached there is still an orderly relation between key-pecks at various locations in the interval and the delay of reinforcement. The hypothesis also explains why the response rate should decrease with variable-time schedules: since the response contiguous with reinforcement is strengthened the most and is likely to be incompatible with key-pecking, the number of pecks declines. The inconsistent delays of reinforcement inherent in such schedules may be responsible for the patterns of responding with variable-interval and variable-time schedules.

The pairing of two stimuli without reference to responding defines the Pavlovian conditioning paradigm. Viewed in this way, the response-independent schedules, which paired the blue stimulus with the presentation of food independent of responding, demontrated the effectiveness of fixed and variable schedules in Pavlovian conditioning in differentially determining the temporal distribution of key-pecks. The consideration of Pavlovian conditioning raises the question of the extent to which some component of the response to food became conditioned to the blue light. The blue light's evocation of behavior initially controlled by food may have affected the pattern of key-pecking, even though the classically conditioned response and the operant key-pecking response were quite different from each other. An experiment by Trapold, Carlson, and Myers (1965) is relevant in this context. They found that a fixed-time schedule facilitated positively accelerated responding with a fixed-interval schedule although the response reinforced on the fixed-interval could not occur when the fixed-time schedule was in effect. The regular presentation of a stimulus, therefore, influenced the temporal distribution of a subsequent operant response. Perhaps the behavior both in that experiment and the present one was determined by a response, originally made to food, that became anticipatory. Another explanation not involving Pavlovian conditioning is that the facilitation in the Trapold *et al.* (1965) study occurred via transfer from some response reinforced adventitiously with the response-independent schedule, and, as

described in the preceding paragraph, the present patterns and rates of responding stemmed from a temporal gradient of reinforcement. Since Pavlovian and operant conditioning may act jointly to determine the characteristics of responses, there is nothing inherently incompatible about the two explanations that requires proposing them as mutually exclusive alternatives. However, because the relevance of operant conditioning to the development of key-pecking as the predominant response in the present experiment is evident, and the occurrence of any Pavlovian conditioned response is conjectural, it is reasonable to emphasize operant reinforcement in explaining the behavior. As noted by Brown and Jenkins (1968), the use of a Pavlovian conditioning procedure indicates neither that the response that becomes predominant has been classically conditioned nor that some other classically conditioned response mediates the behavior.

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