MULTIPLE FIXED-INTERVAL SCHEDULES: TRANSIENT CONTRAST AND TEMPORAL INHIBITION[1]

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Pigeons were exposed to four cycles per session of a multiple schedule in which each cycle involved twelve 60-sec fixed intervals followed by four 180-sec intervals [(12 FI 60-sec)(4 FI 180-sec) schedule]. Post-reinforcement pauses were shorter during the first few short intervals of each cycle than during later short intervals, and increased over the four long intervals of each cycle (positive and negative transient contrast). A (12 FI 15-sec)(4 FI 45-sec) schedule showed similar results. These two schedules differed in some other respects indicating effects of absolute FI duration on stimulus control. Differences in contrast properties between both these procedures and multiple variable-interval schedules were related to the pause-producing property of reinforcement on FI (temporal inhibition). Behavior under two other multiple fixed-interval schedules—(2 FI 360-sec)(1 FI 720-sec) and (3 FI 360-sec)(1 FI 720-sec)—differed in certain respects from both the (12 FI x-sec)(4 FI 3x-sec) schedules. These differences may be related to differences in the number of successive fixed intervals within a component (run length).

A previous experiment (Staddon, 1967) showed that pigeons exposed to a cyclic fixed-interval schedule with a cycle involving 12 short (1 min) and four long (3 min) intervals, responded most rapidly during the long intervals. This effect was due to an approximately constant post-reinforcement pause, combined with an approximately constant "running" response rate; i.e., to the pigeons' failure to adjust their pause to the prevailing interreinforcement interval. The present experiment investigated the effect of stimuli differentially associated with the long and short intervals respectively on pigeons' responding under this and three other cyclic procedures.

METHOD

Subjects

Four male, White Carneaux pigeons, approximately 5 yr old at the start of the experiment, were used. The birds had all been used in a variety of experiments and just before the start of this experiment had received extensive training under a two-valued cyclic-interval schedule (Staddon, 1967). The birds were maintained at 80% of their free-feeding weights throughout.

Apparatus

A standard Grason-Stadler one-key operant conditioning chamber for pigeons was used. The response key could be transilluminated with white, red, or green light. A relay "feedback" click accompanied each effective response. During reinforcement (3-sec access to mixed grain) house and key lights were out and the grain magazine was illuminated. White noise and the noise of the ventilating fan masked most extraneous sounds. Automatic scheduling and recording apparatus was located in an adjoining room. Data were recorded on printing and digital counters and a cumulative recorder.

Procedure

Four different two-valued cyclic schedules were investigated. For each schedule a cycle involved a sequence of "short" interreinforcement intervals followed by a sequence of "long" intervals. Four cycles comprised a session. The sequence of conditions, number of sessions, and relevant response rates appear in Table 1. The schedule cycles are abbreviated in the form a FI x-sec, b FI y-sec, to indicate a cycle comprising a fixed intervals of duration x followed by b fixed intervals of

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duration y (a mixed schedule). Parentheses, e.g., (12 FI 60-sec)(4 FI 180-sec), indicate that the bracketed intervals were associated with unique discriminative stimuli, usually red and green key lights (a multiple schedule). With the exception of Condition 4, 12 FI 60-sec, 4 FI 180-sec, when the response key was white throughout, differential stimuli were always associated with "long" and "short" intervals. For Birds 401 and 442, green was always associated with the shorter value and red with the longer; for 402 and 404 the opposite was true. Condition 2 was the (12 FI 60-sec)(4 FI 180-sec) schedule but with a 1-min timeout (TO) inserted at the change from long to short intervals or *vice versa* [(12 FI 60-sec)(TO 60-sec)(4 FI 180-sec)(TO 60-sec) procedure]. Conditions were changed only when the pattern of responding, judged by daily visual inspection of response rate and pause during successive interreinforcement intervals through each session, appeared stable. Birds were run daily throughout the experiment.

RESULTS

Properties of the Multiple Schedule: (12 FI 60-sec)(4 FI 180-sec)

There are three possible measures of behavior under these schedules: response rate during each interreinforcement interval, post-reinforcement pause, and "running" rate, *i.e.*, response rate following the first response of an interval. These three measures are not independent. In the following discussion, attention is focused primarily on post-reinforcement pause and response rate throughout each interval; running rate is mentioned where necessary to clarify the contribution of changes in post-reinforcement pause to changes in response rate. Average response rate throughout the long (180 sec) and short (60 sec) interval components (overall rate) is discussed first, followed by discussion of sequential changes in rate and pause throughout the cycle.

Asymptotic overall response rate data appear in Table 1. Three of the four birds showed negligible differences between their rates in the presence of the stimuli associated with the long and short intervals, respectively, for the three (12 FI 60)(4 FI 180) conditions (Conditions 1, 3, and 7). Bird 402 consistently responded faster during the short intervals, however. With the same sequence of inter-reinforcement intervals, but without differential discriminative stimuli (Condition 4: 12 FI 60, 4 FI 180), all four pigeons responded faster during the long intervals, replicating the previous result with this schedule (Staddon, 1967).

Interpolating 60-sec timeouts between component transitions [Condition 2: (12 FI 60)(TO 60)(4 FI 180)(TO 60)] increased overall rate in both short and long intervals, for three of the birds, by comparison with the previous (12 FI 60)(4 FI 180) condition. This increase was maintained, however, when timeouts were omitted again in Condition 3. The pattern of responding observed in Condition 3 proved recoverable (stable) during Condition 7, the third replication of the (12 FI 60)(4 FI 180) procedure. Thus, the effect of timeouts during Condition 2 probably reflects the metastable (*i.e.*, stable during a condition but

Table 1

Condition	Schedule Cycle	Sessions (range)	401 Short	401 Long	402 Short	402 Long	404 Short	404 Long	442 Short	442 Long	MEAN Short	MEAN Long
1	(12 FI 60) (4 FI 180)	74	41	43	64	33	10	9.3	24	24	35	27
2	(12 FI 60) (TO 60) (4 FI 180) (TO 60)	44	38	35	97	35	23	23	36	42	49	34
3	(12 FI 60) (4 FI 180)	55	51	42	96	44	24	29	32	31	51	37
4	12 FI 60, 4 FI 180	40	41	69	58	72	14	31	25	49	35	55
5	(12 FI 15) (4 FI 45)	18-19	61	42	142	38	29	18	55	42	72	35
6	(2 FI 360) (1 FI 720)	43	60	37	22	21	47	15	44	17	43	23
7	(12 FI 60) (4 FI 180)	52-53	41	61	81	39	40	35	35	42	49	44
8	(3 FI 360) (1 FI 720)	25	59	22	38	15	51	20	43	30	48	22

Experimental conditions, number of sessions (range over the four birds) and mean response rate per minute for the four pigeons in the "long" and "short" components (average of the last three days of the 13-day period covered by the figures). One cycle of each procedure is given, with the fixed-interval and timeout (TO) values in seconds. Parentheses indicate components associated with distinctive stimuli. Four cycles made up an experimental session.
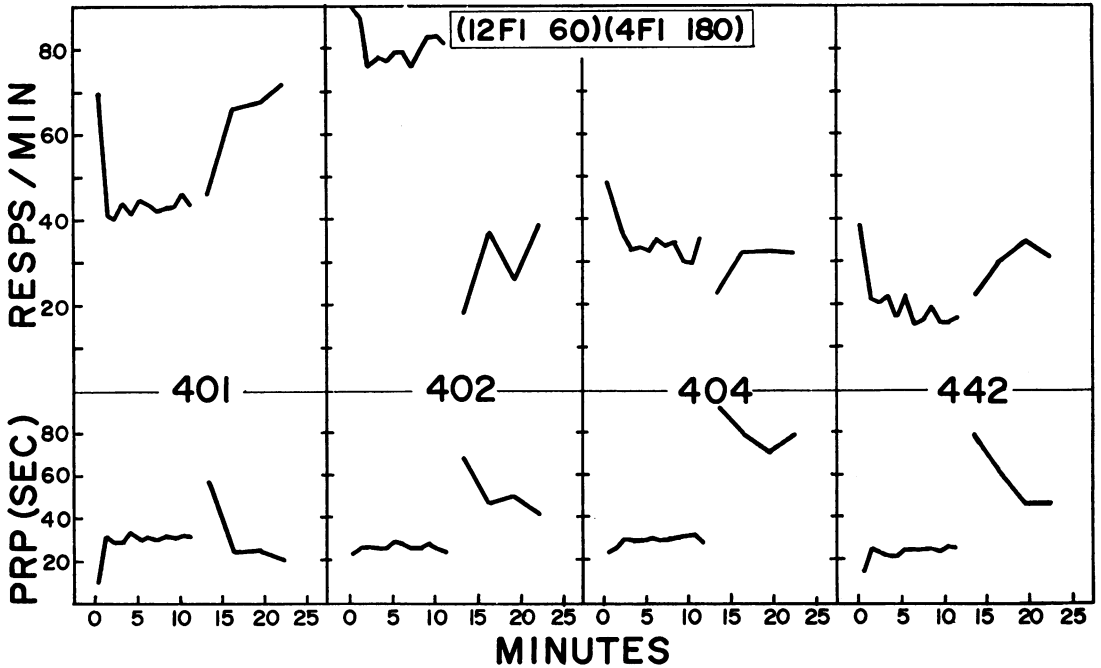
Fig. 1. Post-reinforcement pause and response rate over each interreinforcement interval during an average cycle of the (12 FI 60)(4 FI 180) multiple schedule (Condition 7). Points are mean, median data over 13 days of asymptotic responding for each of the four birds. The first 12 intervals of the session are excluded from the averages.

not recoverable following a change of conditions, *cf.* Staddon, 1965) state of behavior during Condition 1, rather than a reliable effect of timeout as such.

Figure 1 shows response rate and post-reinforcement pause during an average cycle of the (12 FI 60)(4 FI 180) procedure for the four birds (Condition 7). The first 12 short intervals of each session are excluded from these averages because behavior during these intervals sometimes differed from performance during the rest of the session. All four pigeons showed a longer post-reinforcement pause and lower rate during the first (and sometimes the second) long interval of each cycle than during later long intervals (*negative transient contrast*, Nevin and Shettleworth, 1966). Similarly, three of the four showed a shorter post-reinforcement pause and higher rate during the first few short intervals of each cycle than during later short intervals (*positive transient contrast*). Apart from these transients, baseline response rate (*i.e.*, rate during the last few intervals of each component) was not very different, for the group as a whole, between short and long intervals. On the other hand, post-reinforcement pause was reliably longer

during the long intervals than during the short for three of the four birds.

These results, plotted as a group average, appear in the right panel of Fig. 2. Control by the discriminative stimuli is most clearly seen in the post-reinforcement pause, and in the positive and negative transients of pause and rate. Comparison with the pattern of responding under the same reinforcement cycle, but without differential discriminative stimuli (left panel, Condition 4) emphasizes these effects. Without differential stimuli, baseline rate was higher in the long intervals than in the short and the transient during the first short interval of each cycle resembled negative transient contrast rather than positive. Post-reinforcement pause was much the same throughout the cycle. These results replicate the previous experiment with this schedule (Staddon, 1967).

The dashed lines in the top panel of Fig. 2 show the mean response rate following the first response of each interval (running rate), averaged across the four birds for the mixed (left panel) and multiple (right panel) conditions. These averages are representative of the individual data in both cases. Two points can
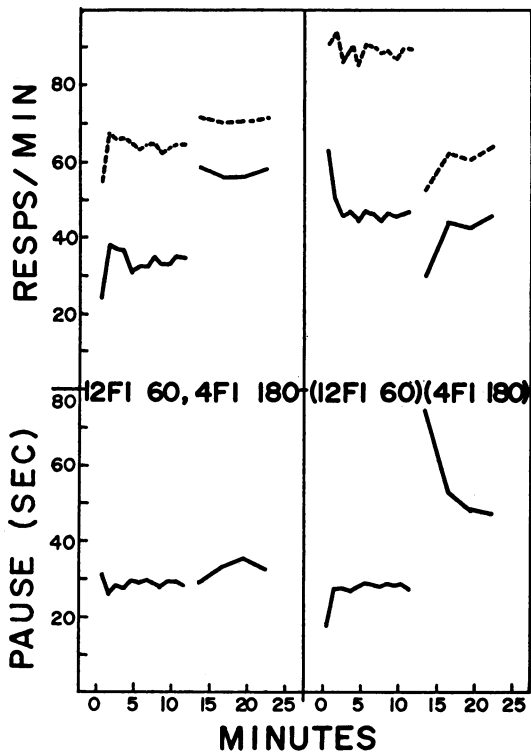
Fig. 2. Left panel: An average cycle of the 12 FI 60 4 FI 180 mixed schedule (Condition 4), averaged over the four pigeons. Right panel: An average cycle of the (12 FI 60)(4 FI 180) multiple schedule averaged across the four birds (Condition 7). Dashed lines are "running" rates, *i.e.*, rate following the first response of an interval. Other details as in Fig. 1.

be made about the data for the mixed schedule: (1) running rate was slightly higher during the long intervals than during the short. This suggests a positively accelerated pattern of responding following the first response of each interval, as expected under a fixed-interval schedule. The rather small difference between these two running rates suggests that this acceleration was small. (2) Running rate was considerably lower during the first short interval of the cycle than during later short intervals. Because the birds were presumably unable to predict the transition from long to short intervals, and because pause changed little across the long intervals, this change reflects slower acceleration of responding during the last 180-sec interval of each cycle than during the first; *i.e.*, an increase in the curvature of the FI "scallop" from first long interval to last. Both these findings confirm the results of the previous experiment with this procedure. For the (12 FI 60)(4 FI 180) proce-

dure (right panel of Fig. 2), each individual bird showed a running rate profile across the four 180-sec intervals that closely resembled the rate profiles in Fig. 1. This similarity accounts for the resemblance between the average rate and average running rate curves in Fig. 2. The running rate profile across the short intervals was similar for all birds and, like the average, showed no contrast effects: running rate was always approximately constant across the twelve 60-sec intervals of each cycle. Thus, for both the individuals and the aggregate, both running rate and post-reinforcement pause contributed to the negative transient contrast in terms of rate, but the positive transient contrast was due entirely to changes in post-reinforcement pause.

Figure 3 shows the effects of interpolated blackouts (Condition 2) on the multiple schedule performance. The outcome, in terms of rate and pause across the cycle, is similar to the picture in terms of overall rate within each component: response rate, especially during the short intervals, increased during the timeout condition, but the increase was largely maintained after return to the original condition. Data from the first few sessions under Conditions 2 and 3 indicated some enhancement of both positive and negative transient interactions in both cases for two birds (402, 404).

Other Multiple Cyclic Schedules

Both (12 FI 60)(4 FI 180) and (12 FI 15) (4 FI 45) schedules belong to a more general set of (12 FI x)(4 FI $3x$) schedules, whose members differ only in the time parameter x. Comparisons between them therefore afford some insight into the effects of absolute fixed-interval duration on stimulus control. The overall response rate data in Table 1 show quite a different picture under the (12 FI 15)(4 FI 45) procedure than under the schedule with longer intervals (Conditions 5 and 7). All four birds responded faster during the short intervals than during the long; only Bird 402 consistently behaved in this way under the longer schedule. For three of the four birds, response rate was higher during the 15-sec intervals of this schedule than during the short intervals of any other condition. For the group as a whole, overall response rate, across both 15- and 45-sec intervals, was somewhat higher than during any other condition.
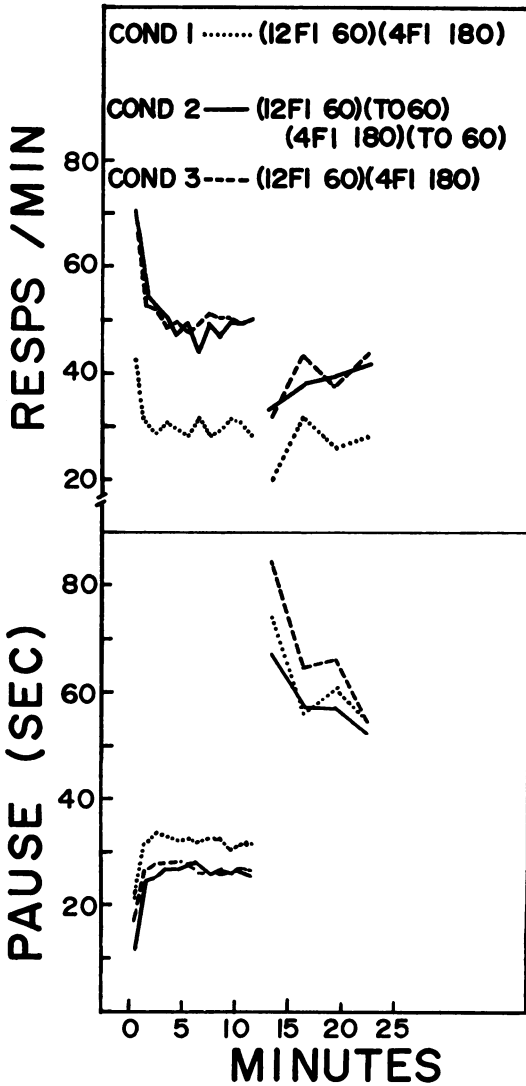
Fig. 3. An average cycle under the (12 FI 60)(4 FI 180) procedure (Conditions 1 and 3), and the same procedure with 60-sec timeouts between components [(12 FI 60)(TO 60)(4 FI 180)(TO 60)] (Condition 2). Data are averaged across four birds. Other details as in the previous figures.
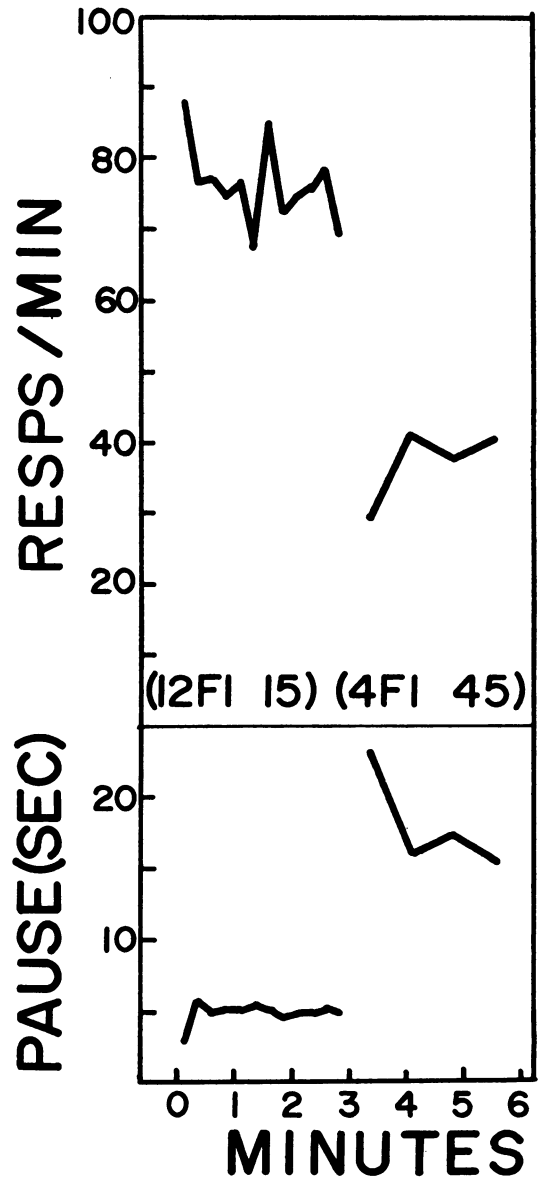

Fig. 4. An average cycle under the (12 FI 15)(4 FI 45) schedule (Condition 5). Other details as in the previous figures.

Figure 4 shows an average cycle under the (12 FI 15)(4 FI 45) schedule. Individual data are not shown because the variability across subjects was of the same order as under the longer procedure (Fig. 1). In terms of post-reinforcement pause, the data are quite similar to the (12 FI 60)(4 FI 180) schedule (*cf.* Fig. 2): there was both positive and negative transient contrast, and baseline pause (*i.e.,* pause during the last few intervals of each component) was longer during the long inter-

vals than during the short. However, the birds paused for a larger fraction of both short and long intervals under the shorter schedule: mean baseline pauses (estimated from the figures) were 10 sec and 33 sec for the 15-45-sec schedule, 28 and 48 sec for the 60-180-sec schedule (Fig. 2). The running rate data for this condition (not shown) resembled the data for the (12 FI 60)(4 FI 180) condition: approximately constant running rate across the short

(15 sec) intervals, and a profile similar to the rate profile across the long (45 sec) intervals.

In terms of response rate over each interval (top panel, Fig. 4), baseline rate was higher during the short intervals than during the long for three of the four birds. This difference was not as great as the average suggests, however, because Bird 402 showed a much larger difference than the other birds (as it did under the longer schedule, cf. Fig. 1). These results differ from the picture under the longer schedule (Fig. 2) where baseline rate did not differ between short and long intervals for the group as a whole.

In terms of overall response rate (Table 1), the third and fourth procedures studied here [(2 FI 360)(1 FI 720) and (3 FI 360)(1 FI 720)] resemble the (12 FI 15)(4 FI 45) schedule more than the (12 FI 60)(4 FI 180) schedule: all birds responded consistently faster during the short intervals than during the long. Two points suggest that the mechanism may be quite different, however: (1) Bird 402 showed small rate differences between short and long intervals during these two conditions, by comparison with the other three birds, but showed much the largest differences during the two shorter conditions. (2) Response rate during the first short interval of each cycle (average cycle data, Fig. 5) was lower than rate during later intervals for both these last two procedures (negative transient contrast), rather than higher as in the first two schedules (positive transient contrast).

The average cycle data in Fig. 5 show that response rate and pause during the two short intervals of the (2 FI 360)(1 FI 720) schedule were the same as during the first two short intervals of the (3 FI 360) (1 FI 720) cycle. Moreover, response rate during the third short interval of (3 FI 360)(1 FI 720) was somewhat lower than during the second short interval of the cycle. Thus, the increase in rate during the second short interval of the (2 FI 360)(1 FI 720) cycle cannot be attributed to an anticipation of the succeeding long interval, but must represent a progressive effect of the sequence of short intervals.

DISCUSSION

The schedule with a cycle comprising twelve 60-sec intervals followed by four 180-sec intervals, the (12 FI 60)(4 FI 180) schedule, pro-
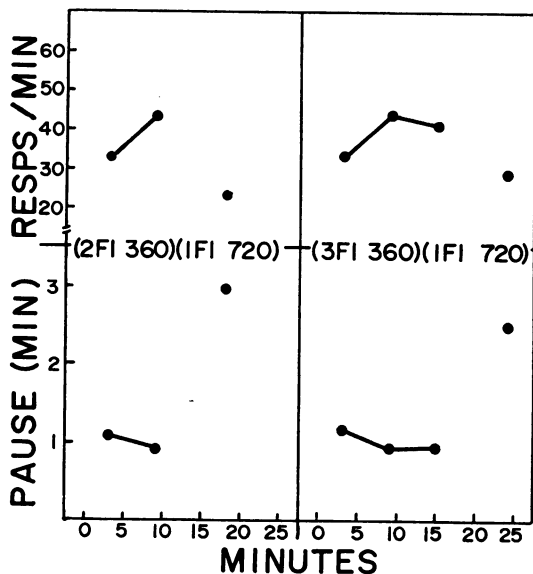

Fig. 5. Left panel: An average cycle under the (2 FI 360)(1 FI 720) schedule (Condition 6). Right panel: An average cycle under the (3 FI 360)(1 FI 720) schedule (Condition 8). Data are mean medians, averaged across the four birds, for 13 days asymptotic responding under each condition.

vides a point of reference for this experiment. It showed control of baseline post-reinforcement pause by the differential stimuli, and negative transient contrast in terms of both pause and "running" rate, but positive contrast only in terms of pause. The similar (12 FI 15)(4 FI 45) schedule produced similar results in terms of baseline pause and negative transient contrast. It differed in terms of overall rate in the short and long intervals: rate in both components was much the same (for the group as a whole) in the 60-180-sec procedure, but generally higher during the short intervals in the 15-45-sec schedule.

The transient interactions characteristic of these two schedules resemble a number of results in the literature (e.g., Catania and Gill, 1964; Williams, 1965; Nevin and Shettleworth, 1966; Bernheim and Williams, 1967). Thus, Nevin and Shettleworth observed an initially higher response rate after the onset of a relatively positive discriminative stimulus, and an initially lower rate after the onset of a relatively negative stimulus (positive and negative transient contrast) in a multiple variable-interval, variable-interval schedule.

The transient interactions in this experiment, and in a multiple fixed-interval-extinc-

tion experiment reported by Catania and Gill (1964), were permanent and recoverable. The term *transient* therefore loses the connotation of impermanence that attaches to its use by Nevin and Shettleworth (1966)—they found transient contrasts during the first few sessions only of their variable-interval procedures. In the context of multiple fixed-interval schedules, the term transient refers only to the fact that response rate changes within a schedule component, and not to a change in this change over sessions, as in the variable-interval procedures of Nevin and Shettleworth.

At asymptote, the major behavioral difference between FI and most VI schedules is the inhibitory (in the restricted sense of pause-producing) effect of reinforcement on FI (*cf.* Ferster and Skinner, 1957, p. 222; Staddon, 1967; Staddon and Innis, 1969*a* and *b*). The absence of transient contrast at asymptote on VI, and its reliability on FI as demonstrated in the two (12 FI *x*)(4 FI 3*x*) schedules of this experiment, strongly implicates temporal inhibition as the factor responsible for transient contrast. However, the results of Condition 2, where timeouts were introduced between components [(12 FI 60)(TO 60)(4 FI 180)(TO 60)], indicate that a simple interpretation of inhibition as summating across reinforcements, independent of the prevailing stimulus, is not adequate to describe these contrast effects. This view implies a reduction of negative transient contrast and an enhancement of positive transient contrast by comparison with the (12 FI 60)(4 FI 180) procedure without timeout. While a small effect of this sort is discernible in the group average data in Fig. 3, it is not sufficient to confirm this interpretation as a major determinant of responding under these procedures.

In terms of response rate in each interval, the (12 FI 60)(4 FI 180) schedule showed large transient contrast effects (*cf.* Fig. 2), but no difference in baseline rate between the two components. The (12 FI 15)(4 FI 45) schedule showed smaller transients, but larger differences in baseline rate favoring the short intervals. Since these two schedules are identical in all respects, save absolute FI duration, these differences indicate that stimulus control on FI schedules is not independent of FI duration.

The other two cyclic schedules investigated here (2 FI 360)(1 FI 720) and (3 FI 360)(1 FI 720), resembled the (12 FI 15)(4 FI 45) schedule in showing higher overall rates during the short intervals than during the long. They differed from both the (12 FI *x*)(4 FI 3*x*) schedules in showing negative (rather than positive) transient contrast after long-short interval transitions. Three kinds of difference between these two pairs of schedules may account for this behavioral difference: (1) The different absolute fixed-interval durations involved— 15-45 sec and 60-180 sec, on the one hand, and 360-720 sec on the other. (2) The different ratios between the short and long interval durations—three to one *vs.* two to one. (3) The number of fixed intervals that occurred in succession within a multiple schedule component (run length)—the short schedules have run lengths of 12 and four, for short and long intervals respectively; the longer schedules have run lengths of two (or three) and one, respectively. The second factor is not large in percentage terms, by comparison with the behavioral differences observed, which suggests that it is probably not a major factor, although it certainly plays some role (contrast is not to be expected when the ratio is one to one, for example). Absolute interval duration is also unlikely to be crucial because the two (12 FI *x*)(4 FI 3*x*) schedules differed along this dimension but did not differ substantially in terms of transient contrast. Thus, the differences in transient contrast effects between these two schedules and the (2 FI 360)(1 FI 720) and (3 FI 360)(1 FI 720) schedules may be largely attributable to differences in run length.

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